A Novel Broadband Quasi-fractal Binary Tree Dipole

Chen Xing
College of Electronics and Information Engineering, Sichuan University, China

Abstract—With the development of fractal theory, fractal geometries are widely used in the antenna design. In this paper, a novel dipole antenna based on the quasi-fractal binary tree is proposed. To achieve broadband characteristics, the proposed antenna is optimized in an automated design, making use of the Genetic Algorithm (GA) in conjunction with NEC (Numerical Electromagnetic Codes) and cluster parallel computation. A design result is presented. A prototype of the designed antenna has been fabricated and tested. Results of the measurement verify the designed antenna is able to provide a broad impedance bandwidth.

DOI: 10.2529/PIERS060904094821

1. INTRODUCTION

Fractals are geometrical shapes, which are self-similar, repeating themselves at different scales. With the development of the fractal theory, the nature of fractal geometries has caught the attention of antenna designers. The utilization of fractal geometries in antenna design has led to the evolution of a new class of antennas, called fractal shaped antennas [1].

As one class of fractal geometries, the fractal tree has already been exploited in antenna designs to produce multi-band characteristics or to achieve miniaturization [2–4]. The fractal tree includes several families such as the binary, three dimensional, ternary, and etc. As illustrated in Fig. 1, the structure of a canonical binary fractal tree can be defined by the following parameters: a length of the trunk $LT$; Branch angle $2\theta$ or branch half angle $\theta$; Scale ratio $S$ that is the length ratio between a child branch and its parent branch as well as between a first level branch and the trunk; The number of iteration $N$.

In this paper, a dipole antenna based on a quasi-fractal binary tree is presented. Different from a canonical binary fractal tree, the length of the trunk of a quasi-fractal binary tree is independent from the length of branches, i.e., the scale ratio only denotes the length ratio between a child branch and its parent branch. The configuration of a quasi-fractal binary tree dipole is shown in the Fig. 2. Besides parameters $LT$, $\theta$, $S$, and $N$, we need one more parameter, i.e., the length of the first level branch $LB$, to describe the structure of the proposed antenna.

![Figure 1: The first 3 iterations of a binary fractal tree.](image1)

![Figure 2: Configuration of a 3rd iterated quasi-fractal binary tree dipole.](image2)
2. AUTOMATED ANTENNA DESIGN USING GA AND NEC

To achieve broadband characteristics, the proposed antenna will be automated designed making use of parallel Genetic Algorithm (GA) in conjunction with NEC (Numerical Electromagnetic Codes) on a cluster system.

The GA [5] is a non-linear, robust stochastic optimization algorithm based on the Darwinian theory of decent with modification by natural selection. It has found great utility in electromagnetic optimization tasks including the design of various antennas [6, 7].

NEC is a Method-of-Moments (MoM) simulator for wire antennas, which was developed at Lawrence Livermore National Laboratory in the early 1980’s. As a well-known antenna simulator, it is widely used in antenna simulation and design [6–9]. In this research, the second version of NEC (NEC2) is used for computing the input impedance of the proposed antenna.

An automated antenna design based on GA usually invokes hundreds or even thousands numerical simulations, hence is computationally intensive. Since the GA exhibits an intrinsic parallelism and allows a very straightforward implementation on parallel computers, we implement the GA-based antenna design into parallel computation to make the computation more effective. The computation is parallelized in a master-slave model and is carried out in a Beowulf cluster system, which is composed of 16 AMD 1700+ processors interconnected by a fast 100 Mb/s Ethernet and uses the message passing interface (MPI) library. One processor, named the master processor, controls the antenna design procedure. While the other processors, called slave processors, carry out the numerical simulations using NEC2.

3. AUTOMATED DESIGN OF THE QUASI-FRACTAL BINARY TREE DIPOLE

In this paper, the quasi-fractal binary antenna is assumed to be made of 1 mm-diameter copper wires, operate at a center frequency of 2450 MHz, and be fed by a 50 Ω coaxial cable through a 1 : K balun (contraction for “balanced to Unbalanced”) [10], which is employed for eliminating the unbalanced currents and for impedance transformation.

The design goal of the proposed antenna is to achieve a broad impedance bandwidth at the center frequency. Therefore, the fitness function is defined as

\[ F = C^* BW, \]  

where \( C \) is a weight factor and set to be 0.2, \( BW \) is the impedance bandwidth in GHz.

In the GA optimization procedure, total 5 parameters, i.e., \( LT \), \( BT \), \( \theta \), \( S \), \( N \) and \( K \), will be optimized. \( LT \) and \( BT \) are confined within the range of 5 mm to 100 mm, \( \theta \) is restricted to be from 5° to 60°, \( S \) is between 0 and 1, and both \( N \) and \( K \) are chosen from integers of 1 to 6.

A set of GA-based automated design processes are executed. In each of them, a binary GA carries out 200 generations with the number of individuals in a population \( N_{ind} = 200 \), the probability of crossover \( P_c = 0.5 \), and the probability of mutation \( P_m = 0.2 \).

4. RESULTS AND DISCUSSION

The result of the automated design is: \( LT = 8.0 \) mm, \( BT = 41.7 \) mm, \( \theta = 8.5^\circ \), \( S = 0.7 \), \( N = 5 \), and \( K = 4 \). Simulated by NEC, the input impedance and the corresponding VSWR (Voltage Standing Wave Ratio) of the designed quasi-fractal binary tree dipole are illustrated in the Fig. 3. One can

![Figure 3: NEC computed input impedance and VSWR of the design quasi-fractal binary tree dipole.](image-url)
observe that the designed antenna has a wide 2:1 VSWR impedance band from 1150 MHz to 3700 MHz.

To validate the result of the automated antenna design, a prototype of the designed antenna has been fabricated and tested. As shown in Fig. 4, the prototype antenna is on an organic plastic board, and fed by a 50Ω coaxial cable through a 1:4 balun. The return loss of the prototype antenna was measured using a Hewlett-Packard 8510 Network Analyzer. The Fig. 5 compares the computed and measured VSWR of the designed antenna. The measurement verified the designed quasi-fractal binary tree dipole possesses an encouraging capability of broadband.

Figure 4: The photo of the fabricated quasi-fractal binary tree dipole.

Figure 5: Comparison of the computed and measured VSWR for the quasi-fractal binary tree dipole.

5. CONCLUSION
This paper proposes a dipole antenna based on the quasi-fractal binary tree. The GA in conjunction with the NEC and cluster parallel computation is employed for automated design of the proposed antenna to achieve a wide impedance bandwidth. The designed antenna was fabricated and tested. Results of the measurement show the proposed quasi-fractal binary tree dipole possesses an encouraging capability of broadband.

ACKNOWLEDGMENT
The work was supported by a grant from the National Natural Science Foundation of China (No. 10476013).

REFERENCES


