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Design of Frequency Reconfigurable Microstrip Patch Antenna for Wireless Applications

Meryl Lopes, Amita Dessai

Abstract*: Modern telecommunication systems require miniature antennas with multiband characteristics that support multiple wireless applications. This paper presents a pentagon shaped microstrip patch antenna that works at 7.5GHz with a return loss of -43.48dB. The antenna has been designed on 1.59 mm FR-4 substrate with dielectric constant of 4.4 and loss tangent of 0.02. The pentagon shaped microstrip patch antenna has been modified into a dual band and a triple band antenna by applying fractal shape and frequency reconfiguring the antenna geometry. Proposed antenna finds applications for defense and secure communication, C band (4 GHz to 8 GHz) and X band (8 GHz to 12 GHz) applications where antenna can be used for satellite communication and RADAR applications. Proposed antenna has been designed using IE3D and results are analyzed in terms of gain, return loss, directivity and bandwidth.

***Index Terms*: Fractal antenna, Microstrip, Multiband, Reconfigurable antenna**

I. INTRODUCTION

In the present scenario [2], of wireless communication, there is a need of compact communication system, so multiband antennas are required. Generally, small antennas capable of resonating at multiple bands are in great demand. One of the techniques to reduce size of patch is to make use of fractal geometry. The advantage of fractal geometry is that, it helps in size shrinkage and also provides better impedance matching. This approach allows antenna to operate at multiple frequencies thereby minimizing the number of antennas required. Microstrip antennas find applications in aircraft, satellite and missiles where important requirements are size, weight and complexity. Although they are light in weight and have multiple resonance, they have disadvantages like low bandwidth, poor gain and low efficiency. Hence, fractal geometry is used to overcome these disadvantages. These important characteristic features of fractals can be utilized in antenna design to achieve the following advantages: miniaturization, multiband / wideband antennas and better efficiency. Reconfiguration enables an antenna to dynamically modify its frequency and radiation characteristics in a controlled and reversible manner. In order to ensure reconfiguration, an inner mechanism (RF switches, varactor or pin diodes, mems switches) which enable intentional redistribution of RF current over antenna surface and produce reversible modification over its properties is used. In this paper a single band pentagon patch has been designed and then it's reconfigured to dual band and triple band antenna using fractal geometry. Results have been obtained by applying a switching mechanism to the geometry by using IE3D simulation software.

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* Correspondence Author
Meryl Lopes*, Electronics and Telecommunication Department, Goa College of Engineering, Farmagudi, Ponda Goa, India, E-mail: meryllopes26@gamil.com
Prof. Amita Dessai, Electronics and Telecommunication Department, Goa College of Engineering, Farmagudi, Ponda Goa, India, E-mail: amitachari@gec.ac.in

II. ANALYSIS OF PATCH ANTENNA

In this section, a comparison is done between the 3 types of radiating patch that is rectangle, circle and pentagon at the design frequency of 7.5GHz. Further, a comparison is done between the two types of feeding techniques, the microstrip feedline technique and the coaxial probe feed technique.

A. Shape of the Radiating Patch

The patch was designed for rectangle, circle and pentagon shape for a frequency of 7.5GHz. It was observed from the return loss curve that the pentagon patch had minimum return loss as compared to the other shapes at the designed frequency and was considered the best. The S11 curve for the same is shown in Fig. 1.and a comparison for the return loss of the 3 radiating patches is shown in TABLE I.

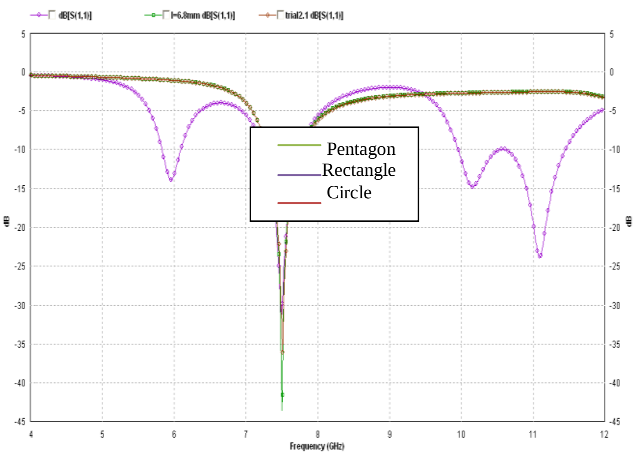

Fig. 1.Comparison between the 3 Radiating Patch Shapes

Table I. Comparison of the 3 Radiating Patches

S. No	Shape of patch	Resonant frequency(GHz)	Return loss(dB)
1	Pentagon	7.5	-43.48
2	Circle	7.5	-35.38
3	Rectangle	7.5	-31.19

B. Type of Feeding Technique

The pentagon patch was excited by using microstrip feed line technique and coaxial probe feed technique. It was observed from return loss curve that the patch showed better performance using coaxial probe feed technique as shown in Fig. 2. The return loss obtained by using microstrip feed line was -12dB and that for coaxial probe feed was -43.48dB.

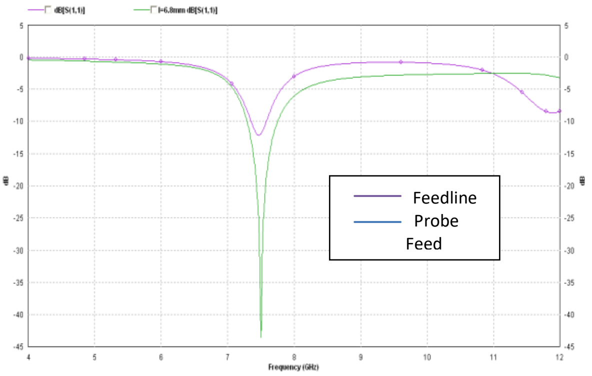

Fig. 2. Comparison between Microstrip Feed Line and Coaxial Probe Feed for Pentagon Patch

III. DESIGN PROCEDURE

In this section, first the designing of the pentagon patch is considered which is followed by use of fractal geometry and frequency reconfiguration for multiband performance.

A. Pentagon Patch Design Equations

The design parameters for FR-4 substrate, dielectric constant ($\epsilon r = 4.4$), substrate thickness (h = 1.59mm), the resonant frequency (fr = 7.5GHz) and loss tangent =0.02 are taken for designing the base geometry of proposed antenna. Length of pentagon patch has been computed [8] by using the equations (1)-(4).

$$F = \frac{8.791*10^9}{fr\sqrt{\varepsilon_r}} \tag{1}$$

The radius of the patch,

$$a = \frac{F}{\sqrt{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left[\frac{\pi F}{2h}\right]+1.7726\right]}} \tag{2}$$

The effective radius of the patch,

$$a_e = a\left(1+\frac{2h}{\pi\varepsilon_r a}\left(\ln\left(\frac{\pi a}{2h}\right)+1.7726\right)\right)^{0.5} \tag{3}$$

After finding the effective radius of the patch, the length of the patch can be found as follows

Length of the pentagon patch = 1.175 $*a_e$ (4)

The initial calculated length of the patch is found to be l=6.575mm with an effective radius of 5.596mm. The pentagon patch is simulated in IE3D using the initial estimates as shown in Fig. 3.

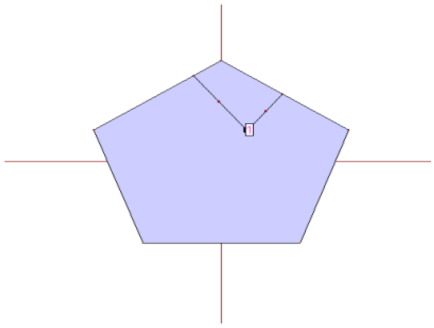

Fig. 3. Base Geometry

The patch is found to be resonating at 7.74GHz with a return loss of -44.66dB.

The patch is then optimized by changing the length of the patch .For a patch length of 6.8mm the resonance is obtained at 7.5GHz with a return loss of -43.48dB as shown in Fig. 4.

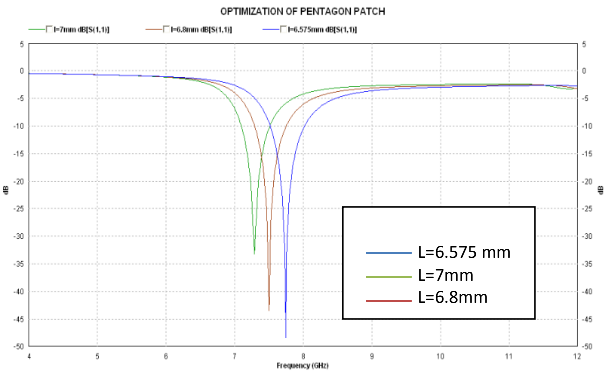

Fig. 4. Optimization of Pentagon Patch

The pentagon patch designed produces a single band of frequency with an impedance bandwidth of 6.12% in the frequency range 7.295GHZ-7.754GHz centered at 7.5GHz.

B. Fractal geometry

For designing a multiband antenna, first, the fractal part has been considered, and then, the addition of reconfigurability feature has been carried out. By using basic geometry relations, the first iteration has been carried out as follows

$$\frac{y}{a} = 2.618 \tag{5}$$

Where y = length of the original pentagon patch
a = length of the inner pentagon patch

$$x = y - 2a \tag{6}$$

Where x = base length of the isosceles triangle

$$z = \sqrt{a^2 - x1^2} \tag{7}$$

Where z=height of the isosceles triangle
X1= x/2

This gives us x=1.606mm and z=2.469mm. The first iteration has been designed in IE3D as shown in Fig. 5.

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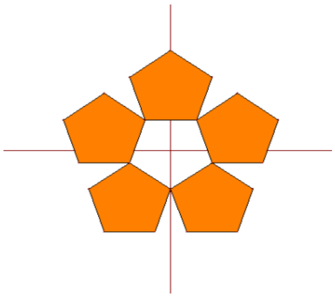

Fig.5. Fractal Geometry

Now the pentagon patch has been reconfigured by using a switching mechanism. 3 switches S1, S2 and S3 have been used appropriately in the fractal geometry to produce double band and triple band antenna.

C. Frequency Reconfiguration of the patch

Reconfiguration of the fractal pentagon patch antenna has

been carried out by using 3 switches in various positions of the geometry.

- *Dual Band Antenna*

In this section 2 switches, S1 and S2 will be used at appropriate locations in the proposed pentagon fractal patch to obtain dual band frequency response.

i) Switch position 1

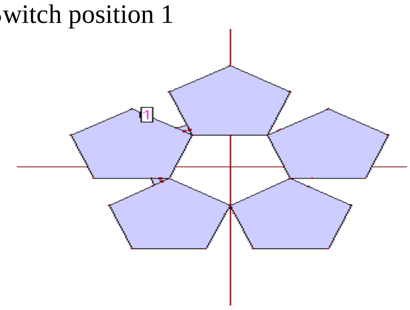

Fig.6. Switch S1 and S2 in position 1

ii) Switch position 2

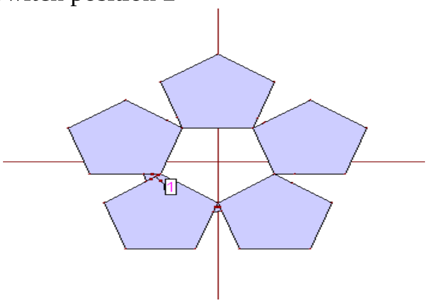

Fig. 7 Switch S1 and S2 in position 2

iii) Switch position 3

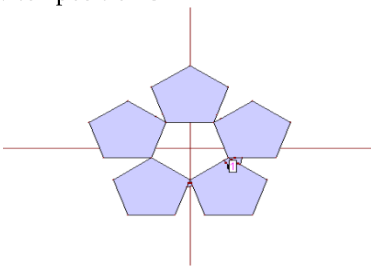

Fig. 8. Switch S and S2 in position 3

iv) Switch position 4

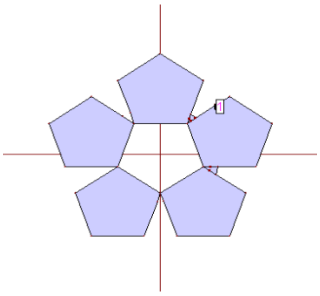

Fig. 9.Switch S1 and S2 in position 4

v) Switch position 5

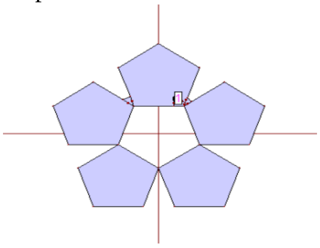

Fig. 10.Switch S1 and S2 in position 5

- *Triple Band Antenna*

In this section 3switches, S1, S2 and S3 will be used at appropriate locations in the proposed pentagon fractal patch to obtain triple band frequency response.

1. Switch position a

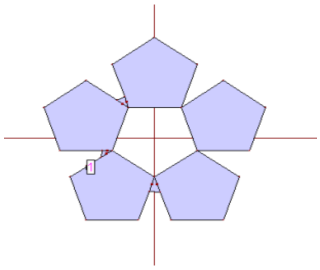

Fig. 11.Switch S1, S2 and S3 in position a

2. Switch position b

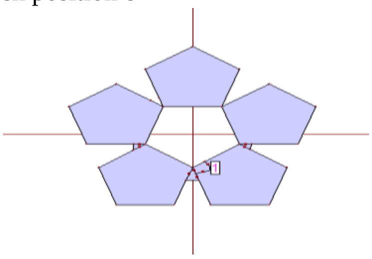

Fig. 12.Switch S1, S2 and S3 in position b

3. Switch position c

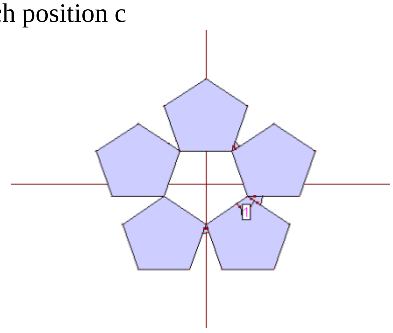

Fig. 13. Switch S1, S2 and S3 in position c

4. Switch position d

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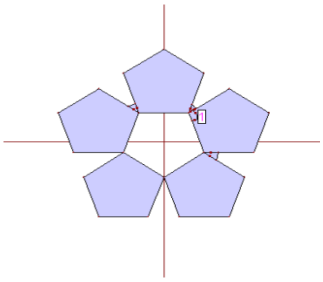

Fig.14. Switch S1, S2 and S3 in position d

5. Switch position e

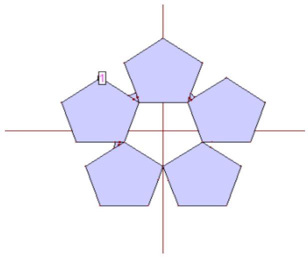

Fig.15. Switch S1, S2 and S3 in position e

IV. RESULTS

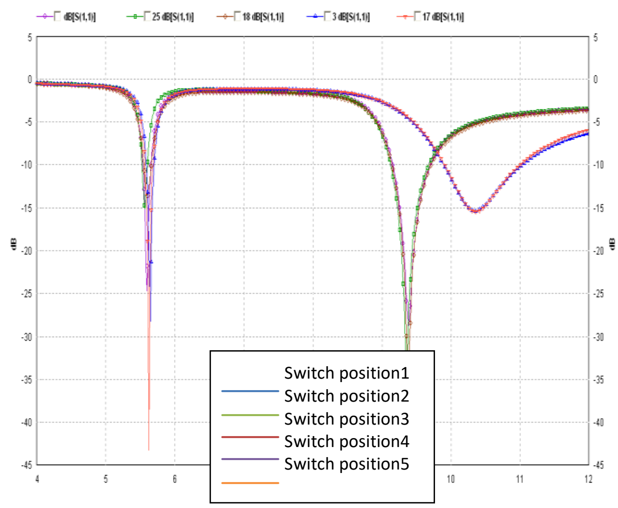

Fig.16. S11 curve for various switch positions for dual band antenna.

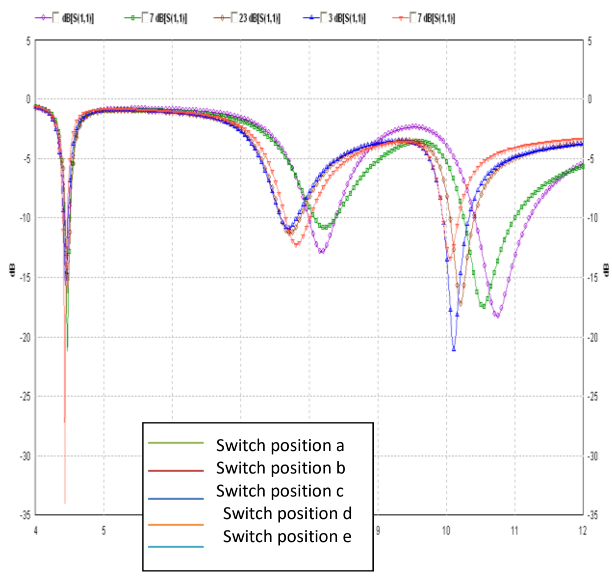

Fig.17. S11 curve for various switch positions for triple band antenna.

The pentagon shaped antenna is designed and analyzed using IE3D. It is further analyzed for fractal geometry and reconfiguration. The antenna is excited through coaxial probe feed. S-parameter, Return loss, impedance bandwidth are analyzed and the summary of all the results for dual band and triple band antenna have been shown in table II and III respectively.

Table II: Summary of Results for Single Band and Dual Band Antenna

S_N0	Resonant Frequency (GHz)	Return Loss(dB)	Frequency Range (GHz)	Impedance Bandwidth
Patch	7.5	-43.48	7.295-7.75	6.12%
Switch position 1	i) 5.63 ii)10.36	-41.07 -15.45	5.57-5.68 9.91-10.99	2.18% 10.52%
Switch position 2	i)5.56 ii)9.36	-14.96 -35.03	5.5246-5.5 9.13-9.672	1.46% 5.78%
Switch position 3	i)5.60 ii)9.38	-13.57 -35.46	5.549-5.66 9.147-9.70	2.05% 6.03%
Switch position 4	i)5.64 ii)10.36	-27.63 -15.4	5.59-5.70 9.83-11.03	2.04% 11.62%
Switch position 5	i)5.59 ii)9.38	-24.18 -28.61	5.54-5.66 9.38-9.70	1.967% 5.72%

Table III: Summary of Results for Triple Band Antenna

S. No	Resonant frequency (GHz)	Return loss(dB)	Frequency range(GHz)	Impedance Bandwidth
Switch position a	i)4.47 ii)8.22 iii)10.53	-20.9 -10.28 -17.48	4.42-4.516 8.07-8.377 10.25-11	1.83% 3.58% 6.92%
Switch position b	i)4.48 ii)7.71 iii)10.26	-11.53 -11.63 -23.73	4.44-4.51 7.59-7.86 10.05-10.41	1.65% 3.45% 3.508%
Switch position c	i)4.45 ii)7.68 iii)10.04	-23.77 -11.10 -11.49	4.409-4048 7.59-7.69 9.95-10.32	1.66% 1.38% 3.57%
Switch position d	i)4.42 ii)7.82 iii)10.05	-30.15 -12.23 -13.39	4.40-4.47 7.65-8 9.95-10.18	1.67% 4.51% 2.28%
Switch position e	i)4.46 ii)8.18 iii)10.74	-14.93 -12.85 -18.27	4.42-4.5 8-8.385 10.41-11.21	1.66% 4.71% 7.40%

V. CONCLUSION

The single band pentagon shaped patch was designed for **7.5GHz** with an impedance bandwidth of 6.12%, gain of 3.498dBi, directivity of 6.827dBi and efficiency of 46.085%. The patch was then modified for multiband performance using fractal geometry and reconfigured to produce dual band and triple band antenna. For dual band antenna, **5.4GHz (5.56-5.64GHz**) band was obtained which can be used for Wi-Fi and cordless telephone applications. **(9.36-10.36GHz)** band was obtained which can be used for military requirement for land, airborne and naval radars. For triple band antenna, **(4.42-4.48GHz)** band was obtained which can be used for C band applications.

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(7.72-8.22GHz) band was obtained which can be used by military for satellite (uplink) and in earth exploration satellite(downlink).**(10.05-10.74GHz)** band was obtained which can be used for terrestrial broadband applications.

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