A NOVEL HILBERT FRACTAL ANTENNA FOR WIMAX APPLICATIONS AND MILITARY COMMUNICATIONS

A PROJECT REPORT

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BONAFIDE CERTIFICATE

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INTERNAL EXAMINER

EXTERNAL EXAMINER

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ABSTRACT

To meet the growing demand for bandwidth in communication, different antennas have to be designed. In this paper we aim at developing two novel antennas that is compatible with the WiMAX applications and Military Communications. The novel antenna should have a compact size, low profile, low power, low cost, easy fabrication, and sufficient transmission range. In this study, we investigate a novel miniature antenna based on the Hilbert Curves. Space-filling geometries such as the fractal Hilbert curve have been proved to be useful to design miniature antennas, high-directive radiators and high-impedance surface. We investigate these antennas by focusing on the 1 GHz to 12 GHz band.

This paper is organized as follows. First, a miniature Hilbert antenna is designed for application in the 2.95–3.14 GHz band within a 10 dB bandwidth. Then the ground plane is modified to improve the gain of the antenna. By employing Hilbert geometry, an overall size reduction of 52.5% was achieved compared to the conventional rectangular patch antenna. The bandwidth of these antenna less than 10 dB are 190 MHz (2.96–3.14 GHz) which is meant for WiMAX applications and 1.67 GHz (6.97-8.64 GHz) which is meant for uplink transmission in military communication satellite. The percentage of the bandwidth is 6.27%. and 20.97 % respectively. Then an array of 20×10 elements is created which improves the gain tremendously. The gain of the 200 element array is 14.7 dB. The measurement results indicate that the antenna shows good performance.

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LIST OF ABBREVATIONS & ACRONYMS

LPDA	**Log Periodic Dipole Array**
HPBW	**Half Power Beam Width**
VSWR	**Voltage Standing Wave Ratio**
HFSS	**High Frequency Structural Simulator**
CPW	**Co Planar Waveguide**
WiMAX	**Worldwide Interoperability For Microwave Access**
VHF	**Very High Frequency**
UHF	**Ultra High Frequency**
UMTS	**Universal Mobile Telecommunication System**
Wi-fi	**Wireless Fidelity**
SCFA	**Sierpinski Carpet Fractal Antenna**
PTP	**Point To Point**
BFWA	**Broadband Fixed Wireless Access**

CHAPTER 1

INTRODUCTION

1. Fractals

According to Webster's dictionary, a fractal is defined as being "derived from the latin fractus which means broken, irrespective of various extremely irregular curves or shapes that repeat themselves at any scale on which they are examined. The term "Fractal" means linguistically "broken" or "fractured" from the Latin "fractus." The term was coined by Benoit Mandelbrot, a French mathematician about 20 years ago in his book "The fractal geometry of Nature". Names like G. Cantor (1872), G. Peano (1890), D. Hilbert (1891), Helge von Koch (1904), W. Sierpinski (1916) Gaston Julia (1918) and other personalities played an important role in Mandelbrot's concepts of a new geometry. Nathan Cohen, professor at Boston University built the first known fractal antenna in 1988. Cohen's efforts were first published the first scientific publication about fractal antennas in 1995, since then a number of patents have been issued.

Fractal is a geometrical shape that has the property of selfsimilarity, which means, each part of the shape is a smaller version of the parent shape or original shape. Fractals can be classified as natural and mathematical fractals.

1.1.1 Natural antennas:

As the name suggests, the fractals which are found in nature all around us are natural antennas. These are also called as random fractals. These geometries have been used to characterize the structures which are difficult to define with the Euclidean geometries. Most of these geometries are infinitely further divisible, each division being copy of the parent. Some of the examples of natural antennas are length of coastline, branches of trees and plants, rivers, galaxies etc.

1.1.2 Mathematical antennas:

The mathematical antennas are those which undergo iterations based on equations. They are also called as deterministic fractals. The deterministic fractals are visual. The two dimensional fractals are made of a broken line called the generator. Each of the segments which form the broken line is replaced by broken line generator at corresponding scale for a step of algorithm. And repeating the steps infinitely results in geometrical fractals. The examples of mathematical antennas are Koch, sierpinski gasket, Mandelbrot sets etc. The number of iterations is based on iterated function systems.

1.2. Fractal Dimensions

The term "Dimension" in mathematics has different meanings. The "Topologic Dimension" is the most common of them in which a point has the dimension 0, a line has the dimension 1, a surface has the dimension 2 and a cube has dimension 3. In other words, one could describe the dimension of an object with a number of parameters or coordinates.In fractal geometries, fractal dimension is the unique feature. There are different notations of the dimension of fractal geometries, such as topological dimension, Hausdorf dimension Box counting dimension, and self-similarity Dimension. Among these, the self-similarity dimension is one of the most important parameters for the characterization of the fractal geometries. The self-similarity dimension of the fractal geometry is defined as

$$D_s = \log(N) / \log(1/s)$$

where N is the number of self-similar copies and s is the scale factor.

1.3. Iterated Function Systems: Language of Fractal

Fractals have some infinitely repeating pattern. Instead of the word "repeat" we use a mathematical synonym "iterate" and the process is called iteration. Iterative function system (IFS)is an extremely versatile tool for convenient generation of fractal geometries. The iterative function system is a collection of self-affine transformations given by,

$$W(x) = A\,x + t = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x1 \\ x2 \end{bmatrix} + \begin{bmatrix} e \\ f \end{bmatrix}$$

The matrix A is given by:

$$A = \begin{bmatrix} \left(\frac{1}{s}\right)\cos(\theta) & -\left(\frac{1}{s}\right)\sin(\theta) \\ \left(\frac{1}{s}\right)\sin(\theta) & \left(\frac{1}{s}\right)\cos(\theta) \end{bmatrix}$$

The parameters a, b, c and d are defined by scaling and rotation of initial geometry and e and f denote the translation.

Fractal design has two components:

i) Initiator (0th stage): the basic shape of the geometry.

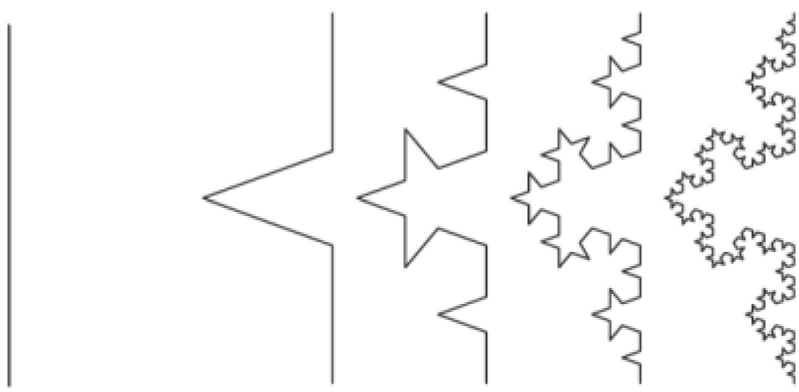
ii) Generator: the shape which gets repeated in a pattern on the initiator in subsequent stages of different dimensions.

There are several techniques to develop and to produce fascinating images. Two techniques popularized by Mandelbrot's book are the

1.3.1 Koch construction

One starts with a straight line, which is the initiator. This is partitioned into any number of equal, say three parts, and the segment at the middle is replaced with two others of the same length. This results in the first iterated version of the geometry and is called the generator. The higher iterations of the geometry can be obtained by further repeating this process. Each segment in the first iterated curve is ⅓ the length of the initiator.

Figure 1.1 Geometrical Construction of Standard Koch Curve



1.3.2. Function iteration in the complex domain.

The generator is used to add or subtract from the area of the initiator n from each subsequent iteration stage in a fixed pattern thus culminating in the fractal structure.Random processes can be used to generate random fractals.

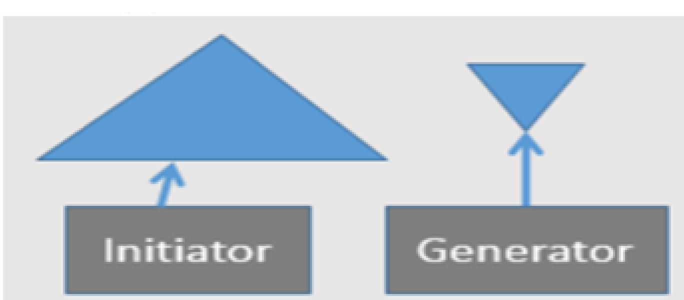


Figure 1.2 Initiator and Generator of a Sierpinski Gasket Fractal

1.4. Why Fractals are used?

Small antennas are of prime importance because of available space limitations on the devices and the oncoming deployment of diversity and multi input and multi output (MIMO) systems. Fractal geometry provides the solution by designing compact and multiband antennas in a most efficient and sophisticated way with better antenna performance. Fractals can be used in two ways to enhance the antenna designs. The first method is in the design of miniaturised antenna elements. The second method is to use self-similarity in the geometry.

1.4.1 Fractals as space filling geometries

Hilbert curve is widely used in the miniaturization of antenna element because of its space-filling property. A line can meander in such a way as to effectively almost fill the entire sheet. The space filling property lead to the curves that are electrically long but fit into a compact space and lead to the miniaturization of the antenna elements. Due to this space filling property, the fractal antennas occupy space in more effective manner as compared to the traditional Euclidean antennas and hence results in miniature antennas.

1.4.2 Fractals as multiband antennas

Fractal show multiband or log periodic behaviour that has been attributed to self-similar scale factor of the antenna geometry. When an object is composed of smaller copies of the original geometry, it is said to be self-similar. A self-similar object can be described as a cluster, which is again made up of smaller clusters that are identical to the entire geometry. Thus, within the whole geometry, an infinite number of similar copies can be found. Hence, fractal geometries are said to have no characteristic size.

1.5 Fractal Geometries

Many patterns in the nature are so irregular and fragmented that they exhibit not only a higher degree, but also a higher level of complexity. Hence, Mandelbrot proposed a newgeometry and its use in various diverse fields. The geometry describes many of the irregular and fragmented patterns of nature around us. Mandelbrot coined the term 'fractal' from theLatin word 'frangere' which means to break, to create irregular fragments. He used the term fractal to describe some complex and convoluted objects such as mountains, coastlines and many other natural phenomenon.

1.5.1 Sierpinski Carpet

Sierpinski carpet fractal is realized by successive iterations on a simple square patch, which is called as the zeroth order iteration. A square of dimension equal to one third of the mainpatch is subtracted from the centre of the patch to obtain the first order iteration. This process is repeated continuously further to obtain next order iterations. The pattern is defined in such a way that each consequent etched square is one third in dimension as compared to the previous one sharing the same centre point.

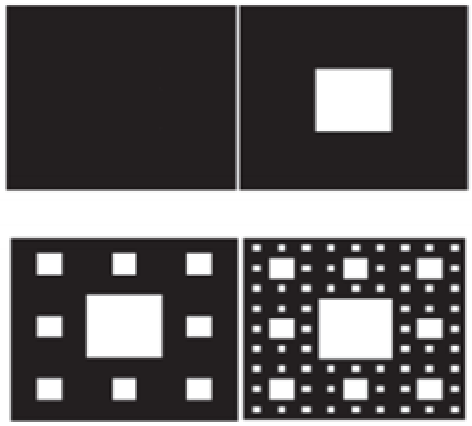


Figure 1.3 Sierpinski carpet Antenna upto 3 iterations

Sagne et al. (2013) designed a microstrip fed Sierpinski carpet fractal antenna (SCFA) up to 3rd iteration. The size of the patch is reduced by 33.9% compared to the conventional microstrip antenna. The designed antennas can be used for various applications such as military and meteorological satellite communication(8 to 12.5 GHz), Wi-Fi (5.1 - 5.825 GHz), PTP communication in US military (6 GHz), radar and navigation services, broadband fixed wireless access (BFWA) services, UMTS (1920 - 2170 MHz), Medium and High Capacity P-P (7725-8275 MHz), Bluetooth, WiMAX applications etc.

1.5.2 Koch Curve

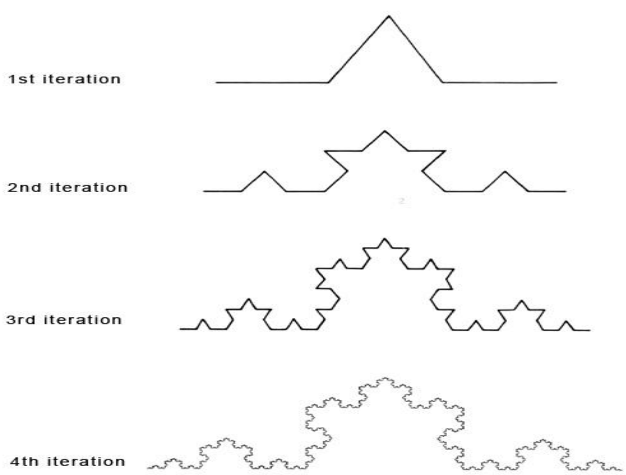


Fig 1.4 Koch iterations

In 1998 the von Koch monopole became the first reported fractal small antenna that improved the features of some classical antennas in terms of resonance frequency, radiation resistance and bandwidth. A Koch curve is generated by replacing the middle third of each straight section with a bent section of wire that spans the original third. Each iteration adds length to the total curve which results in a total length that is 4/3 the original geometry.

1.5.3 Minkowski Curve

The Minkowski curve is also known as Minkowski Sausage and was dated back to 1907 where a German mathematician,Hermann Minkowski, investigated quadratic forms and continued fractions. Minkowski loop (Fig. 1.5) can be used to reduce the size of the antenna by increasing the efficiency with which it fills up its occupied volume with electrical length. A Minkowski fractal is analysed, where the perimeter is near one wavelength. The comparison of several iterations with a square loop antenna is done to illustrate the benefits of using a fractal antenna

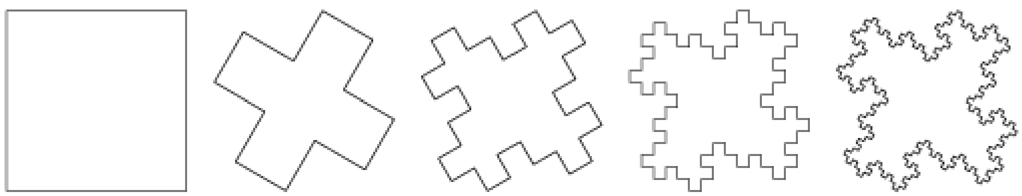


Fig 1.5: Minkowski iterations

1.5.4 Hilbert curve

The first few iterations of Hilbert curves are shown in Figure 1.6. It may be noticed that each successive stage consists of four copies of the previous, along with the additional line segments. The geometry so obtained is a space-Filling curve that is with the large number of iterations the entire area it occupies will be filled. Apart from this the geometry also has the following properties: self-Avoidance (as the line segments do not intersect each other), Simplicity (since the curve can be drawn with a single stroke of a pen) and self- Similarity. Because of these properties, these curves are often called FASS curves

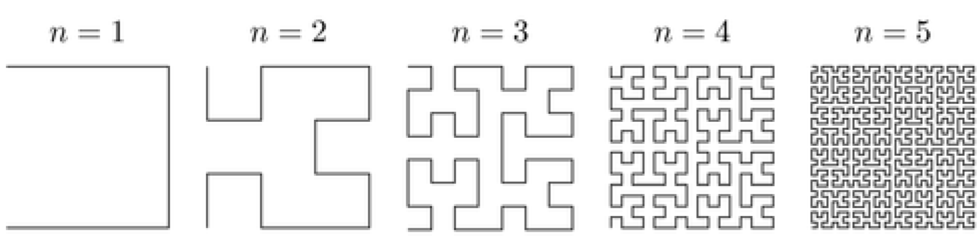


Fig 1.6: Hilbert curve

1.5.5 Circular Microstrip Antenna

The advantage of fractal antennas is that fractal shape of simple microstrip patch antennas can be obtained.

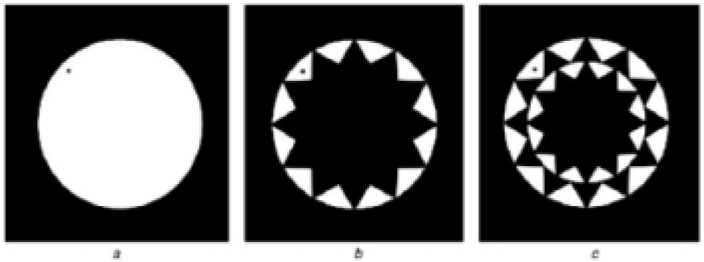


Fig 1.7.Circular Microstrip Patch Antenna

1.5.6 Pythagoren Tree Fractal

The construction of a Pythagoras tree begins with a square. Two other squares are constructed upon this square, each scaled down by a linear factor, such that the corners of the square coincides pair wise. The same procedure is then applied recursively to the smaller two squares. Figure 1.8 shows the iteration in the construction process

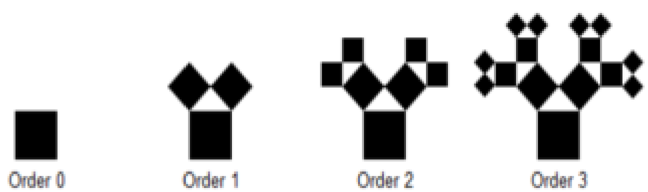


Fig 1.8 Iterations of Pythagorean tree

1.6 Benefits of fractal antenna

A fractal antenna is an antenna with are complex geometric designs that uses a self-similar design to increase the length, or the perimeter of material that can receive or transmitelectromagnetic radiation within a given total surface area or volume. Some key benefits of fractal antennas area:

- Fractals, through their self-similar property, are natural systems where this complexity provides the sought after antenna properties. Fractal Antennas radically alter the traditional relationships between gain, bandwidth and antenna size, allowing antennas that are more versatile, compact and powerful.

- Fractal versions of all existing micro strip antenna types can be obtained.

- Fractal Antenna’s technology leads to unique improvements in antenna arrays, increasing their bandwidth, allowing multiband capabilities, decreasing size load and enabling optimum smart antenna technology.

- Increased bandwidth, gain and multiband behaviour in addition to smaller size.

- These qualities of fractals enable the production of high performance antennas that are typically 50 to 75 percent smaller than traditional ones.

- Further fractal antennas are more reliable and lower cost than traditional antennas as antenna performance is attained through the geometry of the conductor, rather than with the accumulation of separate components or separate elements that inevitably increase complexity and cost.

1.7 FRACTALS IN NATURE

While fractals are a mathematical construct, they are found in nature, which has led to their inclusion in artwork. These objects display self-similar structure over an extended, but finite, scale range. For example, Ferns and trees are fractals found in nature and can be modeled on a computer by using a recursive algorithm This recursive nature is obvious since a branch from a tree or a frond from a fern are miniature replicas of the whole: not identical, but similar in nature. The connection between fractals and leaves is currently being used to determine how much carbon is contained in trees. A tree is a large, complex object, it is formed by repeating a simple process over and over again. This is a basic principle of fractals. Thus the repetition of branching that forms the tree also generates the tree's self-similarity.

Natural objects that are approximated by fractals include:

- ✓ ferns and trees
- ✓ clouds
- ✓ river networks
- ✓ Even coastlines may be loosely considered fractal in nature.
- ✓ mountain ranges
- ✓ craters
- ✓ snow flakes
- ✓ lightning,
- ✓ systems of blood vessels and pulmonary vessels
- ✓ ocean waves
- ✓ DNA and heartbeat can be analyzed as fractals

1.8 FRACTAL APPLICATIONS

Fractals are not just complex shapes and pretty pictures generated by computers. Anything that appears random and irregular can be a fractal. Fractals permeate our lives, appearing in places as tiny as the membrane of a cell and as majestic as the solar system. Fractals are the unique, irregular patterns left behind by the unpredictable movements of the chaotic world at work.

- Telecommunications:

A new application is fractal-shaped antenna that reduce greatly the size and the weight of the antennas . The benefits depend on the fractal applied, frequency of interest, and so on. In general the fractal parts produces 'fractal loading' and makes the antenna smaller for a given frequency of use. Practical shrinkage of 2-4 times are realizable for acceptable performance. High performance is attained.

- Antenna engineering :

The primary motivation of fractal antenna engineering is to extend antenna design and synthesis concepts beyond Euclidean geometry. Obtaining special antenna characteristics by using a fractal distribution of elements is the main objective of the study on fractal antenna arrays. It is widely known that properties of antenna arrays are determined by their distribution rather than the properties of individual elements. Since the array spacing (distance between elements) depends on the frequency of operation, most of the conventional antenna array designs are band-limited. Self-similar arrays have frequency independent multi-band characteristics. Fractal and random fractal arrays have been found to have several novel features. Variation in fractal dimension of the array distribution has been found to have effects on radiation characteristics of such antenna arrays. The use of random fractals reduce the fractal dimension, which leads to a better control of side lobes. Synthesizing fractal radiation patterns has also been explored . It has been found that the current distribution on the array affects the fractal dimension of the radiation pattern. It may be concluded that fractal properties such as self-similarity and dimension play a key role in the design of such arrays.

- Astronomy:

Fractals may be revolutionized the way that the universe is seen. Cosmologists usually assume that matter is spread uniformly across space. But observation shows that this is not true. Astronomers agree with that assumption on “small scales”, but most of them think that the universe is smooth at large scales. However, a group of scientist claims that the structure of universe is fractals at all scales.

- Computer science:

Actually the most useful use of fractal in computer science is the fractal image compression. This kind of compression uses the fact that real world is well described by fractal geometry. By the way, images are compressed much more than by usual way (example: JPEG format etc).

- Medicines:

Biosensors interaction can be studied by using fractal

- Surface Physics:

Fractal used to describe the roughness of surface. A rough surface characterized by a combination of two different fractals.

- Application in technology:

Fractal Antennas, Fractal transistor, Fractal heat exchangers, Digital imaging, Signal and image compression, Computer and video game design, Computer Graphics Fractals in network

CHAPTER 2

LITERATURE SURVEY

[1] A Miniaturized Hilbert Inverted-F Antenna for Wireless Sensor Network Applications

[Jung-Tang Huang, Jia-Hung Shiao, and Jain-Ming Wu]

Miniaturized inverted-F antennas (IFAs) are proposed for wireless sensor network applications in the 2.45 GHz band. By employing Hilbert geometry, an overall size reduction of 77% was achieved compared to the conventional rectangular patch antenna. The proposed antenna can be easily built in a miniaturized wireless sensor network (WSN).According to the design rules presented in this paper, antennas can be simulated rapidly. An experimental prototype of the miniature antenna was fabricated on a 1.6-mm-thick FR4 substrate. The bandwidth of this antenna less than 10 dB is 220 MHz (2.32–2.54 GHz) and the percentage of the bandwidth is 9.1%. The peak gain is 1.4 dBi.

The gain values can be effectively adjusted if we appropriately design the shape and size of the ground plane. For instance, during the process of simulation, we can observe that adjusting the length L of the ground plane improves the gain of the antenna. This means that the ground plane plays an important role in this type of single-ended antennas offering in some situation more gain and/or bandwidth. The reason behind the improvement in gain is that the equivalent electric capacitance of the antenna increases with a reduction in the size of the ground plane. Consequently, we need to further adjust the impedance matching. The lengths of the ground plane and fractal trace will influence the center frequency of the antenna. Hence, we can improve the antenna gain by adjusting the length of the ground plane appropriately. The decrease in antenna electrical length leads to increase in operating frequency.

[2] Study of Compact Hilbert Curve Fractal Antennas for Implantable Medical Applications

[S. Suganthi, Dr. S. Raghavan, Dr. D. Kumar, Dr. J. Arputha Vijaya Selvi]

The investigation is on the performance of two Hilbert curve based fractal implantable microstrip antennas (HCFA1 and HCFA2) and they have been carried out in this work using numerical simulations. The original Hilbert curve has been modified and the new structures were explored and simulated to find the suitability of the same for air-to-air wireless and IMD applications. The use of CPW feed system resulting in broader bandwidth is remarkable. The antennas were simulated in the air as well as human muscle tissue environments and found resonating in the recommended ISM band with nominally good antenna characteristics. Also the near and far filed characteristics are satisfactorily good. The proposed antennas are compact, wideband and easy to fabricate providing suitability for meeting the present demand for low profile wireless and IMD antennas.

[3]A Miniaturized Hilbert PIFA for Dual-Band Mobile Wireless Applications

[Mohammed Z. Azad and Mohammod Ali, Senior Member, IEEE]

A miniaturized planar inverted-F antenna (PIFA) is proposed for dual-band mobile phone application in the 900- and 1900-MHz bands. By employing a Hilbert geometry, an overall size reduction of 50% was achieved compared to a conventional rectangular PIFA. The proposed antenna can be easily printed on the inside surface of the plastic housing of a mobile phone or other wireless device. An experimental prototype of this miniature antenna was fabricated on 0.125 mm thick Duroid 5880 substrate. Measured results demonstrate dual-band characteristics with good radiation patterns. In all cases, the low resonant frequency pattern at ϕ=0 shows uniform coverage in the azimuthal plane which is desirable in mobile wireless application with the component being dominant. In the elevation plane, ϕ=90, the pattern resembles that of a dipole antenna with some cross-polarization (suppressed below 20 dB). In the elevation plane the pattern has a butterfly shape. The peak gain at 910 MHz is 2.4 dBi and at 1912 MHz it is 4.6 dBi. A longer antenna and ground plane at the high frequency results in a more directive pattern and, hence, the high gain.

[4]A New Class of Miniature Embedded Inverted-F Antennas (IFAs) for 2.4 GHz WLAN Application

[Mohammed Ziaul Azad, Student Member, IEEE, and Mohammod Ali, Senior Member, IEEE]

Due to the limited space availability on the printed circuit board (PCB) of a wireless device, antenna miniaturization is crucial. Furthermore, the presence of internal mobile phone and GPS antennas on or near the same circuit board limits the space availability and creates potential problem of undesired coupling between antennas. A meander-line antenna can be proposed to conserve space. Fractal and Hilbert-shaped antennas were proposed to achieve antenna size reduction. Recently, we introduced a miniaturized (50% smaller than a conventional PIFA) modified Hilbert PIFA for 900/1900 MHz band mobile phone application.

In this paper, the properties of a new class of miniature embedded IFAs are investigated: the Hilbert IFAs. We explore these antennas with a concentration on the 2.4 GHz IEEE WLAN. This antenna is at least 70%smaller than a conventional embedded inverted-F antenna. A new concept to determine the operating frequencies of Hilbert IFAs is introduced, which uses the principle of inductance equivalence. A detailed study of the antenna performance as a function of substrate loss tangent and material conductivity is presented. Finally, examples of decoupled antenna diversity schemes are given where the isolation between antennas is better than -20 dB.From the obtained results it is found that as the loss tangent of the dielectric is increased the bandwidth is increased and also quality factor, gain and antenna efficiency decreases. Also increasing the height h of the antenna increases its bandwidth.

[5]A Monopolar Quad-Band Antenna based on a Hilbert Self-Affine Pre-Fractal Geometry

[Renzo Azaro, Federico Viani, Leonardo Lizzi, Edoardo Zeni, and Andrea Massa]

It has been demonstrated that by using Hilbert geometries usually result in a significant size reduction, compared to standard geometries, such as a λ/4 monopole. However, a large amount of energy is stored in the near field of the antenna and higher ohmic losses arise. Thus the resonant frequencies of the small antennas built exploiting the Hilbert geometry lower when increasing the iteration level, while keeping fixed the external dimensions of the antenna. Moreover, the radiation characteristics of the radiator worsen by decreasing the radiation resistance. Furthermore, the fundamental resonance frequency turns out to be higher than the corresponding one of a λ/4 monopole with the same physical length. Such a phenomenon is mainly due to the coupling between the different turns of the Hilbert shape that define a shorter equivalent path for the current.

The effect gets stronger when the fractal iteration i increases and a saturation of the miniaturization capability verifies in correspondence with large values of i. In addition, the resonant efficiency decreases with increasing antenna iteration due to the increase in total metallic path length. From a practical point of view, such considerations suggest that only the first few fractal iterations can be profitably employed for miniaturization purposes (e.g., $i \leq 5$ or $i \leq 6$) Taking into account the properties and limitations previously pointed out, the Hilbert curve is employed in this letter for the design of a miniaturized and multistandard monopole antenna.

[6]Response Of Planar Inverted F Antenna Over Different Dielectric Substrates

[Ankit P Dabhi, Shobhit K Patel]

In modern era, a demand has increased to design antennas having multiband and wideband characteristics for mobile terminals. This paper expresses the bandwidth, return loss and gain variations of a Planar Inverted F Antenna. Here, the antenna is built on a small ground plane size of 60mm x 60mm. In this paper, Planar Inverted F Antenna with a radiating patch of fixed dimensions of 15.3mm x 15.3mm is studied using different dielectric substrates.

Various dielectric materials to the measure the performance of the PIFA like air, fr4, duroid, mica, rogers3210, silicon nitrate and so on. Some dielectric materials act as perfect dielectrics which have loss tangent equal to zero while others have loss tangent greater than zero referred to as lossy materials. The PIFA having air substrate gives best performance in the terms of bandwidth compared to the other substrates while the gain varies differently in the different substrates based on their permittivity. The bandwidth obtained is 300 MHz while the VSWR is 1.25 when the structure is simulated using air substrate. The current distribution in PIFA using different substrates mainly varies in the meandered patch with reference to the short circuit plate. It is seen that as when the antenna dimensions are kept constant, the normalized simulated resonant frequencies tends to go down. The bandwidth is not much affected for lossy substrates but the gain drops linearly with the rise in the substrate permittivity. On the contrary, there is a considerable decrease in bandwidth and gain with the increase in permittivity for perfect dielectric.

[7]Resonator-Based Analysis of the Combination of Mobile Handset Antenna and Chassis

[Pertti Vainikainen, Member, IEEE, Jani Ollikainen, Outi Kivekäs, and Ilkka Kelander]

In this paper, the performance of the mobile phone handset antenna–chassis combination is analyzed based on an approximate decomposition of the waves on the structure into two resonant wave modes: the antenna-element wave mode and the chassis wave mode. A double resonator equivalent circuit model is presented and used to estimate the impedance bandwidth and the respective distribution of radiation losses with typical parameter values at 900 and 1800 MHz. Thus, the antenna element works mainly as a matching element, which couples to the low resonant wave mode of the chassis. At 1800 MHz, the contribution of the antenna element wave mode is larger. By enhancing the coupling and by tuning the chassis resonance, it is possible to obtain an impedance bandwidth of over 50% (6-dB return loss) at both at 900 and 1800 MHz. The results given by the equivalent circuit study are fully supported by those of three-dimensional phone-model simulations, including calculation of the SAR and efficiency values. In prototyping, the 6-dB bandwidth of 5.5% was obtained at 980 MHz with a non radiating coupling element with a volume of 1.6 cm3 on a 120-mm-long chassis.

In this paper, it is shown that the behavior of fairly small radio devices like mobile handsets with the maximum dimension in the range of approximately 0.25λ-1λ can be described by treating the system of antenna and chassis as a combination of the separate wave modes of the antenna element and the chassis. An equivalent circuit was introduced for the input impedance and it was used for investigating several significant properties of the system. The results were also confirmed by electromagnetic simulations and prototyping. It was shown that by matching the resonant frequencies of the antenna element and the chassis, very large bandwidths can be obtained. It was also noticed that at 900 MHz, where the chassis wavemode typically dominates, the antenna element has only a minor effect on the properties of the near and far fields of the mobile handset.

[8] A 31.5 GHz Patch Antenna Design for Medical Implants

[Yasir Ahmed, Yang Hao and Clive Parini]

The design of antennas for communication with implants inside the human body has received considerable attention from the research community. The design of these antennas is quite challenging, as there is a limit on the amount on power that can be transmitted and also on the size of these devices. Typically these devices are allowed to have a peak transmit power of 25 uW (−16 dBm), which is quite insufficient at higher frequencies especially when embedded deep into the tissue. Today these implants are being used to monitor as well as facilitate the working of various human organs, for example, as cardiac pacemakers. Thick substrates with low permittivity result in antenna designs with high efficiency and large bandwidths. Thin substrates with high permittivity lead to a smaller antenna size but with a lower bandwidth and a high radiation loss.

Rogers RT6002 in our design with a permittivity of 2.94 and a loss tangent of 0.0012 is used in our model. We have used a microstrip line feed since it is relatively easy to model, match, and fabricate. It results in low- antenna bandwidths (2–5%); however, this is sufficient for our application. Although a signal level −76.95 dBm might be sufficient in theory, it would not be adequate in a realistic scenario where the signal would experience multipath fading and interference from other wireless equipment. However, it must be noted that we have considered a simple dipole antenna at the receiver with a nominal directional gain. Since there is no limitation on the size of the external equipment, we can make use of a large antenna with a very high gain along the direction of transmission. In some scenarios, it might also be possible to place the antenna close to the body (closer than 1 m) further improving the quality of the received signal. Finally, it must be noted that the return loss of the antenna increases inside the body (+11.81 dB) and there is also some frequency detuning (1.14%). Higher return loss is a desirable characteristic but frequency detuning is not and can be removed by adjusting the dimensions of the antenna such that the null occurs at the desired frequency.

[9] **Miniaturization of Superconducting Filters Using Hilbert Fractal Curves**

[Mario Barra, Carlos Collado, Jordi Mateu, Member and Juan M. O’Callaghan]

To reduce the thin film high temperature superconductors(HTS) cost and relax the cooling requirements, miniaturization techniques for size reduction of planar filters are especially important in HTS filter design. These techniques may include several ways of folding the transmission line in forms of loops, hairpins, spirals or even fractal shapes, all of which have low RF losses despite their small size. In this work we explore the possibilities of using fractal Hilbert curves for the realization of HTS resonators and filters.

The fractal structure was analyzed considering several levels of iteration and putting in evidence the effect of the different geometrical parameters on the obtainable miniaturization level and quality factors. The performance in terms of quality factor of a single Hilbert 2 GHz resonator with a side of 3.58 mm, has been tested at 77 K yielding a quality factor of about 26 000. Quasi-elliptic and Chebyshev filters have been realized, showing the flexibility of the Hilbert curve to design resonators with good coupling properties. Both filters have been fabricated in 10 mm× 10 mm double sided 700 nm YBCO thin films on 0.508 mm thick MgO substrate. The measured minimum insertion losses (0.1 dB–0.2 dB) confirm the good tradeoff between quality factor and reduced dimensions.

CHAPTER-3

FRACTAL ANTENNA

3.1 FRACTALS AS ANTENNAS

In modern wireless communication systems, multiband and low profile antennas are in great demand for both commercial and military applications. This has led to antenna research in various directions; one of them is using fractal shaped antenna elements. Traditionally, every antenna operates at a single or dual frequency bands, where different antennas are needed for different applications. Using fractals as antennas may offer better radiation pattern and may also offer more controlling parameters to designer.

Fractal antennas are multi-resonant and smaller in size. Qualitatively, multi-band characteristics have been associated with the self-similarity of the geometry and Hausdorff dimensions are associated with size. Research towards quantitative relation between antenna properties and fractal parameters is going on extensively. Any variation of fractal parameters has direct impact on the primary resonant frequency of the antenna, its input resistance at this frequency, and the ratio of the first two resonant frequencies. In other words, these antenna features can be quantitatively linked to the fractal dimension of the geometry. This finding can lead to increased flexibility in designing antennas using these geometries. These results have been experimentally validated.

A fractal antenna's response differs markedly from traditional antenna designs, in that it is capable of operating with good-to-excellent performance at many different frequencies simultaneously. Normally standard antennas have to be "cut" for the frequency for which they are to be used and thus the standard antennas only work well at that frequency. This makes the fractal antenna an excellent design for wideband and multi-band applications. There are many benefits when we applied these fractals to develop various antenna elements.

By application of fractals to antenna elements:

• We can create smaller antenna size.

• We achieve resonating frequencies that are multiband.

• optimize for gain.

• Achieve wideband frequency band or multiband frequencies.

Most fractals have infinite complexity and detail that can be used to reduce antenna size and develop low profile antennas. Self-similarity concept can achieve multiple frequency bands because of different parts of the antenna are similar to each other at different scales . Combination of infinite complexity and self-similarity makes it possible to design antennas with various wideband performances.

3.2 WIDEBAND FRACTAL ANTENNAS

It is intuitive that the self similarity property of fractals will result in multiple resonances. The multiple resonances can be converted into wide band characteristics by bringing the resonance frequencies closer and letting the bands overlap. If the fractal parameters are controlled properly, this can be achieved. In general, for any antenna to have wide band characteristics, the parameters discussed below have to be taken into account. The impedance bandwidth of a micro strip antenna can be determined from frequency response of its equivalent circuit. For parallel-type resonance, the half power bandwidth is given as:

$$BW = \frac{2G}{Wo\frac{dB}{dw}}$$

Where Y = G + jB is the input impedance at the resonance frequency. This bandwidth is also defined as VSWR ~ 2 bandwidth. Hence, in terms of VSWR

$$BW = \frac{VSWR - 1}{Q\sqrt{VSWR}}$$

Where, Q is the quality factor use in design for the structure. As Q decreases, the system becomes lossier and bandwidth increases. Hence, if r decreases, BW increases and if thickness of substrate increases, bandwidth again decreases. Further achievement of antenna bandwidth can be obtained by increasing gap coupling or direct coupling with the ground plane. And slow resistance transformation also helps in increasing bandwidth.

3.3 ANTENNAS BACKGROUND

There is a wide variety of antenna structures allowing operation on just one band, narrow-band antennas, or several bands, known as multi-band or broadband antennas. Narrow band antennas include not only single dipoles or verticals but also directive arrays. Such arrays have high gain and directivity to make the antennas more efficient to a certain direction. With these antennas signals coming from the back will be rejected due to its Front to Back ratio, this is the ratio of the maximum directivity of an antenna to its directivity in the opposite direction. The most interesting multi-band antenna is the log-periodic, also known as log-periodic dipole array (LPDA). These antennas are broadband, multi-element, unidirectional with an impedance and radiation characteristics that are continually repeated as a logarithmic function of the excitation frequency.

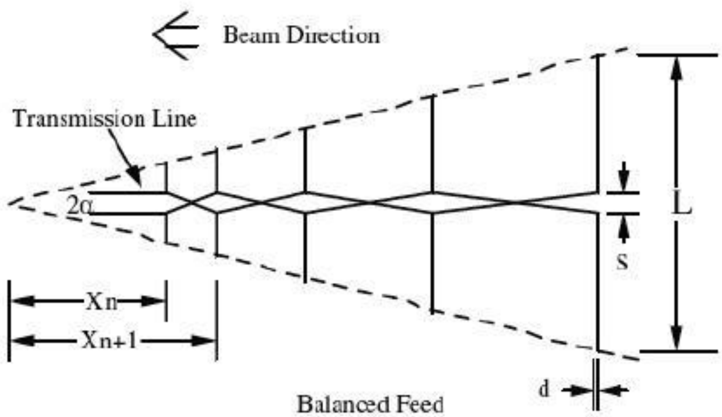


Figure 3.1 Log Periodic Antenna

A **log-periodic antenna** (**LP**) is a multi-element, directional, narrow-beam antenna that operates over a broad band of frequencies. Xn is the distance from the apex element, L is the length of the dipole, α is the apex angle and S is the spacing between any 2 dipoles. The antenna normally consists of a series of dipoles positioned along the antenna axis, spaced at following a logarithmic function of the frequency. It is normal to drive alternating elements with 180° (π radians) of phase shift from one another. This is normally done by connecting individual elements to alternating wires of a baltelevision receivers, especially in the VHF band. LP's are also used for UHF, but have more recently been increasingly replaced by the Grey-Hoverman antenna and similar designs. Broadband property of Log-periodic Antenna comes from self-complementary antenna that has always constant input impedance, 60π≒188.4 (Ω), independent of the frequency and its shape with Infinite freedom. This antenna design is used where a wide range of frequencies is needed while still having moderate gain and directionality. It is sometimes used for a (VHF/UHF) television antenna.

These antennas are calculated to be self-similar therefore; they could be considered as fractal antennas. LPDA was originally designed at the University of Illinois in the USA.

3.4 ANTENNA PROPERTIES

There are several important antenna characteristics that should beconsidered when choosing an antenna for your application as follows:

- **Operating frequency**

The operating frequency is the frequency range through which the antenna will meet all functional specifications. It depends on the structure of the antenna in which each antenna types has its own characteristic towards a certain range of frequency. The operating frequency can be tuned by adjusting the electrical length of the antenna.

- **Return Loss**

Return loss is the ratio, at the junction of a transmission line and a terminating impedance or other discontinuity, of the amplitude of the reflected wave to the amplitude of the incident wave. The return loss value describes the reduction in the amplitude of the reflected energy, as compared to the forward energy. Return loss can be expressed as

$$RL = 20 Log \left| \frac{Z_1 + Z_2}{Z_1 - Z_2} \right|$$

where :

Z1 = impedance toward the source

Z2 = impedance toward the load

- **Bandwidth**

Bandwidth can be defined as “the range of frequencies within which the performance of the antenna, with respect to some characteristics, conform to a specified standard. The bandwidth of an antenna is the range of frequencies over which it is effective, usually centered on the resonant frequency. Bandwidth is a measure of frequency range and is typically measured in hertz. For an antenna that has a frequency range, the bandwidth is usually expressed in ratio of the upper frequency to the lower frequency where they coincide with the -10 dB return loss value. The formula for calculating bandwidth is given as

$$\%BW = \frac{f_h - f_l}{\sqrt{f_h f_l}} x100\%$$

where :

fh= lower frequency that coincide with the -10 dB return loss value
fl= upper frequency that coincide with the -10 dB return loss value

- **Polarization**

Represents the sense and orientation of the electromagnetic waves far from the source. There are three main types of polarization:

Elliptical: Elliptical left hand, Elliptical righthand
Circular: Circular left hand, Circulat right hand
Linear: Vertical, Horizontal

- **Antenna radiation patterns**

The radiation pattern is a graphical representation of the characteristics of an antenna radiation in a certain direction as shown in fig 3.2 . These characteristics include radiation intensity, field intensity and polarization. It is normally represented with rectangular or polar plots and it is expressed in dB. The radiation pattern is a plane cut and represents one frequency and one polarization. The radiation pattern of an antenna is the geometric pattern of the relative field strengths of the field emitted by the antenna. An antenna radiation pattern is a 3-D plot of its radiation far from the source. Antenna radiation patterns usually take two forms, the elevation

Pattern and the azimuth pattern. The elevation pattern is a graph of the energy radiated from the antenna looking at it from the side .The azimuth pattern is a graph of the energy radiated from the antenna as if looking at it from directly above the antenna .

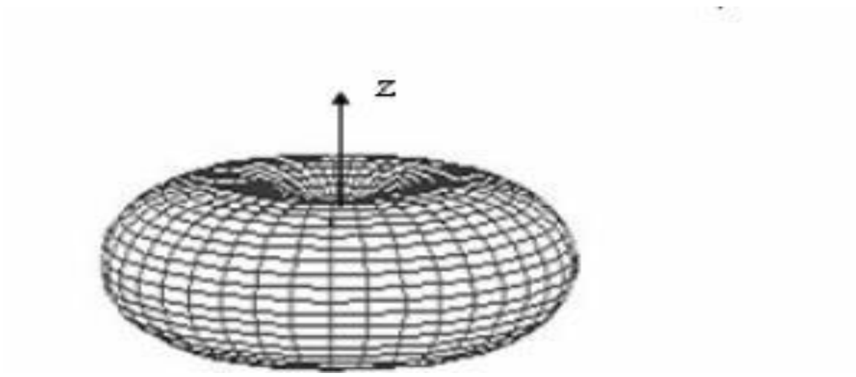


Figure 3.2 Radiation pattern of antenna

- **HPBW**

The HPBW Half Power Beamwidth is a way of measuring the antenna directivity. This means that if the main lobe of an antenna is too narrow, the directivity is higher. It can be determined by taking out 3dB (half power) with respect to the main lobe power level.

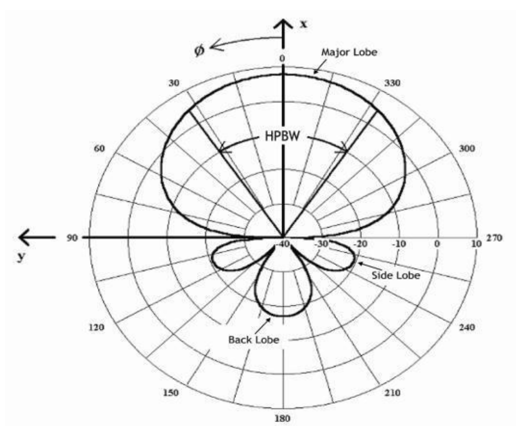


Figure 3.3HPBW

- **Gain**

There are two types of gain, Absolute Gain and Relative Gain.

The Absolute Gain of an antenna is defined as the ratio between the antennas radiation intensity in a certain direction and the intensity that would be generated by an isotropic antenna fed by the same input power, therefore it can be given as,

$$G(\theta,\phi) = \frac{U(\theta,\phi)}{U_0}$$

$$U_0 \text{ is given by} : U_0 = \frac{P_{in}}{4\pi}$$

where $G(\theta,\phi)$ is the gain of the antenna in a certain direction, $U(\theta,\phi)$ is the radiationintensity in a certain direction and U0 is the radiation intensity of an isotropic antenna. Pin is the input power.

The Absolute Gain is expressed in dBi as its reference is an isotropic antenna.

The Relative Gain of an antenna is defined as the ratio between the antenna radiation intensityin a certain direction and the intensity that would be generated by a reference antenna.The Relative Gain is expressed according to reference antenna.

- **Directivity**

The directive gain of an antenna is a measure of the concentration of the radiated power in a particular direction. It may be regarded as the ability of the antenna to direct radiated power in a given direction. It is usually a ratio of radiation intensity in a given direction to the average radiation intensity. The maximum directive gain is called as the directivity of an antenna and is denoted by D. This is an important parameter that allows us to measure the concentration of radiated power in a certain direction. It is given by:

$$D(\theta,\phi) = \frac{U(\theta,\phi)}{U_0}$$

where D(q;f) is the directivity of the antenna in a certain direction,U(q;f) is the radiation intensity in a certain direction and U0 is the radiation intensity of an isotropic antenna. Another way of measuring the directivity of an antenna is to calculate the HPBW.

- **Voltage Standing Wave Ratio (VSWR)**

The voltage standing wave ratio (VSWR) is defined as the ratio of the maximum voltage to the minimum voltage in a standing wave pattern. It is given as,

$$VSWR = \frac{V_{max}}{V_{min}}$$

The VSWR can also be calculated from the return loss (S11) which means that it is also an indicator of antennas efficiency. With the return loss we can determine the mismatch between the characteristic impedance of the transmission line and the antennas terminal input impedance. If the magnitude of the reflection coefficient is known the VSWR can be determined by:

$$VSWR = \frac{1+|S_{11}|}{1-|S_{11}|}$$

The VSWR increases with the mismatch between the antenna and the transmission line and decreases with a good matching. The minimum value of VSWR is 1:1 and most equipments can handle a VSWR of 2:1, the bandwidth of an antenna can be determined by the VSWR or the return loss. The best performance of an antenna is achieved when the VSWR under2:1 or the return loss is -10dB or lower.

- **Resonant frequency**

The "resonant frequency" and "electrical resonance" is related to the electrical length of an antenna. The electrical length is usually the physical length of the wire divided by its velocity factor (the ratio of the speed of wave propagation in the wire to the speed of light in a vacuum). Typically an antenna is tuned for a specific frequency, and is effective for a range of frequencies that are usually centered on that resonant frequency.

3.5 ADVANTAGES OF FRACTAL ANTENNA

Advantages of fractal antenna

- Good input impedance matching.
- They have broadband and multiband frequency response
- Compact size compared to conventional antennas
- Mechanical simplicity and robustness
- Operation in huge frequency

3.6 APPLICATIONS OF THE FRACTAL ANTENNA

There are many applications of the fractal antennas. Fractal antennas can make a real impact. The recent growth in the wireless communication needs the compact integrated antennas. So the fractals antenna has efficiently to fill a limited amount of space. Examples of these types of application include personal hand-held wireless devices such as cell phones and other wireless mobile devices such as laptops on wireless LANs and network able PDAs. Fractal antennas can also have applications that include multiband transmissions. Fractal antennas also decrease the area of a resonant antenna, which could lower the radar cross-section. This benefitcan be used in military applications.

Such type of antenna can be used for

- UWB system
- Microwave medical imaging
- vehicular radar and
- precision positioning.

3.7 ANTENNA FEEDING TECHNIQUES

Antenna is fed by variety of methods. These methods are classified into two categories Contacting and Non Contacting. In Contacting method- the RF power is fed directly to the radiating patch using connecting element. In non-contacting method- Electromagnetic field coupling is done to transfer power.

- **Inset Feed**

Since this typically yields a high input impedance, we would like to modify the feed.

Since the current is low at the ends of a half-wave patch and increases in magnitude toward the center, the input impedance (Z=V/I) could be reduced if the patch was fed closer to the center. One method of doing this is by using an inset feed . This method can be used to tune the input impedance to the desired value .

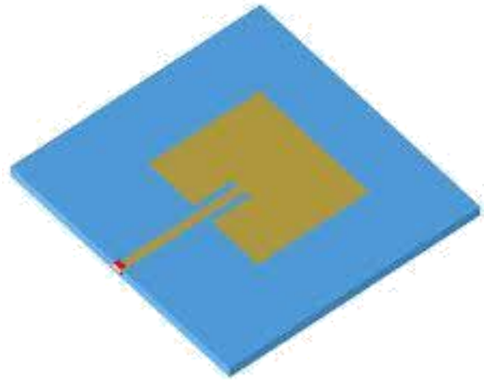


Figure 3.4Inset Feed

- **Coaxial Cable Or Probe Feed**

Microstrip antennas can also be fed from underneath via a probe. The outer conductor of the coaxial cable is connected to the ground plane, and the center conductor is extended up to the patch antenna. The position of the feed can be altered as before (in the same way as the inset feed, above) to control the input impedance.

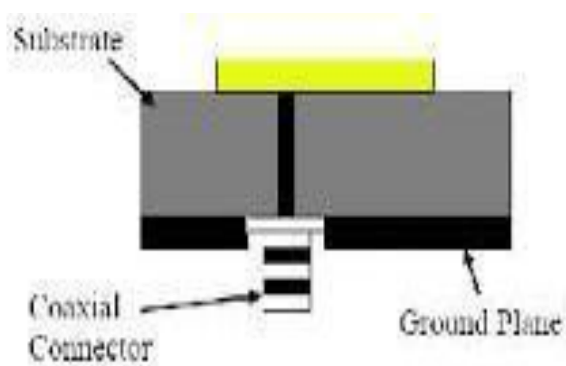


Figure 3.5 Coaxial Cable Feed

- **Coupled (Indirect) Feeds**

The feeds above can be altered such that they do not directly touch the antenna. For instance, the probe feed can be trimmed such that it does not extend all the way up to the antenna. The inset feed can also be stopped just before the patch antenna. Advantage of the coupled feed is that it adds an extra degree of freedom to the design. The gap introduces a capacitance into the feed that can cancel out the inductance added by the probe feed.

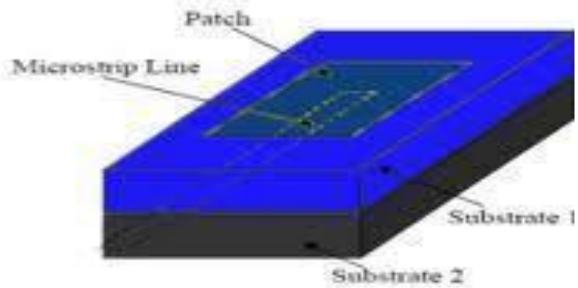


Figure3.6 Coupled (Indirect) Feeds

- **Aperture Feeds**

Another method of feeding microstrip antennas is the aperture feed. In this technique, the feed circuitry (transmission line) is shielded from the antenna by a conducting plane with a hole (aperture) to transmit energy to the antenna, as shown in Fig. 2.10. The upper substrate can be made with a lower permittivity to produce loosely bound fringing fields, yielding better radiation. The lower substrate can be independently made with a high value of permittivity for tightly coupled fields that don't produce spurious radiation. The disadvantage of this method is increased difficulty in fabrication.

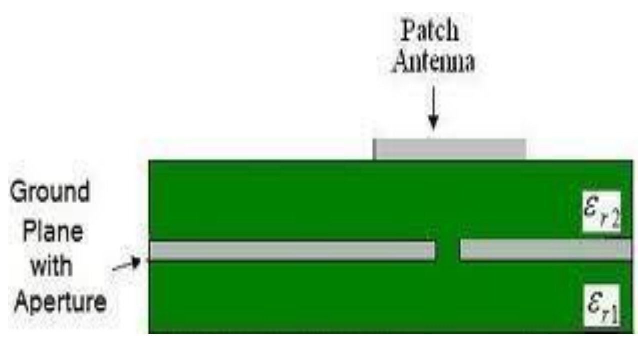


Figure 3.7Aperture Feeds

- **CPW**

A Coplanar Waveguide (CPW),is composed of a median metallic strip separated by two narrow slits from a infinite ground plane. Coplanar waveguide (CPW)-fed monopole antenna has become very popular in WLAN and WiMAX systems, owing to its many attractive features such as, wider bandwidth, low radiation loss, a simple structure of a single metallic layer and easy integration with WLAN integrated circuits. Another important advantage of CPW-fed is wider bandwidth than CPS and micro strip line. With co-planar waveguide (CPW) feeds, extra advantages are acquired, such as wider bandwidth, better impedance matching and less dispersion .

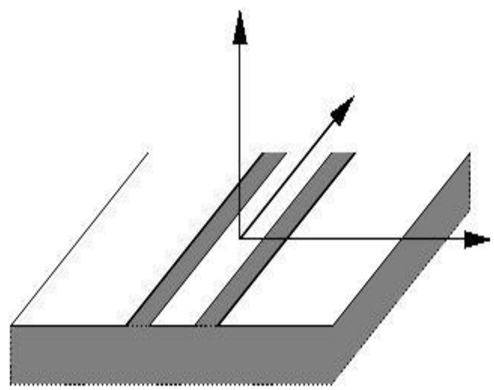


Figure 3.8Coplanar Waveguide

CHAPTER 4
ANSOFT HFSS

4.1 HFSS Description

ANSYS HFSS software is the industry-standard simulation tool for 3-D full-wave electromagnetic field simulation and is essential for the design of high-frequency and high-speed component design. HFSS offers multiple state-of the-art solver technologies based on either the proven finite element method or the well established integral equation method. You can select the appropriate solver for the type of simulation you are performing.

Engineers rely on the accuracy, capacity, and performance of HFSS to design high-speed components including on-chip embedded passives, IC packages, PCB interconnects and high-frequency components such as antennas, RF/microwave components and biomedical devices. With HFSS, engineers can extract scattering matrix parameters (S,Y, Z parameters), visualize 3-D electromagnetic fields (near- and far-field) and generate ANSYS Full-Wave SPICE models that link to circuit simulations. Signal integrity engineers use HFSS within established EDA design flows to evaluate signal quality, including transmission path losses, reflection loss due to impedance mismatches, parasitic coupling and radiation.

Each HFSS solver is based on a powerful, automated solution process where you are only required to specify geometry, material properties and the desired output. From there HFSS will automatically generate an appropriate, efficient and accurate mesh for solving the problem using the selected solution technology. With HFSS the physics defines the mesh; the mesh does not define the physics.

ANSYS HFSS software contains the technology, solvers and capabilities needed to model RF and microwave as well as signal- and power-integrity issues.

Main features:
- Automatic Adaptive Meshing
- Solver Technologies
- Advanced Finite Array Simulation Technology
- Mesh Element Technologies
- Advanced Broadband SPICE Model Generation
- Optimization and Statistical Analysis
- EDA Design Flow Integration
- High-Performance Computing
- Powerful Post-Processing Capabilities

CHAPTER 5

PROPOSED METHOD

5.1 DESIGN FORMULA

$$S(n) = \frac{2^{2n} - 1}{2^n - 1} L$$

Where S(n) is total segment length,

n is order of the Hilbert curve

L is the side dimension

$$d = \frac{L}{2^n - 1}$$

Where d is the length of each line segment

5.2 DESIGN PROCEDURE

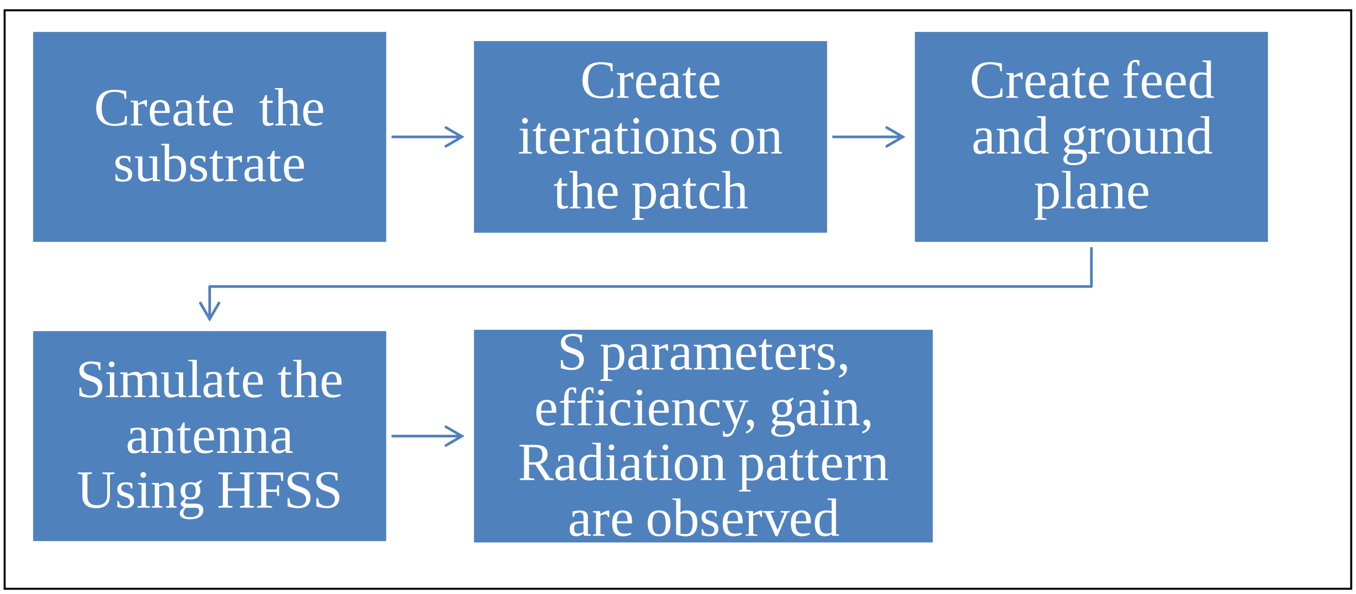


Figure 5.1 Design flow of overall process in Ansoft HFSS

The three essential parameters in the design of an antenna are,

- Frequency of operation
- Dielectric constant of substrate
- Thickness of substrate

Steps involved

Step1

A dielectric medium is defined manually by defining the values of dielectric constant and loss tangent.

Step2

Create the substrate using the defined dielectric medium of the required thickness and height.

Step 3

The radiating part is defined in the shape of fractal and proceeded up to the required number of iterations. The patch is assigned a boundary.

Step 4

The feed (CPW) to the antenna is defined. The excitation to the feed is also defined.

Step 5

Create the ground plane, radiation box and assigned them with boundaries.

Step 6

The Analysis set up is made by adding solution set up and frequency sweep.

Step 7

The Validation check and analyze all is done. Far field set up is done and the results are obtained in HFSS results.

5.4 FRACTAL ANTENNA DESIGN

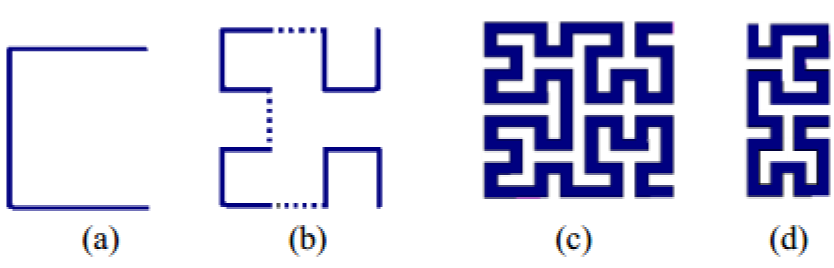


Figure 5.2 Hilbert curve construction steps

Hilbert Antenna with CPW feed

STEP 1:

The overall dimension of the substrate is 20 × 20 mm^2. The antenna is designed using HFSS on a FR4 substrate.FR stands for Flame Retardant, FR4 is other name for "Glass reinforced epoxy laminated sheets". It is a commonly used PCB material. The reasons for its ubiquity as a PCB material are its high dielectric strength, high mechanical strength, light weight and resistance to moisture. The patch is made of PEC(perfect electric conductor) and a perfect E boundary is assigned to it. Relative dielectric constant=4.4,Thickness=1.6mm

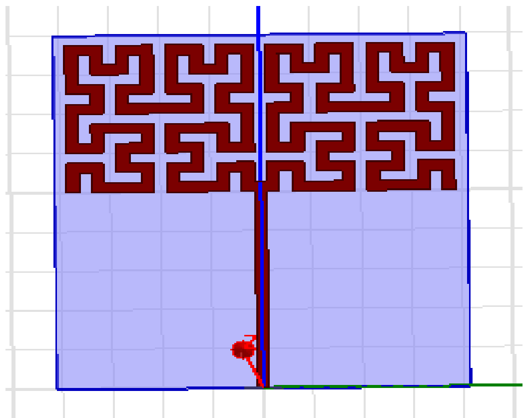


Figure 5.3 Creation of Hilbert patch

STEP 2:

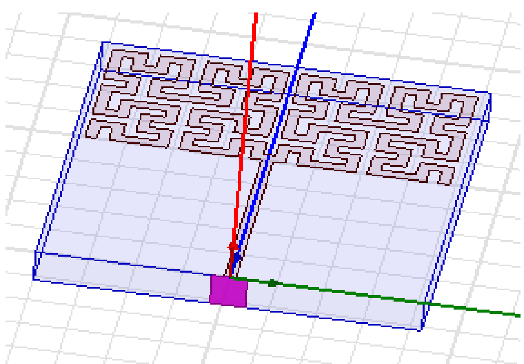


Figure 5.4 Creation of Lumped Port

The need for coaxial feed at the bottom of the structure is avoided and a lumped port is used at the edge for feeding. In a lumped port, the excitation is applied at a point/cell, as a voltage or current. Lumped ports can be used, if the geometry/material discontinuities are nearer/closer to the point of excitation. Wave ports can only be applied to external boundary, whereas lumped ports can be applied to both external and internal. But de-embeding is only possible in wave ports.

STEP 3:

Ground plane is created. The ground plane is in the same plane as that of the patch and its dimensions are 7.5 × 9.5 mm^2. The ground plane is assigned a perfect E boundary.

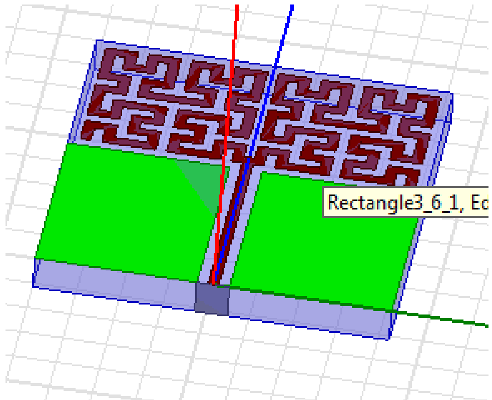


Figure 5.5 Creation of ground planes

STEP 4:

An array of 20×10 elements, with distance between any 2 elements in both u and v directions is 10 mm.

STEP 5:

To achieve higher bandwidths, modified ground plane structures are investigated. The gain values can be effectively adjusted if we appropriately design the shape and size of the ground plane. The reason behind the improvement in gain is that the equivalent electric capacitance of the antenna increases with a reduction in the size of the ground plane.

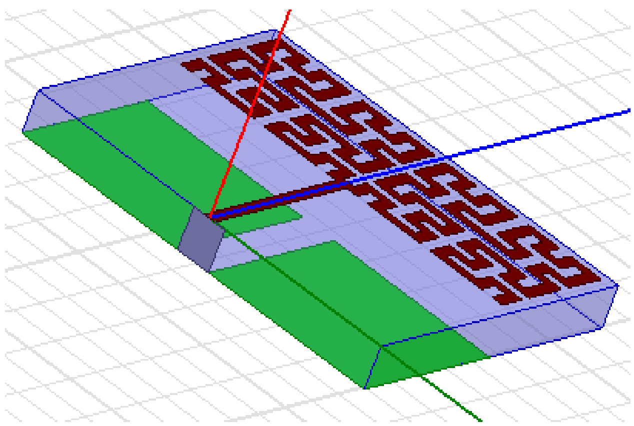


Figure 5.6 Hilbert antenna with modified ground plane

The common steps to be followed after designing the antenna are as follows

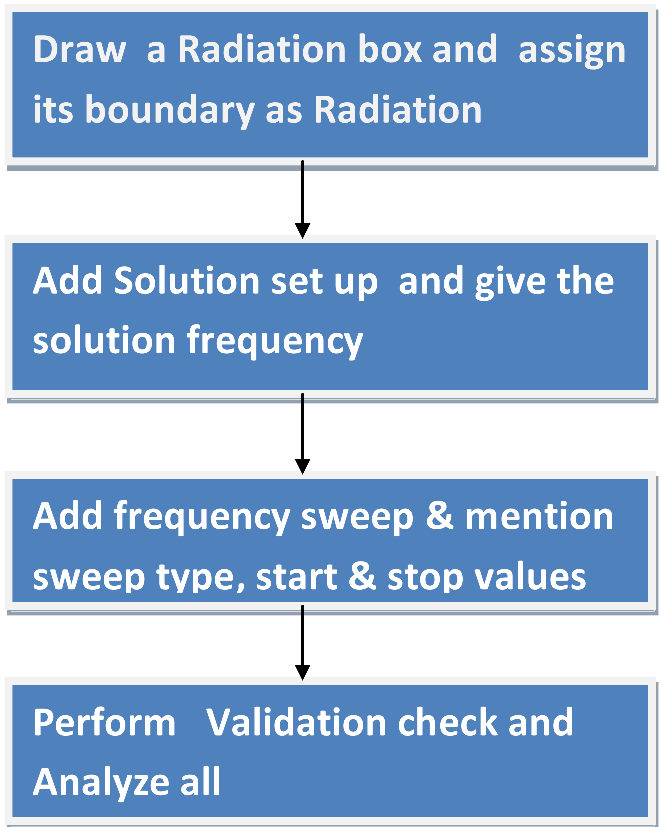


Figure 5.7 Steps after designing the antenna

4.5 OVERALL DESIGN

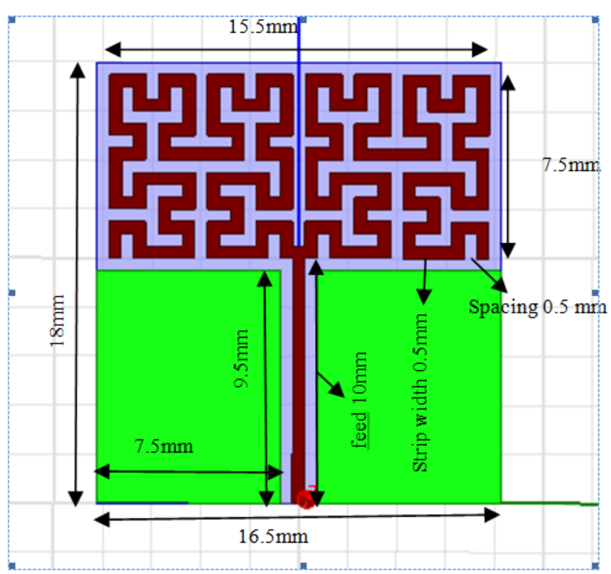


Figure 5.8 Overall design of CPW fed antenna

CHAPTER 6

RESULTS AND DISCUSSIONS

6.4 RESULTS

6.4.1 3D Radiation Pattern

The 3-D radiation pattern of the designed antenna is shown below.The designed antenna gives an omnidirectional radiation pattern. Here the red color regions indicate those with maximum field intensity**.**

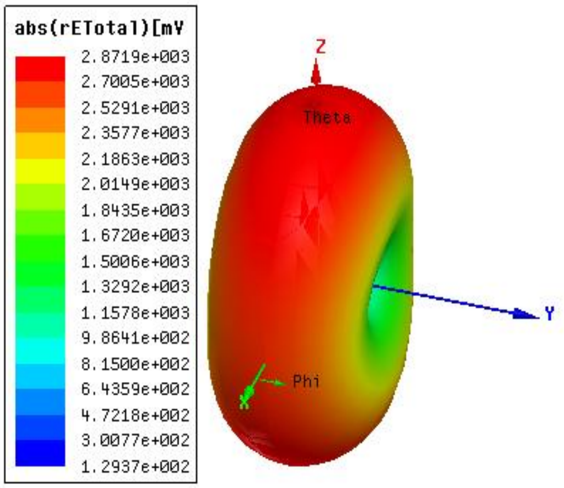


Figure 6.1 3-D Polar plots of Total Electric fields field of CPW fed antenna

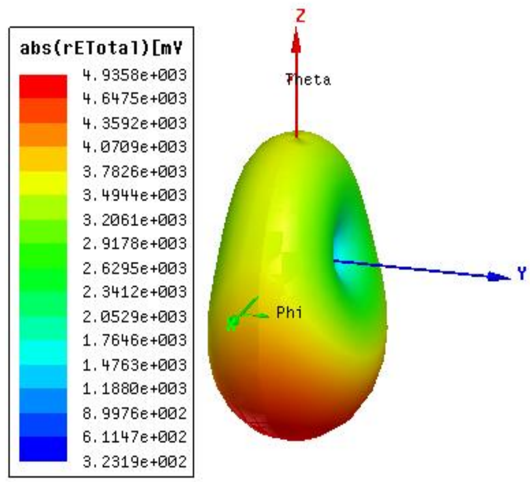


Figure 6.2 3-D Polar plots of Total E field of modified antenna

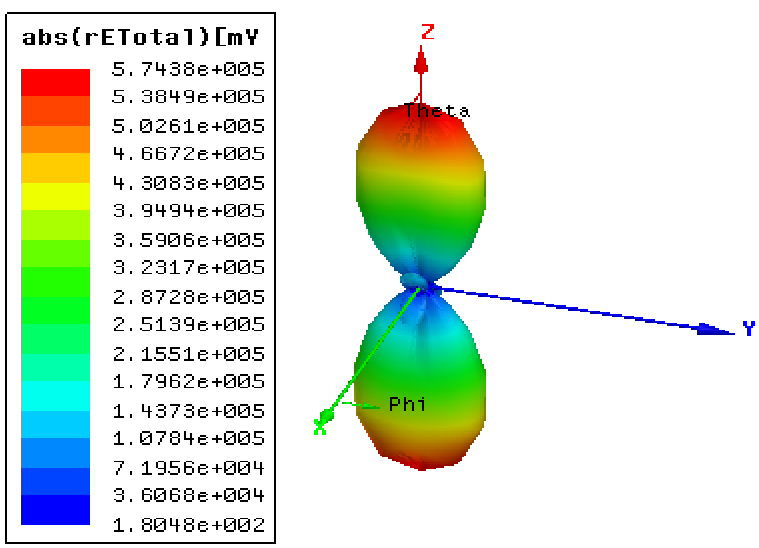


Figure 6.3 3-D Polar plot of Total Electric field of 20×10 array

6.4.2 Bandwidth

- For various resonant frequencies, various bandwidths are obtained.
  - ➢ F1 = 1.44 GHz, the bandwidth is 200 MHZ (from 1.32 GHz to 1.52 GHz)
  - ➢ F2 = 3.03 GHz, the bandwidth is 190 MHZ (from 2.95 GHz to 3.14 GHz)

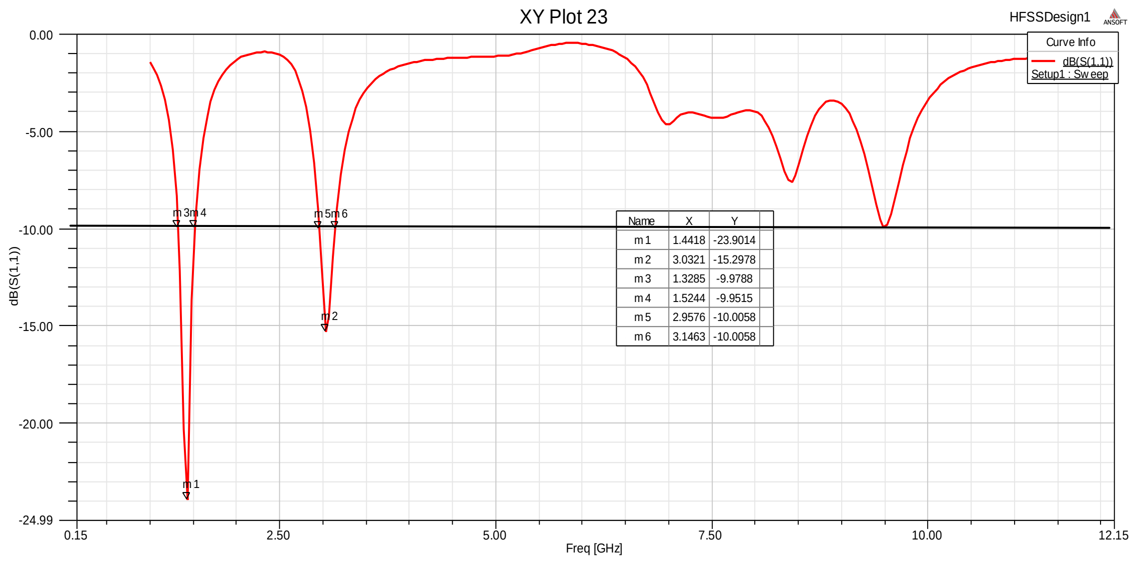


Figure 6.4 Bandwidth of CPW fed antenna

- For the antenna with modified ground plane, the S-parameter is shown below
- ➢ F1= 7.96 GHz, the bandwidth is 1.67 GHz (from 6.97 GHz to 8.64 GHz)

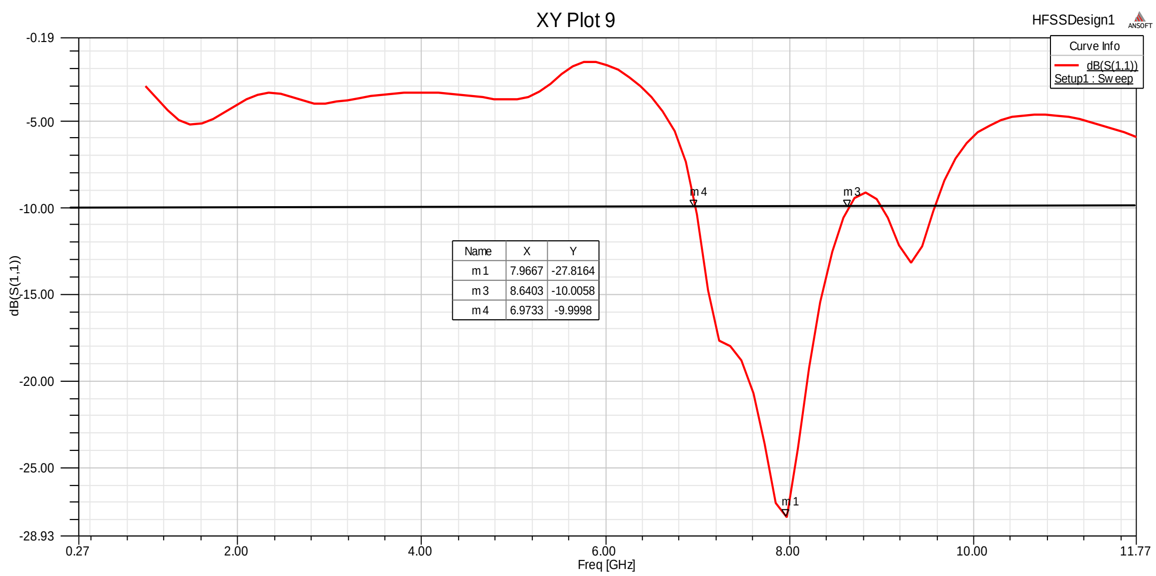
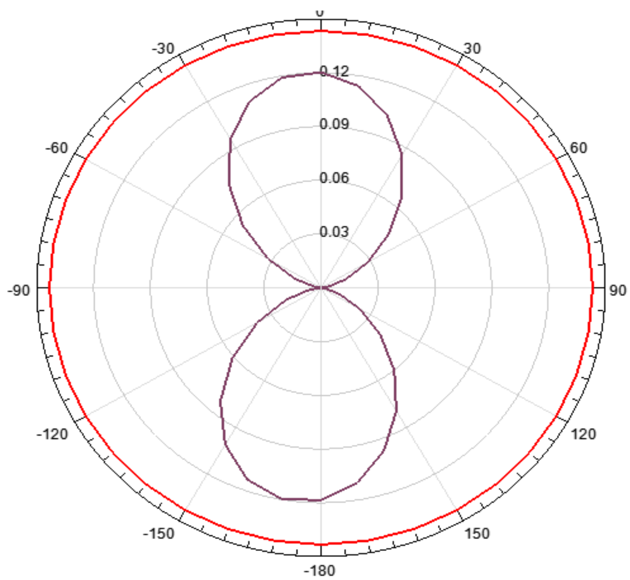


Figure 6.5 Bandwidth of modified antenna

6.4.3 Gain

Gain is the ratio of radiation field intensity of test antenna to that of the reference antenna. It is usually expressed in dB. Red colour is theta=0 deg and violet colour is theta=90 deg



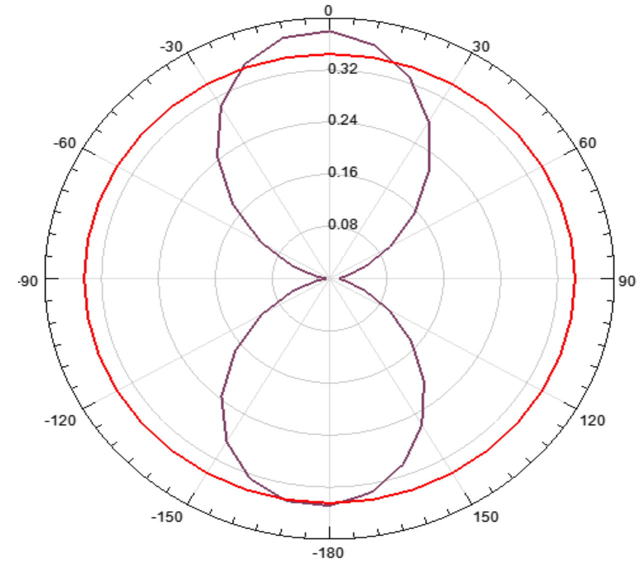


Figure 6.6 2-D plot of absolute gain value in E and H plane for CPW fed antenna

Figure 6.7 2-D plot of absolute gain in E and H plane for modified antenna

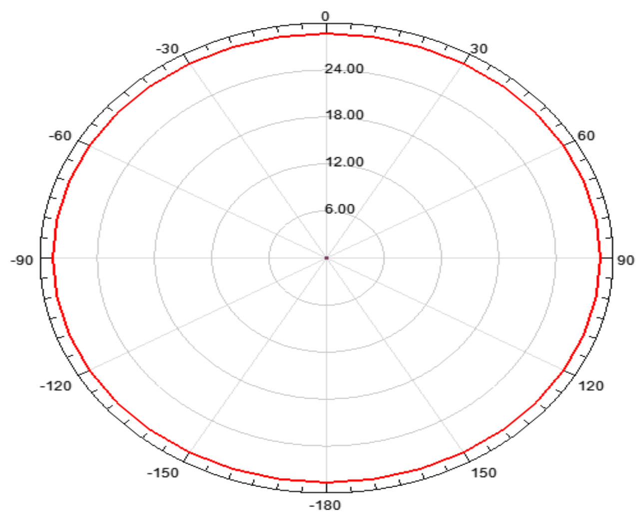


Figure 6.8 2-D Plot of absolute gain value in E and H plane for 200 element array

6.4.5 Return Loss :

It is a measure of the effectiveness of an antenna to deliver of power from source to the antenna. The resonance occurs at 1.44 GHz and 3.03 GHz with return loss values of -23.9 db and -15.2 db respectively

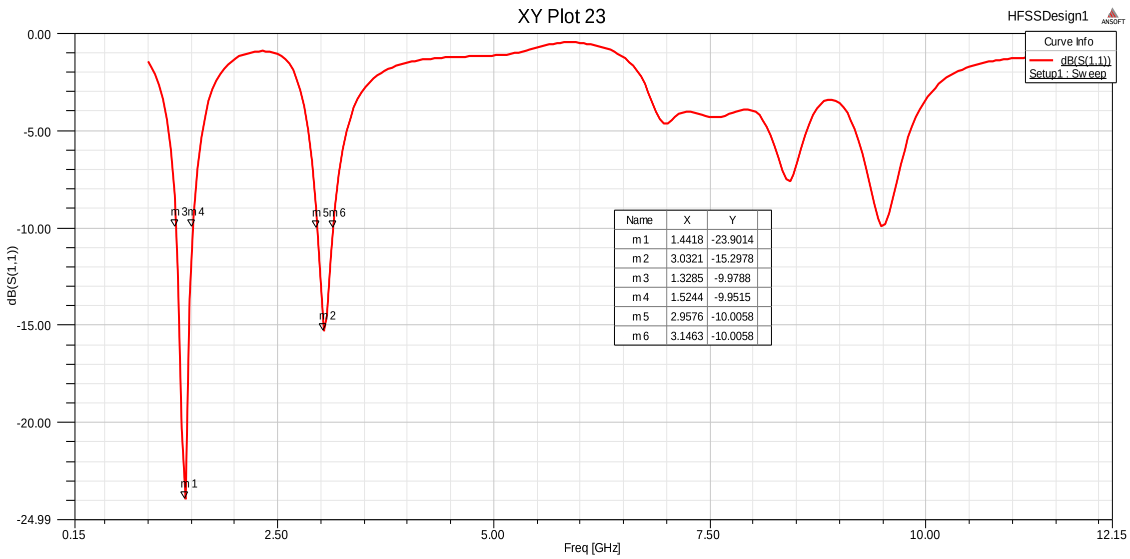


Figure 6.9 Return loss of CPW fed antenna

The resonance occurs at 7.96 GHz with return loss values of -27.8 db

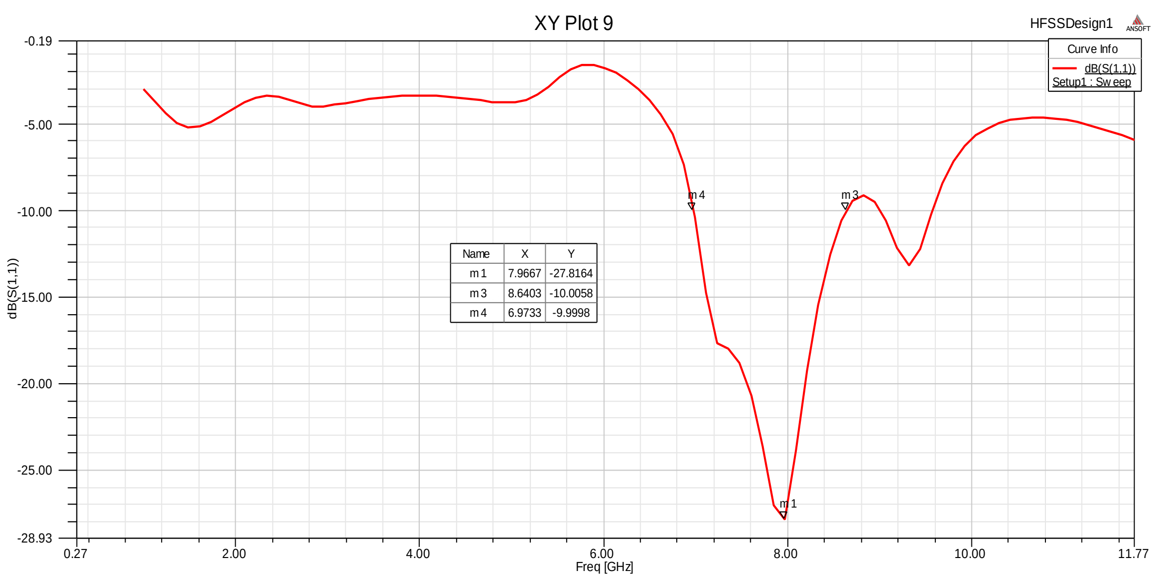


Figure 6.10 Return loss of the modified antenna

6.4.6 Voltage Standing Wave Ratio (VSWR)

It is defined as a measurement of the mismatch between the load and the transmission line. For ideal case the value of VSWR is 1 and for better matching, VSWR value should be as small as possible. The VSWR is 1.13 and 1.41 at 1.44 GHz and 3.03 GHz respectively

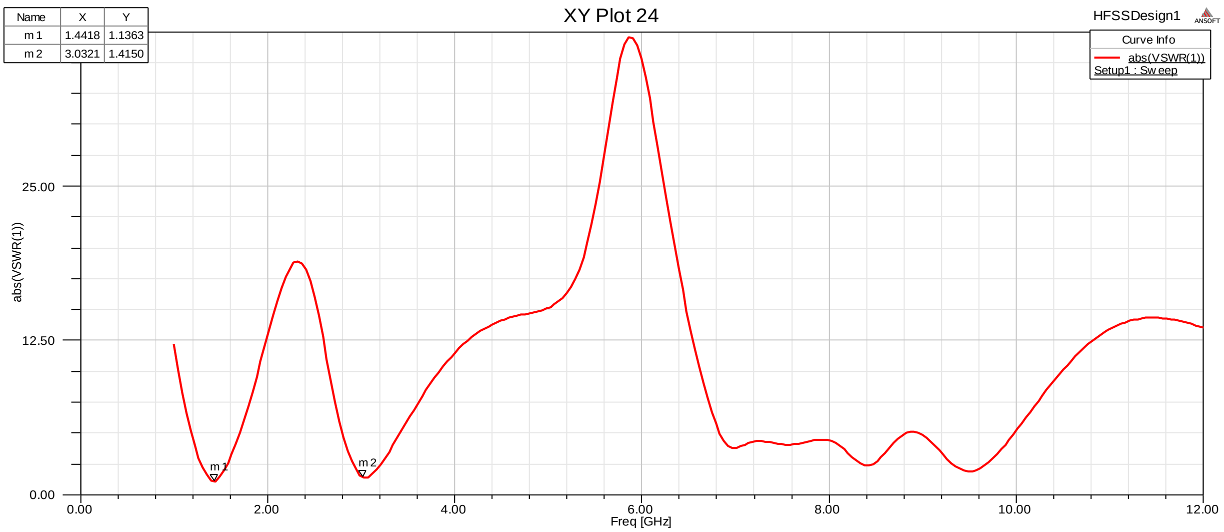


Figure 6.11 VSWR of the CPW fed antenna

For the above antenna with modified ground plane structure, the VSWR is 1.08 at 7.96 GHz

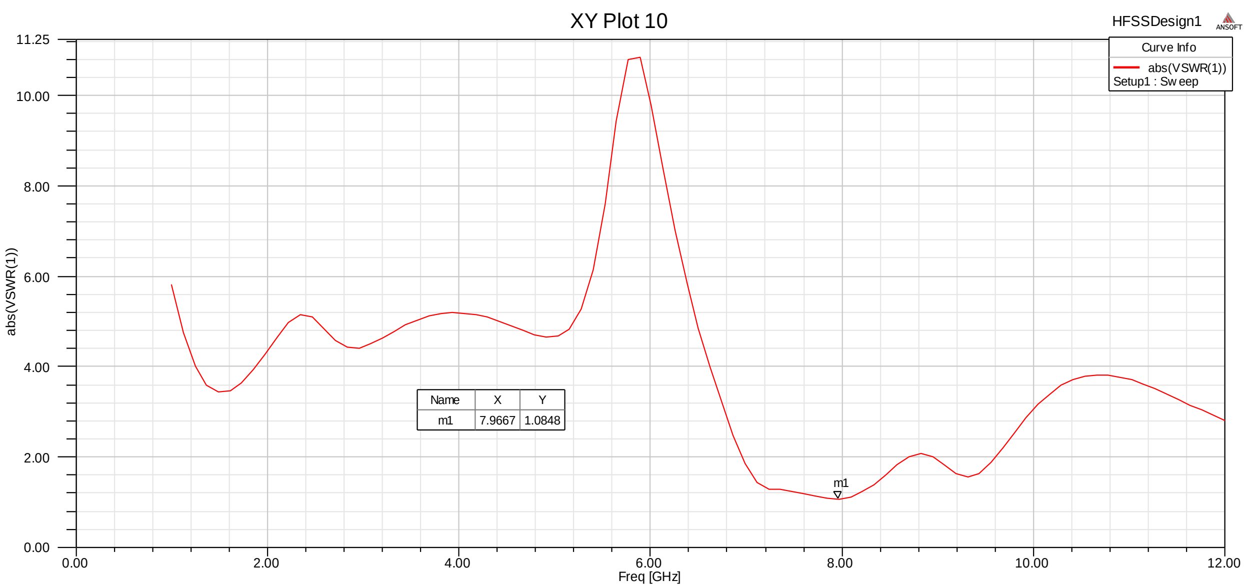


Figure 6.12 VSWR of the modified antenna

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

The CPW fed Hilbert antenna and the same Hilbert antenna with modified ground plane have been designed and simulated using Ansoft HFSS. The CPW fed Hilbert antenna has a radiation efficiency of 91% whereas the Hilbert antenna with a modified ground plane has a radiation efficiency of 82%.The first antenna operates from 2.95 GHz to 3.14 GHz which is useful in fixed WiMAX applications(2.5 GHz to 3.5 GHz). The second one with modified ground plane operates from 7.96 GHz to 8.64 GHz reliable for uplink operation of military communication satellite(7.9 GHz to 8.4 GHz). Both of these antennas have wide bandwidth, Omni directional radiation pattern and good impedance matching. Such antennas are less fragile and can be integrated with ICs. The gain of these antennas are satisfactory for wireless systems.

The proposed antenna has more variables to tune to desired response, iterations, scale factor, angle. By increasing iteration and optimizing antenna parameters with proper values, a very good impedance matching and improvement in bandwidth can be obtained.

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LIST OF PUBLICATIONS

Conferences

- Presented a paper titled "**A Novel Hilbert Fractal Antenna For ISM band Applications and Military Communications**" in the *fourth national conference on Emerging Trends in Computer Communication and Informatics(ETCCI'15)* during 23 & 24 February 2015 at Tamilnadu College of Engineering, Coimbatore.

- Presented a paper titled "**A Novel Hilbert Fractal Antenna for WiMAX Applications, X-band and C-band communications**" in the *conference on Emerging Technologies and its Applications in Computers* during 27 & 28 March 2015 at PSG College of Technology, Coimbatore.

Journal

- The paper titled "**A Novel Hilbert Fractal Antenna For ISM band Applications and Military Communications**" has been selected for publication in the journal *Coimbatore institute of information and technology(CIIT)*