OPTIMIZATION OF WIRE ANTENNAS BY USING GENETIC ALGORITHMS DIRECTLY IN THE TIME DOMAIN *

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ABSTRACT

In this communication Genetic Algorithms (GAs) optimizers are applied, directly in the time domain, to the design of broadband thin-wire antennas. The broadband characteristics of the antennas are achieved by loading the wires with combinations of passive loads, trying to maximize the fidelity of the response while keeping the efficiency as high as possible.

INTRODUCTION

It is well known that the broadband characteristics of thin-wire antennas can be controlled by using resistive loads. Appropriate values of resistors located along the antenna geometry reduce unwanted reflections of the current at the ends of the wires enhancing the travelling-wave component of the current and therefore extending the bandwidth [1]. As resistively loaded antennas suffer from low efficiency, several authors have proposed broadband designs including capacitors [2], combinations of resistive and capacitive loading [3] and even other reactive elements [4].

We propose to apply Genetic Algorithms (GAs) techniques [5] to select the appropriate values of passive linear loads, to be located at specific points along thin-wire antennas to achieve a maximum bandwidth with the minimum possible losses. The loads can be either resistors (R), capacitors (C) or a combination of these elements. The GA optimization of wire antennas has been addressed in the literature quite extensively in the frequency-domain [5] and recently, in the time domain [6] for the case of resistively loaded antennas. The contribution of this work is to extend the method proposed in [6] to include the possibility of using both resistive and reactive loads. To work explicitly in the time domain provides wide-band information and allows us to optimize the entire operating spectrum of the antenna in a single run, as opposed to the frequency domain formulation which repeatedly calls for the electromagnetic solver at many frequencies within the band of interest.

The formulation employed is based on the solution of the Electric Field Integral Equation (EFIE) for thin-wire antennas with arbitrarily connected passive linear elements using a marching-on-in-time procedure to obtain the transient response of the antennas [7]. The main characteristics of the GAs are a real coded formulation and the capability of multi-objective optimization of both input fidelity, defined as a time domain parameter that accounts for the input impedance, and the energy radiated by the wire antenna.

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NUMERICAL FORMULATION

The study has been carried out using a computer code that calculates, in the time domain, the currents induced on a thin-wire antenna when it is excited by an arbitrary electromagnetic signal. It is based on the solution of the EFIE using the Method of Moments in the Time Domain (MoMTD). For the case of a thin wire with passive loads connected in series at specific points along the wire, the EFIE is given by [7]:

$$\hat{s}\cdot\vec{E}^i(s,t)=\frac{\hat{s}}{4\pi\varepsilon_0}\cdot\int_C\left[\frac{\vec{R}}{cR^2}\frac{\partial I(s',t')}{\partial s'}-\frac{\vec{R}}{R^3}q(s',t')+\frac{\hat{s}'}{c^2R}\frac{\partial I(s',t')}{\partial t'}\right]ds'+ \\ +I(s,t)\cdot R_l(s)+L_l(s)\frac{\partial}{\partial t}I(s,t)+\frac{1}{C_l(s)}\int_0^t I(s,\tau)d\tau \tag{1}$$

where *C(s')* is the wire axis contour, $\hat{s}'$ and $\hat{s}$ are the unitary vectors over the source and field points, separated by a distance $\vec{R}$; *I(s',t')* and *q(s',t')* denote the unknown current and linear charge distribution at source point *s'* at retarded time *t'=t-R/c*; $\vec{E}^i(s,t)$ is the field applied to the observation point *s* and $R_l(s), L_l(s), C_l(s)$ are the values of the resistance, inductance and capacitance per unit length respectively, located at the observation point *s*.

Equation (1) is solved applying the point matching form of the MoMTD using two-dimensional, Lagrangian interpolation as basis functions. This transforms (1) into a matrix equation at each time step which is solved for the current *I*(s,t) by marching on in time [7].

The parameters needed for the specific multi-objective GAs adopted in this work are the field radiated at any particular direction, the calculation of which is straightforward from the current distribution, and the fidelity in the response, which is computed from the cross-correlation between input voltage and output current [7] by using the expression:

$$\rho_{VI}=\left[\frac{\left|\hat{\sigma}_{VI}(t)\right|}{\sqrt{\hat{\sigma}_V(0)\hat{\sigma}_I(0)}}\right]_{\max} \tag{2}$$

where $\hat{\sigma}_{VI}$, $\hat{\sigma}_V$ and $\hat{\sigma}_I$ are the cross- and auto-covariances of both the input voltage and output current signals, respectively, computed directly in the time domain. From the field calculated at the direction of maximum radiation the normalized radiated energy is evaluated as $\varepsilon(\theta,\varphi)=\sum_t\left|E^{rad}(\theta,\varphi,t)\right|^2$.

Real coded GAs are employed so one chromosome, which characterizes one individual, is represented by a set of real numbers (or genes). GA uses a single-point crossover operator with a probability of crossover of 80%. For the mutation operator, it uses an inverse error function with a typical deviation of 0.1 times the range of the gene, and a probability of 0.4%. In the optimization of one parameter, the best individual in each generation is selected by a weighted roulette wheel scheme. For multi-objective optimizations the selection operator is based on the Pareto domination concept, with a triangular niching function added to guarantee the diversity in the population.

RESULTS

We now present some illustrative numerical results to demonstrate the effectiveness of the numerical procedure presented.

As a starting point in the design of a broadband thin-wire antenna using only capacitors, we have considered the monopole antenna proposed in [2]. The wire antenna has a length of 163 mm and its radius is 1.5 mm. It is loaded, in the original design, with an inductance of L=$1.257\cdot10^{-8}$ H at the feed point, and four capacitances $C_1=2.122\cdot10^{-12}$ F, $C_2=1.273\cdot10^{-12}$ F, and $C_3= C_4=6.366\cdot10^{-12}$ F, which are located at 32.1 mm, 62.3 mm, 90.5 mm and 140.9 mm, respectively, from the feed point. GA optimization schemes have been applied to select other possible values for the capacitors at the same points as with the original monopole so that the fidelity of the antennas is improved. The values allowed for the capacitors range from $C_{min}=0.1\cdot10^{-12}$ F to $C_{max}=20\cdot10^{-12}$ F which roughly correspond to $0.1\cdot C_2$ to $10\cdot C_1$. The antenna is excited at its center with a voltage $V^i(t) = \cos(2\pi f_0 \cdot t)\cdot e^{-g^2\cdot(t-t_m)^2}$, where $f_0 = 0.9$ GHz, $g = 6\cdot10^8$ s^{-1}, and $t_m = 3.577$ ns. This specific temporal dependence was chosen because its frequency spectrum has components in the interval between 0.6 GHz and 1.2 GHz, which is where the antenna presents broadband performance according to the results shown in [2]. The antenna was discretized by using 16 segments (4 genes in each chromosome), and 512 temporal intervals of duration 33.958 ps were computed in every case.

The optimization seeks a maximum fidelity response at the feeding point, and the selected final values, after 400 generations of 40 individuals each, are $C_1=0.1597\cdot10^{-12}$ F, $C_2=13.612\cdot10^{-12}$ F, $C_3= 3.562\cdot10^{-12}$ F, and $C_4=15.363\cdot10^{-12}$ F. A fixed inductance of L=$2\cdot10^{-8}$ H is added at the feeding point in order to compensate the negative values obtained for the reactance. Figure 1 shows the real and imaginary parts of the input impedance of the monopole against frequency of both the original and the optimized monopole, calculated via Fourier transform from the temporal response. As the fidelity parameter is 0.8763 in the original design, and 0.9575 in the GA optimized monopole, we conclude that, regarding its broadband characteristics, the new design has a better performance than the one proposed in [2].

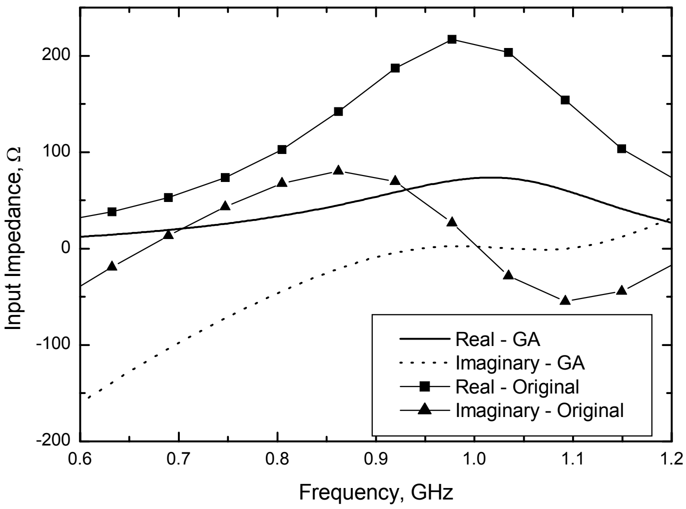

Fig. 1. Input impedance of broadband monopole.

As a second example, we consider a multi-objective optimization of a 0.5 m long monopole antenna. The design specifications aim for the maximum broadband input impedance response up to 2.5 GHz, and also seeks to maximize the energy of the radiated electric field in the broadside direction. The antenna, with a radius of 3.8 mm, is fed at the center with a Gaussian, delta-gap, voltage source of $V^i(t) = e^{-g^2\cdot(t-t_m)^2}$ where $g = 5\cdot10^9$ s^{-1}, and $t_m = 0.4292$ ns. For the MoMTD analysis, the monopole is discretized by using 16 segments. The GA scheme selects, at each segment except the delta-gap feeding, the optimal value of a RC series circuit (30 genes per chromosome). The resistance values allowed for the GA optimization have been selected as a discrete set from the Wu-King distributed resistance profile [1], that is, from R=0 ohms to 446.125 ohms, and the capacitances have been chosen so that their corresponding impedances in the range of frequencies of interest are also contained in the Wu-King resistive distribution which gives $C_{min}=3.125\cdot10^{-15}$ F and $C_{max}=62.5\cdot10^{-12}$ F.

Figure 2 shows a diagram of the niched Pareto GA distribution after 5000 generations of 100 chromosomes each. The corresponding monopole loaded with a Wu-King resistive profile [1] is added to the diagram as an example of a high fidelity-low efficiency antenna. With the aid of this Pareto distribution, the designer is able to choose the individual that best fits the specifications compromising between low losses and wide bandwidth.

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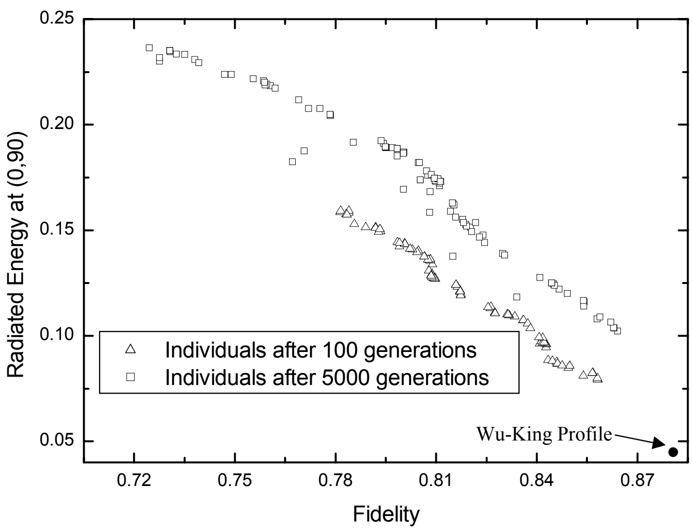

Fig. 2 Multiobjective optimization diagram.