Design of a Small-size Broadband Circularly Polarization Microstrip Antenna

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Abstract. The information transmission of wireless system in coal mine has been faced with severe challenges, and the traditional wireless measurement method has the problems of low anti-interference ability and low reliability. The wireless system based on the temperature, humidity and harmful gas measurement of ultra-high frequency radio frequency identification (UHF RFID) technology can effectively improve the reliability of the system and enhance the safety of the operation in the coal mine. In order to detect the status in the coal mines in real time, this paper designs an ultra-high frequency micro-strip antenna with high gain, wide frequency band and circular polarization. Through the simulation, it can show the influence of different parameters on the antenna performance and obtain the optimal design size of the antenna with center frequency of 915MHz. Finally, through the experiment, it can obtain the micro-strip antenna with the gain of 3.84dBi and the circular polarization frequency band of 75MHz which meets the application of the ultra-high frequency radio frequency identification system in the coal mines.

1. Introduction
With the development of radio technology and radar technology, the radio technology has a broad application prospect. However, in some environments such as coal mine tunnels, the electromagnetic waves emitted by the radio antenna will be blocked by some obstacles such as tunnel walls, thus causing reflection, scattering, diffraction and other phenomena, that is, multipath effect[1-2], which limits the application of wireless communication. At present, the wireless communication system in coal mine generally has some problems such as weak ability of receiving signal, low anti-interference performance and large background noise, which prevents the wireless communication technology from being widely used in coal mine. Therefore, it is of great significance to establish a reliable communication system in the coal mine for improving the modern management level and labor productivity of coal mine.

Adopting the wireless system to measure the temperature, humidity, harmful gas and other data in the coal mine has greatly improved the safety of mining, can effectively enhance the space utilization rate, and can obtain the data detected in multiple directions[3]. Moreover, the antenna is an indispensable part in the field of wireless communication. For example, in such a long and narrow area as a coal mine, the antenna system usually adopts omnidirectional antenna to cover it. However, in this environment, the signal is high in the penetration loss and large in the free space loss, and the attenuation trend of the signal is different at different positions[4]. Therefore, the traditional omnidirectional antenna is difficult to meet the coverage requirements, and there are some phenomena such as unstable signal distribution and blind spots. The application of ultra-high frequency radio frequency identification technology can improve these problems and realize long-distance passive information transmission in the coal mines[5].

The micro-strip antenna is an important part of ultra-high frequency radio frequency identification
system, which has been deeply studied by scholars from all over the world. Deshmukh and other people cut L-shaped slots in the radiation patch to increase the bandwidth of the antenna and then analyze it[6]. After that, they studied the U-shaped slot micro-strip antenna and proposed and the size optimization formula of U-shaped slot[7]. Professor Jiuhan Lu used double L-shaped slots as the ultra-high frequency planar circularly polarization micro-strip antenna of the feed network[8]. Associate Professor Weiping Ding of PLA University of Technology designed a dual polarized micro-strip antenna combining L-shaped probe and H-shaped slot coupling[9]. Based on the above documents mentioned, this paper designs a small-sized broadband circularly polarization micro-strip antenna, which requires the frequency band to cover from 900MHz to 950MHz and axial ratio to be less than 3dB.

2. Structural design, simulation and optimization of antenna

As shown in figure 1, the antenna structure designed in this paper adopts a rectangular wide slot antenna structure with a circle shape. This structure has the advantages of wide antenna frequency bandwidth, simple production and low mask tolerance requirements. In order to increase the antenna bandwidth, the radiation surface adopts the L-shaped radiation band with the rough turning point to excite two resonant diaphragms with the phase difference of 90 degrees. The broadband circularly polarization antenna is formed by the mode of feeding of the F-shaped micro-strip antenna.

![Figure 1. Antenna structure chart](image)

In the figure, the antenna slot is Dx in length and Dy in width. The first horizontal line length of the F-shaped strip carved at the bottom of the baseboard is L1. The second horizontal line adjusts the input impedance of the circularly polarization antenna as a tuning stub and is placed above the annular ground plane with the length of L2. At the same time, it leaves a slot with the width of G1 with the annular ground plane to create the capacitance effect. The vertical length of the micro-strip feed line is L3, the width of the horizontal connecting strip is W2, and the micro-strip feed line width is W3. The L-shaped radiation band is W1 in length and L4 in width. The width of the connecting rod is D1. The L-shaped band at the turning point is D2 in width and D3 in the length. Based on the above parameters, this antenna model is simulated and optimized to design a micro-strip antenna with the standard performance.

The design method of the antenna is generally based on the theoretical analysis of the antenna, and the antenna structure is analyzed and optimized by the simulation software. Finally, the performance of the antenna is verified by the experiment. This paper uses the software simulation analysis to simulate and optimize the antenna. There is much simulation software, such as CST based on the finite integral in time domain and frequency domain, ANSYS based on finite element method and ADS based on moment method. This paper uses ANSYS to simulate and design the antenna, and optimize and analyze the important dimension parameters to complete the antenna design.

2.1. Design of L-shaped slot structure

In order to increase the working bandwidth of circularly polarization antenna, the parameters of D1, D2 and D3 of L-shaped slot are properly adjusted and simulated to obtain the simulation results such as axial ratio and bandwidth. Among them, the size parameters of D2 and D3 have obvious influence on the frequency band, and the influence effect is as shown in figure 2.
The value of $D_2$ will affect the center frequency and axial ratio of the antenna. With the increase of $D_2$, the center frequency of the antenna will gradually increase and the degree of circular polarization will decrease. The parameter of $D_3$ has a great influence on the center frequency of the antenna. Through the simulation result, it can show that when the value of $D_2$ is 3.5mm and the value of $D_3$ is 8mm, the center frequency of the antenna is approximately 915MHz.

2.2. Design of the antenna with the square slot structure
The parameters of $D_x$ and $D_y$ of the square slot are adjusted to simulate the antenna. The simulation results are as shown in figure 3.

It can be seen from the figure that the increase of the size of $D_x$ reduces the center frequency of the return loss, and its value has a great influence on the circularly polarization of the antenna. When the value of $D_x$ is 78mm, the antenna is circularly polarization in the operating frequency band and has the lowest return loss, which meets the job demand. When the value of $D_y$ is 83mm, the antenna has the
lowest return loss and its center frequency is around 880MHz. The center frequency can be moved to 915MHz by adjusting other parameters to meet the antenna demand.

2.3. Design of the antenna with the F-shaped feed line structure

By adjusting the width and length of the F-shaped feed line, the axial ratio, return loss and impedance of the antenna designed in this paper are simulated. The simulation results are as shown in figure 4.

![Image](https://placehold.it/500x300)

Figure 4. Influence of F-shaped structure on the antenna performance

The simulation results show that the value of G1 has a great influence on the return loss and axis ratio of the antenna. When the value of G1 is 1mm, the axial ratio is less than 3dB and the return loss is less than -20dB. The increase of the size of L1 will reduce the frequency band and center frequency of the return loss. The frequency band with the antenna axial ratio of 3dB shifts to the left. When the value of L1 is 43.75mm, the frequency band is between 890MHz and 948MHz. The change of the value of L2 will cause the change of antenna impedance, so as to change the realized impedance by adjusting the value of L2. The size of W2 has little effect on the frequency band of the antenna and can’t be considered too much.

Combined with the above size results, the optimized parameters of the antenna can be finally obtained, as shown in table 1:
Table 1. Antenna parameter choice

| Parameter | Value (mm) | Parameter | Value (mm) | Parameter | Value (mm) |
|-----------|------------|-----------|------------|-----------|------------|
| Dx        | 78         | L1        | 36.5       | W3        | 0.5        |
| Dy        | 84         | L2        | 36.5       | R         | 60         |
| W1        | 43         | L3        | 27.5       | G1        | 1          |
| W2        | 7.2        | L4        | 44.65      |           |            |

According to the parameters in the table, the designed antenna is simulated and the results are as shown in figure 5. It can be seen from the figure that the obtained micro-strip antenna gain is larger than the design target of 3dBi. The bandwidth is 0.18MHz when the standing wave ratio is less than 1.4. The frequency band is between 870MHz and 970MHz when the return loss is less than -20dB. The return loss is -42dB when the center frequency is 915MHz. When the frequency is between 900MHz and 970MHz, the axial ratio of the antenna is less than 3dB and the antenna is circularly polarization. Through the above simulation to analyze the characteristic impedance of the antenna in the frequency band, adjust the antenna impedance to match to 52.89Ω+j1.57. In conclusion, the intersection frequency band of the axial ratio and the return loss of S11 are between 900MHz and 970MHz, which meets the demand of antenna bandwidth in the design target and the antenna gain also meets the design target.

3. Experimental analysis
The feasibility of the antenna is verified by the experiment. The performance of the fabricated micro-strip antenna is tested by using a network analyzer and an anechoic chamber. The antenna is as shown in figure 6. By placing the antenna designed in this paper at the receiving end and rotating it by 180, the gain of the antenna can be obtained.
The experimental result is as shown in the figure 7:

According to the experimental results, the S11 frequency band of the antenna's return loss shifts to the left, but still covers 870-940MHz. The frequency band with the voltage standing wave ratio (VSWR) lower than 1.4 is 865MHz-1GHz, which meets the requirements. From the Smith impedance diagram in figure 7(c), it can be seen that the characteristic impedance of the antenna varies from 53Ω+1.6969JΩ to 45Ω+11.991Ω when the frequency band is between 900MHz and 930MHz and is 50.489Ω-1.7545Ω when the frequency band is 915MHz, which is basically consistent with the target value of 50Ω and has good matching performance. As the experimental results is shown in figure 7(d), the gain is 3.48dBi when the antenna is at 915MHz, which meets the design requirement that the target value of antenna gain is larger than 3dBi. To sum up, the circular broadband circularly polarized micro-strip antenna designed in this paper meets the task requirements.

4. Conclusion
In order to solve the problem that the signal of the traditional antenna in the coal mine is unstable and can’t meet the coverage requirements, this paper designs a small-size ultra-high frequency micro-strip antenna with high gain, wide frequency band and circular polarization by using UHF RFID technology, analyzes the key parameters of the antenna by using ANSYS simulation software, and obtains the law of the influence of different parameters on the antenna performance, thus obtaining the optimal design size of the antenna. Finally, through experiments, it can be concluded that the gain of the antenna designed in this paper is 3.48dBi and the circular polarization band reaches 75MHz. The theory is consistent with the experiment and meets the application requirements.
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