

Modified Sierpinski Carpet Fractal Antenna for the Wireless Applications



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Abstract The modified Sierpinski carpet fractal antenna is designed and fabricated to obtain multiband for wireless communication applications. The size of the patch antenna is of 30 mm × 30 mm. In terms of wavelength, the antenna size is 0.34 λ at the lowest frequency (where λ = wavelength at the resonant frequency). The obtained results of the proposed antenna fulfill existing need and the VSWR obtained is in acceptable range. Three measured resonant frequencies appeared at 3.4 GHz, 4.49 GHz and at 5.13 GHz for second iteration. The bandwidth obtained is 100 MHz, 50 MHz and 190 MHz, respectively, in these three bands. The gain obtained is 2 dBi, 2.4 dBi and 3.8 dBi at the respective three resonant frequencies. The measured results show that antenna is multiband in nature and is appropriate for wireless communication applications.

Keywords Fractal · Multiband antenna · Sierpinski carpet antenna · Scaling factor

1 Overview

With the progress of the wireless communication field, future system is likely to deliver multimedia and communication services based on high data rate. Numerous applications such as radar communication measurement system, imaging and hand-held wireless devices required integrated antenna of low cost, small size and low profile with appreciable broadband performance. Because the radiation method of employing different antennas for different frequency bands results in space limitation, multiband antenna [1–6] should be utilized to integrate more than one communication service in a wireless device.

Fractal geometry is a type of geometry that has a number of distinct characteristics [1]. Fractals are having space-filling curves, which means that electrically huge features can be competently packed into a tiny part, allowing the antenna to be smaller [7].

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Fractals are having the self-similar property in that some parts of it have the same shape as the general geometry, but only at a smaller scale [7, 8]. Fractals' self-similarity feature causes multiband behavior [9–11]. The self-similar features of fractal antenna allow them to operate on wide range of frequencies [2, 3].

The second iteration of a modified Sierpinski carpet shaped fractal antenna has been designed in this paper. When compared to a non-fractal square antenna of the same physical area, the modified Sierpinski carpet shaped fractal antenna shows an effective resonance at a lower frequency.

Fractal structure is generated by iterated function system (IFS). Fractal antenna structure is iterated by using scaling factor [9] which is expressed as

$$\xi = \frac{h_n}{h_n + 1} \quad (1)$$

where

- ξ = scaling factor ratio
- h = height of iterated antenna
- n = iteration number.

The fractal antenna has a Sierpinski carpet shape in which two iterations have been performed. The experimental and simulated results show that antenna behavior is multiband in nature. With the increase in iteration order, resonant frequency gets lowered fulfilling the property of fractal antennas [12–14].

There are four sections in this study. The antenna design and structure are described in Sect. 2. Section 3 presents the simulated and measured results. The conclusion is found in Sect. 4.

2 Design of Antenna

The Sierpinski carpet fractal antenna has been modified. The IE3D software (MoM) is used to simulate the proposed antenna. The FR4 epoxy is used as a substrate. The substrate measures 1.575 mm thickness, and 4.3 is the substrate's dielectric constant (r). The square shape is cut out of the square patch antenna's center, indicating the first iteration, followed by the second iteration. The redesigned Sierpinski carpet shaped fractal antenna iterations are depicted in Fig. 1. The proposed antenna has a side length of 30 mm (without iteration). For the first iteration, a square with a 10 mm side length is carved out of the antenna's center. The fractal antenna contains four identical squares at its corners in the second iteration. 3.33 mm is the length of each square's side.

The length of the antenna is computed mathematically [8, 9] using Eq. (2).

$$L = \frac{c}{2f_r \sqrt{\epsilon_{\text{eff}}}} - 2\Delta L \quad (2)$$

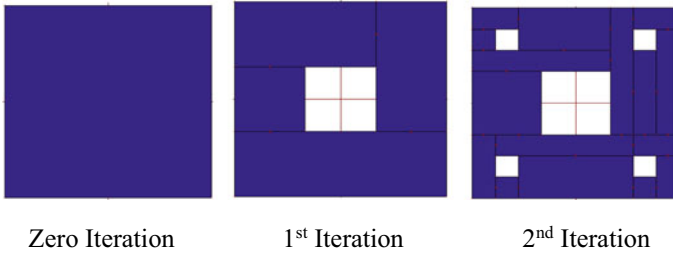


Fig. 1 Iterations of the proposed antenna

where

c = speed of light in vacuum

f_r = resonant frequency

ϵ_{eff} = effective permittivity and it is calculated using Eq. (3) [15, 16].

$$\epsilon_{\text{eff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(\frac{1}{\sqrt{1 + 12 \frac{d}{W}}} \right) \quad (3)$$

where

ϵ_r = relative permittivity

d = thickness of substrate

W = width.

The width (W) is calculated by using Eq. (4)

$$W = \frac{c}{2f_r} \sqrt{\frac{2}{\epsilon_r + 1}} \quad (4)$$

Equation (5) is used to determine the patch's extended incremental length.

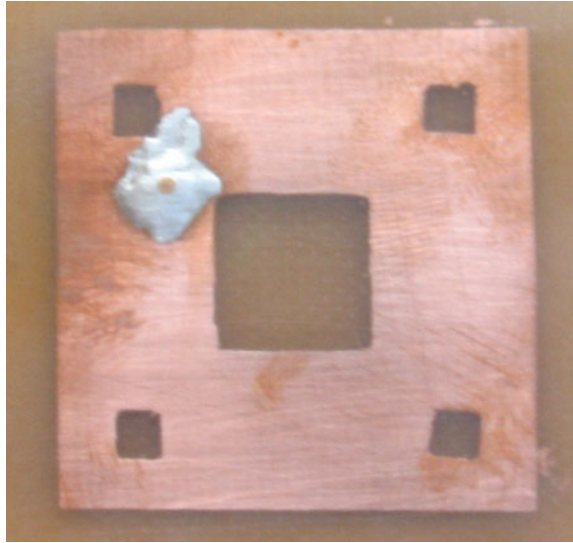
$$\Delta L = 0.412d \frac{(\epsilon_{\text{eff}} + 0.3) \left(\frac{W}{d} + 0.264 \right)}{(\epsilon_{\text{eff}} - 0.258) \left(\frac{W}{d} + 0.8 \right)} \quad (5)$$

The antenna is coaxially fed at the location $x = 6$ mm and $y = 8$ mm.

Figure 1 shows the iterations of the proposed antenna.

Figure 2 shows the snapshot of the fabricated antenna utilizing FR4 substrate. The coaxial probe SMA connector is used to feed the antenna.

Fig. 2 Snapshot of the built antenna



3 Results and Discussion

3.1 Simulated and Experimental Results

The proposed antenna is simulated using IE3D electromagnetic simulator. The antenna configurations with different iterations in the previous section have been simulated. Figure 3 shows the measured return loss (S_{11}) characteristics of the modified Sierpinski carpet fractal antenna. The designed antenna resonates at three frequencies, i.e., having center frequency at 3.4 GHz, 4.49 GHz and 5.13 GHz at second iteration.

The resonance shifts downward as the iteration goes, and due to the space-filling technique, discrete multiband responses are recorded. With larger repetition orders, this result demonstrates the frequency dropping phenomenon.

Figure 4 depicts the experimental set-up using site analyzer to test the fabricated antenna.

Figure 5 depicts the simulated gain versus frequency plot of the designed antenna.

The gain versus frequency plot shows that the antenna has 2.0 dBi gain at 3.4 GHz whereas at 4.49 GHz it is 2.4 dBi and at 5.13 GHz, the gain is 3.8 dBi. The bandwidth obtained is 100 MHz, 50 MHz and 190 MHz at three respective resonant bands (Fig. 6; Table 1).

The value of VSWR lies from 1 to 2 at resonant frequencies. The VSWR is calculated by

$$\text{VSWR} = \frac{1 + S_{11}}{1 - S_{11}} \quad (6)$$

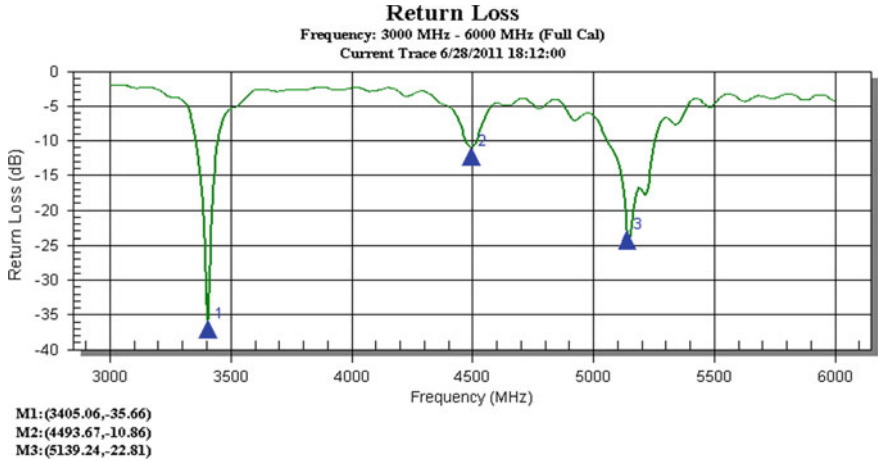


Fig. 3 Measured return loss of proposed antenna with second iteration



Fig. 4 Experimental set-up

4 Conclusion

The Sierpinski carpet fractal shape is used to design and fabricate a fractal antenna. The measured resonant frequencies of the fabricated antenna are 3.4 GHz, 4.49 GHz and 5.13 GHz with a gain of 2.0 dBi, 2.4 dBi and 3.8 dBi, respectively. The bandwidth obtained is 100 MHz, 50 MHz and 190 MHz at three respective resonant bands. Thus, the designed antenna is miniaturized and multiband with considerable bandwidth compatible for wireless communication applications.

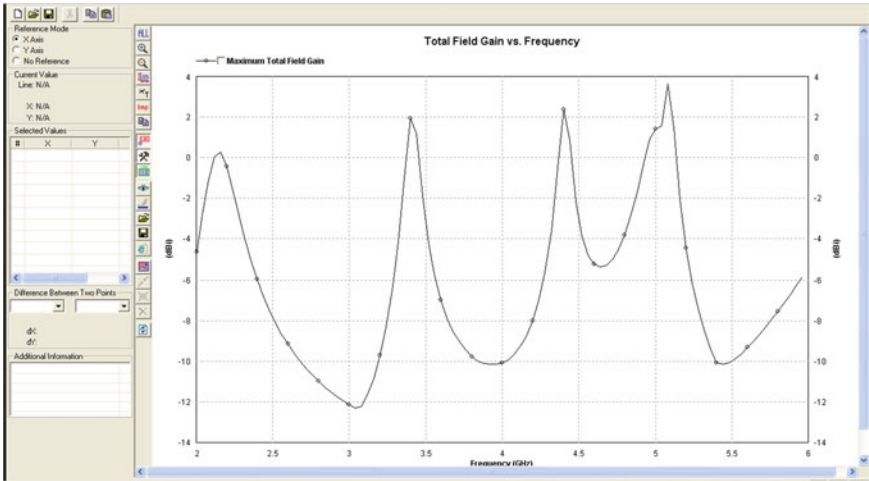


Fig. 5 Gain versus frequency plot

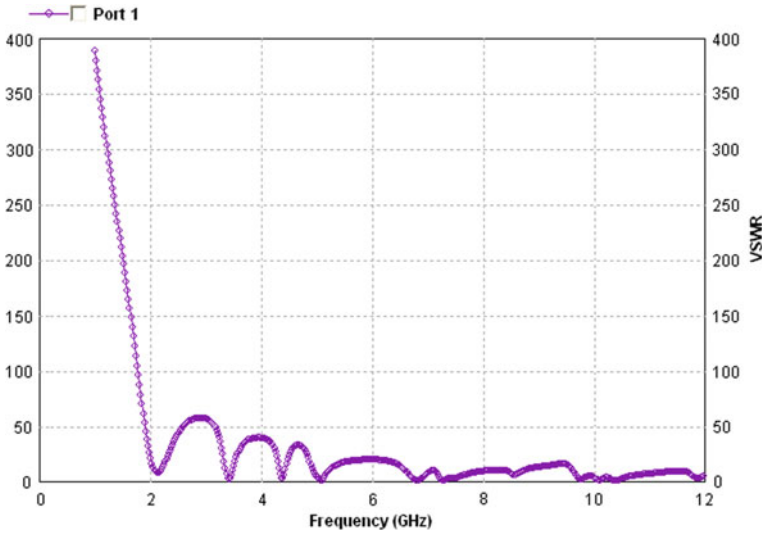


Fig. 6 VSWR characteristics of the proposed antenna

Table 1 Measured return loss of fabricated antenna with second iteration

Band	Resonant frequency (GHz)	Return loss (dB)
M1	3.40	-35.66
M2	4.49	-10.86
M3	5.13	-22.81

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