Wire Antennas Optimizations on Various Platforms using Radial Basis Functions and Evolutionary Algorithms

by

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Contents

Abstract

High Frequency (HF) and Very High Frequency (VHF) electromagnetic waves have been used as the means of long-distance communication for decades. Nevertheless, in the design of wire antennas for HF and VHF devices, size reduction is one of the critical issues due to wavelengths of in ranges from 1 to 100 meters. It is well known that inductive and capacitive loadings can effectively change the current distribution along an antenna, reducing the self-resonant frequency, and hence the antenna size. Various types of inductive and capacitive loadings can be implemented on the wire antennas using ideal lumped components or realistic winding structures, such as zig-zag and helix shapes. Nevertheless, the physical limits of electrically small antenna can greatly constrain the dimensions, and the design of optimally varying windings will significantly increase the complexity in the modeling and simulation process. Furthermore, size reduction can also introduce significant degradation in both efficiency and bandwidth, and thus, obtaining a design with balanced performance becomes a challenging task, which is addressed in this thesis.

The work presented in this thesis contributes to the research by proposing and applying a generic methodology to the optimal design of size-reduced HF and VHF wire antennas. The electromagnetic simulator, NEC-2 (Numerical Electromagnetic Codes), based on the method of moments, is used to provide fast and accurate numerical estimation of the performance for the antennas. To drive the electromagnetic simulator, an evolutionary optimizer is developed using both genetic algorithm (GA) and particle swarm algorithm (PSA) for multi-objective optimization (MOO). The combination of these tools, i.e. electromagnetic simulator and optimizers, is applied to address the trade-offs of the small antenna design as well as to achieve faster convergence efficiently to the global optimal region. The in-house developed tool is named MATNEC, and couples antenna geometry modeling, electromagnetic simulation, and evolutionary optimization into an automated program. Several strategies have been used to reduce the simulation and optimization complexity with, in particular the application of radial basis function expansions to compactly describe the antenna structure. This effectively converts the optimization process from optimizing the antenna configuration directly to optimizing the parameters of mathematical expansion, thus achieving a significant complexity reduction.

In the application of the proposed technique in this thesis, three types of inductive loadings are successively introduced into the design of optimized wire antennas, producing a marked increase in performance in all cases. Firstly, as preliminary study, lumped inductive loadings along a monopole are used to effectively verify the optimization methodology and the antenna shortening theory. Secondly, a non-uniform zig-zag winding structure is considered to effectively verify the roles of optimized distributed inductive loadings formed by the antenna wire itself and also allowing for experimental validation of the findings. Thirdly, non-uniform helical antenna structures are also considered and verified experimentally. The optimal designs were verified both in bandwidth and in efficiency using a "Wheeler Cap" approach. The optimized results provide useful guidelines for the design of wire antennas for both HF and VHF communications.

The thesis also provides an investigation of the robustness of the optimized design in non-ideal environments. Optimized devices are integrated on various platforms or with near-by objects, and the re-optimization is carried out including the non-ideal environment. The weak impact from non-ideal environments and the similar results from re-optimization effectively demonstrate the strong functionality and robustness of the proposed design and optimization strategy for real-world applications. Mutual interaction between multiple antennas is also investigated, and the result illustrates the weak interference of the optimized antennas when used in an array environment.

Statement of Originality

This work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published written by another person, except where due reference has been made in the text.

I give consent to this copy of the thesis, when deposited in the University Library, being available for loan, photocopying and dissemination through the library digital thesis collection.

Signed

Date

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Conventions

Typesetting

This thesis it typeset using the LATEXsoftware. WinEdt build 5.5 was used as an effective interface to LATEX.

Referencing

The referencing and citation style adopted in this thesis are based on the Institute of Electrical and Electronics Engineering (IEEE) Transaction style.

Units

The units used in this thesis are based on the international system of units (SI units).

Prefixes

In this thesis, the commonly used numerical prefixes to the SI units are ″p″ (pico, 10^{-12}), ″n″ (nano, 10^{-9}), ″μ″ (micro, 10^{-6}), ″m″,(milli,10^{-3}), ″k″(kilo, 10^{3}), ″M″(mega, 10^{6}), and ″G″(giga, 10^{9}).

Spelling

Australian English spelling is used in this thesis.

Author Publications

Journal

[1] S. Zhao, C. Fumeaux, and C. J. Coleman, "Miniaturised HF and VHF antennas based on optimised non-uniform helical structures," *IET Microwaves, Antennas and Propagation*, vol. 6, pp. 603–610, 2012.

Conference

[1] S. Zhao, C. Fumeaux, and C. Coleman, "Optimal positions of loading for a shortened resonant monopole using genetic algorithm," in *International Conference on Electromagnetics in Advanced Applications, ICEAA 2010*, Sydney, Australia, September 2010, pp. 705–708.

[2] S. Zhao, C. Fumeaux, and C. Coleman, "Optimal loading configurations of a shortened resonant wire antenna using evolutionary optimizers," in *Twelfth Australian Symposium on Antennas, ASA 2011*, Sydney, Australia, February 2011.

[3] S. Zhao, C. Fumeaux, and C. Coleman, "Optimal helical antenna with continuously varying radius using evolutionary optimizers," in *IEEE International Symposium on Antennas and Propagation, AP-S 2011*, Washington, USA, July 2011, pp. 757–760.

[4] S. Zhao, C. Fumeaux, and C. Coleman, "Evolutionary optimization of zig-zag antennas using gaussian and multiquadric radial basis functions," in *Asia-Pacific Microwave Conference, APMC 2011*, Melbourne, Australia, December 2011, pp. 1594–1597.

[5] S. Zhao, C. Fumeaux, and C. Coleman, "Optimized helical monopole antennas for portable VHF communication devices," in *IEEE International Symposium on Antennas and Propagation, AP-S 2012*, Illinois, USA, July 2012.

Abbreviations

AMP Antenna Modeling Program

EFIE Electric Field Integral Equation

ESA Electrically Small Antenna

FBW Fractional Matched VSWR Bandwidth

FDTD Finite Difference Time Domain

GA Genetic Algorithm

G-RBF Gaussian Radial Basis Function

HF High Frequency

MFIE Magnetic Field Integral Equation

MoM Method of Moments

MQ-RBF Multiquadric Radial Basis Function

NEC Numerical Electromagnetic Codes

PEC Perfect Electric Conductor

PIFA Planar Inverted F Antenna

PSA Particle Swarm Algorithm

PSO Particle Swarm Optimization

RBF Radial Basis Function

SAL Small Antenna Limit

VSWR Voltage Standing Wave Ratio

VHF Very High Frequency

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