

# **Helical Antenna Optimization Using Genetic Algorithms**

by

Raymond L. Lovestead

Thesis submitted to the Faculty of the  
Virginia Polytechnic Institute and State University  
in partial fulfillment of the requirements for the degree of

Master of Science

In

Electrical Engineering

Ahmad Safaai-Jazi, Chairman

D.A. de Wolf

Gary S. Brown

October 1999

Blacksburg, Virginia

Keywords: Genetic Algorithms, Helical Antenna, Circular Polarization, NEC-2.

Copyright 1999, Raymond Lovestead

# Helical Antenna Optimization Using Genetic Algorithms

by

Raymond L. Lovestead  
A. Safaai-Jazi, Chairman  
Electrical Engineering  
(ABSTRACT)

The genetic algorithm (GA) is used to design helical antennas that provide a significantly larger bandwidth than conventional helices with the same size. Over the bandwidth of operation, the GA-optimized helix offers considerably smaller axial-ratio and slightly higher gain than the conventional helix. Also, the input resistance remains relatively constant over the bandwidth. On the other hand, for nearly the same bandwidth and gain, the GA-optimized helix offers a size reduction of 2:1 relative to the conventional helix. The optimization is achieved by allowing the genetic algorithm to control a polynomial that defines the envelope around which the helix is wrapped. The fitness level is defined as a combination of gain, bandwidth and axial ratio as determined by an analysis of the helix using NEC2.

To experimentally verify the optimization results, a prototype 12-turn, two-wavelength high, GA-helix is built and tested on the Virginia Tech outdoor antenna range. Far-field radiation patterns are measured over a wide frequency range. The axial-ratio information is extracted from the measured pattern data. Comparison of measured and NEC-2 computed radiation patterns shows excellent agreement. The agreement between the measured and calculated axial-ratios is reasonable. The prototype GA-helix provides a peak gain of more than 13 dB and an upper-to-lower frequency ratio of 1.89. The 3-dB bandwidth of the antenna is 1.27 GHz (1.435 GHz – 2.705 GHz). Over this bandwidth the computed gain varies less than 3 dB and the axial-ratio remains below 3 dB.

## **Acknowledgements**

I would like to thank my advisor, Dr. Ahmad Safaai-Jazi, for his assistance in designing this thesis topic. Without his guidance this thesis would not be possible. I would also like to thank the members of my graduate committee, Dr. D.A. DeWolf and Dr. Gary Brown, for their helpful advice.

I also would like to thank Mr. Randall Nealy, Mike Barts and Eric Caswell for their help with the antenna pattern measurements. The Antenna Group at Virginia Tech provides an invaluable service with their antenna measurement capabilities.

Finally, I want to thank my mother and father for their support during my college career. Without their encouragement I would never have been successful in college. I want to thank my loving wife Tara for her support and patience during my masters program.

# Table of Contents

<b>Chapter 1. Introduction.....</b>	<b>1</b>
<b>Chapter 2. Introduction to Genetic Algorithms.....</b>	<b>3</b>
2.1 The Genetic Algorithm.....	3
2.2 Applications.....	4
<b>Chapter 3. Genetic Algorithm Theory.....</b>	<b>6</b>
3.1 Genetic Algorithms.....	6
3.2 GA Setup.....	8
3.3 GA Operations.....	9
3.3.1 Selection.....	10
3.3.1.1 Population Decimation.....	10
3.3.1.2 Roulette Wheel Selection.....	11
3.3.1.3 Tournament Selection.....	11
3.3.2 Crossover.....	11
3.3.3 Mutation.....	12
3.3.4 Elitist Strategy.....	13
3.4 Recommendations.....	13
3.5 A Simple Example.....	15
3.5.1 Initial Population.....	15
3.5.2 Elitist Strategy.....	17
3.5.3 Selection, Mating and Mutating.....	17
3.6 Application to Antenna Problems, The Double Vee-Dipole.....	21
3.6.1 Setup.....	22
3.6.2 Solutions.....	23
<b>Chapter 4. The Helical Antenna.....</b>	<b>25</b>
4.1 Conventional Helical Antenna.....	25
4.2 Modified Helical Antennas.....	31
4.3 NEC2 Analysis of the Axial Mode Helix.....	35

<b>Chapter 5. GA-Optimized Helical Antenna.....</b>	<b>40</b>
5.1 Introduction.....	40
5.2 Shape.....	41
5.3 Fitness Function.....	46
5.3.1 Fitness Function: Example #1.....	46
5.3.2 Fitness Function: Example #2.....	47
5.3.3 Fitness Function: Example #3.....	48
5.4 GA Setup.....	50
5.5 GA Solution.....	52
5.6 Performance.....	57
5.7 Comparison of the GA-Optimized Helix with the Conventional Helix.....	60
5.8 Complete Solutions.....	65
5.9 Empirical Design Equations.....	69
<b>Chapter 6. Far-Field Measurements of the GA-Optimized Helical Antenna... </b>	<b>70</b>
6.1 Antenna Construction.....	70
6.1.1 Antenna Geometry.....	70
6.1.2 Construction Method.....	72
6.2 Measurement Procedures.....	76
6.3 Measurement Results.....	78
6.4 Final Note.....	90
<b>Chapter 7. Conclusions.....</b>	<b>92</b>
7.1 Summary of Results.....	93
7.2 Recommendations for Future Work.....	93
<b>References.....</b>	<b>95</b>
<b>Appendix.....</b>	<b>97</b>
<b>Vita.....</b>	<b>106</b>

## List of Figures

Figure 3.1	GA flowchart.....	7
Figure 3.2	The crossover process.....	12
Figure 3.3	Initial population converted to decimal and evaluated.....	16
Figure 3.4	The members selected using tournament selection.....	18
Figure 3.5	To illustrate the mating procedure.....	18
Figure 3.6	The mated population.....	19
Figure 3.7	Mutated population.....	20
Figure 3.8	The population that will serve as the next generation.....	20
Figure 3.9	Double vee-dipole geometry and parameters.....	21
Figure 3.10	Example of a chromosome for the double vee-dipole.....	22
Figure 3.11	Comparison of known double vee-dipole with the GA double vee-dipole.....	24
Figure 4.1	Conventional helix antenna geometry.....	27
Figure 4.2	Bandwidth ratio versus number of turns from equation (4.3).....	28
Figure 4.3	Peak gain of a variable length helix with pitch angle = $12.8^\circ$ [19].....	29
Figure 4.4	Gain versus frequency for a 5- to 35- turn helix [19].....	30
Figure 4.5	Variations of winding and tapering for the helix antenna [18].....	32
Figure 4.6	Various axial-mode helical antenna configurations.....	33
Figure 4.7	Gain and axial-ratio characteristics of two nonuniform helices.....	34
Figure 4.8	Peak gain of the helix as a function of length [28].....	37
Figure 4.9	Plot of gain versus radius for several length helices [28].....	38
Figure 4.10	Plot of gain versus radius for several length helices.....	39
Figure 5.1	Example of a 6 <sup>th</sup> order polynomial fitted to radius points.....	42
Figure 5.2	Helix obtained from a 6 <sup>th</sup> order polynomial.....	44
Figure 5.3	Example of a 2 <sup>nd</sup> order polynomial helix.....	45
Figure 5.4	Example #1, gain and AR curves.....	47
Figure 5.5	Example #2, gain and AR curves.....	48

Figure 5.6 Example #3, gain and AR curves.....	48
Figure 5.7 Plot of the polynomial used to generate the GA-optimized helix.....	52
Figure 5.8 Plot of GA-optimized helix design for 2 GHz.....	54
Figure 5.9 Side view of GA-optimized helix design for 2 GHz.....	55
Figure 5.10 Circumference versus length for GA-optimized helix.....	56
Figure 5.11 Pitch angle versus length for GA-optimized helix.....	56
Figure 5.12 Directivity and axial ratio for $2\lambda$ , 10 turn GA-optimized helix.....	58
Figure 5.13 Input radiation resistance for the GA-optimized helix.....	59
Figure 5.14 Input reactance for the GA-optimized helix.....	59
Figure 5.15 Axial ratio and gain curves for optimal and conventional helices.....	61
Figure 5.16 Radiation resistance of optimal and conventional helices.....	63
Figure 5.17 Imaginary part of the input impedance for helices.....	63
Figure 5.18 Directivity and axial ratio for a $3\lambda$ helix with varying turns.....	68
Figure 6.1 Template for helix support structure.....	74
Figure 6.2 Antenna structure with wire helix wrapped around it.....	74
Figure 6.3 Photograph of the actual GA-optimized helix built.....	75
Figure 6.4 Antenna measurement setup.....	76
Figure 6.5 Directivity and axial ratio of $2\lambda$ , 12 turn GA-optimized helix.....	79
Figure 6.6 NEC2 wire input file.....	80
Figure 6.7 Measure versus simulated power patterns, 1.6-1.9 GHz.....	81
Figure 6.8 Measure versus simulated power patterns, 2.0-2.3 GHz.....	82
Figure 6.9 Measure versus simulated power patterns, 2.4-2.7 GHz.....	83
Figure 6.10 Measure versus simulated power patterns, 2.8-3.1 GHz.....	84
Figure 6.11 Measure versus simulated power patterns, 3.1-3.5 GHz.....	85
Figure 6.12 The half power beamwidth of the simulated and measured antennas...	86
Figure 6.13 Antenna test range on the top of Whittemore.....	88
Figure 6.14 Measured and simulated axial ratio.....	89
Figure 6.15 Measured and simulated axial ratio at $0^\circ$ , $10^\circ$ and $20^\circ$ .....	90

## List of Tables

Table 4.1	Parameter limits for the conventional helix.....	31
Table 5.1	Example of lopsided percent bandwidth.....	49
Table 5.2	Example of fitness value calculation.....	50
Table 5.3	GA variable setup information for optimizing the helical antenna.....	51
Table 5.4	Summary of GA-optimized helix performance.....	57
Table 5.5	Conventional helix parameters.....	60
Table 5.6	Performance of the conventional versus GA-optimized helix.....	62
Table 5.7	Comparison of a conventional helix to other GA-optimized helices.....	64
Table 5.8	GA-optimized helix spreadsheet.....	69