Abstract – This project studies the Sierpinski Carpet fractal antenna in terms of optimality. A 3D full-wave FDTD model of the structure is developed and used in conjunction with a neural network optimization procedure. As an original engineering design based on the idea of a broken fractal geometry is suggested. The modified fractal antennas are shown to have the capability of being optimized, in terms of its return loss, in a narrow frequency band.

Related Fundamental Issues

The self-similarity properties of fractal shapes can be translated into electromagnetic behavior and may result in a multiband antenna. Yet, studies of fractal antennas have been practically limited to rather non-systematic explorations of design ideas and nearly accidental findings of fortunate characteristics.

- Since fractals are known to be suitable models for nature, is the fractal geometry of an antenna optimal in some sense?
- Which properties (if any) of fractal antenna geometries may be responsible for multiband/wideband performance?

1. The Sierpinski Carpet Fractal

This project is focused on the Sierpinski Carpet (SC) fractal and the related antenna. The SC fractal is defined using eight specific affine transformations $W_i$, which are initially applied to the unit square $S_0$.

The first four SC iterations $i = 1, ..., 4$:

2. Modeling the Antenna

The project considers two types of antennas: an antenna built of patches (A), and an antenna built of slots (B).

The algorithms which are based on the affine transformations and are capable of generating the geometries of both types of antennas have been implemented as completely parameterized models for QuickWave-3D, the 3D conformal FDTD electromagnetic simulator. The models were used to calculate the return-loss characteristics of both antennas.

Valuating the QuickWave-3D Model

Resonant Frequencies of the Patch SC Antenna ($i = 3$) – substrate: Duroid 5880 ($\varepsilon_r = 2.2 – j0$); 196x196 mm; probe: 22.9 mm from the edge of the main patch; $r = r = 1$ mm, $s = 1.6$ mm

| Measured [1] | 1.5 | 4.5 |
| Calculated [2] | 1.49 | 3.01 | 3.36 | 4.28 | 4.48 | 5.49 | 5.96 |
| Our model | 1.48 | 2.98 | 3.34 | 4.25 | 4.43 | 5.43 | 5.89 |

SC Antenna: Patches & Slots

SC Antenna – substrate: Duroid 5880; 78x78 mm; $r = 0.3$ mm, $s = 1.0$ mm

3. Fractal Modifications

This project focused on trying to improve the multiband and wideband properties of the SC antenna. The original results from this work concern the process of modifying the SC fractal geometry for $i = 2$.

Specifically, the project considers two types of modifications:

1) the systematic outward movement and rotation of the smallest elements with respect to the center element.
2) the pseudo-random motion of the smallest elements within their immediate sub-domain.

4. Optimization Problem & Results

To perform the numerical FDTD-backed optimization, we use a neural network procedure [3] and solve the following optimization problem:

Find the geometry of the return loss less than an assigned level $s$ in a specified frequency range $[f_1, f_2]$.

NB: For the modification which considered the pseudo-random motion of the smallest elements, the optimization procedure produced a configuration which had a return-loss characteristic which was well within the range of optimality.

5. Conclusions

- The developed 3D model of the SC antenna was proven to be adequate.
- Variations in the geometry of the SC fractal antenna allow for very limited control over the frequency characteristics: the SC pattern is not optimal in terms of bandwidth/wideband performance.
- It was possible to “tune” the antenna at particular frequencies and increase the widths of the frequency bands by using the pattern of a broken fractal.

The results constitute a complete original engineering design of the broken SC fractal antenna.

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References


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