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Design of a Fractal Slot Antenna for Rectenna System and Comparison of Simulated Parameters for Different Dimensions

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ABSTRACT: In the modern era we required a compact system having a high gain, efficiency and broad bandwidth. For rectenna (antenna + rectifier) system we need such an antenna which can receive more radio frequencies from the surroundings and gives to rectifier which works on one or more frequency band or multiband operation. For fulfill these requirements we proposed a fractal slot antenna which gives multiband operation on 2.45 GHz. In this paper, we compare the simulation parameters on the basis of dimensions.

Keywords: Rectenna; Multiband; Efficiency; Fractal Slot antenna and Gain.

INTRODUCTION: Modern wireless applications have challenged antenna designers with demands for low-cost and compact antennas along with a simple radiating element, signal-feeding configuration, good performance, and easy fabrication. In the modern era, the large reduction in power consumption achieved in electronics, along with the numbers of mobiles and other autonomous devices is continuously increasing the attractiveness of low-power energy-harvesting techniques [1]. For energy harvesting techniques we need a compact rectenna system at the receiver side of the harvesting system. The "wireless battery" is named as a rectenna which consists of an antenna and a rectifying circuit, where the antenna collects the incoming RF signals, and the rectifying circuit converts this RF energy into utilizable DC power [2] as shown in Fig. 1. The good feature of a rectenna for an electrical device would extend the device's lifetime and application fields.

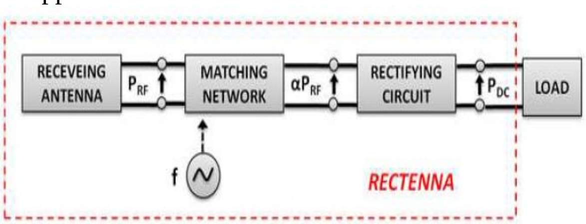

Figure 1: Block diagram of rectenna system

In the last few year different types of antennas are used for designing a rectenna system. Different antenna having specification for each rectenna system, like some of the antenna, is omnidirectional and some are bi-directional [3]. Microstrip patch antenna is a miniature directional antenna. Among the various types of antennas used as rectennas, microstrip patch antennas are gaining popularity due to their low profile, light weight, low production cost, simplicity, and low cost to manufacture using modern printed-circuit technology [4].

Another reason for the wide use of patch antennas is their versatility in terms of resonant frequency, polarization, and impedance when a particular patch shape and mode are chosen [5]. In this paper, we proposed a fractal slot antenna. Fractal shapes are inspired by nature. These can be applied for antenna design to achieve the wide bandwidth, compact size for multiband antenna etc. The fractal geometries have two properties in general which are self-similarity and space filling. Fractals have different shapes like: Hilbert curve, Sierpinski gasket and Koch snowflake etc [6]. These different shapes are used for designing different types of antennas. These geometries were first proposed by Mandelbrot in 1953 [7]. In the fractal antennas, we use different types of shapes of fractal. Due to the self-similarity and space filling properties, fractals come out as an attractive way to design an antenna, these properties allow the wider band and multiband operations and space filling properties leads to a reduction in size, which allows the antenna to be fabricated in a smaller space. Fractal antennas have been used as miniature multiband antennas in which self-similarity property is used to cause the antenna resonate on a number of frequency bands [8].

MATERIALS AND METHODS:

Antenna design: For making an efficient rectenna system we need an antenna which having high gain, low return loss, compact size and having high efficiency. Fulfilling these requirements we proposed a fractal slot antenna which having high radiation efficiency, low return losses, high bandwidth and which resonant at multiband of frequency. This fractal antenna is called the fractal slot antenna because used Koch rectangular slots inside the patch.

A rectangular microstrip patch antenna is taken as the initiator of the fractal antenna, as shown in Fig.2 (a). The resonant frequency fr, dielectric material of the substrate ε_r, and thickness of substrate h are the three essential parameters for the design of the patch antenna. A design frequency of 2.45 is chosen. A design frequency of 2.45 is chosen because of its low-cost components, location in the industrial, scientific, and medical band, and extremely low attenuation through the atmosphere. This frequency is used in WLAN, Bluetooth, RFID-based wireless sensor nodes, and other wireless applications. The patch is placed on a Teflon (relative permittivity, ε_r = 2.2, dielectric loss tangent tanδ = 0.0009, and h = 1.6 mm) substrate. The design procedure for the patch antenna is based on a transmission line model.

Dimensions of rectangular microstrip patch antenna are calculated by following a simplified formulation: For an efficient radiator, a practical width that leads to good radiation efficiencies is given by

$$w = \frac{V_0}{2f_r}\left(\frac{\varepsilon_r+1}{2}\right)^{\frac{-1}{2}} \qquad (1)$$

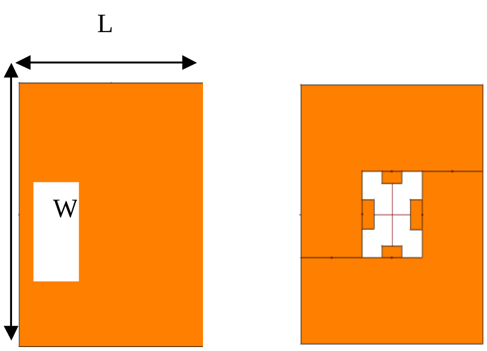

Figure 2 (a): Rectangular microstrip patch antenna, (b) Shape of slot fractal antenna.

The effective dielectric constant can be obtained by

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r+1}{2}\left(1+\frac{12h}{w}\right)^{-1/2} \qquad (2)$$

The dimension of the patch along its length is extended on each end by a distance ΔL due to the fringing effect. A very popular and practical approximation relation for the normalized extension of the length is given by

$$\Delta L = 0.412h\left(\frac{\varepsilon_{eff}+0.3}{\varepsilon_{eff}-0.258}\right)\frac{\left(\frac{W}{h}+0.264\right)}{\left(\frac{W}{h}+0.8\right)} \qquad (3)$$

The actual length L of the patch is given by

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{eff}}\sqrt{u_0\epsilon_0}} - 2\Delta L \qquad (4)$$

W, L, ε_r, ε_{eff} are the width of the patch, length of the patch, resonant frequency, dielectric constant of the substrate, and effective dielectric constant of the substrate, respectively, in equations (1)–(4). Microstrip antenna can be fed by different methods; here coaxial feeding techniques are used. The ground dimensions of the antenna calculated by simple transmission line model.

Antenna dimensions are shown in table 1. From the dimensions of antenna initiator of antenna is designed. For fractal slot antenna dig a hole in one-third part of a rectangular patch. In next step insert a Minkowski loop slot on the inner side of a patch as shown in Fig. 2(b).

Table1: Dimensions (in mm).

S. No.	Frequency band (GHz)	Dimensions in mm	
		Length (L)	Width(W)
1	2.45	40.6	48.6

RESULTS AND DISCUSSION:

Simulation Results: ***Antenna Performance*** **-** We designed fractal patch antenna. Such fractal antennas have multiple bands or are genuinely wideband. They may replace a suite of antenna systems, disposing of tuning and matching circuitry, and fit in unique or constrained form factors. Also, we can use this antenna for rectenna system. The antenna is simulated using IE3D software, which is a high-performance full-wave EM field simulator for arbitrary three-dimensional volumetric passive devices using the Microsoft Windows graphical user interface. Initially, the rectangular patch antenna is designed with the procedure discussed in Section 2. Then, the shape of the fractal antenna is performed up to the 1st iteration. The simulated initiator and its iterations are shown in Fig. 2. The parameters mentioned are above W, L is the width and length of the patch is shown in Fig.2. We simulate the fractal microstrip antenna using IE3D Software. We get best results when the feed point is changed. In such case, the return loss curve dips the maximum. Since there is no specific way of finding this point, we vary the feed point position and try to get the best results by trial and error. Fig. 3 shows the fractal antenna with feed for 2.45 GHz.

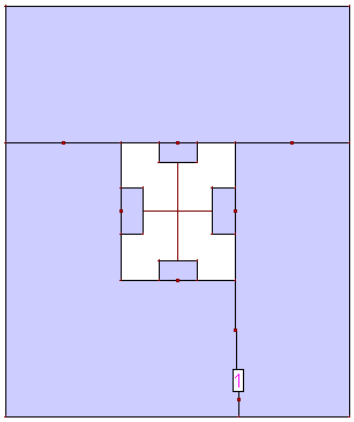

Figure 3: Feed to slot fractal antenna at 2.45 GHz.

The antenna parameters that are analyzed to evaluate their performance are the return loss, radiation pattern, gain, and directivity. The simulated return loss for slot fractal antenna as shown in Fig. 4.

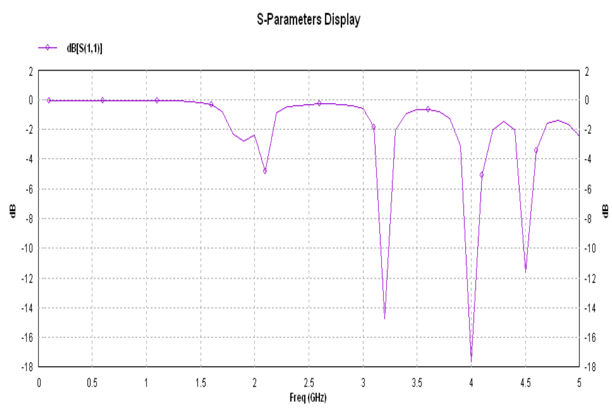

Figure 4: Return loss curve for proposed antenna.

The first graph or curve resonant at three frequency and values of return loss (S_{11}) for 3.19, 4.0 and 4.5 GHz is -14.3556 dB,-17.1182 dB and -11.4664. Return loss value is greater than 10 dB; it means reflection losses are very small for fractal slot antenna and having a broad bandwidth. We designed a fractal antenna for ISM band as shown in Fig. 4(a), which is not resonant at 2.45 GHz band. For, that we change the dimensions of a patch for required band by increased or decreased the length and width of a patch. Change dimensions of antenna and get the best dimension which gives the results for 2.45 GHz frequency as shown in Table 2.

Table 2: Changed dimensions (in mm).

S. No.	Frequency band (GHz)	Dimensions in mm	
		Length (L)	Width(w)
1	2.45	34.02	46.77

Fig.5 shows the fractal slot antenna with feed for 2.45 GHz for new dimensions of the rectangular patch as given in table 2.

The simulated return loss for fractal slot antenna as shown in Fig. 6. The graph or curve resonant at three frequency and values of return loss (S_{11}) for 2.43, 4.14 and 4.8 GHz is –17.6146 dB,-15.0704 dB and -20.3896.

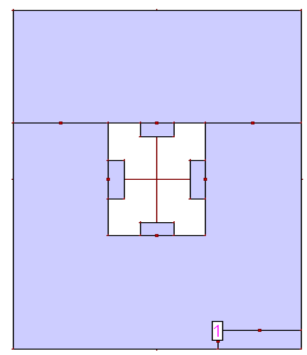

Figure 5: Feed to fractal slot antenna at 2.45 GHz frequency band for changed dimensions.

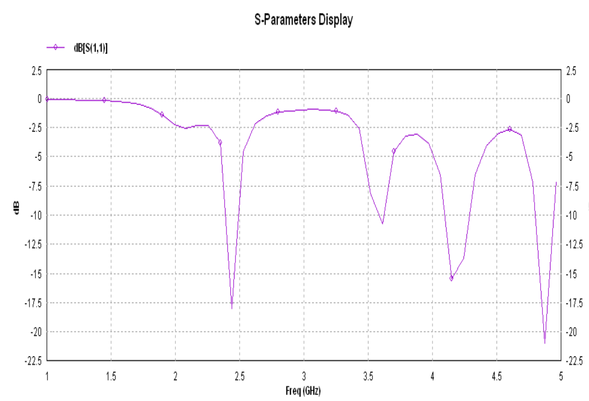

Figure 6: Return loss curve for proposed antenna with changed dimensions.

Return loss value is greater than 10 dB; it means reflection losses are very small for slot fractal antenna and having a broad bandwidth. Impedance bandwidth for both simulated antenna is high. The fractal antenna resonant at one or more frequencies it means it behaves like a multiband antenna. The gain of a fractal antenna is obtained is positive and having value is very high. Gain as a parameter measures the directionality of a given antenna. An antenna with a low gain emits radiation in all directions equally, whereas a high-gain antenna will preferentially radiate in particular directions. The gain for both antennas is shown in Fig. 7(a-b).

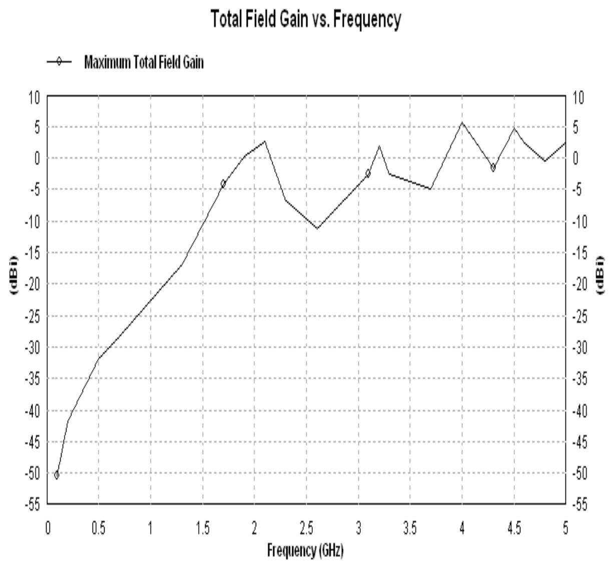

Figure 7 (a): Total field gain curve for proposed antenna.

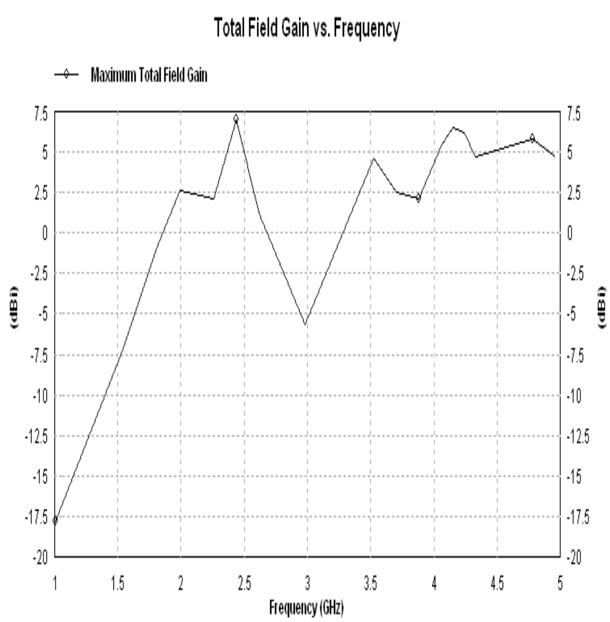

Figure 7 (b): Total field gain curve for proposed antenna with changed dimensions.

Fig. 7(a) and 7(b) shows the gain for both the antenna is positive and gain for changed dimensions antenna is very high. Gain and another simulated parameter are elaborated in table 3.

Radiation pattern or antenna efficiency and radiation efficiency for the different antenna are shown in Fig. 8 (a-b) and Fig. 9(a-b).

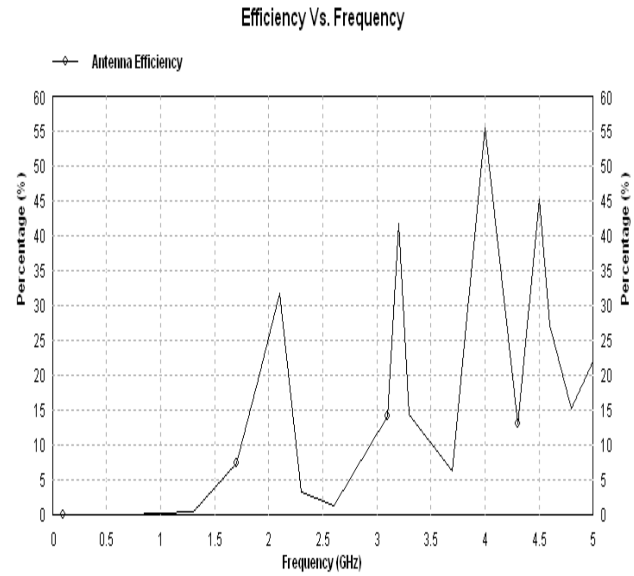

Figure 8(a): Antenna efficiency graph for proposed antenna.

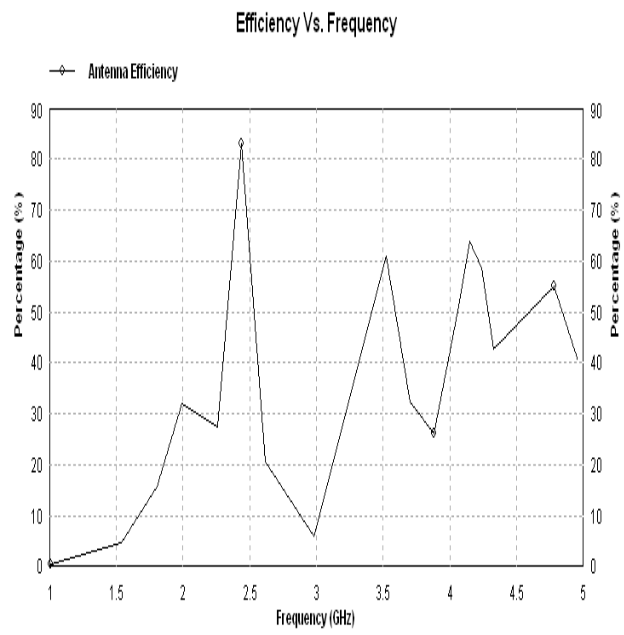

Figure 8(b): Antenna efficiency graph for proposed antenna with changed dimensions.

Antenna efficiency of the fractal slot antenna is more than of 60% for all frequency response as shown in Fig 8(b). Radiation efficiency for slot fractal antenna is always 80% after changes the dimensions of an antenna and before is 55%.

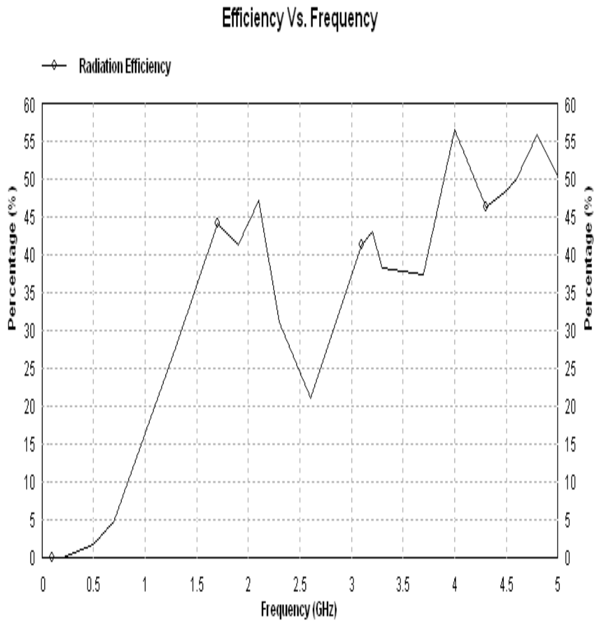

Figure 9(a): Radiation efficiency graph for proposed antenna.

Table 3: Comparison the simulated parameters for different frequency bands.

Simulation parameters	*Frequency bands (GHz)*					
	2.45			*2.45 with changed dimensions*		
	3.19	4.0	4.5	2.43	4.14	4.87
Return loss s_{11}(dB)	14.35	17.11	11.46	17.61	15.07	20.38
Gain (dBi)	1.88	5.39	4.57	6.80	6.40	5.66
Directivity (dBi)	5.79	8.12	8.14	7.73	8.40	8.41
Radiation efficiency %	43.00	55.94	48.62	84	65.44	65.29
Antenna efficiency %	40.98	54.90	42.68	81.70	62.97	53.35

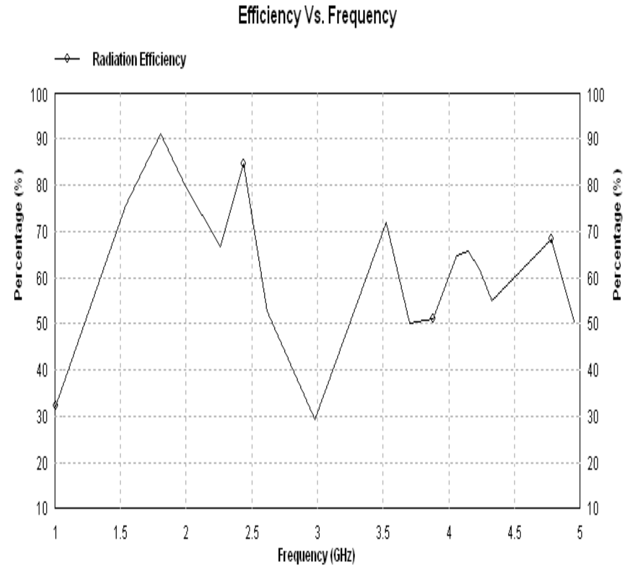

Figure 9(b): Radiation efficiency graph for proposed antenna with changed dimensions.

Table 3 gives the comparisons of different simulation parameters with a change of dimensions for fractal slot antenna. From the table 3, we get the better results after changed the dimensions of an antenna and resonant at ISM band. The gain for 2.45 GHz frequency is very high. The gain for fractal slot antenna is high it means the antenna is a directional antenna or emit radiation in particular direction and radiation efficiency, antenna efficiency is also high. Impedance bandwidth is good. For rectenna system required an antenna which resonant more than one frequency band and having low return losses, high gain. The proposed antenna fulfills all the requirements of rectenna system.

CONCLUSION: A fractal slot antenna which operates at 2.45 GHz is designed for rectenna system. The proposed antenna gives a multiband frequency response. The Gain of an antenna for a different frequency band is 6.80 dBi, 6.40 dBi and 5.66 dBi. The gain of an antenna is high, it behave like a directional antenna. Directivity is more than 60 percent. Antenna efficiency is also high. It makes a compact system because we can use this antenna where we required more than one frequency response or for rectenna system.

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