Designing a Dual-Feed Circular Polarization Antenna

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Abstract: This paper describes a novel dual-feed circularly polarized antenna, and the dual feeding mode is realized by grooving on the antenna radiator. The antenna utilizes air dielectric material to meet the requirements of low weight and cost. Test results demonstrate that the antenna exhibits capacitive loading between the metal antenna patch and the ground floor, allowing for adjustment of the working frequency of the dual-feed circularly polarized microstrip antenna. Specifically, the original center frequency of 2.264 GHz was reduced to 1.582 GHz, facilitating antenna miniaturization and broad bandwidth. With a return loss (S11) below -10 dB, a bandwidth of 72 MHz (1.552-1.624 GHz) was obtained. Additionally, the dual-feed microstrip antenna incorporates a 90° bridge, resulting in circular polarization gains of 2.26 dBi at 1.561 GHz and 2.45 dBi at 1.575 GHz. Overall, the antenna design offers a large working bandwidth and excellent circular polarization characteristics, making it suitable for a wide range of applications in satellite navigation and positioning terminals.

Keywords: Air dielectric; Circular polarization; Dual-feed; Microstrip antenna

1. Introduction

The antenna is the key signal transceiver component in a terminal system, and its performance directly affects the quality of satellite communication. the frequencies utilized in common satellite navigation and positioning systems for end-users predominantly reside within the 1.575 GHz (L1 & B1C) and 1.561 GHz (B1I) bands. Additionally, the antenna must exhibit right-hand circular polarization (RHCP) characteristics to effectively interface with these systems [1-3].

Circularly polarized microstrip antennas offer the benefits of being low profile and lightweight, with strong anti-interference capabilities and the ability to receive signals with arbitrary polarization. However, traditional single-feed circularly polarized microstrip antennas are often limited in performance and application scenarios [4-6]. In response to the demands of modern industrial terminal products for satellite communication, the dual-feed circularly polarized microstrip antenna has emerged as the market mainstream. This antenna not only enhances the positioning accuracy of satellite navigation but also caters to the evolving needs of satellite communication in various scenarios [7,8].

In this paper, we designed a circularly polarized microstrip antenna for satellite navigation positioning

using an air dielectric scheme [9]. The antenna consists of an upper metal radiator and a lower glass fiberboard (FR4, 1.2 mm thick) with a copper-coated ground plane. The dual feeding design is achieved through slot structures on the antenna radiator. To achieve circular polarization, we integrated an SMD 90-degree 3dB coupler made of ceramic dielectric material. This coupler excites two feeders with equal amplitude and a 90-degree phase difference. Our antenna is compatible with both USA and China satellite navigation positioning systems.

2. Design of circular polarization antenna

As shown in **Figure 1**, a dual-feed circularly polarized microstrip antenna can achieve circular polarization by exciting two linearly polarized waves of equal amplitude and a 90° phase difference (TM_{01} and TM_{10} modes) through feeding terminals A and B [10,11].

The dielectric constant of the microstrip antenna's dielectric material is used in the relevant calculations, as outlined below [12,13]:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{-\frac{1}{2}} \tag{1}$$

$$W = \frac{c}{2f}\left(\frac{\varepsilon_r + 1}{2}\right)^{-\frac{1}{2}} \tag{2}$$

$$L = \frac{c}{2f\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{3}$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{4}$$

where h is the height of the dielectric plate, W and L are the width and length of the radiating metal patch, respectively, and $\triangle L$ is the length of the equivalent radiating gap.

The electric field radiation is expressed as Equation 6.

$$E = \frac{f(\theta, \varphi)}{\varepsilon_r - \sin\theta\cos^2\varphi}[\hat{\theta}(\varepsilon_r - \sin^2\theta) + \hat{\varphi}\varepsilon_r\cos\theta\cos\varphi] \tag{5}$$

$$f(\theta, \varphi) = \frac{\sin(kL\sin\theta\cos\varphi)}{kL\sin\theta\cos\varphi} \tag{6}$$

Where $\hat{\theta}$ and $\hat{\varphi}$ are unit vectors of spherical coordinates θ and φ, respectively.

Parameter k is the wave number of free space, expressed in the following formula:

$$k\frac{L}{2} = \frac{\pi}{2\sqrt{\varepsilon_r}} \tag{7}$$

The radiative electric field expression formulas of the E plane (y-z) and the H plane (x-z, when $\varphi = 0$) are as follows:

$$E = E_0\cos\left(k\frac{L}{2}\sin\theta\right)\hat{\theta} \tag{8}$$

$$E = E_0 \frac{sin\left(k\frac{L}{2}sin\,\theta\right)}{k\frac{L}{2}sin\,\theta}cos\,\theta\,\hat{\varphi} \qquad (9)$$

E_0 is expressed as Equation 10:

$$E_0 = \frac{jk\frac{L}{2}HM}{\pi r}e^{-jkr} \qquad (10)$$
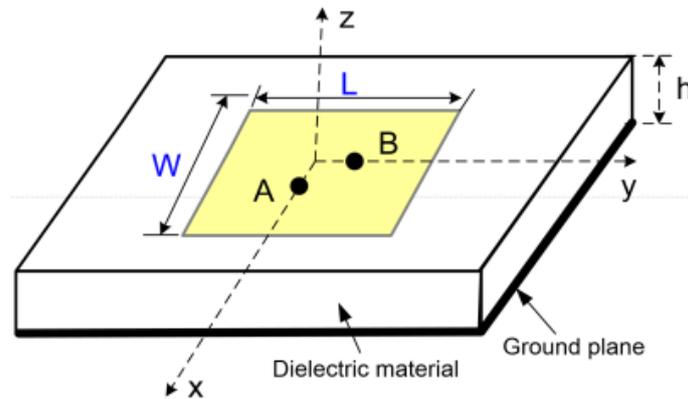
Figure 1. Microstrip antenna structure

3. Structural design

The operating frequency of a dual-feed circularly polarized microstrip antenna was determined by its geometry and the dielectric constant of its substrate. The dielectric material used was air, with a dielectric constant of 1.0. The antenna radiator was designed using metal stamping technology. The dimensions of the antenna were 35 mm in length and width, with an air dielectric height of 6 mm. The ground plane was made of metal-clad copper on a glass fiberboard (FR4) with a thickness of 1.2 mm and dimensions of 50 mm in length and width, as shown in **Figure 2**.
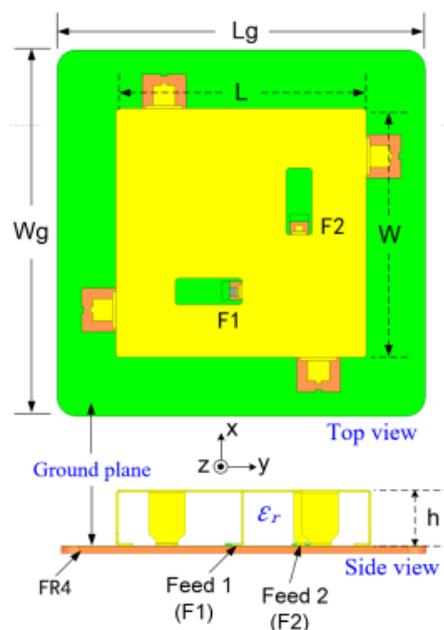
Figure 2. Structure of the double-feed circular polarization microstrip antenna

Metal pins were reserved on the four sides of the metal patch antenna to connect it to the base plate, and slots were cut into the base plate to design a matching circuit. Capacitive loads (C1, C2, C3, C4) were inserted between the metal patch and the ground plane to lower the operating frequency of the metal patch antenna, achieving miniaturization and wide bandwidth, as shown in **Figure 3**. The bandwidth met the operating requirements of GPS and BDS (L1 and B1C: 1575 MHz and B1I: 1561 MHz). The antenna was composed of an upper metal antenna oscillator and a lower glass fiber (FR4) base plate. The two feeding points were designed using a slot structure on the antenna radiator. A 90-degree 3dB coupler made of SMD-type ceramic dielectric material was integrated to generate two feeding signals with equal amplitude and a 90-degree phase difference, achieving circular polarization.
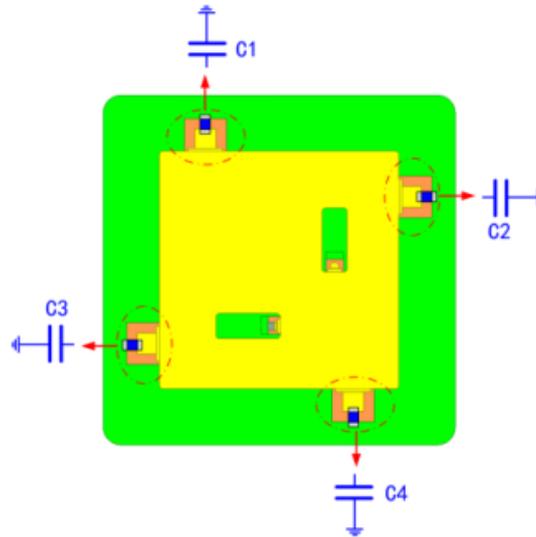
Figure 3. Schematic of the added capacitive load

4. Simulation and experimental results

Under the parameters of size, length $W = L = 35$ mm, and height of air dielectric $h = 6$ mm, simulation results showed that without capacitive loads, the S-parameter curves of ports F1 and F2 were almost completely overlapping. When the return loss was less than -10 dB, the S-parameter curves of the antenna were almost identical, providing a bandwidth of 42 MHz (2.244-2.286 GHz). By loading capacitive loads between the metal antenna patch and the ground plate with optimal values of C1 = 0.9 pF, C2 = 0.9 pF, C3 = 0.6 pF, and C4 = 0.6 pF, the S-parameter curves of the antenna ports F1 and F2 also matched almost completely, reducing the working frequency of the dual-feed circularly polarized microstrip antenna. When the return loss was less than -10 dB, a bandwidth of 78 MHz (1.542-1.620 GHz) was obtained, as shown in **Figure 4**.

Measured results of the antenna without capacitive load also showed that the S-parameters were nearly identical. With a return loss of less than -10 dB, the bandwidth was 46 MHz (2.246–2.292 GHz). When the simulation model was loaded with the specified capacitive loads, the S-parameter curves remained nearly overlapping, and the original center frequency of 2.264 GHz was adjusted down to 1.582 GHz, achieving a frequency reduction percentage of 30%. This adjustment provided a bandwidth of 72 MHz (1.552–1.624 GHz) when the return loss was less than -10 dB, as shown in **Figure 5**. The test and simulation results were consistent, successfully covering the GPS and BDS (L1 and B1C: 1575 MHz and B1I: 1561 MHz) bands.
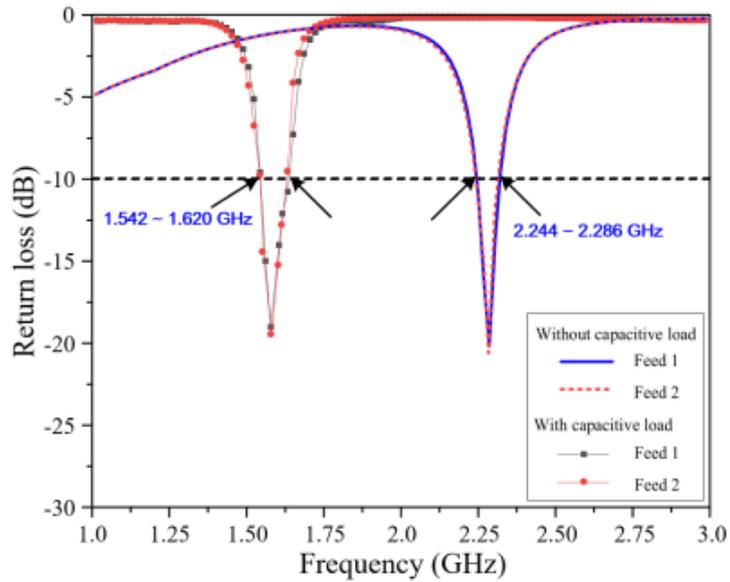
Figure 4. Simulated return loss of the proposed antenna
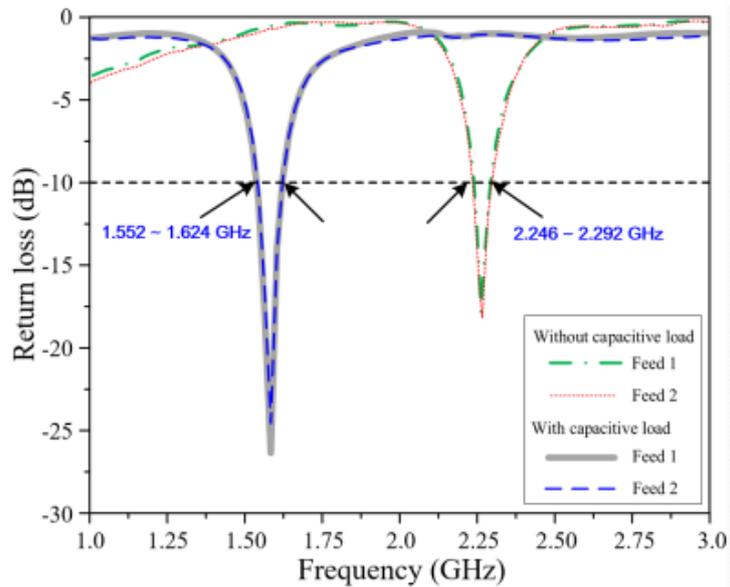
Figure 5. Measured return loss of the proposed antenna

Figure 6 shows the comparison of the gain and efficiency between the simulation and actual measurement of the dual-feed microstrip antenna loaded with a capacitive load. The results indicate that both gain and efficiency are stable within the working band, and the simulation and measurement curves are in good agreement, demonstrating consistent performance. **Figure 7** presents the measured gain and efficiency of the antenna with the capacitive load and integrated 90° coupler. At the frequency of 1.561 GHz, the gain and efficiency of the antenna were 2.26 dBi and 41.3%, respectively. At 1.575 GHz, the gain and efficiency were 2.45 dBi and 44.7%, respectively.
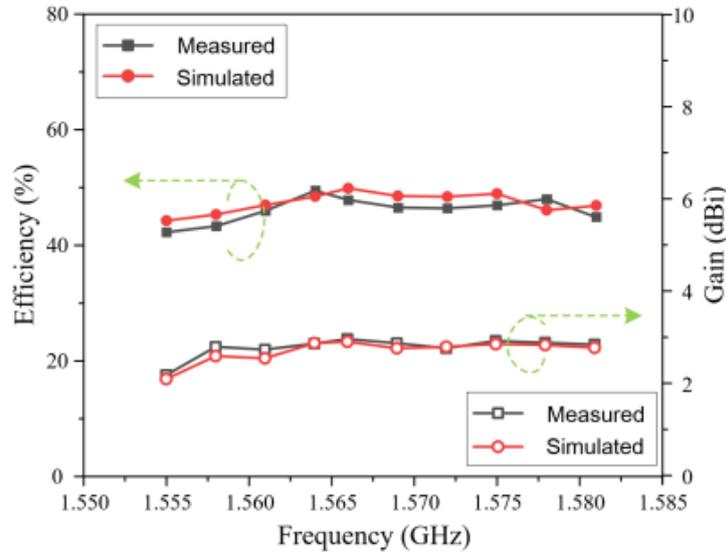
Figure 6. Gain and efficiency of the proposed antenna (with capacitive load)
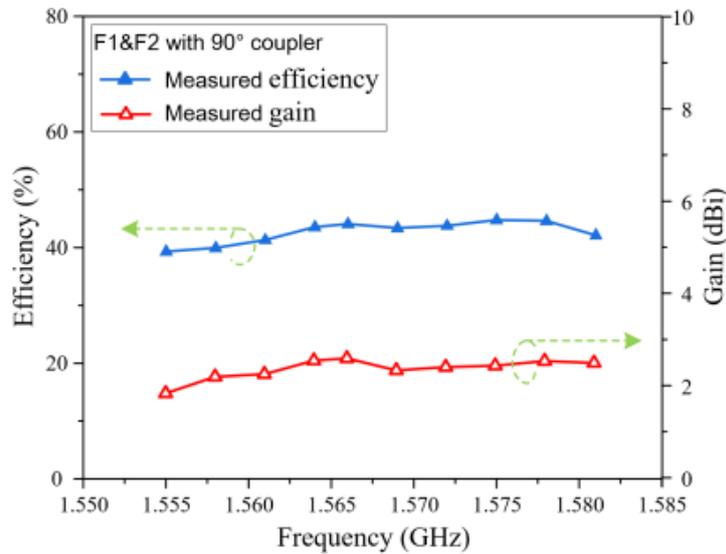
Figure 7. Measured gain and efficiency of the proposed antenna (with capacitive load and 90° coupler)

5. Conclusion

In this paper, a dual-feed circular polarized microstrip antenna with an integrated bridge was designed. Air was utilized as the dielectric material to meet the requirements for lightweight and cost-effective antennas. By loading a capacitive load, the working frequency of the antenna was adjusted from the original center frequency of 2.264 GHz to 1.582 GHz, achieving a frequency reduction of 30%. This adjustment enabled antenna miniaturization and provided a large bandwidth, making the antenna suitable for widespread use in satellite navigation and positioning terminals.

Disclosure statement

The authors declare no conflict of interest.

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