AN OPTIMIZED MICROSTRIP PATCH ANTENNA BASED ON SLOTTED FRACTAL GEOMETRY USING HFSS

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***ABSTRACT*: This paper presents an improved multiband fractal geometry based, Slotted patch, Slotted ground, Microstrip patch antenna. The proposed antenna is simulated by finite element method based, Ansys HFSS 13 software. FR4 (lossy) is used as a substrate to design the final antenna. The inset microstrip line feed is used as feeding technique. After applying 2 iterations on the rectangular patch, a multiband antenna has been designed. It is further improved by slotting on patch, ground & then by adding strips to the patch. This antenna operates at C, X, Ku, K band with useful bandwidth and excellent return loss, gain, Directivity and front to back ratio.**

***Keywords*: Multiband, Fractal geometry, slotting, return loss, HFSS**

INTRODUCTION

An Antenna is a transducer that converts alternating current into radio frequency(RF) fields & vice versa. Due to planer structure, low profile, low cost and very easy fabrication, Microstrip patch antennas are very useful for wireless communication applications in the microwave frequency range. [1]

Microwave frequency range is very useful in ISM(industrial, scientific and medical) band, Mobile communication, wifi, satellite communication, broadcasting, radar communication etc., requires an antenna, which is able to perform well in multiple frequency bands.

Microstrip occupies a place in the Electromagnetic spectrum with frequency above ordinary radio waves and below infrared light, ranging from 300 MHz to 300 GHz. This range is called microwave spectrum. Bands of frequencies in the microwave spectrum are designated by letters. As per the "Radio society of Great Britain" (RSGB), microwave spectrum is divided as-

BAND NAME	FREQUENCY RANGE(GHZ)
L	1 – 2
S	2 – 4
C	4 – 8
X	8 -12
Ku	12-18
K	18-26.5
Ka	26.5-40
Q	33-50
U	40-60
V	50-75
W	75-110
F	110-140
D	110-170
	UPTO 300

These different frequency bands of above table, used in various fields of mobile and wireless communication have driven the demand of an antenna that can operate in multiple frequencies. For this purpose the Microstrip patch antenna is most suitable with its inherent capabilities such as low profile, low cost, less weight, multiband support etc.

Although they are less bulky and capable of resonating at different bands but they suffer from disadvantages like low bandwidth, low gain, poor polarization, high Q, and low efficiency. There are number of techniques for improving these drawbacks, which includes use of fractal geometry, defective ground structure, cutting slots on the patch etc. [2], [3].

The objective is to design a simple, easy to fabricate, high performance, multiband Microstrip patch antenna.
In this paper first I have designed an inset fed rectangular Microstrip patch antenna, that produces multiple bands resonating at 7.1Ghz,11.6Ghz,13Ghz and 15.7Ghz with excellent return loss. The frequencies that we are getting for this antenna,cover C, X and ku bands, which have many applications in wireless communication such as GSM, DCS, CDMA & satellite communication.

2). LITERATURE SURVEY

Further this antenna is modified to get increment in number of frequencies, over which antenna resonates. For this purpose, several methods have been applied from the literature. As we know by [4] that the full ground plane reduces the antenna capacitance because the capacitance is developed by the slots or splits in the structure. When the capacitance is raised, the resonance shifts to the higher frequencies and the inductance is increased, resonance shifts to the lower frequencies.
When the ground size is reduced to the half of its size, the capacitance is increased and the resonance shifts towards the higher frequency and when a slot is made in the half ground plane, the resonance frequency is increased,for increased capacitance effect. [4]
Further,in [5] the desired frequencies are obtained by cutting slots in the patch and impedance matching is done by providing defective ground. An increase in dielectric constant provides size reduction, for the leaky dielectric and cavity resonator type antennas.
Cutting slots in the patch increases effective length and disturb electric field. Two slots have been cut in the patch in order to generate two additional frequencies other than natural resonance of the patch. These slots increase the effective length of the patch without increasing the physical length. [5]
In [6], another method is known as fractal geometry, used to improve antenna characteristics. By using fractal geometry area of patch can be reduced. Fractal geometry provides size shrinkage and better impedance matching. It helps to get multiple bands of frequencies by applying iterations. Fractal means broken or irregular fragments. Fractal geometry increases resonance length of the patch, so current has to travel a long path and hence it helps to get multiple bands of resonance. Fractal geometry and slotted ground had been used to obtain multiband and broadband characteristics [6]
Further in [7], another method is used to enhance number of frequency bands by adding strips of different shapes and length to the patch. By adjusting the length of each strip, the desired frequency bands can be obtained. [7]
While [8], uses the technique of scaling and tight packing of strips for multiband operation. Here an L shaped probe is used, which is generating resonance due to series combination of inductance and resistance, while the patch is generating another resonance due to its parallel RLC resonant circuit type behavior. [8]
However these type of antennas are having specific characteristics and the number of bands are limited and with comparatively more return loss.
Further, in this paper, the designed inset fed rectangular Microstrip patch antenna is improved by application of fractal geometry, slotted ground, slotted patch and adding extra strips.

ANTENNA DESIGN AND RESULTS

The antenna design and simulation are done by me in Ansys HFSS 13, which utilizes finite element method for solving. The main objective of the present work is to get multiple resonant frequencies with excellent return loss. We have achieved it by applying fractal geometry and slotting on the patch & ground as well as with the use of strips on the patch.
In this antenna, FR-4 (lossy) is used as a dielectric substrate having a height of 0.07874 cm and a relative dielectric constant of 4.4. The dimension of the substrate is 2.3*2.93*0.07874cm. For the resonant frequency of 10GH, the antenna has been designed, using the standard design formulas [1].
Following are the steps, which we have followed for calculating the parameters for designing the rectangular patch antenna:

A) Width of the patch :

$$W = \frac{c}{2fr}\sqrt{2/(\varepsilon r + 1)}$$

Here,
c=speed of light
fr= operating frequency = 10GHz
Ɛr = dielectric permittivity =4.4

B) Length of the patch :

$$L = Leff - 2\Delta L$$

Here,

$$Leff = \frac{c}{2fr\sqrt{\varepsilon reff}}$$

and,

$$\varepsilon reff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2\sqrt{(1+12\times h/w)}}$$

And ΔL is calculated as

$$\Delta L = 0.412h\frac{(\varepsilon reff+0.3)(w/h + 0.264)}{(\varepsilon reff-0.258)(w/h + 0.8)}$$

Here ΔL is length extension.

C) Width of the feed :
For an impedance of 50ohm

$$A = \frac{Z0}{60}\sqrt{\varepsilon r + 1/2} + \frac{(\varepsilon r-1)(0.23*0.11/\varepsilon r)}{(\varepsilon r+1)}$$

& $$B = \frac{377\pi}{2Z0\sqrt{\varepsilon r}}$$

Hence, $$wf = 2h/\pi\{B-1-\ln(2B-1)+ \frac{(\varepsilon r-1)}{\varepsilon r*2}[\ln(B-1)+0.39+0.69/\varepsilon r]\}$$

D) Distance between Feed and lower side of antenna :

$$Li= \frac{L}{\pi} * \cos^{-1}(Z0/Rin)$$

Here,
Z0 = characteristics impedance
Rin = Resonant input impedance, when the patch is fed at the radiating edge.

Figure 1: The geometry of proposed MPA

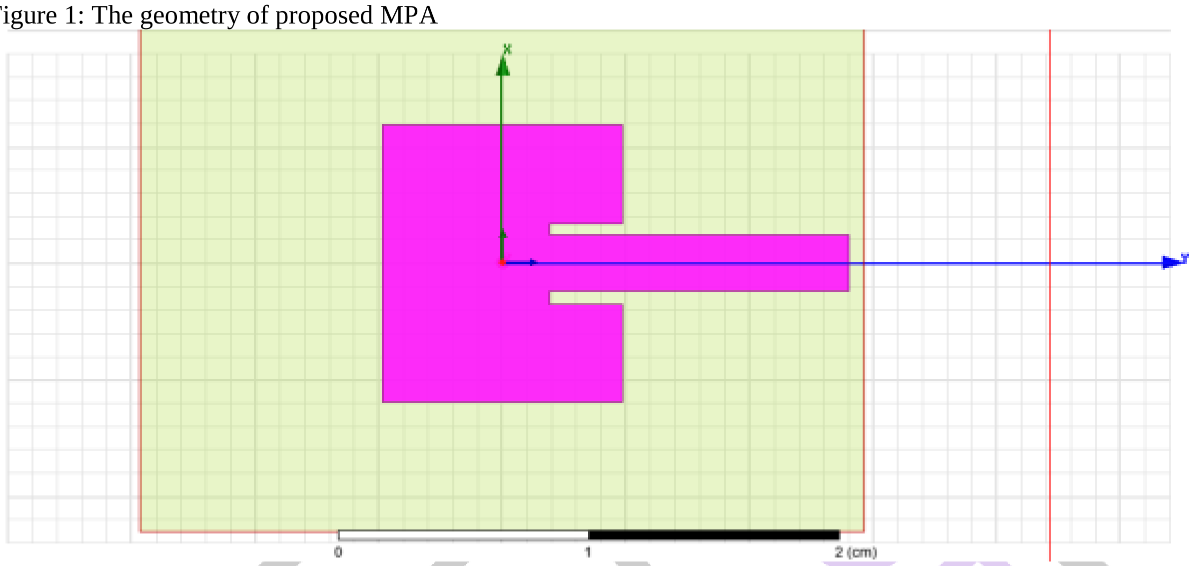


Figure 2: Dimensions of rectangular MPA

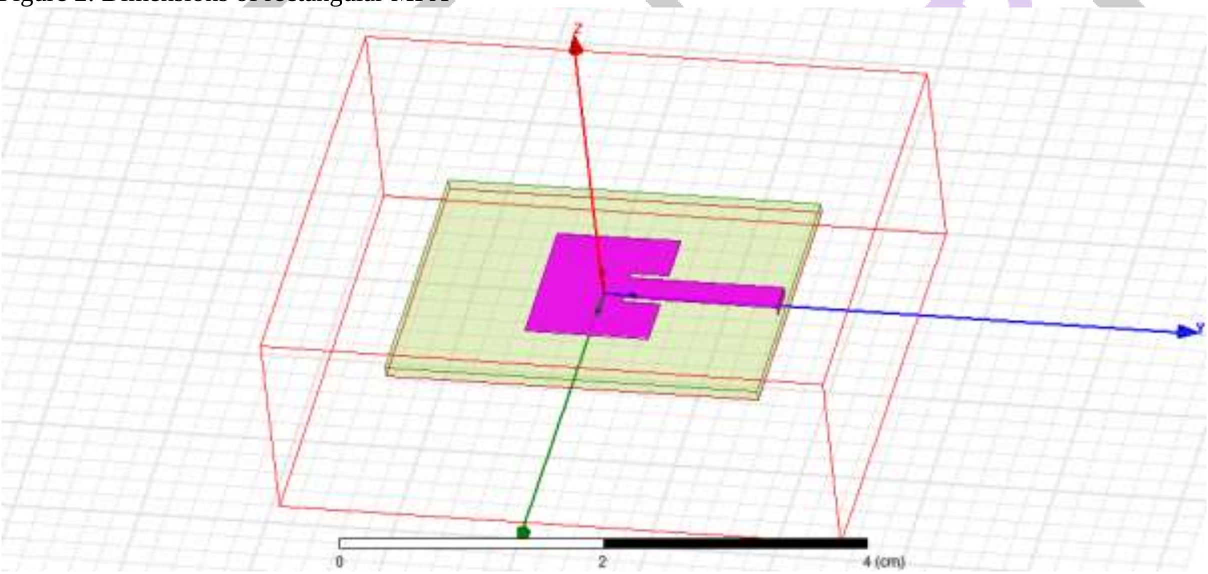
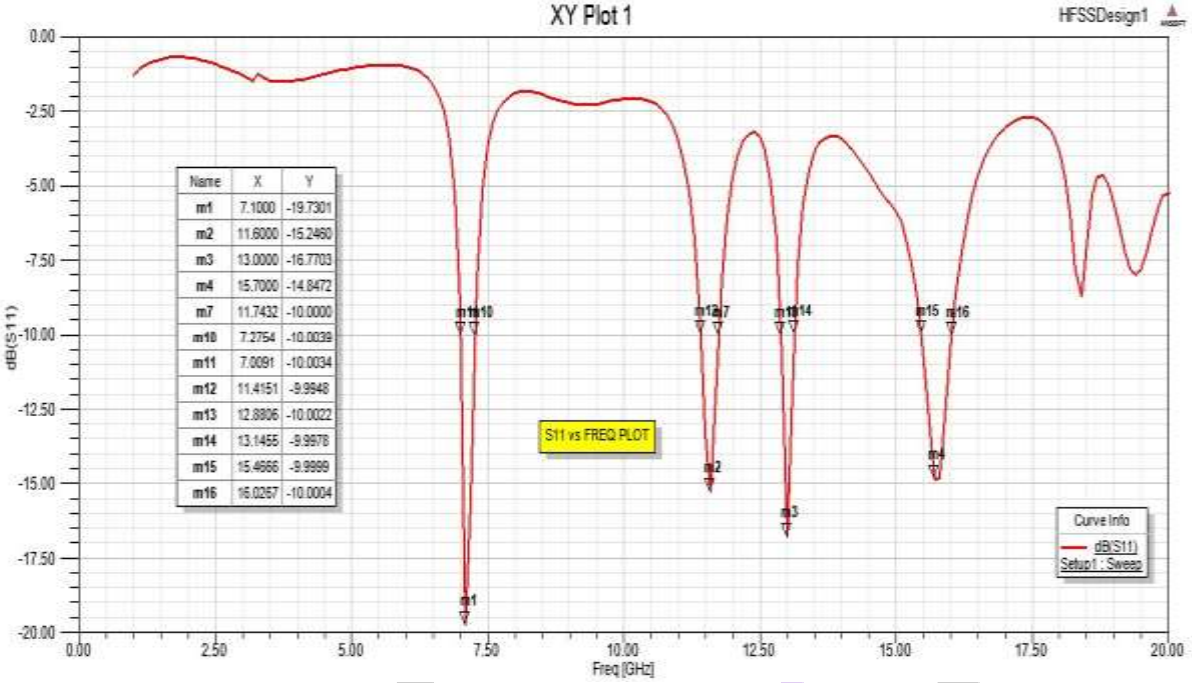


Table 1: Rectangular patch antenna parameters

Parameter	Name of the parameter	Value
wg	Ground width	2.3cm
lg	Ground length	2.93cm
h	Height of the substrate	0.07874cm
wp	Rectangular Patch width	1.19cm
lp	Rectangular Patch length	0.97cm
wf	Feed width	0.243cm
gi	Inset gap	0.05cm
li	Inset length	0.295cm
lf	Feed length	0.914cm

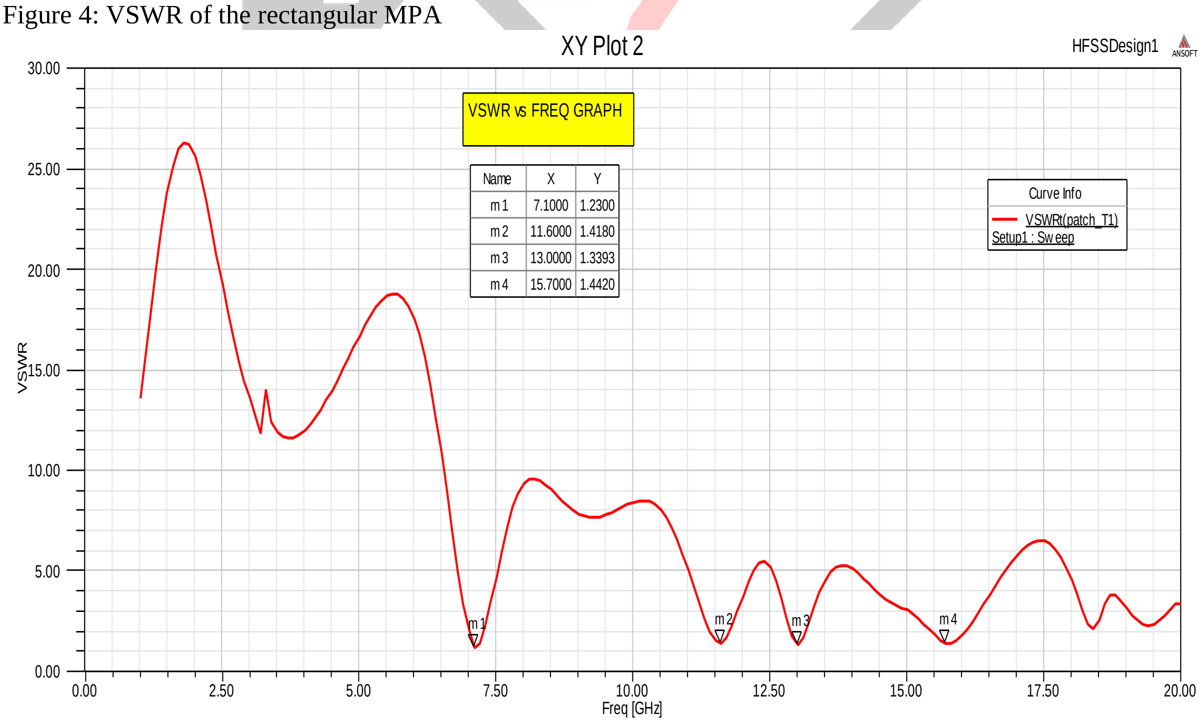
The performance of this inset fed rectangular patch antenna is analyzed by measuring S11 parameter (return loss), VSWR, Directivity, gain, E and H field radiation pattern with a frequency range of 0 to 20 GHz.
This antenna shows resonance at four different bands.
Figure 3: S11 of rectangular patch antenna



From the above figure of return loss, it is clear that the propagating wave crosses the - 10dB line four times within the range of 1 to 20GHz. The first resonance is found at 7.1GHz and the return loss is -19.73dB. The corresponding -10dB return loss bandwidth of the first resonance is 266.3MHz.
Similarly, we have calculated the bandwidth of rest of the three resonant frequencies and tabulated it below with associated return loss and band covered.
Table 2: Return loss and bandwidth of rectangular patch

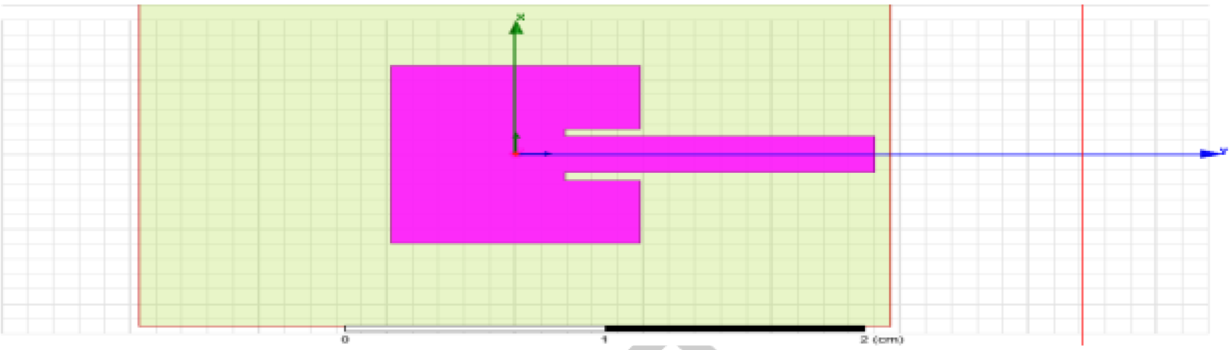
RESONANT FREQ. (GHz)	BAND COVERED	RETURN LOSS(dB)	BANDWIDTH(MHz)
7.1	C	-19.730	266.3
11.6	X	-15.246	328.1
13	Ku	-16.770	264.9
15.7	Ku	-14.847	560.1

Figure 4: VSWR of the rectangular MPA

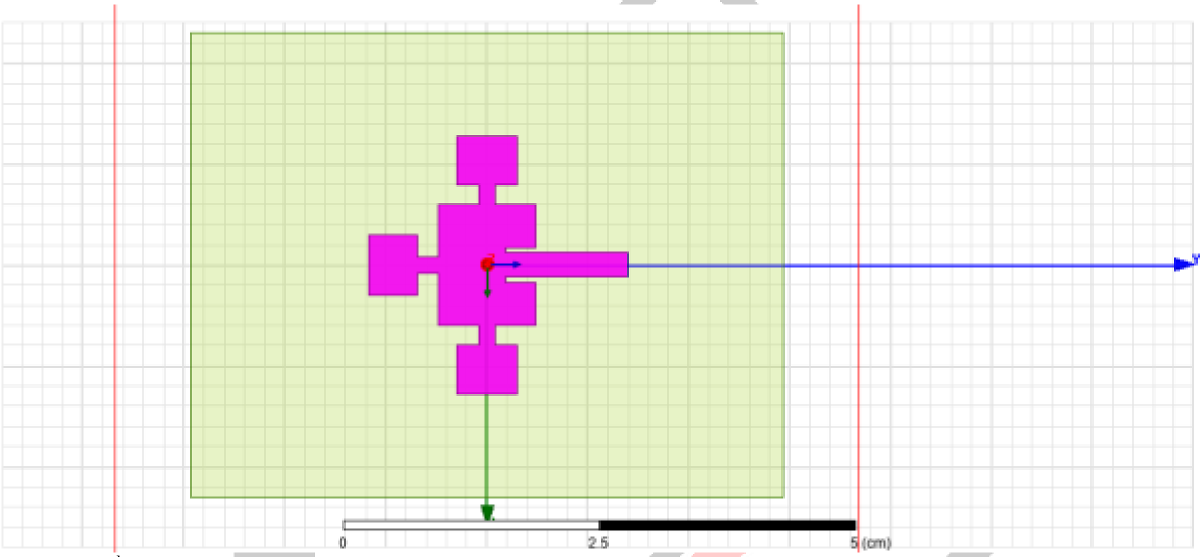


The figure 4 illustrates the VSWR parameter of the patch antenna. The propagating wave intersects the 2dB line 4 times at the resonant frequencies. Here, the VSWR values are found to be less than 2 pointing out the good matching conditions.
Since, our main concern for designing a patch antenna was multiband operation, hence to improve number of bands of this antenna, fractal geometry designing is used as it provides multiband [6].
The generation of fractal geometry based patch at different iteration stages is shown below.
Figure 5: Generation of rectangular shaped patch in 1st and 2nd iterations:

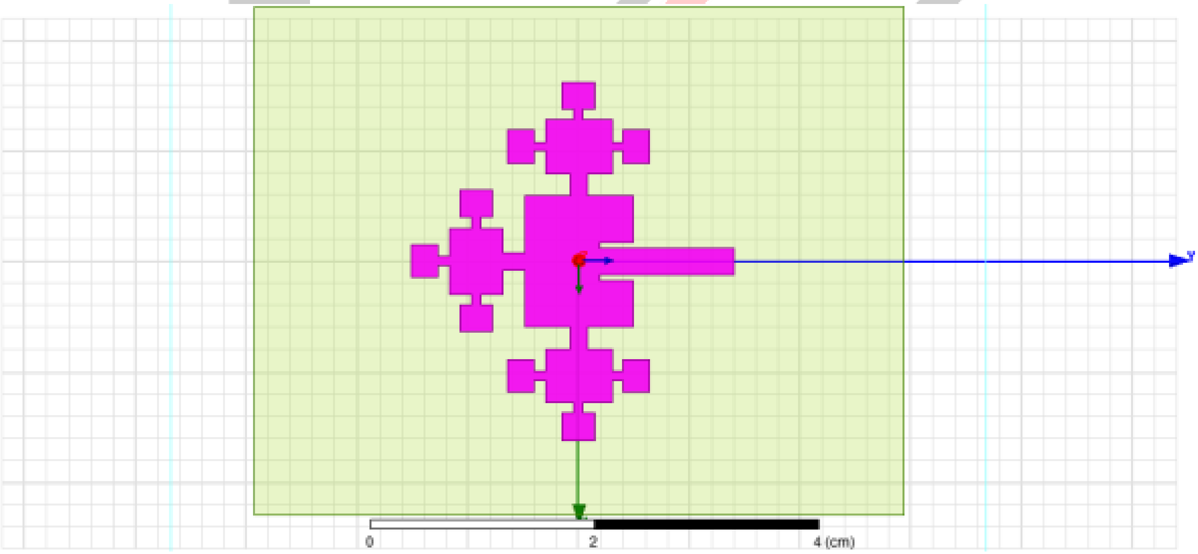
1. 0^{th} iteration:



2. 1^{st} iteration:



3. 2^{nd} iteration:



The 0th iteration shows the rectangular patch antenna, I have designed first. For the first iteration, we have reduced the size of rectangular patch antenna by the factor of 2. Hence, in the 1^{st} iteration, the length of the patch is Lp/2 & width of the patch is Wp/2. The strip connecting smaller rectangular from the main rectangle is having dimensions as wp/6 & Lp/6.
In the size of the ground, the length is doubled to cover, the whole patch. Further, in the 2^{nd} iteration, again the dimensions are reduced by a factor of 2.
After 1^{st} iteration, number of resonant frequencies is increased from 4 to 5, with improved return loss & bandwidths. The figure drawn below shows the S11 plot for 1st iteration.

Figure 6: S11 for 1st iteration

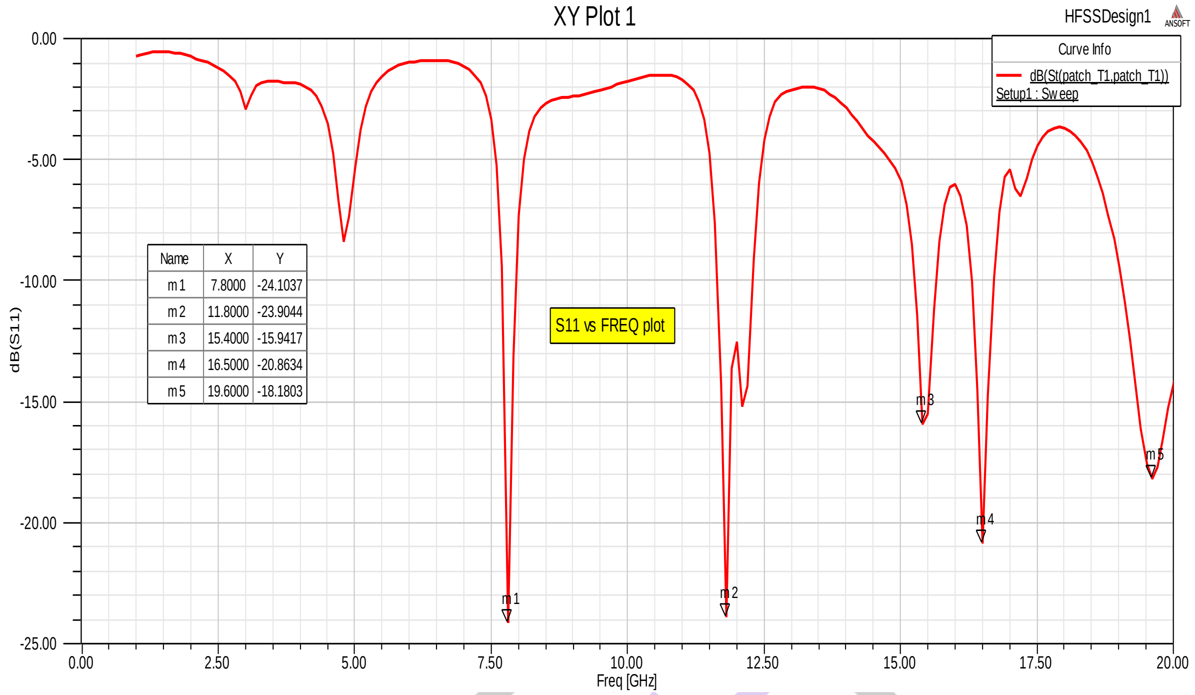


Table 3: S11 & bandwidth of the 1st iteration

RESONANT FREQ. (GHz)	BAND COVERED	RETURN LOSS(dB)	BANDWIDTH(MHz)
7.8	C	-24.1037	250.2
11.8	X	-23.9044	647.1
15.4	Ku	-15.9417	392.7
16.5	Ku	-20.8634	398.5
19.6	K	-18.1803	>963.9

To further improve number of resonant frequencies, 2nd iteration has been applied & its results are also as per the expectations. In the 2nd iterations S11 plot; we are getting 7 resonant frequencies.

Figure 7: S11 for 2nd iteration

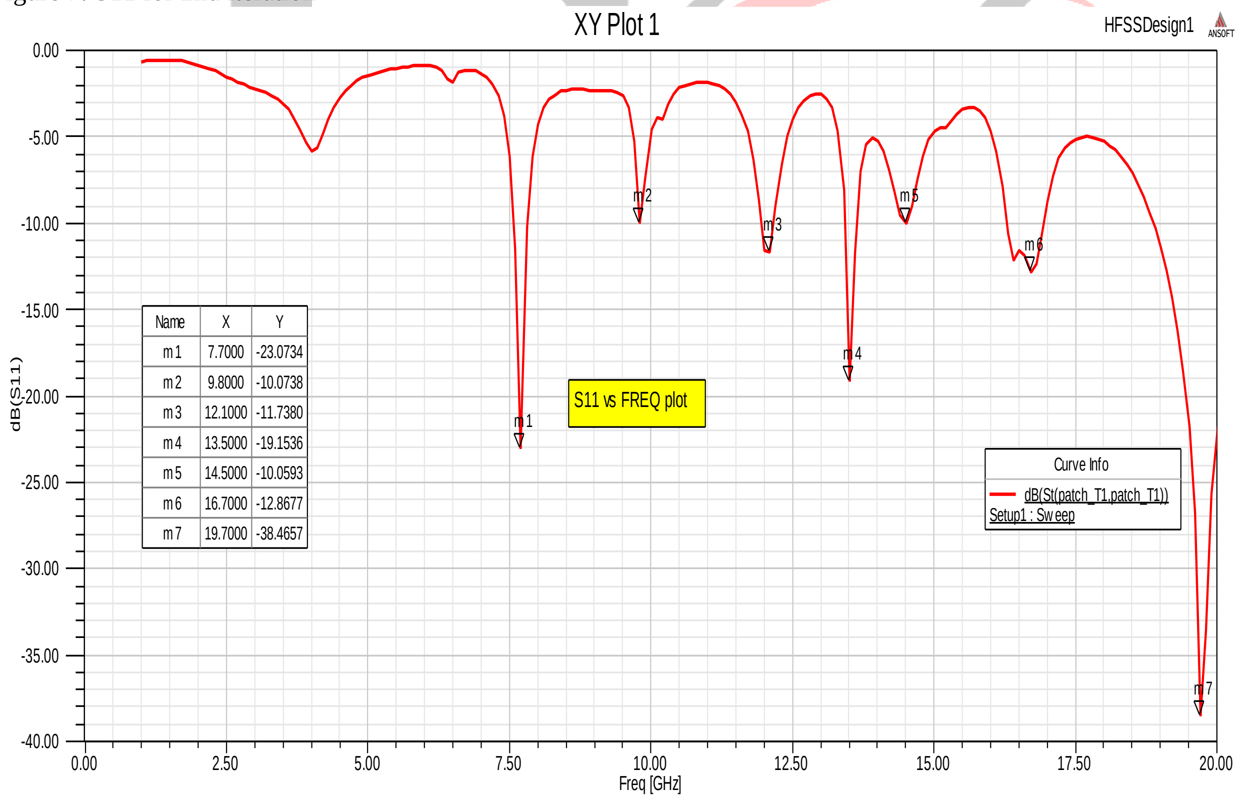
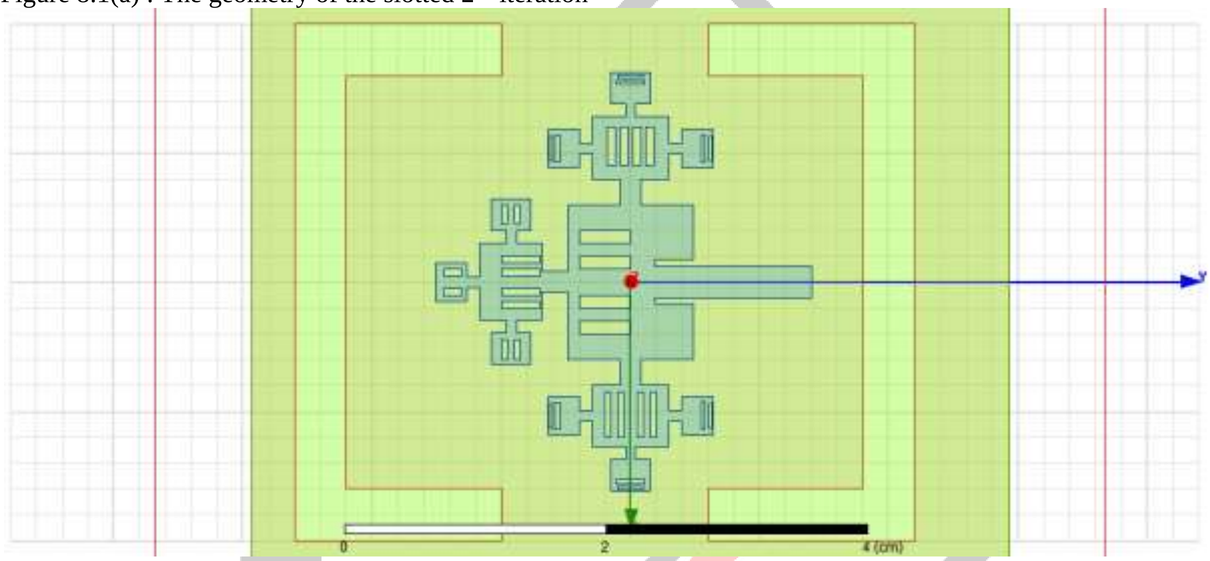


Table 4: S11 and bandwidth for the 2nd iteration

RESONANT FREQ. (GHz)	BAND COVERED	RETURN LOSS(dB)	BANDWIDTH(MHz)
7.7	C	-23.0734	234.9
9.8	X	-10.0738	nominal
12.1	Ku	-11.738	219
13.5	Ku	-19.1536	218.8
14.5	Ku	-10.0593	nominal
16.7	Ku	-12.8677	657.1
19.7	K	-38.4657	> 1134.5

Results after 2nd iteration are quite satisfied, but to improve gain & Directivity of the antenna, we have further introduced slots in the patch, as well as in the ground plane. As we know that cutting slots in the patch increases the effective length of the patch and disturbs the electric field, in order to generate additional frequencies, other than the existing resonant frequencies [5].
Slots in the patch have been cut based on parametric studies in the patch, in order to improve its performance. Specifically, the current density plot of 2nd iteration is considered and areas of patch having low current density are slotted to improve S11 as well as gain and Directivity. Along with it, the technique of ground cut has also been applied in the ground plane, which reduces the resonance frequency and size of the antenna [5].

Figure 8.1(a) : The geometry of the slotted 2nd iteration



As a result of slotting, after the 2nd iteration, number of resonant frequencies is improved to 8, with excellent return loss and bandwidth and improved Directivity and gain . Further we improved it by adding strips to the patch, resulting in 9 resonant frequencies with better return loss, gain, bandwidth and excellent front to back ratio. The design and results are shown below.

Figure 8.1(b) : The geometry of the final design of MPA

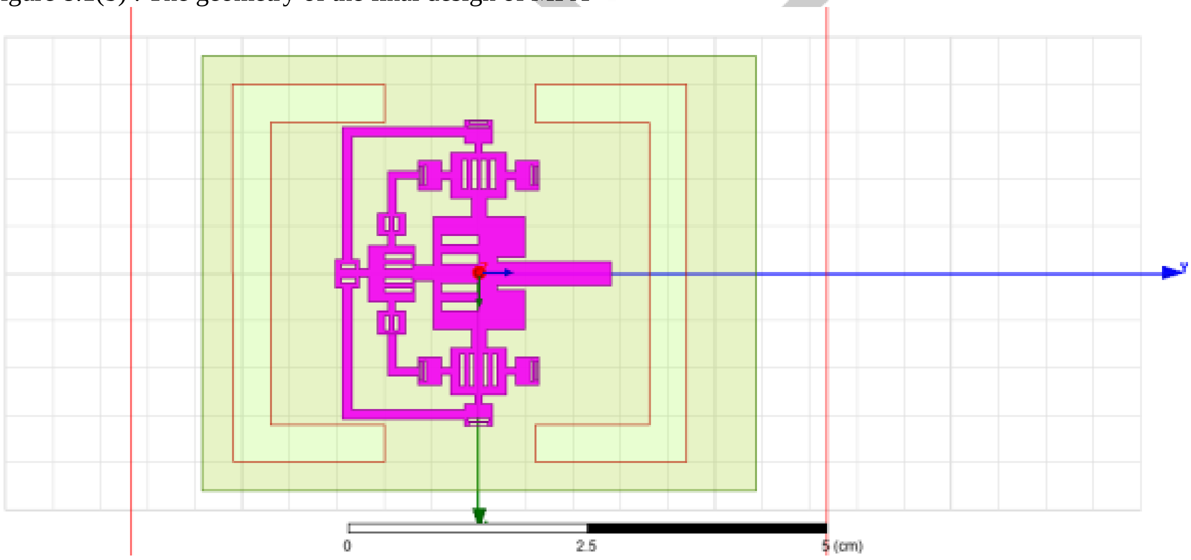


Figure 8.2: S11 of slotted 2nd iteration patch

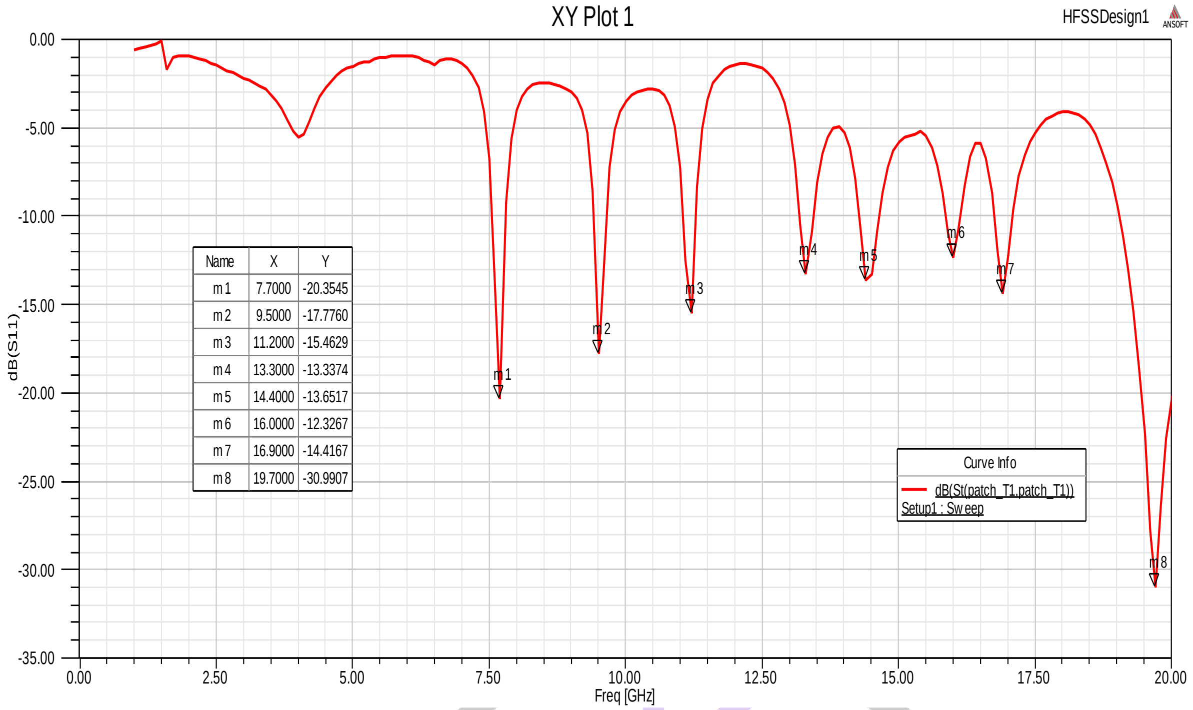


Table 5: S11 & bandwidth of 2nd iteration after slotting in the patch and ground

RESONANT FREQ. (GHz)	BAND COVERED	RETURN LOSS(dB)	BANDWIDTH(MHz)
7.7	C	-20.3545	243.7
9.5	X	-17.7760	232.5
11.2	X	-15.4629	224.6
13.3	Ku	-13.3374	247.9
14.4	Ku	-13.6517	362.2
16	Ku	-12.3267	273.1
16.9	Ku	-14.4167	344.7
19.7	K	-30.9907	>968.4

To further improve, front to back ratio, as well as gain of the patch, strips are added in the design of the patch, making the results excellent in form of number of resonant frequency, gain, Directivity, VSWR, return loss, front to back ratio as well as bandwidth. The results are shown below:

Figure 9: S11 for the final design of the patch

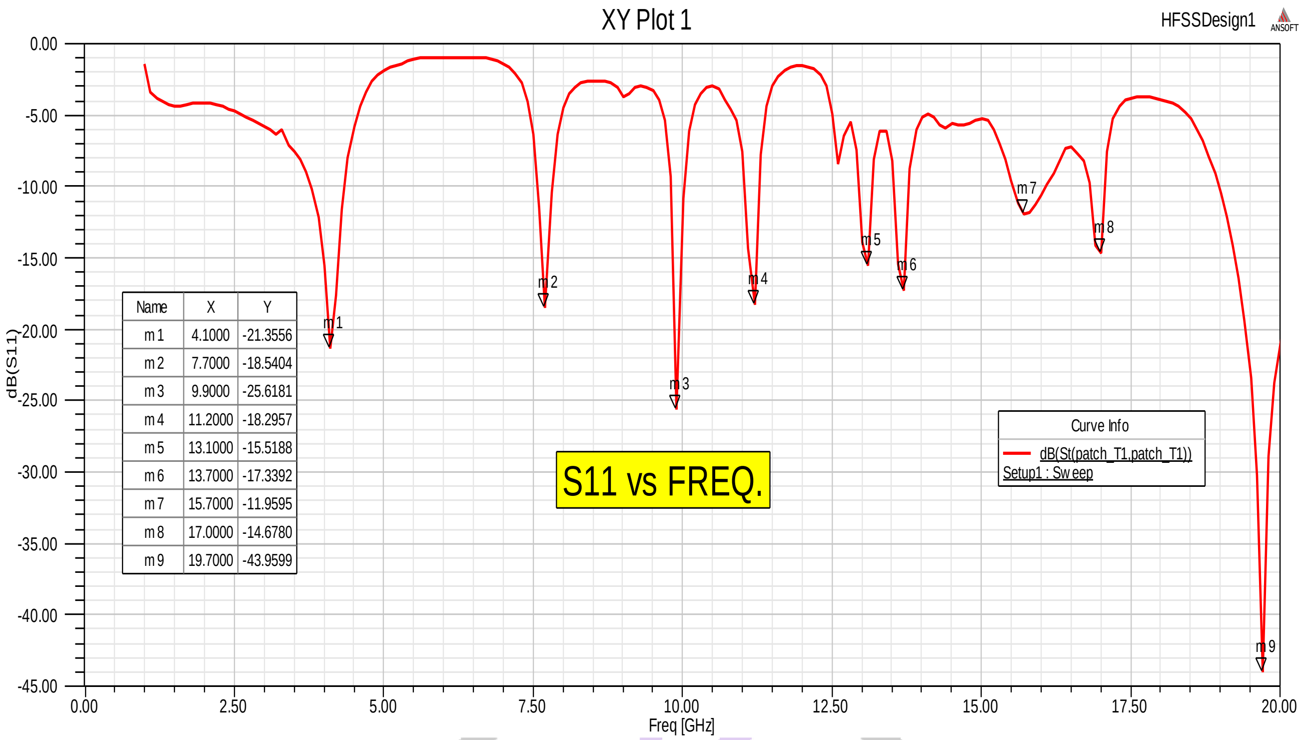


Figure 10: Gain vs. freq. plot for the proposed antenna

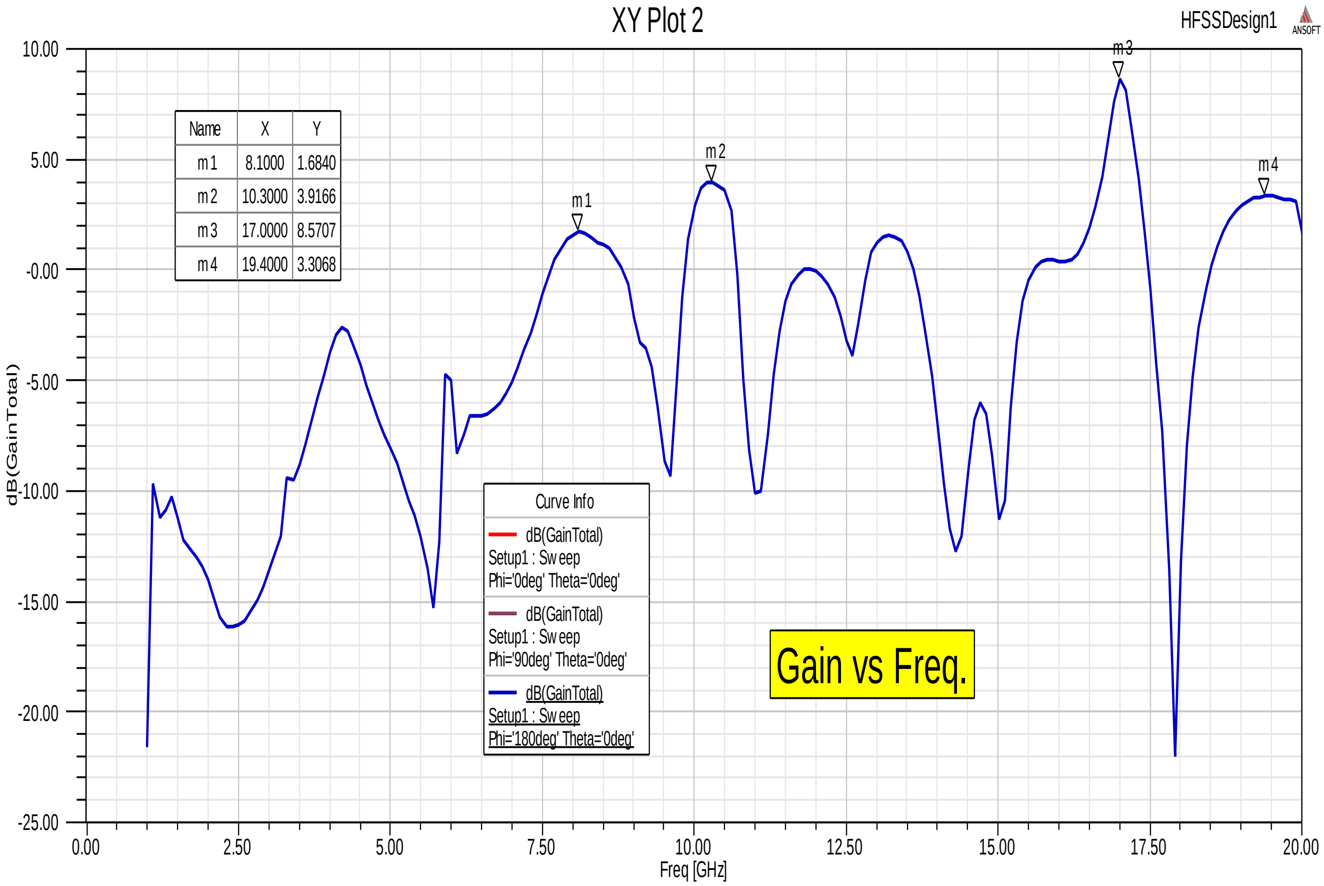


Figure 11: VSWR plot

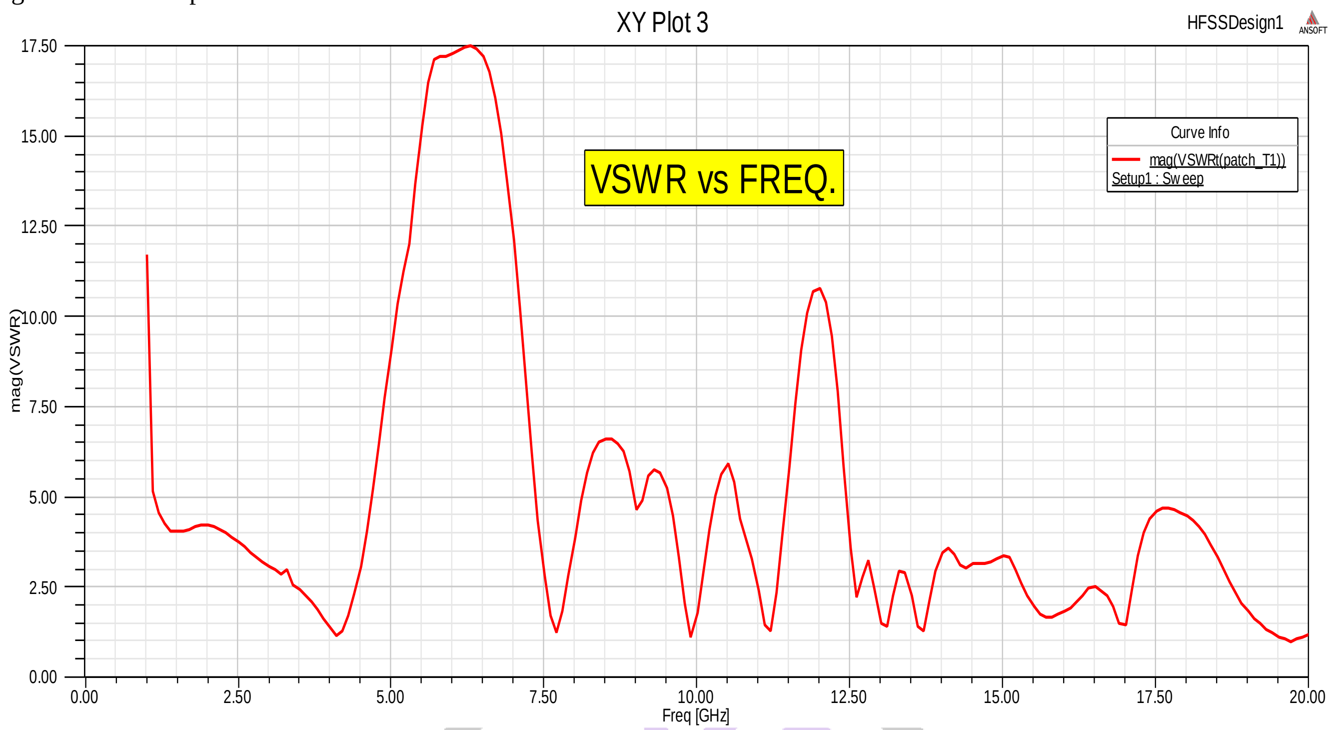


Table 6: S11 and bandwidth of the final design

RESONANT FREQ. (GHz)	BAND COVERED	RETURN LOSS(dB)	BANDWIDTH(MHz)
4.1	C	-21.3556	565.7
7.7	C	-18.5404	238.7
9.9	X	-25.6181	213.3
11.2	X	-18.2957	243.9
13.1	Ku	-15.5188	240.7
13.7	Ku	-17.3392	261.7
15.7	Ku	-11.9595	528.2
17	Ku	-14.6780	262.1
19.7	K	-43.9599	>1028.2

Table 7: Performance comparison between proposed and some existing antennas

REFERENCES	BANDS COVERED	BANDWIDTH(MHz)	APPLICATIONS
[4]	C, X, Ku & K	358,537,445,1553,1036,2182	WLAN, C-BAND,SATELLITE COMMUNICATION
[5]	S & C	NOMINAL	WIFI,BLUETOOTH & WIMAX
[6]	C & X	150,135,520,1200	DEFENCE COMMUICATION SYSTEMS, SATELLITE COMMUNICATION, RADAR
[7]	L & S	800, 230	GSM, WLAN, ISM BAND APPLICATIONS
[8]	S & C	510,1025	MOBILE COMMUNICATION, ANTENNA ARRAY DESIGNING
PROPOSED ANTENNA	C,X, Ku & K	565.7,238.7,213.3,243.9, 240.7,261.7 528.2,262.1,1028.2	ISM BAND,WLAN, C-BAND,SATELLITE COMMUNICATION, RADAR

CONCLUSION AND FUTURE SCOPE

In this paper, from above discussion, it has been concluded that by applying different iterations of fractal geometry, Slotting the patch and ground and then adding strips to the patch, characteristics of the antenna has been improved a lot. Initially rectangular patch is taken and antenna resonates at 4 frequencies. By applying iterations of fractal geometry, number of resonant frequency increases from 4 to 9. Further by applying fractal geometry and then by slotting the patch and ground, the effective area has been decreased and gain and Directivity as well as bandwidth gets increased.

Proposed antenna finds applications for defense and secure communication, C band, X band, Ku band and k band. In these bands antenna can be used for satellite communication and Radar applications. In future Meta materials can be applied to this antenna which may further improve its characteristics of antenna.

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