Helical Antennas - Empirical Analysis

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I. INTRODUCTION

The Helical Antenna was invented by Dr. John D. Kraus, and thoroughly described in detail in his 1988 book *Antennas* [1]. Dr. Kraus is widely considered to have pioneered most of the modern work on axial mode helices, and his book *Antennas* still serves as a common reference in many modern texts [2].

The axial mode helix typically operates in the ultra-high-frequency (UHF) range, and has seen widespread usage in space systems due to its near circular polarization, broadband properties, and high directivity.

This paper builds upon the previous paper, *Helical Antennas Lecture Report*, to provide an empirical analysis (through simulations) of the effect of antenna electrical geometry on axial mode operation. Specifically, the effect of the helical circumference of the antenna, as well as the number of turns in the helix, will be analyzed with respect to their effects on the radiation patterns, polarization, and bandwidth ratio. These results will also be compared to theoretical predictions.

II. METHODOLOGY

The simulation of the axial mode helix was initially conducted using the *CST Suite Student Edition* software; however due to limitations in the number of allowable mesh cells used in the student edition simulation, accurate simulation of the axial mode helix was not possible. Figure 1 shows the designed *CST* axial mode helix antenna, as well as the mesh used to simulate the structure - the smallest mesh cell here is greater than thickness of the wire. The *CST* simulations were not obtained with confidence due to the aforementioned limitation, and consequently *ANSYS HFSS v15.0* was used to provide all the simulation results presented in this paper. A model of the axial mode helix designed/simulated in *HFSS* is provided in Figure 2.

The *HFSS* solution type setting used in determining all field-related parameters was a driven-modal, composite-excitation simulation. The driven modal simulation provides S-matrix solutions in terms of the reflected and incident powers of waveguide modes - a natural choice since the axial-mode helix is a travelling wave structure. Transient analysis was also a possible simulation choice, however since we are not dealing with any form of pulsed excitations, the driven modal appeared better suited for our application than the driven transient. Lastly a composite-excitation was chosen over a network-analysis since we are only interested in exciting a single port of the antenna (with its own unique excitation), and need not perform any sort of network analysis over multiple ports.
TABLE I
BASELINE HELICAL ANTENNA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Circumference of cross-section</td>
<td>300 mm</td>
</tr>
<tr>
<td>α</td>
<td>Pitch angle</td>
<td>15°</td>
</tr>
<tr>
<td>S</td>
<td>Interloop spacing</td>
<td>80.4 mm</td>
</tr>
<tr>
<td>Material</td>
<td>Material of the helix conductor</td>
<td>PEC</td>
</tr>
<tr>
<td>N</td>
<td>Number of turns of helix</td>
<td>8</td>
</tr>
<tr>
<td>f</td>
<td>Frequency of operation</td>
<td>1 GHz</td>
</tr>
</tbody>
</table>

III. RESULTS

A. Baseline Helix

Before examining the consequences of varying the electrical circumference and the number of turns in the helix, we first establish a baseline axial mode helical antenna operating ideally. This baseline will serve as a reference for comparison. The dimensions and operating parameters of the baseline helix are presented in Table I. Two key things to note about the baseline helix are that its circumference is equal to exactly $\lambda$ at the operating frequency, and that its pitch angle is $15^\circ$, thereby satisfying the criteria for optimal axial-mode operation [1].

The 3D and 2D radiation patterns of the baseline helix are shown in Figures 3 and 5 respectively. Of notable importance in the aforementioned pattern figures is the prominent end-fire behaviour. Here our baseline showcases a highly directive main-lobe, with radiation concentrated along the main axis of the antenna.

Figure 4 depicts the axial ratio of the antenna, and Figure 6 the overlay plot of $E_\phi$ and $E_\theta$ components in the E-plane. Figures 4 and 6 are important in showcasing the near-circular polarization of the antenna. The axial ratio in Figure 4 is 2.6 dB in the endfire direction ($\theta = 0$). 2.6 dB $\sim$ 0 dB - the condition for perfect circular polarization. In addition, the $E_\phi$ and $E_\theta$ components in Figure 6 are almost completely identical in the endfire direction, another indicator of near-perfect circular polarization in the axial direction.

To sum up, our baseline axial mode helix has a highly directive main lobe oriented along the main axis of the antenna, and produces near-circular polarization in the axial direction as well.

B. Varying Electrical Circumference

Axial mode operation is contingent upon the circumference of the helix being on the order of a wavelength. In the previous paper, *Helical Antennas Lecture Report*, it was shown that axial-mode helices were broadband antennas with a bandwidth ratio of $B_r \sim 2$. In this subsection, we will take the centre of the band to be 1 GHz, corresponding to the operating frequency of our baseline antenna, and we will examine the behaviour of the antenna at the edges of the band (0.7 GHz and 1.4 GHz).

At 0.7 GHz, without changing the physical dimension of the antenna in Table I, the electrical circumference of the helix...
becomes $C_\lambda = 0.7$ where $C_\lambda$ is the circumference measured in wavelengths. At this frequency, the back lobe becomes more prominent, and the main beam widens and starts shifting off of the axial direction (shown in Figure 7). In addition, as can be seen from Figures 8 and 9, the polarization starts to deviate greatly from the circular case with an axial ratio of 21.2 dB.

Essentially, the ideal axial performance starts to deviate at the edge of the band. The field starts to unravel from a single contained main lobe, and beings to lose its directivity and polarization. Beyond a certain frequency, the antenna will not be able to naturally adjust it’s guided phase-shift to achieve the maximum directivity condition (Hansen-Woodyard) - at least not within a reasonable range of the condition - and the antenna will leave the axial mode of operation. For the sake of brevity, it is simply stated that deviation from the ideal axial mode also occurs at the upper frequency in the band, however the manner in which the field will "unravel" at the upper frequency in the band will be very different from the manner in which the field will unravel in the lower frequency in the band.

Figure 10 shows the beam solid angle of the axial mode helix, (same properties as those provided in Table I), plotted versus frequency. The red portion of the curve represents the effective bandwidth of the antenna (0.7GHz - 1.4GHz). In this range the antenna operates predictably, and displays a convex directivity manner as expected. Outside of the red-band, operation of the antenna deviates from prediction, and no longer operates as an axial mode helix. The maximum directivity of the axial mode helix occurs around $C = 1.2\lambda$, these results are consistent with those presented in Kraus [1].

C. Varying the Number of Turns ($N$)

Varying the number of turns in the helix also has noticeable performance effects. Figures 11 through 14 all have the circumference of the helix fixed at $1\lambda$, however have reduced the number of helical turns relative to the baseline to only 2 turns ($N=2$ whereas the baseline had $N=8$).

Noticeable differences in the 3D and 2D radiation patterns
are that the main beam has significantly widened relative to the N=8 baseline. Despite a widening of the main beam, axial radiation is still generally maintained in the N=2 case. The reduced winding case also presents a larger axial ratio in the end-fire direction, representing a more elliptical polarization than the N=8 case. Despite the degradation in the accuracy of the circular polarization in the N=2 case, the axial ratio is still generally low enough to indicate a circular polarization. The $E_\phi$ and $E_\theta$ components in Figure 14 do not overlap as much as they did in the N=8 case, but still overlap enough to support our extrapolation of circular polarization.

Therefore, it is seen that reducing the number of turns in the axial mode helix generally does not affect the mode of operation, but does still slightly degrade the performance with respect to directivity, and circular polarization. Consequently, the number of turns in the axial mode helix does not play as large a role in the antenna performance as the circumference, which provides the major constraint on the bandwidth ratio.

REFERENCES