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Analysis of a Fractal Microstrip Patch Antenna

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***Abstract*- There are number of methods that can be used to reduce the size of the antenna especially when it is too be used at lower operating frequencies. Fractal is one of the ways which can be used to miniaturize antennas due to their space filling ability. It helps in fitting large electrical lengths into small volume. In this paper the effect of increase in electrical length at each iterative step in the generation of the fractal is studied.**

***Index Terms*- Fractal patch antenna, Compact microstrip antenna, size reduction.**

I. INTRODUCTION

Mobile communications has become an important part of the life. Original applications such as mobile phones, GPS, Bluetooth technology have shown tremendous growth, and new applications such as tagging, wireless local area network, wireless internet are emerging everyday. Mobile means practical for user and easily transportable. Thus the mobile terminals for wireless application should be light, small, and should have low energy consumption to satisfy these requirements. Due to greater integration of electronics, the size of transceiver needed for the mobile applications have decreased drastically. Hence the size of the antenna should be compatible with the dimensions of the receiver or the repeater system, especially at the lower microwave spectrum.

Several techniques for reducing the size of the patch have been presented in the past. Simplest of all methods is the use of substrate material with high dielectric constant [1] but it results in narrow bandwidth and poor efficiency due to surface wave excitation. Cost of low loss, high dielectric constant material is another problem. Other methods reported in the literature are shorting posts [2, 3], use of short circuits [4, 5], partially filled high permittivity substrate [6], and cutting slots in the radiating patch [7, 8]. The short circuit and shorting posts pose the problem of cross-polarization and partially filled permittivity substrate sometimes offers fabrication problem. Fractal geometries [9, 10] in the antenna application are becoming major concern for many researchers these days. Due to the fractal configuration large electrical length is fitted into the small physical volume. Thus the high convoluted shape of a fractal allows to reduce the overall volume occupied by the resonating element.

In this paper the effect of increase in electrical length at each iterative step in the generation of the fractal is studied.

II. ANTENNA DESIGN

First of all, a conventional square microstrip patch antenna with patch dimension $L \times W$ as 28.2 mm x 28.2 mm, printed on a dielectric substrate FR-4 (ε_r = 4.4) of thickness 1.6 mm, with resonating frequency 2.46 GHz is designed as shown in Fig.1. This conventional antenna is treated as the basis for the comparison in terms of size reduction.

Next, the structure is modified by the addition of multiple V-groove along the length and width in three steps, which corresponds to the three iterations of the fractal generation. The addition of the groove is based upon the "Koch curve". three equal parts. The middle part is replaced by two straight lines meeting at 60^0 angle (a bent) and they fit into the original gap in an equilateral triangular fashion as shown in the Fig. 2. Thus the dimension of each newly generated straight line is now one third of the original straight line and each side of the square when stretched out, increases by one third of the original length. The iterative process of dividing a straight line into three equal segments and replacing the middle by a bent curve is continued. In the true fractal, this process is repeated for infinite number of times. In the present work, three iterations are considered and the fractal patch obtained is shown in the Fig. 3. This figure shows the proportionate reduction in patch area by keeping the total perimeter of the square constant after each fractal iteration. Thus with each iteration, the total perimeter of the square increases by 4/3 times the original perimeter of the square. It is observed that although the length of the radiating patch with proportionate reduction is kept constant at 28.2 mm but the resonant frequency does not remain constant at 2.46 GHz.

The fractal patch configuration printed on the same substrate of the same thickness is modeled in the IE3D and simulated for each iterative step. After each iteration, the dimension of the fractal patch and feed position are optimized using genetic algorithm optimizer, to obtain the stipulated frequency of 2.46 GHz. The size of the fractal patch obtained after each iteration to make it resonate at 2.46 GHz. is shown in Fig. 4. The electrical characteristics of patch after each iteration is tabulated in Table 1.

A fractal patch antenna printed on FR-4 substrate, with coaxial feed is shown in Fig. 5. The result for the resonating frequency was verified experimentally and is shown in the Fig. 6. A good agreement between the simulated and experimental result is evident from the characteristic obtained.

To study the effect of the substrate on size reduction, a similar fractal patch configuration is The starting structure is a square patch. Each straight segment of the square is divided into simulated with the same thickness 1.6mm on a foam substrate for the same operating frequency 2.46 GHz. The comparison of reduction in patch area of two fractal patches with the $\epsilon_r = 4.4$ and $\epsilon_r = 1.07$ is shown in Table 2.

III. RESULTS AND DISCUSSION

The resonant frequency of the patch is determined after each iteration. It is found that the resonant frequency of the patch reduces after every iteration due to increase in the electrical length. After the third iteration the patch area is calculated using equation (1) and is found to be reduced by 54% with $\epsilon_r = 4.4$ and by 56% for $\epsilon_r = 1.07$ at a given frequency of operation.

$$\textit{patch area} = (\textit{Length})^2 - \textit{area of slits or/and grooves} \quad (1)$$

It is evident that the reduction in patch area decreases with higher iterations. Each iteration adds length to the total curve. The total length at the end of the last iteration can be calculated by (2)

$$\textit{Total length} = L\left(\frac{4}{3}\right)^n \quad (2)$$

Where n is the number of iterations and L is the original starting straight length.

The proportionate reduction that is keeping the perimeter same for all the patches generated after each iteration and actual area reduction obtained after the optimization to resonate at the same stipulated frequency 2.46 GHz. is not the same. After first iteration, patch area reduces by approximately 40% for $\epsilon_r = 4.4$ and by 48 % for $\epsilon_r = 1.07$, but from second to third iteration it is only by 5% for both the cases.

The reason is evident from the Fig. 7, showing the vector current distribution on the fractal patch (with third iteration) obtained as a result of simulation. It can be seen that the current does

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not strictly follow the edge path, but rather follows a slight curved path. Going for higher iteration means addition of more edges in the patch. But additions of these small edges do not help much in increasing the electrical length, resulting in decrease of reduction in patch area for higher iterations. The reduction in patch area with each iteration is shown in Fig. 8 for both the substrate. It is evident from the figure that the reduction in area with each iteration follows approximately the same trend irrespective of the substrate used. The trend in variation of gain can be seen in Table 1. Obviously, the gain decreases with each iteration, which is less affected with the air as a dielectric substrate. The pattern plot of the fractal patch printed over dielectric substrate with ϵ_r = 4.4 obtained after third iteration is shown in Fig. 9.

IV. CONCLUSION

Fractal patch antennas are good candidates for size reduction as large electrical length can be fitted into the small physical volume. However, to make the antenna resonate at a particular frequency the useful range of size reduction lies only upto third iterations. Maximum size reduction results after first iteration only. Subsequent iterations result in decrease in percentage of size reduction such as only 5% or less than this is obtained after third iteration. Therefore one can limit the iterations upto third iterations only. Going for the higher iteration adds mostly the small edges, which is practically not useful in increasing the electrical length.

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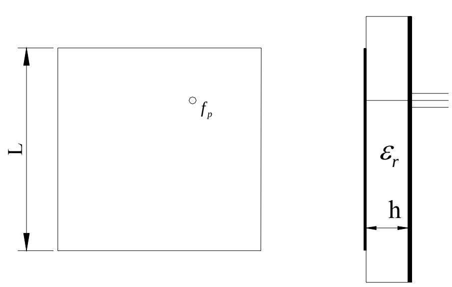

Fig.1. Top and side views of a conventional square microstrip patch antenna

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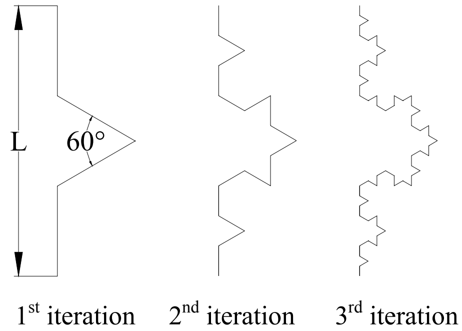

Fig.2 Fractal generation based upon Kotch curve

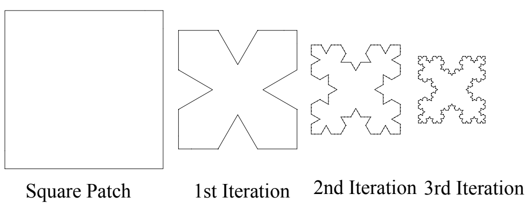

Fig.3 Proportionate reduction in patch area by keeping the total perimeter of the square constant with each fractal iteration

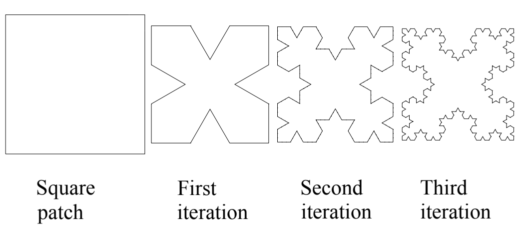

Fig.4 Generation of a Fractal patch for resonating frequency 2.46 GHz

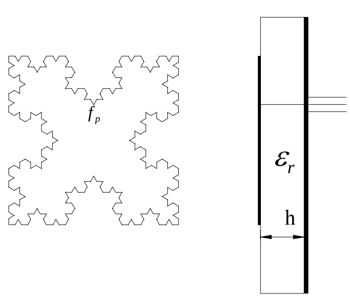

Fig.5 Fractal patch obtained after third iteration

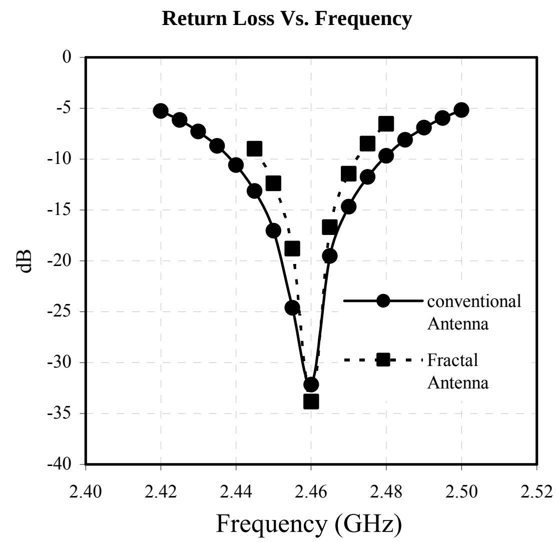

Fig.6a Simulated Return loss characteristic of fractal patch antenna designed for 2.46 GHz as shown in Fig. 5.

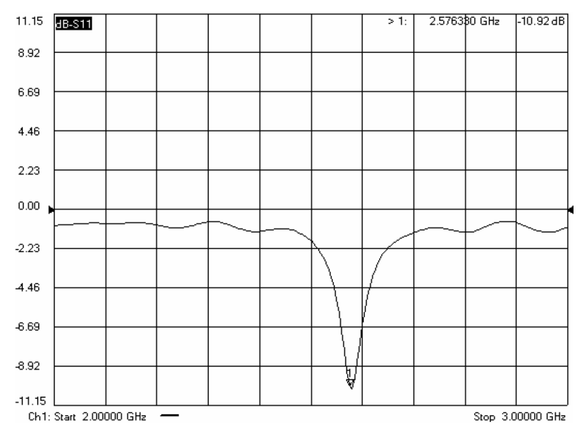

Fig.6b Measured Return loss characteristic of fractal patch antenna designed for 2.46 GHz.

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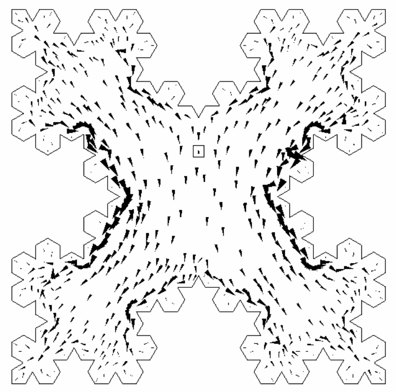

Fig.7 Current distribution and path on the surface of a Fractal patch antenna

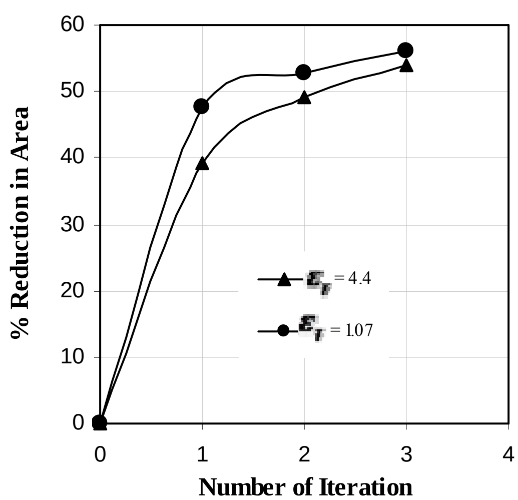

Fig.8 Percentage reduction in area with each iteration for substrate with ε_r = 4.4 and ε_r = 1.07 at f_r =2.46 GHz

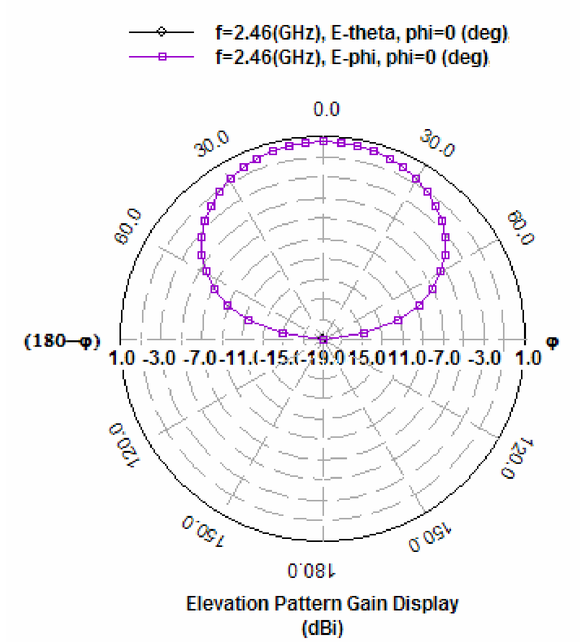

Fig. 9a Radiation pattern of fractal patch antenna at 2.46 GHz in X-Z plane

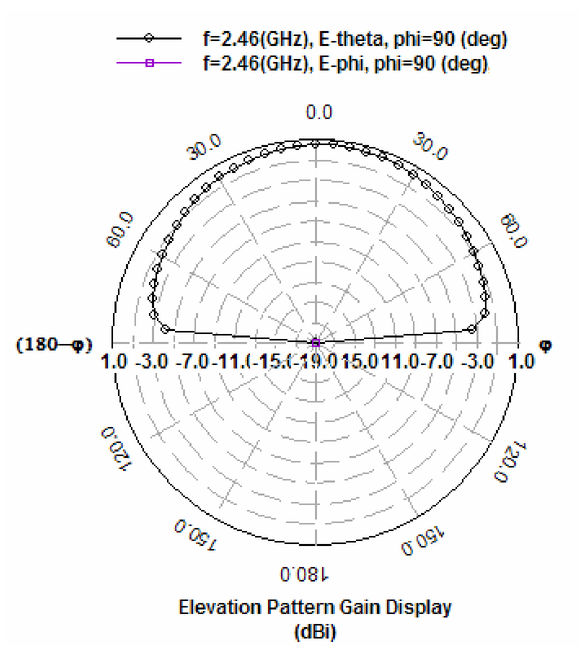

Fig. 9b Radiation pattern of fractal patch antenna at 2.46 GHz in Y-Z plane

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Table 1Characteristics and percentage reduction in area after each iteration during fractal generation keeping the operating frequency constant at 2.46 GHz.

S.N.	Shape		VSWR BW (MHz)	Gain (dBi) $\varepsilon_r = 4.4$	Gain (dBi) $\varepsilon_r = 1.07$
1	Conventional Square Patch		43	3.41	9.15
2	Fractal Generation	1st Iteration	30	1.6	8.23
3		2nd Iteration	31	1.09	8.00
4		3rd Iteration	26.8	.878	7.9

Table 2 Comparison of fractal generation with two substrate with $\varepsilon_r = 4.4$ and $\varepsilon_r = 1.07$

S.N.	Shape		New Patch Dimension (mm)		% Reduction in Area	
			$\varepsilon_r = 4.4$	$\varepsilon_r = 1.07$	$\varepsilon_r = 4.4$	$\varepsilon_r = 1.07$
1	Conventional		28.2	55.32	--	--
2	Fractal Generation	1st Iteration	24.45	45.91	39.29	47.68
3		2nd Iteration	24.05	44.81	49.02	52.68
4		3rd Iteration	23.17	44.42	54	56.05