New Design Methodology for Electrically Small HF Antenna

James Baker, Magdy F. Iskander
Hawaii Center for Advanced Communications
University of Hawaii - Manoa
Honolulu, HI, USA
jmbaker@hawaii.edu

Abstract—**The design of electrically small HF antennas continues to be a challenging effort, primarily due to the tradeoffs involved in reducing antenna electrical size while attempting to maintain some level of acceptable impedance and bandwidth at lower frequencies. Current doctrine dictates that optimization can only be achieved when the conductive elements are placed on the surface of the sphere enclosing the volume of the antenna. This paper presents an alternative design methodology that actually uses the inner volume to achieve self-resonances at much lower frequencies within a given volume, with performance consistent with the fundamental properties related to antenna height, volume, and wire length. This methodology offers designers an alternative when the design requirements and restrictions on maximum height and volume would otherwise not support self-resonance at a lower required frequency. Four alternative designs have been simulated and performance parameters including radiation resistance, Q, bandwidth, and the minimum operating frequency have been compared. Results from these simulations are presented and tradeoffs discussed.**

I. Introduction

The design of electrically small HF antennas for use in coastal surface wave radar systems continues to be a challenge, especially for applications such as homeland security and military operations. These applications typically require mobile and rapidly transportable radar systems that can be deployed to remote, desolate, or other undeveloped locations with no site preparation or infrastructure [1]. The design challenges are primarily due to the tradeoffs involved in designing an antenna small enough in size so that it can be quickly positioned at a site without reducing antenna electrical size while attempting to maintain some level of acceptable impedance and bandwidth at lower frequencies. Current doctrine dictates that optimization is achieved when the conductive elements are placed on the surface of the sphere enclosing the volume of the antenna. This paper presents an alternative design methodology that actually uses the inner volume to achieve self-resonances at much lower frequencies within a given volume with performance consistent with the fundamental properties related to antenna height, volume, and wire length. This methodology offers designers an alternative when the system design requirements and restrictions on maximum height and volume would otherwise not support self-resonance at a lower (yet required) frequency. Several new antenna designs based on this concept are presented along with simulation and experimental results. The antenna models presented were simulated using Numerical Electromagnetics Code (NEC) version 4.1 [2] running under the 4NEC2 [3] application. All designs presented have height restricted to 95 cm with $ka < 0.5$ throughout the HF band (3-30 MHz). All designs have single feed points with no external matching networks and use AWG #10 copper wire over an infinite PEC ground plane.

II. A Different Design Approach

The design approach presented herein provides innovative methods to more fully utilize the entire volume of the space enclosing the antenna, and is a departure from methods typically described in current publications. This new design methodology promotes the use of the inner volume of the antenna geometry as opposed to only using the outer surface of the enclosed volume. One method of accomplishing this is the introduction of helical elements in a meandering line geometry that occupies the internal volume of the antenna. Another innovation introduced is the intentional placement of "top-loading" components inside the antenna volume instead of on top of it.

A. Helical Meandering Line Antenna

This antenna uses meandering helical elements to maximize the total wire length enclosed in a given spherical volume. The antenna height is 90 cm and the enclosed spherical radius is 1.05 meters. The initial design consisted of three folded arms, each with four helical elements connected in a meandering pattern from the center of the antenna volume. Prototypes for this design were constructed and field tested with experimental results available in [4] and [5]. The design is presented in Fig. 1 below.

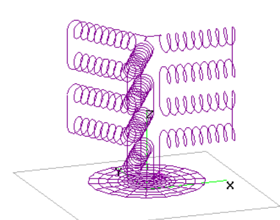

Fig. 1. Helical Meandering Line Antenna

B. Toroidal Helical Antenna

The new method can also be applied to canonical antenna designs such as the helical antenna. The helical geometry can be modified to replace the straight wire sections with helical elements creating a toroidal helical antenna. An example of this geometry is presented in Fig. 2 below. This design also provides additional options for inserting top-loading elements inside the volume for achieving lower self-resonant frequencies without increasing the overall volume of the antenna, and provides additional options for increasing wire length by modifying the radius and/or pitch of the helical coils.

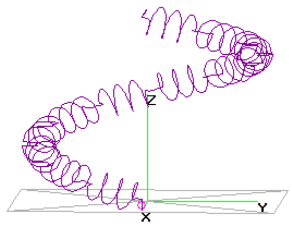

Fig. 2. Toroidal Helical Antenna

The self-resonant frequency of this design was further reduced by adding top-loading in the form of a two-turn toroidal helical element on the interior of the antenna volume as depicted in Fig. 3 below.

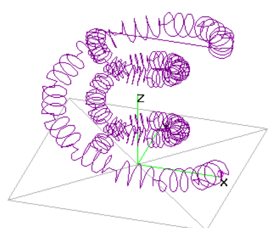

Fig. 3. Toroidal Helical with interior top-loading

These designs also allow for the use of folded arms to increase the antenna impedance in order to offset the reduction in resistance due to the increase in resonant wavelength. This technique is well documented and widely used in optimizing electrically small antenna [6] and provides similar levels of improvement in impedance when used in the new methodologies presented. Depicted in Fig. 4 is another variation on the design theme with four arms.

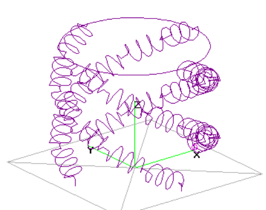

Fig. 4. Four-arm Toroidal Helical.

III. Results

A performance comparison is presented in Table I. The values for Q in Table I were calculated using the impedance values obtained from NEC output files based on the algorithm from Yaghjian and Best [7]. The values for resistance, *ka*, and Q are consistent with established limitations for electrically small antenna as described in [7].

TABLE I. DESIGN COMPARISON.

Antenna	**Parameters**				
	Self-Resonance (MHz)	***Resistance (Ohms)***	***ka***	***Q***	***Wire Length (meters)***
Helical MLA	15.6	20	0.36	111	34.1
Toroidal Fig. 2	15.0	2	0.32	173	9.3
Toroidal Fig. 3	8.5	2	0.19	355	48.0
Toroidal Fig. 4	16.1	38	0.35	64	40.0

IV. Conclusions

A new design methodology for reducing the size of electrically small antenna has been presented and demonstrated. Compact HF antenna designs that are self-resonant at multiple frequencies throughout the HF band have been described and demonstrated. The design methodology provides alternatives for new design geometries and also provides a method for lowering self-resonant frequencies without increasing the volume of the antenna. The total height of the antenna is less than one meter, thus presenting a very low profile compared to traditional and current antenna designs in this frequency band. The compact design and low profile allow for portability with minimal site preparation and environmental impact, making these designs suitable for applications requiring rapid response or covert operations.

References

[1] M. F. Iskander, Z. Yun, N. Celik, H.S. Youn, N. Omaki, J. M. Baker, "High-Frequency and Passive Radar Designs for Homeland Security Applications," *Marine Technology Society Journal*, Vol. 45, No. 3, pp. 111—119, May/June 2011.

[2] NEC 4.1, software, Lawrence Livermore National Laboratory, http://ipo.llnl.gov.

[3] 4NEC2, software, Arie Voors, http://www.qls.net/4nec2.

[4] J.M. Baker, H.S. Youn, N. Celik, and M.F. Iskander, "Low-Profile Multifrequency HF Antenna for Coastal Radar Applications", *IEEE Antennas and Wireless Propagation Letters*, Vol. 9, 2010, pp. 1119-1122.

[5] J.M. Baker, M.F. Iskander, H.S. Youn, and N. Celik, "High Performance Compact HF Antenna for Radar and Communication Applications", *IEEE AP-S Int. Symp.*, Toronto, Ontario, July 2010.

[6] S.R. Best, "The Performance Properties of Electrically Small Resonant Multi-Arm Folded Wire Antennas*", IEEE Antennas and Propagation Magazine*, Vol. 47, No. 4, August 2005, pp. 13-27.

[7] A.D. Yaghjian, S.R. Best, "Impedance, Bandwidth, and *Q* of Antennas", *IEEE Transactions on Antennas and Propagation*, Vol. 53, No. 4, April 2005, pp. 1298-1324.