Design of Circular fractal antenna for multiband wireless application

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ABSTRACT: This dissertation presents a circular multiband fractal antenna which is designed for multiband wireless applications. Sierpinski Gasket approach is used to make circular fractals of scaled dimensions. The fractal antenna has the multiband operation due to the self-similar property in fractal geometry. Fractal geometry leads to improved bandwidth, radiation efficiency and reduced size. The proposed antenna resonant frequencies are centred at 2.6 GHz, 4.8 GHz, 5.6 GHz, 6.3 GHz, 7 GHz, 8 GHz, 8.6 GHz and 9.2 GHz with atleast 200 MHz bandwidth. Circular patch antenna is used as the basic geometry and 3 stages of iterations produced the proposed design. Radius of the base antenna is 24 mm.

I-INTRODUCTION

An antenna is a device which is transmitted or received EM waves from one end to another end. So it is a medium between free-space and a guiding device [1]. Antenna is a basic requirement of any communication system & is connecting links between the transmitter and free space [1]. Coaxial line or hollow lines are used as a guiding element and it is used to transport EM waves from the Tx end to antenna or from antenna to Rx end [1]. ANTENNA PARAMETERS are below

1. FREQUENCY BANDWIDTH: Frequency band in which an antenna radiate correctly, called frequency bandwidth. The bandwidth may be defined in terms of % also. the centre frequency of band below the highest and lowest frequency in a bandwidth.

$$\mathrm{BW}\,\% = \frac{f_H - f_L}{f_C}$$

Where $f_h$the highest frequency band & f_l is the lowest frequency band, andf_c is the centre frequency in the band.

2. INPUT IMPEDANCE: Input impedance is defined as “the impedance presented by an antenna at its terminals or the ratio of the voltage to current at a pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point [1]. Tx line are typically designed for 50Ω characteristics impedance .This is a standard value of Tx line . If the value of impedance is different from 50Ω or 75Ω, then there is a mismatch and an impedance matching circuit is required.

3. REFLECTION COEFFICIENT: Reflection coefficient (RC) is the ratio of the amplitude of the incident wave to the reflected wave. Waves reflect at a discontinuity manner in a Tx, the complex ratio of the electric field strength of the reflected wave to that of the incident wave.

4. VOLTAGE STANDING WAVES RATIO (VSWR): It is also important parameters which gives an estimate of the amount of power reflected to the wave guide or Tx that is feeding the antenna. VSWR can be define by reflection coefficient,. If reflection coefficient is given, then the VSWR is defined by the following formula:

$$\mathrm{VSWR} = \frac{|V_{max}|}{|V_{min}|} = \frac{1+|\Gamma|}{1-|\Gamma|}$$

II- DESIGN METHODOLOGY

In this chapter, the procedure for designing a Circular fractal micro strip Antenna for multiband and wireless applications designed for use in wireless Communication.

DESIGN SPECIFICATIONS The three essential parameters for the design of a Circular Micro strip Patch Antenna is:

- Resonant Frequency (fr): The resonant frequency of the antenna must be selected appropriately. The wireless Communication System uses the frequency range of microwave frequency e.g GHz. Hence the antenna designed must be able to operate in this frequency range.

- Dielectric constant of the substrate (Ɛr): The dielectric material selected for the design is FR4_ epoxy which has a dielectric constant of 4.4. A substrate with a dielectric constant has been selected since it reduces the dimensions of the antenna.

- Height of dielectric substrate h : For the microstrip patch antenna to be used in wireless communication, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate is selected as 1.6 mm.

So that the values of the three parameter are

fr = 2.4 GHz

h=1.6mm
Ɛr =4.4 (FR4)

$$F = \frac{8.791 \times 10^9}{fr\sqrt{Ɛr}}$$

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi Ɛr F}\left[\text{In}\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}}$$

We have described the design procedure for radius a

Step 1: Calculation of the F : here the resonant frequency fr is 2.4 GHZ and the value of dielectric constant Ɛr is 4.4.

$$F = \frac{8.791 \times 10^9}{fr\sqrt{Ɛr}}$$

Step 2: calculation the radius of Circular patch a: following equation gives the radius of circular patch antenna given by

$$a = \frac{F}{\left\{1+\frac{2h}{\pi Ɛr F}\left[\text{In}\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{\frac{1}{2}}}$$

Where h =1.6 mm, Ɛr =4.4

Step 3: Determination of feed point location:

Microstrip feed line is used in this design. As shown in Figure the feed point must be located at that point on the patch, where the input impedance is 50 ohms for the resonant frequency. Hence, a trial and error method is used to locate the feed point. For different locations of the feed point, the return loss (R.L) is compared and that feed point is selected where the R.L. is most negative. There exists a point along the length of the patch where the R.L is least.

Figure 1 Block diagram of design flow

DESIGN MODEL-1

This was the basic antenna designed to verify the formula for the design of circular patch antenna.

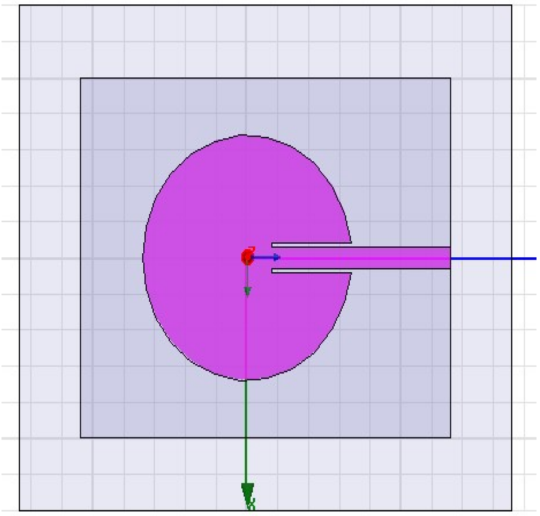

Figure 2 Inset feed basic circular patch antenna

Dimensions of the basic circular antenna with inset feed.

Table 1 Dimensions of the basic circular antenna with inset feed.

Length of the ground	60 mm

plane (Lg)	
Width of the ground plane (Wg)	50 mm
Height of the substrate (h)	1.6 mm
Radius of the patch (R)	17 mm
Length of the Microstrip feed line (Lf)	29 mm
Width of the Microstrip feed line (Wf)	3 mm
Length of inset (y0)	13 mm

Table 1 design parameters

The geometry of the proposed antenna is shown in fig. It consists of a circular patch antenna on FR4 substrate of thickness 1.6mm and relative permittivity 4.4. The substrate has a length of Lg=60 mm and the width of Wg= 50 mm. The radius of the circular patch is about 17 mm.

Inset Feed and input impedance: If the microstrip line feeds the patch antenna at the edge it leads to high input impedance. Since practically the wire used even to feed the microstrip line is a coaxial cable the input impedance of the antenna cannot be high. It should match with the characteristic impedance of the coaxial wire (50 ohms). Since the current is low at the edges of a half wave patch and large in magnitude toward the centre, the input impedance could be reduced if the patch was fed closer to the centre [4].

One method is to move the feed point inside the patch by cutting a slot that is slightly greater than the width of the transmission line.

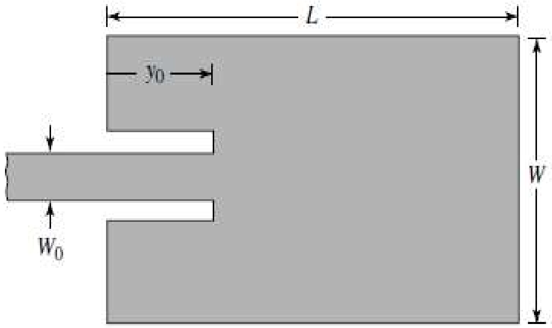

Figure 3 Inset feed

Input impedance of the patch antenna can be calculated using the expression given below [1]

$$\mathrm{Z_{in}} = \frac{1}{2\mathrm{G1}}$$

G1 is the conductance of the patch antenna.
G1 can be calculated by the expression below

$$\mathrm{G1} = \begin{cases} \frac{1}{90}\left(\frac{\mathrm{W}}{\lambda_0}\right)^2 & \mathrm{W} \ll \lambda_0 \\ \frac{1}{120}\left(\frac{\mathrm{W}}{\lambda_0}\right) & \mathrm{W} \gg \lambda_0 \end{cases}$$

W is the width of the patch and λ_0 is the operating frequency. G1 actually gives input resistance at the edge of the antenna. HFSS can also be used to calculate by simulation the input impedance of the designed antenna.

The depth of the inset y0 can be calculated using the formula below [3]

$$\mathrm{Zin}(\mathrm{y} = \mathrm{y}_0) = \frac{1}{2\mathrm{G1}}\left(\cos\left(\frac{\pi}{\mathrm{L}}\mathrm{y}_0\right)\right)^2$$

Width of the feedline is 3 mm and height of substrate is 1.6 mm resulting W0/H ratio of 1.875 (>1). To obtain the characteristic impedance of 50 ohms following equation is used [2]:

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}} \times \left[\frac{W_0}{h} + 1.393 + \frac{2}{3}\ln\left(\frac{W_0}{h} + 1.444\right)\right]}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W_0}\right]^{\frac{1}{2}}$$

ε_{eff} is the effective dielectric constant. W0 is the width of the feed line and h is the height of the substrate from the ground plane.

DESIGN MODEL -2 (proposed design)

The proposed design is a fractal antenna. Circular shaped fractals are cut from a circular base shape. This fractal design is inspired from Sierpinski Gasket Fractal antenna design. In this design conductor of same shape as the base geometry is removed from the patch. The patterns that are removed from the patch must be of scaled lengths for every successive iteration.

In our design the size of the first fractal is decided from the formula of basic circular antenna design.

In the first iteration two circles of 20 mm diameter are cut along the axis of the feed line. In the second iteration two circles of 12 mm diameter are taken away perpendicular to the axis of feed. In the third and last iteration four circles of 4 mm diameter each are deducted from the corner resulting from previous two iterations.

The size of the fractal is the odd multiple of 4, starting from 5. For example the first fractal is 20 mm (4 * 5), second fractal is 12 mm (4 * 3) and the last fractal is 4 mm (4 * 1). Table shows the dimensions of the final antenna designed.

Table 2 Dimensions of the final antenna designed

Base antenna diameter = 48 mm	
Lg	85 mm
Wg	60 mm
Lz	26.05 mm
D0	48 mm
D1	20 mm (4*5)
D2	12 mm (4*3)
D3	4 mm (4*1)

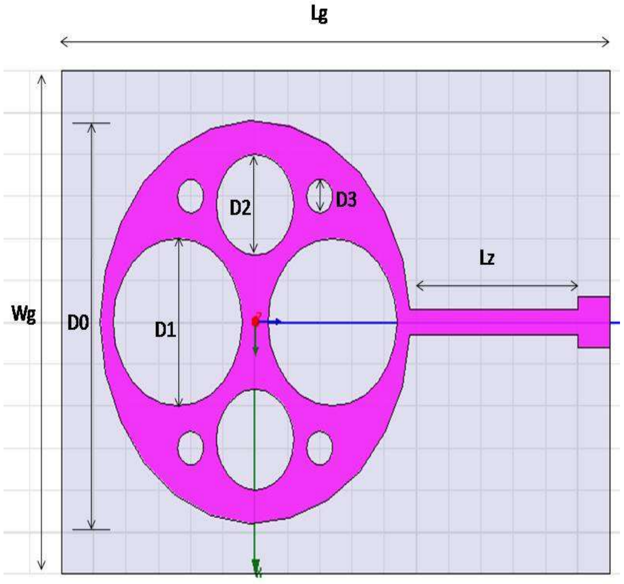

Figure 4 Dimensions of the final antenna designed

Radius of the base shape is 24 mm. The base radius was kept bigger because of two reasons:

(a) To incorporate as many fractals as possible: if the antenna radius was kept around 17 mm (as calculated from the formula), cutting fractals out of it was possible hardly for one or two iterations.

(b) To extend the frequency of operation: wavelength of 24 mm directly corresponds to about 1.25 GHz. and we wanted to include as many frequencies from ISM band as possible. Cutting fractal will anyways give resonance at higher frequencies.

Design iterations:

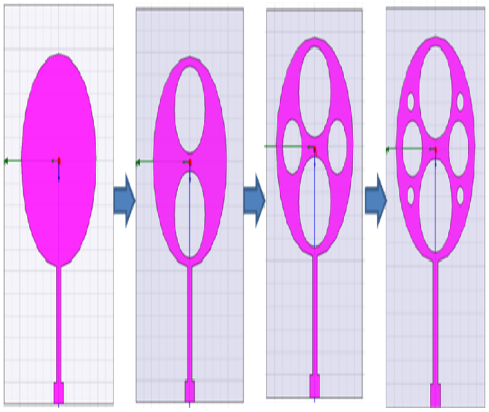

Figure 5 Iterations in making final design of fractal antenna

Base circular antenna is of the diameter 48 mm. This length is calculated keeping in mind the resonant frequency of 2.4 GHz. Since the shape of the antenna is circular there is only one parameter that can be changed (radius of the patch). This changes the resonant frequency of the antenna [4]. A circular antenna inherently works on more than one frequency because it supports higher order modes in TMmnp. In the first iteration shown by S1, two circular patches are cut along the axis of the feed line (D1=20 mm). In the second iteration (S2), two more circles are subtracted from the base shape perpendicular to the feed axis (D2=12 mm). In the third and final iteration (S3) four circles of diameter D3=4 mm are cut from the remaining diagonal spaces in the base circular patch. Every iteration shows better response in terms of bandwidth, current distribution and radiation properties. Fig 1 shows the final structure of the antenna, all the dimensions are shown in Table 1. Fig 2 shows the progressive process of cutting fractals in each stage to get the final result.

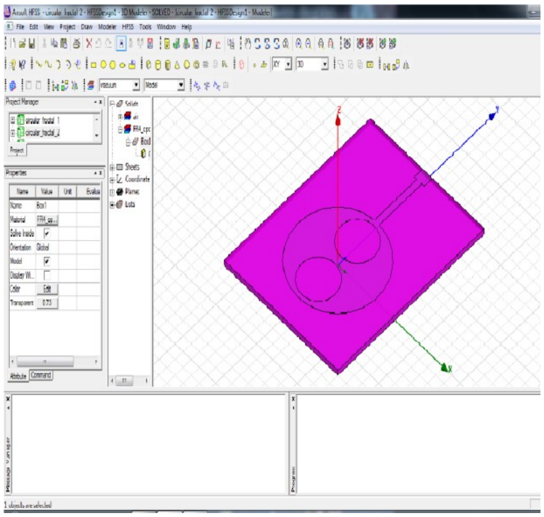

Figure 5 FASS design top

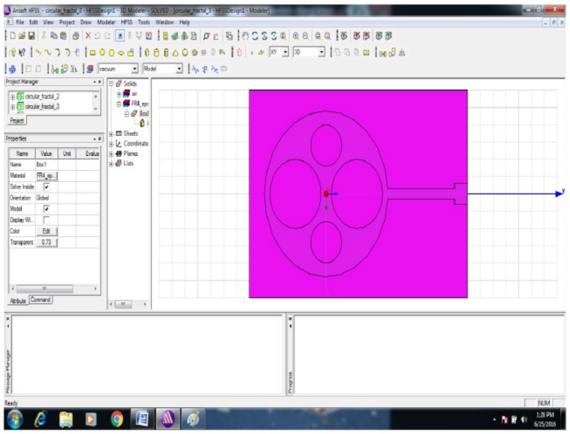

Figure 6 FASS design side

III-RESULTS AND COMPARATIVE ANALYSIS

RETURN LOSS: Efficiency of an antenna at a given frequency can be estimated by measuring the return loss (i.e. S11 parameter). Return loss of an antenna tells how much supplied power is not used by the antenna.

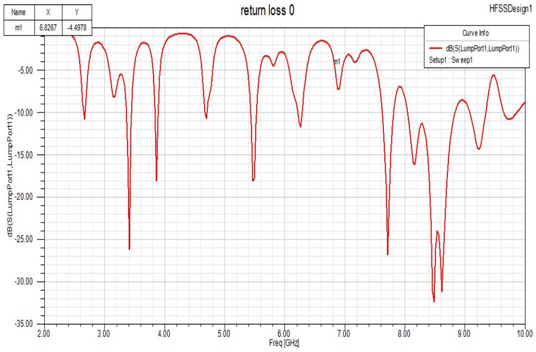

Figure 7 Return loss-iteration 0

BANDWIDTH: The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. Using tools like HFSS the bandwidth is calculated from S11 graph. -10 dB is taken as the reference and the first and the second intersection of the return loss curve with -10 dB line is taken as fl and fh respectively. The bandwidth of the proposed antenna is not less than 100 MHz for any operating frequency

INPUT IMPEDANCE:Input Impedance of the antenna is the impedance at its terminals or the ratio of the voltage to current at a pair of or the ratio of appropriate components of the electric to magnetic fields at a point. The input impedance of an antenna should be such at it is easily fed and is real rather than complex. Input impedance of the proposed antenna is around 50 ohms for each frequency

VSWR:VSWR (Voltage Standing Wave Ratio) is also an important parameter which gives an estimate of the amount of power reflected to the transmission line that is feeding the antenna. VSWR ideally should be 1 means no power is reflected from the antenna. VSWR of the proposed antenna are is shown in the table 4. It is not more than 1.48.

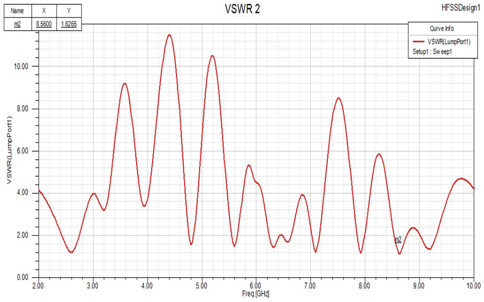

Figure 8 VSWR of the proposed antenna

This radiation pattern is shown on the frequency of 2.4 GHz at each iteration.

Base Paper			Proposed Work		
Frequency (GHz)	Return loss (base paper db)	VSWR	Frequency (GHz)	Return loss (designed antenna db)	VSWR
10.3	-14.06	1.49	2.4	-20.72	1.2
16.7	-20.96	1.2	4.8	-13	1.5
21.7	-14.48	1.47	5.6	-14	1.48
25.1	-15.3	1.41	6.32	-15	1.44
43.3	-14.69	1.45	7	-20.5	1.2
49.3	-12.54	1.62	8	-23	1.1
--	--	--	8.77	-24	1.3

COMPARATIVE ANALYSIS OF RETURN LOSS

Table 3 Return loss of designed antenna (final iteration) and base paper

IV-CONCLUSION

The proposed design uses Sierpinski gasket fractal to design a multiband fractal antenna. It uses three iterations that makes antenna wideband and reduces the volume. The design is a very good contender for a mobile handset antenna since it works on ISM band and 4-5 more frequencies and its radiation pattern is omni-directional. Moreover the design is very simple because the only shape used either as base shape or as fractal is a circle of scaled size.

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