# Compact Metamaterial Antenna for Wireless Applications

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***Abstract*—This paper presents a new compact, wide band and high selective, metamaterial antenna for wireless applications. The proposed antenna is designed using metamaterial Square Split ring resonator. The antenna is centred at 13.26 GHz for the applications of ku band. The antenna's outer Square SRR length is 2.2mm and the inner one is 1.5mm which forms the base for the antenna. It is enhanced with Koch Fractal design for improving antenna parameters. The design procedures of the proposed antenna are discussed. The antenna's performance is examined in terms of full wave simulation and experimental measurements.**

## I. INTRODUCTION

The present revolution has seen various models of mobile phones and other devices that require compact antennas with advanced features. The recent years have witnessed increase in demands on communication systems. The modern telecommunication systems require antennas with wider bandwidths and smaller dimensions than conventionally possible[1]. In recent years several fractal geometries have been introduced for antenna applications with varying degrees of success in improving antenna characteristics. Some of these geometries have been particularly useful in reducing the size of the antenna[3].

The research work presented here is primarily intended to analyse geometrical features of fractals that influence the performance of antennas using them. Along with square SRR, Koch fractal antenna is also designed and simulated. In this project Koch fractal antenna is combined with a square SRR antenna. Depending upon the satisfaction of various users the antenna must be small and provide wide number of applications[2]-[5]. This project helps in miniaturization of the antenna and in improving different parameters like bandwidth, VSWR and return Loss. The parameters of the Koch fractal antenna, the square SRR structure and the integrated antenna is observed and compared. These features of the antenna are essential for wireless applications.

## II. SQUARE SRR THEORY AND DESIGN

The split ring resonator (SRR) is a common structure to obtain negative effective permeability and is used in designing metamaterials. The SRRs possess large magnetic polarizability and exhibit negative effective permeability for frequencies close to their resonance frequency. They also show a large magnetic dipole moment when excited by a magnetic field directed along its axis. SRRs consist of a pair of concentric metallic rings, etched on a dielectric substrate, with slits etched on opposite sides. SRRs can produce an effect of being electrically smaller

when responding to an oscillating electromagnetic field. These resonators have been used for the synthesis of left handed and negative refractive index media, where the necessary value of the negative effective permeability is due to the presence of the SRRs. This antenna is often built of printed circuit board material and the substrate makes up the patch antenna's dielectric.

Fig. 1.1 shows a schematic view of a SSRR having strip width c and spacing d between the rings. gl and g2 are gaps within the inner ring and outer ring, respectively. It is printed on a dielectric substrate with dielectric constant, Cr and thickness h.

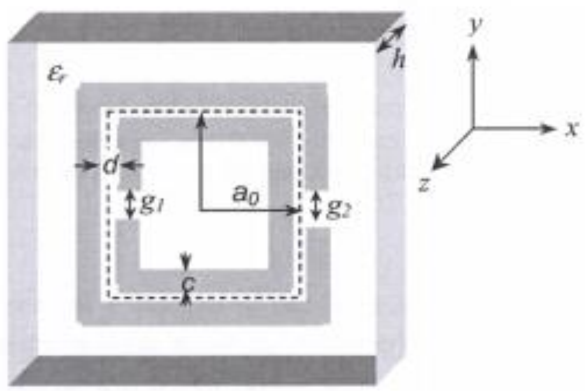
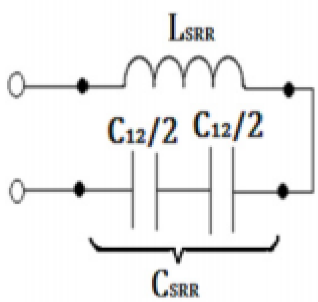



Fig.1.1 Square SRR Geometry

A thicker substrate increases the gain to some extent, but may lead to undesired effects like surface wave excitation: surface waves decrease efficiency and perturb the radiation pattern. The patch in the antenna is usually made of copper (Cu) or gold (Au). A good performance from the patch antenna can be expected with a thick dielectric substrate and low dielectric constant as this gives better efficiency, larger bandwidth and better radiation

Antenna parameters like resonant frequencies, substrate thickness, length and width of the antenna have to be taken into account. The resonant frequency is 13.26 GHZ. FR4 epoxy substrate is used as substrate material.

FR-4 glass epoxy is a popular and versatile high pressure thermo set plastic laminate grade with good strength to weight ratios.




SRR EQUIVALENT CIRCUIT

The total inductance (LSRR) and total capacitance (CSRR) for SRR ring can be evaluated by using following equations:

The total inductance is expressed as,

$$L_{SRR} = (\mu_0 \div 2) * (l_{avg} \div 4) * 4.86 * [\ln(0.98 \div \rho) + (1.84(\rho))]$$

where, ρ is the fill ratio which describes the hollowness of MSRR and is expressed for two number of rings as,

$$\rho = ((N-1)(s+t) \div (1-(N-1)(s+t)))$$

And $L_{avg}$ is the average strip length calculated as,

$$L_{avg} = 4 * (1-(N-1)(s+t))$$

Total capacitance is expressed as,

$$C_{SRR} = (1 \div 2) * [(2 * l) - (3 \div (t+s)))] * C_0$$

where, C0 is per-unit-length capacitance between two parallel strips having width (w) and separation (s), given by,

$$C_0 = \varepsilon_0(k * ((\sqrt{(1-k2)}) \div k(k)))$$

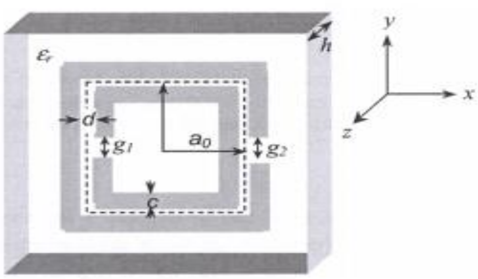
K(o)is the complete elliptic integral of the first kind and k can be expressed as,

$$K = ((s \div 2) \div (t + (s \div 2)))$$

Subsequently the resonant frequency of SRR can be evaluated,

$$F_r = 1 \div (2 * \pi * (\sqrt{L_{SRR}} * \sqrt{C_{SRR}})))$$

These are the design equations of Square SRR. Through these equations we can design the Square SRR antenna.




| PARAMETER | DESCRIPTION | VALUE(mm) |
|---|---|---|
| Ls | length of substrate | 2.5 |
| H | Thickness of substrate | 0.25 |
| $L_1$ | Length of First Ring | 2.2 |
| $L_2$ | Length of Second Ring | 1.5 |
| C | Thickness of Rings | 0.2 |
| D | Spacing Between Rings | 0.15 |
| $g_1$, $g_2$ | Length of Split in Rings | 0.3 |

**Table 1.1 Dimensions of the proposed antenna**

## III. KOCH FRACTAL ANTENNA THEORY AND DESIGN

Koch curve, proposed in 1904 by the Swedish mathematician Helge von Koch. Taking a segment of straight line (as initiator) and rise an equilateral triangle over its middle third, it results a so called generator. Note that the length of the generator is four-thirds the length of the initiator. Repeating once more the process of erecting equilateral triangles over the middle thirds of strait line results which is presented in the figure 1.3.1. The length of the fractured line is now (4/3)2. Iterating the process infinitely many times results in a "curve" of infinite length,which, although everywhere continuous - is nowhere differentiable. such nondifferentiable curves is a fractal.

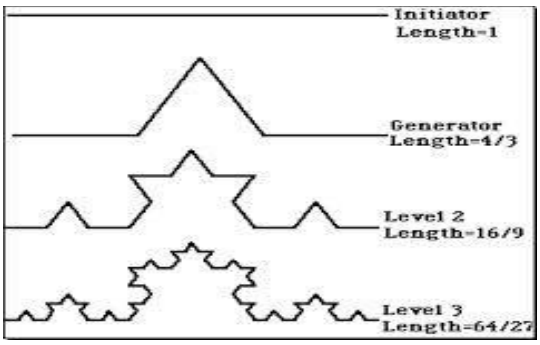



Fig 1.3 Koch Fractal Geometry

In the design of Koch Fractal Structure three iterations are made. The diagrammatic representation of the iterations are shown below

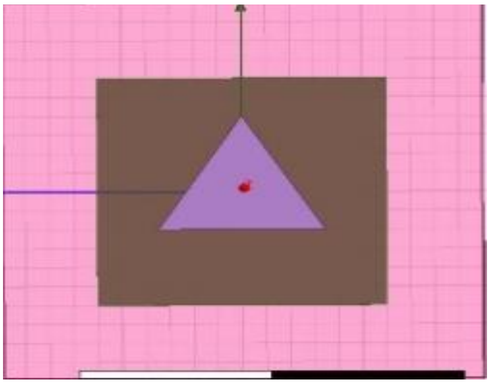


Fig 1.4 0th Iteration of Koch Fractal Design

Koch Fractal antenna is a representative fractal antenna. Usually, it is a triangle configuration in zero proceedings stage. The design is constructed over the FR4 epoxy substrate. A coaxial Perfect Electric conductor feed is given. In this iteration the patch is constructed of one triangle .

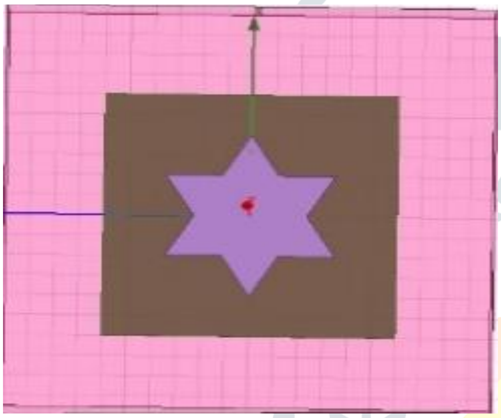


Fig 1.5 1st Iteration of Koch Fractal Design

The previous iteration serves as the base for the first iteration. Now another triangle which is of same size but opposite in direction is constructed and this is merged with the existing design to form the patch for the antenna. This forms a shape of a star and this also enlarges the patch's perimeter.

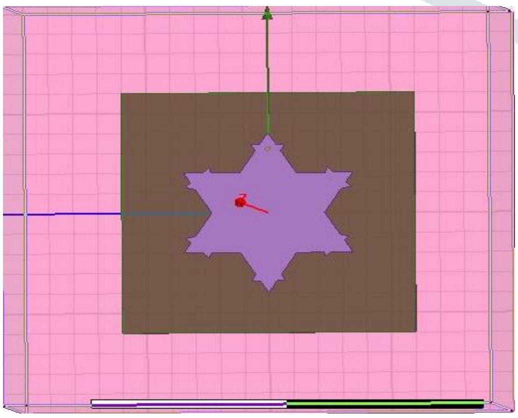


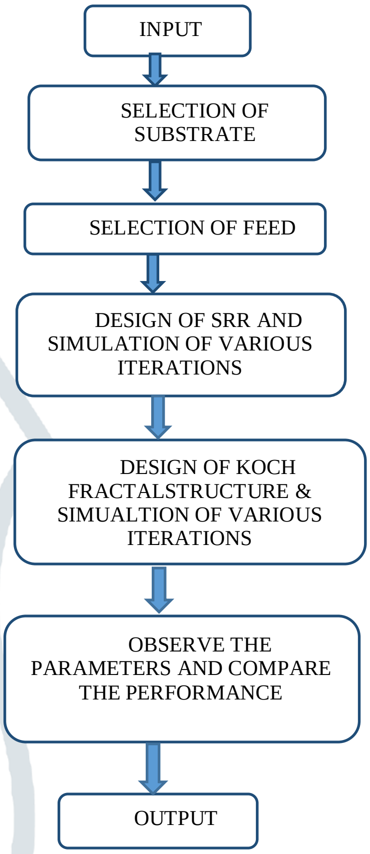
Fig 1.6 2nd Iteration of Koch Fractal Antenna

By keeping the design of the first iteration as the base the second iteration is carried out. In this iteration for the six sides of a star(result obtained from previous iteration) six triangles is constructed of small size. By positioning in perfect manner the 2nd Iteration is carried out. This further increases the perimeter of the patch and therefore there will be the gain in its parameters. This forms the final iteration of Koch Fractal antenna design.

IV. THEORY AND DESIGN OF PROPOSED ANTENNA

In this chapter the design and development of Square SRR, Koch fractal and the design of integrating them into a single structure is highlighted. Various iterations are done and the design is simulated. The performance of both, the individual Square SRR and Koch fractal, and the integrated structure is observed and analysed.

To design a compact metamaterial antenna following steps are followed.




The Split Ring Resonator (SRR) is preferred because it provides a stop-band phenomenon and a negative permeability in the vicinity of resonance frequency. The antenna which is designed consists of a substrate over which the SRR is kept at the centre. The Micro-strip feed is used. The feed line is also at the centre with respect to the substrate. Here we have used FR4 Epoxy as a substrate which has a dielectric constant of 4.4. There are design equations to calculate the length, width and other parameters of the antenna

The Koch Fractal structure is selected due to its Compact size compared to antennas of conventional schemes, while maintaining good to excellent efficiencies and gains. This antenna is placed on the bottom side of the SRR.

It is fed by a co-axial feed which is united with the micro-strip line of SRR. An equilateral triangle structure is iterated to obtain the desired Koch structure.

The proposed antenna is a combination of two antenna, a Square SRR and a Koch Fractal antenna. Both these structures are integrated symmetrically in top and bottom faces of the substrate. The substrate is made of FR4_epoxy which has a dielectric constant of 4.4.

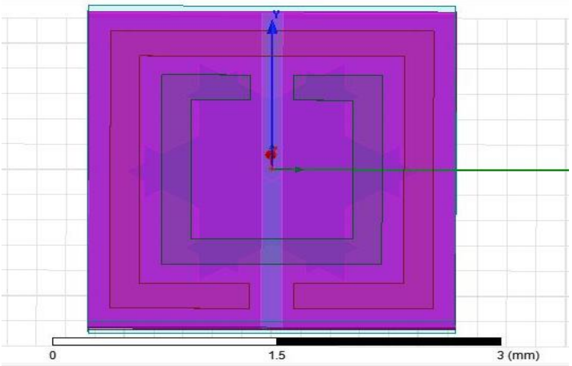



Fig 1.7 Top View Of the Proposed Antenna

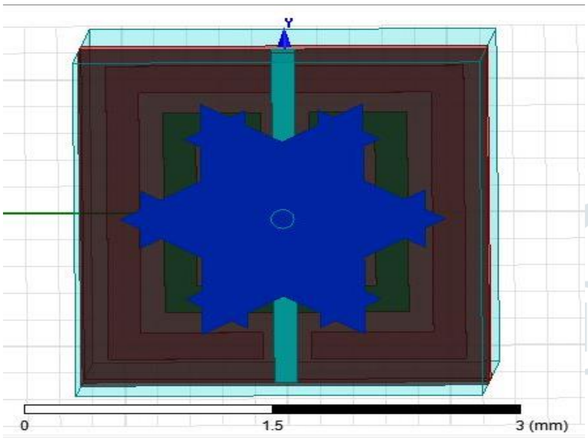



Fig 1.8 Bottom View Of the Proposed Antenna

In the proposed model, a conventional microstrip line is loaded with planar square SRR/SR in two configurations. The resonators are made up of copper metal. The SRR/SR is coupled to microstrip line by placing it at distance‘s’, in the same plane. This coupled line is modelled on FR4_epoxy substrate of thickness, has 0.25mm, dielectric permittivity, εr =4.4 and tan δ = 0.02. g.

The length of the SRR is 2.2mm and the width is taken as 2.2mm. The gap of split in both rings is 0.3mm and spacing between the rings is 0.15mm. SRR is equivalent to LC circuit which is depicted in Figure 4.3.Total inductance (LSRR) is the length of SRR for two numbers of rings. The gap of SRR acts like capacitance. The distribution capacitance (C12/2) is the capacitance between the inner ring and outer ring.

IV. FABRICATION AND MEASUREMENTS

In this section the measurement results for the proposed simulated antenna are pointed out. The measurements are Done Using HFSS software. HFSS means High Frequency Structure Simulator. The results obtained Using HFSS are S11 and Bandwidth, Gain, VSWR and Radiation Pattern. Let’s see all of them in detail.

Now we see the Results of the Proposed antenna. Firstly we see about the Return Loss (or) S11.

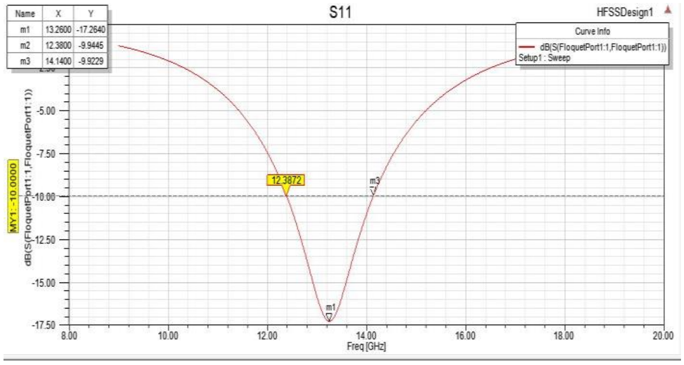



Fig 1.9 S11 or Return Loss For Proposed Antenna

In Telecommunications, return loss is the loss of power in the signal returned/reflected by a discontinuity in a transmission line or optical fibre. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line. It is usually expressed as a ratio in decibels (dB).

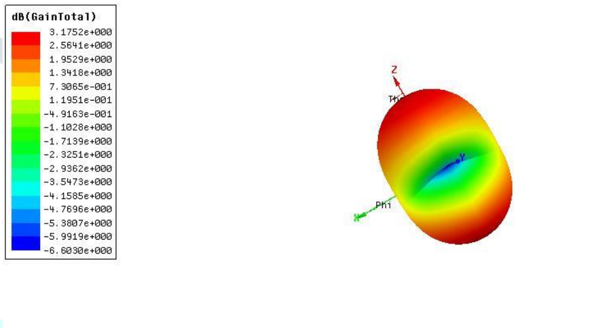



Fig 1.10 3D PLOT OF PROPOSED ANTENNA

A relative measure of an antenna's ability to direct or concentrate radio frequency energy in a particular direction or pattern. The gain of the antenna is not the same as the gain of the amplifier in which case it is the ratio of output to input. The gain of the antenna is related to the directivity.

**G=e D**

However there are various sources of antenna system loss that which contributes to the degradation of gain such as

- Losses due to impedance mismatches
- Losses due to transmission line
- Conductive and dielectric losses in the antenna

As the proposed antenna is the combination of two antenna’s (Koch fractal antenna and Square SRR design then the gain of this antenna will be 3.17dB).

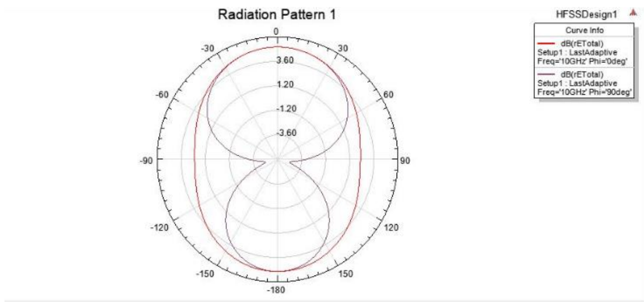



Fig 1.11 Radiation Pattern Of Proposed antenna

A radiation pattern defines the variation of the power radiated by an antenna as a function of the direction away from the antenna. It is also defined as a mathematical function or graphical representation of the radiation properties of antenna as a function of space coordinates .On the cases of antenna, it is very necessary to study about the distribution of energy radiated by the structure towards the surrounding space.

Radiation pattern of the proposed design takes the property of both the antennas and finally from the figure 1.11 we can clearly see that the antenna is radiating in all the directions and it is a "omnidirectional antenna".

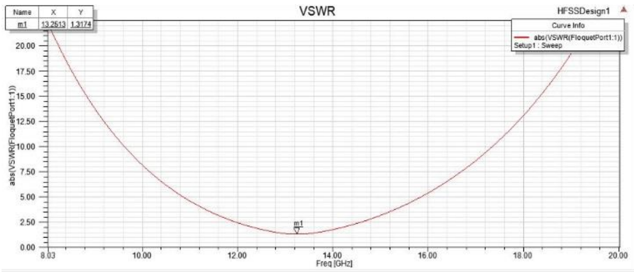



Fig 1.12 VSWR OF PROPOSED ANTENNA

VSWR stands for Voltage Standing Wave Ratio is a function of the reflection coefficient which describes the power reflected from the antenna. The VSWR is always a real and positive number for antennas. The smaller the VSWR is, the better the antenna is matched to the transmission line and the more power is delivered to the antenna. The minimum VSWR is 1.0. In this case, no power is reflected from the antenna, which is ideal.

VSWR of the proposed antenna is the combination of both the antennas. The proposed antenna's VSWR value somewhere lies in between both the antennas and for us the value is 1.3

## V. CONCLUSION

In today's modern world where smart antennas play a vital role in the wireless field both fractal antenna and Square SRR are advanced technologies. The efficiency of the antenna depends on its shape and size. Various parameters are also responsible for its performance. The fractal antenna helps in reducing the size of the antenna considerably making it compact. The return loss obtained from the proposed antenna after many iterations is less and the gain is high. The experimental values and simulated results are compared. Expected results are obtained.

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