Octagonal Shaped Fractal Slot Loop Antenna Loaded with Dielectric Resonator

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***Abstract*---This paper presents the design and fabrication of multiband fractal co-planer waveguide (CPW)-fed slot antenna having defected ground structure (DGS) which confirms the multiple wireless standards. Minkowski fractal geometry is applied on an octagon which provides a miniaturized design and generates multiple bands. Defected ground structure is used to improve the bandwidth and gain of the antenna. The slot loop formed is acting as a hybrid antenna as it performs both the task of antenna and also of a feed mechanism which is required by a dielectric slab to radiate. The proposed antenna exhibit multiple frequency bands, thus we can call it as multi-band antenna.**

***Keywords* --- dielectric loading, slot antenna, fractal antenna, multiband antenna, defected ground structure, CPW-feed, return loss**

I.INTRODUCTION

In today's world, we require greater bandwidth for voice and data application in mobile communication world. Number of frequency bands is also increased, as there is different band for different application. It is very difficult to employ different antenna for different band as in today's world devices, a single devices needs to perform various applications, therefore we require multi-bands antennas which can satisfy our need. Different designs are proposed by number of researchers, which provide different techniques aiming multiband antenna [1]-[5], but the best and most popular ones is etching slots out of ground plane or patch [1]-[3], in short we call it as 'slot antenna'. In slot antenna, the effective radiating aperture is reduced; therefore lower gain value is obtained. There are many other methods for increasing the bands like stacking of patches, reactive loading using shorting pins, fractal antenna etc. [4]-[6]. However fractal shaped antenna is the best method in our case as it reduces the overall size of the antenna as well as produces multiple resonant bands.

Fractal antennas employ fractal geometry i.e. self-symmetrical repeating pattern[7]-[9]. It increases the current path and hence resonant frequency is reduced and bands are increased. Many researchers investigated separately on fractal and slot antenna [11]-[12], but this technique i.e. combination of fractal and slot antenna is yet rarely used. This combination generated a fractal slot loop antenna which is fed by co-planer waveguide feed (CPW) and this designed prototype radiates at different frequencies and can be used for applications like personal communication services around 1800 MHz, WLAN 2.3 GHz, Bluetooth (2.5-2.6 GHz), WIMAX (3.4- 3.6GHz), IMT band around 4.5 GHz, 5-6 GHz wide band for WLAN and WIMAX. Antenna is also capable to work on 6-7.5 GHz band which can be utilised for 5G mobile communication in future use.

Inspire of using fractals and slots two another techniques are also incorporated in this design, the one is DGS i.e. defected ground structure and other one is loading of dielectric resonator slab on the designed fractal slot loop. DGS technique improves the gain of the antenna. Squared loop slots (eliminating its bottom side as shown in Fig. 1) are etched from the ground plane, which enhances the performance of antenna. DRA technique involves placing a dielectric slab of ceramic materials, which improves the E-field distribution and prevent them from diverging[10]. They direct the E-field and hence increase the directivity.The paper is organised into three sections section I gives the introduction, section II describes the detail description about the design of the proposed antenna, and section III describes the results that how different parameters are affecting the performance of antenna and finally the section IV gives the conclusion application of the designed structure. Simulation is done on CST software.

II.ANTENNA DESIGN PROCEDURE AND PARAMETRIC STUDY

The design procedure includes two steps. In the first part octagonal slot loop is designed and fractal geometry is imposed on the boundaries of that octagonal shaped slot loop. CPW feeding method is used as shown in fig. 1. Slot loop shown in the fig. 1 is formed by etching out the copper which is placed on the substrate FR4 having thickness 1.6 mm, relative permittivity of 4.4, and dimensions of L*W = 60*70 mm. The coplanar waveguide feed line having 50 ohms characteristics impedance is designed with central conductor width of s = 4.2 mm and a gap width of 0.3 mm. After the octagon is designed fractal geometry is incorporated on the boundaries so that we can have multiple bands which are the main aim of this design. Fractals could be iterated up to many stages but is found that for this particular design the second order iteration is sufficient for our need.

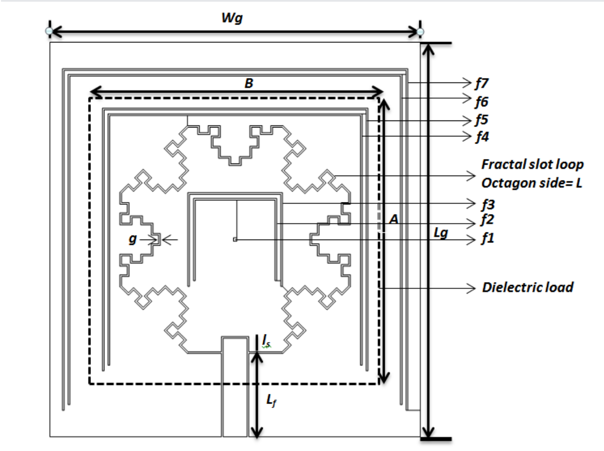

Fig.1 (a) layout of designed fractal slot antenna loaded with dielectric resonator

Fig. 1 (b) fabricated antenna

The fractal is formed by shifting the middle one third of each segment i.e. indentation lengthinner word to some extent which is called indentation width shown in fig. 2. Indentation factor ‘i’ is defined as ratio of indentation width to indentation length.

A. Generation of fractal slot loop

As previously said the octagonal slot loop is taken as an initiator for the fractal design. There is a mismatch of characteristic impedance between coplanar waveguide feed line having length s = 4.2 mm and slot width. Due to this mismatch, radiations can’t occur and hence we need a solution for this problem. Problem is overcome by using an open circuited coplanar waveguide stub having length ‘l_s’ which helps in improving the mismatching conditions and enhance the working of the designed antenna. Fig. 3 shows the return loss plot of the antenna with and without using CPW stub. It is observed that as the effective length of the current path is increased, there in an improvement in resonance characteristics of antenna, hence as discussed earlier, fractal geometry is applied on the boundaries which increase the effective current path. The variation in resonance frequency by varying the indentation width and keeping the indentation length fixed at one third of segment can be seen in fig. 2. It can also be noticed that when we increase the fractal iteration there is decrease in resonance frequency, the reason for that is same as discussed earlier that is change in effective current path. It is observed that as the fractal iterations are increased resonant bands are increased.

$$i = \frac{indentation \quad width}{indentation \quad length} \qquad (1)$$

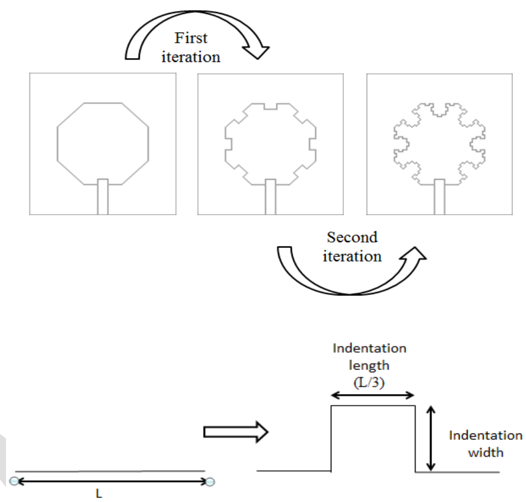

Fig.2 Generation of fractal slot loop

After making this octagonal fractal slot loop, 7 square loops with one side eliminated having one side dimension f1, f2, ….f7, as shown in fig.4 are also etched out. These slots improve the gain and fundamental frequency of the antenna.These square looped slots can be said to be working like defected ground structure (DGS). 6-7 GHz band is mainly because of these slots. The current path increases and we get more number of bands in smaller size. It is also seen that the square slot loops are responsible for reducing the size of antenna as due to these slots the antenna size is reduced to 65 * 75 mm from 100 * 100 mm.

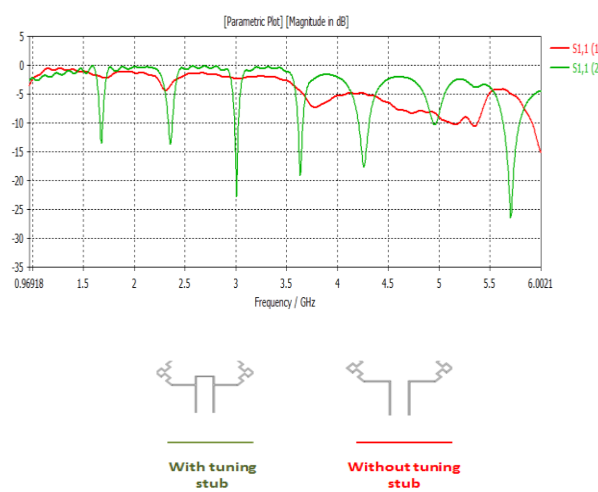

Fig.3 Return loss plot with and without tuning stub

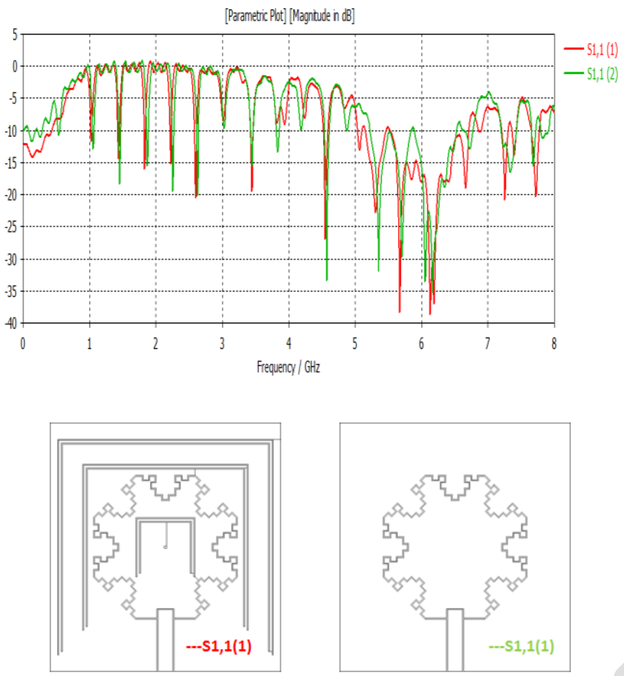

Fig.4 Simulated S_{11} (dB) for with square loops and without square loops

B. Loading of dielectric resonator on the fractal slot loop

The uneven nature of the slots in fractal loop will create diverging E-fields hence reducing the gain and directivity of the designed antenna. Also it can be observed that as slot lines always tends store more energy and hence radiate less, this problem could be solved by using DRA structures, i.e. by placing a dielectric slab of dimension A*B on the antenna which would enhance the radiations and improve directivity as shown in fig.5. We can also increase the effective permittivity of the slot antenna which reduces the resonant frequency by placing a resonator i.e. dielectric slab on top of the antenna. Tuning of frequency can also be done by using this property. The entire 5-6 GHz band can also be utilised, which is another reason for using this dielectric slab. 5-6 GHz band is very useful in IEEE Wireless Local Area Network (WLAN).

The dimensions of the slab are chosen in such a way that it resonates around 5 GHz WLAN band. In fig.5 it is shown that how the gain varies by varying the height of the dielectric slab. As the slab is made to resonate around 5 GHz, it can be seen in the graph that maximum variation occurs around 5 GHz as the height is changed.

The model named Marcatilli's model is used to calculate the dimensions of the resonator slab placed on designed antenna [13].

$$f_r = \frac{c}{\sqrt{\varepsilon_r}} k = \frac{c}{\sqrt{\varepsilon_r}} \sqrt{k_x^2 + k_y^2 + k_z^2} \quad (2)$$

Where,

$$k_x = \frac{\pi}{A};$$

$$k_z = \frac{\pi}{2H};$$

$$k_y \tan(k_y \, B) = \sqrt{(\varepsilon_r - 1)k_0^2 - k_y^2}$$

and

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \quad (3)$$

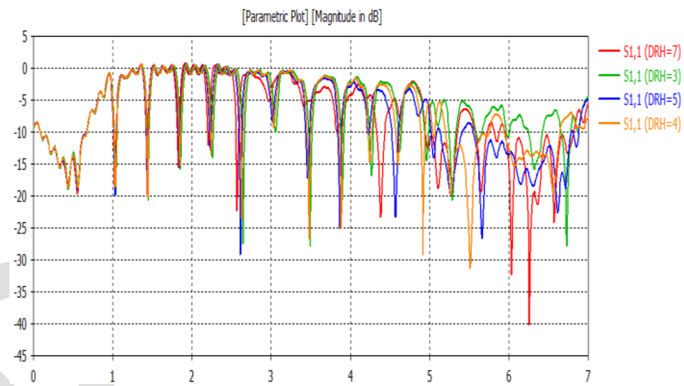

Fig.5 S_{11} (dB) simulated for different heights of dielectric slab

The final dimensions for the designed antenna which are obtained by optimising various antenna parameters are given in table I

Table I

Final design parameters of antenna

Parameter	values
Ground plane dimensions (L*W)	65 mm * 70 mm
Substrate dimensions	65 mm * 70 mm
Octagon single side dimension (l)	16.5mm
Stub length (l_s)	3mm
Slot width (g)	0.3 mm
First indentation factor	1
Second indentation factor	0.7
Dielectric slab dimension (A*B*H)	48mm* 52mm* 5mm

III. Results and Discussions

In this paper, octagonal shaped fractal shaped antenna is designed having fractal geometry on its boundaries and the whole design is loaded with dielectric resonator slab with dielectric permittivity i.e.$\varepsilon_r = 10$. Change in the s-parameter or return loss plot is shown by varying different parametersi.e. indentation factors (i_1 and i_2), slot width (g), height of dielectric slab, etc. each parameter has its own importance in return loss plot. Change in indentation factors i.e. i_1 and $i_2$concludes that the fundamental frequency is decreased and return loss is also increased as the factors are increased form

0.1-1 as shown in fig.6 and fig.7. With proper optimisation of both the parameter is found that the best results occur when i_1 is ‘1’and i_2 is set to ‘0.7’.

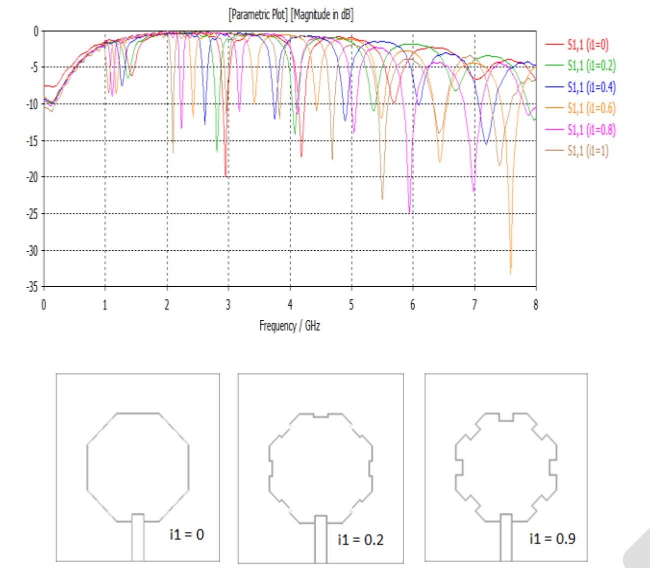

Fig.6 S_{11} (dB) simulated for various indentation factors ‘i_1’

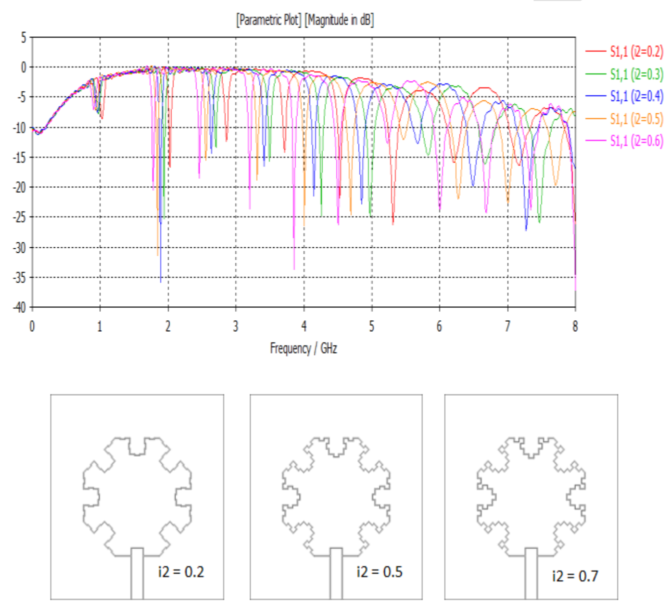

Fig.7 S_{11} (dB) simulated for various indentation factors ‘i_2’

The slot width ‘g’ is also varied from 0.2- 0.4 and is it concluded from return loss plot shown in fig. 8 that fundamental frequency and gain is best at 0.3 mm. hence we chose this slot width for our final fabricated antenna.

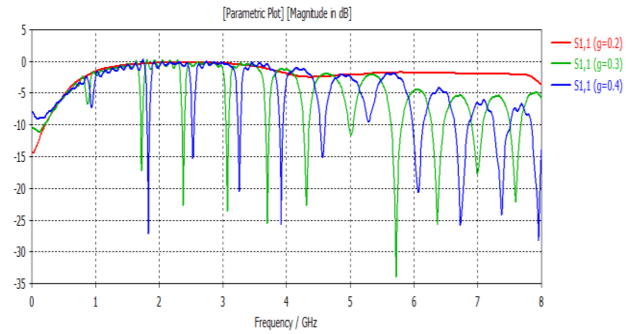

Fig.8 S_{11} (dB) simulated for various slot width ‘g’

In fig. 9 the effect of fractal geometry is shown, here we can see that as the iteration is increased, return loss plot becomes better and fundamental frequency is decreased. This happens because as the iteration is increased, the current path increases, surface current density increases and hence antenna performance is improved.

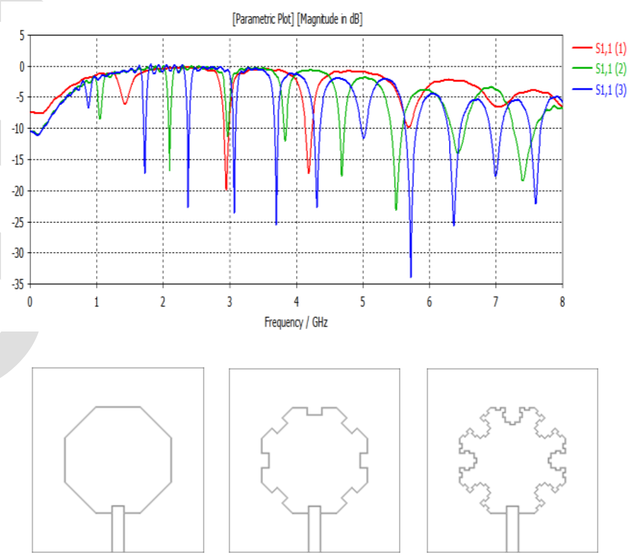

Fig.9 S_{11} (dB) simulated for three stages of fractal iteration

The final simulatedresults for the designed antenna are shown in fig. 10(a). These results are obtained after placing a dielectric slab of permittivity 10 on the designed antenna. The resonator improves the gain to large extent. Number of resonating frequencies is also increased due to placing of slab. The 5-7 GHzband which is separately shown in fig. 10(b) is mainly due to resonator as resonator directs the radiations to particular direction, hence increasing the directivity of antenna. The radiation pattern shown in fig. 11 at each frequency depicts that antenna radiates with acceptable gain over different frequency bands. The measured results and fabricated antenna are shown in fig. 10 (c) and 1(b). Results are measured without the dielectric slab and they are in agreement with the simulated results.

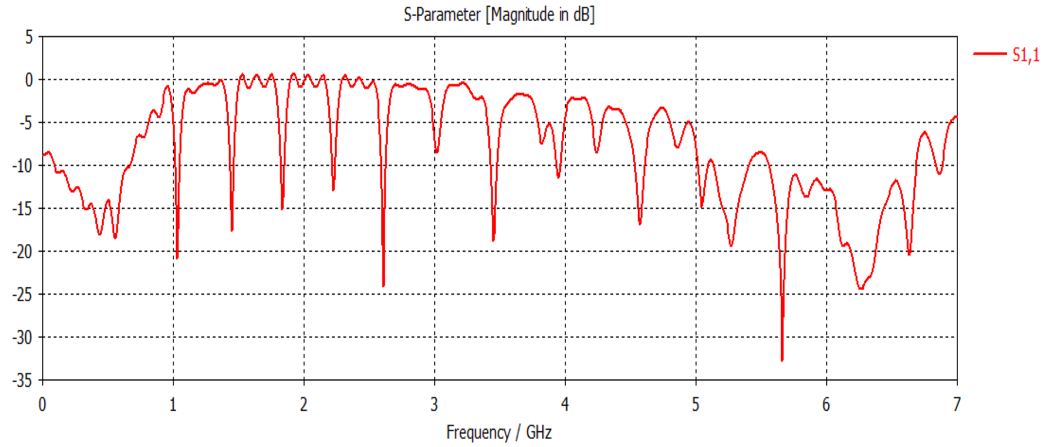

Fig. 10(a)

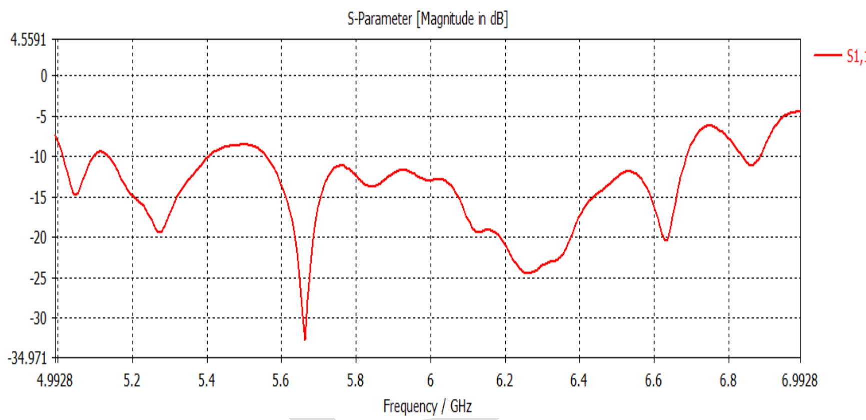

Fig. 10(b)

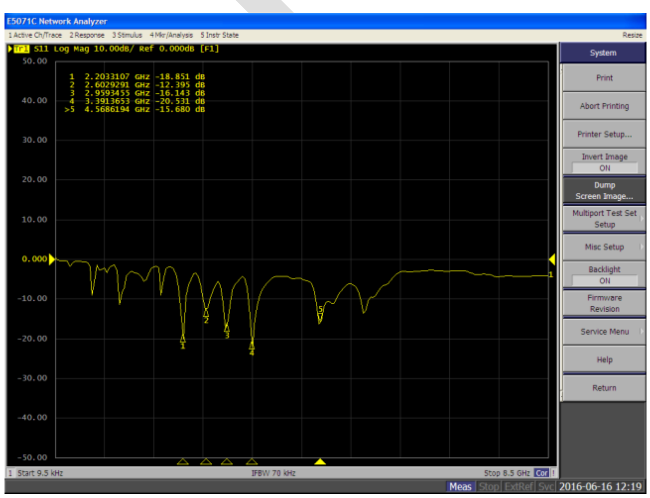

Fig. 10(c)

Fig. 10 (a) S_{11} (dB) simulated for final design (b) S_{11} (dB) simulated showing wide band 5.5 GHz – 6.7 GHz (c) measured results for the designed antenna

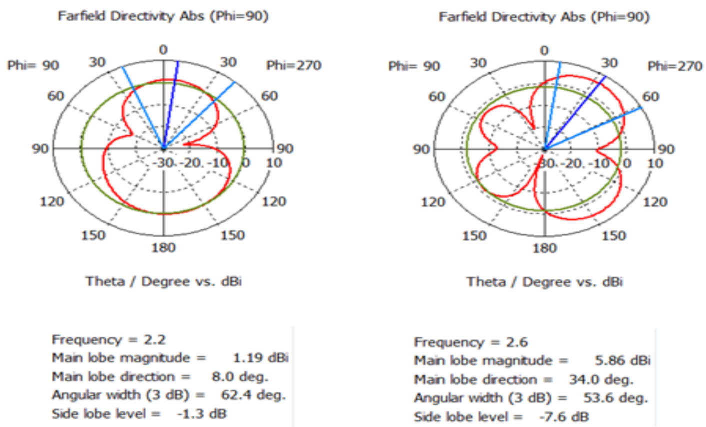

Fig. 11(a) radiation pattern at 2.2 GHz and 2.6GHz

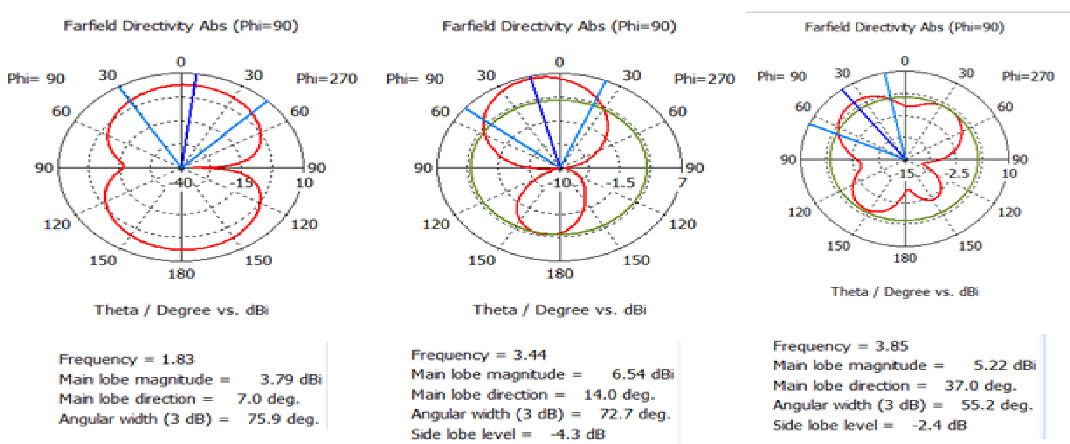

Fig. 11 (b) radiation pattern at 1.83 GHz, 3.44GHz and 3.85GHz

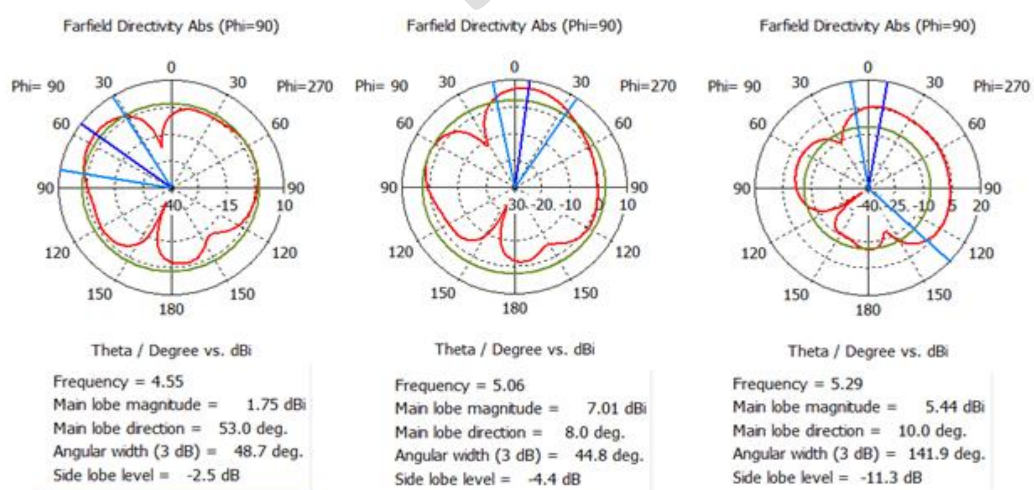

Fig. 11 (c) radiation pattern at 4.55 GHz, 3.44GHz and 3.85GHz

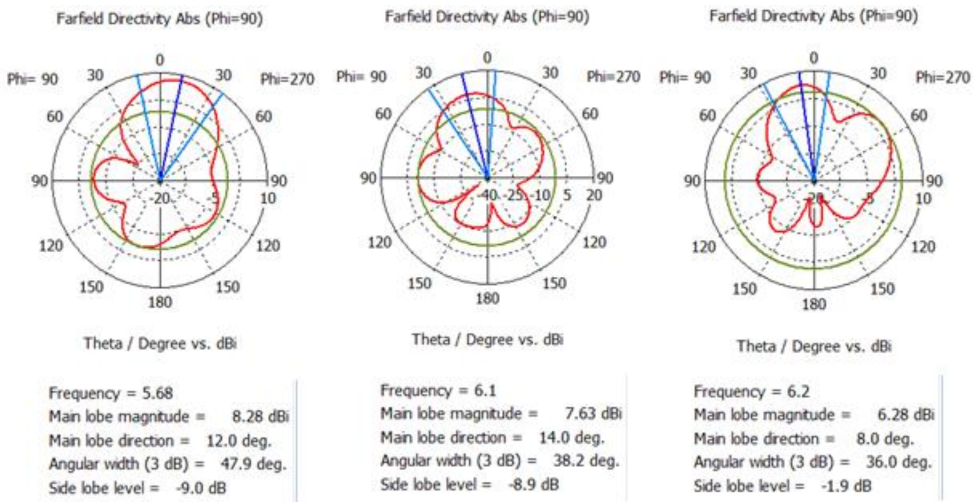

Fig. 11 (d) radiation pattern at 5.68 GHz, 6.1GHz and 6.2GHz

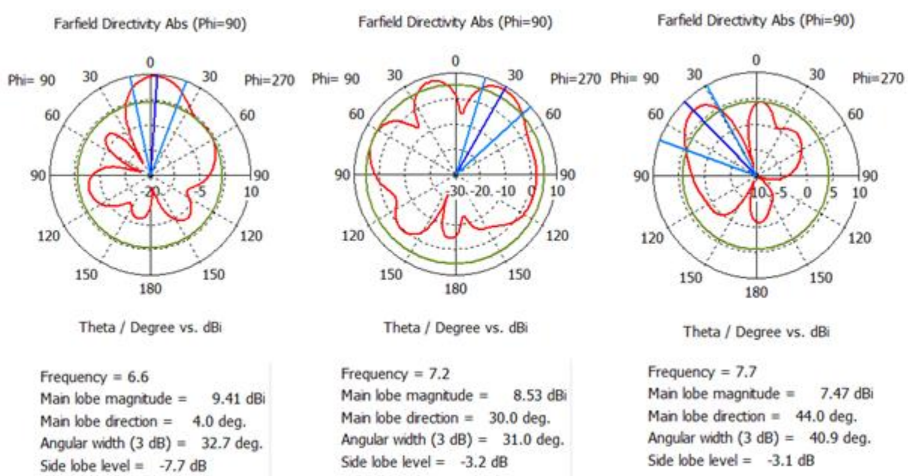

Fig. 11 (e) radiation pattern at 6.6 GHz, 7.2GHz and 7.7GHz

IV. CONCLUSIONS AND APPLICATIONS

An investigation is done on how we can use the fractal slot loop antenna loaded with dielectric resonator for the multiband performance. Minowski fractal geometry is applied on boundaries of octagonal shaped loop, design is fed by CPW feed and it is characterised. Parametric study is done to optimise the exact parameters which are best in improving the gain and radiation pattern. The final design which is simulated is able to work on frequencies which are very much useful in wireless communication like personal communication services around 1800 MHz, WLAN 2.3 GHz, Bluetooth (2.5-2.6 GHz), WIMAX (3.4- 3.6GHz), IMT band around 4.5 GHz, 5-6 GHz wide band for WLAN and WIMAX. Antenna is also capable to work on 6-7.5 GHz band which is going to be utilised for 5G mobile communication in future use.

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