A Simple Dual-Frequency Circularly Polarized Slot Antenna With a Modified Crossed Patch

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Abstract. A simple single-layer single-fed dual-frequency circularly polarized (cp) antenna with a crossed patch is proposed in this paper. The modified crossed patch with dual-frequency cp provides a new method for the design of other multi-frequency cp antennas. A horizontal stub is introduced at the upper end of the long arm and sharp angles protrude from both ends of the short arm to achieve dual circular polarization at low frequency (1.64 GHz) and high frequency (3.45 GHz), respectively. The antenna proposed in this paper can be applied to WIMAX with a compact size of 53 × 60mm$^2$. The experimental results show that the impedance bandwidth of 250 MHz (1.55 GHz-1.8 GHz) and 1440 MHz (2.2 GHz-3.64 GHz), and the 3 dB axis-ratio bandwidth of 250 MHz (1.52 GHz-1.78 GHz) and 520 MHz (3.08 GHz-3.6 GHz) are achieved in these two bands respectively. The proposed antenna has been printed and fabricated, and the measured results are in good agreement with the simulated results.

1. Introduction

Recently, dual-frequency circularly polarized antenna has been widely used in wireless communication systems owing to its high polarization efficiency which can meet the demands of various communication devices. Dual-frequency circular polarization can be realized by single-feed or dual-feed. The dual feeds excite two orthogonal modes with equal amplitude and orthogonal phase at the orthogonal position to achieve cp [1]. However, single-feed cp antennas are more compact and simple as they do not require external polarizers. Dual-frequency cp excited by a single feed can be formed by perturbing the loading slot of the patch at the appropriate position and changing the current path [2-5]. These dual-band cp designs include slots in the middle of rectangular patch and T-shaped slots inserted in four sides [2], cross-shaped slots in the middle of rectangular patch, rectangular slots in four sides and L-shaped strips extending to reduce size [3], S-shaped slot in the middle of the upper patch and rectangular slot in the middle of the lower patch[4], and a ring slot and four unequal-length slots in the middle of the patch [5]. In [6], eight slots and eight metal short-circuit pins were designed on the circular patch at the bottom of the stacked patch. The omnidirectional circular polarization of 1.57 GHz and the linear polarization of 2.4 GHz are realized by exciting TM01 mode and TM02 mode respectively. However, many dual-band circular polarized antennas reported have relatively narrow impedance bandwidths and axial ratio bandwidths, so some documents are currently increasing the bandwidth of circularly polarized antennas. A circularly polarized printed antenna was designed for dual-band WiFi operation at 2.45 GHz and 5.10 GHz [7]. Slot loading and slot coupling were applied to the disk patch to obtain impedance bandwidths of 100 MHz and 170 MHz, respectively. The dual-frequency circularly polarized antenna proposed in [8] uses an F-shaped feed structure and parasitic
components to achieve 22.22% and 10.53% axial ratio bandwidths at 1.8 GHz and 3.3 GHz, respectively.

2. Antenna Configuration

Figure 1 shows the configuration of the proposed dual-frequency CP antenna with a modified crossed patch. The proposed antenna is designed on the basis of slot-coupled antenna since it has a wider impedance bandwidth [9]. The antenna is printed on an FR4 substrate (thickness $h = 1.6$ mm, relative permittivity $\varepsilon_r = 4.4$ and loss tangent $\tan \delta = 0.02$) with a rectangular slot and a crossed patch on the front side and fed with electromagnetic coupling by microstrip on the other side. The modified crossed patch composed of a long arm of 28mm and a short arm of 17mm which is the main part to achieve dual-frequency cp. It is printed in the middle of a rectangular slot with a length of 33 mm and a width of 31 mm on the front side of the substrate, and the offset angle is 45°. The circular polarization is produced by two orthogonal modes having a 90° phase difference between $a$ and $b$ and equal amplitudes. In order to generate a resonance mode at lower frequencies, a horizontal stub of $l_1$ is extended at upper end of the long arm of the crossed patch. The perturbation sharp angles on both sides of the short arm can generate circularly polarized waves at higher frequencies. Table 1 lists the size parameters of the final antenna after parameter optimization.

![Figure 1. Geometry of the dual-frequency cp slot antenna with a crossed patch.](image)

| Parameter | Value | Parameter | Value |
|-----------|-------|-----------|-------|
| $l_g$     | 53    | $w$       | 6     |
| $w_g$     | 60    | $l_1$     | 8.8   |
| $l_s$     | 33.6  | $w_j$     | 4.2   |
| $w_s$     | 31.7  | $w_f$     | 2     |
| $l_a$     | 28    | $l_f$     | 29.6  |
| $l_b$     | 17    | $h$       | 1.6   |

3. Antenna Design and Analysis

![Figure 2. Four modified prototypes of the proposed antenna.](image)
As shown in Figure 2 (a)-(d), the design procedure of dual-frequency circularly polarized antenna is illustrated by introducing four antenna prototypes. Ant.1 is a crossed patch with a 45 degree anticlockwise tilt in the middle of the rectangular slot, and the microstrip line is coupled to feed on the other side of the substrate; Ant.2 is modified on the basis of Ant. 1, protruding a horizontal stub at the upper end of the long arm; Ant.3 introduces a sharp angle at the side of the short arm on the basis of Ant.2; Ant.4 is the proposed dual-frequency circularly polarized antenna, which extends horizontally stub at the upper end of the long arm and double sharp angles at both ends of the short arm. In order to excite the frequency of about 1.6 GHz, the size of the square groove can be roughly determined by the following formula [9]:

$$f = \frac{c}{2w\sqrt{\varepsilon_{re}}}$$  \hspace{1cm} (1)

where $c$ is the speed of light in the air, $\varepsilon_{re}$ is the effective dielectric constant and $w$ is the length of square slot. Accordingly, the initial square slot gap in this design is approximately 30 mm. Figure 3 (a) and (b) show the return loss coefficients $S_{11}$ and axial ratios of the four antennas, respectively. The proposed slot microstrip antenna has a wide impedance bandwidth at high frequencies. With the improvement of the crossed patch, the lower frequency can be excited when the horizontal stub is added to the upper end of the long arm. With the modification of the short arm, the impedance matching at higher frequency becomes better. As can be seen from Figure 3 (b), the addition of horizontal stub generates circular polarization waves at lower frequencies. The improvement of the sharp angle on one side of the short arm of Ant. 3 results in the generation of high frequency circularly polarized waves. Finally, after these improvements, Ant.4 can generate good circularly polarized waves in both frequency bands, and these changes also significantly increase the axial ratio bandwidth.

The crossed patch is designed diagonally for circular polarization. By choosing the appropriate size of the long arm (la) and the short arm (lb), the equivalent excitation surface magnetic current in the rectangular groove is perturbed appropriately, and a stub as well as two sharp angles are added to perturb the surface current on the crossed patch, thus two orthogonal resonance modes are excited. In order to verify the dual-frequency circular polarization characteristics of the modified crossed patch, the simulation analysis of the crossed patch is carried out separately. In order to avoid the influence of other factors, the antenna consists of only one crossed patch and feed, as shown in Figure 4 (a). It is obvious that the modified crossed patch has dual-frequency circular polarization characteristics as shown in Figure (b). Since the purpose of this study is to illustrate the dual-frequency circular polarization characteristics of the proposed crossed patch, there is no specific size adjustment for a certain frequency, only the patch is separated from the proposed slot antenna. The modified crossed patch has a compact size with a long arm of 28 mm and a short arm of 17 mm, which can be easily integrated into other antennas to achieve multi-frequency circular polarization.
Figure 4. Schematic diagram (a) and axial ratio (b) of the separated crossed patch.

Figure 5 shows the surface current distributions simulated by HFSS of the proposed antenna at 1.64 GHz and 3.45 GHz, respectively. It can be seen that the current at the lower frequency of 1.64 GHz is mainly distributed on the square ground plane, while the current at the high frequency of 3.45 GHz is mainly distributed on the crossed patch. The modified crossed patch has dual-frequency circular polarization performance as explained above, so for the sake of simplicity, only one frequency circular polarization mechanism is illustrated here. The current distribution on the patch in the slot of the proposed antenna is shown in Figure 6. In order to show the forming conditions of circular polarization wave more clearly, the current distribution of the upper half of the crossed patch is intercepted and amplified. The zoomed parts at the 0°, 90°, 180° and 270° phase states the dynamic distribution of current. At 0°, the current is mainly concentrated on the long arm (-45° direction), while at 90°, the current is mainly distributed on the short arm (+45° direction). For 180° and 270°, the direction of the current is opposite, which means that the phase of the current in the direction of -45° and 45° is orthogonal. The right-handed circular polarization (RHCP) field is generated by anticlockwise rotation over time.

4. Experimental Results

To verify the performance of the proposed antenna, the dual-frequency cp antenna was fabricated and tested by the N5234A PNA-L vector network analyzer. The measured results in Figure 7(a) show the impedance bandwidth for the lower band is about 240MHz from 1.55GHz to 1.79GHz (15% centered at 1.6 GHz), and the bandwidth of higher frequency is about 1466MHz from 2.2 GHz to 3.66 GHz (45% centered at 3.25 GHz). The measured 3-dB AR bandwidth of 14.1% and 15% are achieved in lower
frequency and higher frequency. The inner illustration in Figure 7(b) shows the experimental setup for measuring the proposed antenna and Figure 7(c) illustrates the measured gain and efficiency of the proposed dual-frequency cp antenna is better than 3dBi and 70% respectively. Figure 8 shows the far-field radiation patterns in both the xoz-plane and yoz-plane at 1.6 and 3.25 GHz. The radiated CP wave in +z direction is RHCP while in -z direction is LHCP. The simulation and test results are basically consistent. The deviation is due to the accuracy of the HFSS simulation software, antenna processing errors and the test environment. The comparison between the measured performances of the proposed antenna and antennas reported in [2]-[5] and [7]-[8] is listed in Table 2. The proposed dual-frequency circularly polarized antenna shows larger impedance and 3-dB AR bandwidths in both bands and has a more compact size.

![Antenna Prototype](image1)

![Simulated and Measured Efficiency and Gain](image2)

![Simulated and Measured S11 and Axial Ratio](image3)

![Simulated and Measured Radiation Patterns](image4)

![Xoz Plane](image5)

![YoZ Plane](image6)

**Figure 7.** Photograph of the antenna prototype (a), measured and simulated efficiency and gain (b), simulated and measured S11 and axial ratio for the proposed antenna (c).

**Figure 8.** Simulated and measured radiation patterns at 1.6 GHz(a) and 3.25 GHz(b).

| Ref. | Size; mm² | Freq.; GHz | S11 BW% | AR BW% |
|------|-----------|------------|----------|--------|
| [2]  | 75×75     | 1.5/3      | 1.17/1.05| 2.8/2.9|
| [3]  | 100×100   | 1.227/1.575| 2.4/3.8  | 0.65/0.64|
| [4]  | 115×115   | 1.22/1.57  | 16/12.5  | 6.9/0.6|
5. Conclusion
In this paper, a dual-frequency dual circular polarized antenna is proposed. The antenna has a simple structure, and only uses a single layer patch and a single feed. The dual-frequency circular polarization is realized mainly by the modified crossed patch in the rectangular slot. It has been proved that the improved crossed patch has dual-frequency circular polarization performance with wide impedance and axial ratio bandwidths. The impedance bandwidth of the antenna is 250MHz and 1440 MHz, and the axial ratio bandwidth of the antenna is 230MHz and 520 MHz respectively.

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