A REVIEW OF ELECTRICALLY SMALL GENETIC ANTENNAS

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1. INTRODUCTION

One of the most challenging problems in antenna design is that of the electrically small antenna. For this investigation we define the size of the antenna as that enclosed within a cube of height, h/λ over an infinite ground plane. Thus the total volume within which the equivalent antenna in free space is confined is $2\,(h/\lambda)^3$. This definition is chosen because the computations are done with the Numerical Electromagnetics Code (NEC) [1], which uses Cartesian coordinates. The parameters which best characterize the performance of a small antenna are the quality factor, Q, and the Voltage Standing Wave Ratio (VSWR). The lower the Q, the more broadband the antenna; the lower the VSWR, the easier it is to transfer power from the transmission line to the antenna. The main problem in small antenna design is that as the size of the antenna is decreased its radiation resistance approaches zero and its reactance approaches plus or minus infinity. Most small antennas are inefficient and non-resonant, have a high VSWR and thus require matching networks.

In these investigations we use a genetic algorithm (GA) [2] in conjunction with NEC to search for resonant wire configurations that best utilize the volume within which the antenna is confined. The GA is an iterative optimization process that imitates the adaptation and evolution of a species of organism. The objective of this optimization is to minimize the VSWR and corresponding Q of an electrically small self-resonant antenna. In order to obtain a resonant antenna, the total length of the wire should be at least λ/4, the length of a resonant monopole. Thus, as the size of the cube within which the antenna is enclosed is decreased, more wire segments have to be used. We investigated configurations having from 2 to 10 wire segments and for all cases resonant antennas were obtained. The antennas were simulated and then built and measured. The GA optimization was done at a frequency of about 400 MHz. Intuitively, the antenna should consist off segments that are orthogonal where possible and which do not contain parallel wires that are too close together.

The electrical size of the antenna can be further reduced if it is immersed in a dielectric. Since the antennas have a very odd shape, we decided that the most convenient dielectric would be a powder; genetic antennas having 7-and 10-wire segments were immersed in dielectric powders having dielectric constants of 4, 9 and 12.

One of the main limitations of the small antenna is that as it becomes smaller, its radiation resistance decreases. As a result, unless a matching network is used, it is very difficult to transfer power from a 50-ohm coaxial line to the antenna. We show that it is possible to match an electrically small genetic antenna to a 50-ohm coaxial line by using a matching post which is placed near the base of the antenna. We demonstrate this technique by simulating and then measuring the 7-wire and 10-wire antennas. A sketch of the 7-wire genetic antenna with the matching post is shown in Fig.1.

2. APPROACH

To begin the GA process, a cost function, which contains the parameters to be optimized, must first be defined. For this investigation, the only parameter to be optimized was the VSWR. Other parameters such as radiation pattern and gain were not included since they do not vary very much for small antennas. We next identify a population of possible antenna configurations. We chose a GA design space that consisted of a grid of points enclosed in a cube of height h/λ; these are the possible vertices of the wires that are to be connected to form the antenna. The GA randomly selects a sample population of wire configurations. Ideally the size of this population should be large enough so that a wide selection of possible configurations is included, but not too large such that the computation time becomes unnecessarily long. As in the evolutionary process of "survival of the fittest," chromosomes having the best scores were mated and produced offspring while the poor performers were removed from the population. With succeeding generations the performance of the chromosomes continually improved and an "optimized" solution was ultimately obtained. We selected genetic antennas having from 2 to 10 wires connected in series. The corresponding volumes decreased from a cube slightly less than .1 λ on a side to a cube of less than .03λ on a side. The GA produced a resonant antenna that was optimized at a single frequency. The conductance at the resonant frequency, f_0 was calculated. The frequencies below resonance, f_1 and above resonance, f_2 at which the conductance dropped to ½ the value at resonance were determined and the Q was calculated from

$$Q = f_0 / (f_2 - f_1) \quad (1)$$

For the antennas immersed in a dielectric, containers were filled with a dielectric powder, which is manufactured by Emerson & Cuming and is designated as ECCOSTOCK HiK Powder. We used powders having dielectric constants of 4, 9 and 12. The loss tangent for $\varepsilon_r' = 4$ was .0004; the loss tangents for $\varepsilon_r' = 9$ and 12 were both .0007. The bulk densities were 2.12, 2.55 and 2.70 g/cc respectively. It was very important to tap the containers repeatedly so that the powder settled to its proper bulk density. The 7-and 10-wire antennas were immersed in a styrofoam coffee cup filled with the powder. The cup had a conical shape with a base dimension having a diameter of 5 cm and tapered up to a diameter of 8.5 cm; the height of the cup was 9 cm.

The idea of using a matching post to increase the radiation resistance of an electrically small antenna stemmed from the research that was originally done on Inverted-L antenna and Inverted-F antennas [3]. Fujimoto *et al* [4] later analyzed both the inverted –L and -F antennas in detail and showed that it was possible to use the matching post of the inverted – F antenna to change both the radiation resistance and reactance of the inverted – F antenna as a function of frequency and further showed that at nearby frequencies the antenna could be matched to a 50-ohm coaxial line. Finally, Best [5] has shown that many electrically small antennas having a low radiation resistance can be matched to a 50-ohm coaxial line by using an inductive matching post. He also showed that although the impedance match of the antenna is improved, the Q of the antenna remains essentially unchanged; we believe that this will also hold for the genetic antennas.

3. RESULTS

The GA simulation produced very odd antenna configurations. The antennas were fabricated out of 1/16-inch diameter copper tubing that was bent to the computed shape. Because of the complex configuration of the antenna, it was only possible to obtain a shape that approximated the computed design. The antenna was mounted over a 1.2 x 1.2 meter ground plane (about 1.6λ x 1.6λ at 400 MHz) and fed from a coaxial line terminated with a Type N connector. The admittance and VSWR were measured with a Hewlett-Packard Model 8510 Network Analyzer.

Most genetic antennas were designed to have a resonant frequency near 400 MHz. The electrical length of the height of the cube containing these antennas decreased from about .1λ to near .025λ. The total length of the wire that makes up these antennas was usually between .25λ and .35λ. In Figures 2 and 3 we plot the computed and measured radiation resistance and Q as a function of the electrical length of the height of the cube within which the antenna is enclosed. We note that as the cube size deceased from a height of .096λ to .026λ, the computed radiation resistance decreased from about 12 ohms to less than 1 ohm while the Q increased from about 16 to 590. The measured results compared very well with the computations, considering the fact that the computations were made for an antenna over an infinite ground plane; also, as mentioned previously, it was not possible to build the antennas to the exact dimensions of the computed models.

The resonant frequencies of the 7-wire and 10-wire genetic antennas in free space were 388.3 and 524.8 MHz respectively. When placed in a dielectric, the resonant frequencies decreased by about 35%, 50%and 55% for dielectric constants of 4, 9 and 12 respectively, so the electrical sizes decreased accordingly. The radiation resistance decreases approximately linearly with the corresponding decrease in resonant frequency while the Q rises sharply as the resonant frequency becomes lower; these results are shown in Figs. 2 and 3.

Simulated admittance plots, with and without the matching posts are shown in Fig. 4 for the 7-wire antenna. The resonant frequency of the simulated unmatched antenna is 403.4 MHz; the conductance is .37 mhos, the radiation resistance is 2.7 ohms and the corresponding VSWR is 18.6. The electrical height of the antenna at resonance is .045 λ. When the matching post is inserted, the minimum VSWR is reduced to 1.13 at a frequency near resonance of 406 MHz, the corresponding input admittance is now .022-j.002 mhos and the input impedance is 45.8+j3.8 ohms. The admittance for the fabricated 7-wire antenna is also shown in Fig. 4. The unmatched antenna has a resonant frequency of 381.6 MHz, the admittance is 444.2 mhos, the impedance is 2.26 ohms and the VSWR is 22.1. When the matching post is inserted, a VSWR of 1.13 is obtained at a frequency of 389 MHz; the corresponding admittance and impedance are .019-j.002 mhos and 50.4-j4.4 ohms; the electrical height is.057 λ. These results are best explained from the admittance charts. In each case, we note that the admittance of the unmatched antenna intersects the 20 mmho conductance circle at a frequency higher than the resonant frequency. By inserting the matching post, we add the equivalent of a parallel inductance at the input and this moves the admittance toward the center of the chart at that frequency. Although not exact, it does provide a qualitative explanation as to how the post behaves as a matching circuit.

4. SUMMARY

This process for designing small antennas using a genetic algorithm produced new resonant antenna configurations that probably could not have been obtained using other optimization methods. Using intuition, it would seem that the wires should be arranged so that they are orthogonal where possible; also nearly parallel wires that are too close together should be avoided, thus minimizing the transmission-line currents that increase the antenna Q. Upon examining the resultant antenna designs it seemed as though the GA also converged to antenna designs that incorporate these principles. The preliminary results are very encouraging. These antennas are very inexpensive and can be easily fed from a coaxial line.

ACKNOWLEDGEMENT

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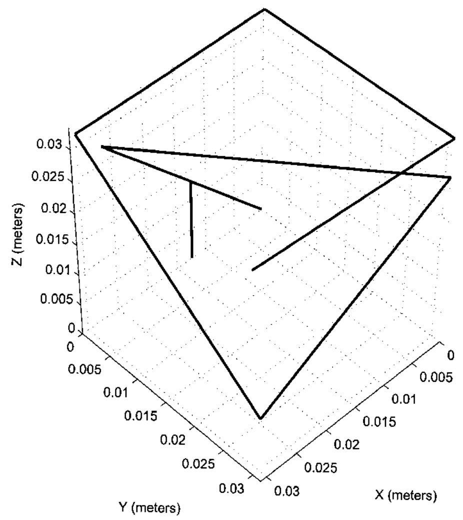

Fig.1 7-wire genetic antenna with matching post

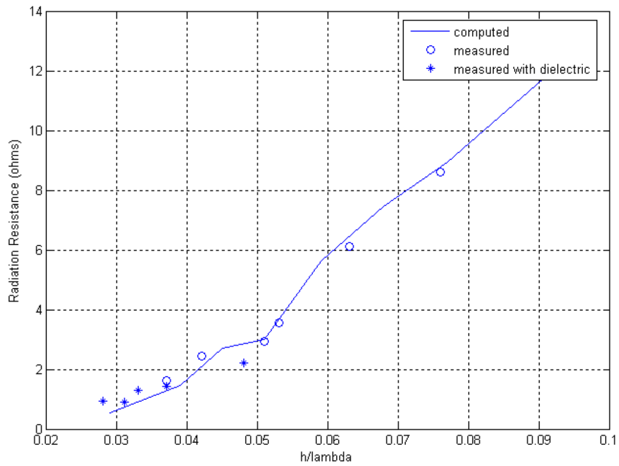

Fig.2 Radiation resistance vs height for 7-wire genetic antenna

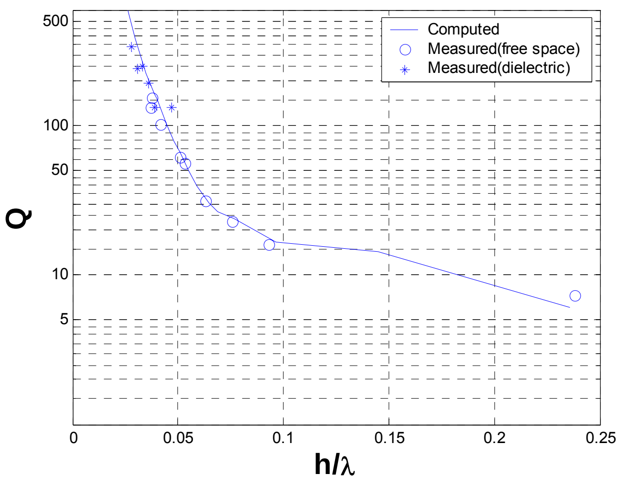

Fig.3 Q vs height for 7-wire genetic

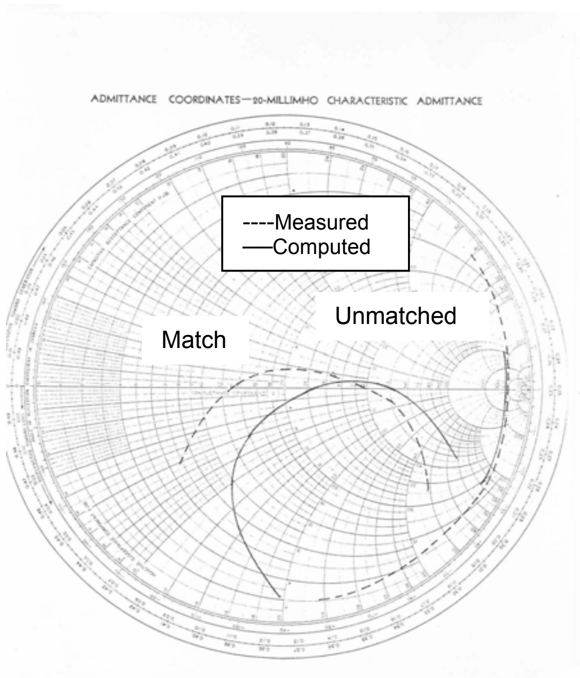

Fig. 4 Measured and computed admittance antenna plots for 7-wire genetic antenna with and without matching post