Design of Dual-band Microstrip Circularly-polarized Antenna with High Stable Phase Center

Zhang Botian, Jin Jing, Fan Haoliang, Cao Zhenxin

Abstract: Dual band, RHCP are essential to satellite receiving antenna and antenna phase center variations are a major error source of satellite navigation and positioning system, which cannot be ignored in high precision surveying applications Based on above application background, this article focuses on the analysis and the design of dual-band microstrip RHCP antenna with high stable phase center. In this study, we did research on a new design of microstrip antenna with 4 orthogonal configured probes with equal amplitude and 90° phase offset that can attain RHCP and high phase center stability and we applied stacked construction of two layers to the antenna for dual band. To satisfy the complicated feed network, we drew the feed circuit of three Wilkinson combiners in Advanced Design System and we built an HFSS design of to test and verify our overall design. As expected, simulation results show that: the antenna B1, B3 band axial ratio is less than 3dB, and the equivalent phase center deviation is less than 1mm in 60 degrees of antenna's main beam, which satisfies the requirements in millimeter scale accuracy of satellite navigation and positioning.

Key words: micro-strip antenna; phase center; dual band; Wilkinson power divider

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1 Introduction

At present, there are three kinds of satellite navigation system globally in the operation, American’s GPS system, Russia’s GLONASS system and China's Compass system. As satellite navigation and positioning system, one of its most important features is the high-precision measurement with the measurement accuracy of mm-class level, and it can be widely used in geodesy, engineering surveying, deformation measurement of large scale building and other fields.

In satellite measurements, the antenna phase center represents the observed subject, which means the measured distance is the distance from the satellite antenna phase center to the receiver antenna phase center. Theoretically, antenna phase center should consist with its geometric center, but because of the antenna characteristics, machining and other reasons, the phase center changes with the direction and strength of input signal. Therefore, because the instantaneous position of the antenna phase center (commonly known as the phase center) does not overlap the theoretical one, there is a certain deviation which has certain impact on results of satellite baseline solution. In light of this kind of influence can be up to a few millimeters to several centimeters, how to reduce the impact of the antenna phase center becomes an important factor that should be considered in the Compass measurements. [1]

2 Micro-strip antenna design

2.1 Stable phase center

If the electromagnetic waves radiated by the antenna as a spherical wave, and then the center of the sphere is the phase center of the antenna. Whether an antenna has a phase center or not depends entirely on the form of the antenna. Even if the antenna has one, it is generally only an apparent phase center of the antenna within a certain range of the main lobe. The stability of antenna phase center is the quantity of the dispersion degree of the antenna phase center of various tangent planes, and the minimum radius of the sphere containing all the phase center point of tangent plane.

[2]

Micro-strip antenna has many advantages. It has a low profile and light weight. It can be shaped into a variety of carriers. Feed network can be printed with the antenna which is suitable for mass production of printed circuit technology. It can achieve circular polarization, dual polarization and dual-band working easily. Therefore the satellite measurements antennas often use micro-strip antenna. [3]

One of the characteristics of the micro-strip antenna is that it can achieve circularly polarized easily. Circularly polarized micro-strip antenna has two forms: resonance micro-strip patch and traveling wave micro-strip linear antenna. Here the former is adopted. The basic principle of the resonant patch radiating circularly polarized wave is that: two mutually perpendicular linearly polarized electric field components is produced, with equal amplitude, and a phase difference of 90°.

Square patch of Figure 1 has four orthogonal configured probes with the phase 0°、90°、180°、270° sequentially. According to the cavity model theory of the rectangular micro-strip antenna, every pair of two adjacent feed points excite a pair of polarization orthogonal degenerate mode, and meet the working conditions of the circular polarization: two modes with equal amplitude, 90° phase shift, and guaranteed by the feed-forward electrical network. Additionally, every pair of probes located on the same axis has a 180° phase shift. TM01 or TM10 mode they excited is non-inverting superimposed, while unwanted TM02 and TM20 mode cancel each other out and TM11 mode is not able to motivated, bringing about a high purity of polarization. [4...8]

Here a feed laminated structure of the four feed-points in micro-strip patch dual-band antenna is proposed. It makes use of the Wilkinson power divider and phase shifter to design feed network to provide dual circular polarization, providing the four feed-point the amplitude required by dual circular polarization and phase excitation in order to reach the required the dual-band work and stable phase center.

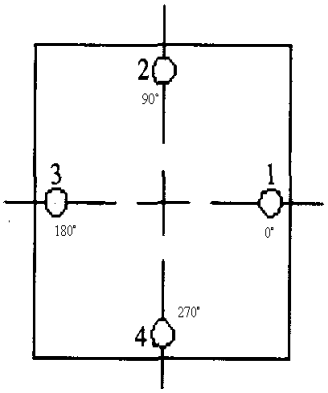

Fig. 1 Geometry of the four-feed micro-strip Compass antenna.

2.2 Antenna Design

The structure of the double antenna is shown in Figure 2. That antenna consists of 4 feed-points, right-handed circularly polarized micro-strip patch antenna of different frequency bands. Two layers of the patch are square, concentrically placed above the dielectric substrate. Lower patch antenna (B3) is the low-band; upper patch antenna (B1) is the high band. The low-band patch antenna can be used as the high band antenna's ground because of its bigger patch. The ground contact surface of duplex print version can be used as transmit antennas' ground strata and the other surface is designed as the feed network. In order to facilitate the design of the feed network, the dielectric constant of the two dielectric substrates have a distinct difference: the lower antenna dielectric substrate $\varepsilon_1 = 2.5$, with a thickness of 5 mm, the upper antenna dielectric substrate $\varepsilon_2 = 9.8$, with a thickness of 4 mm.

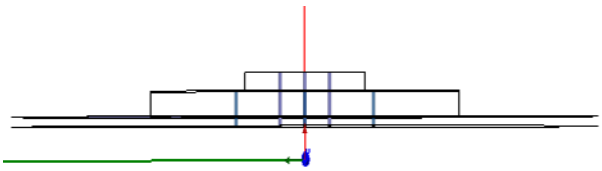

Fig. 2 Geometry of the stacked-patch micro-strip Compass antenna.

Using the transmission line model method to calculate rectangular micro-strip antenna size: [4]

W.V.Schneider's empirical formula：

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10h}{a}\right)^{-\frac{1}{2}} \quad (1)$$

E.Hammererstad's empirical formula:

$$\Delta l = 0.412h\left(\frac{\varepsilon_e + 0.3}{\varepsilon_e - 0.258}\right)\left(\frac{a/h + 0.264}{a/h + 0.8}\right) \quad (2)$$

The resonator length is:

$$b = \frac{c}{2 f_r \sqrt{\varepsilon_e}} - 2\Delta l \quad (3)$$

Since using the above formula to calculate the length of the resonator will cause changes of rest of the parameters, in the actual calculation use Matlab program to refine the resonant frequency and the resonant input resistor iteratively to give the actual dimensions: the lower side length of patch al=75.4mm, the feed-point position xl=34,7mm, the upper side length of patch au=29.7mm, the feed point location xu=7.8mm.

3 Feed Electrical Network Design

The purpose of the feed network is to drive the feed points with equal amplitudes and

a 90° phase shift to obtain right-hand circular polarization (RHCP) and to provide a matched input to the antenna. This was done using the micro-strip feed network, shown in Fig. 3. Three Wilkinson power combiners are used to add the signals from the four feed lines at the feed points with equal amplitudes and the proper phase shifts. As seen from Fig. 3, each pair of feed lines crosses each slot arm in opposite directions. This introduces a 180° phase shift between lines at opposite point feeds. This phase shift, together with the 90° phase shift between points required for circular polarization, results in a sequential rotation in phase of 0°, 90°, 180°, and 270° around the four feed points. The two Wilkinson combiners closest to the feed points combine power from adjacent feed ports after introducing a 90° phase shift in one of the input lines. The last Wilkinson combiner adds the outputs of the previous combiners after introducing a 180° phase shift in one of its input lines. The input and output impedances of the combiners is 50Ω for simplicity in impedance matching. Each Wilkinson combiner also requires a 100Ω isolation chip resistor located at the gap between the two input lines. This resistor does not absorb power unless there is an imbalance in the input signals.

As discussed in [9], the parallel feed arrangement used here has the advantage of providing accurate phase and amplitude for signal combining. In contrast to the simpler series feeding technique, however, the parallel-feed method takes more space and incurs more loss due to the presence of three power combiners. [10]

Based on the analysis, the feed network of the B1, B3 frequency, the dielectric constant of the dielectric plate $\varepsilon = 3.66$, the thickness $h = 1.524mm$ is worked out. By modeling and Simulation parameters in ADS, a circuit diagram of the feed network is attained.[11]

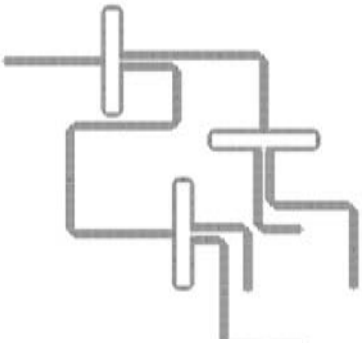

Fig. 3 Microstrip feed network layout for circularly polarized stacked-patch

4 Antenna performance simulation

This design uses software Ansoft HFSS12.0 to simulate antenna environment by setting the boundary conditions and test optimized parameters.

The S parameter obtained by the simulation is shown in Figure 4. Reflection coefficient in B1, B3 band is less than 20dB which meets the general requirements for the project.

The axis ratio simulation results are shown in Figure 5, 6. Simulation results show that dual axis ratio is less than 3dB in the main beam of ± 60 °which means the operated dual-band circularly polarized antenna is achieved.

Meanwhile, the simulation results recording phase of right-handed circularly polarized electric field variables in the azimuth angle range of 360 ° within the main beam ± 60 ° are shown in Figure 7-8, attaining the deviation of B1 band phase center is less than 0.9 °, the deviation of B3 band phase center is less than 1.6°, deviation of the equivalent phase center of the two frequency both within ± 1mm, phase center remaining stable in a point near the symmetry axis in the antenna between two layers of antenna patch.

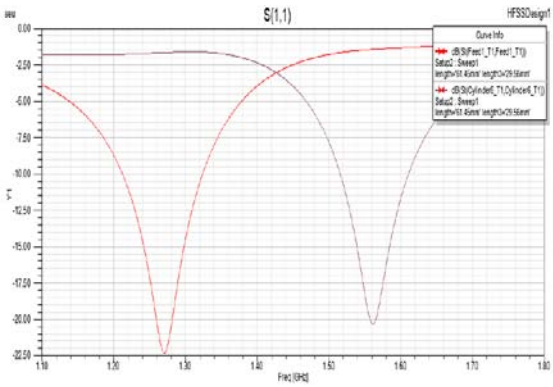

Fig. 4 Simulated results of dual-band reflection coefficient

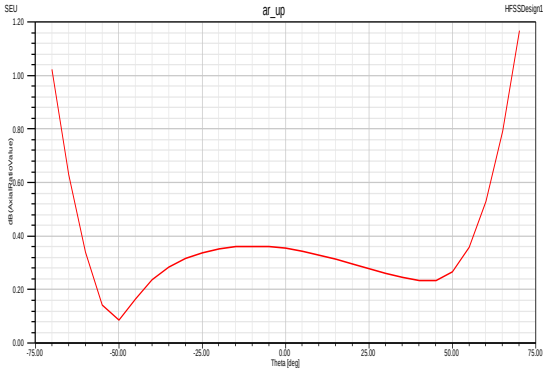

Fig. 5 Simulated results of B1 band axial ratio

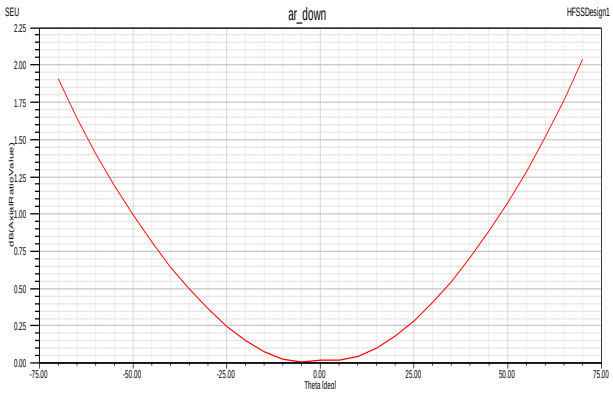

Fig. 6 Simulated results of B3 band axial ratio

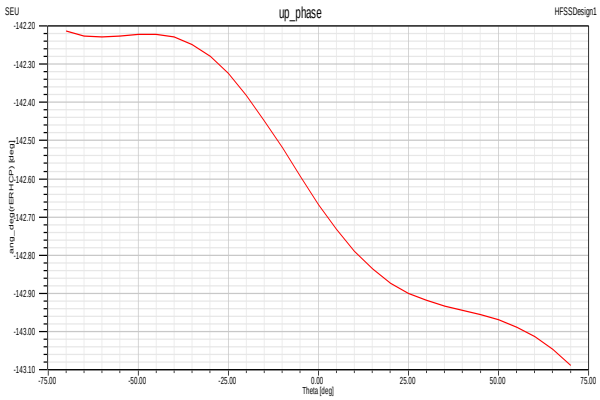

Fig. 7 Simulated results of B1 band far-field phase diagram

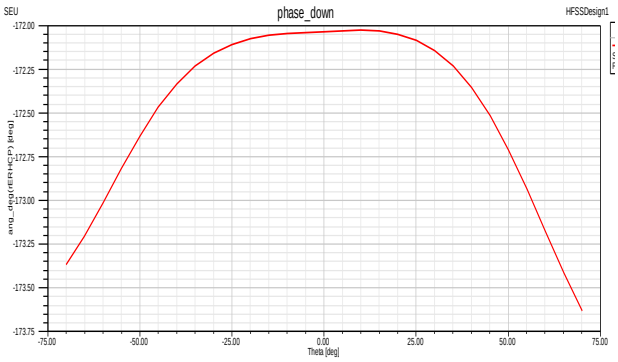

Fig. 8 Simulated results of B3 band far-field phase diagram

4、Conclusion

This paper researches on a dual-band high stable phase center dual-layer micro-strip antenna which utilizes dual-layer micro-strip structure realizing dual-frequency working mode, adopts symmetrical structure with four feed-point achieving a high and stable phase center and right-hand circular polarization function and work out feed network parameters by ADS. The reflection coefficient of the antenna, RHCP gain and phases of right-hand circularly polarized electric field variables achieved by simulation of Matlab, Ansoft HFSS 12.0 prove satellite micro-strip antenna with such structures phase center stability reaches millimeter level which improves the accuracy level of the satellite antenna navigation and measurement.

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