A Compact Dual-Band Assembled Printed Quadrifilar Helix Antenna for CNSS Application

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***Abstract*- This paper presents a novel compact dual-band printed quadrifilar helix antenna (PQHA) for application in Compass Navigation Satellite System (CNSS) of China. This antenna is consisted of two quadrifilar helix elements that are arranged at inner and outer cylinder. It works at the B1 (1.561GHz) and S (2.492GHz) bands. Each four spiral arms is excited by a series feed network in equal magnitude and successive 90° phase difference. It achieves the axial radiation pattern at B1 band, furthermore, it produces the shaped-conical radiation pattern at S band that is benefit for receiving the navigation signal from low elevation angle. Simulations show that 10dB impedance bandwidth of the proposed novel compact CNSS dual-band PQHAs are 15.4% at B1 band and 14.2% at S band. In addition, the axial ratio bandwidth is less than 3 are 12.8% and 2.8% at B1 and S band, respectively. The isolation between two quadrifilar helix elements is higher than 27dB.**

I. INTRODUCTION

Compass Navigation Satellite System (CNSS) or "BeiDou" in its Chinese name is the first regional satellite system in the world, which has been widely used in navigation, mapping, time service, communications, etc. Antenna is quite important in CNSS system as the media to transfer electromagnetic signals. It is required that CNSS antennas should be circularly polarization, and have broad impedance and axial ratio bandwidths.

A very attractive candidate for these applications is the resonant quadrifilar helical antenna (QHA) and more recently the conventional printed quadrifilar helical antenna (PQHA) due to their performances in terms of circular polarization, good axial ratio (AR), light weight, high dimensional stability, ease of fabrication and low cost [1]. Although some PQHA structures are already small, further size reduction is necessary to satisfy the space limitations of CNSS terminal. As a result of the service function of the CNSS is more and more, so, we hope that antenna can work in dual-band or multi-band. In addition, it is desirable in many satellite and ground station applications to produce low elevation radiation pattern. Compact printed quadrifilar helical antenna with Iso-Flux-Shaped pattern was introduced in [2], but it only working at one frequency. Assembled QHAs for CNSS are proposed to achieve duplex communication. The two QHAs are stacked together from top to bottom as an entity, which will lead to antenna's size more larger and is not satisfied for the space limitations of CNSS terminals [3]. A compact PQHA with integrated feed network was realized for satellite mobile communication systems at L1 band [4].

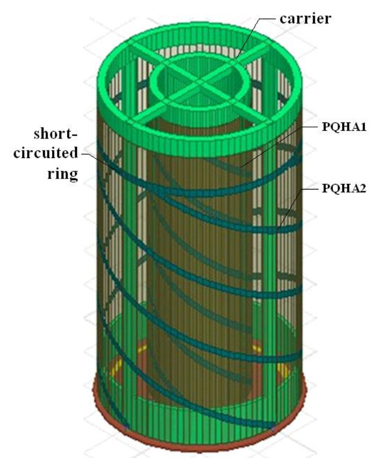


Fig 1. Structure of the proposed compact CNSS PQHAs.

In this paper, we present a novel compact dual-band printed quadrifilar helix antenna suitable for CNSS. The two PQHAs are arranged from inside to outside. The inside PQHA is working at S band (2.492GHz) and the outside one is working at B1 band (1.561GHz). For the S satellite navigation signal always from the low elevation direction, the S PQHA achieves the shaped-conical radiation pattern, which is benefit for receiving the low elevation signal. And the B1 PQHA maintains axial radiation pattern. The software Ansoft HFSS has been used to optimize the design. In section Ⅱ, the design of radiation element and power divider network are introduced. The simulated results are discussed in section Ⅲ.

II. ANTENNA DESIGN

This CNSS dual-band antenna comprises of two PQHAs with the employed feeding networks working at center frequency 1.561GHz (PQHA2) and 2.492GHz (PQHA1) respectively, as shown in Fig. 1. The inside PQHA1 works at high frequency band and the outsider PQHA2 works at low frequency band. Its polarization type are right-handed circularly polarization (RHCP).

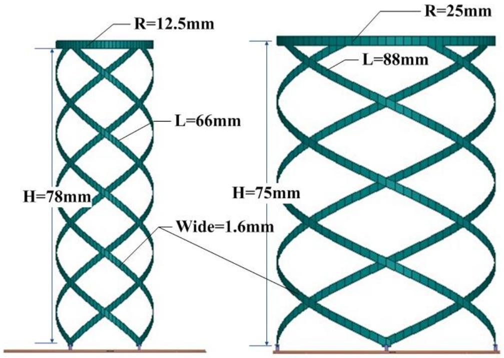
A. Radiation Element Design and Pattern Control

It is seen from Fig. 1 that each PQHA has four radiation elements connecting to a short-circuited ring in their top and a series feeding network on their bottom, forming an antenna unit. The thin substrate that supports PQHAs is rolled up with cylindrical structure, its relative permittivity of 2.2 and thickness of 0.125mm. Based on design theories in [5], the parameters of the PQHA can be set by the following equation:

$$H = N\sqrt{(1/N^2)(L-2r_o)^2 - 4\pi^2 r_o^2}$$

Where H means the axial length of the helix; L means the length of the helix element; r_o means the radius of the helix; N means the number of turns for one element.

The detail parameters of PQHAs are showed following in Fig. 2.



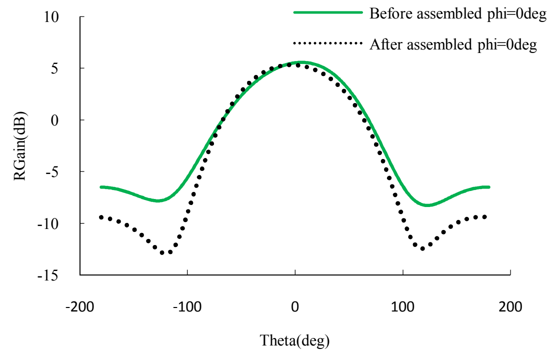
(a) S band (b) B1 band

Fig 2. Parameters of PQHAs.

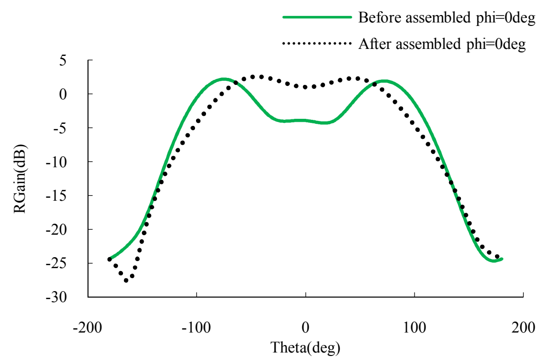
To achieve the shaped-conical pattern at S band and axial pattern at B1 band, the radius of PQHA is a key parameter that should be optimized. The effects of radius for QHA was analyzed in [5] . the radiuses of PQHAs are 12.5mm at S band and 25mm at B1 band. The corresponding radiations are shown in Fig.3 (a) and (b), respectively. The maximum gain direction of shaped-conical pattern is at 74deg. The investigations of radiation patterns that affected by the mutual coupling are also given in Fig.3. It is seen that the B1 radiation pattern remains stable in the existence of the S PQHA. However, the S radiation pattern is deteriorated by the mutual coupling. The maximum gain direction of shaped-conical pattern is from 74deg to 45deg, for the existence of the B1 PQHA. While the S PQHA radius is defined, the pitch angle of helix can be adjusted to optimize the peak gain direction slightly. The optimization results are listed in Table I, which can be served as a guideline to the design. Therefore, in order to achieve the radiation requirement of CNSS at 2.492GHz, The pitch angle 38deg is selected.

B. The Design of Power Divider Network

Two series-type feed networks are printed on the substrate, its relative permittivity of 2.2 and thickness of 0.5mm. Fig. 4 shows the topologies of the feed networks. Starting from the 50-Ω input microstrip line, the power is divided into four outputs in an equal amount using the branch-line power divider. The feeding length between the two ports is a quarter wavelength so as to provide 90° phase differential. The feed



(a) B1 band

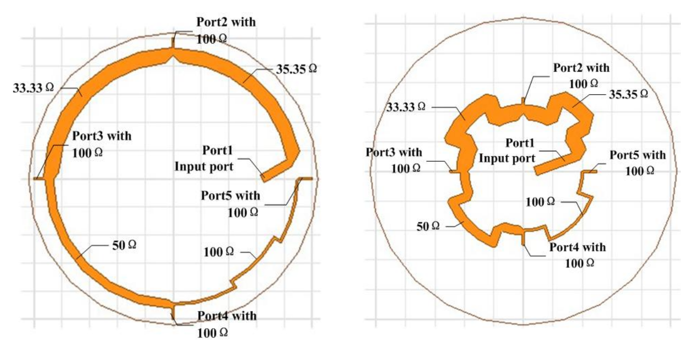


(b) S band

Fig 3. Gain patterns before and after assembled.

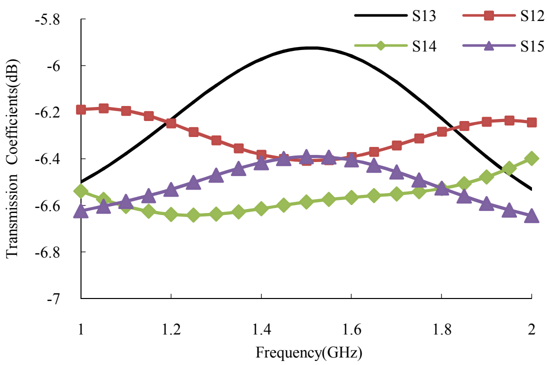
TABLE I
DETAIL DATA AT 2.492GHz FOR DIFFERENT PITCH ANGLES

Pitch angle (deg)	Maximum gain direction(deg)	Maximum gain (dB)	Gain in phi=0deg(dB)
35	θ=48	2.36	0.58
38	θ=45	2.58	1.04
41	θ=42	2.62	1.40

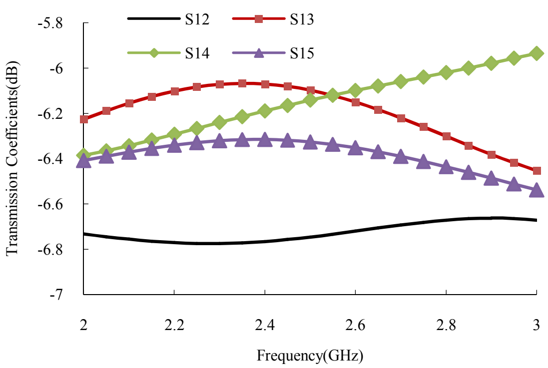


(a) B1 band (b) S band

Fig 4. Topologies of the antenna feed network [6].

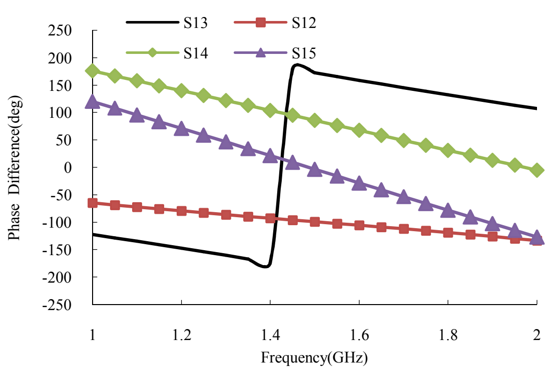


(a) B1 band

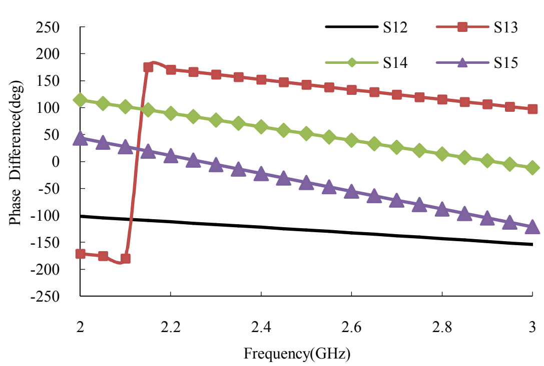


(b) S band

Fig 5. Simulated transmission coefficients of the network.

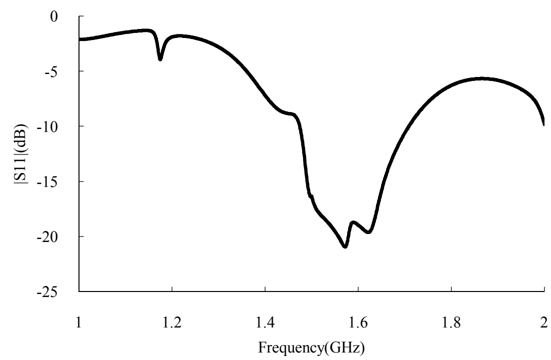


(a) B1 band

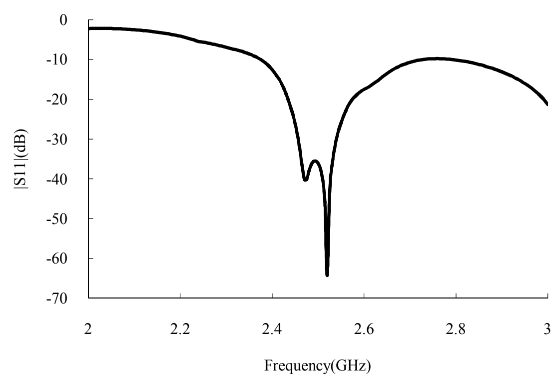


(b) S band

Fig 6. Simulated phase differences between four output ports of the network.



(a) B1 band



(b) S band

Fig 7. Simulated |S11| of the proposed CNSS compact PQHAs.

network provides an equal distribution of RF signal power to the four helix windings in quadrature phase rotation with 0º, 90º, 180º and 270º phase differentials.

Figs. 5-6 show simulated transmission coefficients and phase differences of the designed feed network. Transmission coefficients from the input port to four output ports, are ranging from -6 to -6.7dB. The phase differences are about 90°±2° at working frequency. As a result, the power divider delivers quadrature phase-shifting.

III. Simulation Results

CNSS dual-band PQHAs with the employed feed network are modeled in HFSS, as showed in Fig. 1. All the simulation results are achieved by HFSS software.

Fig. 7 shows the results of reflection coefficient for the proposed PQHAs on working frequency bands. The PQHA1 exhibits simulated 10dB impedance (|S11|<10dB) bandwidth of about 14.2%, from 2.37 to 2.73GHz and the PQHA2 exhibits simulated 10dB impedance (|S11|<10dB) bandwidth of about 15.4%, from 1.47 to 1.71GHz.

Fig. 8 shows the isolation between two PQHA elements. It is showed that the PQHAs have good isolation on two frequency bands, -43dB at 1.561GHz and -27dB at 2.492GHz. Simulated RHCP radiation patterns at φ=0° and φ=90° of the proposed CNSS compact PQHAs are shown in Fig. 9. The gain of B1 PQHA can achieve 5.3dBi in axial direction. The maximum

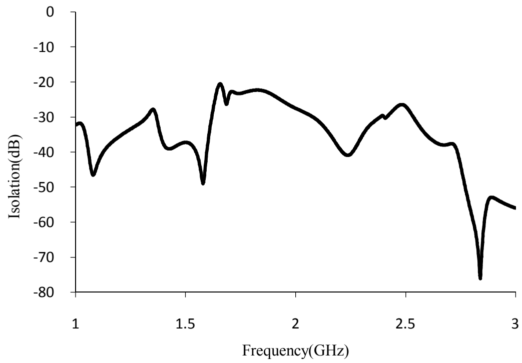


Fig 8. Isolation between the two PQHAs.

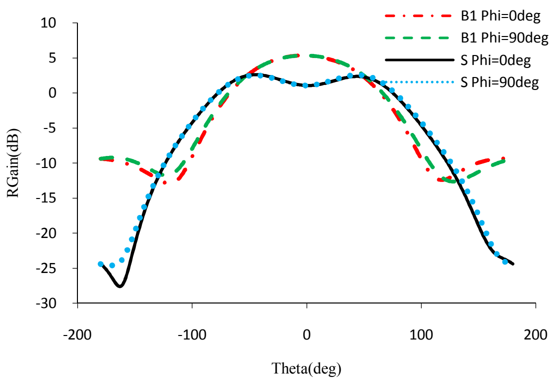


Fig 9. Simulated gains of the proposed CNSS compact PQHA.

gain of S PQHA can obtain at θ=45°, which is 2.6dBi.

Fig. 10 shows the results of AR for the PQHA. The proposed CNSS compact PQHA exhibits excellent Circular Polarized (CP) radiation. The simulated AR values of PQHA are less than 3dB at bore sight through the whole working frequency bands. The PQHA1 exhibits simulated AR less than 3dB bandwidth of about 2.8%, from 2.44 to 2.51 GHz. The PQHA2 exhibits simulated AR less than 3dB bandwidth of about 12.8%, from 1.4 to 1.6 GHz. Good AR values also indicate that the feed network proposed could generate stable quadrature feed phases for PQHA.

IV. Conclusion

In this paper, a novel compact dual-band quadrifilar helix antenna is proposed for CNSS application. The size of antenna is reduced by arranging two elements in outer and inner carriers. It obtains axial radiation pattern at B1 band and shaped-conical radiation pattern at S band, through optimizing the radiuses of PQHAs.

The simulation shows the bandwidth of return loss for the proposed PQHAs are 15.4% in B1 band and 14.2% in S band. The gain of PQHA1 is 2.6dBi at θ=45° and PQHA2 is 5.3dBi at axial direction. The AR bandwidths of 3dB are 12.8% in low frequency and 2.8% in high frequency. This design is very suitable for application on vehicles like trains, cars and so on. It can be widely used in CNSS. More measured results will be presented at the conference.

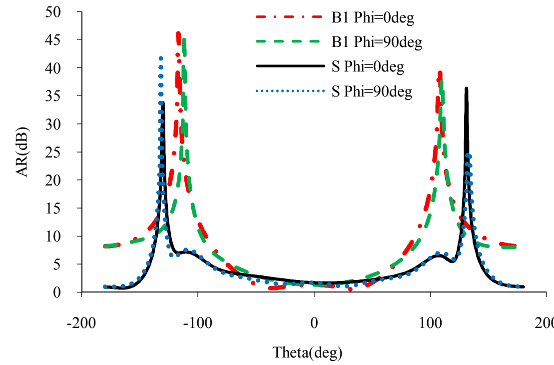


Fig 10. Simulated AR of the proposed CNSS compact PQHAs.

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