International Journal of Hybrid Information Technology
Vol.8, No.8 (2015), pp.245-252
http://dx.doi.org/10.14257/ijhit.2015.8.8.25

Design of Sierpinski Carpet Fractal Antennas by Improving the Performance and Reducing the Size for Wide Band and Mobile Applications

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Abstract

The paper presents the designs of two Sierpinski carpet fractal antennas. The fractal properties have been applied in order to designs compact and wideband antennas. The antennas are analyzed in term of radiation parameters such as reflection coefficients, voltage standing wave ratio and radiation patterns. The results shows that the bandwidths of the antennas at the reflection coefficient less than -10dB are 5.5GHz and 7.25GHz ranging from 8.3GHz to 2.8GHz and 4.75GHz to 12GHz respectively. The directivities of antenna are 5.109dBi, 6.952dBi, 6.696dBi and the gains are 5.11dBi, 6.95dBi, and 6.7dBi. The bandwidth is largest at high resonance points with increasing the number of iterations. The proposed designs are suitable for wireless applications such as Wi-Fi, WiMAX, WLAN, Bluetooth, WCDMA and GSM.

Keywords: *Sierpinski carpet; Fractal antenna; Wideband, Return loss; Gain*

1. Introduction

In recent years the microstrip antenna has been widely analyzed, studied and developed. The microstrip antenna has the characteristics of small size, light weight and low fabrication cost. On the other hand there are some limitations of microstrip antenna such as low gain and narrow bandwidth. The dimensions and wavelength of the antenna have the relation which is stated as the antenna cannot be efficiently radiated if the size of the antenna is less than $\lambda/4$ (λ is the wavelength) because the gain, bandwidth and radiation resistance are reduced and so the size of the antenna is increased [1]. The fractals antennas are adopted for size reduction and multiband/wideband characteristics [2]. The size reduction is mainly due to the self-similarity property of fractal geometry and made of many copies of themselves with different scale factors. The space filling characteristics of fractal antenna result in increasing electrical length of the antenna. The miniaturization effect of the fractal antenna is because of the lengthening of the surface current line. The electrical length of the antenna is increased and the structure can be miniaturized [3-5]. These characteristics of the fractal geometries have been used to design multiband and compact size antenna. A lot of fractal geometries are available but only a limited number are used in the design of microstrip antenna. One of them is the Sierpinski Carpet geometry. The proposed designs are fed from the corner due to which the sizes of the antennas are further reduced. The performances of the antenna like the return loss and radiation patterns are not affected [6-8].The fractal concept has been used to obtain wideband operation, low profile and high bandwidth sierpinski carpet antennas.

2. Antennas Configuration

The process of iteration is performed up to third iteration. The Substrate of thickness 1.6mm FR-4 board having the relative permittivity of $\varepsilon_r = 4.4$ is used. The antenna is fed from the corner by coaxial cable having the inner and outer diameters of SMA connector

ISSN: 1738-9968 IJHIT

are 0.6mm and 2mm respectively as shown in the Figure 1 and 2. The dimension of the ground plane is 300 × 300mm^2 and thickness of 1mm is used in the proposed designs.

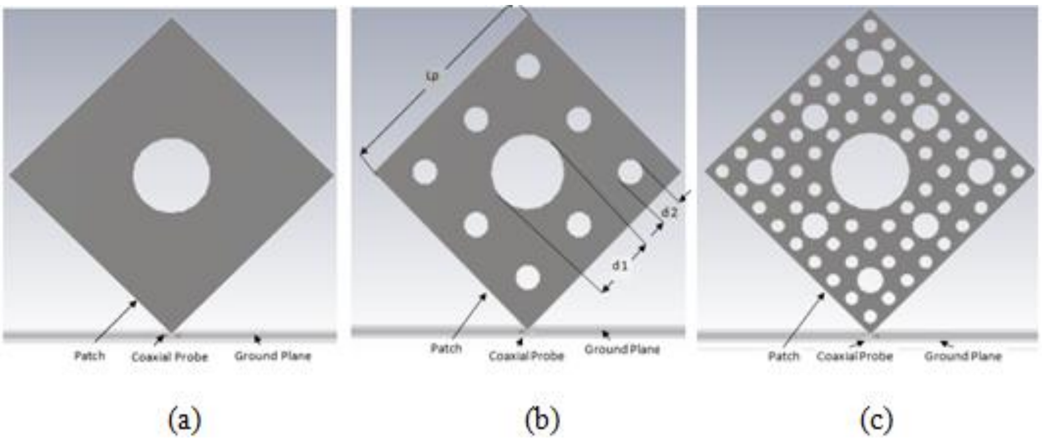


Figure 1. (a) First Iteration (b) Second Iteration (c) Third Iterations of sierpinski Carpet Fractal Antenna 'A' (design in CST Microwave Studio)

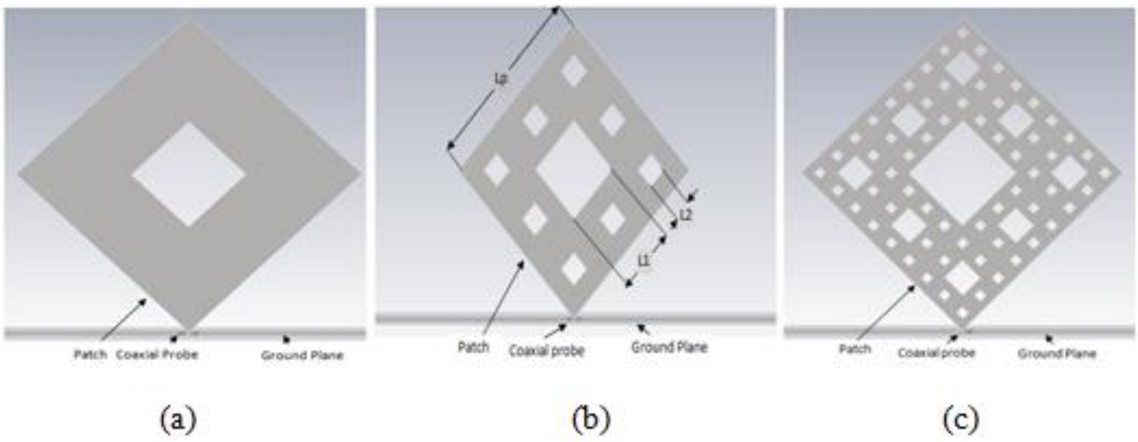


Figure 2. (a) First Iteration (b) Second Iteration (c) Third Iterations of sierpinski Carpet Fractal Antenna 'B' (design in CST Microwave Studio)

The scale factor of antennas are 1/3 and the stage of iteration is n=3.The size of the substrate and the patch are the same. The dimensions of the patch and substrate are 54×54mm^2. The thickness of the patch is 0.1mm and design from perfect conducting material. The dimension of the patch is finite, so the fields undergo fringing effect at the edge of the patch. The fringing effect is explained by the following expression.

$$\varepsilon_{\mathrm{reff}} = \frac{4.4+1}{2} + \frac{4.4-1}{2}[1+\frac{12\mathrm{h}}{\mathrm{W}}]^{-\frac{1}{2}} = 4.15 \qquad (1)$$

'ε_r' is dielectric constant and 'h' is the thickness and 'w' represent the width of the substrate while 'ΔL' is the extended electrical length of the patch due to fringing effect and can be determined by the following expression.

$$\frac{\Delta \mathrm{L}}{\mathrm{h}} = 0.412\frac{(4.15+0.3)\left(\frac{\mathrm{W}}{\mathrm{h}}+0.264\right)}{(4.15-0.258)\left(\frac{\mathrm{W}}{\mathrm{h}}+0.8\right)} = 0.742\mathrm{mm} \qquad (2)$$

The effective length of the patch is

$$L_{eff} = L + 2(0.742) \tag{3}$$

$$L_{eff} = 55.5\text{mm} \tag{4}$$

Where ‘L’ is the length of the patch with no fringing effect. When $L_{eff} = \lambda g/2$, then resonance frequency occurs. Where ‘λg’ is the substrate guided wavelength.

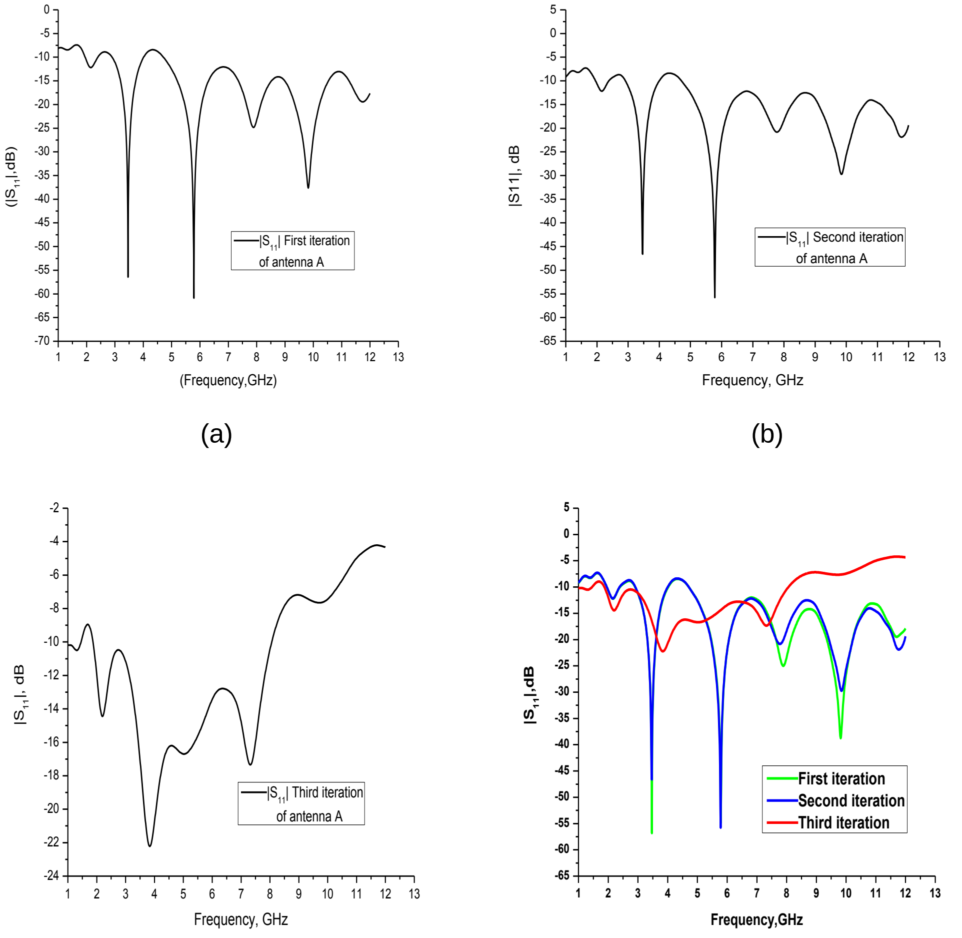
$$f_r = \frac{1}{2(55.5)\sqrt{\mu_o \varepsilon_o}\sqrt{\varepsilon_{eff}}} = \frac{1}{2L_{eff}}\frac{v_o}{\sqrt{\varepsilon_o}} = 0.9085 \approx 1\text{GHz} \tag{5}$$

Where ε_o is the permittivity u_o is the permeability and v_o is the speed of light. By using equation (5), the first resonance frequency is 1GHz and according to fractal theory the second resonance frequency is 3GHz and third resonance frequency is 9GHz. The CST Microwave Studio has been used to simulate, design and parametrically analyze the two proposed antennas.

3. Results and Discussion

The return loss of antenna A is illustrated in the figure 3.The first iteration of the antenna resonant in the frequency range 1.88GHz to 8.63GHz and their impedance matching is good as their return loss is less than -20dB in all the resonance frequencies. The bandwidth is (8.63 – 1.88) GHz = 6.75GHz. The second iteration of the antenna resonates from 3GHz to 4.13GHz and from 4.6 GHz to 12.6GHz. The return loss is below -15dB and the bandwidth is 8GHz. The third iteration of the antenna A resonates in the range of frequencies from 2.3GHz to 8.3GHz and the bandwidth is 6GHz. The return loss is less than -15dB which show good impedance matching. The operating frequencies of the antenna A are suitable for many wireless communication applications suchasPCS(1.85-1.99)GHz,GSM(1.851.99)GHz,WCDMA(1.922.16)GHz,UMTS1(1.92–2.17)GHz,WiMax(2.11–2.2),WLAN(5.15-5.35&5.75–5.8)GHz,Wi-Fi(5.15-5.82)GHz, RFID(5.725–5.875)GHz etc.

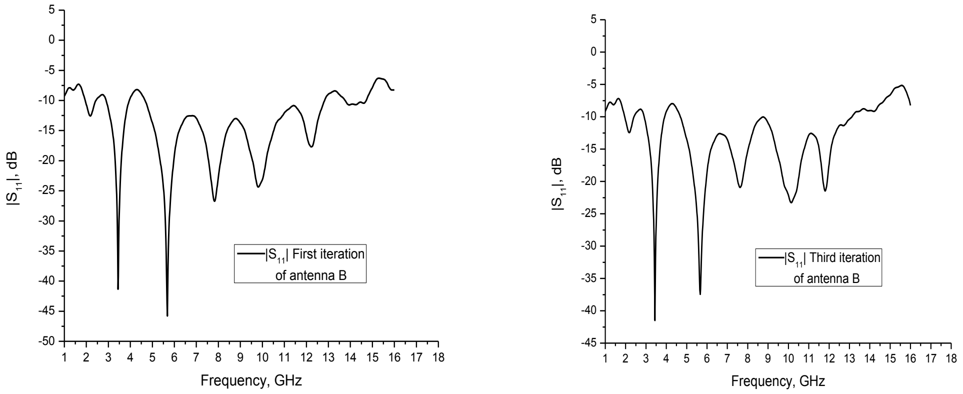
The reflection coefficient plots of antenna B up to third iteration are demonstrated in the Figure 4. At the first iteration the antenna resonates in the frequency range from 2.84GHz to 12.8GHz. The return loss is less than -15dB which show good impedance matching at this frequency range. At the second iteration the antenna resonates from 3GHz to 4 GHz and from 4.6GHz to 12.5 GHz. The return loss at the resonance frequency 3.4Ghz is -40dB and at the central frequencies 5.6GHz, 7.6GHz, 10Ghz and 11.8GHz have the simulated reflection coefficients of -37dB,-20dB,-23dB and -21dB. At the third iteration the antenna resonates in two range of frequencies, the first is from 3GHz to 4GHz which is suitable for WLAN (3.65 – 3.70) GHz. The second range of frequency is from 4.75GHz to 12 GHz and the return loss is less than -12dB. At this range of frequency band the proposed design has suitable for many wireless communication applications such as WLAN, IEEE802.11a (5.20GHz) and IEEE802.11a (5.775GHz), Wi-Fi (5.15 – 5.82) GHz, RFID (5.725 – 5.875) GHz etc.



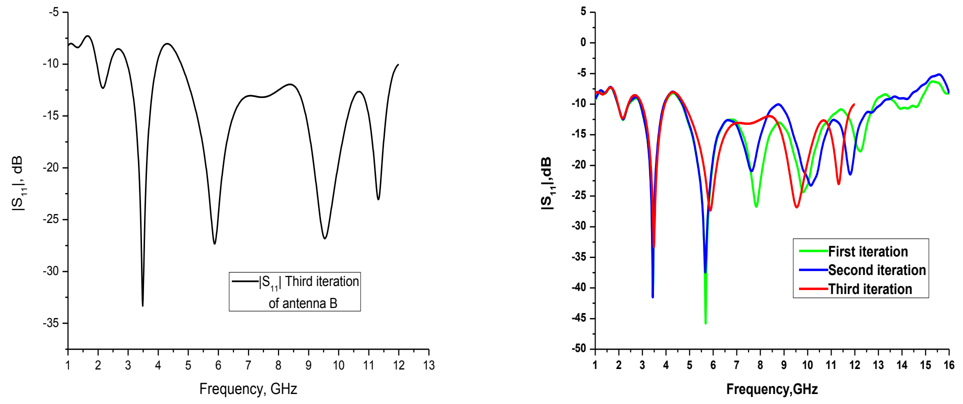
(a) (b)

(c) (d)

Figure 3. Reflection Coefficient Plots of Sierpinski Carpet Fractal Antenna 'A' (a) First Iteration (b) Second Iteration (c) Third Iteration (d) Comparison of Return Loss



(a) (b)



(c) (d)

Figure 4. Reflection Coefficient Plots of Sierpinski Carpet Fractal Antenna 'B' (a) First Iteration (b) Second Iteration (c) Third Iteration (d) Comparison of Return Loss

The voltage standing wave ratio can be calculated by the following equation.

$$\mathrm{VSWR} = \frac{1+|S_{11}|}{1-|S_{11}|} \tag{6}$$

The Voltage standing wave ratio of antenna A up to third iteration is illustrated in Figure 5. The third iteration of the proposed design have the VSWR of 1.46, 1.52, 1.16, 1.32 and 1.35 at the frequencies of 2.21GHz, 3.28GHz, 3.8GHz, 5.2GHz and 7.38Ghz respectively. The Figure 6, demonstrates the voltage standing wave ratio of first second and third iteration of Sierpinski carpet fractal antenna B. The VSWR of the antenna B at the third iteration are 1.64, 1.06, 1.09, 1.62, 1.09, and 1.17 at 2.18GHz, 3.51GHz, 5.8GHz, 8GHz, 9.54GHz and 11.3GHz respectively.

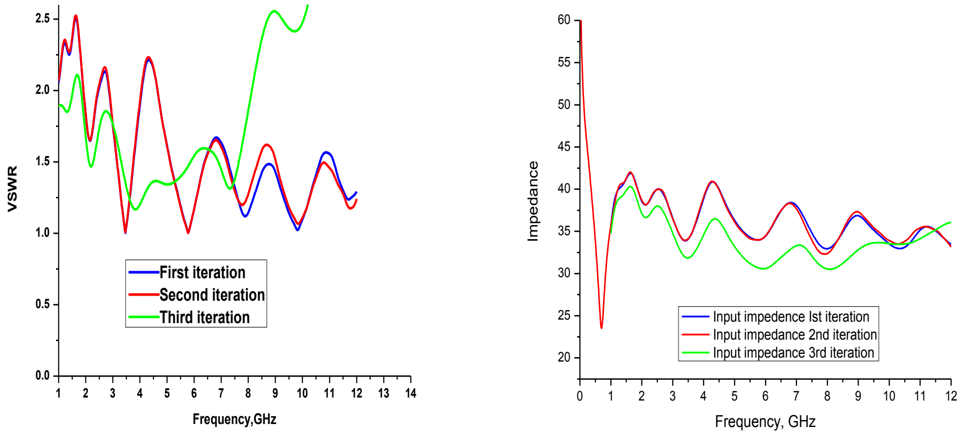


Figure 5. Impedance and Voltage Standing Wave Ratio Plots of First, Second and Third Iterations of Sierpinski Carpet Fractal Antenna 'A'

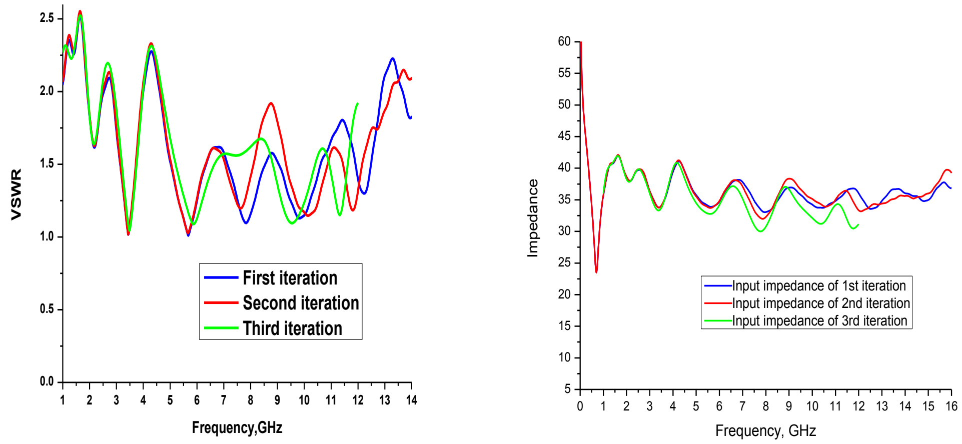


Figure 6. Voltage Standing Wave Ratio Plot and Impedance Plot of First, Second and Third Iteration of Sierpinski Carpet Fractal Antenna 'B'

The polar radiation patterns of Sierpinski carpet fractal antennas A and B at third iteration have demonstrated in the Figure 7 and 8. The main lobe direction and magnitude have been mention under each plot. The polar radiation patterns of antenna A illustrate that at the resonance frequency 2.18GHz, the main lobe magnitude and direction have 4.3dBi and 151^o. The 3dB angular width which is also known as half power beam width in the elevation plane has 47^o. The half power beam width is shown by two thin lines which show that when the directivity increases the angle between the two lines decreases. At the resonance frequency 3.8GHz the main lobe magnitude and direction have 4.3dBi and 151^o respectively. While at the central frequency 7.32GHz the main lobe magnitude and direction have 6.3dBi and 128^o respectively. The directivities of antenna A at third iteration are 5.109dBi, 6.952dBi, 6.696dBi and the gains are 5.11dBi, 6.95dBi, 6.7dBi at the resonance frequencies of 2.8GHz, 3.8 GHz and 7.32 GHz respectively.

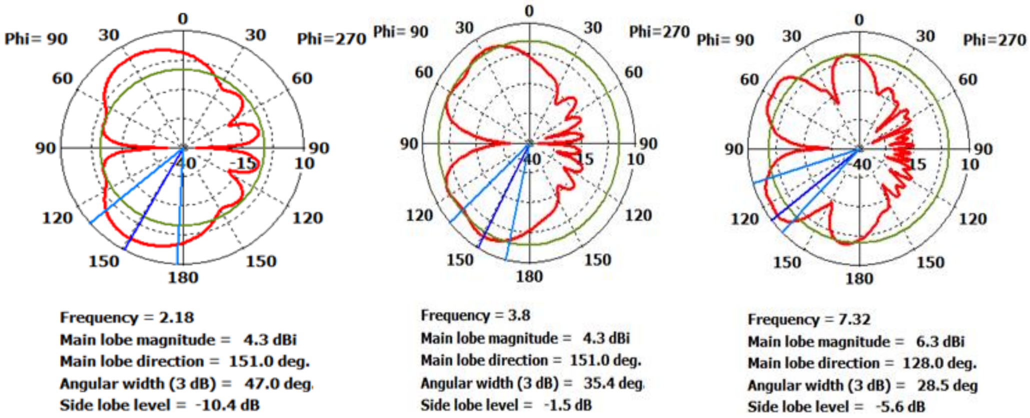


Figure 7. Polar Radiation Pattern of Sierpinski Carpet Fractal Antenna 'A' at Third Iteration

In case of antenna B, the radiation patterns shows that at the resonance frequency 3.49GHz the main lobe magnitude is 4dBi and direction is 32^o. The half power beam width, in the elevation plane is 34.4^o. At the resonance frequency 5.8GHz, have 3dB angular width of 19.4^o. The main lobe magnitude and direction are 4dBi and 147^o respectively.

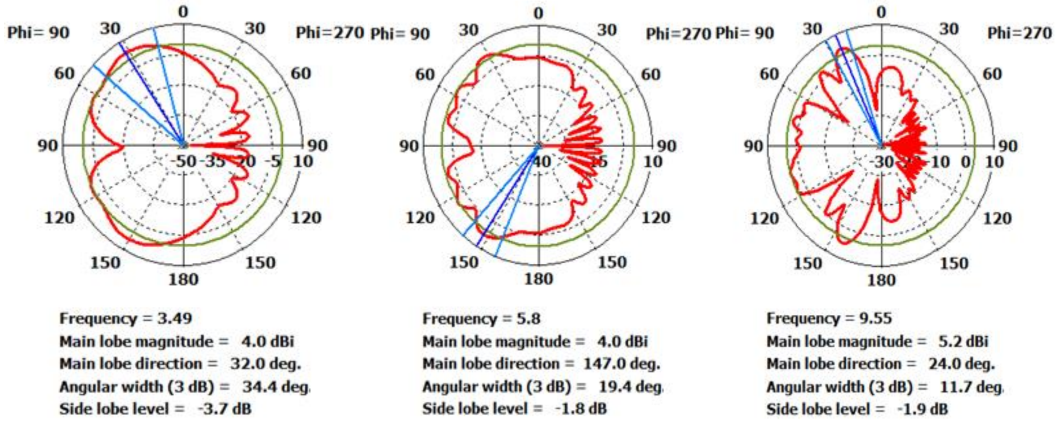


Figure 8. Polar Radiation Pattern of Sierpinski Carpet Fractal Antenna 'B' at Third Iteration

The main lobe magnitude and its direction at the central frequency 9.55GHz are 5.2dBi and 24^{o}. The half power beam width is 11.7^{o}. The directivities of the antenna B at the third iteration are 4.105dBi, 4.163dBi, 5.21dBi and the gains of the antenna are 4.1dBi, 4.16dBi and 5.2dBi respectively.

4. Conclusion

The sierpinski carpet fractal antennas are designed for wideband applications. The parameters of antennas such as reflection coefficients, voltage standing wave ratios, input impedances and radiation patterns are analyzed using CST Microwave Studio and bring improvements in the performance and reduction in the size of the antennas. The antennas are simulated in first, second and third iterations and various parameters are compared. The proposed designs are suitable for many wideband and mobile wireless applications. The impedance bandwidths are sufficient to cover most of the wideband applications. The first, second and third frequencies are determined theoretically which show agreement with the fractal antenna concept.

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