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Modified Sierpinski Fractal Based Miniaturized Dual Band Patch Antenna

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Advisor: Prof. Dong-You Choi

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This is to certify that the master's thesis of

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Acronyms

HFSS	: High Frequency Structure Simulator
VSWR	: Voltage Standing Wave Ratio
GHz	: Gigahertz
ISM	: Industrial Scientific and Medical
MPA	: Microstrip Patch Antenna
RFID	: Radio Frequency Identification
WLAN	: Wireless Local Area Network
TM	: Transverse Magnetic
PCB	: Printed Circuit Board
SWR	: Standing Wave Ratio
RF	: Radio Frequency
dB	: decibel
dBi	: dB (isotropic)
dBd	: dB (dipole)
WiMax	: Worldwide Interoperability for Microwave Access
CPW	: Coplanar Waveguide
FR4	: Flame Retardant
FEM	: Finite Element Method
EM	: Electro-magnetic
SCMPA	: Sierpinski Carpet Microstrip Patch Antenna
MHz	: Megahertz

ABSTRACT

Modified Sierpinski Fractal Based Miniaturized Dual Band Patch Antenna

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The necessity for compact size, light weight, and low cost antennas has increased in recent years with the widespread deployment of wireless communications. Compact antennas can achieve the same performance as large antennas do with low price and ease with integrated technology. Hence, reduction of antenna size is becoming an important design parameter. Also, dual-frequency microstrip antennas have the advantage of doubling the system capacity for transmission and reception. Thus, the antenna with miniaturization and multi band functionality are beneficial to cope with the rapid growth of wireless systems. The proposed work in this thesis is focused on designing a multiband antenna with significant size reduction.

Microstrip patch antennas with several advantages such as conformal nature, low profile, and economical to manufacture have made them suitable candidate to design an effective antenna for modern wireless system. Conventional patch antennas are modified in various ways to obtain a miniaturized multiband antenna. In presented work, the basic geometry of microstrip patch antenna is modified by incorporating fractal structure. The fractal's space filling capability can be utilized

to reduce the antenna size and their property of being self-similarity enables antenna to have a large number of resonant frequencies.

The proposed work initiated with the design of simple fractal, Sierpinski carpet on the edge-fed rectangular patch antenna. The fractal iteration of 2^{nd} order was chosen for further modification because of its significant size reduction along with fabrication ease. Through the process of analysis and simulation, it was seen that inset fed Sierpinski fractal antenna with perturbation and the stub can resonate at two frequencies with fine impedance matching. The antennas are designed using finite element method based High Frequency Structure Simulator (HFSS) and their performances are demonstrated in terms of return loss, impedance matching, radiation pattern and VSWR. The size reduction of 25.98% was obtained with a resonant frequency at 2.45 GHz and 5.8 GHz (ISM band frequencies). The designed dual band antenna is fabricated on FR4 substrate and the slight deviation observed from simulated result is due to environmental effect and fabrication inaccuracies. This verifies that high degree of complexity in the structure of the antenna is not required to obtain a compact multiband patch antenna using fractal geometry.

요 약

변형된Sierpinski프랙탈구조를기반으로한

소형듀얼밴드패치안테나

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최근들어무선통신시장에안테나의소형화, 경량화, 저가격화의필요성이증가하고있으며, 소형안테나는낮은가격으로큰안테나와동일한성능을이룰수있을뿐만아니라다른시스템과의 접목이용이하다.따라서안테나크기의축소는설계의중요한요소가되고있다.또한듀얼밴드마이크로스트립안테나는일반적인단일밴드안테나에비해송수신시많은장점을갖는다. 그러므로, 소형및다중밴드기능을가진안테나는급속도로성장하고있는무선통신시스템에매우적합하다. 그러므로, 본논문에서는소형화된듀얼밴드안테나설계에중점을두었다.

마이크로스트립패치안테나는인쇄기판으로제작하기때문에제작이쉽고, 대량생산에적합하며경제적인특징으로인해현대무선통신시스템의안테나로많이활용되고있다. 기존의패치안테나는소형의다중밴드안테나를위하여다양한방식으로기본적인구조만을변형시켜왔다.

논문에서는마이크로스트립패치안테나의기본적인구조에Sierpinski carpet 프랙탈구조를활용하여기본구조, 1차반복구조, 2차반복구조, 3차반복구조안테나를설계하였다. 그리고, 제작의용이성과안테나성능, 크기축소율등을고려하여최종적으로는 2차반복구조를변형하여고조파를제거한듀얼밴드마이크로스트립패치안테나를제작하였다. 제안한안테나는 3차

원초고주파해석시뮬레이션프로그램인Ansoft사의HFSS(ver. 10)를이용하였으며, 반사손실, 임피던스매칭, 방사패턴, VSWR을시뮬레이션하였다. 실제 FR4 기판에제작한변형된 2차 반복구조안테나는 ISM 대역인2.45 GHz 및 5.8 GHz에서공진을확인할수있었으며, 기본구조에비해약 25%의크기를축소할수있었다. 따라서소형다중밴드안테나를위하여매우복잡한구조의안테나가아닌프랙탈구조를활용함으로써가능하다고판단된다.

I. Introduction

A. General overview

Wireless communication systems have progressed at a remarkable pace and the antenna is an essential element in its success. The antenna could not be abandoned in any wireless technology as it is the only medium present, to receive and transmit signals. The explosive growth of wireless applications demands for low cost, low profile, miniaturized and single wireless transceiver to support multi-band operations. Among various types of antennas, microstrip patch antenna (MPA) is gaining popularity for use owing to their advantages such as simple, lightweight, economical to manufacture using modern printed circuit technology and ease of integration with feed networks. The other reason for a wide use of patch antenna is the versatility of patch antenna in terms of resonant frequency, polarization, pattern and impedance when particular patch shape and mode are chosen.

New generations of wireless systems aim to perform on more than one frequency band. Some applications require the antenna to be as miniaturized as possible. The presented work is concerned not only on operating patch antenna on two frequency bands but also on size reduction of patch antenna. The multiband reduced size antenna occupies less space, avoids using two antennas, expands mobility options, and simplifies installation. Different types of variation can be made in patch antenna design to obtain this objective. Among several design techniques, the application of fractal geometry to conventional patch antenna structure to obtain a compact sized multiband antenna has been introduced recently in antenna design. The fractal patch antenna is designed using the recursive nature of fractal. The unique properties of fractal antennas: Space-filling property and Self-similarity property can be utilized to design small sized antenna and multiband antenna respectively.

This thesis presents a simple and effective design approach to obtain a compact dual band antenna by applying fractal geometry to the conventional patch antenna. The unlicensed ISM band center frequencies at 2.45 GHz and 5.8 GHz, has been selected for the study. The 2^{nd} iteration of inset fed modified Sierpinski carpet containing a perturbation and small stub is etched on the rectangular patch antenna to obtain a miniaturized dual band fractal patch antenna.

B. Objective

The objectives of the research are:

- To obtain a miniaturized patch antenna without affecting antenna performances such as return loss, radiation pattern, and impedance matching.
- To design a dual band antenna operating at 2.45 GHz and 5.8 GHz with fine impedance matching at both frequencies.
- To filter unwanted frequencies without using an additional filter component.

C. Thesis contribution

Modern communication systems usually require antennas with compactness and low cost. They often require dual band operation and the requirement is obvious when the same antenna supports multiple applications. Thus, they find dual band microstrip antennas very useful and sometimes unavoidable. The dual band antenna operating at 2.45 GHz and 5.8 GHz ISM bands is presented in this thesis. The designed antenna can be used in microwave band for RFID applications and in

WLAN application 802.11b/g and 802.11a, as it can operate at 2.45 GHz and 5.8 GHz. It can be used to develop a dual band rectenna which can be used for power transmission at either frequency depending upon power availability. Designing a miniaturized dual band antenna is a challenging task and is often designed with a high degree of complexity. In contrast to the designs presented on various researches, the proposed approach presents a simple and effective approach of obtaining multi band patch antenna with significant size reduction.

D. Thesis organization

The remainder of this thesis is organized in modular chapters and its outline is as follows:

Chapter 2 presents the background information related to the thesis. Section A of this chapter explains microstrip patch antenna including its historical development, basic structure, the principle of operation, feeding technique, advantages, and disadvantages. Section B demonstrates a fractal antenna overview, its unique characteristics and different fractal structures. Finally antenna parameters are briefly explained in section C.

Chapter 3 summarizes the various techniques adopted in previous research work to obtain miniaturization and dual band functionality in patch antenna and fractal antenna.

Chapter 4 discusses in detail the design of dual band fractal patch antenna with reduced size. The design specification is represented in section A. The design procedures adopted in the proposed work is explained in section B. The sequential procedure applied to obtain a compact multiband antenna followed by demonstration of dual band antenna simulated results, in terms of return loss, impedance matching, radiation pattern and VSWR are described in section C. The measured result of dual band antenna and its comparison with simulated result are presented in section D.

Chapter 5 presents the concluding remarks, with scope for further research work.

II. Background

A. Microstrip patch antenna

1. Historical development of patch antenna

Microstrip patch antennas (also called as patch antenna) are among the most common antenna types in use today, particularly in the popular frequency range of 1 to 6 GHz. The origin of microstrip antennas apparently dates back to 1953, when Deschamps proposed the use of microstrip feed lines to feed an array of printed antenna elements. The printed antenna elements introduced there were not microstrip patches, but flared planar horns.

Microstrip antenna had its first intense development in the 1970s, as communication systems became common at frequencies where its size and performance were very useful. At the same time, its flat profile and reduced weight, compared to parabolic reflectors and other antenna options, made it attractive for airborne and spacecraft applications. Munson introduced MPA in a symposium paper in 1972 which was followed by a journal paper in 1974. The early work of Munson on microstrip antennas for use as a low profile flush mounted antennas on rockets and missiles showed that this was a practical concept for use in many antenna system problems. Several mathematical models were produced for this antenna and its applications were extended to many other areas.

The most important workshop was held in Las Cruces, NM in 1979. It was also at that time when the first books on microstrip antennas were printed. By the early 1980s basic microstrip antenna elements and arrays were fairly well established in terms of design and modeling. A major contributing factor for advances of microstrip antennas is the revolution in electronic circuit miniaturization brought about by developments in large scale integration. As conventional antennas are often bulky and costly part of an electronic system, microstrip antennas based on photolithography technology are seen as an engineering breakthrough.

2. Basic structure of patch antenna

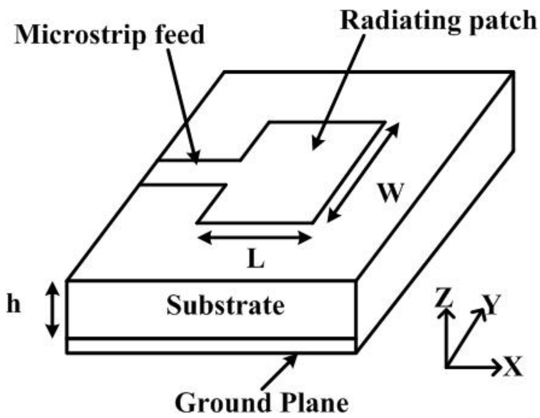

Figure 2.1: Basic structure of microstrip patch antenna.

In its most basic form a microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate with a ground plane on the other side as shown in Figure 2.1. The patch is generally made of a conducting material such as copper or gold and can take any possible shape. Square, rectangular, dipole, and circular are the most common because of ease of analysis, fabrication, and performance prediction. The radiating patch and feed lines is usually photo etched on the dielectric substrate.

3. Principle of operation of patch antenna

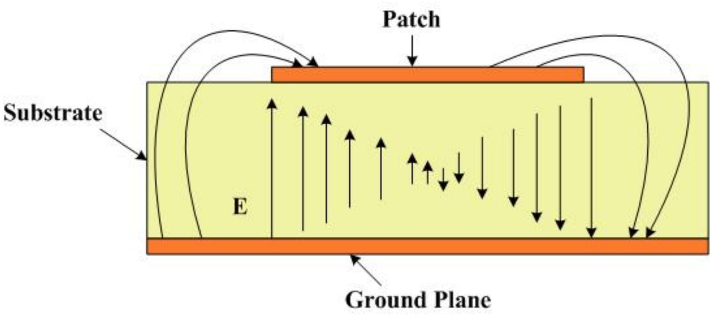

Figure 2.2: Field illustration of Rectangular patch antenna

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. Opposite charges are established at the bottom of the patch and at the top of the ground plane when the patch is excited at a resonant frequency. The attractive force will hold most of the charges between the two surfaces. In the meantime, the repulsive forces of the same charges on the patch surface will push some of the charges to the edges creating fringing fields because of which patch antenna resonates. The fundamental mode of a rectangular patch is often denoted using cavity theory as the Transverse Magnetic (TM) 10 mode. The electric field distribution of rectangular patch antenna is shown in Figure 2.2. The electric field is approximately constant along the width of the patch and goes through a phase reversal along the length of the patch. A rectangular patch antenna could be considered as containing two parallel radiating slots separated by length which is typically a half wavelength in the dielectric material.

4. Feeding techniques

Several configurations can be used to feed microstrip antennas. The four most popular are coaxial probe, microstrip line, proximity coupling, and aperture coupling and are shown in Figure 2.3 [1]. Coaxial probe feeding and microstrip line feeding techniques are contacting feeding method, in contrast to them proximity coupling and aperture coupling are non-contacting feeding method. In coaxial-line feeds, the inner conductor of the coax is attached to the radiation patch and the outer conductor is attached to the ground plane. It is easy to fabricate and has low spurious radiation. However, it has a narrow bandwidth and is difficult to model especially for thick substrate. The microstrip feed line is a conducting strip usually of smaller width connected to the patch. It is easy to fabricate, simple to match by controlling the inset position but spurious radiation increases with the increase in substrate thickness that limits the bandwidth.

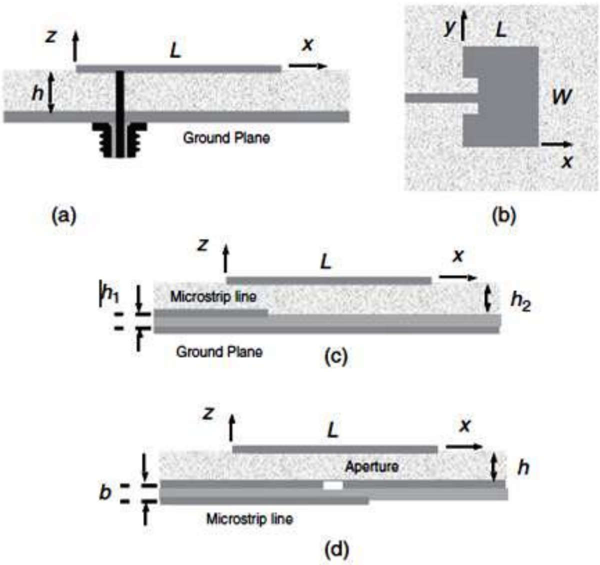

Figure 2.3: Feeding methods for microstrip antennas: (a) Coaxial feed, (b) Microstrip line, (c) Proximity-coupled feed, and (d) Aperture-coupled feed

Proximity coupling has the largest bandwidth and low spurious radiation. The patch is present on top of the first substrate while the second substrate contains the microstrip feed line on the upper side and the ground plane on the lower side in this technique. Aperture coupled feed consists of two substrates separated from the ground plane. The energy of the microstrip feed line present on the bottom side of the lower substrate is coupled to the patch through a slot in the ground plane separating the two substrates. The ground plane isolates the feed from radiation element and minimizes interference of spurious radiation.

5. Advantages and disadvantages of patch antenna

Microstrip antennas are inexpensive and easy to manufacture using modern printed circuit technology (PCB). It can enjoy all the advantages of PCB with all of the power dividers, matching networks, phasing circuits, and radiators. In addition, as the backside of the micro strip antenna is a metal ground plane, the antenna can be directly placed onto a metallic surface of an aircraft or missile. Some of the preeminent advantages of the microstrip antennas are listed below:

- Low profile, light weight and small in size
- Easy to fabricate and low fabrication cost
- Easy to feed
- Easy to use in an array or incorporate with other microstrip circuit elements
- Can be made thin so that the aerodynamics of any aerospace vehicles would not be affected
- Can be easily mounted onto missiles, rockets and satellites without much alteration
- Possible to achieve linear, circular (left hand or right hand) polarizations with simple changes in feed position
- Easy to obtain dual frequency operations
- Compatible with modular designs (solid state devices such as oscillators, amplifiers, variable attenuators, switches, modulators, mixers, phase shifters, etc. can be added directly to the antenna substrate board)

- Feed line and matching networks are fabricated all together with antenna structure

The main disadvantages of microstrip antennas include potentially lower radiation efficiency compared with other antennas (although this depends significantly on the substrate permittivity and thickness) and small bandwidth. Some of the disadvantages are listed below:

- Low bandwidth (but can be improved by a variety of techniques).
- Efficiency is limited by conductor and dielectric losses (Conductor and dielectric losses become more severe for thinner substrates) and by surface-wave loss (Surface-wave losses become more severe for thicker substrates).
- Poor isolation between feed lines and radiating elements

B. Fractal antenna

1. Overview

Fractal belongs to a class of geometrical shapes that is composed of multiple iterations of a single elementary shape. The fundamental building blocks of fractals are the scaled versions of the fractal shape. The history of fractals has begun by the research of Gaston Julia, and continued with the findings of Benoit Mandelbrot. Mandelbrot extracted the “fractal” term from “frangere”, a Latin verb, meaning to break or fragment. He was examining the shapes created by Gaston Julia, by iterating a simple equation and mapping this equation in the complex plane, where Gaston Julia, a mathematician in the 1920’s (who was working without the benefit of computers) could not describe these shapes using Euclidean geometry. By studying fractals, a whole new geometry has been created by mathematicians depicting the universe; beyond the boundaries of Euclidean geometry. The complexity of nature is clearly captured by fractals than Euclidean geometry. The interpretation of mountains and clouds as cones and ellipsoids respectively in Euclidean geometry is not as accurate as fractal geometry [2].

The application of fractals can be found in various fields such as image compression algorithms, weather prediction, integrated circuits, filter design, fractal electrodynamics, and other disciplines. Fractal electrodynamics is one of the major applications of fractals, in which the fractal geometry is combined with electromagnetic theory to explore a new class of radiation, propagation, and scattering problems. Antenna theory and design have become one of the most promising areas of fractal electrodynamics research. Developed over the last 20 years, fractal antennas have proven to be the first fundamental important breakthrough in antenna technology in the last half century. A fractal element antenna is shaped using fractal geometry. Fractal antenna can produce fractal versions of all existing antenna types, including dipole, monopole, patch, conformal, spiral, helical and others, as well as compact variants of each, possible through fractal technology. The conventional antenna shape that is used as a starting geometry in designing fractal antenna is known as generator or initiator. In the presented work, fractal geometry is applied to microstrip patch antenna resulting in fractal patch antenna.

2. Characteristics of fractal antenna

Among several properties that characterize fractals, self-similarity/self-affinity and space-filling properties are of interest in terms of antenna design. The self-similarity and self-affinity properties of a fractal can be relatively understood as copies of the entire structure within the same structure at different scales. An image is reduced by the same factor in all directions for self-similarity; however, a self-affine fractal has a different scale factor for different directions. This unique feature of fractal geometry can provide additional flexibility in the antenna design, since by selecting the scale factors appropriately; resonances can be spaced by different factors. Hence, it has been perceived that self-similar/self-affine property of fractals is useful to design multi frequency antennas such as in Sierpinski Gasket [3].

Fractals are space-filling contours, meaning electrically large features can be efficiently packed into small areas. Since the electrical lengths play such an important role in antenna design, this efficiently packing can be used as a viable miniaturization technique. In antenna design using fractal geometry, removal of metallization results in the lengthening of current path resulting in reduction of resonant frequency which decreases the overall dimension at the required frequency. This efficient volume filling nature of fractal is useful to design small antennas such as Sierpinski carpet [4].

3. Different fractal structure

Fractal antennas can be designed in many shapes. Though different fractal geometries are available, a very few can be used in the design of microstrip antennas. This section will present a brief overview of some of the common fractal geometries that have been found to be useful in developing new and innovative designs for antennas.

a. Sierpinski gasket

Figure 2.4: Few stages of a Sierpinski gasket fractal

The procedure for geometrically constructing Sierpinski gasket fractal begins with an equilateral triangle contained in the plane. The next step in the construction process is to remove the central triangle with vertices that are located at the midpoints of the sides of the original triangle. This process is then repeated for the three remaining triangles in the next iteration. A similar procedure is continued in other stages as shown in Figure 2.4 [5]. The black triangular areas represent a metallic conductor, whereas the white triangular areas represent regions where metal has been removed.

b. Koch snowflake

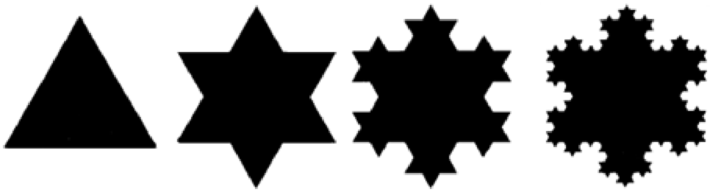

Figure 2.5: Few stages of a Koch snowflake

This fractal also starts out as a solid equilateral triangle in the plane. However, unlike the Sierpinski gasket, which is formed by systematically removing smaller and smaller triangles from the original structure, the Koch snowflake is constructed by adding smaller and smaller triangles to the structure in an iterative fashion. This process is clearly represented in Figure 2.5 [6], where the first few stages in the geometrical construction of a Koch snowflake are shown.

c. Hilbert curve

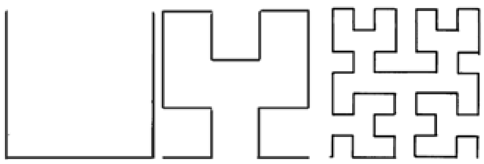

Figure 2.6: Few stages of Hilbert curve

The first four steps in the construction of the Hilbert curve are shown in Figure 2.6 [6]. The Hilbert curve is an example of a space-filling fractal curve that is self-avoiding (i.e. has no intersection points).

d. Minkowski island fractal

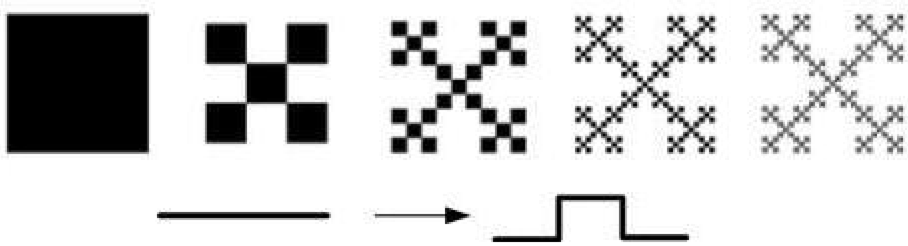

Figure 2.7: Few stages of Minkowski island fractal

The starting geometry (generator) of the Minkowski island fractal is a Euclidean square. Each of the four straight segments of the starting structure is replaced with the structure shown at the bottom of the Figure 2.7 [5]. This iterative generating procedure continues for an infinite number of times and few stages are shown in Figure 2.7.

e. Sierpinski carpet

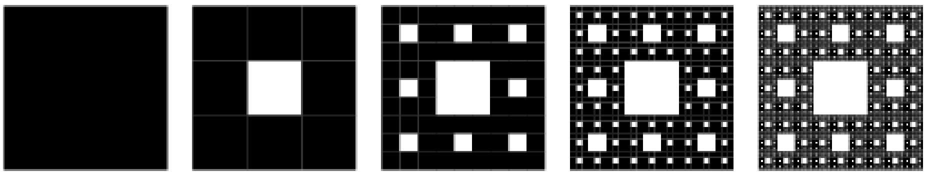

Figure 2.8: Few stages of Sierpinski carpet

In Sierpinski carpet design, initially the rectangular patch is divided into nine smaller congruent rectangles and the central rectangle is removed. In further iteration, the remaining eight rectangles are divided into nine more congruent rectangles, removing the central rectangle from each rectangle, and the similar procedure is followed in other iteration as depicted in Figure 2.8 [7].

C. Antenna glossary

1. Input impedance

Generally, input impedance is important to determine power transfer between transmission line and the antenna. The maximal power transfer only happens when the input impedance of the antenna and the input impedance of the transmission line is matched. If antenna impedance is different from the transmission cable impedance, reflected wave will be generated at the antenna terminal and travel back towards the energy source. This reflection of energy causes a reduction in the overall system efficiency. Hence, the most efficient coupling of energy between an antenna and its transmission line occurs when the characteristic impedance of the transmission line and the terminal impedance of the antenna are the same and have no reactive component. In this case, the antenna is considered to be matched to the line. The antenna is usually designed with terminal impedance of about 50Ω or 75Ω to match the common values of available coaxial cable.

2. VSWR

Voltage Standing Wave Ratio (VSWR) also called as Standing Wave Ratio (SWR) is the ratio between the maximum voltage and the minimum voltage along transmission line. The VSWR, which can be derived from the level of reflected and incident waves, is an indication of how well or efficiently an antenna terminal input impedance is matched to the characteristic impedance of the transmission line.

Increase in VSWR indicates an increase in a mismatch between the antenna and the transmission line and vice versa. The VSWR is given by equation (2.1).

$$\mathrm{VSWR} = \frac{1 + S_{11}}{1 - S_{11}} \qquad (2.1)$$

Where S_{11} is the return loss.

The value of VSWR in between 1 and 2 (1<VSWR<2) is needed for functional antenna. When none of the RF signal sent to the antenna is reflected at its terminal, there will be no standing wave on the transmission line and the VSWR has a value of one. However, if the antenna and transmission line are not matched, then some fraction of the RF signal sent to the antenna is reflected back along the transmission line. This causes a standing wave, characterized by maxima and minima, to exist on the line. In this case, the VSWR has a value greater than one. The VSWR is easily measured with a device and VSWR of 1.5 is considered excellent, while values of 1.5 to 2.0 is considered good, and values higher than 2.0 may be unacceptable.

3. Gain

The gain of an antenna in a given direction is the amount of energy radiated in that direction compared to the energy an isotropic antenna would radiate in the same direction when driven with the same input power. The gain is essentially a measure of the antenna’s overall efficiency. If an antenna is 100% efficient, it would have a gain equal to its directivity. However the isotropic antenna is hypothetical and there are many factors that affect and reduce the overall efficiency of an antenna. The maximum gain is the gain in the direction in which the antenna is radiating its most of the power. The gain of an antenna is usually expressed in decibels (dB). When the gain is referenced to the isotropic radiator, the units are expressed as dBi; but when referenced to the half-wave dipole, the units are expressed as dBd. The relationship between these units is given by equation (2.2).

$$G_{dBd} = G_{dBi} - 2.15dB \quad (2.2)$$

4. Radiation pattern

The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a constant distance. The radiation pattern is a reception pattern as well, since it also describes the receiving properties of the antenna. The radiation pattern is three dimensional, but usually the measured radiation patterns are a two dimensional slice of the three dimensional pattern, in the horizontal or vertical planes. These pattern measurements are presented in either a rectangular or a polar format. The radiation pattern in the region close to the antenna is not the same as the pattern at large distances. The term near field refers to the field pattern that exists close to the antenna, while the term far field refers to the field pattern at large distances. The far field is also called the radiation field. Ordinarily, the radiated power is of interest in terms of antenna performance, therefore antenna patterns are usually measured in the far field region. For pattern measurement it is important to choose a distance sufficiently large to be in the far field, which is out of the near field region.

5. Return loss

The return loss (S_{11}) is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line. The relationship between SWR and return loss is given by equation (2.3).

$$S_{11}(\text{dB}) = 20\log_{10}\frac{\text{SWR}}{\text{SWR}-1} \tag{2.3}$$

6. Bandwidth

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2:1. The bandwidth can also be described in terms of percentage of the center frequency of the band as given in equation (2.4).

$$\text{Bandwidth} = 100 \times \frac{F_H - F_L}{F_C} \tag{2.4}$$

Where F_H is the highest frequency in the band, F_L is the lowest frequency in the band, and F_C is the center frequency in the band.

7. Smith chart

The Smith chart is a tool to visualize the impedance of a transmission line and antenna system as a function of frequency. Smith chart is a graphical method of displaying the impedance of an antenna, which can be a single point or a range of point. Every point on this chart is the polar representation of the reflection coefficient. The center of the Smith chart is the point where the reflection coefficient is zero. This is the only point where no power is reflected by the load impedance.

III. Motivation

A. Miniaturization techniques

The design of compact antenna has been inevitable to cope with the rapid growth of wireless applications. Several methods have been suggested to reduce the size of microstrip antennas. They include the use of high dielectric constant substrates [8], modification of the basic patch shapes, short-circuiting the patch to the ground plane, superstrates [9] and other techniques that combine these three methods. With the use of the high dielectric constant substrates, the guided-wavelength underneath the patch is reduced and, hence the resonating patch size is also reduced. The reduction ratio is approximately related to the square root of 'ε_r' (permittivity). Employing high dielectric constant substrates is the simplest solution, but it exhibits narrow bandwidth, high loss and poor efficiency due to surface wave excitation. Modification of the basic patch shapes allows substantial size reduction; however, some of these shapes will cause the inefficient use of the available areas. Shorting-posts were used in different arrangements to reduce the overall dimensions of the microstrip patch antenna. This section will summarize some of the techniques adopted for size reduction in patch antenna and fractal antenna.

A circular patch antenna reduces the antenna radius by introducing slots in the circular microstrip disk antenna from the calculated result of 16.5 mm to 15.5 mm of the proposed one, yielding 12% size reduction in [10]. A square aperture coupled patch antenna with a cross shaped slot etched on its surface permits a patch size reduction of 32.5% in [11]. A two-port, meandered, square patch antenna with forty slits on the perimeter, ten on each side is investigated in [12] obtaining 48% reduction in size. The slits disturb the currents flowing on the surface, forcing them to meander and thus, increasing the electrical length of the patch antenna in both dimensions. A square patch with two orthogonal pairs of irregular and unsymmetrical slits is proposed in [13] to increase the surface current path length using slits in the antenna reducing the size to 40%. The antenna composed of the interconnection of four corner patches alternating with four strips and a fifth central patch represents a surface reduction of 60% in [14].

Apart from these techniques and unlike Euclidean geometry, application of fractal geometry is introduced in antenna designing for size reduction of patch antenna. The fractal structure's space filling property can be utilized to obtain compact size. Geometry optimization is adopted in miniaturization through fractal geometry. The application of modifying the geometry of conventional antenna is to increase their electrical length that lengthens the surface current paths and cause a shift in resonant frequency. Thus, by reducing the dimensions of the patch, we can get much more compact antenna than their conventional counterpart with the same resonant frequency. The various designs have been proposed to reduce the size of the antenna by integrating a fractal on a patch antenna. A microstrip antenna with Koch shaped fractal defects on the patch surface with RO4003 substrate is presented in [15] to reduce the size of the antenna. A small-size microstrip antenna is proposed in [16] by inserting Sierpinski carpets into the single patch and etching inner and outer edge according to Koch curves. The Koch island fractal boundary microstrip antenna has been numerically and experimentally analyzed in [17] to obtain the considerable area reduction. A fractal butterfly patch antenna is introduced in [18] as a miniaturized patch antenna. An edge-fed Sierpinski fractal based patch antenna having a significant size reduction is presented in [4].

B. Dual band techniques

Traditionally antenna operates at a single frequency band and a different antenna is needed for different application. This will cause a limited space and place problem. In order to overcome this problem, multiband antenna can be used where a single antenna can operate in many frequency bands and allow simultaneous transmission of video, voice, and data information. Two approaches are typically used to obtain wideband frequency ranges: the use of stacked patches and the activation of different modes of the patch. The first approach incorporates a multi layered patch substrate that will resonate at different frequencies. However, this method increases the height of the antenna. The second approach achieves dual-frequency operation by activating two modes under the patch, such as the TM10 and TM30 modes or the TM10 and TM01 modes. Several techniques have been explored and various approaches have been proposed for the methods of obtaining reconfigurable antennas. Some of them are briefly explained in following paragraphs.

The frequency tuning is achieved through rotational motion of the circular patch that contains four different shapes corresponding to a different set of resonant frequencies in [19]. The different RF shapes are three circular patches and one slotted triangle. The four sets of frequencies, “2.4-2.6 GHz”, “2.6-3.4 GHz”, “4-5 GHz” and “3-4 GHz/5.26-7 GHz” are covered by the four different shapes. A triangular shaped corner truncated short circuited antenna with V-shaped slot for dual band operation (2.5-2.55 GHz and 3.4 to 3.7 GHz WiMax bands) is proposed in [20]. The two resonant modes are excited simultaneously by placing two shorting walls with a V-shaped slot in the patch. A square patch antenna containing two rectangular slots properly positioned along its diagonal can function as a dual band antenna in [21]. Frequency diversity is achieved by controlling the electrical length through switching of the pin diode on the U-slot of a corner truncated square patch antenna in [22].

The self-similarity/self-affinity of fractal geometry can be employed to obtain multi band antenna. A square microstrip patch antenna embedded with modified Sierpinski gasket slots exhibits a larger size reduction along with dual-frequency operation in [23]. A dual wideband CPW-fed modified Koch fractal printed slot antenna containing simple tuning slot, suitable for WLAN and WiMAX operations, is proposed in [24]. A novel dual band fractal-shaped microstrip antenna for RFID applications designed to cover the frequency of ISM Bands (2.45 GHz and 5.80 GHz) is presented in [25]. A circular patch antenna with fractals produces a dual band operation for the C-band applications in [26].

IV. Antenna design

Today's wireless applications have challenged antenna designers with demands for low cost and compact sized multi band antenna yet with a simple radiating element, signal feeding configuration, good performance, and easy fabrication. A modified Sierpinski carpet patch antenna with inset fed is designed to obtain these results. This chapter explains the design specifications, design implementation strategy, simulation result, and measured results.

A. Design specifications

The resonant frequency f_r; dielectric material of the substrate ε_r; and thickness of substrate h; are the three essential parameters for the design of the patch antenna. A design frequency of 2.45 GHz and 5.8 GHz is chosen because of its low-cost components, located in the ISM band, and extremely low attenuation through the atmosphere. The designed antenna fulfills the requirements of ISM bands 2.45 and 5.8 GHz for RFID applications and other wireless applications. The patch is placed on an FR4 substrate. The design specification of fractal patch antenna is given in Table 4.1.

Table 4.1: Design specifications of microstrip patch antenna

Antenna	Fractal Patch Antenna
Substrate	FR4
Relative permittivity	4.7
Dielectric loss tangent	0.019
Height of the substrate	1.6 mm
Operating frequency	2.45 GHz and 5.8 GHz
Feeding method	Microstrip line feed
Polarization	Linear

B. Design procedure

This section begins with the procedures to design a conventional rectangular patch antenna which is followed by the microstrip inset feeding technique adopted in the presented work. Then, the procedures to obtain ground plane dimension and applying fractal structure to the conventional patch are explained.

1. Rectangular patch design

A rectangular microstrip patch antenna is taken as the generator of the fractal antenna. The most popular models for analysis of microstrip patch antennas are the transmission line model, cavity model, and full wave model (which include primarily integral equations/moment method). The transmission line model is the simplest of all and it gives good physical insight but it is less accurate and is more difficult to perform model coupling. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give less insight as compared to the two models mentioned above and are far more complex in nature. In our case, transmission line model is adopted to design the antenna. Basically the transmission line model represents the micro strip antenna by two slots of width W and height h, separated by a transmission line of length L. The microstrip is essentially non homogeneous line of two dielectrics, typically the substrate and air. The patch dimensions are calculated by following a simplified formulation in transmission line model [27].

For an efficient radiator, a practical width that leads to good radiation efficiencies is given by

$$W = \frac{V_0}{2f_r}\left(\frac{\varepsilon_r + 1}{2}\right)^{-1/2} \tag{4.1}$$

Where W, f_r, ε_r, V_0 are the width of the patch, resonant frequency, dielectric constant of the substrate, and free space velocity of light respectively.

The effective dielectric constant is essentially constant for low frequencies. At intermediate frequencies its value begins to monotonically increase and eventually approach the values of the dielectric constant of the substrate. The effective dielectric constant can be obtained by

$$\varepsilon_{eff} = \left(\frac{\varepsilon_r + 1}{2}\right) + \left(\frac{\varepsilon_r - 1}{2}\right)\left(1 + 12\frac{h}{W}\right)^{-1/2} \tag{4.2}$$

Where ε_{eff} is effective dielectric constant of the substrate.

The dimension of the patch along its length is extended on each end by a distance ΔL owing to the fringing effect. A very popular and practical approximation relation for the normalized extension of the length is given by

$$\Delta L = 0.412h \frac{(\varepsilon_{eff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{W}{h} + 0.8)} \qquad (4.3)$$

Where h is the height of the substrate.

The actual length L of the patch is given by

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{eff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \qquad (4.4)$$

Where μ_0 and ε_0 are permeability of free space and permittivity of free space respectively.

2. Feeding techniques

Antenna performance depends largely on feeding technique and optimum feed point. In single layer antenna design, microstrip line and coaxial probe feeding are widely used because of its simplicity in designing and fabrication. The impedance control in microstrip feeding can be obtained by edge feeding, inset feeding, and feeding through an additional matching network called as a quarter - wave transformer. The presented work has adopted a microstrip line feeding with inset feed as feeding method. The inset feed introduces a physical notch, which in turn introduces a junction capacitance. The physical notch and its corresponding junction capacitance influence the resonance frequency. As the inset feed point moves from the edge decreases monotonically and reaches zero at the center. The input impedance of the inset-fed microstrip patch antenna mainly depends on the inset distance (length of the notch) and to some extent on the inset width (width of the notch). The resonant frequency is much affected by the variation in the inset width than in inset length [28].

The inset distance is calculated by using equation (4.5).

$$R_{50} = R_{inp} \cos^2 \frac{\Pi y_0}{L} \tag{4.5}$$

Where R_{50}, R_{inp}, y_0 are 50Ω resistance, input impedance of the antenna and inset distance respectively.

3. Ground dimensions

The transmission line model is only applicable to infinite ground planes; however, for practical considerations, a finite ground plane is used. The size of the ground plane should be greater than the patch dimensions by approximately six or twelve times the substrate thickness so that the results are similar to those obtained using an infinite ground plane. Hence, the ground plane dimensions are given by

$$L_g = 6h + L \tag{4.6}$$

$$W_g = 6h + W \tag{4.7}$$

Or

$$L_g = 12h + L \tag{4.8}$$

$$W_g = 12h + W \tag{4.9}$$

Where L_g, and W_g, are the length of the ground plane and the width of the ground plane respectively.

For the proposed design, equation (4.9) is selected to calculate the width of the ground plane and the length of the ground plane is modified as shown in equation (4.10) for better performance of the antenna.

$$L_g = 12h + L + L_f \tag{4.10}$$

Where L_f is the length of the feed.

4. Fractal iterations

In this thesis, simple fractal structure Sierpinski carpet is etched on the rectangular patch antenna. The conventional rectangular patch antenna is the generator of fractal iterations. The patch is divided into nine smaller congruent rectangles, and the central rectangle is removed and similar procedure is followed in subsequent iterations for the remaining rectangles.

The iterative process is based on the following rules:

$$N_n = 8^n \tag{4.11}$$

$$L_n = \left(\frac{1}{3}\right)^n \tag{4.12}$$

$$A_n = \left(\frac{8}{9}\right)^n \tag{4.13}$$

Where N_n is the number of rectangles covering the radiating material, L_n is the length ratio, and A is the ratio for the fraction area. As the iterations are added, an area of the radiating patch is removed.

C. Simulation procedure and its result

The antenna is simulated using a finite element method (FEM) based Ansoft HFSS Ver.10, which is a high-performance full-wave EM field simulator for arbitrary 3D volumetric passive devices using the Microsoft Windows graphical user interface. HFSS pioneered the use of the FEM for EM simulation by developing and implementing technologies such as tangential vector finite elements, adaptive meshing, and adaptive Lanczos-Pade sweep (ALPS). This section will explain a stepwise procedure applied to obtain miniaturized dual band fractal patch antenna. In all simulated antennas the calculated values did not resonate at required frequencies. Therefore, parametric analysis of HFSS is performed in all designed antennas.

1. Edge-fed Sierpinski carpet fractal antenna

Miniaturization techniques for fractal structures involve the process of removing some part of the basic structure. In the proposed design, the removal procedure is done in an iterative fashion. The Sierpinski carpet of different iteration order is etched on the edge-fed rectangular patch antenna. Initially, the rectangular patch antenna is designed using the procedure mentioned in section IV (B) under "Rectangular Patch Design" title. The microstrip line feeding is chosen because of its ease in fabrication and integration. The iteration of Sierpinski Carpet Microstrip Patch Antenna (SCMPA) is performed up to 3rd order. The designed rectangular patch antenna (Generator) and its iterations are shown in Figure 4.1(a), 4.1(b), 4.1(c) and 4.1(d) respectively. The details can be seen in [4].

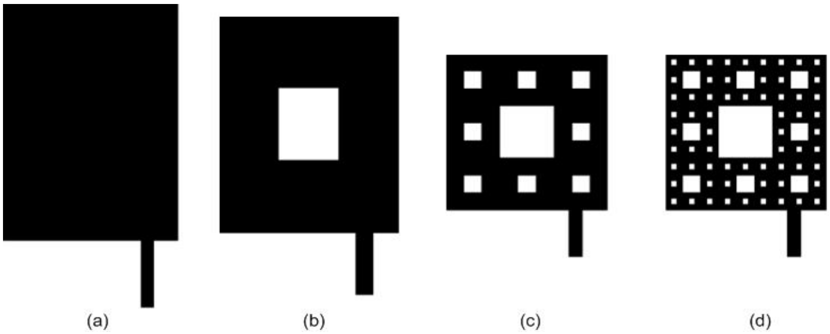

Figure 4.1: Edge-fed Sierpinski carpet (a) Generator (b) Iteration 1 (C) Iteration 2 (d) Iteration 3

Table 4.2: Dimension and output of edge fed Sierpinski carpet and its iterations

Antenna		**Generator**	**Iteration 1**	**Iteration 2**	**Iteration 3**
Dimension	W (mm)	27	23.58	**23.66**	23.66
	L (mm)	34.41	34.41	**32.4**	32.4
	Area reduction		12.67%	**21.19%**	21.19%
Output	Return loss (dB)	36.17	40.73	**34.11**	39.47
	Impedance BW (MHz)	60 MHz	60 MHz	**60 MHz**	60 MHz
	Impedance (Ω)	50.42	49.13	**50.63**	50.13
	Gain (dB)	3.68	2.64	**2.46**	2.43
	VSWR	1.03	1.02	**1.04**	1.02

Table 4.2 compares the size reduction and antenna performance of all four antennas. The area reduction of 12.67%, 21.19% and 21.19% with respect to the conventional rectangular patch antenna (Generator) is seen in 1st, 2nd and 3rd iteration respectively. The antenna performances in terms of reflection loss, impedance matching, and antenna gain is almost similar in 1st, 2nd and 3rd iteration as depicted in Table 4.2. Hence, it is verified that size reduction through fractal

geometry does not affect antenna performances. Also, it is perceived that the increment of the iteration order of fractal antenna leads to a higher degree of miniaturization. The antenna performance and size reduction of the 2nd and 3rd iteration are similar. However, the 3rd order antenna is more complicated in structure and can have fabrication inaccuracies. Thus, 2nd fractal iteration is chosen to perform further modifications in its structure in order to obtain the dual band antenna.

The return loss of 2nd order iterated edge-fed Sierpinski fractal antenna is shown in Figure 4.2. This antenna resonates at 2.45 GHz but also contain unwanted frequencies as shown in this graph.

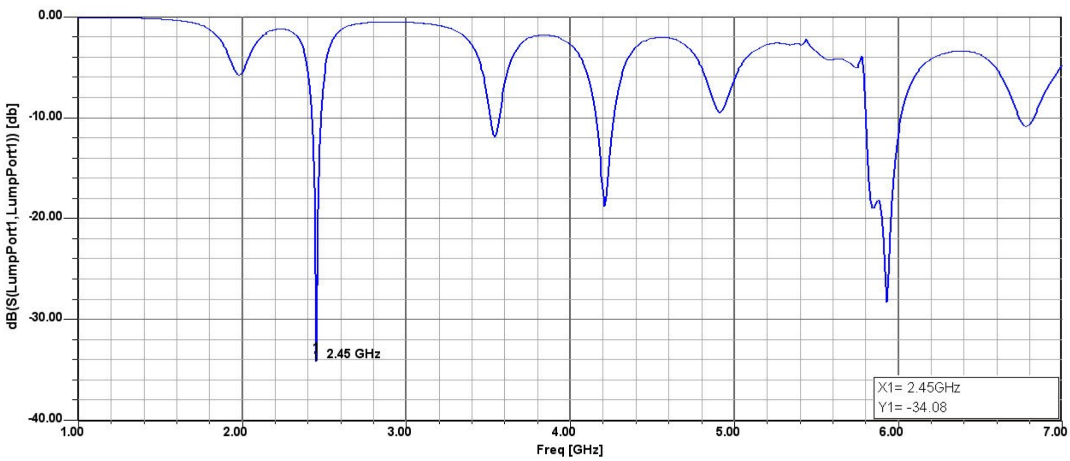

Figure 4.2: Return loss of 2nd order edge-fed Sierpinski carpet

2. Inset-fed Sierpinski carpet fractal antenna

In 2nd Step, the feeding configuration of 2nd order SCMPA is changed from edge-fed to inset-fed. Figure 4.3 shows the inset-fed modified SCMPA, where the fractal carpet is replaced by the inset notch in one of the sections. After introducing inset in 2nd order SCMPA the unwanted harmonics are removed. Figure 4.4 depicts the return loss of 2nd order inset fed modified SCMPA antenna which shows a frequency dip at 2.45 and 6.04 GHz. The unwanted harmonics have been removed without using an additional filter component. However, the obtained higher frequency is not according to our objective. The higher frequency should be obtained at 5.8 GHz. Hence, this inset-fed modified SCMPA had undergone further modification.

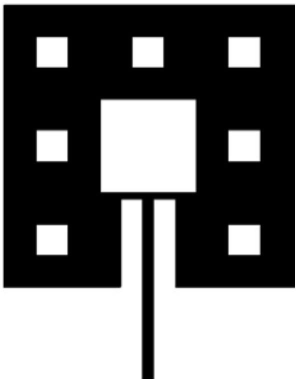

Figure 4.3: Second order inset-fed modified Sierpinski carpet

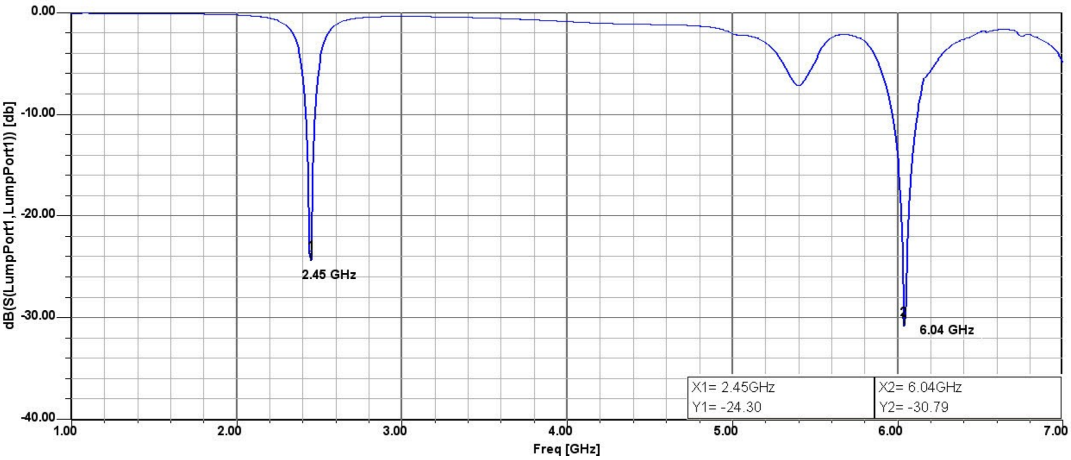

Figure 4.4: Return loss of 2nd order inset-fed modified Sierpinski carpet

3. Inset-fed Sierpinski carpet fractal antenna with perturbation and stub (Dual band antenna)

To obtain the higher frequency at 5.8 GHz, a perturbation is added at the corner of the patch. This resulted in a higher frequency of 5.8 GHz. But the modified antenna with perturbation did not result in a better impedance match. Hence, small stub is added in the feed line. The simulation procedure of the antenna needs to go through a number of parametric analyses in order to resonate at 2.45 GHz and 5.8 GHz with fine impedance matching. Thus, obtained dual band miniaturized antenna is shown in Figure 4.5 with its dimension in millimetre.

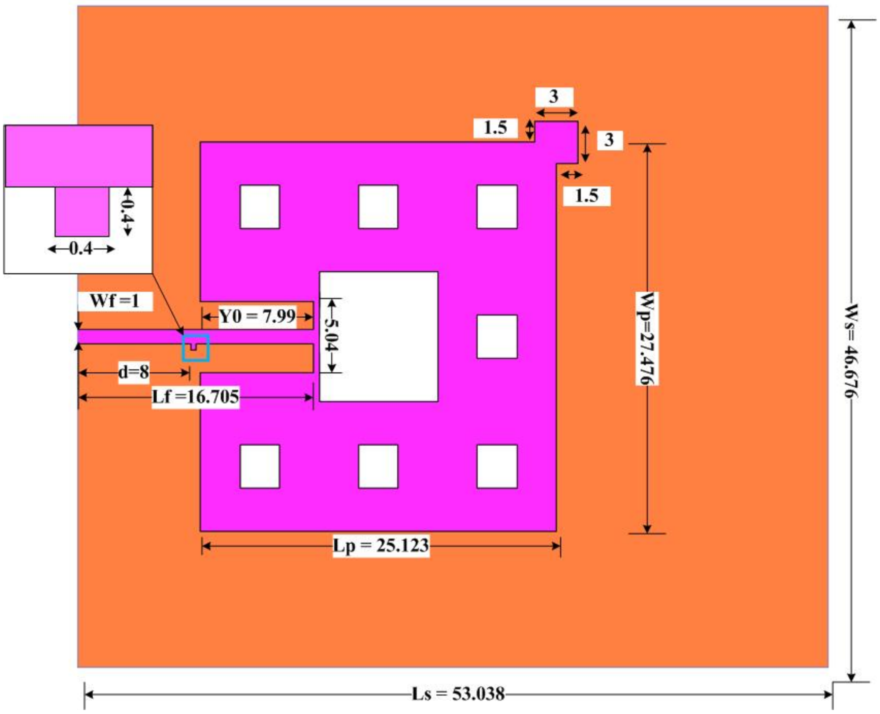

Figure 4.5: Dual band fractal antenna

The performance of miniaturized dual band modified SCMPA is demonstrated in terms of return loss, impedance matching, radiation pattern, and VSWR.

The simulated return loss (S_{11} versus frequency) of the dual band fractal antenna is shown in Figure 4.6. The antenna is resonated at 2.45 GHz and 5.8 GHz. The return loss is 35.52 dB and 39.56 dB at 2.45 GHz and 5.8 GHz respectively. The impedance bandwidth is the difference in frequency at -10 dB. The impedance bandwidth of 60 MHz and 200 MHz is obtained at 2.45 GHz and 5.8 GHz respectively. The bandwidth of the antenna in term of percentage is defined by

$$\text{Bandwidth} = \frac{f_{max} - f_{min}}{f_r} \times 100\% \qquad (4.14)$$

Where f_{max} and f_{min} are determined at -10dB. f_r is the resonance frequency. The bandwidth percentage is 2.44% and 3.44% at 2.45 GHz and 5.8 GHz respectively.

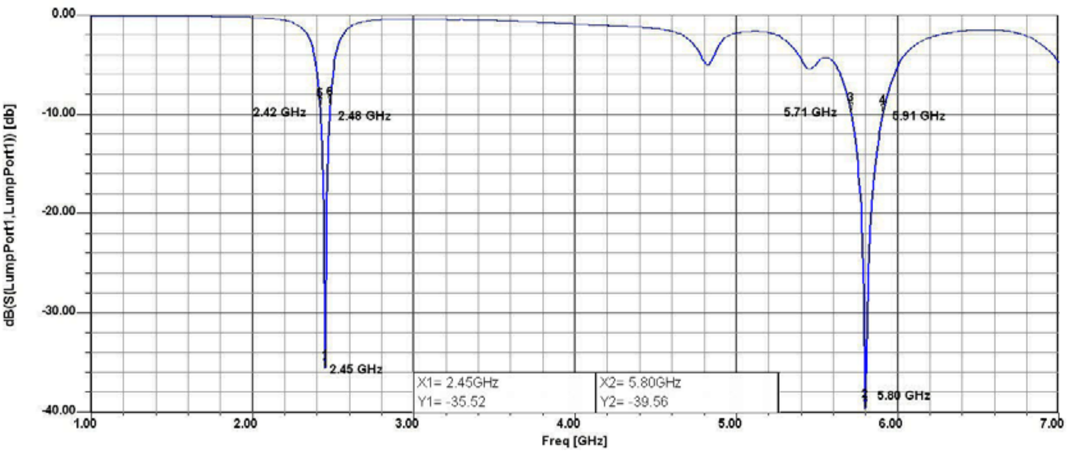

Figure 4.6: Return loss of dual band antenna

The impedance of the antenna and transmission cable must be same for an efficient transfer of energy. The basic objective is to obtain an impedance of 50 Ω of the antenna, as the transmission line is typically designed with this impedance. An impedance matching circuit is required in the case of a mismatch. Figure 4.7 shows the simulated scattering parameter of the designed antenna at 2.45 GHz and 5.8 GHz. Smith chart is a plot of the reflection coefficient. Since the reflection coefficient corresponds directly to impedance, Smith chart is the plot of the impedance. The smith chart has 2.45 GHz and 5.8 GHz at the center of the chart which verifies that designed antenna have zero reflection coefficients and an antenna is perfectly matched.

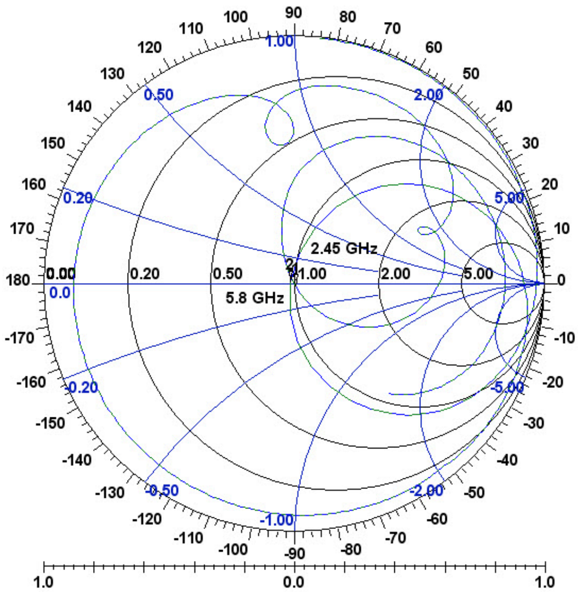

Figure 4.7: Smith chart of dual band antenna

The obtained impedance from the simulation is nearly equal to 50 Ω as shown in Impedance Versus Frequency curve in Figure 4.8. The real part of Z parameter is nearly equal to 50 Ω and Imaginary part is around 0° at both frequencies. Figure 4.7 and Figure 4.8 shows that good impedance matching is obtained at both the frequency band even when the size is reduced through fractal geometry.

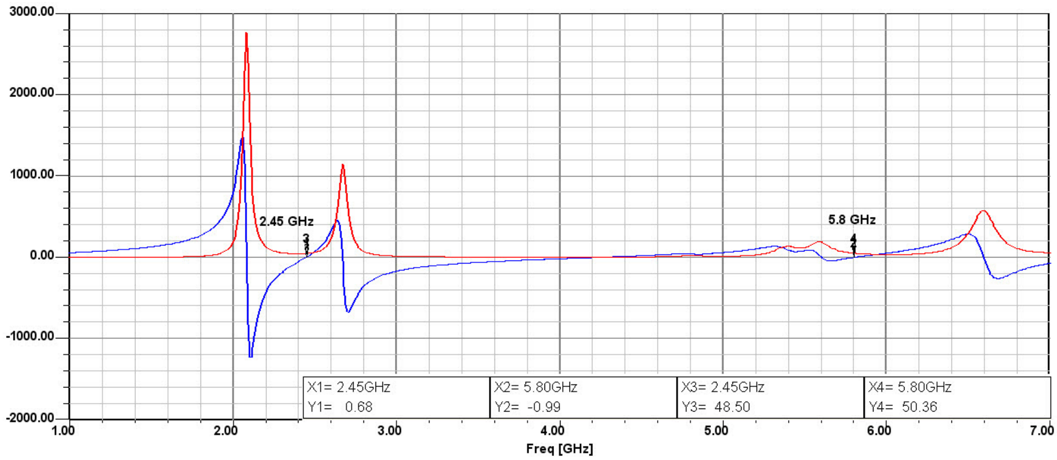

Figure 4.8: Impedance versus frequency curve of dual band antenna

The far-field simulated radiation pattern at 2.45 GHz and 5.8 GHz is shown in Figure 4.9 (a) and 4.9 (b) respectively. Two radiation curves with Φ= 90 (red) and Φ = 0° (blue) are shown for θ varying from -180˚ to 180˚ in both the figures. The maximum simulated gain of 2.651 dB and 2.676 dB is achieved at 2.45 GHz and 5.8 GHz respectively.

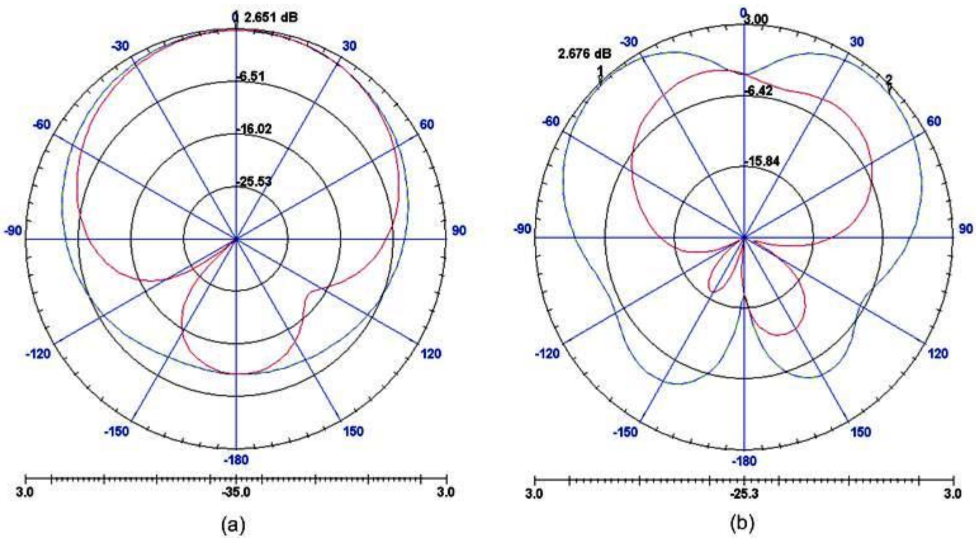

Figure 4.9: Radiation pattern of dual band antenna (a) at 2.45 GHz (b) at 5.8 GHz

The VSWR characteristics of the designed antennas fall in the range of 1 to 2. The VSWR is seen as 1.03 and 1.02 respectively at 2.45 GHz and 5.8 GHz as illustrated in Figure 4.10.

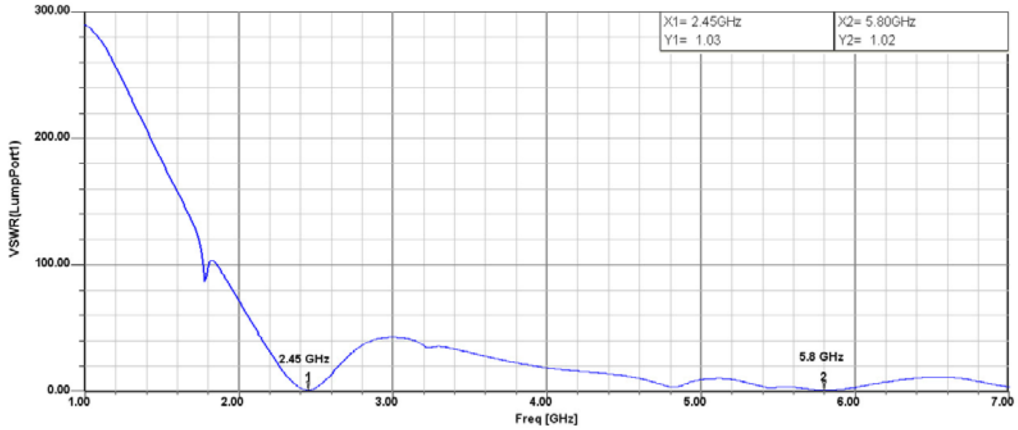

Figure 4.10: VSWR of dual band antenna

Table 4.3 compares the simulated result of 2nd order SCMPA (Figure 4.1 (C)) and proposed dual band antenna. The dual band antenna is 25.98% smaller than a conventional rectangular patch antenna. It is seen that antenna performance of the dual band antenna is similar to 2nd order SCMPA yet having the advantage of the greater size reduction with multi band functionality.

Table 4.3: Comparison of 2nd order SCMPA and dual band antenna

Antenna	**2nd Order SCMPA**	**Dual Band**	
	2.45 GHz	2.45 GHz	5.8 GHz
Return loss	34.11	35.52	39.56
Impedance BW	60 MHz	60 MHz	200 MHz
Impedance	50.63	48.5	50.36
Gain	2.46	2.651 dB	2.676 dB
VSWR	1.04	1.03	1.02
Area reduction (%)	21.19	25.98	

D. Fabrication result

The modified second order Sierpinski fractal with perturbation and stub has noteworthy size reduction and is able to operate at 2.45 GHz and 5.8 GHz. Also, the size reduction and dual band functionality did not affect the antenna performance as shown in Table 4.3. Thus, the designed dual band antenna is fabricated on FR4 substrate. The fabricated antenna is shown in Figure 4.11.

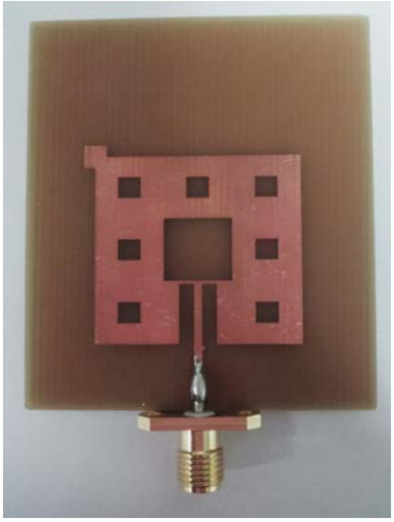

Figure 4.11: Fabricated dual band antenna

The measurement of return loss, smith chart and VSWR is carried out using an Agilent Network Analyzer, N5230A. SMA connectors are used to interface to the network analyzer. The measured return loss is shown in Figure 4.12. The antenna is resonated at 2.45 GHz and 5.76 GHz with a return loss of 21.2 dB and 18.22 dB respectively. The impedance bandwidth is 50 MHz and 120 MHz at 2.45 GHz and 5.76 GHz respectively. The bandwidth percentage calculated from equation (4.14) is 2.04% and 2.08% at 2.45 GHz and 5.76 GHz respectively. The measured Smith chart and VSWR is shown in Figure 4.13 and Figure 4.14 respectively.

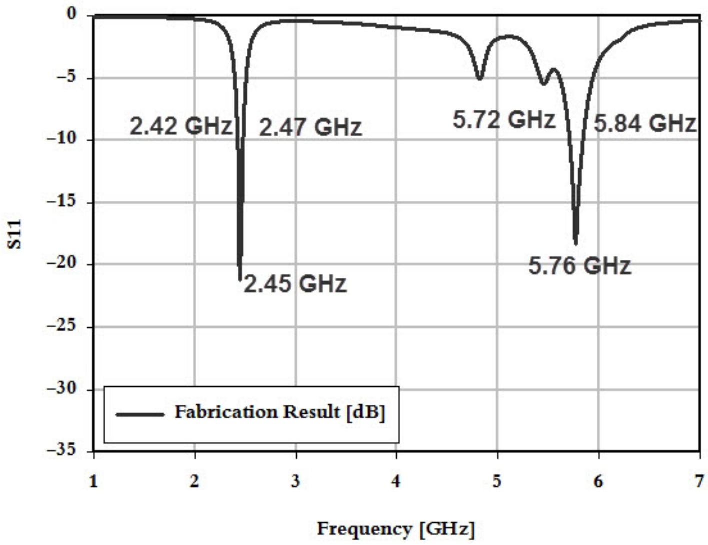

Figure 4.12: Measured return loss of dual band antenna

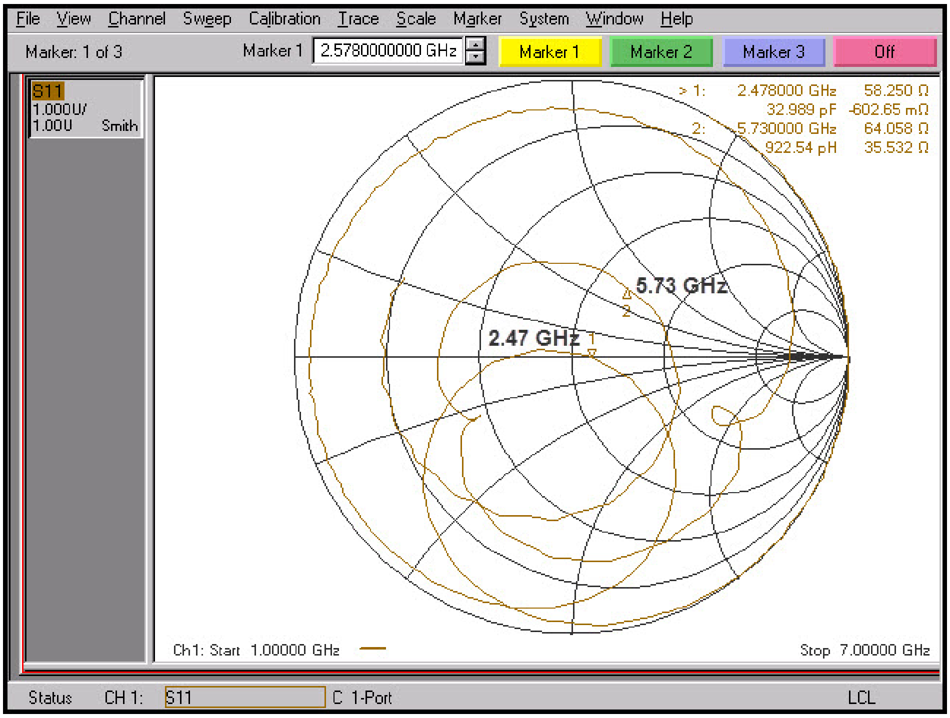

Figure 4.13: Measured Smith chart of dual band antenna

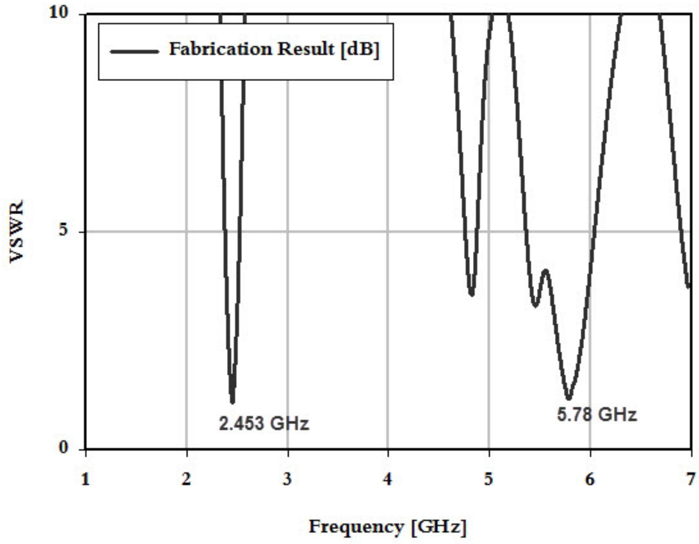

Figure 4.14: Measured VSWR of dual band antenna

A comparison between the simulated and measured outputs is listed in Table 4.4. The higher frequency has shifted slightly in frequency versus S_{11} curve. However, low frequency is obtained exactly at 2.45 GHz. The measured impedance bandwidth and bandwidth percentage are also similar compared to simulated result. In the Smith chart resonant frequency is shifted to 2.47 GHz and 5.73 GHz as shown in Figure 4.11. The reason for this shift can be due to the FR4 board has relative permittivity value varying from 4.7 to 4.9. However, simulation is done with permittivity of 4.7. Also, the measurement is done in an open room and environmental effects can degrade the performance. The frequency is slightly shifted in the VSWR graph as shown in Figure 4.11. Nevertheless, the VSWR is still in between 1 and 2. The deviations observed between the simulated and measured results are partly attributed to the environmental effects and partly attributed to inaccuracies in the antenna manufacturing process. And also other factors may have effects such as chemical used in etching accuracy and surface finish. The shape of the simulated and measured waves appears almost similar although their reading points vary slightly.

Table 4.4: Comparison of simulated and measured result of dual band antenna

	Simulated		**Measured**	
Resonant frequency	2.45 GHz	5.8 GHz	2.45 GHz	5.76 GHz
Return loss	35.52 dB	39.58 dB	21.2 dB	18.22 dB
Impedance bandwidth	60 MHz	200 MHz	50 MHz	120 MHz
Bandwidth percentage (%)	2.44	3.44	2.04	2.08
	Simulated		**Measured**	
Resonant frequency	2.45 GHz	5.8 GHz	2.453 GHz	5.78 GHz
VSWR	1.03	1.02	1.108	1.191

V. Conclusions and future work

The design of modified Sierpinski fractal based microstrip patch antenna having a noteworthy size reduction and operating at two frequencies, 2.45 GHz and 5.8 GHz is presented in this thesis. The simulation procedure went through a series of steps to obtain a compact dual band antenna. Eventually, it is verified that modified 2^{nd} order Sierpinski carpet patch antenna with perturbation and the stub can function as multi band antenna with reduced size. The fractal iteration of 2^{nd} order reduced the size because of the space filling nature of fractal geometry. The self similarity characteristic of fractal generated two resonating frequencies but higher frequency is not seen at 5.8 GHz. Therefore, the perturbation is added to make this higher frequency resonate at 5.8 GHz and to obtain fine impedance matching at both the frequencies, a stub is added to the feed line.

The simulations of all antennas are done in HFSS version 10. The designed antenna has simulated return loss greater than 35 dB with good impedance matching in both the frequencies. The simulated gain of 2.651 dB and 2.676 dB is attained at 2.45 GHz and 5.8 GHz respectively with size reduction of 25.98%. The designed dual band antenna is fabricated on FR4 substrate to verify its simulation result. The measured return loss is obtained at 2.45 GHz and 5.76 GHz with considerable return loss and impedance bandwidth. The measured VSWR is also seen in between 1 and 2. The slight deviation seen in fabricated result is because of the external environment and inaccuracies in the antenna manufacturing process.

Taking everything into consideration, it can be concluded that applying fractal geometry to patch antenna is a simple and effective technique to obtain multi band antenna with minimal size. The proposed design can be etched on some other substrates such as Teflon with low permittivity for higher gain. Also, its array antenna can be designed to increase the gain of the antenna. A stacked Sierpinski carpet fractal antenna can be designed instead of a single antenna to obtain wide bandwidth. This antenna can be integrated with rectifier circuit generating rectenna which can harvest RF energy at dual frequencies.

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