Reconfigurable Miniature Three Dimensional Fractal Tree Antennas

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I. Introduction

The radiation characteristics of antenna configurations based on fractal tree structures have been recently studied in [1-4]. When used as antenna elements, fractal tree structures can be designed to produce multiband characteristics [1,2] or to achieve miniaturization [3,4]. A set of dipole antennas that use fractal tree structures as end loads to achieve a resonant frequency lower than a standard dipole of comparable length have been considered in [3,4]. In addition it has been shown that increasing the density of fractal tree end loads can significantly improve the miniaturization of such antennas [4]. In this paper, two design examples are considered where these miniature fractal tree antennas are made reconfigurable by the introduction of strategically placed reactive loads or RF switches. The first design is a fractal dipole antenna that operates at several frequency bands by adding reactive loads in the tree structure. The second design considered is a reconfigurable miniature dipole antenna that achieves a 43% size reduction with respect to its conventional counterpart (i.e., a half-wave dipole for the lowest operating band) and has a tunable bandwidth of nearly 70%.

II. General Geometric Description of Three Dimensional Fractal Tree Antennas

Fractals are objects which have a self-similar structure repeated throughout their geometry. This self-similar structure may be produced by the repeated application of a generator, and in the case of fractal trees, the generator is defined as a junction from which several smaller branches, called child branches, split from a parent branch. The manner in which these branches separate are determined from four different parameters for each child branch: scale, elevation, rotation, and twist. The scale of a branch represents how long a child branch is with respect to its parent branch. The elevation angle of a branch is the angle formed between the parent branch and the child branch. In this way a branch with an elevation angle of 0° is in line with its parent branch and a branch with an elevation angle of 90° is perpendicular to it. The rotational angle determines the angle that each branch points around the axis of the parent branch. The position of the rotational angle is relative to the previous two branches, i.e. the parent and the grandparent branches. Finally, the twist angle is an additional angle that is added from the parent branch onto the rotational angles of each child branch.

III. Self-Reconfigurable Reactive Loaded Center-Stubbed Fractal Tree Monopoles

Reactive loads can be used to make a typical monopole antenna resonant at more than one frequency. These reactive loads behave as an open circuit at some frequencies and a short circuit at others, effectively making an antenna self-reconfigurable (i.e., reconfigurable without the need for RF switches). This concept can also be applied to fractal tree monopoles to produce an antenna that not only is resonant at more than one frequency but also is miniature in size due to the presence of the space-filling end-load structure.

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In this case study, a fractal tree structure with 4 branches and a center stub is considered. It has been shown that fractal tree antennas that incorporate a center stub can be designed to have a reduced resonant frequency and low reflection properties [4]. Fractal tree dipole antennas can be designed to have low values of VSWR by using generator branching schemes with sufficiently small elevation angles. Also, the resonant frequency of fractal tree dipole antennas may be reduced by considering geometries which have a more dense configuration of branches. In this manner a center stubbed fractal tree antenna can take into account both of these design considerations by increasing the density of the fractal branching structure while, at the same time, keeping the elevation angles small with respect to the generator. The center-stubbed fractal tree antenna can be created from the generation parameters listed in Table 1.

The third stage center-stubbed fractal tree monopole can be made to operate at more than one frequency by adding series LC loads inside the fractal tree end-load structure. An advantage of the fractal tree antenna is the ability to place the loads in the branches of the fractal tree structure to provide more flexibility in the design of miniature multi-band monopole antennas by allowing the resonances to be placed closer together. Using five distinct reactive loads, a tri-band version of the third stage 4-branch, 45° fractal tree monopole with center stub is presented and discussed here. Four loads are placed near the top of the first stage of the outer four branches. A fifth load is placed near the bottom of the first stage of the center stub. Figure 1 shows the position of the loads on the 4-branch, 45° fractal tree monopole with center stub.

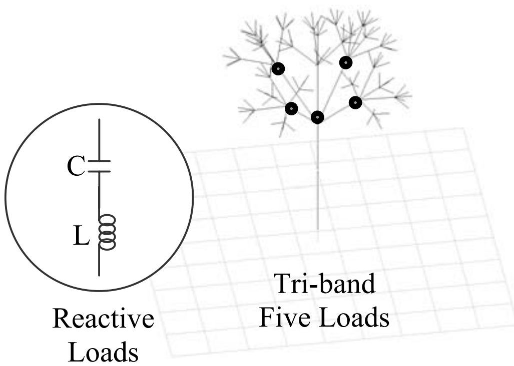

Figure 1: Tri-band 4-branch fractal tree monopole with center stub.

Scale	Elevation	Rotation	Twist
0.5	45°	45°	0°
0.5	45°	135°	0°
0.5	45°	225°	0°
0.5	45°	315°	0°
0.5	0°	45°	45°

Table 1: Generation parameters for the 4-branch, 45° tree with center stub.

The loaded antenna has three primary resonances at 330 MHz, 800 MHz, and 2220 MHz. A five-element matching network can be used to allow the antenna to perform efficiently at each resonant frequency. The VSWR plots for the matched and unmatched tri-band center-stubbed fractal tree and the unloaded single band fractal tree monopole are compared in Figure 2.

IV. Miniature Reconfigurable Fractal Tree Antenna Using RF Switches

Recently there has been a considerable amount of interest in design concepts for reconfigurable antennas capable of operating over a broad range of frequencies. In this section a reconfigurable antenna design approach will be introduced that exploits the branching structure of fractal tree dipoles. Because the current is distributed over the entire end-load, the effective removal or switching off of even relatively large sections of the fractal tree structure will reduce the resonant frequency only by small amounts. This property of reconfigurable fractal tree antennas can be exploited to allow the resonances of the antenna to be spaced close enough together to cover all of the frequencies between adjacent bands. Second, because the fractal tree structure has many parallel paths for the current to flow, then only a relatively small number of switches may be required to achieve tunability over a desired range of frequencies.

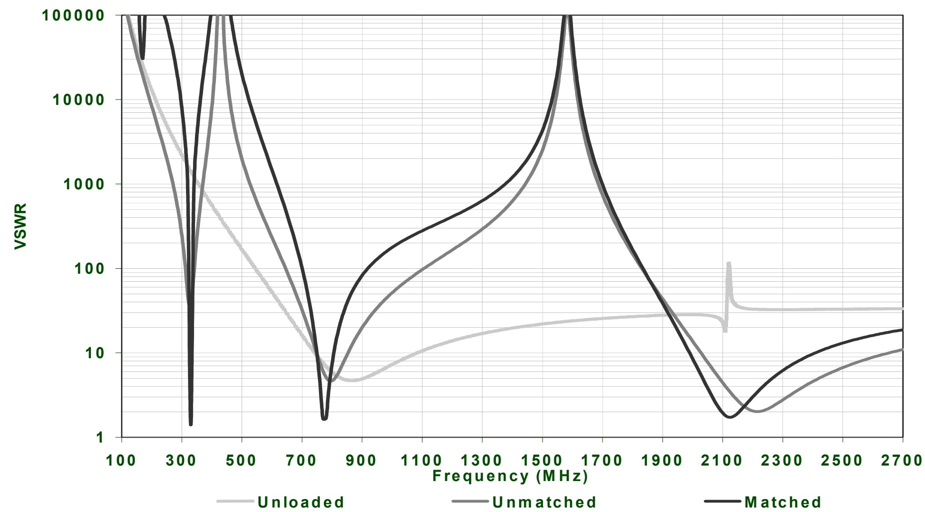

Figure 2: VSWR versus frequency for matched and unmatched cases.

A design is presented here where, RF switches are strategically placed on the third stage, six-branch 50° - 30° fractal tree dipole antenna to make it reconfigurable (i.e., tunable) over a bandwidth of 68%. The six-branch 50° - 30° fractal tree dipole alternates between two values for the elevation angle of the fractal tree (the generation parameters for this antenna are listed in Table 2). The antenna uses 204 separate switches placed throughout both tree structures (a total of 102 on each end) to produce 20 reconfigurable states. The locations of these RF switches are illustrated in Figure 3. The switches are placed at every junction inside the tree structure with the exception of the junction joining the base to the first stage. The junctions joining the first and second stages all have six switches associated with each of the six branches. In addition the 36 junctions between the second and third stage of the fractal structure have switches associated with each of them. The six junctions between the second and third stages that are nearest to the center axis of the antenna (i.e., those that are closest to being vertical) also have six switches associated with each of the six branches. The remainder of the junctions between the second and third stage of the fractal tree have only one switch, which is placed near the end of the branch below the junction. For this particular design, there are 20 different combinations of switch settings which correspond to 20 different resonant frequencies at which the reconfigurable antenna is capable of operating.

The resulting antenna can be reconfigurable from 770 MHz to 1570 MHz for a bandwidth of 800 MHz with a VSWR of under 3:1 and is reconfigurable from 970 MHz to 1570 MHz for a bandwidth of 560 MHz with a VSWR of below 2:1. Figure 4 shows the VSWR curves for each of the 20 different reconfigurable states. Each of the 20 reconfigurable states is represented by a separate VSWR curve (indicated by light gray lines) with the lowest resonant frequency representing the state with all the switches closed and the highest resonant frequency representing the state with all the switches open. The remaining states are achieved by opening the switches progressively from the top to bottom. In addition, for three of the reconfigurable states the antenna effectively operates as a 50°-30° fractal tree dipole with fractal stages 3, 2, or 1. The VSWR curves for these three special cases are indicated on the graph by thick dark gray lines. Finally the solid black line represents the overall minimum VSWR the antenna can be configured to for a particular frequency over the entire operating range of the antenna.

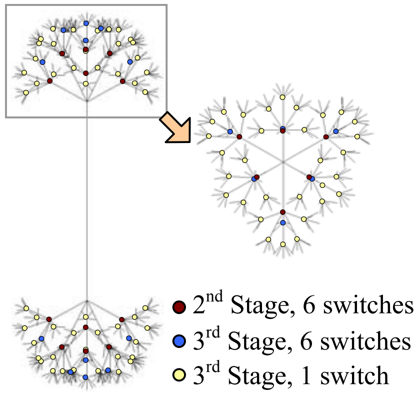

Figure 3: Miniature reconfigurable fractal tree antenna using RF switches.

Scale	Elevation	Rotation	Twist
0.5	50°	0°	0°
0.5	30°	60°	0°
0.5	50°	120°	0°
0.5	30°	180°	0°
0.5	50°	240°	0°
0.5	30°	300°	0°

Table 2: 6-branch 50° - 30° fractal tree.

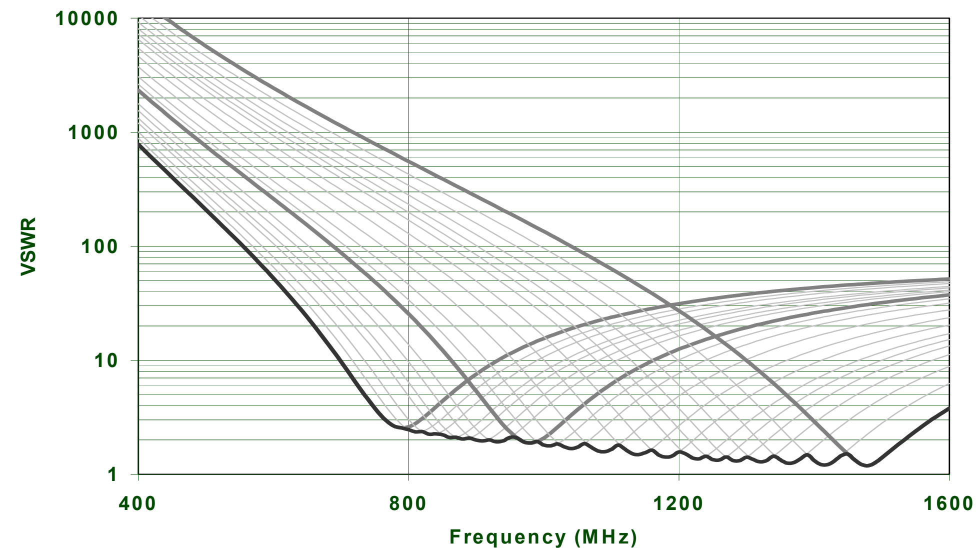

Figure 4: VSWR versus frequency curves for each reconfigurable state.

References

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