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SIERPINSKI CARPET FRACTAL ANTENNA ARRAY USING MITERED BEND FEED NETWORK FOR MULTI-BAND APPLICATIONS

D. Prabhakar[1], P. Mallikarjuna Rao[2] and M. Satyanarayana[3]
[1]Department of Electronics and Communication Engineering, DVR & Dr. HS MIC College of Technology, Kanchikacherla, India
[2]Department of Electronics and Communication Engineering, AU College of Engineering (A), Andhra University, Visakhapatnam, India
[3]Department of Electronics and Communication Engineering, M V G R College of Engineering (A), Vizianagaram, India
E-Mail: prabhakar.dudla@gmail.com

ABSTRACT

In the last few decades, there is an incredible growth in wireless communication which has led to the need for antennas with increased gain, bandwidth and low profile. To achieve wideband/multiband antennas, one technique is by applying fractal shapes into antenna geometry. This paper focuses on Sierpinski carpet fractal antenna (SCFA) Array using Mitered Bend feed network to increase the gain. These antennas are designed using HFSS on FR4 substrate with dielectric constant of 4.4 and fed with 50 ohms micro strip line. SCFA an array has been fabricated and tested using a VNA and the fabrication results are good in comparison with the simulation ones, thereby suggesting the credibility of all the designed antennas.

Keywords: Sierpinski carpet fractal antenna, Mitered Bend feed network.

INTRODUCTION

Antenna is a specialized transducer that converts radio frequency (RF) signals into alternating current (AC) or vice versa. There are two basic types of antenna: (1) the transmitting antenna, which is fed with AC from electronic equipments and generates an RF field, and (2) the receiving antenna, which intercepts RF energy and delivers AC to electronic equipment. Antenna is three dimensional and lives in a world of beam area, steradians, square degree, and solid angle. It has self and mutual impedances. Antenna also has polarizations: linear, elliptical, and circular. All types of antenna have the same fundamental principle which mentions that radiation is produced by accelerated (or decelerated) charge.

A fractal antenna is an antenna that uses a fractal design to maximize the length of material that transmits or receives electromagnetic signals within a given total surface area. Due to this reason, fractal antennas are very compact and hence are anticipated to have useful applications in cellular telephone and microwave communications. Fractal antenna's response differs markedly from traditional antenna designs, in the sense that it is capable of operating optimally at many different frequency ranges simultaneously. Fractal antennas are antennas that have the shape of fractal structures. The fractal antennas consist of geometrical shapes that are repeated. Each one of the shapes has unique attributes. There are many fractal geometries such as Sierpinski gasket, Sierpinski carpet, Koch Island, Hilbert curve and Miskowski. [1]- [4]

Sierpinski carpet

Sierpinski carpet fractal antenna is the widely studied fractal geometry for antenna application. The fractal antenna consists of geometrical shapes that are repeated. Each one of these has unique attributes. The self similarity that distributed on this antenna is expected to cause its multi-band characteristics. On the other hand, it can solve a traditional antenna that operates at single frequency.

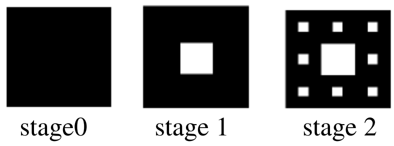

Figure-1. Sierpinski carpet square antenna with third iteration.

The Sierpinski carpet is constructed using squares geometries. In order to start this type of fractal antenna, it begins with a square in the plane and is divided into nine smaller congruent squares where the open central square is dropped. The remaining eight squares which are divided into another nine smaller congruent squares with each central are dropped. Figure-1 shows the process of iteration for Sierpinski carpet fractal antenna. The iteration process is done till second iteration. [5]- [6].

DESIGN OF FEED NETWORK FOR AN ARRAY

In the farthest communications, antennas with high directivity are regularly required. Single element antenna is not suitable for high gain or high directivity. High gain can be achieved by an assemblage of antennas, called an array. In the construction of an array, feed network design is essential. Feed network is used in an array to regulate the amplitude and phase of the radiating elements in order to control the beam scanning properties. [7]-[8] Thus, in selecting and optimizing the feed network, the design of an array is crucial. Different types of feed networks are parallel feed, T-Split power divider, Quarter wave transformer, and Mitered bend feed.

Mitered bend feed network

The transmission lines in the feed networks have many bends in order to guide the signals to/from the elements. A 90° bend in a micro strip line produces a large reflection from the end of the line. Some signal bounces around the corner, but a large portion reflects back the way

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the signal travelled down the line. If the bend is an arc of radius at least three times the strip width, then reflections are minimal. This large bend takes up a lot of real estate compared to the 90° bend. A sharp 90° bend behaves as a shunt capacitance between the ground plane and the bend. In order to create a better match, the bend is mitered to reduce the area of metallization and remove the excess capacitance. The signal is no longer normally incident to micro strip edge, so it reflects from the end down the other arm. Figure-2 shows a straight bend (90° bend) and Figure-3 shows a mitered bend.

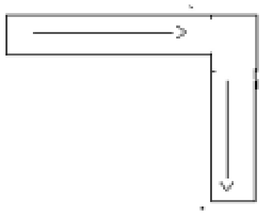

Figure-2. 90° bend.

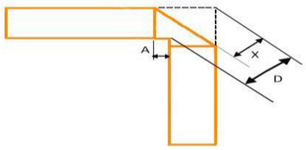

Figure-3. 45° Miter bend.

$$D = W\sqrt{2}$$
$$X = W\sqrt{2} * (0.52 + 0.65 * e^{(-1.35*\frac{W}{h})}$$
$$A = X\sqrt{2} - W$$

Design requires T junction and miter bending (MBEND) modification to generate low insertion loss at the input port. Mitered T-junction and micro strip bends were applied in order to have low reflection and insertion losses. The mitered T- junction of 3dB power divider is shown in Figure-4.

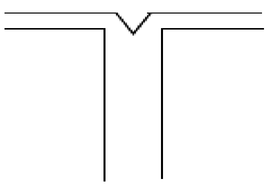

Figure-4. Mitered 'T' bend.

ANTENNA DESIGN

In order to use same antenna for different applications required the antenna to be a multiband antenna and miniaturized to suit different wireless applications. The geometry of Sierpinski Carpet Antenna up to 2nd iteration is presented. The Polish mathematician WaclawSierpinski (1882–1969) presented the Sierpinski carpet.

The design starts with Sierpinski Carpet Planar Monopole Antenna. The first basic rectangular patch is designed. In the first iteration, the basic square patch is segmented by removing the middle square from it, by taking scale factor of 1/3rd. For second iteration, scaling is done on remaining eight squares with scaling factor of 1/3rd. This basic rectangular patch is designed on a FR4 substrate of thickness 1.6 mm and relative permittivity of 4.4. The dimensions of the patch are calculated using the formulas given in below: [9]-[12]

A. Calculation of width (W)**:**

Width of the patch antenna is calculated by using

$$W = \frac{c}{2f_0\sqrt{(\varepsilon_r + \frac{1}{2})}} \quad (1)$$

Where $c = 3 * 10^8 m/s$

B. Calculation of actual length (L)**:**

The effective length of patch antenna depends on the resonant frequency (f_0).

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \quad (2a)$$

Where $\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (2b)$

Actual length and effective length of a patch antenna can be related as

$$L = L_{eff} - 2\Delta L \quad (3)$$

Where ΔL is a function of effective dielectric constant ε_{reff} and the width to height ratio $\left(\frac{W}{h}\right)$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (4)$$

C. Calculation of feed width (W_f)**:**

To achieve 50Ω characteristic impedance, the required feed width to height ratio $\left(\frac{W_f}{h}\right)$ is computed as

$$\frac{W_f}{h} = \begin{cases} \frac{8e^A}{e^{2A} - 2} & \frac{W_0}{h} \le 2 \\ \frac{2}{\pi}\left\{B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\} & \frac{W_0}{h} \ge 2 \end{cases} \quad (5a)$$

Where $A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r + 1}{\varepsilon_r - 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \quad (5b)$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \quad (5c)$$

D. Miter Bend designed equation (D)**:**

$$D = w\sqrt{2}$$
$$X = W\sqrt{2} * (0.52 + 0.65 * e^{(-1.35*\frac{W}{h})} \quad (6)$$
$$A = X\sqrt{2} - W$$

E. The number of Iterations is,

$$N_n = 8^n \quad (7)$$

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F. The ratio of fractal length is,

$$L_n = \left(\frac{1}{3}\right)^n \quad (8)$$

G. The ratio for the fractal area after the n^{th} iteration is,

$$A_n = \left(\frac{8}{9}\right)^n \quad (9)$$

Where n is iteration n^{th} stage number.

RESULTS

Dimensions of Sierpinski carpet fractal antenna

The patch has the dimensions of 27 mm x 9 mm. For the first iteration, the basic square patch is segmented by removing the middle square from it, by taking scale factor 1/3, so a Rectangular slot of dimensions 9 mm x 5 mm is made in the patch. Keeping the first iteration constant. For second iteration segments are done on remaining eight squares following the scale factor of $1/3^{rd}$. The second iteration is made with the dimensions of 4 mm x 2 mm.

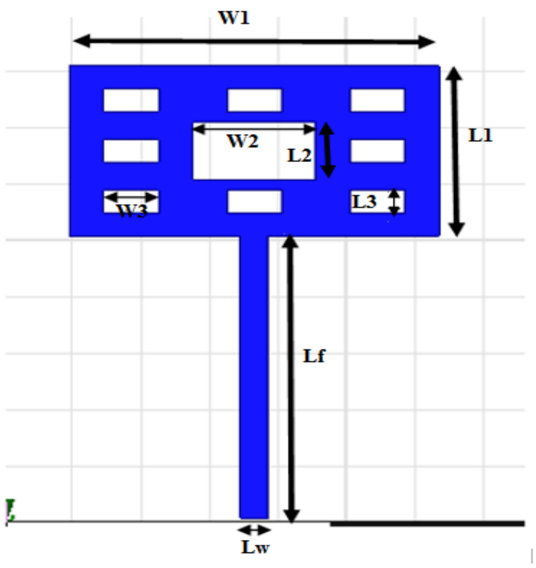

Figure-5. Structure of single element Sierpinski carpet fractal antenna.

Table-1. Dimensions of single element carpet fractal antenna.

Parameter	**Value** (mm)
W1	27
W2	9
W3	4
L1	15
L2	5
L3	2
Lf	25
Lw	2

Two element Sierpinski carpet antenna array with mitered bend feed network is designed and fabricated with the Design equations and is shown in Figures 6 and 7 respectively. Simulated and practical results such as reflection coefficient, VSWR, and gain are observed in Figure-8, Figure-9, Figure-10 and Figure-11 and Figure-12 respectively.

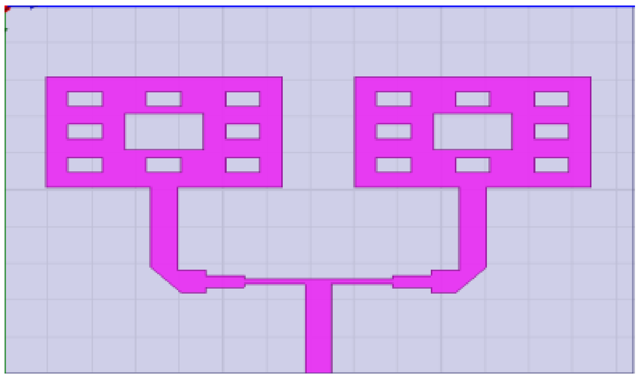

Figure-6. Geometry for 2 element antenna array of Mitered Bend Feed Network.

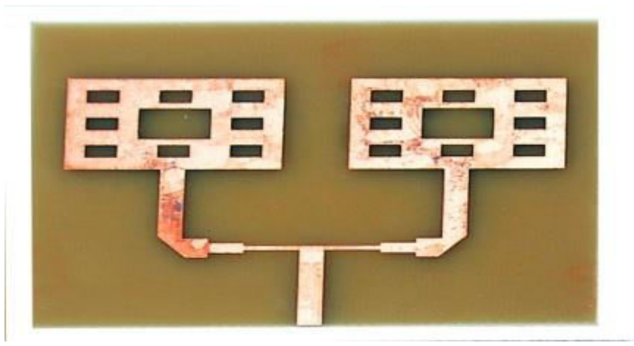

Figure-7. Fabricated patch of 2 element antenna array of Mitered Bend Feed Network.

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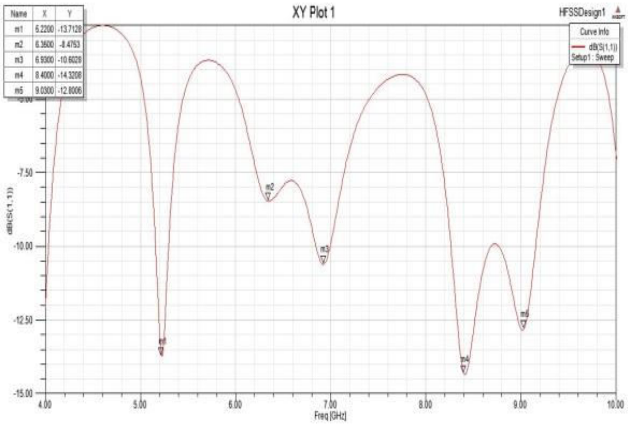

Figure-8. Reflection coefficient curve of the 2 element antenna array of Mitered Bend Feed Network.

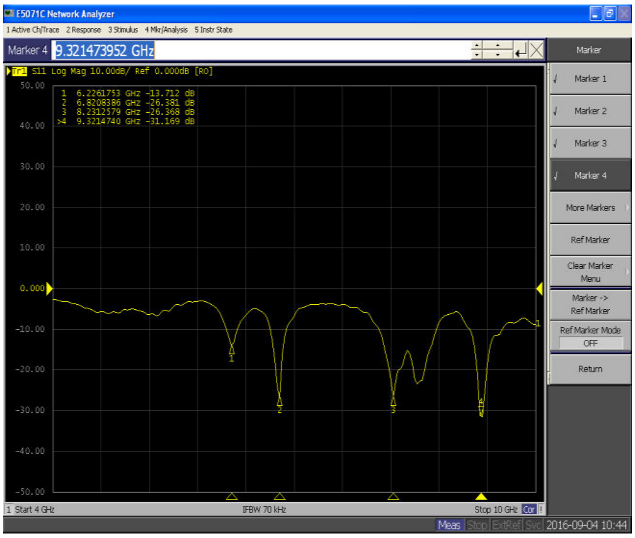

Figure-9. Reflection coefficient curve of fabricated 2 element antenna array of Mitered Bend Feed Network.

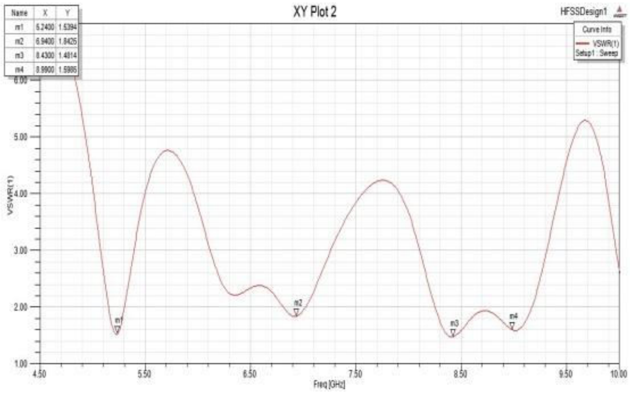

Figure-10. VSWR curve of the 2 element antenna array of Mitered Bend Feed Network.

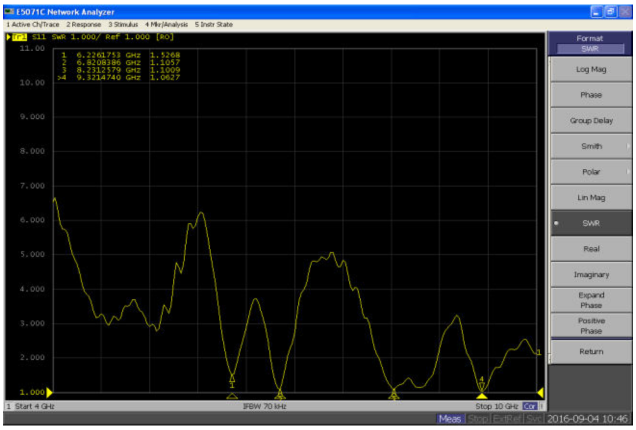

Figure-11. VSWR of fabricated 2 element antenna array of Mitered Bend Feed Network.

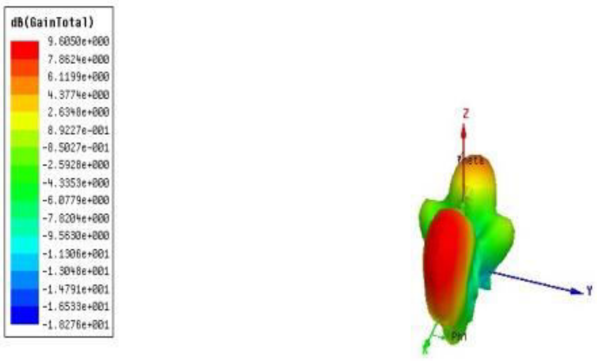

Figure-12. Gain plot of the 2 element antenna array of Mitered Bend Feed Network.

Table-2. Result of element Sierpinski Carpet Antenna Array with Mitered Bend Feed Network.

<table>
<tr><td rowspan="2">Resonant Frequency (GHz)</td><td>Simulated</td><td>5.2
6.9
8.4
9.0</td></tr>
<tr><td>Measured</td><td>6.2
6.8
8.2
9.3</td></tr>
<tr><td rowspan="2">Reflection coefficient (S11) in dB</td><td>Simulated</td><td>-13.71 at 5.2 GHz
-10.6 at 6.9 GHz
-14.3 at 8.4. GHz
-12.8 at 9.0 GHz</td></tr>
<tr><td>Measured</td><td>-13.71 at 6.2 GHz
-26.38 at 6.8 GHz
-26.38 at 8.2 GHz
-31.16 at 9.3 GHz</td></tr>
<tr><td rowspan="2">VSWR</td><td>Simulated</td><td>1.5 at 5.2 GHz
1.8 at 6.9 GHz
1.4 at 8.4 GHz
1.5 at 8.9 GHz</td></tr>
<tr><td>Measured</td><td>1.5 at 6.2 GHz
1.1 at 6.8 GHz
1.1 at 8.2 GHz
1.0 at 9.37 GHz</td></tr>
<tr><td>Gain in dB</td><td>Simulated</td><td>9.605</td></tr>
</table>

CONCLUSIONS

In this paper a micro strip feed Sierpinski carpet fractal antenna (SCFA) array is designed and implemented by using mitered bend feed network. Then there is an observed improvement in gain from 1.77 dB (single element) to 9.605 dB (2 elements). It can be summed up that multi bands are developed besides the resonance frequency. For further improvement in gain, increase the number of elements in the array.

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