Design of A Novel Single-feed Antenna for Global Positioning System

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***Abstract*—This paper presents the design of a circularly polarized microstrip antenna for global positioning system (GPS). This single-feed and single-layer antenna works at the L1 (1559-1615MHZ) frequency band for civil use of GPS. There are two pairs of symmetric rectangular slots and circular slots in the diagonal directions respectively. The right-handed circular polarization (RHCP) is obtained by using the slight difference between the rectangular and circular slots. Four E-shaped shots are embedded on the ground plane to improve the antenna gain. The results show that the antenna gain has increased some 0.83dB. The -10dB impendence bandwidth is 39.3MHz and the 3dB axial ratio is 14.9MHz. It is obvious that this antenna can be used in GPS.**

Keywords*—*single-feed; circularly polarized (CP); axial ratio; bandwidth

I. INTRODUCTION

Global positioning system (GPS) was built by the United States. Nowadays, it is one of the most popular global positioning and navigation systems and enjoys a large share of the market. The system is widely applied in navigation, surveying, mapping, monitoring and communication fields. Due to the increasing demands for GPS, the key is to solve the problems of GPS receiver antenna technology. Microstrip patch antennas [1-3] and quadrifilar helix antennas [4-6] are generally adopted for GPS antenna. As the structure of quadrifilar helix antenna is relatively complicated, it is not easy to fabricate the antenna and the cost of fabrication is high. So the antenna in this paper uses a microstrip patch antenna because of its ease of fabrication, low profile and low cost. GPS antenna is right-handed circularly polarized. Circularly polarized (CP) antenna can receive an arbitrarily polarized wave and the wave of circularly polarized antenna can also be received by any arbitrarily polarized antenna. In view of these characteristics, CP antennas are widely applied in navigation systems.

Problems in the design of CP antenna are mainly feed methods and ways of realization of circular polarization. Feed methods of CP antennas are coaxial-probe feeder and microstrip line feeder. Microstrip line feeder needs to consider more elements, which involve the quarter wavelength microstrip line. So the overall size of microstrip antenna will increase. Single-feed CP antenna has more compact size compared with the CP antenna fed by microstrip line. Many ways are adopted to realize circular polarization. Common methods producing circular polarization are truncating corners [7-8], notching, opening slits, and adding tuning stubs [9-14]. In [15], two pairs of square ring slots are etched along the diagonals of the patch to realize circular polarization, and via holes are used to realize miniaturization.

In this paper, the design of a microstrip antenna with rectangular slots and circular slots along the diagonal directions to realize circular polarization is proposed. The circularly polarized microstrip antenna is single-feed to be compact. By adjusting the dimensions of the slots, the two orthogonal modes will be excited. The two modes have the phase difference of 90°, thus forming the circular polarized wave. Due to the small antenna gain of about 0.15dB, four structures of E-shaped slots are etched on the ground plane in order to improve the gain of antenna. The results show that after etching E-shaped slots, the antenna gain has been greatly increased. It will be easier to meet the needs of practical engineering applications.

II. ANTENNA DESIGN

The transmission line mode is adopted in this paper to calculate the dimensions of the antenna patch. The patch and substrate are square with the relative dielectric constant of ε_r, thickness of H and the central frequency of f_r. The length of patch can be given by

$$L = \frac{\lambda}{2} - 2 * \Delta L = \frac{1}{2 f_r \sqrt{\varepsilon_{reff}} \sqrt{u_0 \varepsilon_0}} - 2 * \Delta L \qquad (1)$$

where λ is the free-space wavelength and the effective relative dielectric constant ε_{reff} is given by

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

$$W = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{v_0}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (3)$$

where v_0 is the velocity of light in free space.

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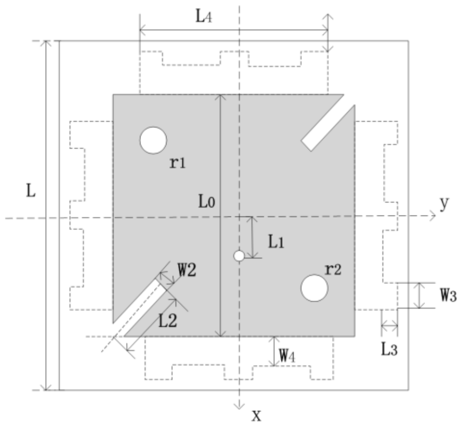
The added length of the patch is given by

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

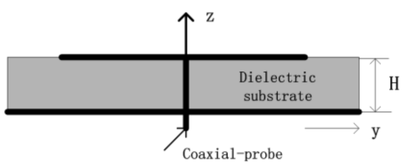
Geometry of the single-feed and single-layer microstrip antenna is shown in Fig. 1. The dielectric substrate is FR4-epoxy and the relative permittivity is ε_r = 4.4, the thickness of the substrate is H = 1.6 millimeters and the loss tangent is tanδ= 0.02. The patch is fed by a 50 Ohm coaxial probe. Fig. 1 (a) is the top view of the antenna. The shaded part in the graph is the patch. It can be seen from the graph that there are two pairs of symmetric rectangular slots and circular slots along two diagonals of the patch respectively. There is slight dimensional difference between the rectangular and circular slots. By adjusting the size of them, two equal amplitude and phase difference of 90 degrees of orthogonal degenerate mode (TM10 and TM01) can be excited, resulting in the right-handed circular polarization (RHCP).

Fig. 1(b) presents the specific location of the etched E-shaped slots on the ground. The four E-shaped slots are symmetric in orthogonal directions. As the loss angle of the antenna is big, the E-shaped slots can be used to increase the antenna gain. Slots on the ground will change antenna inductance and capacitance value, thus producing resistance effects and greatly improving the antenna gain.

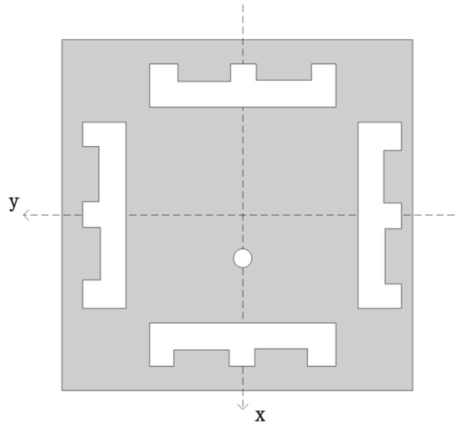
The initial value of L_0 can be calculated by (1), (2), (3) and (4). By optimizing the parameters of the antenna shown in Fig. 1, the overall dimensions are：L= 70mm, L_0= 43.5mm, L_1= 10.6mm, L_2= 10.3mm, W_2= 2.4mm, L_3= 1mm, W_3= 2mm, L_4= 35mm, W_4= 2mm, r_1= r_2= 2.1mm. Center points of the circles are (-15,-15,0) and (15,15,0).



(a)



(b)



(c)

Fig. 1. Geometry of the single-feed circularly polarized antenna for GPS: (a) top view, (b) cross-sectional view, and (c) bottom view.

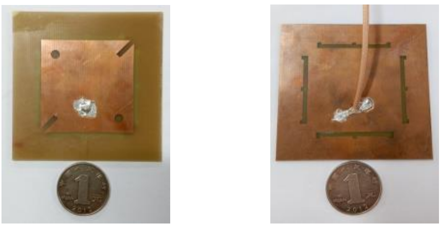
III. Results and Discussion

The antenna structure proposed in the paper was modeled and simulated in the simulation software HFSS3 13.0. And the material object was fabricated and can be seen in Fig. 2. In anechoic chamber, the vector network analyzer E5071C was used to measure the printed circuit board. The simulation and measurement results are shown as below.

As can be seen from Fig. 3, the simulated -10dB impedance bandwidth of the antenna is from 1.5642 to 1.6036 GHz (39.3 MHz). At center frequency (1.57542GHz) of L1 for the GPS antenna, the value of reflection coefficient is -16.68dB. The spectrum covers the GPS L1 frequency band and it is certain that the simulation results satisfy the requirements. It can be seen that measurement results have shifted compared with the simulation results, this is due to the measurement results have been influenced by the parameter error of medium plate, loss of SMA connector and measurement environment. But it can be seen that the results of measurement and simulation are in reasonable range of error. Fig. 4 is the simulation curve of axial ratio. It can be seen that the 3 dB axial ratio bandwidth is 1.5665 to 1.5814 GHz (14.9 MHZ), the axial ratio is 1.8372 dB at 1.57542 GHz. The antenna has realized the expected circular polarization.

Fig.5 has compared the gain results of ground plates with and without the four E-shaped slots. It is obvious that the antenna gain is small (0.1485dB) without four E-shaped slots on the ground at 1.57542GHz. After etching the four slots, the antenna gain has increased to 0.9579dB, which has increased by 0.8247dB. It can be concluded that the E-shaped slots can increase the antenna gain greatly and this antenna is able to meet the needs of practical projects.

Fig. 6 presents the simulated normalized radiation patterns at the center frequency of 1.57542GHz, Fig. 6 (a) and (b) are results of RHCP and left-handed circular polarization (LHCP) on the xz-plane and yz-plane respectively. As can be seen, the radiation intensity of RHCP is obviously much stronger than that of LHCP radiation. The RHCP antenna gain is 20dB more than LHCP antenna gain. The antenna shows good RHCP performance at 1.57542GHz. The RHCP gain is about 0.9245 and the antenna has excellent front lobe characteristic, thus



(a) (b)

reaching to the actual request.

Fig. 2. Fabricated prototype of the proposed antenna: (a) top view and (b) bottom view.

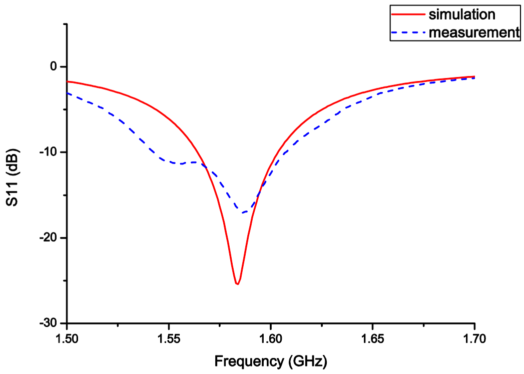


Fig. 3. Simulated and measured reflection coefficients of the proposed GPS antenna.

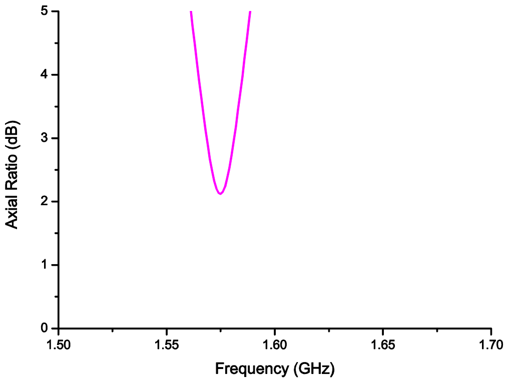


Fig. 4. Axial ratio of the proposed antenna.

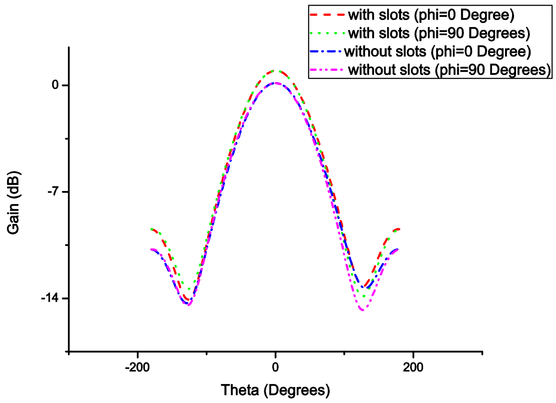
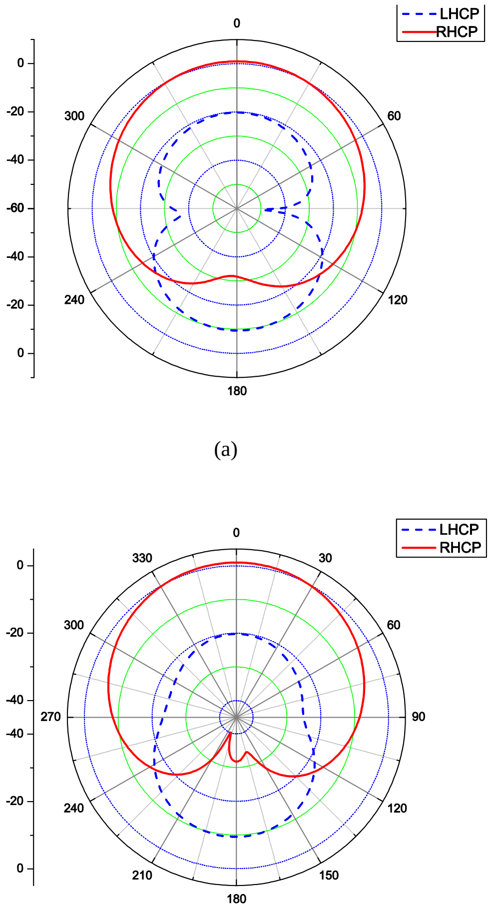


Fig. 5. Comparison of antenna gain with/without the four E-shaped slots at the frequency of 1.57542GHz.



(a)

(b)

Fig. 6. Normalized radiation patterns of the proposed antenna at 1.57542GHz: (a) xz-plane and (b) yz-plane.

IV. CONCLUSION

The paper proposes a CP antenna with symmetric rectangular slots and circular slots along the diagonal directions. In addition, the antenna gain has been greatly increased by adding E-shaped slots on the ground plane. After optimizing the parameters of the antenna and comparing simulated results with measured results, it is found that the reflection coefficient, -10 dB impedance bandwidth, axial ratio at the resonant frequency , -3dB axial ratio bandwidth and normalized radiation patterns can meet the requirements of global positioning system (GPS).

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