A Conical Quadrifilar Helix Antenna for GNSS Applications

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***Abstract*-A broadband conical quadrifilar helix antenna is presented in this paper. The broadband characteristic is achieved by tapering the helices, utilizing conical geometry and adjusting the dimensions of the cone-shape support. The bandwidth, defined for a VSWR<2, is about 25% across 1155-1327MHz and 1447-1617MHz, covering all of the frequencies of Global Navigation Satellite System including GPS, GLONASS, Galileo and Compass. The antenna is fed by a wideband four-output-ports feed network with equal magnitude and consistent 90° phase shift. The final antenna obtains excellent circular polarisation, a good gain (greater than 4.5dB at boresight) and good axial-ratio performance over a wide angular range for Global Navigation Satellite System applications.**

Key Words: Conical Quadrifilar Helix Antenna, Global Navigation Satellite System (GNSS), wideband feed network.

I. INTRODUCTION

Global Navigation Satellite System (GNSS) will in effect be fully deployed and operational in a few years [1], with its spectra spreading densely across 1164–1300 and 1559–1610 MHz, therefore, a broadband or dualband antenna is required for its applications. Moreover, hemispherical radiation patterns with good circular polarization in the bandwidth are required for global positioning systems [2]. In these systems, circular polarization antennas are widely used for signals transmission due to their insensitivity to ionospheric polarization rotation.

A prime candidate for these applications is the resonant quadrifilar helical antenna (QHA) [3] and the printed quadrifilar helical antenna (PQHA) [4] due to their salient features, such as: low cost, light weight, hemispherical coverage and good circular polarization. A typical quadrifilar helix antenna consists of four helices equally spaced and wrapped around a common cylindrical structure. At one end of that structure, each helix is connected to a feed network or an equal-power 4-way combiner with the following phase relationship: 0, -90, -180, -270 degrees.

To cover all the GNSS frequencies, these antennas require broadband properties. However, the bandwidth of a conventional PQHA operating under resonant modes, is typically 5-8% while the tapered PQHA (TPQHA) is 14% in L-band [5], both of which are insufficient for GNSS applications. In the past decades, several techniques have been described in the literature for dual-band behavior [6]-[8]. Other techniques have been proposed to broaden the bandwidth of the QHA: for instance, using a conical geometry [9] obtains a 18.5% bandwidth. The FPQHA presented in [10] considerably increases the QHA bandwidth, as 30% has been achieved. But unfortunately GPS-L5 and Galileo-E5a (1166.22-1186.68MHz) are out of the band.

In this paper, the helices of the proposed antenna are tapered and wrapped around a conical structure of relative permittivity $\varepsilon_r = 2.2$ to obtain a Conical PQHA (CPQHA). By adjusting the dimensions of the cone, the equivalent impedance of the antenna will be changed and matched. Finally, the bandwidth of the proposed antenna is about 25%, covering all the GNSS frequencies. In the design process, commercial simulation software HFSS has been used [11].

The remainder of this paper is organized as follows. Section II describes the antenna configuration and the feed network. Measurement results are given in Section III. Section IV presents conclusions.

II. CONFIGURATION

A. Antenna Configuration

The planar unwrapped antenna is illustrated in Figure 1. The four arms of the antenna were printed onto a thin dielectric substrate of relative permittivity $\varepsilon_r = 2.2$ and of thickness h=0.15*mm*, wrapped around a conical support, and mounted on the ground plane of the feed network which will be presented in Part B.

Figure 1. Picture of the unwrapped helix.

As presented in [5] and [9], tapering technique and conical geometry can enhance the bandwidth of the QHA. In this paper, these two techniques are utilized to broaden the bandwidth. One of the helical arms, starting from +*x* axis in the *x-o-y* plane, can be described by the following equations:

Equations of the lower line:

$$\begin{cases} x(\varphi) = (r_1 - \dfrac{h\tan\theta}{2n\pi}\varphi)\cos(-\varphi) \\ y(\varphi) = (r_1 - \dfrac{h\tan\theta}{2n\pi}\varphi)\sin(-\varphi) \quad 0 \le \varphi \le 2n\pi \\ z(\varphi) = \dfrac{h}{2n\pi}\varphi \end{cases} \tag{1}$$

Equations of the upper line:

$$\begin{cases} x(\varphi) = \left\{ r_1 - \dfrac{h\tan\theta}{2n\pi}\varphi - \left[w - \dfrac{w_1}{\dfrac{h-(w-w_1)\cos\theta}{h}2n\pi}\varphi \right]\sin\theta \right\}\cos(-\varphi) \\ y(\varphi) = \left\{ r_1 - \dfrac{h\tan\theta}{2n\pi}\varphi - \left[w - \dfrac{w_1}{\dfrac{h-(w-w_1)\cos\theta}{h}2n\pi}\varphi \right]\sin\theta \right\}\sin(-\varphi) \\ z(\varphi) = \dfrac{h}{2n\pi}\varphi + \left[w - \dfrac{w_1}{\dfrac{h-(w-w_1)\cos\theta}{h}2n\pi}\varphi \right]\cos\theta \\ 0 \le \varphi \le \dfrac{h-(w-w_1)\cos\theta}{h}2n\pi \end{cases} \tag{2}$$

where n is the number of turns, r_1 is the initial radius, w is the initial width of the arms and h is the height of the support which consists of two parts as shown in Figure 2(b) and (c).

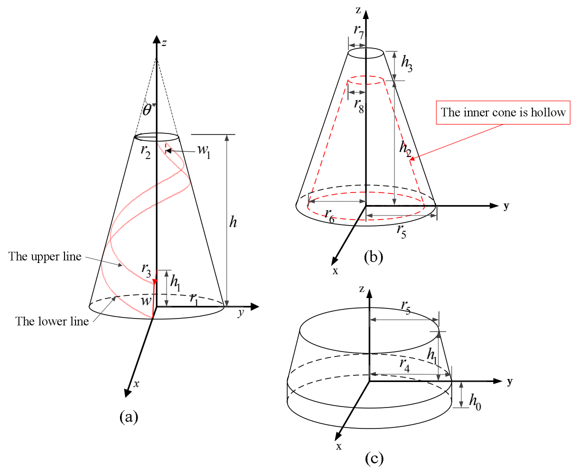


Figure 2. (a) One arm wrapped around the cone, (b) The upper part of the support, and (c) The lower part of the support.

The geometrical parameters of the final antenna are listed in Table I. Figure 3 is the simulated VSWR of the antenna. It is observed that the voltage standing-wave ratio (VSWR) is lower than 2 across 1155-1327 MHz and 1447-1617 MHz, covering all the GNSS frequencies.

TABLE I
GEOMETRICAL PARAMETERS

r_1(mm)	36.65	h_0(mm)	2
r_2(mm)	5.15	h_1(mm)	7
r_3(mm)	30.79	h_2(mm)	65
r_4(mm)	36.5	h_3(mm)	8
r_5(mm)	33.74	w(mm)	16
r_6(mm)	30.24	w_1(mm)	8.5
r_7(mm)	5	θ(°)	21.49
r_8(mm)	5	n	1
h(mm)	80		

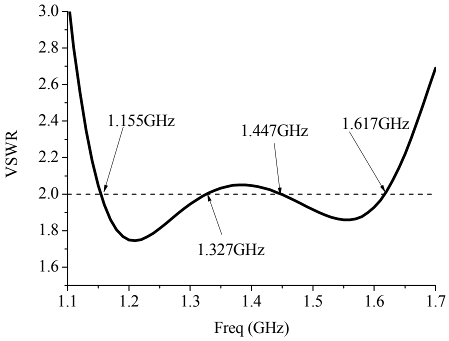


Figure 3. The simulated VSWR of the proposed antenna.

B. *Feed Network Configuration*

The feeding system has to provide constant magnitudes and 90° phase differences to the four helices of the CPQHA over the operating frequency band. However, the conventional directional coupler and rat-race coupler generate a narrow bandwidth of 90° phase shift, which are not adequate for the proposed antenna. To feed the proposed antenna, a wideband feed network composed of three Wilkinson dividers and three broadband phase shifters [12] has been designed. According to [12], the wideband 90° phase shift was achieved when $z_{m1} = 61.9\Omega$, $z_{s1} = 125.6\Omega$ while $z_0 = 50\Omega$; the condition for 180° phase shift is $z_{m2} = 80.8\Omega$, $z_{s2} = 62.8\Omega$. The designed feed network is centered at 1.4GHz, and achieved by adjusting the length and width of every segment of the microstrip line on a PC board with relative permittivity of 2.65. The simulation and measurement results of the feed network will be described in Section III. Figure 4 is the photograph of the designed feed network.

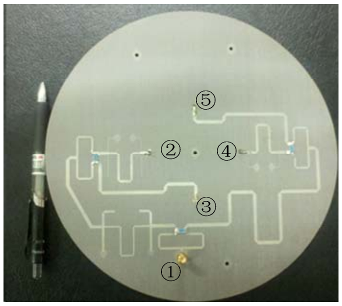


Figure 4. Photograph of the designed feed network.

III. EXPERIMENTAL RESULTS

Measured VSWR, magnitude response and phase difference of the designed feed network were obtained using the Agilent vector network analyzer as shown in Figures 5, 6 and 7. A frequency shift mainly due to the machining error can be seen from Figures 5 and 6. In addition, it is observed that the maximum difference between measured magnitude and that of simulated is about 0.3 dB in the band of 1.15-1.65 GHz. The measured phases, with respect to that of Port 2, of the output ports at several frequencies are listed in Table II. One can see that the phase shift unbalance is less than 4°.

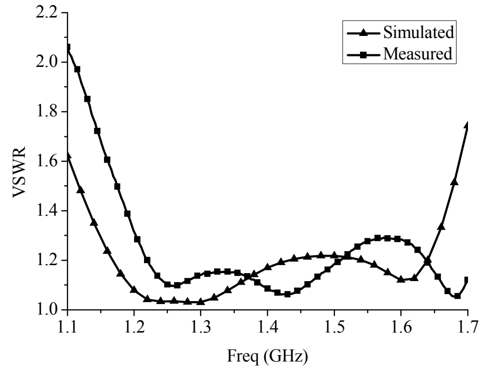


Figure 5. The VSWR against frequency of the designed feed network.

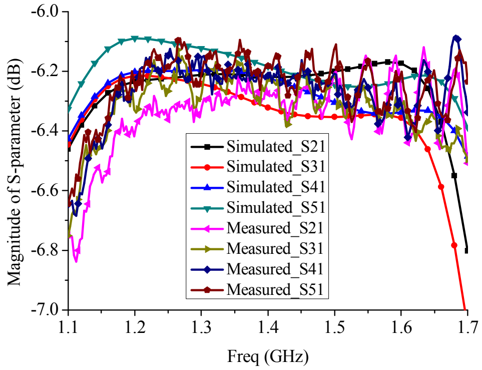


Figure 6.The magnitude response of the designed feed network.

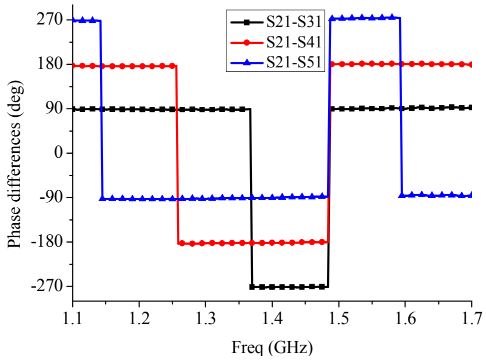
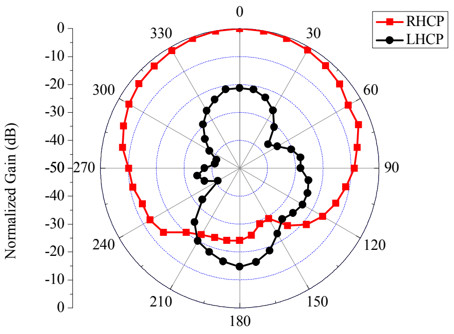


Figure 7. The measured phase difference of the designed feed network.

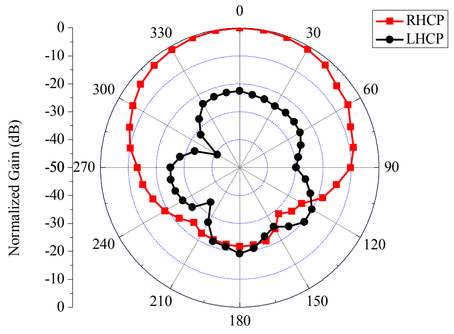
TABLE II
THE MEASURED PHASES AT SEVERAL FREQUENCIES

Freq(MHz) Port	1176	1561	1575	1602
2	0	0	0	0
3	88.437	89.678	91.015	90.150
4	176.074	180.298	180.804	180.282
5	92.634	273.679	273.683	86.159

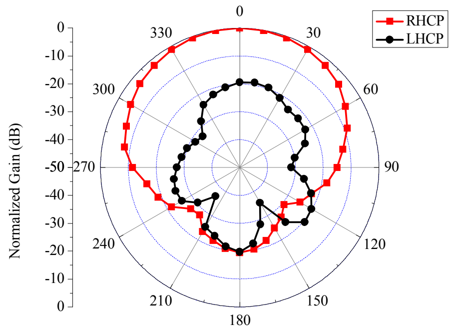
The far-field radiation patterns, measured in an anechoic chamber in magnitude and phase for linear polarizations and combined to give the circular polarization, are shown in Figure 8 at frequencies of 1176, 1561, 1575 and 1602 MHz.



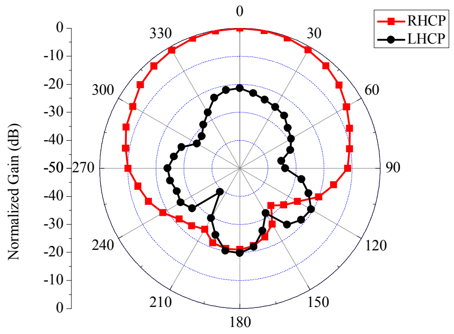
(a) 1176MHz



(b) 1561MHz



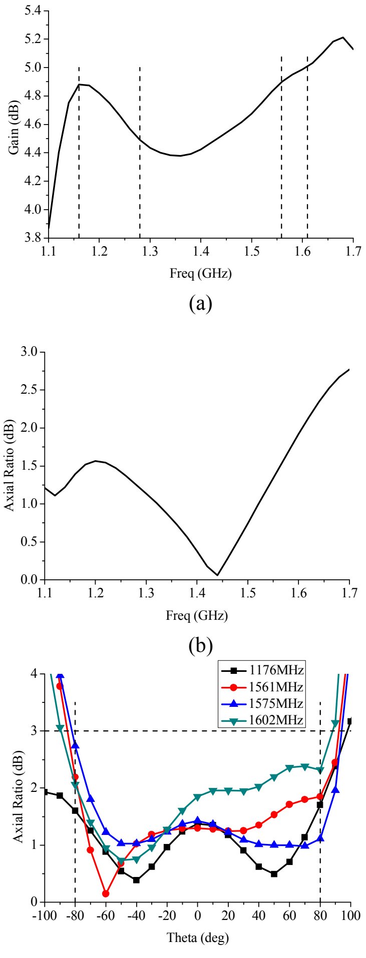
(c) 1575MHz



(d) 1602MHz

Figure 8. Measured radiation pattern of the proposed antenna.

Figure 9(a) and (b) depict the dual broadband characteristics of the RHCP gain and axial ratio. The measured RHCP realized gain is greater than 4.5 dB in the interesting GNSS bands. Moreover, the axial ratio is less than 3 dB from -80° to 80° in the elevation plane, showing that the antenna has a broad pattern coverage.



(a)

(b)

(c)

Figure 9. Measured (a) RHCP Gain, (b) AR versus frequency, and (c) AR versus elevation angle.

IV. CONCLUSION

In this paper, a broadband conical PQHA is reported. By tapering the arms, utilizing conical geometry and adjusting the dimensions of the cone-shape support, the antenna obtains a dualband behavior and covers all the GNSS frequencies. A wideband feed network is applied to excite high-performance RHCP radiation. The axial ratio is less than 3 dB from -80° to 80° in the elevation plane and the RHCP realized gain is greater than 4.5 dB at boresight which make the antenna a good choice for GNSS applications.

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