Intelligent mine vehicle terminal antenna based on LTCC technology

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Abstract. A new type of laminate antenna for smart mining vehicle terminal based on low temperature co-fired ceramic (LTCC) technology is proposed. This antenna adopts a simple structure on an LTCC substrate which consists of two layers of rectangular radiating patches with cut corners and a gap inserted in the middle. A laminate structure is designed to cause dual-frequency resonance in order to expand working bandwidth further. A good circular polarization performance can be obtained by adjusting the gap and cut corner size of the upper and lower radiation patches. The software HFSS is used for simulation design. It can be seen from simulation results that the impedance bandwidth (IBW) of the antenna with return loss less than -10dB is 102MHz, ranging from 2.507 to 2.609GHz, and the size of the antenna is 25×28×4.6 mm³.

1.Introduction

In recent years, low-temperature co-fired ceramics (LTCC) technology has been widely used in the field of wireless communication due to the special characteristics of its sintered materials, such as high dielectric constant, low dielectric loss, and high quality [1]. Compared with traditional printed circuit boards, LTCC technology has great advantages in the design of multi-layer miniaturized antennas [2], because it can use through holes, buried holes and blind holes at any position on the substrate. LTCC has multiple layers and the manufacturing process is flexible and mature which can realize the integration of any number of LTCC layers [3]. In addition, adding passive components such as resistors and capacitors to the LTCC structure can produce multifunctional devices that meet high-performance requirements [4], provide high-quality and high-frequency characteristics of small loss tangent for microwave radio frequency integrated circuits. It is recognized that miniaturization, light weight and high frequency performance in the millimeter wave band are the most promising technologies.

With the rapid development of the wireless communication field, the demand for circularly polarized (CP) microstrip antennas with multi-band operating frequencies and high gain has increased. The CP antenna has the effect of reducing polarization mismatch and suppressing multipath interference, and it does not require a hard directional design between the receiving and transmitting antennas. The working bandwidth of CP microstrip patch antennas studied in the past is about 1% [8]. In recent years, some techniques to expand the bandwidth have been developed, such as stacked patch antennas [9], L-shaped or zigzag probe feeds electric patch antenna [10] and so on. The above-mentioned antenna structure and new feeding method can expand the bandwidth to about 15%. It is also possible to add parasitic patches on the radiating patch or notch it to generate a new resonant
frequency\cite{11}. It is also possible to cut the angle of the radiating patch and use the I-type branch to make the impedance bandwidth (IBW) of the antenna (S11<-10dB) and axial-ratio (AR<-3dB) bandwidth are 24% and 17.3%, respectively\cite{12}.

Based on previous studies, a vehicle-mounted terminal antenna for smart mining is proposed in this paper. Wide bandwidth is realized by using two stacked patch antenna structures which can form two resonant circuits, so that the antenna produces two resonant frequency points. When this two resonance frequency points are appropriately close, the bandwidth is increased.

A good impedance matching can be achieved and two orthogonal degenerate modes can be excited by adjusting and optimizing the position of the feed point. And then, the rectangular patch gap and corner size can be optimized in order to obtain better circular polarization performance, while wide-side radiation can be achieved. The impedance bandwidth of the antenna is 102MHz, and the range is from 2.507 to 2.609GHz. The size of the antenna is 25×28×4.63mm.

The design details and characteristics of the antenna will be discussed in detail.

2. Antenna Design and Analysis

The choice of substrate material (dielectric constant and loss tangent) and the thickness of the substrate are important factors that affect the size of the microstrip antenna. When the substrate becomes thicker, the surface wave will be generated, which will affect the radiation characteristics of the antenna. Choosing a substrate with a high dielectric constant can achieve a miniaturized antenna design, but it will also reduce the antenna's radiation efficiency. Consider the application of vehicle terminal in actual engineering, LTCC material with relative dielectric constant of 14 and loss tangent of 0.002 is selected as the lower dielectric substrate, and LTCC material with relative dielectric constant of 6 and loss tangent of 0.001 is selected as the upper dielectric substrate, with thicknesses of 3mm and 1.6mm, respectively.

Fig.1(a) shows the three-dimensional geometry of the designed antenna in detail. In order to expand the bandwidth and increase the gain of the antenna, the designed antenna is shown in Fig.1(b) which composed of upper and lower laminated patches and LTCC dielectric substrate. The upper radiating patch is rotated 90 degrees relative to the lower radiating patch, the lower radiation patch can be regarded as the ground plane of the upper radiation patch, feed probe is directly connected to the upper patch through the circular hole of the lower radiation patch, lower patch is indirectly coupled and fed through the coaxial inner core and the circular hole gap on the patch. Fig.1(c) is the top view of the antenna, the size of the lower layer radiating patch is slightly larger than that of the upper layer, and the resonance frequency caused by it is 2.52GHz, while the resonance frequency caused by the upper layer radiating patch is 2.58GHz. Circularly polarized radiation can be realized by adjusting the position of the feed point and the size of the rectangular radiating patch cut corner and insertion gap. That’s because separation of degenerate quadrature modes is realized, so that the phase difference of the impedance of the two modes is 90 degrees.

![Fig. 1. Geometry of the proposed antenna.](image)

In order to explore the process of antenna design, four prototypes of the proposed antenna are shown in Fig.2. Ant.1 is the initial model of the final designed antenna, but the simulation result of Ant1 antenna as shown (Ant.1 curve) in Fig.3 do not get a good working bandwidth. The second step is to insert a rectangular slot in the middle of the radiation patch on the basis of the Ant.1, but the
simulation results show that the main influence is the resonant frequency of the antenna. The third step is to add a layer of LTCC dielectric substrate and a rectangular radiation patch with cut corners on the basis of the Ant.2. As shown (Ant.3 curve) in Fig.3, the working bandwidth becomes wider, this can also explain the aforementioned use of the resonance frequency of the upper and lower radiation patches to cause an increase in bandwidth. In the fourth step, imitating the second step, insert a rectangular gap in the middle of the uppermost radiating patch to change the effective length of the radiating patch. As shown in(Ant.4 curve) in Fig.3, the two resonant frequencies of the antenna are improved. As it approaches, the working bandwidth of the antenna increases.

Fig.2. Design procedure of the proposed antenna.

Fig.3. Simulated results for Ant. 1–Ant. 4: return loss.

3. Parameter Study Of The Antenna
The position $d$ of the feeding point, the size $w$, $l$ of the upper and lower radiation patches, and the rectangular cut corner size $s_1$, $s_2$ will be discussed in this section in order to study the influence of various parameters on the antenna performance. The proposed design scheme was verified, and the optimal size of the antenna was finally obtained.

Since the upper and lower radiation patches resonate at different frequencies, difficult to find a single point that matches 50Ω. In order to obtain the minimum return loss, strict simulation calculations are carried out. As shown in Fig.4, $S_{11}$ curve gradually increases with $d$ from 2mm to
2.28mm, the $S_{11}$ characteristics gradually improve and affect the resonance frequency of the radiation patch. Finally, 2.22mm is selected as the value of $d$ to determine the position of the feeding point.

![Fig. 4. Effect of $d$ on antenna performance: $S_{11}$.](image)

Fig.5 is the return loss $S_{11}$ curve with changes in $w$ and $l$. As the size $w$ of the lower radiating patch increases, the resonant frequency of the antenna moves towards low frequencies, as the size $l$ of the upper radiation patch increases, the resonant frequency of the antenna also moves to low frequencies, and the two resonant frequencies of the antenna are close. Therefore, by appropriately adjusting the size of the two radiating patches, the resonant frequency of the antenna can be kept within the required range, and the IBW of the antenna can be increased. Finally, 13.4mm is selected as the value of $w$ and 13mm is selected as the value of $l$.

![Fig. 5. Effect of $w$, $l$ on antenna performance: $S_{11}$.](image)

Fig.6 is the return loss $S_{11}$ and the AR(axial ratio) curves with $s_1$ and $s_2$ respectively. From the diagrams (a) and (b), it can be seen that with the increase of $s_1$, two resonant frequencies appear in the antenna, and the impedance matching becomes worse when the resonant frequency moves to high frequency. With the increase of $s_2$, it does not have much effect on the trend of $S_{11}$ curve, but the change of $s_1$ and $s_2$ will affect the circular polarization characteristics of the antenna. Figures (c) and (d) are graphs of the relationship between the axial ratio and the elevation angle theta, indicating that as the size of the cut angle increases, the beam range with the axial ratio less than 3dB will become smaller. Finally, choose 1.93mm as the value of $s_1$ and 3.1mm as the value of $s_2$. 
Based on the above discussion, the optimal detailed size of the designed antenna element is shown in TABLE1. Under the optimal size, the corresponding circular polarization normalized radiation pattern of XOZ plane and YOZ plane antenna at 2.55GHz is simulated, the symmetrical radiation pattern is obvious. In addition, left-handed circularly polarized radiation is realized in the +Z direction, and right-handed circularly polarized radiation is realized in the -Z direction. At the same time, the XOZ plane and the YOZ plane show good broadside radiation.

**TABLE 1 DIMENSION OF THE PROPOSED ANTENNA (UNIT: mm)**

| Parameters | Values(mm) | Parameters | Values(mm) |
|------------|------------|------------|------------|
| a₁         | 28         | w          | 13.4       |
| a₂         | 25         | l          | 13         |
| h₁         | 3          | s₁         | 1.93       |
| h₂         | 1.6        | s₂         | 3.1        |
4. Conclusion

An antenna based on LTCC technology for smart mining vehicle terminal is studied. A good circular polarization performance and impedance matching are achieved by adjusting the position of the coaxial feed and the size of the upper and lower radiation patches. The multilayer structure provides a wide impedance bandwidth. It can be seen from simulation results that a bandwidth of 102MHz, and a maximum gain of 4.2 dBi. The size of the proposed antenna is limited to 25×28×4.6mm³. It can meet the needs of practical applications of in-vehicle terminals.

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