Bandwidth Enhancement through Fractals and Stacking of Microstrip Antenna for Ku-Band Applications

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Abstract-One of the major constraints of a microstrip antenna is its narrow bandwidth. This paper demonstrates the influence of a dual layer staked configuration with the effect of fractal designs on a microstrip square patch antenna, for attaining both wide bandwidth and high gain properties. The proposed design of the antenna in stacked structure shows a total impedance bandwidth for S11<-10dB of 2.56GHz (18.97%) in Ku-band for satellite communication and has dual frequency bands from 11.53GHz to 13.15GHz (1.62GHz) and 15.63GHz to 16.57GHz (0.94GHz) around the resonant frequencies of 12.31GHz and 16.19GHz respectively. The intended design exhibits a 6.39dB gain whereas the radiation efficiency is up to 93.60%.These qualities of wide bandwidth and higher efficiency make the proposed antenna an excellent candidate for satellite based applications.

Keywords-Stacked, Bandwidth, Gain, Radiation Effeicieny.

I. INTRODUCTION

In view of the growing importance and development in wireless communication system, high gain microstrip antennas with broad bandwidth are in great demand for commercial, military and domestic applications. These microstrip patch antennas when compared with other conventional antennas, has great advantages and are associated with improved prospects due to their appealing features like low profile, conformal shape, smaller in dimension, low volume, very lighter in weight and being easy to manufacture [i]. Besides this, these antennas can provide high radiation efficiency, operation in multiband frequencies, flexibility in selecting feed network and can give dual and circular polarization.

Besides all of the advantages mentioned, microstrip antennas have major limitations of low gain and very low impedance bandwidth [ii]. To overcome and tackle these limitations of microstrip antenna, the parameters like length, width, thickness, feeding network configuration of the patch and overall antenna design must be reconfigured in terms of dimensions, structure and material.

A profound understanding and literature survey has been done on the existing information related to the topic. The review of the related literature survey comprises of three major areas of reading which includes; the design of antenna, methods of improving antenna gain, bandwidth and overall performance, and the operation of microstrip antenna in satellite communication bands.The recent efforts by the researchers around the globe is to increase the bandwidth, gain and radiation efficiency of the patch antenna and keeping the fabrication process easy and cost effective.The solution for improving these constraints include several methods like the use of multiple resonators [iii], employing stacking structure configuration [iv], using array configurations [v], increasing the thickness of dielectric substrate [vi], using slots in the antenna geometry [vii], selecting low dielectric constant of the substrate [viii], employing fractal designs [ix] and by improving the impendence matching of microstrip patch antenna [x].

The concept of introducing fractals and multilayer stacking structure in the proposed design is to enhance the gain and the bandwidth and to improve the overall performance of the patch antenna.In dual layer stacking structure configuration, a second parasitic patch is created in front of the feeding patch and both the patches are coupled electromagnetically at certain distance resulting a dual frequency band which results in bandwidth enhancement [xi].The geometry of fractal antenna possesses recursive self-similar fragmented design pattern that is reduced or subdivided by certain mathematical relation. This fragmented self-similar geometrical pattern enhances the total effective electrical length of antenna which provides better prospects in terms of high gain and enhanced bandwidth [xii].

In this work, a microstrip patch antenna with the effect of fractal patches and influence of dual layer staked structure, for achieving high gain and wide bandwidth properties, is proposed and analyzed for the operating frequency in Ku-band of satellite communication using the CST microwave studio.

II. ANTENNA CONFIGURATION

The proposed antenna design has been created on a "loss-free preperm 255" having relative dielectric constant $\varepsilon_r = 4.5$ with substrate thickness of 1.60mm. The ground plane material is made up of pure copper having dimensions as follows; ground plane length g-L=60.00mm, ground plane width g-W=60.00 mm and copper thickness t=0.035mm. The antenna is fed with a 50Ω coaxial cable 3.35mm along x-axis from the center of the patch. The 15GHz has been chosen as the center frequency for the proposed design to work in the Ku-band of satellite communication bands.

A. Basic Square Patch

The design specifications of the basic square patch antenna are specified in Table I.

TABLE I.
DESIGN DESCRIPTION OF SQUARE PATCH ANTENNA

Parameter Description	Description	Value
g-L	Length of ground plane	60 mm
g-W	Width of ground plane	60 mm
t	Thickness of copper	0.035 mm
h	Substrate thickness	1.6 mm
L	Antenna Length	12.52 mm
W	Antenna width	12.52 mm
Coax-x	Coaxial distance from the center along x-axis	3.5 mm
Coax-y	Coaxial distance from the center along y-axis	0.0 mm
Coax-L	Coaxial length along z-axis	-5.0 mm
epsilon	Dielectric constant value	4.5

The Figure 1 illustrates the dimensions of the basic square patch which are 12.52x12.52x0.035 mm.

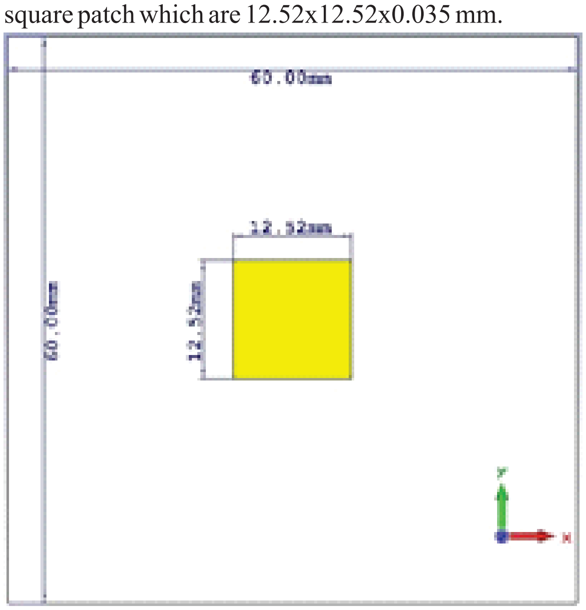

Fig. 1: Square patch antenna

B. Design Specification of Fractal structure

The idea of fractal design employed in the proposed antenna is to improve the bandwidth and gain of the proposed antenna. The geometry of fractal design describes irregular shape reduced or subdivided by certain mathematical relation. An arithmetic algorithm is used in the proposed design to produce effective fractal structure which is created iteratively by cutting every corner side of the patch in a specific span ratio of 1:5 about its parent segment, and so on.

1) 1st Iteration of Fractal Patch: In 1st fractal iteration, the length of four sides of the square patch is cutoff in the ratio of 1:5 and is detached from the parent patch. A specific length of 2.50mm is cutoff and etches out from every corner of each side of length of 12.52mm so a volume of 4x(2.50x2.50x0.035) mm is reduced in first level of iteration. The first iteration of fractal antenna is depicted in figure 2.

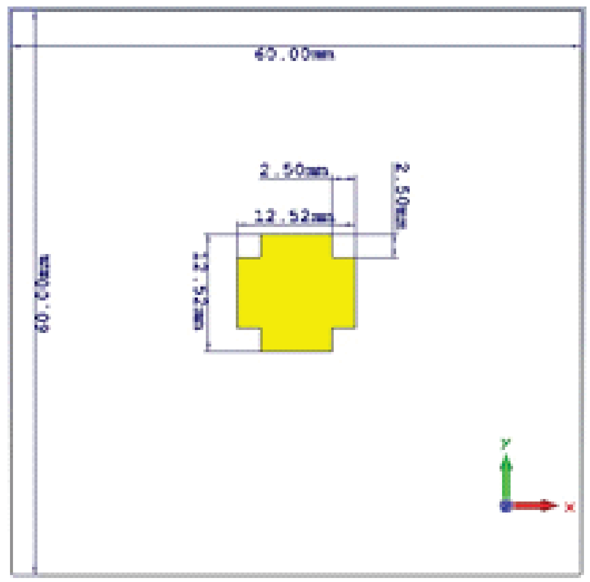

Fig. 2: 1st iteration of fractal patch

2) 2nd Iteration of Fractal Patch: The arithmetic algorithm used in 1st iterated fractal patch is also used in second level of iteration to further reduce the fractal patch by cutting each corner of every side in a specific ratio of 1:5. All the parameters and design specifications of the 2nd iteration are set to be the same as the first one. The figure 3 illustrates the second iteration of fractal patch which shows that a length of 0.5mm is further etched out from every corner side of first iterated fractal patch, that is, a total volume of 8x(0.50x0.50x0.035) mm is further cut off from its parent patch (first iterated fractal patch).

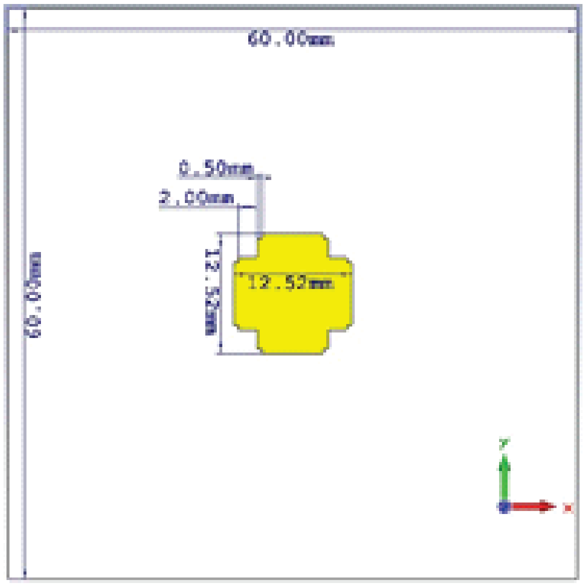

Fig. 3: 2nd iteration of fractal patch

C. Design Specification of Stacking Structure

The stacking structure configuration used in the proposed antenna design is for the improvement in the performance of antenna especially to further increase the impedance bandwidth of the antenna. The proposed design applies a two layer stacking structure containing the radiation patch and the parasitic patch which is coupled electromagnetically at a distance of fh_z=2.65mm as shown in the figure 4.

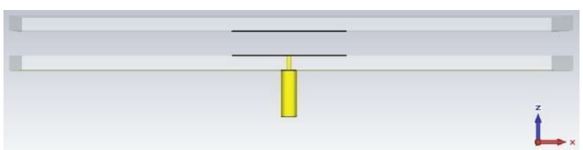

Fig. 4: Side view of stacked configuration

III. Results And Discussion

In this section, the simulated results of proposed antenna are analyzed and discussed. All the three geometrical designs, which is basic square patch, 1st iterated patch and the 2nd iterated patch with/without the influence of dual layer staked configuration has been simulated and discussed in this section.

A. Basic Square Patch

Figure 5 illustrates the simulated frequency response of the square patch at 15GHz and the far-field gain pattern is shown in figure 6. The result demonstrates that the impedance bandwidth for S11<-10dB is 0.50GHz (3.38%) from 14.66GHz to 15.16GHz, At the working frequency 15GHz, the square patch antenna gives a gain of 9.88dB and radiation efficiency of 94.84%.

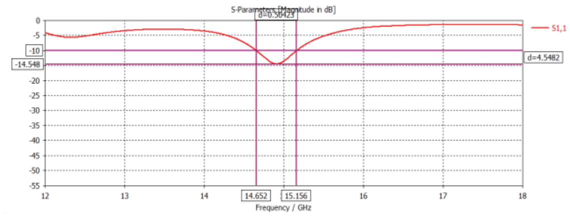

Fig. 5: Frequency response of square patch antenna

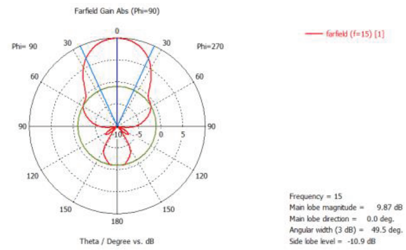

Fig. 6: Gain of square patch antenna

1) Effect of Stacking:As illustrated in figure 4, in order to apply the impression of stacking structure, a parasitic patch of same dimensions and material properties as that of radiated square patch has been introduced and are coupled electromagnetically at a distance of 2.65mm for bandwidth enhancement. Figure 7 demonstrates that the basic square patch when employed in stacking configuration exhibits dual frequency bands from 11.70GHz to 12.50GHz and 14.95GHz to 15.54GHz. The antenna has the total bandwidthof 1.97GHz (10.36%) in Ku band. The dual frequency bands have a bandwidth of 0.79GHz (6.49%) and 0.59GHz (3.87%) around the resonant frequencies of 12.09GHz and 15.19GHz respectively and the impedance bandwidth has been increased from 0.50GHz (3.38%) to 1.98GHz (10.36%). This configuration gives a gain of 7.37dB and 93.56% radiation efficiency as shown in figure 8.

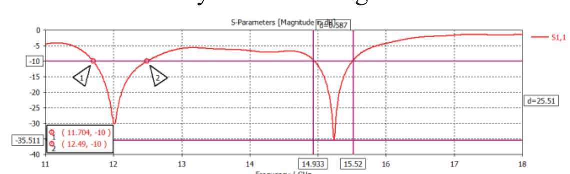

Fig.7: Frequency response of stacked square patch antenna

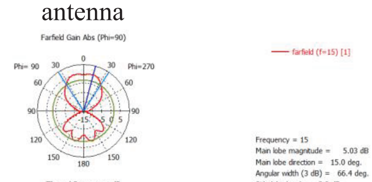

Fig. 8: Gain of stacked square patch antenna

b. 1st Iteration of Fractal Patch

The results in figure 9 and 10 illustrates the effect of 1st fractal level of iteration on the square patch and it is observed that impedance bandwidth of the fractal antenna is improved to 0.75GHz (4.66%), which is 0.25GHz (1.27%) wider than the bandwidth achieved with basic square patch where as the gain of the fractal iterated patch is increased to 10.10dB from 9.89dB.

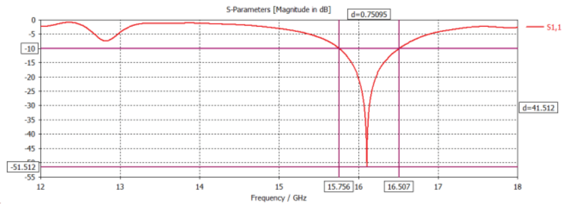

Fig. 9: Frequency response of 1st iterated fractal patch

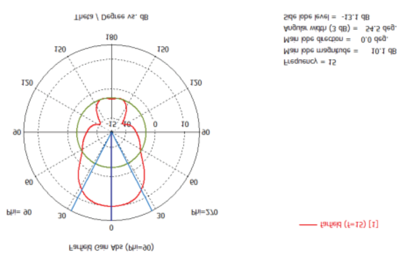

Fig. 10: Gain of 1st iterated fractal patch

1) Effect of Stacking: The 1st iterated parasitic and radiation patch of same fractal design (1st iterated) has been gap coupled in stacking configuration at a distance of 2.65mm. This antenna in stacked structure shows a total bandwidth of 2.56GHz (18.97%). The figure 11 shows that this configuration exhibits two bands of operation from 11.53GHz to 13.15GHz (1.62GHz) and 15.63GHz to 16.57GHz (0.94GHz) around the resonant frequencies of 12.22GHz and 16.21GHz respectively. It is observed that impedance bandwidth for S11<-10dB is 18.98% which is much wider than that achieved in 1st iteration of fractal patch without stacking structure whereas, the gain and radiation efficiency is decreased to 6.38dB and 93.58% respectively.

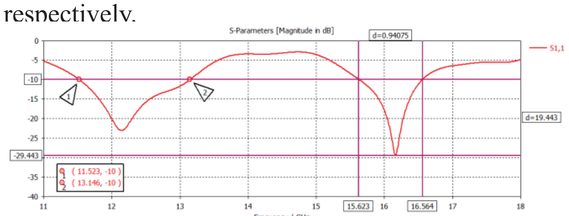

Fig. 11: Frequency response of 1st iterated fractal patch in stacked structure

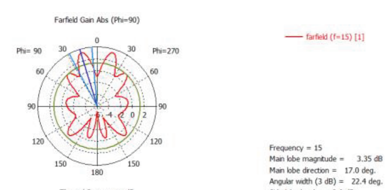

Fig. 12: Gain of 1st iterated fractal patch in stacked structure

C. 2nd Iteration of Fractal Patch

The arithmetic algorithm used in 1st iterated fractal patch is also used in second level of iteration and all the parameters and design specifications of the 2nd iteration are set to be the same as the first one. The figure 13 demonstrates the variation of return loss with frequency for 2nd iterated fractal patch. The result shows that the gain of the antennais increased to 10.13 dB whereas the bandwidth achieved is 0.80GHz (4.89%) which is 0.30GHz wider than that achieved for basic square patch.

The comparison of figure 5, figure 6, figure 9, figure 10, figure 13 and figure 14 demonstrates that the change in radiation patterns that comes from the fractal iteration is almost negligible whereas significant increase in impedance bandwidth is observed as the number of iteration increases. However, for iterations greater than two levels, the antenna design becomes relatively complex and its fabrication process becomes very complicated.

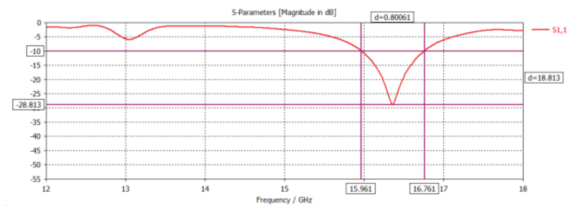

Fig.13: Frequency response of 2nd iterated fractal patch

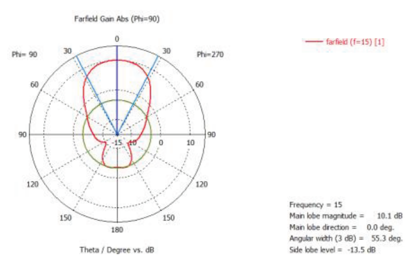

Fig.14: Gain of 2nd iterated of fractal patch

1) Effect of Stacking:A 2nd iterated radiated patch and parasitic patch has been introduced at a distance of 2.65mm in stacking configuration which gives the total bandwidth of 2.44GHz (17.96%) with a gain of 6.32dB in Ku band. This antenna has dual frequency bands from 11.78GHz to 13.41GHz (1.63GHz) around the resonant frequency of 12.55GHz and 15.72GHz to 16.53GHz (0.81GHz) around the resonant frequency of 16.24GHz respectively. It is observed that impedance bandwidth for S11<-10dB is 17.96% which is much wider than that achieved in 2nd iteration of fractal patch without stacking structure and slightly lesser than 1st iterated stacked fractal antenna.

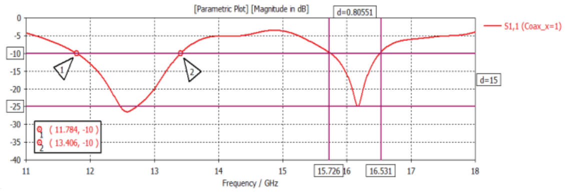

Fig. 15: Frequency response of 2nd iterated fractal patch in stacked structure

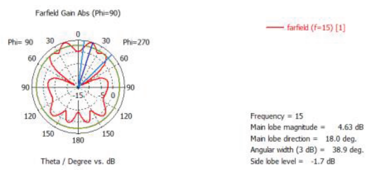

Fig.16: Gain of 2nd iterated fractal patch in stacked structure

IV. Comparison of Results

Table II demonstrates a comparative examination between various geometrical configurations of single microstrip patch.

TABLE II.
COMPARATIVE ANALYSIS BETWEEN VARIOUS PROPOSED CONFIGURATIONS

Geometry	Bandwidth	Radiation Efficiency	Gain
Basic square patch	15.16GHz - 14.66GHz = 0.50GHz =3.38%	94.84%	9.87dB
Basic square patch in stacked structure	12.49GHz - 11.70GHz = 0.78 GHz =6.50% 15.52GHz - 14.93GHz = 0.58GHz =3.85%	93.56%	7.36 dB
1st iteration of fractal patch	16.50GHz - 15.75GHz = 0.75GHz=4.65%	95.40%	10.10 dB
1st iteration of fractal patch in stacked structure	13.15GHz - 11.53GHz = 1.62GHz =13.15% 16.57GHz -15.63GHz = 0.94GHz =5.84%	93.60%	6.39 dB
2nd iteration of fractal patch	16.76GHz -15.96GHz = 0.80GHz =4.89%	94.63%	10.11 dB
2nd iteration of fractal patch in stacked structure	13.41GHz - 11.78GHz = 1.63GHz =12.94% 16.53GHz - 15.72GHz = 0.81GHz =5.02%	96.99%	6.32 dB

V. Conclusions.

The effect of a dual layer staked structure configuration with the influence of fractal designs on a microstrip square patch antenna fed with 50Ω coaxial cable, for attaining both wide bandwidth and high gain properties, is proposed and analyzed for Ku-band of satellite communication.

It is observed that using the stacked configuration and fractal patches in microstrip antenna, it has great impact on the impedance bandwidth, gain and efficiency of the proposed antenna. The result reveals that with the increase in fractal iteration level, the impedance bandwidth of the antenna also increases. The arithmetic algorithm used in the proposed design which is created iteratively by cutting every corner side of the patch in a specific length ratio of 1:5 about its parent segment, provides a high flexibility to achieve wide bandwidth and high gain properties while maintaining the radiation efficiency high in the operating frequency band. Moreover, the concept of stacked configuration used in the proposed design is for the improvement in the performance of antenna especially to further improve the impedance bandwidth.

The result shows that 2nd iteration of fractal patch is the optimum design among un-stacked configuration, whereas in stacked configuration the 1st iterated fractal patch gives optimum results in terms of gain, impedance bandwidth and radiation efficiency.

The results of 2nd iterated fractal patch demonstrates that the gain of the antennais 10.13 dB with 94.64% radiation efficiency whereas the impedance bandwidth for S11<-10dB achieved is 0.80GHz (4.89%) which is 0.30GHz wider than that achieved for basic square patch. The 1st iterated fractal antenna in stacking structure shows a total impedance bandwidth of 2.56GHz (18.97%) and exhibits dual band of operation from 11.53GHz to 13.15GHz (13.12%) and 15.63GHz to 16.57GHz (5.86%) around the resonant frequencies of 12.31GHz and 16.19GHz respectively, whereas the gain is 6.38dB, and the radiation efficiency is up to 93.60%.

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