Dual Band and Dual Circularly Polarized Single Layer Microstrip Patch Antenna

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***Abstract*: Wireless technology is one of the main areas of research in the world of communication systems today and a study of communication systems is incomplete without an understanding of the operation and fabrication of antennas. This was the main reason for our selection of a project focusing on this field. The field of antenna study is an extremely vast one, so, to grasp the fundamentals we focused our research on microstrip patch antenna, due to their immense popularity because of low cost, ease of fabrication and versatile use and is an integral part of most wireless systems. The first part of the project group focused on the study of different types of antennae in the modern industrial applications, antenna fundamentals and their review. The next stage focused on limiting our research to microstrip antennae, their advantages and disadvantages, feed techniques etc. The second part focused on the software aspect- simulation of various patch antennas (which are widely used in cell phones today) with an emphasis simultaneously on dual band patch antennae which provide wireless access services for both WCDMA and WiMAX, while rejecting most of the frequencies between the two bands.**

***Keywords*: Microstrip patch Antenna, Radiation Pattern, Directivity, BeamWidth, Return Loss, High Frequency Software Simulator (HFSS).**

1. Introduction

The goal of this project is to design, simulate and implement single and dual band patch antennae and research for new ideas to implement a higher performance to size ratio of the same. Use of conventional microstrip antennas is limited because of their poor gain, low bandwidth and polarization purity. There has been a lot of research in the past decade in this area. These techniques include use of cross slots and sorting pins, increasing the thickness of the patch, use of circular and triangular patches with proper slits and antenna arrays. Various feeding techniques are also extensively studied to overcome these limitations. So that Our Work was primarily focused on dual band and dual frequency operation of Microstrip patch antennas. Dual frequency operation of the antenna has become a necessity for many wireless applications.

2. Literature review

A. Introduction to micro-strip patch antennas

Microstrip antennas are planar resonant cavities that leak from their edges and radiate. Printed circuit techniques can be used to etch the antennas on soft substrates to produce low-cost and repeatable antennas in a low profile. The antennas fabricated on compliant substrates withstand tremendous shock and vibration environments. Manufacturers for mobile communication base stations often fabricate these antennas directly in sheet metal and mount them on dielectric posts or foam in a variety of ways to eliminate the cost of substrates and etching. This also eliminates the problem of radiation from surface waves excited in a thick dielectric substrate used to increase bandwidth. In its most basic form, a Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Fig. 1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. Arrays of antennas can be photo etched on the substrate, along with their feeding networks. Microstrip circuits make a wide variety of antennas possible through the use of the simple photo etching techniques. In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular and elliptical or some other common shape as shown in Fig. 2. For a rectangular patch, the length L of the patch is usually $0.3333\lambda o < L < 0.5\lambda o$, where λo is the free-space wavelength. The patch is selected to be very thin such that $t \ll \lambda o$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\ \lambda o \leq h \leq 0.05\ \lambda o$. The dielectric constant of the substrate (εr) is typically in the range $2.2 \leq \varepsilon r \leq 12$.The special features of this Micro strip Antenna Makes it Suitable to be Used Rapidly in the Field of Communication

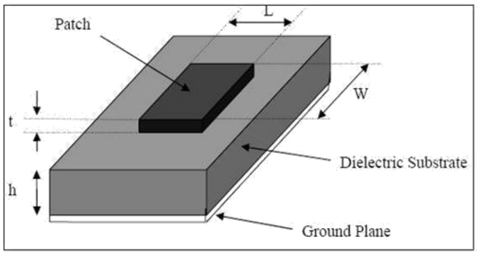

Fig. 1. A Typical Microstrip Patch Antenna

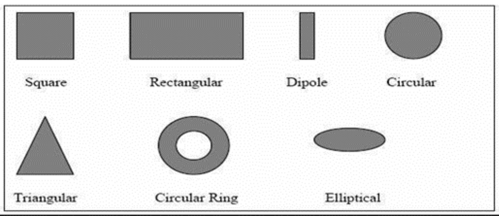

Fig. 2. Typical patch shapes

B. Applications of microstrip patch antennas

Microstrip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore they are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc. The telemetry and communication antennas on missiles need to be thin and conformal and are often microstrip patch antennas. Another area where they have been used successfully is in satellites.

C. Advantages and disadvantages of patch antennas

Some of their principal advantages of microstrip patch antennas are given below:

- Light weight and low volume.
- Low profile planar configuration which can be easily made conformal to host surface.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Can be easily integrated with microwave integrated circuits (MICs).
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid surfaces.

Microstrip patch antennas suffer from a number of disadvantages as compared to conventional antennas. Some of their major disadvantages are given below:

- Narrow bandwidth
- Low efficiency
- Low Gain
- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas
- Low power handling capacity.
- Surface wave excitation

Microstrip patch antennas have a very high antenna quality factor (Q). Q represents the losses associated with the antenna and a large Q leads to narrow bandwidth and low efficiency. Q can be reduced by increasing the thickness of the dielectric substrate. But as the thickness increases, an increasing fraction of the total power delivered by the source goes into a surface wave. This surface wave contribution can be counted as an unwanted power loss since it is ultimately scattered at the dielectric bends and causes degradation of the antenna characteristics. However, surface waves can be minimized by use of photonic band gap structure. Other problems such as low gain and low power handling capacity can be overcome by using an array configuration for the elements.

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3. Feed Techniques and simulation software

A. Feed techniques

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

1) Microstrip line feed

In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure. The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation

2) Coaxial feed

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. The inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane. The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates. Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems. It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the micro strip line feed and the coaxial feed suffer from numerous disadvantages.

B. Aperture coupled feed

In this type of feed technique, the radiating patch and the micro strip feed line are separated by the ground plane. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. The coupling aperture is usually centered under the patch, leading to lower cross polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth.

1) Proximity coupled feed

This type of feed technique is also called as the electromagnetic coupling scheme. Two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%), due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances. Matching can be achieved by controlling the length of the feed line and the width-to-line ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna. It is to be noted that in our project simulations we have used microstrip feed and wave port feed techniques.

C. High frequency structural simulator

HFSS is a commercial finite element method solver for electromagnetic structures from Ansys. The acronym originally stood for high frequency structural simulator. It is one of several commercial tools used for antenna design, and the design of complex RF electronic circuit elements including filters, transmission lines, and packaging. It was originally developed by Professor Zoltan Cendes and his students at Carnegie Mellon University. Prof. Cendes and his brother Nicholas Cendes founded Ansoft and sold HFSS stand-alone under a 1989 marketing relationship with Hewlett-Packard, and bundled into Ansoft products. After various business relationships over the period 1996- 2006, HP (which became Agilent EEs of EDA division) and Ansoft went their separate ways: Agilent with the critically acclaimed FEM Element and An soft with their HFSS products, respectively. A soft was later acquired by Ansys. ANSYS HFSS software is the industry standard for simulating 3-D, full-wave, electromagnetic. Its gold- standard accuracy, advanced solvers and high-performance computing technologies make it an essential tool for engineers tasked with executing accurate and rapid design in high-frequency and high-speed electronic devices and platforms. HFSS offers state-of the-art solver technologies based on finite element, integral equation, asymptotic and advanced hybrid methods to solve a wide range of microwave, RF and high speed digital applications.

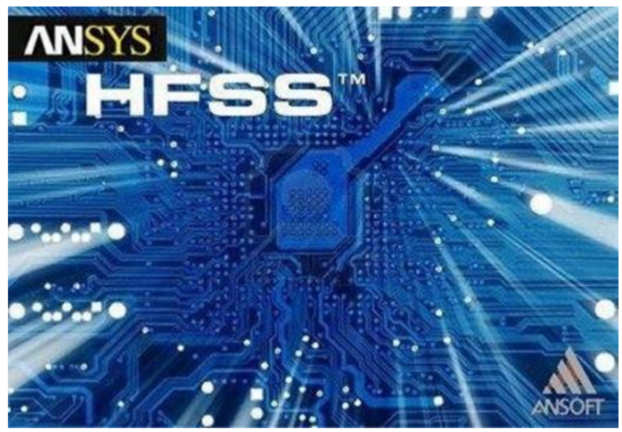

Fig. 3. Ansys-HFSS software logo

4. Results and discussion

A. Design of a simple rectangular patch antenna

The software part of our project revolved around determination of the radiation pattern and return loss curve (s11 vs. frequency) of several simple rectangular patch antennas. From the transmission line model of rectangular patch antennas it is clear that the three essential parameters for the design of a rectangular Microstrip Patch Antenna are:

- *Frequency of operation (fo):* The resonant frequency of the antenna must be Selected appropriately.
- *Dielectric constant of the substrate (εr):* A substrate with a high dielectric constant reduces the dimensions of the antenna, ex: PEC is used in the below simulations.
- *Height of dielectric substrate (h):* For the microstrip patch antenna to be used in certain applications (such as cell phones) it is essential that it is not bulky and to ensure this the height of the dielectric substrate can't be more than a few mm. The effect of all the above 3 factors and the position of feed point on antenna performance was studied by simulating several rectangular patch antennas.

International Journal of Research in Engineering, Science and Management
Volume-1, Issue-12, December-2018
www.ijresm.com | ISSN (Online): 2581-5792

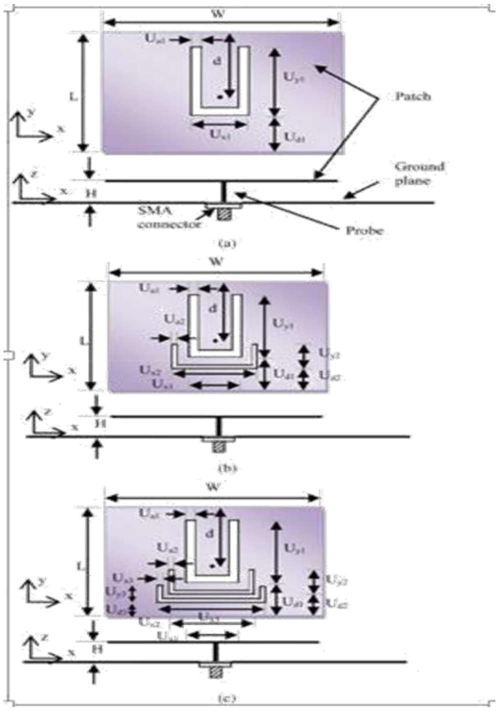

Fig. 4. Geometry of the patch antenna

Table 1
Different types of Patch Antennas and their Structures

Antenna	W	L	H	d	U_{a1}	U_{d1}	U_{x1}	U_{y1}
1a	35.5	26	6	13.5	2.1	4.8	12	19.5
1b	35.5	26	6	13.5	2.1	5.8	13	18.5
1c	35.5	26	6	14.5	2	5.8	14	18.7

Antenna	U_{a2}	U_{d2}	U_{x2}	U_{y2}	U_{a3}	U_{d3}	U_{x3}	U_{y3}
1a	-	-	-	-	-	-	-	-
1b	1	1.5	22	7	-	-	-	-
1c	1	3.5	18	9	1	1.5	22	4

B. Design Steps

Microstrip patch antenna consists of a dielectric substrate sandwiched between a radiating patch on the top and a ground plane at the bottom. At first, the 4 elements of array are constructed individually. Stubs are added to each of the patch and elements are rotated accordingly of given dimensions and thickness is then constructed. The individual patch elements are then combined by using a three different microstrip line feeds. Ground plane is then constructed just as of the same dimensions as the substrate. Materials are assigned as per the permittivity values chosen. Both the patch and the ground plane are given boundary as Perfect E. The microstrip feed connecting the array of patches is fed by coaxial feed which is basically wave port feed. At first a circle is subtracted from ground plane with its center coinciding with the port. A total of three cylinders are used to feed. The outer cylinder will have same radius as that of the circle. One of the smaller cylinders penetrate through the substrate making contact with the patch. Other one will be outside the substrate. Another circle is taken beneath the lower cylinder which acts as wave port feed. Radiation box is constructed such that it converges the entire antenna. The outer feed cylinders are always outside the radiation box. The material is chosen to be air. It is radiated such that all faces except bottom face are radiated. Analysis is set up and sweep is ran in between required frequency range. Various parameters are obtained.

C. Simulations and Results of the above Antennas using HFSS

1) U-slot Patch Antenna

The geometry of the broadband U-slot patch antenna shown in Fig. 5. with the dimensions given in Table 1 Antenna 1a. Air is used as the substrate, with the patch supported by the probe. Simulation results of reflection coefficient and gain of this antenna are given by the solid curves in the figures below. This antenna has an impedance bandwidth of about 33%.

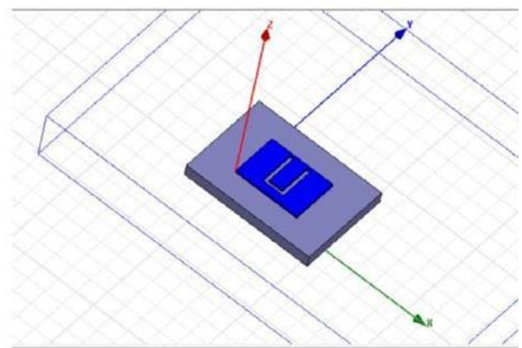
Fig. 5. Structure of U-slot Patch Antenna with appropriate dimensions in HFSS

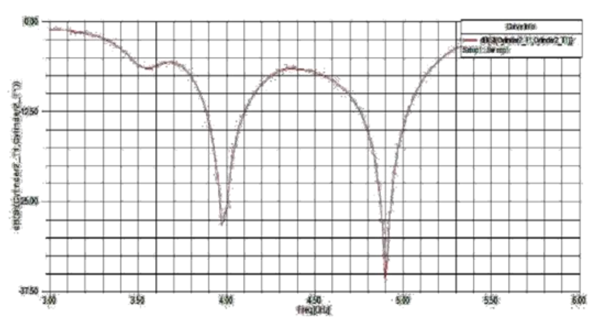
Fig. 6. Return Loss Curve Simulation for U-slot Patch Antenna.

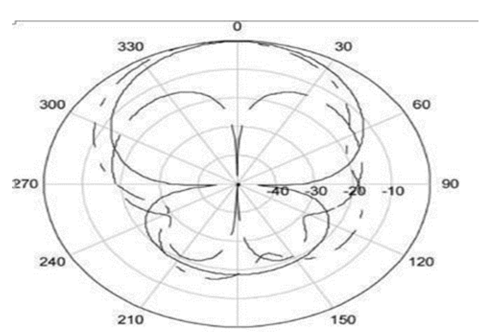

Fig. 7. Radiation Pattern Simulation for U-slot Patch Antenna.

A second U -slot is now cut on the patch Fig 4.6(a) beside. The purpose of this U-slot is not for broad banding purposes, but to introduce a band notch within the broadband antenna. With dimensions of the antenna shown in Table I, Antenna 1b, simulation results of reflection coefficient and gain are given by the starred curves in Fig. figures below. Note that several of the dimensions of the first slot has been slightly modified. The antenna is now a dual-band antenna, with a band from 3.75 GHz to 4.05 GHz and another band from 5.0 GHz to 5.75 GHz. The ratio of the two center frequencies is 1.38.

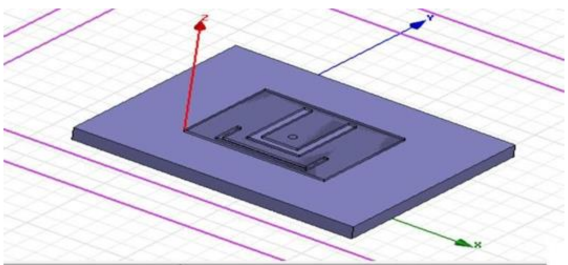

Fig. 8. Structure of Dual Band Patch Antenna

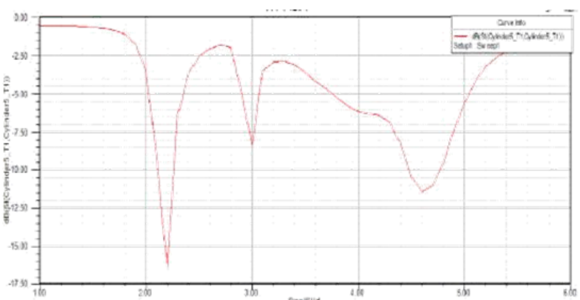

Fig. 9. Return Loss Curve Simulation for Dual Band Patch Antenna.

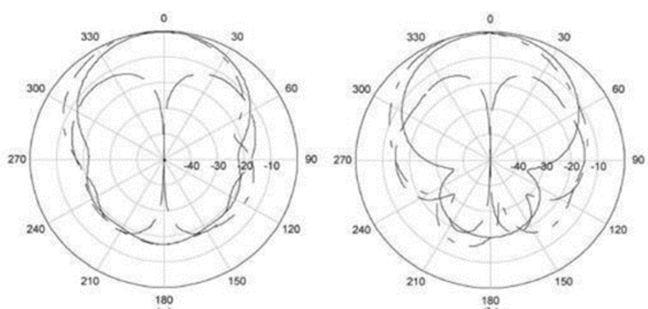

Fig. 10. Radiation Pattern Simulation for Dual Band Patch Antenna

The Fig. 10. Dual band and dual circularly polarized single layer microstrip patch antenna. A planar dual-band array with ort hogonal circular polarizations (CP) in the two frequency bands is proposed in this paper. The array is implemented on a single-layer substrate and easy to be extended to design of a larger array. A new antenna element for such an array is exploited by symmetrically loading stubs on the edges of a square patch. In this work, two pairs of orthogonal modes of the patch, namely, TM10/TM01 and TM30/TM03, are excited simultaneously and used to realize different senses of CP radiation in the two bands. An equivalent transmission-line model of this patch is then developed to describe its working principle and design procedure. To validate its effectiveness, a 2×2- element array prototype operating at 2.53 and 3.59 GHz is designed and fabricated. Both the left- and right-hand CPs, i.e., are obtained simultaneously in the dual bands, and the measured results are found to be in good agreement with the simulated ones.

2) Simulated results: design of antenna:

The Antenna can be designed using the HFSS platform by providing the necessary specification The Obtained results were as follows:

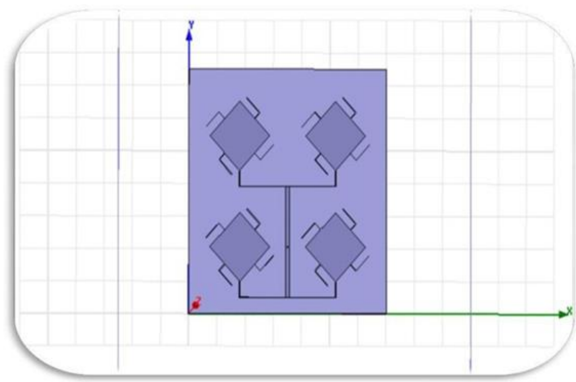

Fig. 11. Proposed Antenna Designed on HFSS software

D. *Return loss curves for different radii of coaxial feed*

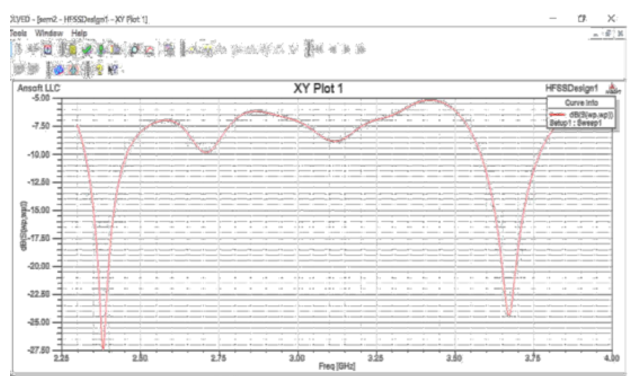

Fig. 12. Return loss curve for a coaxial feed of radius 0.85mm

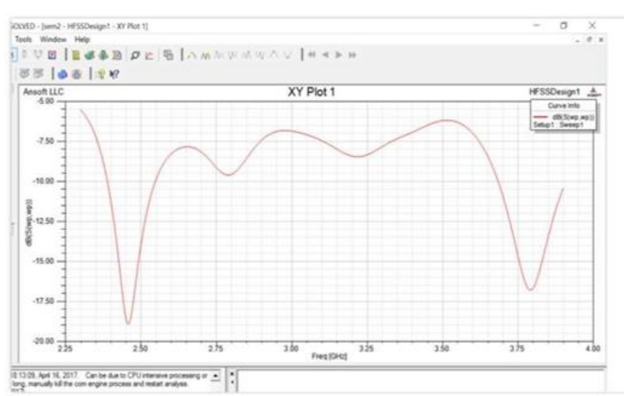

Fig. 13. Return loss curve for a coaxial feed of radius 0.25mm

E. *VSWR (Voltage Standing Wave Ratio)*

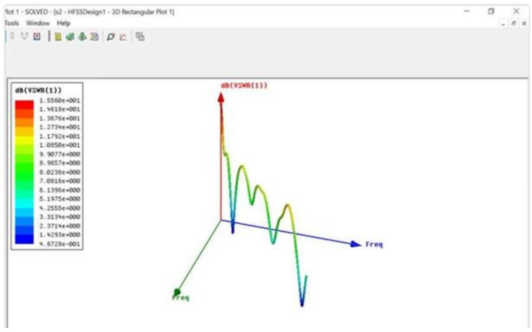

Fig. 14. VSWR of the antenna

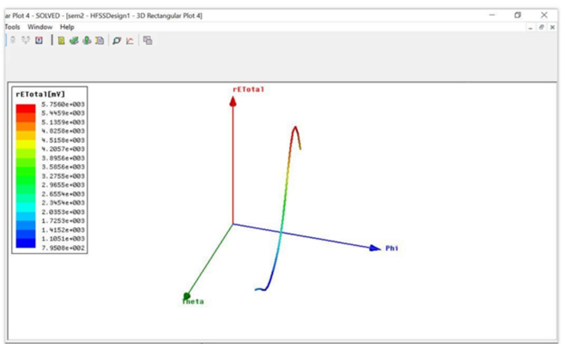

Fig. 15. rE of the antenna

5. Conclusion

Upon the conclusion of our project we made the following assessment of our work: The overall working of antennas was understood. The major parameters (such as Return Loss curves, Radiation Patterns, Directivity and Beam width) that affect design and applications were studied and their implications understood. The construction and different feeding techniques of patch were studied. Several patch antennas were simulated (using HFSS) and the desired level of optimization was obtained. It was concluded that the hardware and software results we obtained matched the theoretically predicted results. Various parameters of the simulated antenna array were tested and verified by gradual change of the dimensions and results were observed. The antenna simulated was tested for various frequency bands by varying patch dimensions and results were observed

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