The Helical Antenna: Description and Design

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INTRODUCTION

Circular polarization is commonly used in satellite applications where the angular direction of the satellites with respect to the receiver changes with time. It is also useful for other applications that experience problems with linear polarization such as reflections from rainfall and mobile systems. This article presents a description and two design methods of a very commonly used circularly polarized antenna, the axial-mode helix antenna. The design methodology is explained via two case studies: a 435 MHz and a 2.4 GHz design.

There are many ways of designing helix antennas. In this article, I focus on two commonly used design methods. One is based on the classic Kraus formula while the second is based on the Emerson formula.

BACKGROUND

The popular helix antenna was invented in the late 1940s by John Kraus, W8JK. His elegant work paved the way for the future research and use of helix antennas, and is used today by many Amateurs for satellite applications. The Kraus formula is used in *The Satellite Experimenter’s Handbook* published by the ARRL. The antenna is basically a wire spring mounted over a finite ground plane. It produces a nearly circularly polarized wave of either Right-Handed or Left-Handed sense depending on the direction that it is wound. If it is wound like an ordinary right-handed wood screw, it will transmit Right Hand Circular Polarization (RHCP), the common case for most systems that Radio Amateurs use. This is probably the only circular polarized antenna where you can actually “see” the sense of rotation.

Since the work of Kraus, there has been a great deal of research on this widely used antenna. Dr. D. T. Emerson of the National Radio Astronomy Observatory in Tucson, Arizona conducted more than 10,000 numerical modelling calculations on helical antennas and compared his results with the theory of Kraus and other researchers. His work has been published in the ARRL *Antenna Compendium* (see references). Also, L.B. Cebik, W4RNL, wrote a comprehensive note on modelling the antenna in Amateur Service (see the Links section).

It must be pointed out that the Kraus method has been successfully used by experimenters for many years and is still considered to be the tried-and-true method. The Emerson method is based on numerical modelling. Very few experimental results are available for the helix design using the Emerson model, which is limited to a length of seven wavelengths.

The models of Kraus and Emerson result in different physical design attributes for a given wavelength and a much different prediction of the helix gain. For example:

- The simple Kraus formula that the gain keeps increasing with length. For lengths greater than a few wavelengths, the gain doubles as the length is doubled.

There is no limit on the gain that be achieved according to the Kraus formula.

- The simple Emerson empirical formula (derived from numerical simulations) predicts a lower gain of (3 to 5 dB) than the Kraus formula. It also shows that the increase in gain with antenna length is significantly less than indicated previously, either from theory or experiment.

This article shows how to design a helix antenna with the aid of a simple calculator. There are two options to select in the calculator: the Kraus method; and the Emerson method. Since there are many parameters in the antenna that can vary, it is possible to use other approaches such as designing from the work of Cebik or building a design based on another *NEC* analysis.

Some notable features of the helix antenna are:

- Ease of design from simple empirical formulas
- Circular polarization produced with no phasing and coupling structures required
- Can be used from 2 metres to 3 cm wavelengths and beyond
- Reasonable gain for a given boom length
- Good bandwidth
- Fairly large side lobes similar to other end fire arrays
- Input impedance near 230 Ω: needs matching to a 50-Ω system
- The resonant frequency depends on the helix *Circumference* which is approximately 1.0 wavelength
- Wire diameter not critical

New Term

The gain of circularly polarized antennas is commonly measured with respect to circularly polarized transmitting *and* receiving antennas. The term for gain in these systems is called *decibels with respect to an isotropic radiator (dBi) under the condition that the system uses circular polarization*. The symbol used is *dBic*. If a linearly polarized antenna is used to receive a circularly polarized signal, there is a 3 dB loss of power due to the fact that one component of the signal is rejected.

Antenna Description

The helix antenna is shown in Figure 1. The antenna is constructed from a wire of the shape of a helix (a spring) which is mounted above a square of circular ground plane and fed via a matching transformer since the input impedance is approximately 230 Ω.

Figure 1

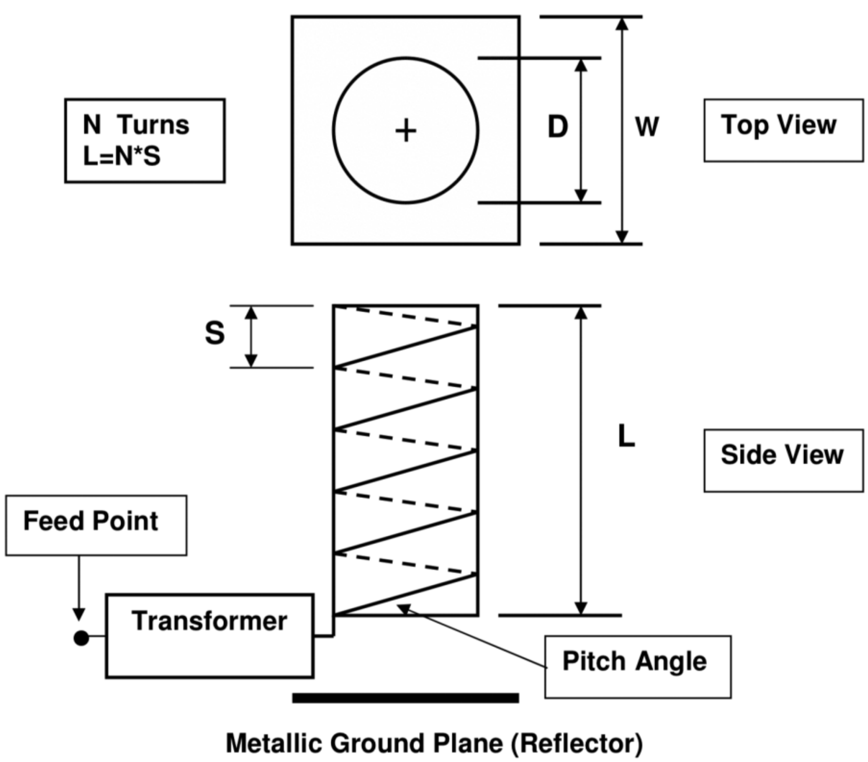

Figure 1: Helix Antenna Drawing. The helix is described by the following parameters: the overall length, *L*, the spacing, *S*, between turns, the diameter, *D*, and the width, *W*, of the ground plane. Another parameter often referred to in the literature is the pitch angle which is related to *S* and *D*.

. The construction of the helix is described by:

- The overall length of the helix, *L*
- The diameter of the helix, *D*
- The spacing between turns, *S*
- The width of the ground plane, *W*. In this article, I use a square ground plane.
- The diameter of the wire which is not critical. Usually a #8 AWG (0.128 inch diameter) wire is used for the 70 cm band.

Other secondary variables can be derived from the above such as the number of turns, N = *L/S,* and the *pitch angle*. The pitch angle is the angle between the wire at any point and a horizontal plane assuming that the helix is mounted vertically. The *Satellite Experimenter's Handbook* by the ARRL presents information for a pitch angle of 12.5 degrees.

It depends on *D* and *S* and is not used directly during the construction phase. It is however a fundamental way of describing any helix such as mechanical gears and many concepts in physics such as wave motion.

The ground plane, a wire mesh for low frequencies and a solid plate for microwave applications is mounted near the first turn of the helix. If a mesh is used, the grid spacing should be less than 0.05 wavelengths (3.5 cm for a 70 cm antenna). The grid spacing used in the 70 cm example presented in this article is 1.5 inches (1.3 cm).

Helix Design: Kraus and Emerson Models

The expected gain versus helix length is shown in Figure 2 for the Kraus and Emerson models. The graph for the Kraus model uses the same parameters as the example given in *The Satellite Experimenter's Handbook* where the circumference, C, equals 1.0 wavelength. $D = C / \pi =$ 0.318 wavelengths and S = 0.221 wavelengths. The pitch angle, α = 12.5 degrees. The parameters used in the Emerson formula are S = 0.24 wavelengths and the circumference *varies* with the length to achieve maximum gain. It is not set to one wavelength as in the Kraus model. The Emerson formula is only valid for lengths between 2 and 7 wavelengths.

Notice that the Kraus formula predicts that the gain goes from 18 to 21 dB, an increase of 3 dB, as the length increases from 4 to 8 wavelengths, while the Emerson formula predicts a change of only 1 dB over the same range.

In addition, there is a large difference in the gain, except for shorter antennas where it is expected that the Kraus formula will be quite accurate. Also shown in Figure 2 is the experimental work of King and Wong which is between the results of Kraus and Emerson.

Figure 2

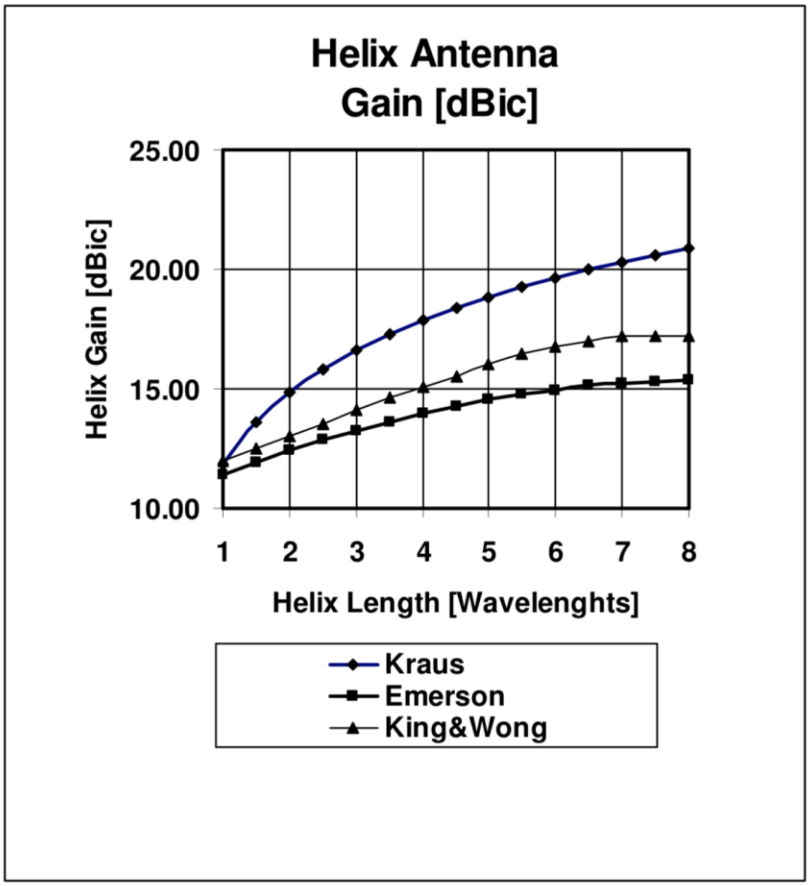

Figure 2: Helix Gain vs Length. This graph shows the gain of the helix antenna using the Kraus and the Emerson models as well as the experimental results from King and Wong. The parameters for the Kraus model are very similar to the Emerson model. The circumference for the Kraus model is 1.0 wavelengths and the spacing between turns is 0.22 wavelengths while the circumference, diameter and pitch angle for the Emerson model vary with the length of the helix. Notice that the experiments by King and Wong fall between the two theories.

The Calculator

The helix Antenna Calculator is easy to use and only has two numerical input pieces of data: the number of turns, *N*, and the frequency in MHz. The number of turns and the frequency determine the remaining dimensions and the performance. The user also must select the method of analysis (Kraus or Emerson) and the units used for the output (inches, metres, centimetres or millimetres).

DESIGN EXAMPLES

The calculations for the design examples given below were made using the helix Antenna Calculator described above. To use the calculator, simply follow the instructions that are provided with the calculator.

Example 1:

The first example is a case study of a 435 MHz (70 cm band) antenna designed and built by Clare, VE3NPC, using the basic Kraus method. Clare has built many successful antennas for use in satellite systems and also designed a novel method for matching the antenna to 50-Ω coax (published in the October 1996 issue of *The Canadian Amateur* magazine). The antenna is shown in Figures 3 and 4 along with the matching section.

The parameters (from the calculator) for the antenna are:

- Number of turns, *N* = 9.5
- Length, *L* = 57.18 inches (2.11 Wavelengths)
- Radius, *R* = 4.32 inches
- Spacing, *S* = 6.02 inches
- Pitch angle = 12.5 degrees
- Length of wire = 264 inches
- Width of rectangular ground plane, *W* = 16.3 inches
- Spacing of grid wires on ground plane = 0.5 inches
- Predicted gain of Antenna from Kraus = 15.0 dBic

Example 2:

The second example is the design of a 435 MHz antenna of 9.5 turns but based on the Emerson design.

The parameters from the calculator are:

- Number of turns, N = 8.75
- Length, L = 57 inches
- Radius, R = 5.11 inches
- Spacing, S = 6.52 inches
- Pitch angle = 11.47 degrees
- Length of wire = 287 inches
- Width of rectangular ground plane, W = 16.3 inches
- Spacing of grid wires on ground plane = 0.5 inches
- Predicted gain of Antenna from Emerson = 12.49 dBic

For this design, both length and the radius of the helix are larger than the design based on the Kraus formula. It is easy to use the calculator to experiment with the number of turns which changes the size and gain of the antenna.

Example 3:

The next example is a 2400 MHz design using the Kraus model.

The parameters from the calculator are:

- Number of turns, N = 30
- Length, L =83 cm (6.65 Wavelengths)
- Radius, R =1.99 cm
- Spacing, S = 2.77 cm
- Pitch angle = 12.5 degrees
- Length of wire = 348 cm
- Width of rectangular ground plane, W = 7 5 cm
- Predicted gain of Antenna = 20 dBic

Example 4:

The final example is a 2400 MHz design using the Emerson model. The antenna length is approximately 7 wavelengths.

The parameters from the calculator are:

- Number of turns, *N* = 27.5
- Length, *L* = 82.5 cm
- Radius, *R* = 2.16 cm
- Spacing, *S* = 3 cm
- Pitch angle = 12.47 degrees
- Length of wire = 382 cm
- Width of rectangular ground plane, *W* = 7.5 cm
- Predicted gain of Antenna = 15 dBic

Figure 3

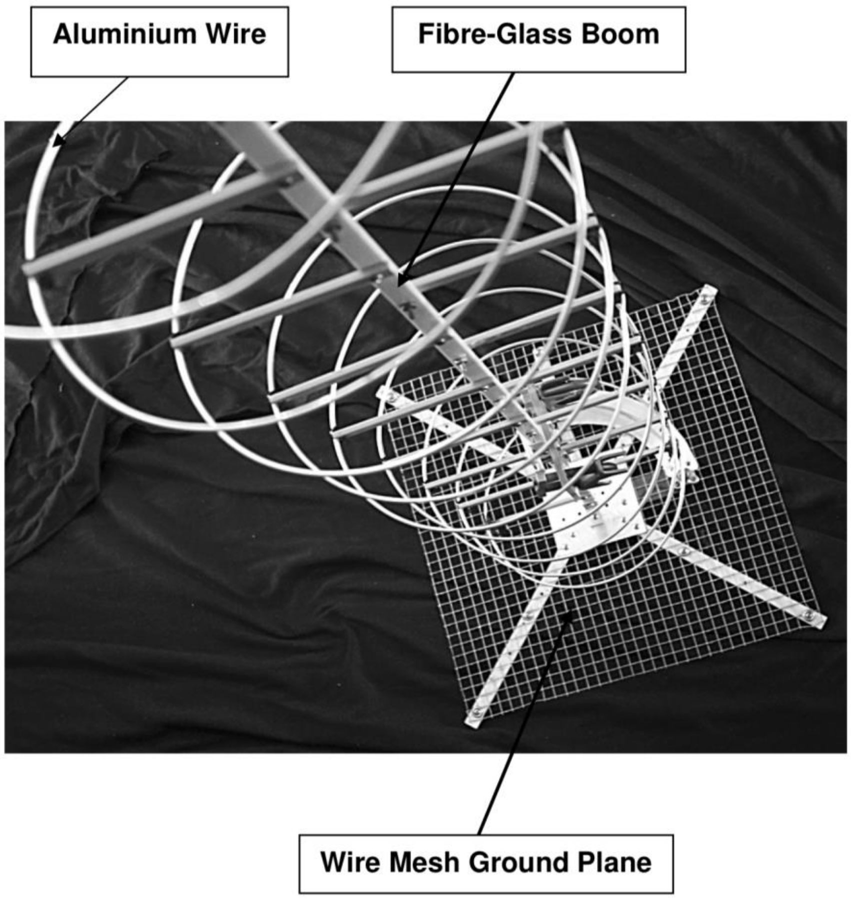

Figure 3: Photograph of the 70 cm antenna designed and built by Clare, VE3NPC. Notice that the boom is fabricated from thin fibreglass fencing material and not metal. We believe that this material is better than either metal or thick PVC piping material. The losses in PVC at UHF frequencies are not well documented. Also, the induced current in a metal boom can produce extra losses if there are any irregularities in the construction of the helix.

Figure 4

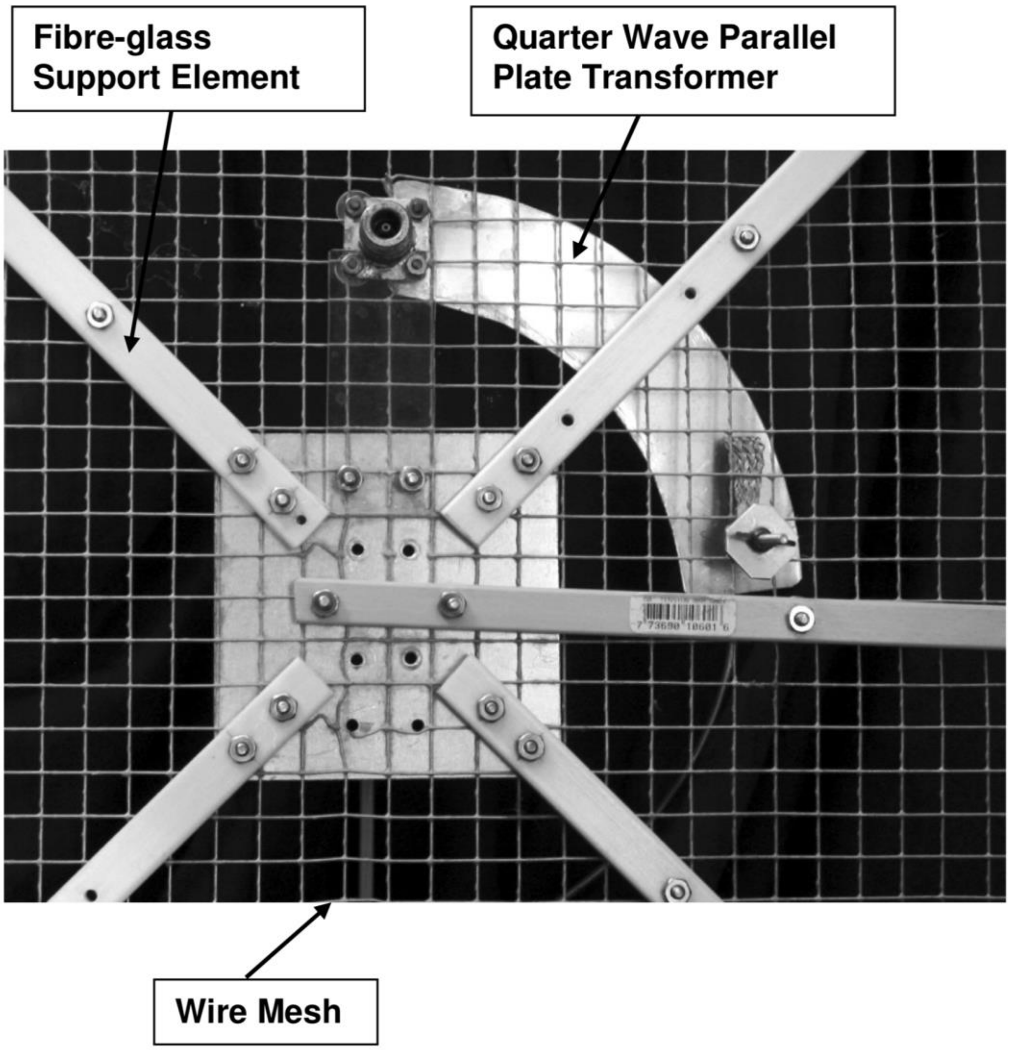

Figure 4: Close up photograph of the back of the antenna near the connector and matching structure. Since the impedance of the helix is approximately 230 Ω, a quarter wave parallel plate transformer of characteristic impedance equal to 107 Ω is used for a 50-Ω system. The characteristic impedance of the transformer used in this design is variable. Notice that the circular length of the transformer is equal to one quarter of a turn (one quarter of a wavelength).

DISCUSSION AND TRENDS

It is interesting to study "what-if" questions using the calculator. For example, here are a few trends:

- The gain only depends on the overall length.
- The beam width depends on the number of turns and the length of the helix.
- The circumference of the helix is close to 1 wavelength at the operating frequency.
- The pitch angle for the Emerson model varies with the number of turns while the pitch angle for the Kraus design is fixed to 12.5 degrees.

This article focused on the antenna gain and its physical dimension. There are many other almost as important items to be considered such as:

- The input impedance. This was studied extensively by Cebik (see the link below). The numerical modelling of Cebik indicates that the input impedance is approximately 230 Ω compared with the commonly quoted value of 140 Ω
- The shape of the beam. The beam shape can vary dramatically with the circumference, *C*. This is why we set *C* to be close to 1 wavelength. For example, a 10-turn helix with *C* = 1.35 wavelengths has multiple side lobes at high levels and a reduced forward gain. The pattern has essentially broken up and is not useable. Even with a well-designed helix, the first side lobes are less than 10 dB below the main beam. This produces problems for tracking satellites. Strong signals can occur for one or two sidelobes of the antenna as well as for the main beam.
- The method of matching the antenna with an impedance of 230 Ω to a standard 50-Ω coaxial cable. This has not been addressed in this article. Clare Fowler, VE3NPC, has solved the problem by designing a quarter-wave matching transformer which is adjustable to accommodate variations in construction and antenna length. See the references at the end of this article for more information.
- The bandwidth. The bandwidth of the helix antenna is intrinsically quite large, in the order of 30%. However, the bandwidth is usually limited by the matching structures used to transform 230 Ω to 50 Ω.
- The accuracy of the polarization. The ideal is to achieve circular polarization, but in practice it will differ slightly and become elliptical in nature.

Links:

**** Note these are no longer available on the RAC website but are available on the Internet archive site "The Wayback Machine"* (https://web.archive.org)

- Helix Design Calculator Helix Design Calculator by VE3KL - Can be used on-line without downloading to your computer
- A simple 50-ohm match for 70cm Helix antennas - October 1996 *TCA* article by Clare Fowler, VE3NPC
- Helical Antennas, Theory and Practice - Design and theory discussed with the Kraus and Emerson formula compared
- L.B. Cebik: "Notes on Axial-Mode Helical Antennas in Amateur Service," See the section on Practical Notes: VHF/UHF. Various online sources.
- Geometry of the Helix - Basic mathematics of the helix structure

References

1) "L Band Helix Antenna Array", Clare Fowler, VE3NPC, *Proceedings of the AMSAT-NA 21st Space Symposium*, Toronto, ON, Canada, October 17-19, 2003

2) "Gain of the Axial-Mode Helix Antenna", D.T. Emerson, *Antenna Compendium*, Volume 4, pp. 64-68, 1995, published by the ARRL

3) King, H.E. and Wong, J.L., "Characteristics of 1 to 8 wavelength uniform helical antennas", IEEE Trans, AP-28, pp. 291-296, March 1980