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Design and optimization of Microstrip Patch Multi Band Antenna for Wireless Communication using Defected Ground Structure with Fractal geometry

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Abstract:
In this paper rectangular slotted defected ground structure (DGS) multiband microstrip fractal antenna has been proposed. The proposed DGS slots uses self affine fractal geometry concept. The geometry is extended up to two iteration which resonates at penta band frequencies. The proposed fractal patch antenna function at 2-4 GHz (S-band) and 4-8 GHz (C-band) frequencies and finds uses for military and secure telecommunication and C band frequency applications like Wi-Fi , Radio Detection & Ranging and satellite communications. All designed antennas are optimized by IE3D software simulation tool with Fire Retardant-4 epoxy (FR-4) material having 4.4 dielectric constant, 1.6mm thick and tan(δ) (loss tangent) 0.02. By placing rectangle structures in the ground plane(DGS) of the proposed antenna the different parameters of all antennas have been examined in terms of antenna radiation efficiency, bandwidth, VSWR, return loss, gain and resonant frequency. The proposed microstrip antenna exhibits multi band, simple structure with low cost dielectric material and overall size has been reduced.

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I. INTRODUCTION

In the present competitive global wireless communication technology market, the electronic devices require compact, high gain and large bandwidth antennas having multiband performance [1]. Therefore there exists the of need separate antennas for different applications, since the conventional antennas generally operates at a single frequency band, where a different antennas are needed for separate communication purposes. Hence it poses problems of limited space and multi frequency performances. To overcome this difficulty a single microstrip antenna can be designed by applying rectangular slots as defective ground structure(DGS) with fractal geometry to make patch antenna to operate at many different frequency bands and also area of the ground structure can be reduced. Now a day's microstrip antennas are more popularly used because of its various advantages and merits such as compact in size, light in weight, low-profile, less space occupation, conformal, compatible with embedded circuit boards, simple to fabricate on the stiff surface of patch antenna and cost effective.

There are several approaches for enhancing parameters of microstrip antenna i.e. application of electromagnetic band gap slots and use of fractal shape geometry [2] and here are many number of techniques and methods that have been designed, developed and fabricated over the previous years. Fractal geometry as stated above is being applied on patch antenna to get reduced antenna size and multi frequency characteristics [3]. Fractal term stands for irregular or broken shapes. They can have different geometries, the most interesting ones are Sierpinski Carpet, Minkowski, Koch curve and Hilbert curve are found in the literature as depicted in Figure 1 [4]. When fractal geometry is applied for the design of

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microstrip antenna, total size of patch antenna reduces and resonant length increases [5].

Figure 2 illustrate Fractal geometry of Minkowski antenna construction steps for antenna design.

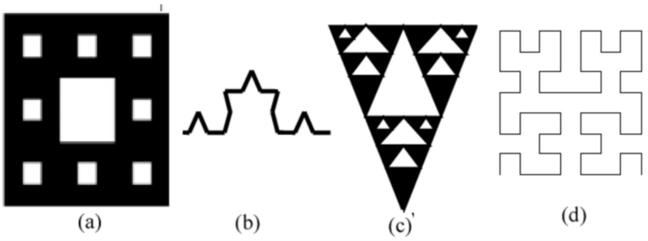

Figure1 (a) Sierpinski Carpet (b) Koch Curve. (c) Sierpinski Gasket (d) Hilbert Curve [4].

The application of fractal geometry to the defected ground structure (DGS) and its use in the design of microstrip antenna and microwave integrated circuits is becoming more attractive.

The recent DGS technique design with fractal geometry is capturing more importance in antenna design due to its uniqueness properties to reduce antenna size, suppression of spurious response and also the enhancement of the return loss.

Hence for designing multiband antennas at compact area, fractal geometry is preferred and by the treatment of fractal geometry to the ground plane (DGS), microstrip antenna design has been presented in this novel research paper. A maximum of two iterations have been used. Section 2 describes the related work. Section 3 focuses on basic antenna design and its operation.

It is also reported that how slotted fractal geometry can be derived in the ground plane from conventional rectangular microstrip geometry.

Results along with discussion are depicted in Section 4. Finally, conclusions of the research work are drawn in Section 5.

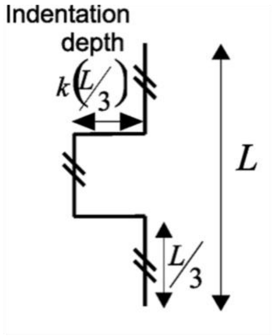

Figure 2: Fractal geometry steps of the Minkowski algorithm [5]

II. Related Work

Fractal word meaning is wrecked or rough geometric contour which can be divided into subsections that can be a rough calculation to the total geometry but in a reduced size. In the recent past years more number of patch antenna structures with the application of fractal structure and DGS investigated in the literature [6-17]. The E shaped DGS fractal geometry patch antenna has 3 multi-resonant behaviors and is described in [6] having 2mm substrate thickness and maximum three iterations have been performed. A rectangular Sierpinski slotted fractal microstrip antenna at fundamental 2.4GHz resonance frequency is designed for wifi application by using RT duriod 5880 with 2.2 dielectric material constant and with a thickness of 1.5875mm and used fractals self-similar property [7]. Design of 8 shaped 4 element MIMO antenna is proposed to obtain operation for UWB wireless applications by using RO4350B substrate, with tan(δ) i.e. loss tangent of 0.004 and dielectric constant of 3.5 [8]. A fractal patch antenna using Sierpinski gasket is designed and compared in terms of VSWR, Return loss and percentage BW DGS technique.[9]. In another work, X shaped multiband fractal patch designed to operate at multiband resonance frequency using DGS where width of the DGS is varied by changing slot size [10]. A novel F slotted fractal microstrip patch is designed and optimized to get maximum of four multiband frequencies for wireless applications and antennas are compared with and without DGS, Dumbbell

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DGS and Slotted DGS[11]. In another work hybrid fractal antenna for wireless communication applications were studied by combining Sierpinski and Minkowski carpet patch antennas with area 45 × 38.92mm [12].Further a modified wheel shaped fractal antenna analyzed for high speed and multi frequency operation [13]. The investigation for Moore and Hilbert fractal antennas were also carried out for multiband frequency of operation and can detect the PD signal [14]. Literature shows a wind band application oriented hexagonal-triangular structure design work was also presented recently with defective ground structure to obtain a bandwidth ratio of 8.4 to operate at multiband frequencies [15]. In another research work Minkowski and Hilbert fractal geometry antennas are examined in terms of microstrip antenna characteristics and proved that combined Minkowski and Hilbert antenna has more number of resonant frequencies compare to individual antennas[16].A dual band small size and having low profile, combined with Sierpinski and Minkowski carpet fractal patch antenna design reported in [17] finds applications in communication of satellites and wireless WBA (Wireless Body Area Networks).

However, still in literature there is a scope in compact and multiband frequency of operation to improve the characteristics of the above stated antennas further by changing the fractal shapes and its size. Therefore proposed work focuses on DGS slotted fractal mircrostrip patch antenna design and optimized with two iterations of minkowski algorithm. The presented microstrip patch resonated at seven different frequency bands and exhibited wide band behavior with size reduction and achieved high gain in the L,S and C band frequency bands which finds applications wireless devices. The designed antennas have low fabrication cost and use simple feeding technique. The various parameters of antenna such as radiation plot, bandwidth, VSWR, return loss, number of resonance frequencies, etc have been investigated thoroughly. The design and optimization is made with IE3D antenna design simulation tool.

III. Antenna Design & Optimization

A. Antenna 1, Iteration 0

The microstrip antenna adopted probe feed and a microstrip antenna size is related to the center frequency f_r. In the proposed design of microstrip antenna, the Length "L" and width "W" of the microstrip patch antenna performs a key role in calculating the resonant frequency of operation of patch antenna. For rectangular microstrip antennas, the length (L) and width (W) of the radiating patch antenna maintained at 28.83X37.26 mm^2 and the effective dielectric permittivity of the microstrip antenna (ε_r) at the requisite resonance frequency as it support the operation of patch or (λ_0= wavelength of free-space) can be designed using the antenna design equations 1 to 5 [18-22] to operate at 2.44GHz.

Calculation of patch antenna width, effective dielectric constant effective length, length extension, real length of the microstrip radiator and ground plane dimensions are carried out with the following equations.

$$W = \left(\frac{c}{2fr}\right)\left(\frac{\sqrt{2}}{\sqrt{\varepsilon r + 1}}\right) \text{-----------} 1$$

$$\mathcal{E}r_{eff} = \frac{\mathcal{E}\,r+1}{2} + \frac{\mathcal{E}\,r-1}{2}\sqrt{1+12\mathrm{h/w}} \text{-------} 2$$

$$L_{eff} = \frac{c}{2fr\sqrt{\mathcal{E}r_{eff}}} \text{----------} 3$$

$$\Delta L = 0.412h\,\frac{\left(\mathcal{E}r_{eff}+0.3\right)\left(\frac{w}{h}+0.264\right)}{\left(\mathcal{E}r_{eff}-0.258\right)\left(\frac{w}{h}+0.8\right)} \text{----} 4$$

$$L = L_{eff} - 2\Delta L \text{-------------} 5$$

$$Lg = L + 6h \text{----------------} 6$$

$$Wg = W + 6h \text{-------------} 7$$

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Where ε_r = Material dielectric constant ,ε_{reff} = Effective dielectric constant, W = Microstrip patch width, h = Dielectric substrate height, ΔL= Patch length extension and speed of light is c.

All the designed microstrip antennas are simulated with IE3D simulation software version 15. The design of patch antenna 1,2 and 3 are carried out using dielectric substrate FR-4 with substrate thickness 1.6 mm, ε_r = 4.4 as the dielectric constant, and the loss tangent = 0.02. The antenna designed values are optimized with IE3D v.15 antenna simulation software tool. The optimization is being carried out with number of iterations for the best impedance bandwidth, gain and for multiband operation. The proposed patch antenna geometry is exposed in figure 1. The overall dimension of the antenna ground plane is 39.7 mm x 47mm.

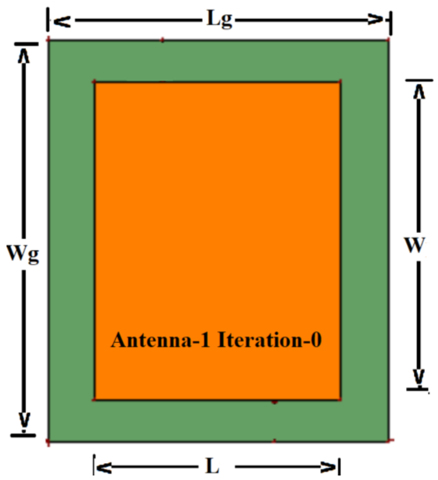

Figure2. Front view of Basic Microstrip Antenna-1 ,Iteration-0

Table 1: Dimensions of antenna geometry-1

Parameters	Dimension mm)
L	28.83
W	37.26
L_g	39.7
W_g	47

B. Antenna 2, Iteration-1

Figure 3 depicts the structure of the designed patch antenna-2 with iteration-1. The design of this presented antenna is done by the use of fractal geometry on the ground plane. In this paper, an rectangular shaped self-affine fractal geometry is constructed from zero iteration structure, as depicted in Figure. 2 by scaling with different scaling factors, that is scaling factor of three in the horizontal direction, and scaling factor of five in the upright direction. This scaling gives fifteen rectangular slots of size 13.2mm x 9.4mm, out of which the central two rectangular structures are removed to make rectangular slots DGS as exposed in Figure. 3, this is called the iteration-1. The designed microstrip patch antenna-2 various parameters are shown in Table-1. The optimization was performed with number of iterations for the best impedance bandwidth, gain, VSWR and for multiband operation. The probe feeding technique is being used for all cases studied here.

Table 2: Dimensions of antenna geometry-2

Parameters	Dimension (mm)
A1	13.2
B1	9.4
C1	13.2
D1	9.4

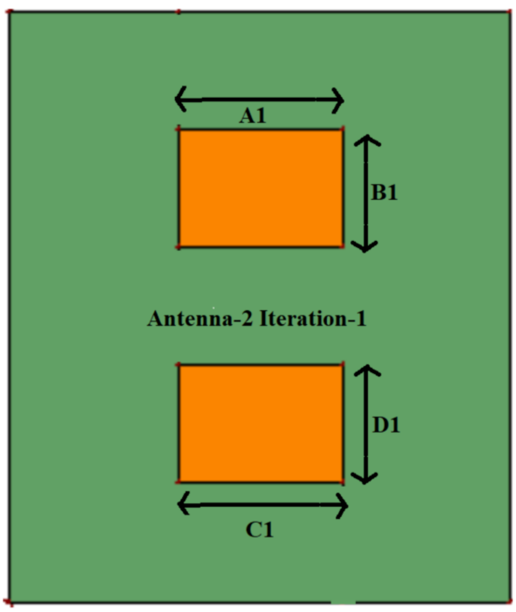

Figure3.Back view of Microstrip Antenna-2 ,Iteration-1

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C. Antenna 3, Iteration-2

Figure 4 shows the design of the proposed rectangular slotted fractal patch antenna-3 resulted with iteration-2. The antenna 3 is constructed by repeating the same scaling process on each of the remaining 12 rectangles i.e. leaving central 3 rectangles, which gives a structure as shown in Figure.4, this is called second iteration and dimensions of the patch antenna 3 are shown in Table-3. Antenna parameters are optimized with number of iterations for the best bandwidth, gain and for multiband operation. The probe feeding technique is being used.

Table 3: List of parameters of antenna geometry-3

Parameters	Dimension (mm)
A2	4.4
B2	1.88
C2	4.4
D2	1.88

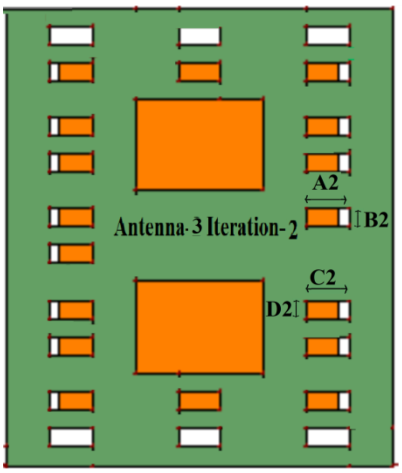

Figure 4. Back view of Microstrip Antenna -3 ,Iteration-2

IV. Results and Discussion

Methods to increase gain can be acquired by changing the material or by use of substrate, but by using simple design and applying DGS structure on ground plane well desired gain as well bandwidth can be obtained the two iterations of the probe fed self-affine rectangular slotted DGS fractal patch antenna using IE3D v.15 antenna simulation software are studied. Many optimizations are performed by changing the DGS size to obtain better values of radiating parameters as in Table 4.The antennas 1, 2 and 3 are designed with low priced FR-4 material having Ɛr=4.4 and simulated result parameters obtained as shown in Table-4. It is evident from the table-4 that these antennas have multiband resonant frequencies with reasonable bandwidth, good return loss, and peak values of gain. The patch antenna-1 with iteration zero is designed and simulated at frequency 2.44 GHz. Optimizations of the results have been obtained by changing the feed point locations to obtain good antenna performance parameters. The proposed antenna-1 has resonated at three multiband frequencies and peak value of 2.02 dB gain, with bandwidth of 71.0879 MHz having return loss of -14.54dB with 1.59 VSWR are obtained at 2.44 GHz frequency and these parameters are suitable for the Wi-Fi and Bluetooth wireless applications. The 3D radiation plot as indicated in figure-6 shows good omnidirectional radiation characteristics. The 3D radiation plot at 2.44 GHz has less than 20db cross polarizations and back radiations are also small. Antenna-1 has achieved an antenna efficiency of 38.83% with maximum field directivity of 5dbi and antenna radiation efficiency of 48.37%.

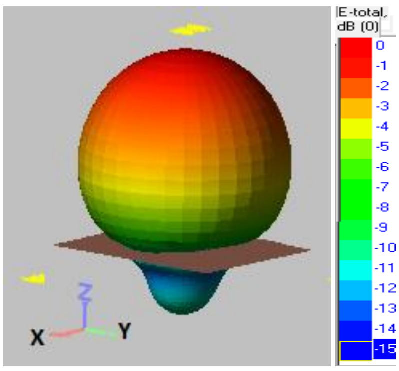

Figure 6 3D Radiation plot of basic microstrip (antenna-1) at 2.44GHz

A method to get multiband and decreasing the area of the antenna has been achieved by the application of first iteration on antenna-1. Many optimizations are performed by changing feed point and fine tuning of slotted DGS structure to obtain better

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values of radiating parameters as in Table 4. The simulated results obtained shows antenna-2 has resulted in five multi band resonant frequency components which are suitable for Wi-Fi and WIMAX applications. Maximum gain of 2.59 dB has been obtained at 2.074 GHz with bandwidth of 39.62MHz with return loss of --11.28dB having 1.80 VSWR which can be used for Fixed point-to-point microwave and mobile communications . A gain of 2.54dB also has been achieved at 3.01380 GHz with bandwidth of 131.794 MHz which finds applications in maritime radio navigations. The figures 7 shows the 2D radiation plot of the presented antennas and depicts good omnidirectional characteristics with less no. of minor lobes and maximum radiation at an angle45^0. Peak radiation efficiency of 26.37% and antenna efficiency of 26.37% has been achieved. The maximum total field directivity obtained is 6.4 dBi at 5.8 GHz. A size reduction of of 13.33 % is achieved by the E shape antenna-2 in comparison with antenna-1.

The result shows that the slotted DGS second iterated fractal antenna-3 has also has multiband resonant frequencies at 2.1047 GHz, 4.32694 GHz & 5.8381GHz, 7.8825 having good returns loss, bandwidth, gain and VSWR as shown in table-4, which are well suitable for ISM, Bluetooth and WIFI After number of iterations for optimized antenna-3 values for feed point locations second iterated fractal antenna-2 has resulted a maximum gain of maximum 1.92 db at 5.8GHz.This proposed antenna-3 has resulted an antenna efficiency of 24.35%, total field directivity of 9.7dBi and antenna radiation efficiency of 26.37% at 5.8GHz. Figure 8 shows simulated proposed antenna-1,2and 3 optimized comparative analysis of return loss(S11) and indicates agreeable return loss. The polar radiation plots simulated at $\phi=90^0$ and $\phi=0^0$ is indicated in figure 8 and shows omni-directional characteristic at 5.35GHz. The diagram depicts that antenna is more directive and has higher bandwidth with regard to antenna 2.Antenna-3 has resulted an overall size reduction of 24%.

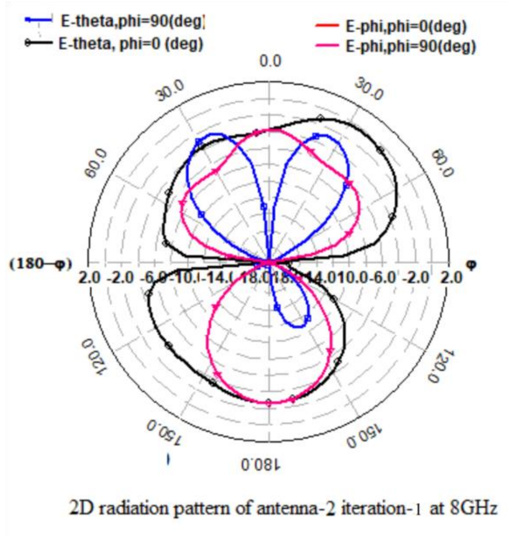

Figure 7: Radiation pattern of antenna-2

Table 4. Optimized results of proposed geometries.

Type of Antenna	Resonant Frequency In GHz	Return Loss(S11) In dB	BW In MHz	Gain db	VSWR
Antenna-1 Iteration-0	2.4476	-14.54	71.0879	2.02	1.59
	3.7636	-11.81	89.2307	-0.40	1.34
	4.5636	-13.51	80.7911	-1.90	1.32
Antenna-2 Iteration-1	2.0574	-11.18	29.6270	2.59	1.80
	3.0138	-10.13	131.794	2.54	1.93
	4.4912	-11.78	178.797	0.58	1.91
	5.8346	19.11	155.329	-0.2	1.25
	8.0014	16.60	261.623	1.38	1.35
Antenna-3 Iteration-2	2.1047	-11.48	43.430	1.36	1.72
	2.9172	-11.66	-	-5.22	1.83
	4.3269	-11.27	50.000	-3.85	1.87
	5.8381	-17.85	162.735	1.02	1.23
	7.8825	14.31	279.507	1.92	1.31

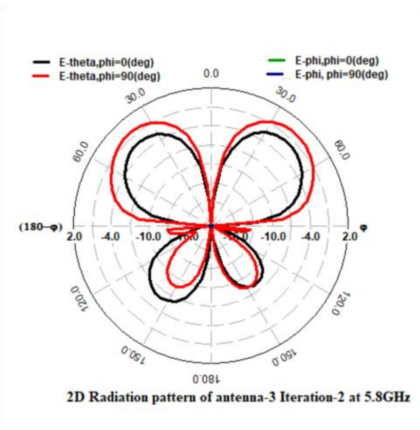

Figure 9: Radiation plot of antenna-3.

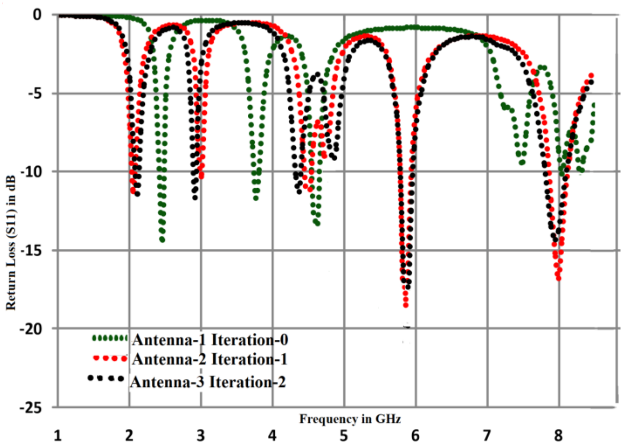

Figure 8 Microstrip antenna1,2&3 comparison of return loss S11

V. Conclusion

Slotted DGS microstrip patch antenna with fractal geometry has been presented. The presented geometry shows overall optimum results compared to the traditional basic microstrip antenna. From the proposed antenna design and analysis done here, it is clear that the low cost and compact sized patch antenna resonated at five multiband frequencies and overall size reduction of 24% is achieved for the 2nd iteration (antenna-3). The operating frequencies obtained with optimum results are 2.44 GHz with the BW of 71.0879MHz having gain of 2.02dB for Basic antenna 1, 2.0574 GHz with bandwidth of 29.62 MHz with gain of 2.59 dB for antenna-2 and 5.8 GHz with bandwidth of 162.735MHz having gain of 1.92 dB for antenna-3 respectively. These frequencies are useful for applications in S band (unlicensed applications) like Wi-Fi, , ISM, and blue tooth modules and maritime radio navigation system.

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