Design of an Electrically Small Circularly Polarized Spherical Folded Helix Antenna

Edward Wawrzynek, Songyi Yen, and Dejan Filipovic
University of Colorado Boulder, CO, USA {edward.wawrzynek,songyi.yen,dejan.filipovic}@colorado.edu

***Abstract*—An electrically small folded helix with an electrical size of $ka = 0.29$ is designed for operation in the GPS L5 band. To reduce axial ratio, parasitic elements around the equator are included in the antenna. The proposed design achieves instantaneous coverage of the L5 band with VSWR $<$ 3:1 and axial ratio below 3 dB over nearly the entire field-of-view. Fabrication considerations are also discussed.**

I. Introduction

Electrically small antennas benefit from small physical size at the expense of narrow bandwidth [1]. Among these, spherical wire antennas have been shown to approach the fundamental bounds on bandwidth [2]. Specifically, the spherical folded helix, made from folded dipoles twisted onto the surface of a sphere, is a practical realization capable of elliptical polarization over a nearly maximum theoretical bandwidth. Herein, we discuss the design of a modified electrically small spherical helix for the GPS L5 band able to balance the spherical modes and reduce the axial ratio below 3 dB over a wide field of view.

II. Helix Antenna Design

The baseline is a four arm, 1.55 turn folded spherical helix antenna, as described in [2], shown in Fig. 1a. The helix is self resonant at $ka = 0.26$ and its radiation dominated by the in-phase TM_{10} and TE_{10} spherical modes. The spherical currents exciting pure TM_{10} and TE_{10} modes are, respectively,

$$\mathbf{J_{TM_{10}}} = J_{TM_{10}} \sin(\theta)\hat{\theta}, \tag{1}$$

$$\mathbf{J_{TE_{10}}} = J_{TE_{10}} \sin(\theta)\hat{\phi}, \tag{2}$$

where $J_{TM_{10}}$ and $J_{TE_{10}}$ are the amplitude of current density for the respective modes. In-phase excitation of these currents causes an orthogonal phase relationship between the resulting TM and TE fields, radiating elliptical polarization [3].

Self resonance is achieved when the reactive energy held in the near field is zero, i.e. when the energies in the TM_{10} and TE_{10} modes are balanced. When electrically small, the TM mode radiates more power relative to its stored energy than the TE mode [4], leading to a power imbalance between the modes in the far field at resonance. This results in an elevated axial ratio, which, for the helix in Fig. 1a exhibits an axial ratio of 3.5 dB.

When the far field powers are balanced, there is extra magnetic energy held in the near field. One approach to compensate this energy is to use a lumped element network. An alternate technique, which maintains self resonance of the antenna, is to couple into higher order TM modes which provide the necessary energy in the near field. Due to the small electrical size of the antenna, these modes do not substantially radiate and provide little disruption to the far field characteristics. The latter approach is implemented as a parasitic conducting loop aligned with the currents in (2) placed around the equator of the helix (Fig. 1b). This loop increases the excitation in the TE_{10} mode and thereby improves the polarization quality of the antenna. Simulation in Ansys HFSS shows that two 27° gaps placed in the ring provide the necessary excitation of higher order modes.

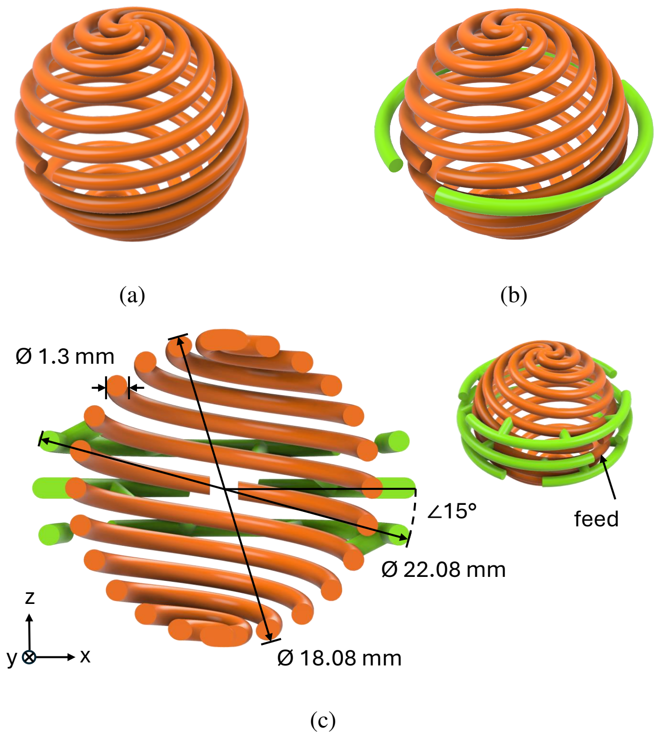

Fig. 1: Spherical folded helix with progressive modification for axial ratio improvement. (a) The spherical folded helix, as described in [2], with thick wires. (b) Addition of a parasitic element around the antenna for axial ratio improvement. (c) Final proposed antenna, with multiple parasitic loops and support elements necessary for manufacturing.

The final proposed design, shown in Fig. 1c, has three such rings oriented around the antenna, each rotated 120° with respect to the others. Conductive supports for the parasitic rings are added for manufacturing. Three supports are distributed across each parasitic arm and connect to the same arm in the helix. Due to weak radial fields in the equatorial plane of the antenna, these supports' placement has little impact on the

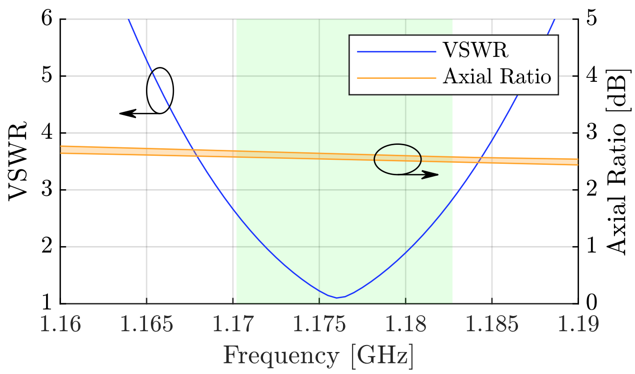

Fig. 2: VSWR and axial ratio over the half-power beamwidth of the proposed antenna. The GPS L5 band is highlighted.

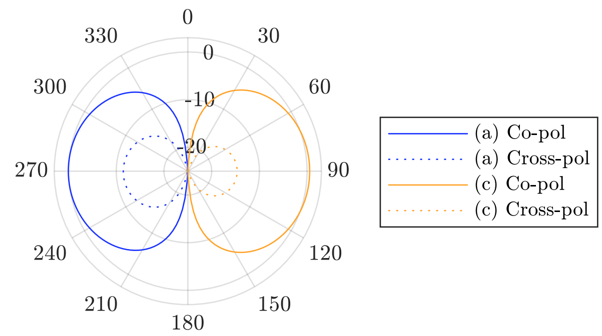

Fig. 3: Elevation cut of co-polarization and cross-polarization of the (a) baseline helix and (c) proposed antenna at 1.175 GHz. The pattern is omnidirectional about the z axis.

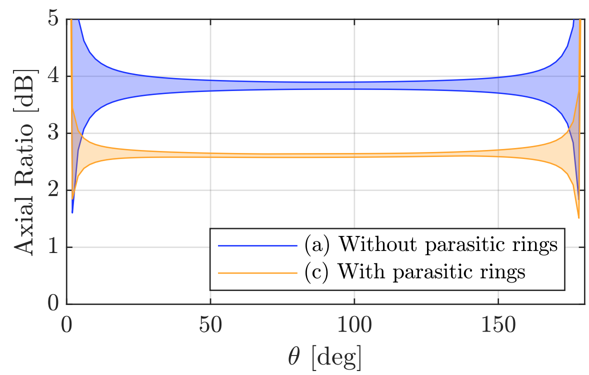

Fig. 4: Axial ratio of the antenna with and without parasitic rings at 1.175GHz. The upper and lower bounds of axial ratio taken over azimuth are shown. Notice that the proposed modifications contribute to reduced variation of axial ratio across azimuth.

helix's electrical characteristics. The antenna design permits simple monolithic manufacturing in a stereolithographic process followed by copper electroplating of the entire structure.

III. Results

TABLE I: Relative modal far field powers.

Mode	(a) Without parasitic rings	(c) With parasitic rings
$TM_{1,0}$	70.7%	64.9%
$TE_{1,0}$	29.3%	35.1%

The proposed antenna's reflection coefficient and axial ratio over frequency are shown in Fig. 2. Self-resonance is at 1.175 GHz with a bandwidth of 8.1 MHz with VSWR $<$ 2:1 and covers the entire L5 band with VSWR $<$ 3:1. The parasitic rings both increase the physical size of the antenna and load the helix, lowering the resonant frequency from 1.540 GHz to 1.175 GHz. The net effect is an increase in the antenna's electrical size to $ka = 0.29$. Furthermore, the axial ratio is below 3 dB within the half-power beamwidth and remains stable over the band. The parasitic rings are successful at increasing coupling into the TE_{10} mode, which is shown in Table I. The imbalance of TM_{10} and TE_{10} and the presence of higher order modes in the near field degrade the antenna quality factor from the fundamental limit, a tradeoff shown in [3]. In particular, as compared to the limit derived in [1], the antenna's quality factor is 2.1 times higher.

The radiation pattern for both the baseline and modified spherical helix is shown on the left and right halves, respectively, of Fig. 3. Co- and cross-pol are denoted by the solid and dashed lines, respectively. The pattern for both is that typical of an electrically small dual-mode radiator with the modified antenna exhibiting a lower cross-pol.

Finally, the axial ratio in elevation with and without parasitic rings is plotted in Fig. 4. It is clear that the axial ratio is reduced to below 3 dB and remains stable over a wide field-of-view, except at the poles.

IV. Conclusion

A modified four arm spherical folded helix antenna with $ka = 0.29$ is designed for circularly polarization over the GPS L5 band. Parasitic elements are placed around the helix to reduce the axial ratio to below 3 dB by strengthening of the necessary spherical modes. Additionally, gaps are included in the parasitics to achieve self-resonance at the desired center frequency. Integration of these parasitic elements into the antenna allows for straightforward monolithic fabrication of the structure.

Acknowledgement

This work is funded by the Office of Naval Research under the grant N00014-23-1-2120.

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