Enhancement in Bandwidth of Microstrip Antenna Using EBG Structures

A Dissertation Submitted

By

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Under the Guidance of

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ABSTRACT

A novel design of the microstrip patch antenna is being proposed in this work. In order to enhance the bandwidth of microstrip patch antennas the three types of microstrip antenna has been designed starting from rectangular patch with rectangular ground and ended with semicircular patch surrounded by EBG Structures at an operating frequency of 5 GHz using HFSS. On simulation it was observed that the -10dB impedance bandwidth of antenna increased from 11.00% to 50.00% showing the improvement of 39.00% with return loss of -23.3419 dB. The semicircular patch with modified circular ground produced a bandwidth of 2.5 GHz which can be used for the ultra-wide band (UWB) applications. The simulation tool that is used for the designing and Simulation is HFSS v.12.

CERTIFICATE

This is to certify that **Sabzar Ahmad Bhat** has completed M.Tech dissertation titled **"Ehnancement in Bandwidth of Microstrip Antenna Using EBG Structures**" under my guidance and supervision. To the best of my knowledge, the present work is the result of his original investigation and study. No part of the dissertation has ever been submitted for any other degree or diploma.

The dissertation is fit for the submission and the partial fulfillment of the conditions for the award of M.Tech in Electronics and Communication Engineering.

Date: Signature of Advisor

Name:

ACKNOWLWDGEMENT

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I would like to thank the entire ECE Department and all the people, who directly and indirectly helped me to achieve one of the major goals of my life.

I would also like to thank my colleagues and my friends who have helped me throughout at various stages of my dissertation.

Last but not least, I deeply express my gratitude to my parents who have always been there for me in good and bad times.

SABZAR AHMAD BHAT

DECLARATION

I hereby declare that the dissertation entitled**, “Enhancement in Bandwidth of Microstrip Antenna Using EBG Structures”** submitted for the M.Tech Degree is entirely my original work and all ideas and references have been duly acknowledged. It does not contain any work for the award of any other degree or diploma.

Date: **Investigator**

Reg No:

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LIST OF ABBERVATIONS

GHz	Giga Hertz
MSAs	Microstrip Antennas
EM	Electromagnetic
EBG	Electromagnetic Bandgap
UWB	Ultra Wide Band
VSWR	Voltage Wave Standing Ratio
FR4	Flame Retardant 4

CHAPTER 1

INTRODUCTION

Since we are living in the 21th century which is sometimes called as the "Century of Technology". One of the fields that emerged and got new heights in this century is the field of science and technology. The mode of communication between any two people living in any part of the world is only possible with the help of the emerging technology in day today life. Day to day life electronic devices is manufactured at very faster rate in order to meet the needs of people to communicate with each other irrespective of their locations. If we see today every device or every communicating media consists of an antenna which is used to transmit or receive the signals. Without antenna the communication is not possible. Antenna is one of the important part of the digital communication systems. Our day to today life is wholly dependent on the antenna device. The satellites which transmit information from the large distances consist of the antenna it is only by the help of antenna we can receive or transmit information from these satellites. Mobile phone which has changed our daily lives consists of an antenna by which the communication is possible. Other devices in which antenna plays a significant role are wireless communication, Radars, GPS devices, WIMAX, laptops, transceivers, dongles, space vehicle navigation, airplanes and many other devices.

The area of antennas is dynamic, and over the last 50 years antenna technology has been an important part of the communications revolution. Various advances that happened during this period are in common use today, however, there are many more problems and tasks that are facing us today one of the problem is demand for system that have greater performance.

According to the Webester's dictionary antenna is defined as a device which radiates or receives electromagnetic waves. According to the IEEE standard antenna is meant for radiating and receiving of radio waves [1]. In other words we can say that it acts as intermediate device between free space and controlling device as shown in Figure 1.1. This controlling device may take the form of coaxial line or a waveguide [1].

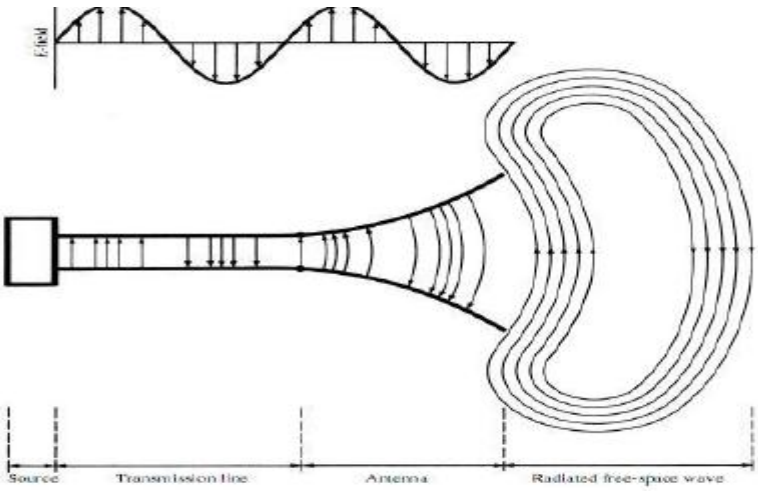


Figure 1.1: Antenna as an Intermediate Device [1].

There are the different kinds of antennas present today such as Wire antennas, Aperture antennas, Array antennas, Reflector antennas, Lens antennas, Horn antennas, Microstrip antennas and many more antennas but out of them the most important antenna which is used in day today life is the microstrip antenna.

Microstrip patch antennas are low profile, economical, low weight antennas which are conformable to planer and non-planer surfaces. They are one of the useful antennas at the microwave frequencies. They can be fabricated by the help of photolithographic techniques. Due to their light weight and low manufacturing cost they become attractive. They are widely used in the antenna arrays because they behave according to the usual standards to surfaces and due to their direct incorporation with the microwave circuitry. Microstrip antennas are widely used and appropriate for the military and viable devices, such as use on aircraft or space antennas because they yield a variety of patterns and polarizations, depending upon the shape of patch which is being used and the mode in which they are excited. Due to their advantages of low back radiation, ease of conformity and high gain they are in increasing demand for wireless communications as compared to the wire antennas.

1.1 SCOPE OF THE STUDY

Wireless communication is enduring to witness incredible growth and broad implementation in a wide variety of applications. There has been an increasing worldwide interest in low profile, low-cost, light weight and wideband system designs. One of the most fundamental components of wireless systems is their antenna. There is always a need of those antennas which have a broad bandwidth so that various applications are covered by a single antenna. In order to meet these requirements microstrip antenna is a good choice since they have various applications in satellite communications, wireless systems. This antenna can be used in very high-data rate and short-range wireless communication systems to modern radar systems But they have a drawback of limited bandwidth if this drawback can be overcome this antenna will become a good choice for the above requirements.

1.2 OBJECTIVE OF THE THESIS

The aim of this thesis is to design and study the performance of the antenna by simulating the different parameters of the microstrip patch antenna. This is a simulation based study. First, the antenna is proposed at 5 GHz. The tool that is used for the design and simulation of the antenna is ANSOFT HFSS v.12. Then, the performance of the antenna is analyzed by simulating the different parameters of the antenna and later on the bandwidth of the proposed antenna is increased by introducing the Electromagnetic Band Gap Structures.

1.3 OUTLINE OF THE THESIS

The thesis is structured as follows:

- Chapter 2 gives the literature review which was conducted during the entire course of study.
- Chapter 3 gives an overview of microstrip patch antenna and Electromagnetic band gap structures, their advantages, disadvantages and applications.
- Chapter 4 discusses about the simulation tool which is used for the design of the antenna.
- Chapter 5 describes the experimental work has been done. The different type of microstrip antennas has been designed and simulated using HFSS and is discussed in detail. The results obtained are discussed
- Chapter 6 describes results that have been obtained after simulating different type of microstrip antennas and results are been discussed.
- Chapter 7 gives the conclusion of the thesis and also discusses about future work.

CHAPTER 2

LITERATURE REVIEW

T. Masri et.al in 2006, conducted a research on narrowband microstrip antenna by designing a spiral fan shaped EBG structures between a patch antenna and its ground plane [2]. They found that by if the number of spiral fan shaped EBG patch structures are increased some good matching characteristics of the antenna are achieved after reaching 13 units and above. They observed that the bandwidth increases when the number of EBG structures was increased.

Moussa ELAYACHI et.al in 2008, studied and conducted a research on printed antennas to miniaturize the antenna [3]. In addition to this, they studied and extended the bandwidth and enhanced the gain of this antenna by designing the Mushroom like type EBG structure. They designed a reference antenna on ground plane which works inside the band of frequencies from 1.85GHz - 2.25GHz. An air-box was designed and settled below the substrate which separated the antenna from the ground plane. Then EBG structures were employed on the ground plane and the thickness of air-box and radiating elements was reduced and they found that by the thickness reduction the bandwidth and gain of the antenna was improved and obtained a planar low profile geometry

Ali A. Dheyab Al-Sajee et.al in 2011, conducted a research to improve the bandwidth of the microstrip patch antenna [4]. They used different dielectric thickness on a simlar antenna as a result the length of the patch changed in every case. As a result they found that the thicker substrate besides being mechanically strong it reduced the conductor losses and increased the radiated power which in turn improved the bandwidth of the antenna.

Neeraj Rao et.al in 2011 conducted a study by designing Microstrip Antenna which can suppress surface waves using periodic structures in Multiple Layer Substrate [5]. They designed an antenna which can achieve a simultaneous increase in gain and bandwidth of microstrip antenna by drilling holes in the substrate and improving the bandwidth by using multiple layers. Improvement in gain was observed by developing electromagnetic band gap structures and increase in bandwidth was ascribed by using of a multiple layer dielectric substrate. They found that these structures have the ability to open a band gap, which is a frequency range for which the propagation of electromagnetic wave is forbidden. They sandwiched one layer of glass in between two layers of silicon so as to reduce the antenna size as much as possible. They found that gain of the antenna can be increased by reducing the loss due to surface wave propagation.

Nabilah Ripin et.al in 2012 conducted a research on microstrip patch antenna which was loaded with EBG structures [6]. They fabricated microstrip patch antenna on the top of the substrate with periodic structures at the ground plane for satellite application. They used Nicolson-Ross-Weir (NRW) method to verify the negative permittivity and permeability of the EBG structure. They designed a reference antenna without EBG structure and an antenna with EBG structure and compared the results between two antennas. It was seen that S11 for antenna with EBG structure gives better performance compared to the S11 of antenna without EBG structured antenna. These S11 values proved that the improvement in the return loss of the antenna which also satisfied the requirement of less than - 10 dB cut off. Antenna with EBG produce higher bandwidth compared to antenna without EBG structured antenna.

Nathan Reynolds et.al in 2012 designed and conducted the study on Low Profile Antenna by using EBG structures [7]. They conducted the research on the patch antenna which was surrounded by the EBG substrates in order to study the radiation characteristics of the antenna. Since the reduction of surface waves increases antenna gain, minimizes the back lobe, which increases directivity, and increases bandwidth. The resonant frequency of the patch antenna is inversely proportional the square root of dielectric constant. Therefore, on increasing the dielectric permittivity of the substrate the resonant length of the patch was decreased which gave a lower profile. They used the mushroom like EBG structure for the patch antenna which was approximated by an effective medium model with lumped LC elements. The small gaps between the patches generates a capacitance and the current along adjacent patches which produces an inductance, as the frequency came closer to the desired frequency results the impedance increased towards infinity which created a frequency band gap. They positioned mushroom-like EBG structure around a probe-fed patch antenna to reduce the performance degrading surface waves.

Ruchika Gupta et.al in 2012 conducted a study on improving the performance of antenna using photonic crystals [8]. They found that there are the two effects due to the surrounding of Photonic crystals around the patch viz parasitic loading effect and cavity. The parasitic effect was the result of the cells which were positioned close to the patch which improved the bandwidth of the antenna but these structures reflected back some energy that EBG cells which are located close to the radiating edges of the antenna elements provide the parasitic loading effect which improves the bandwidth of antenna and these structures also reflect back a part of energy that circulated along the substrate which resulted in cavity effect that tends to decrease the bandwidth of antenna. They simulated a few rows of these structures and less energy was reflected back and parasitic effect became dominant which lead to the significant increase in the bandwidth. The design was simulated using EM Simulation software. The patch antenna which was designed by using the photonic crystals was having impedance bandwidth wider than that of reference antenna.

Ajay kumar et.al in 2013 proposed an antenna in which the surface waves were suppressed by using photonic crystals [9]. These structures were connected to the ground plane. By stop band, the surface waves of the antenna were suppressed. Thus by the suppression of surface waves, the bandwidth of microstrip antenna was improved. The proposed antenna was designed and simulated using HFSS simulation software. The results showed that there was an increase in the bandwidth of an antenna from 9.6% to 15.5%.

Di Wu et.al in 2013, conducted a study and research on dual band microstrip antenna by using mushroom like EBG structure for WLAN application [10]. The antenna that was designed consisted of radiating patch and mushroom like EBG structure cells which greatly influenced the center frequencies of dual band ability. The mushroom like EBG structure was composed of the grounded substrate with periodic square patch above which connected middle of the patches and the ground plane. The antenna was simulated on Computer Simulation technology (CST) Microwave studio.

Gaurav Kumar Sharma et.al in 2013 studied and conducted research on microstrip antenna to improve its performance [11]. They utilized the cylindrical EBG substrate to mend the patch antenna. They fed the antenna with the driven terminal and then integrated it with the EBG substrate to raise the gain and bandwidth of the antenna. The EBG structure that they applied was the arrangement of two interrupted structures with two different periods. They observed that those surface waves which spread along the surface of the substrate can be repressed by the several photonic band-gap structure because of its concerns of forbidden band, that it can spread almost of electromagnetic waves energy in the substrate, and that it has lower return loss (S11) compared to the conventional patch antennas and the enhanced gain. The result showed that due to the coupling between the patch and the EBG structures the bandwidth of the antenna was considerably increased.

Mahmoud Niroo-Jazi et.al in 2013, investigated the possible methods of antenna gain enhancement using artificial materials for enhancing the gain of the antenna by using artificial materials [12]. They etched the patch on the top layer of the dielectric material and three rows of EBG unit cells were surrounding the patch resonator. They designed a unit cell EBG structure to create a band gap in the desired operating frequency band, suppressing the propagating surface waves on the substrate in the E-plane direction. They noticed that by surrounding the patch in both E- and H-planes with EBG, the antenna gain is improved. Moreover, by eliminating the H-plane EBG structure, the peak gain is slightly reduced. However, the total antenna gain was still enhanced. This indicates that the substantial influence of E-plane EBG structure in controlling the wave propagation in the dielectric/air and dielectric/metal interfaces. They further investigated the purpose of gain enhancement by examining the field patterns of the antenna at the operating frequency and they observed from these patterns, the E-plane resonant EBG structure effectively converts the suppressed propagating TM-waves into the radiated ones in both sides of the patch which resulted in the antenna aperture efficiency, and therefore, the antenna realized gain.

Savita.M.S et.al in 2014, conducted a research on uniplaner EBG cells for enhancing the bandwidth and radiation properties of antenna [13] .They loaded the uniplanar EBG cells on the ground plane of microstrip patch antenna and the uniplanar EBG cells were varied and the performance was compared with RMA for bandwidth enhancement by maintaining all the parameter of the radiating patch constant. They observed that on replacing ground plane by uniplanar EBG structure there was a increase in bandwidth which can be credited to the presence of uniplanar EBG cells on the ground plane which is acting as inductance and capacitance.

Vikas et.al in 2014, studied the microstrip antenna and there application in UWB. They studied the effect of parameter variation on the antenna performance [14]. They found that due to the distribution of current along the ends of the radiator. The result showed that on decreasing the dielectric constant of the substrate, on increasing the ground size width the return loss between the resonant frequencies increases but at a specific value of ground width there is a impedance matching, at this value of minimum return loss is achieved and on increasing feed width of the antenna the bandwidth increases.

CHAPTER 3

MICROSTRIP PATCH ANTENNA AND EBG STRUCTURES

3.1 MICROSTRIP ANTENNA

In applications where high performance is vital i-e where weight, cost, performance, size and ease of installation are the bounds low profile antennas may be required. To meet these requirements the microstrip antennas can be used. They are low profile, economical, low weight antennas which are conformable to planer and non-planer surfaces. They are one of the useful antennas at the microwave frequencies i-e, frequencies above to 1 GHz ($f > 1$ GHz).

The simplest form of the microstrip antenna is shown in the Figure 3.1 and Figure 3.2 which consists of a radiating patch on one side of the dielectric substrate and a ground plane on the other side.

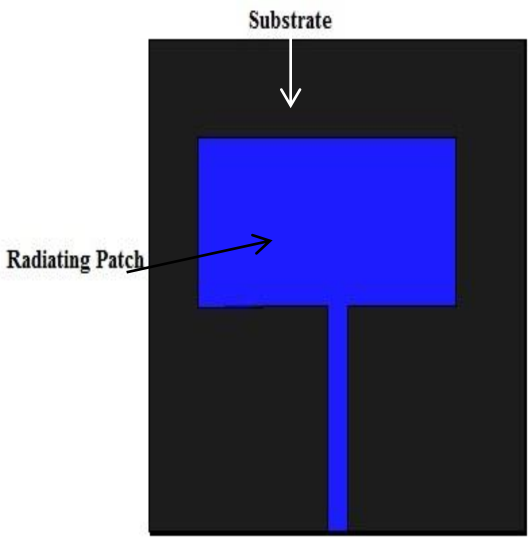


Figure 3.1: Patch on the Substrate

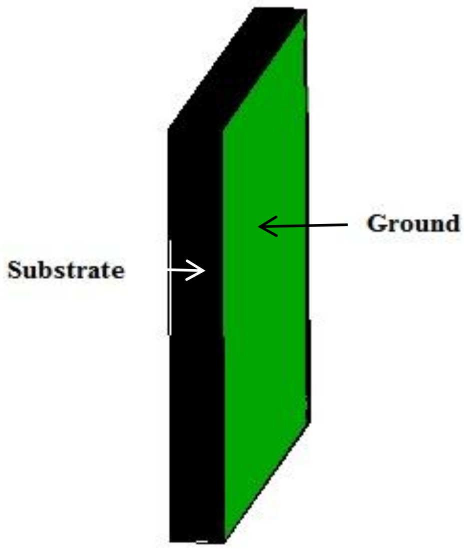


Figure 3.2: Ground Plane below Substrate

The patch is commonly made of the gold, copper and many others i-e the materials with good conductivity and can have any shape. The radiating patch and the lines which feed antenna are commonly photo imprinted on the dielectric substrate.

3.1.1 CHARACTERISTICS OF MSAs

It was the Deschamps in 1953 who first projected the concept of microstrip antennas. However, the practical microstrip antennas were developed by Munson and Howell[1] in

1975. The length of the patch (L) for rectangular patch is typically $0.3333\lambda_o < L < 0.5\lambda_o$, where λ_o is free space wavelength [1]. The patch to be selected should be very thin i-e $t \ll \lambda_o$, where t denotes the thickness of patch. The height (h) of the dielectric substrate is typically $0.3333\lambda_o \leq h \leq 0.5\lambda_o$, where h denotes the height of the dielectric substrate[1]. There are number of substrates which can be used in the designing process of the microstrip antennas, like Duriod, Rogers Ultaralam, FR4_epoxy, Neltec etc. For the good antenna performance, the dielectric constant and the thickness of the substrates play a major role. The substrates should be choosen of low dielectric constant and thick as they provide better efficiency and larger bandwidth [1]

3.1.2 MSAs OPERATION

The patch acts almost as a resonant cavity, where the patch is on the top, the ground plane is on the bottom. The patch edges act as open circuit boundary condition. In the cavity some modes are allowed to exist at different resonant frequencies [1]. At resonant frequency, when the antenna is excited, a strong field is generated inside the resonant cavity and strong current on the surface of patch is produced which produces significant radiation from the fringing fields between the edges of the patch and the ground plane.

3.2 FEEDING TECHNIQUES USED IN MICROSTRIP ANTENNAS

The input impedance and characteristics of antenna is mainly influenced by the feeding techniques which is an important design parameter. Microstrip antenna can be excited by a various methods one of the method is microstrip line feed which is discussed below:

3.2.1 MICROSTRIP LINE FEED

It is one of the simplest types of feeding in which the strip which is conducting is connected to the patch as shown in Figure 3.3. This strip which is conducting should be smaller in width as compared to patch. It has an advantage that it can be fixed on the similar substrate, so as to get the planer structure [15]. It has the drawback that when the spurious feed radiation increases as thickness of the substrate increases.

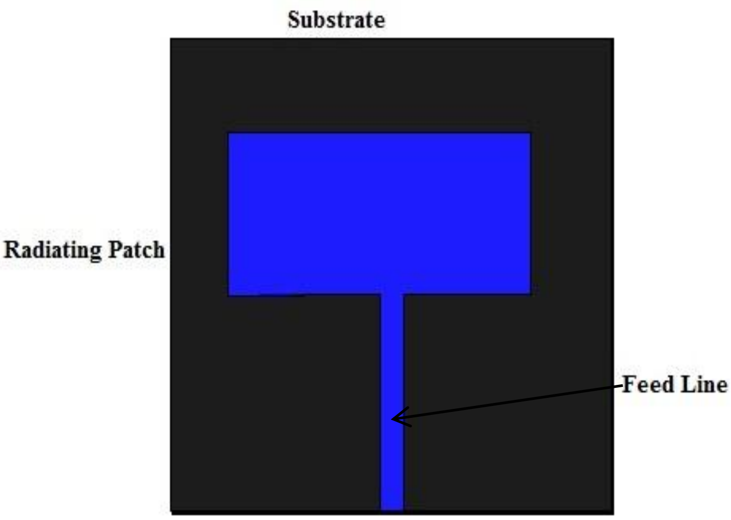


Figure 3.3: Feed Line

3.2.2 COAXIAL FEED

In this type of feeding, the conductor which in the inner side of the spreads through a dielectric and is welded to the radiating patch, while the conductor which is on the outer side is connected to the ground plane as shown in figure 3.4.

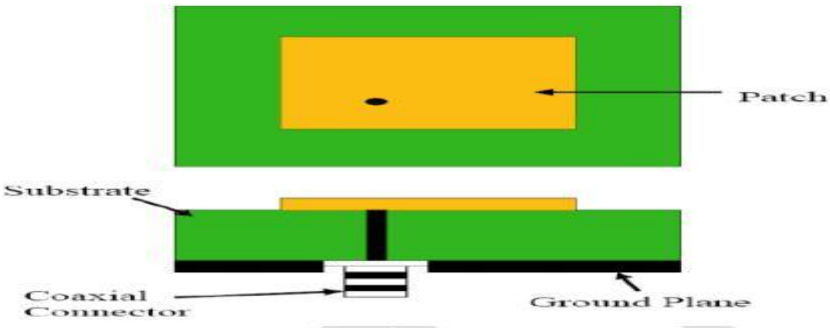


Figure 3.4: Probe Fed RMSA[1].

The main advantage of this feed is that it can be positioned at any location inside the patch to match the input impedance and has low spurious radiation and the drawbacks of this is that it would not be completely planer, it's modeling is difficult and suffers from the narrow bandwidth for the substrates which are thick[15].

3.2.3 APERTURE COUPLED FEED:

In this type of feeding technique, the microstrip feed line is used to couple the feid to the patch by using a small aperture as shown in figure 3.5.

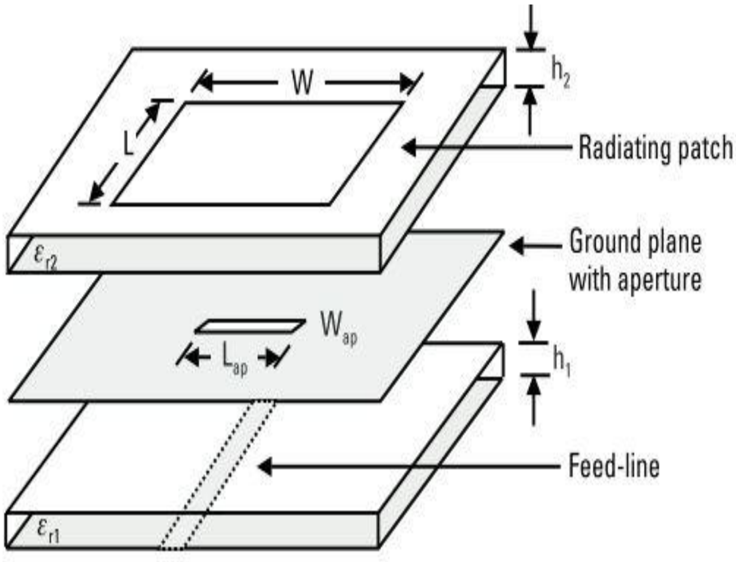


Figure 3.5: Aperture Coupling[15]

The coupling aperture is generally placed under the patch, which leads to the cross polarization due to symmetry of the configuration. The shape, size and the position of the aperture determines the amount of coupling from the feed line to the radiating patch. Its major drawback of this feeding is that it is difficult to fabricate and suffers from the narrow bandwidth[15].

3.2.4 ELECTROMAGNETIC COUPLING SCHEME

This type of feeding technique is also known as the proximity coupling. In this type of feeding to dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on the top of the upper substrate as shown in figure 3.6.

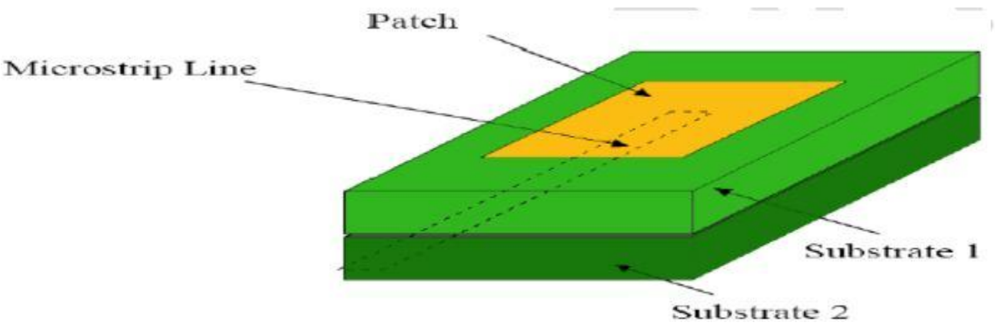


Figure 3.7 Proximity Feed Technique[1]

Its advantage is that it eliminates spurious feed radiation.

3.3 METHODS OF ANALYSIS

The radiating patch in microstrip antenna is generally 2D in structure which is on a thin dielectric substrate. The analysis methods for MSAs on the basis of analytical techniques are classified as:

- The transmission line model;
- The cavity model;
- The MNM.

3.3.1 TRANSMISSION LINE MODEL

For understanding the basic performance of microstrp antenna the transmission line model is used. The microstrip antenna is characterized by width W and height h, parted by a transmission line of length L by low impedance Z_c and transmission line of length L[1].

A. Effects of Fringing

Since the length and width of the patch is limited the fringing is experienced by the edges of the patch. The amount of fringing is a function of the height of the substrate and the dimensions of the patch. In E-plane the fringing is a function of ratio of the length of the patch and height of the substrate and dielectric constant of the substrate. For patch antenna the ratio is greater than 1, therefore fringing is reduced.

The Figure 3.4 shows the electrical field lines of the MSA. Since the majority of electric field lines occur in the substrate and some reside in the air. As W/h>>1 and ε_r >>1, the field lines ponder mostly in the substrate. Therefore as compared to its physical dimensions fringing in this case makes microstrip line look broader electrically therefore effective dielectric constant ε_{eff} is introduced to account for fringing and wave propagation in the line[1].

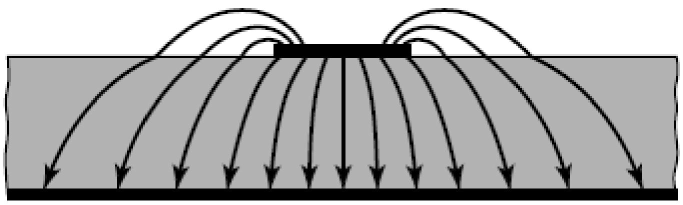


Figure 3.4 Electric Field Lines [1].

Figure 3.5 shows the conductor in the center of microstrip line with dimensions and height above the ground plane rooted into one dielectric.

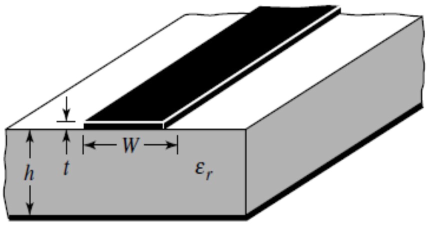


Figure 3.5: Microstrip Line.

the effective dielectric constant is almost constant for the low frequencies and at intermediate frequencies it tends to increase and approaches to the values of dielectric constant of the substrate. The effective dielectric constant is calculated by [1]:

$$e_{reff} = \frac{e_r + 1}{2} + \frac{e_r - 1}{2}[1 + 12\frac{h}{w}]^{-\frac{1}{2}} \quad (3.1)$$

Where e_{reff} = effective dielectric constant.

ε_r = dielectric constant of substrate.

h = height of dielectric substrate.

w = width of the patch.

B. Resonant Frequency, Effective Length and Effective Width

The dimensions of the patch along its length can be stretched by a distance ΔL, which is a function of effective dielectric constant and width to height ratio which is calculated by[1]:

$$\frac{\Delta L}{h} = 0.412 \frac{(e_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(e_{reff} - 0.258)(\frac{W}{h} + 0.8)} \quad (3.2)$$

Meanwhile ΔL is the length of the patch which has been stretched on each side, the effective length of the patch is now calculated by[1]:

$$L_{eff} = L + 2\Delta L \quad (3.3)$$

The resonant frequency of a patch antenna is calculated by[1]:

$$f_r = \frac{v_0}{2L\sqrt{\varepsilon_r}} \quad (3.4)$$

Width W is calculated by:

$$W = \frac{c}{2 f_r} \sqrt{\frac{2}{\in_{reff} + 1}} \qquad (3.5)$$

3.4 ADVANTAGES OF MICROSTRIP ANTENNAS

- They are light weight and low volume antennas which can be made conformal to planer as well as non-planer surfaces.
- The cost for the fabrication of microstrip antennas is low.
- The microstrip antennas having simple feeds can undergo linear as well as circular polarization.
- They can be easily integrated with microwave integrated circuits.
- Feed lines and matching networks can be fabricated simultaneously with the antenna structure.

3.5 DISADVANTAGES OF MICROSTRIP ANTENNAS

- The bandwidth of the microstrip antennas is narrow and they are associated tolerance problems.
- The gain of the microstrip antennas result in the lower side and are very low.
- Most of the microstrip antennas radiate into half-space.
- For high-performance arrays complex feed structures are required.
- Microstrip antennas are usually poor end-fire radiators.
- From the feeds and junctions extraneous radiations occur.
- The power handling capacity of microstrip antennas are usually low.
- In the arrays of the microstrip antennas high mutuall coupling occurs.
- The excitation of surface waves is occurs in microstrip antennas.

3.6 APPLICATIONS OF MICROSTRIP ANTENNAS

For many applications, the advantages of microstrip antennas far overshadow their limitations. Some prominent system applications for which microstrip antennas include:

- Satellite communication.

- Doppler and other radars.
- Radio altimeters.
- Command and control systems.
- Missiles and telemetry.
- Remote sensing and environmental instrumentation.
- Satellite navigation receivers.
- Mobile radio systems.

3.7 ELECTROMAGNETIC BAND GAP STRUCTURES

Periodic structures are found adequately in nature. Periodic structures are the structures which are superimposed on themselves by a parallel displacement over a certain limited distance. The minimum value of this distance is known a period and the structures are known as periodic structures. When these structures intermingle with EM waves, the exciting phenomenon occurs and amazing features result. The structures affect the electromagnetic wave by having features smaller than the wavelength of corresponding electromagnetic wave [16]. The features such as frequency stop bands pass bands, and band gaps could be recognized. The various terms have been used depending upon the field of applications and we categorize them under the terminology of “electromagnetic band gap structures”.

Electromagnetic band gap structures are also called as Photonic crystals which are artificially engineered periodic objects that evade the propagation of EM waves in a stated band of frequencies for all incident angles [17]. They have an ability to control the propagation of EM waves. EBGs have the aim of producing high quality, low loss, and periodic, dielectric structures. EBGs have been contrived for frequencies ranging from a few gigahertzes (GHz) up to a few terahertz (THz), radio, microwave and mid-infrared frequency regions. The planar electromagnetic band gap (EBG) surfaces display unique electromagnetic properties with respect to incident electromagnetic waves as:

- The EBG structures display a frequency band gap when the incident wave is a surface wave over which the surface wave cannot propagate for any incident angles.
- In EBG structures reflection phase varies with frequency when the incident waves are planer in nature. The reflection phase becomes zero at the certain frequency which looks like a perfect magnetic conductor which doesn’t exist in nature.

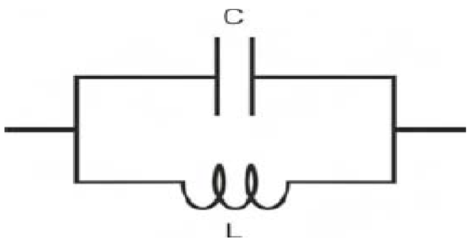
3.8 EBG OPERATION

The process mechanism of the EBG structure can be explained with equivalent lumped LC elements as shown in Figure 3.6(a). The capacitor results from the gap between the patches and inductor results from the current along the adjacent patches [16] as shown in Figure 3.6(b). The impedance of a parallel resonant LC circuit is calculated by [16]:

$$Z = \frac{j\omega L}{1-\omega^2 LC} \qquad (3.6)$$

The resonance frequency of the circuit is calculated by[3]:

$$\omega_0 = \frac{1}{\sqrt{LC}} \qquad (3.7)$$



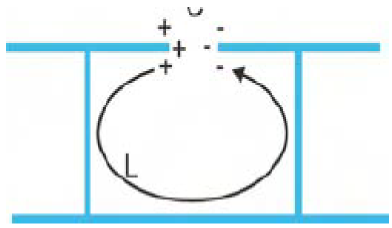


Figure 3.6(a) Parallel Resonant *LC* Circuit   Figure 3.6(b) Capacitances and Inductances

The high surface impedance also ensures that a plane wave will be reflected without the phase reversal.The edge capacitance for the narrow gap situation is given by the following equation[16]:

$$C = \frac{W\varepsilon_0(1+\varepsilon_r)}{\pi}\cosh^{-1}\left(\frac{W+g}{g}\right) \qquad (3.8)$$

The value of the inductor depends on the thickness of the structure and the permeability which is given by the following equation[3]:

$$L = \mu h \qquad (3.9)$$

If we put the values of L and C in equations (3.8) and (3.9), the impedance and resonance frequency can be calculated.

3.9 APPLICATIONS OF EBG STRUCTURE

Some prominent applications were the EBG structures can be used are as follows:

- **Medical Sciences:** Image scanning has become a very important nowadays in the medical sciences. In scan blindness the surface waves come across which have become a problem in order to overcome with this problem EBG structures can be used.

- **High precision GPS:** In many of applications in day today life high precision GPS are used. On determining precisely the phase of the signal, it is hopped to reach a position accuracy of few millimeters. In order to avoid the multipath errors, the backward field radiated should be of few orders in magnitude as compared to field radiated frontwards. In order to achieve such requirement the antenna that excites the surface waves but again electromagnetic band gap structures can be used to eradicate the problems.
- **Antenna Engineering:** The typical EBG applications in antenna designs are described below

  - **Substrates for surface wave suppressions**

The surface wave’s leads electromagnetic wave propagation along the ground plane instead of radiation into free space, these surface waves diminishes the efficiency and gain of the antenna by increasing the back lobe radiations which inturn deteriorates the signal to noise ratio in wireless communication systems. The rising of surface waves also results in the mutual coupling in many designs. Many antennas also integrate EBG structures to reduce the mutual coupling [16].

  - **Antenna substrates for efficient low profile wire antenna designs**

For good radiation efficiency and for designing low profile antennas which are desired in the wireless communications the EBG structures can be used.

CHAPTER 4

SIMULATION TOOL USED

4.1 INTRODUCTION

In this chapter, the simulation tool High Frequency Structural Simulator (HFSS) is been used for the designing and simulation of the antenna is described.

HFSS is a software package designed by the Ansys which is used to calculate electromagnetic behavior of a structure. It is usually used for the designing of antennas, RF electronic circuits such as transmission lines and filters. It was basically developed at Carnegie Mellon University by the group of students which were doing work under Professor Zoltan Cendas.

HFSS is usually used to compute the following:

- Basic electromagnetic field quantities and, for open boundary problems, radiated near and far fields.
- Characteristic port impedances and propagation constants.
- Generalized S-parameters and S-parameters renormalized to specific port impedances.
- Radiation pattern and Gain in Rectangular, 2D and Polar plots.
- The Eigen modes, or resonances, of a structure.

HFSS is the industry-standard simulation tool for 3D full wave electromagnetic field simulation. HFSS provides E-Fields, H-Fields, currents, S- parameters and near and far field radiation field results. Intrinsic to the success of HFSS as an engineering designing tool is its automated solution process where users are only required to specify geometry, material properties and desired output. From here HFSS will automatically generate an appropriate, efficient and accurate mesh for solving the problem using the proven finite element method.

The core of HFSS is based on the finite element method (FEM) where it is numerical technique for finding approximate solutions to partial differential equations (PDE) and their systems, as well as integral equations. FEM is the special case of the more general Galerkin method with polynomial approximation functions. The solution approach is based on eliminating the spatial derivatives from PDE. This approximates the PDE with:

- a system of algebraic equations for steady state problems.

- a system of ordinary differential equations for transient problems.

These equation systems are linear if the underlying PDE is linear, and vice-versa. Algebraic equations systems are then solved using numerical linear algebraic methods.

4.2 PROCEDURE OVERVIEW

The procedure which is fallowed in the designing of the structures in HFSS is shown in the figure 4.1. The first step involved in the designing of the model in the HFSS is to draw the geometric model of the structure that is to be analyzed. Then the objects that are being drawn are assigned the materials of which they are made and various other properties like transparency, color etc. can also be assigned at the same time. The next step is to define the boundaries for the structure such as perfect electric or magnetic conductor. After defining the boundaries the structure is excited by the port or the voltage source which needs to be excited. Once the boundaries and excitations are defined the structure is completely modeled and the solution is set up for the structure. This solution step requires the assignment of the frequency sweep at which adaptive mess requirement takes place. After completion of the solution step the structure is simulated and after the completion of simulation the solution data is post-processed which includes the graphs for the various parameters such as S11 parameter, VSWR and far field plots.

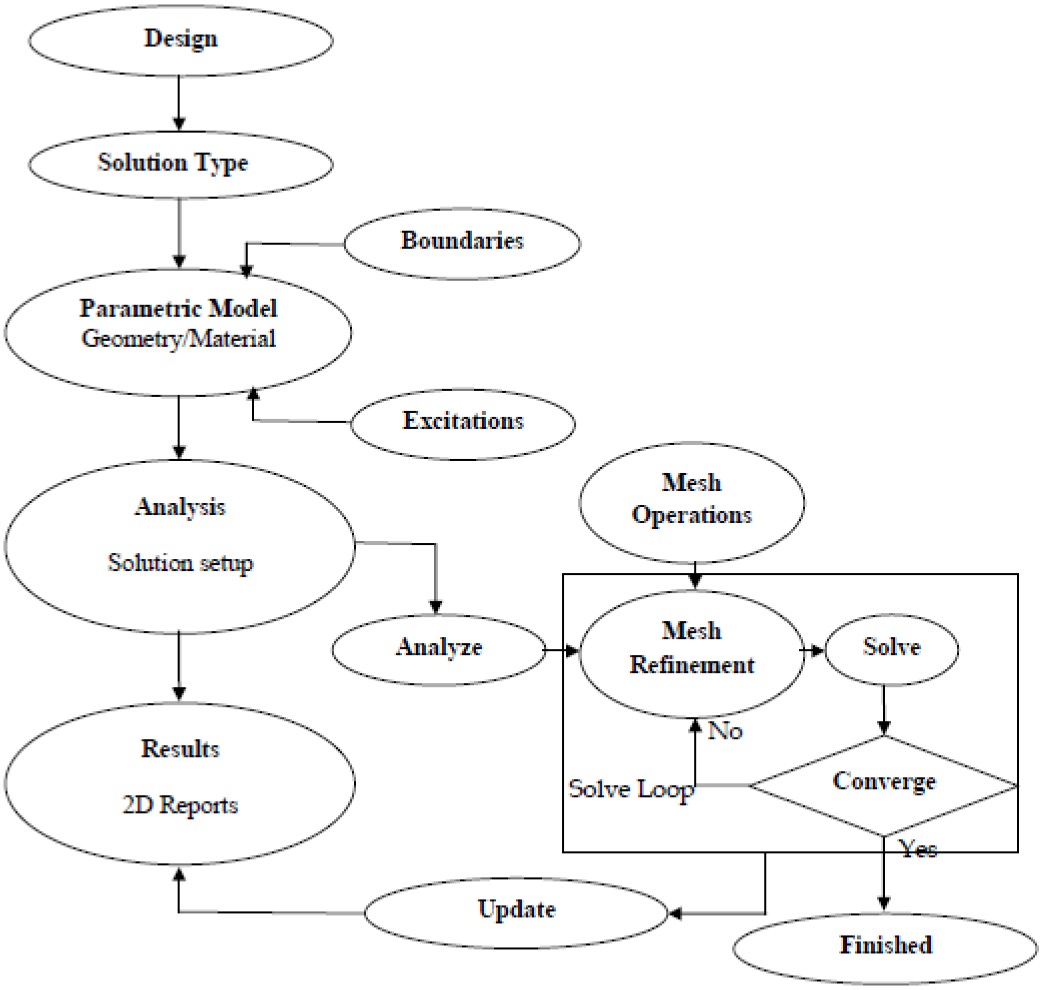


Figure 4.1 HFSS Solution Procedure Overview.

CHAPTER 5

EXPERIMENTAL WORK

5.1 INTRODUCTION

In this chapter the designing and simulation of the various types of microstrip patch antennas operating at the frequency of 5.0 GHz are been designed and described in detail. The simulation is been carried out on HFSS tool which is described in detail.

There are the three types of microstrip antennas which have been designed and studied are as:

- Rectangular Patch with Rectangular Ground Plane.
- Rectangular Patch with Reduced Rectangular Ground Plane.
- Semicircular Patch Surrounded by EBG Structures.

These three types of microstrip patch antenna are described as below:

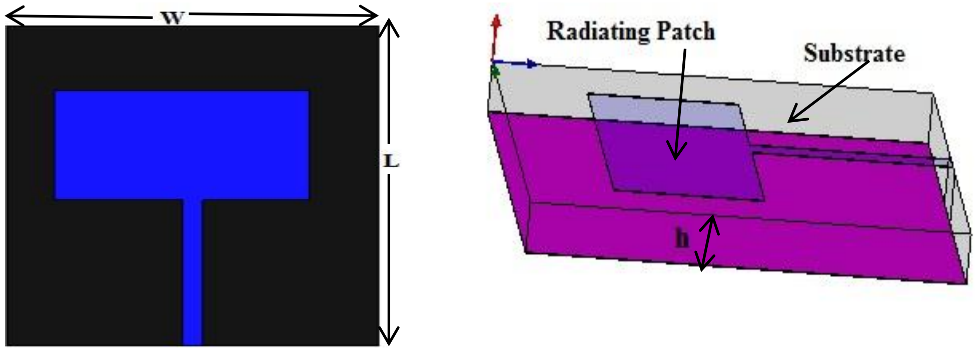
5.2 RECTANGULAR PATCH WITH RECTANGULAR GROUND PLANE

The designing of the antenna is started from rectangular microstrip patch with rectangular ground. The antenna is operated at the frequency of 5.0 GHz. The process of designing and simulation of the antenna is carried out by using HFSS tool and is described in detail.

5.2.1 ANTENNA GEOMETRY

The geometry of the corresponding antenna in both top view and side view is shown in the figure 5.1

:



(a) Top View (b) Side View

Figure 5.1 Rectangular Microstrip Patch Antenna with Rectangular Ground

The color portion of the figure 5.1 (b) shows the ground plane. There is the rectangular shaped patch placed on the grounded dielectric substrate at the height of 0.5 mm. The thickness of the dielectric substrate is denoted by 'h' and the substrate has a dielectric constant which is denoted by ε_r .

5.2.2 SELECTION OF SUBSTRATE

The first step in designing any type of the antenna is to select the type of substrate which has appropriate thickness and loss tangent. Thicker substrates are mechanically strong substrates which increase the radiated power, improve the impedance bandwidth and have low conductor losses but it increases the weight, dielectric losses and surface wave losses [1].

The dielectric constant plays (ε_r) plays the similar role to that of the substrate thickness. There are the many substrates available which are used for the designing of the microstrip antenna whose dielectric constant range generally vary between 2.2 to 12. The substrates which are generally thicker and whose dielectric constant usually lies in the lower end of the range are used because they offer better efficiency and superior bandwidth but they tend to increase the size of the radiating element. The substrates having high loss tangent reduce the efficiency of the antenna due to increase in the dielectric losses.

Considering all these factors, the FR4 dielectric substrate material is chosen whose dielectric constant is 4.7 and loss tangent is 0.02.

5.2.3 LENGTH AND THE WIDTH OF THE PATCH

For an effective radiator, the good radiation efficiency is determined by the width which is calculated by[1]:

$$W = \frac{c}{2 f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (5.1)$$

Where c = Velocity of light.

f_r = Resonant frequency.

ε_r = Dielectric Constant.

Since the dimensions of the patch are limited along the length and width of the patch, the fields at the edges of the patch experience fringing. The amount of fringing is function of the dimensions of the patch and height of the substrate[1]. For such microstrip antennas where the ratio of the length of the patch and height of the patch is greater than 1, the fringing is condensed, still it must be taken into account. Same is the case for the width. For $\frac{W}{h} \gg 1$ and $\varepsilon_r \gg 1$ the electric field lines mostly ponder in the substrate. In this case fringing makes the microstrip line appearance wider electrically as compared to its physical dimensions [1]. Since some waves travel into the substrate and some waves travel into the air, the effective dielectric constant is introduced to account for fringing. The effective dielectric constant can be calculated by[1]:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{w}]^{-\frac{1}{2}} \tag{5.2}$$

Where e_{reff} = effective dielectric constant.

ε_r = dielectric constant of substrate.

h = height of dielectric substrate.

w = width of the patch.

Now the length of the patch can be calculated by[1]:

$$L = \frac{\lambda_g}{2} \tag{5.3}$$

Where λ_g is the guided wavelength which is given by [1]:

$$\lambda_g = \frac{c}{f\sqrt{\varepsilon_r}} \tag{5.4}$$

When fringing is taken into the account the length of the patch is extended by ΔL on both sides and the effective length of the patch now can be calculated by[1]:

$$L = \frac{\lambda_g}{2} - 2\Delta L \tag{5.5}$$

Where ΔL is given by[1]:

$$\frac{\Delta L}{h} = 0.412\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} + 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{5.6}$$

5.2.4 FEEDING TECHNIQUE

In this design the power is fed to the radiating patch by the means of microstrip line feed. The width of the microstrip feed is usually much smaller as compared to the patch. The feed is attached with the lumped port from which the input power is given. This type of feed is easy to fabricate and simple to match. This arrangement has an advantage that it can be imprinted on the same substrate so that the overall structure remains planer, but this arrangement has a disadvantage that when the substrate thickness is increased the surface waves and spurious feed radiation increases. The feed is designed with the characteristic impedance of 50 Ω.

The dimension of the rectangular microstrip patch (Reference antenna) antenna operated at the frequency of 5.0 GHz is given in the table 5.1.

Width of the substrate	**Length of the substrate**	**Width of the Patch**	**Length of the Patch**	**Width of the Feed line**	**length of the Feed line**
35 mm	35 mm	12 mm	24 mm	1.9 mm	16mm

Table 5.1: Dimensions of the Rectangular Patch with Rectangular Ground Plane

5.2.5 DETAILS OF SIMULATION

This section describes the process of designing of the rectangular microstrip patch antenna for the simulation. The Ansoft HFSS v.12 is used for the simulation of antenna.

5.2.5.1 DRAWING

Before drawing the model of antenna, it is necessary to select the solution type from the available types and unit which is to be used in designing of the antenna. In this antenna the driven terminal solution type is been selected and the unit which has been selected is millimeter (mm). The driven terminal solution type is usually used for computing the terminal based S-parameter of passive, high frequency structures.

After selecting the solution type and the unit, the grid plane is selected as XY plane and the antenna geometry is modeled using the available objects in the in the Draw menu as shown in figure 5.2.

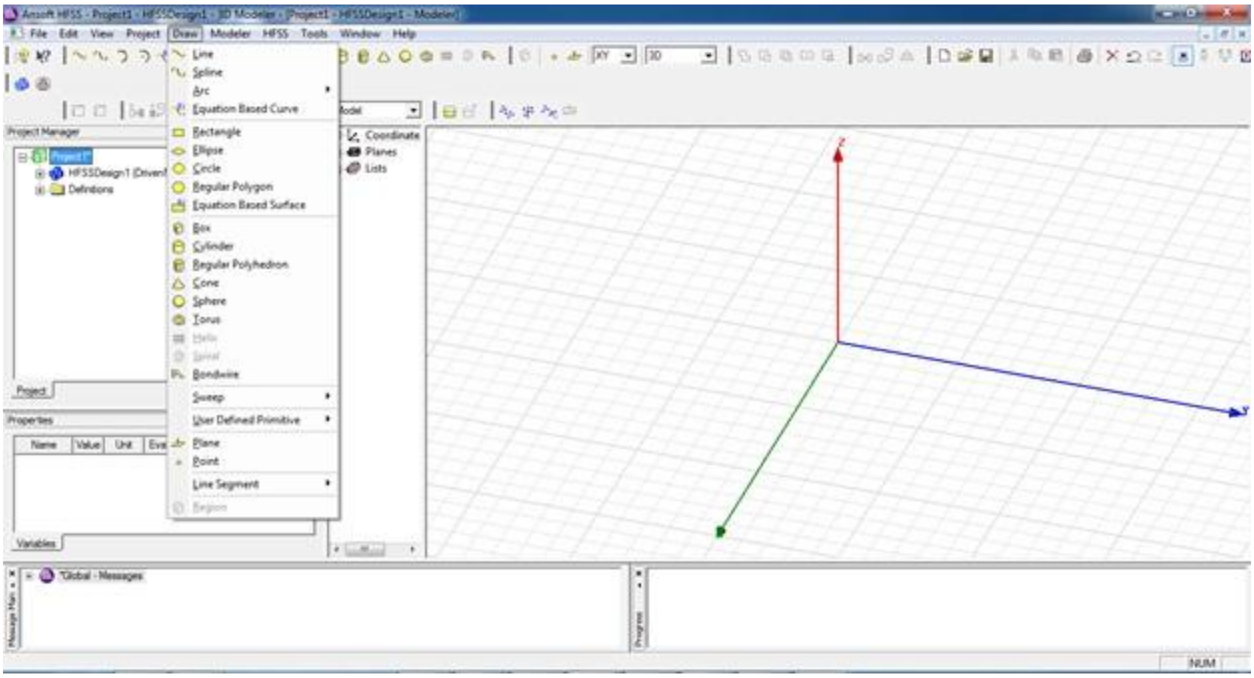


Figure 5.2: Snapshot of list of objects in Draw Menu

Now to draw the substrate the box object is selected from the draw menu. The dimension of the substrate is given into corresponding fields. After drawing the substrate, the ground is drawn below the substrate of same dimensions as of substrate. Now the patch is drawn using above the substrate using the dimensions as given in table 5.1.

After drawing the patch, the microstrip feed line is drawn similarly using the dimensions as given in table 5.1. The feed is united with the patch by using the Boolean in the modular menu of the HFSS by simultaneously selecting the patch and the feed line as shown in figure 5.3. The lumped port is drawn by selecting XZ plane using rectangle in the draw box and is connected with the feed line so as to excite the antenna.

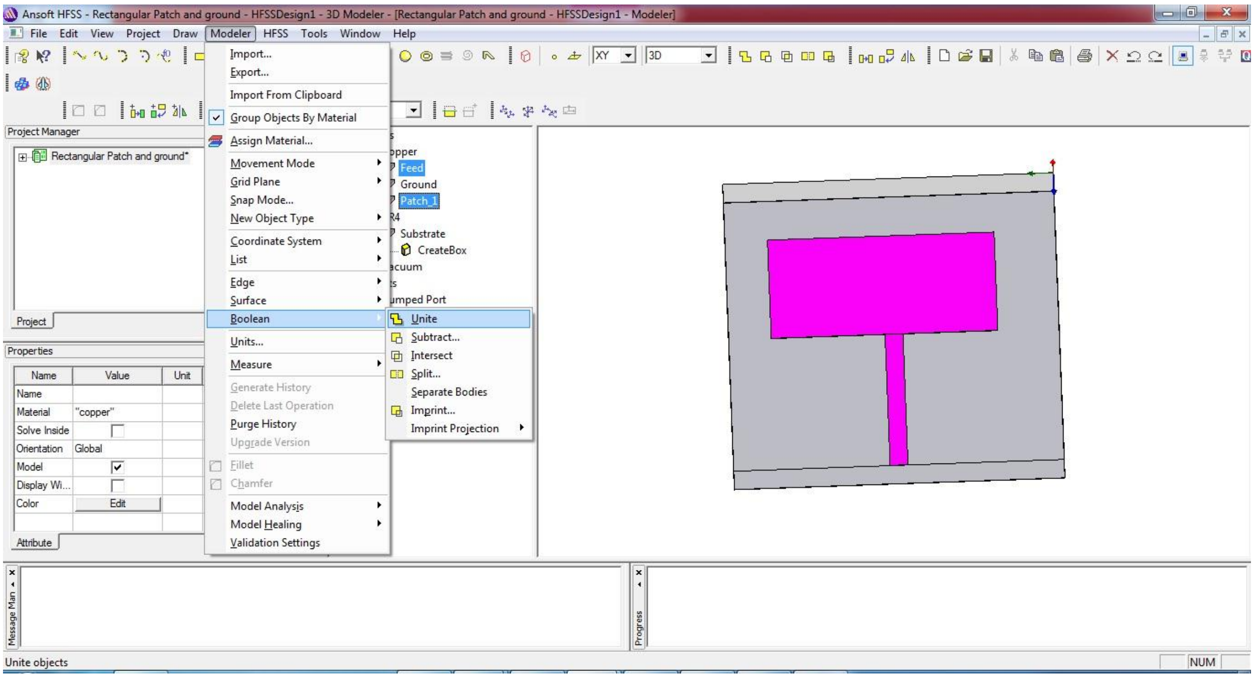


Figure 5.3: Snapshot of Uniting Feed Line and Patch

In order to perform far field calculations HFSS needs an object that is assigned a radiation boundary so box is drawn from the draw menu of HFSS. The 3D view of the rectangular microstrip patch antenna is shown in figure 5.4.

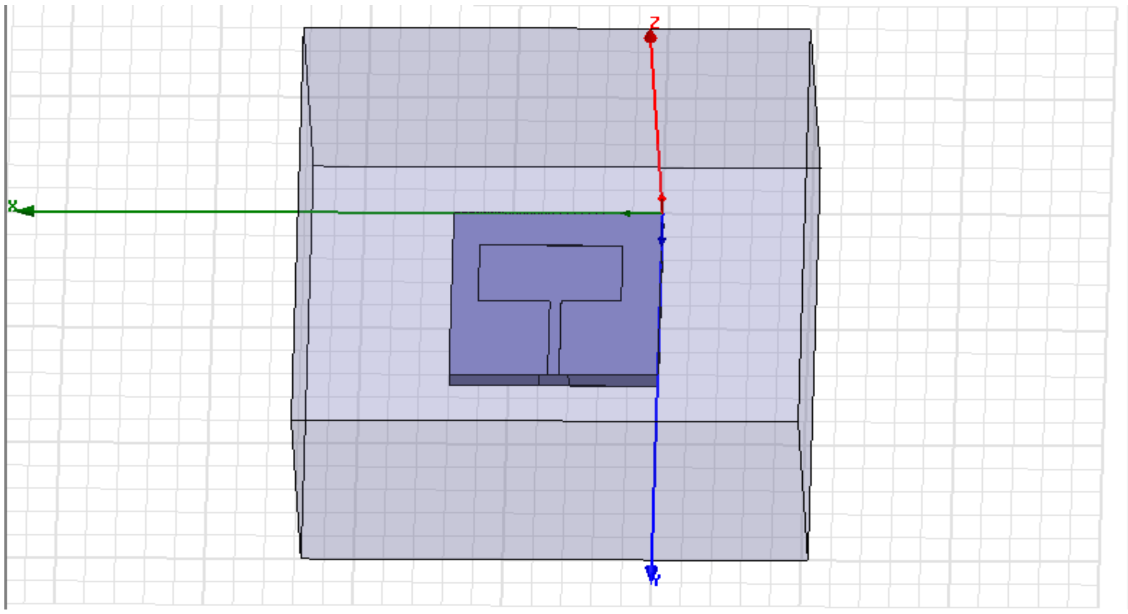


Figure 5.4: 3D View of Rectangular Microstrip Patch Antenna

5.2.5.2 ASSIGNING MATERIALS

After completing the drawing the model of the antenna it is necessary to assign the material properties to the objects. This can be achieved by selecting the objecting and then using the assign material in the modular menu of HFSS as shown in figure 5.5, by selecting assign material the select definition window opens up where the material of our type as shown in figure 5.6. The substrate is assigned the FR4 material having the relative permittivity of 4.7 with dielectric loss tangent of 0.02.

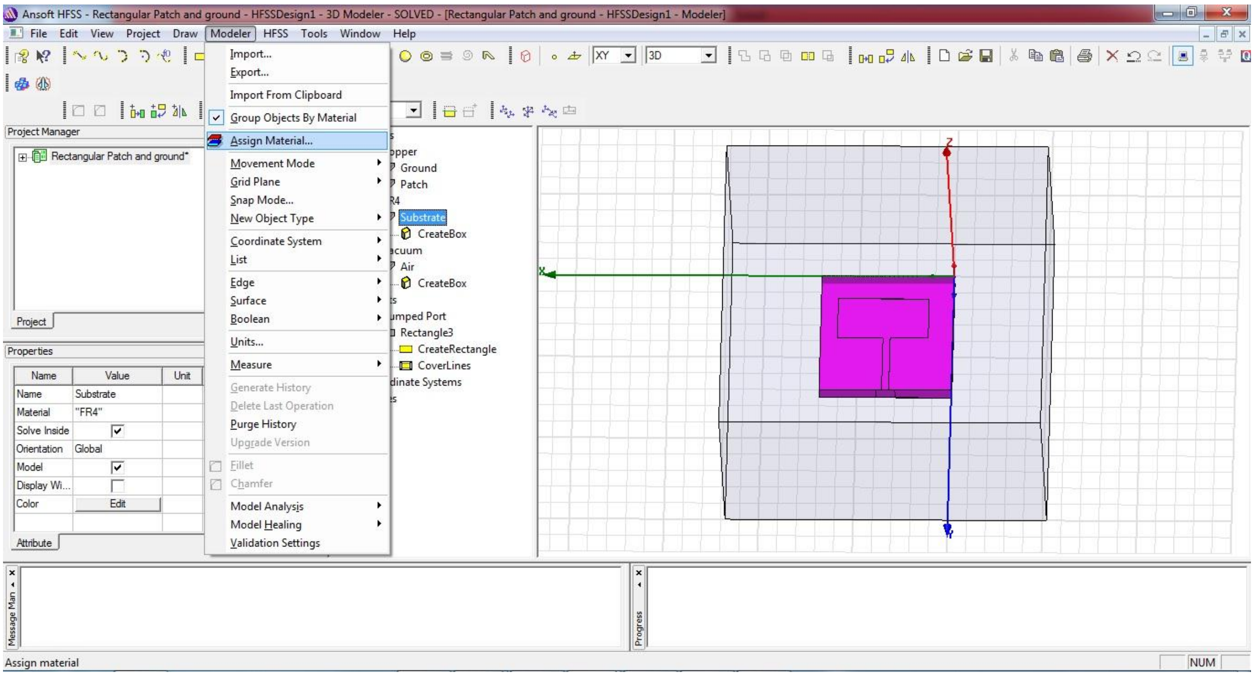


Figure 5.5: Snapshot of the menu showing the Assign Material

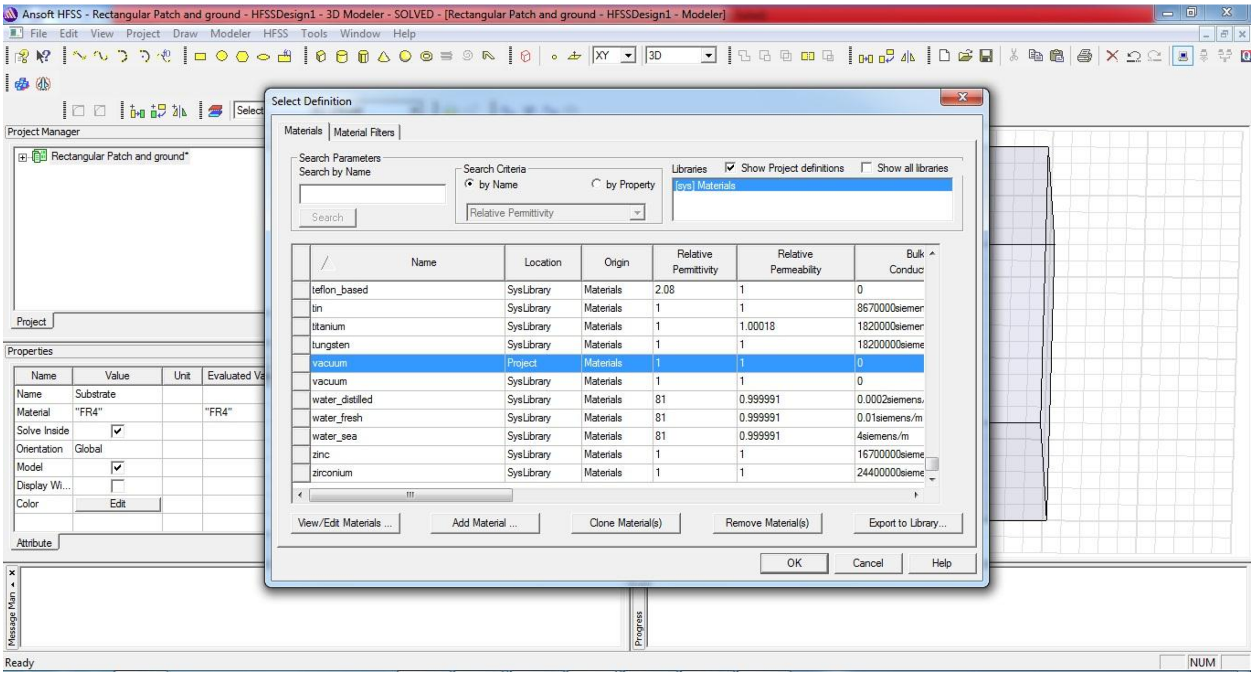


Figure 5.6: Snapshot of the Select Definition Window

After assigning the material to the substrate, similarly the material is assigned for the ground and feed line which is assigned as Copper having the relative permittivity of 1.

The box which was drawn around the antenna for performing far field calculations is known as air box which is assigned a material vacuum having permittivity and permeability of 1.

The next step in the process for setting up the simulation is to assign the boundary conditions to the surfaces, radiation to the air box and excitation to the lump port.

5.2.5.3 ASSIGNING BOUNDARIES AND EXCITATION

Boundary conditions state the field performance at the edges of the problem region and the object interfaces. The boundaries are assigned to the surfaces of the objects by selecting the surface of the object and then the boundaries are assigned from the HFSS menu which opens up assign on selecting assign we can assign the boundaries to the surfaces as shown in figure 5.7. The ground plane and the patch are assigned the perfect E boundaries as shown in figure 5.8 because these are perfectly conducting surfaces. The air box is then assigned a radiation which can be assigned from the same HFSS menu.

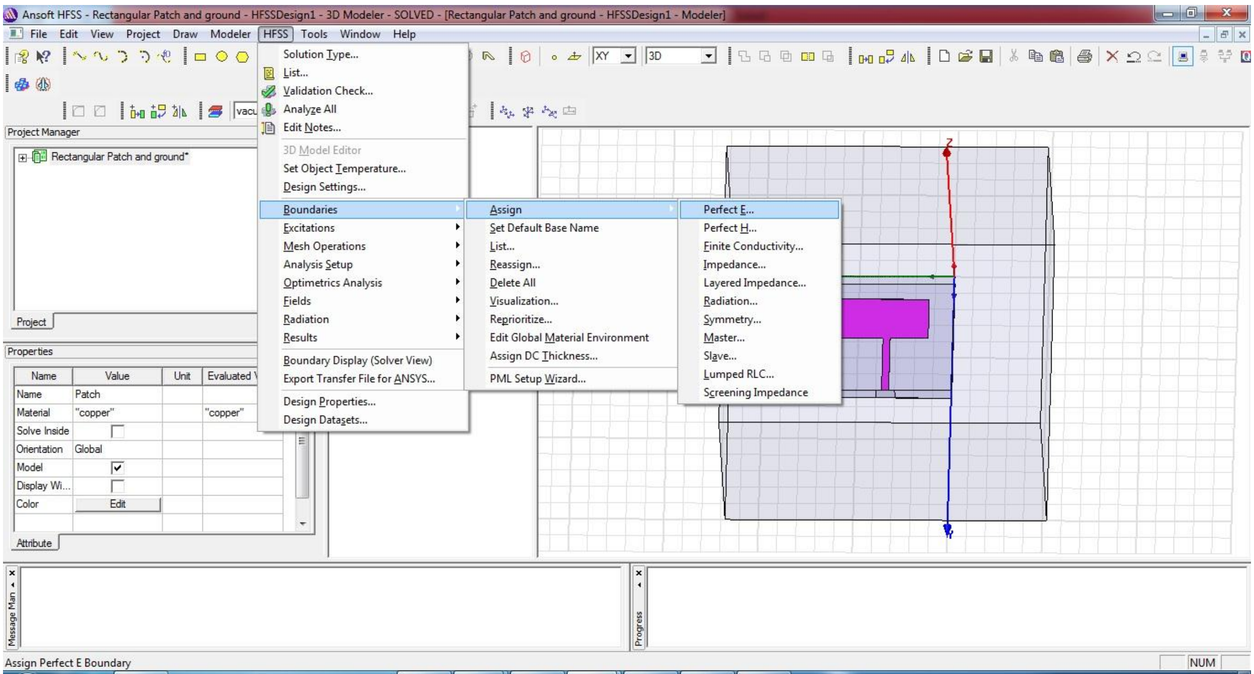


Figure 5.7: Snapshot of Assign Boundary Menu

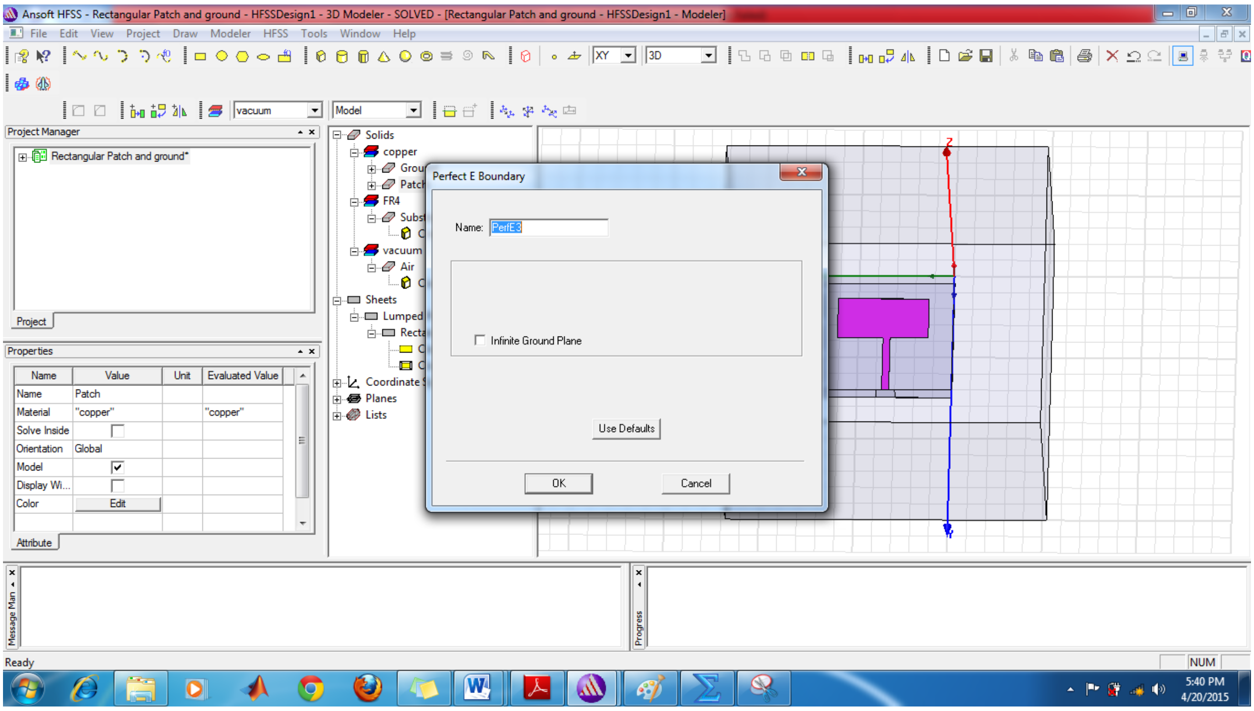


Figure 5.8: Snapshot of Assigning perfect E Boundary Condition to Patch

The excitation to the lump port is given by selecting the lump port then the excitation is assigned from the same HFSS menu from which excitation is selected which opens up assign from which lump port is selected as shown in figure 5.9.

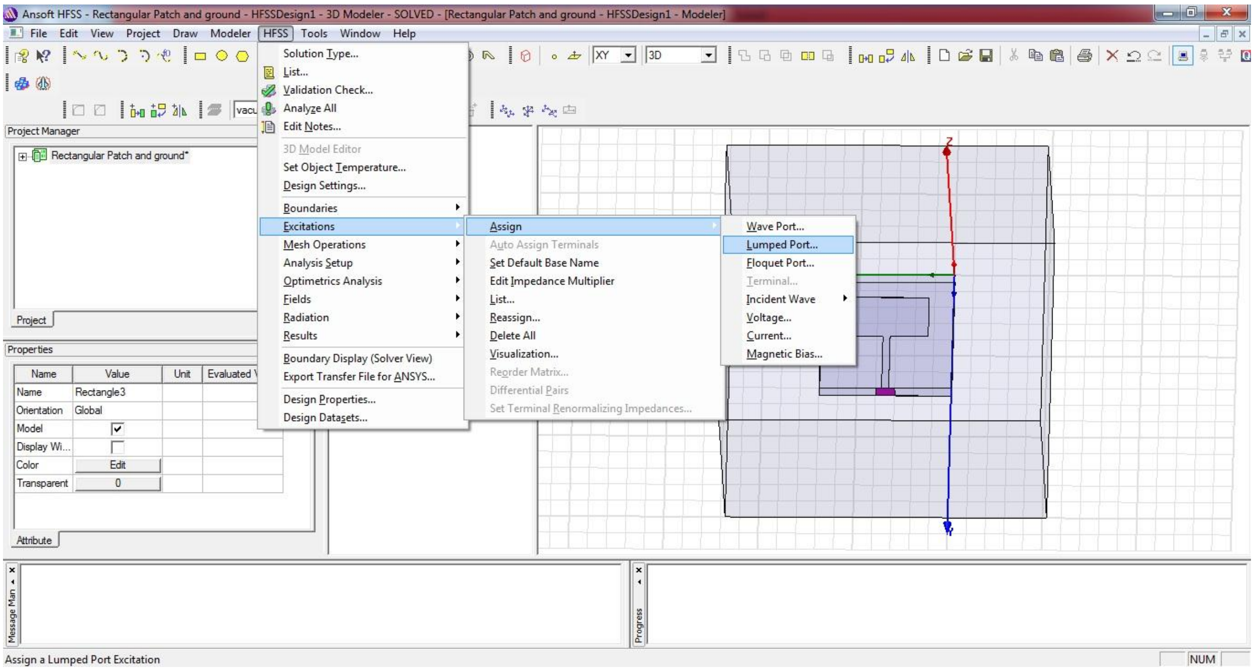


Figure 5.9: Snapshot of Assigning Excitations to Lump Port

On selecting the lump port the lump port mode window opens from which integration line is drawn when integration line is drawn correctly the lump port mode window again opens automatically and shows the integration line is defined as shown in figure 5.10. After the integration line is defined the lump port mode window fallows the lump port post processing window which needs the assigning of impedance as shown in figure 5.11.

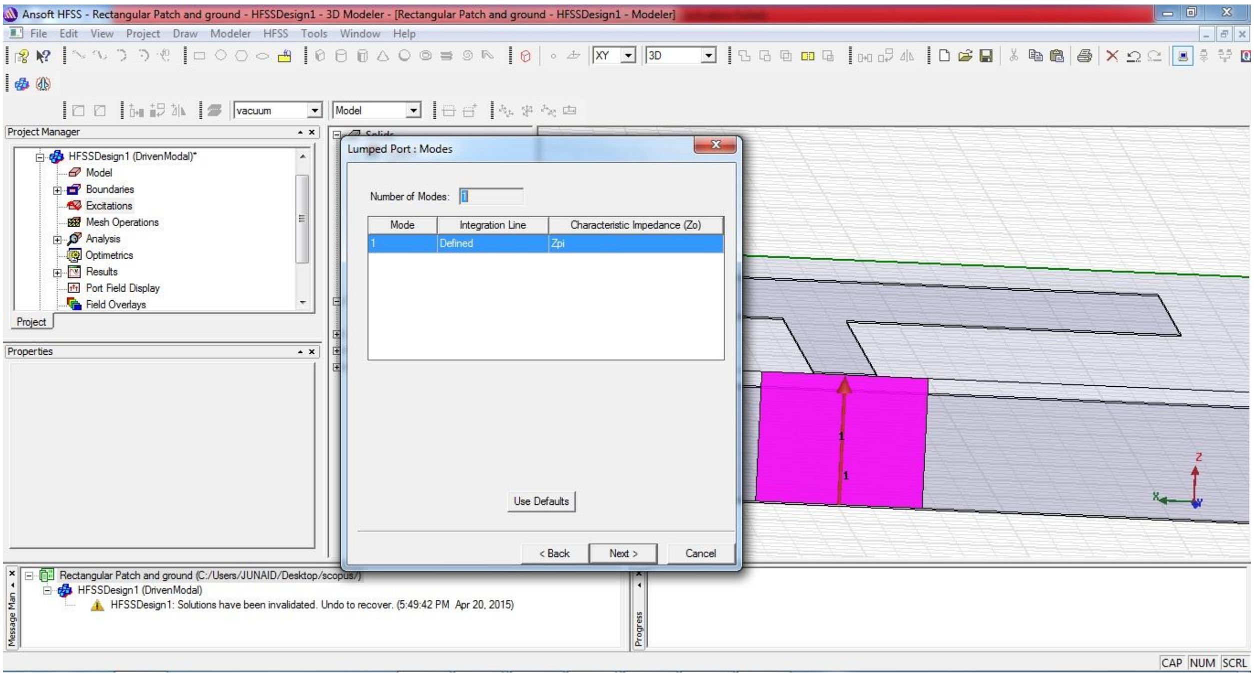


Figure 5.10: Snapshot of Drawing the Integration line to Lump Port

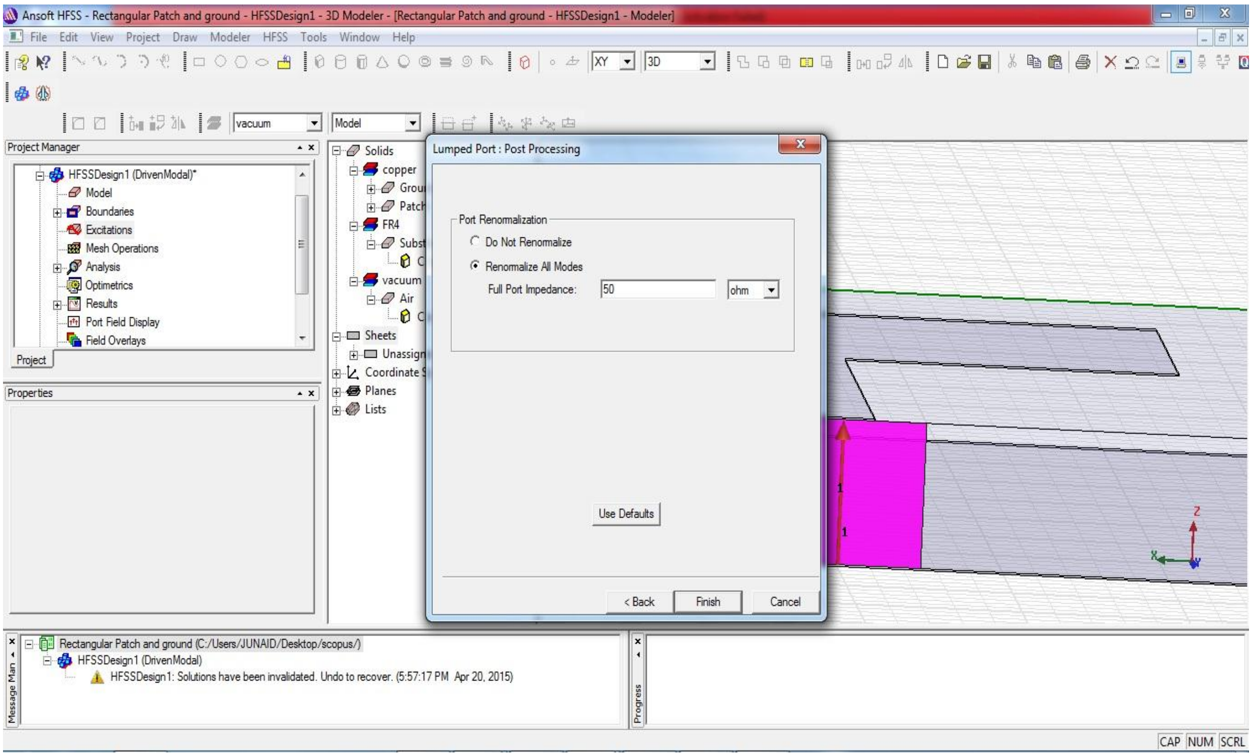


Figure 5.11: Snapshot of Assigning the Impedance to the Lump Port

5.2.5.4 SIMULATION SETUP

The HFSS computes the solution of the designed antenna by adding a solution setup which added by the HFSS menu from where Analysis setup is selected which opens up into add frequency solution as shown in figure 5.12.

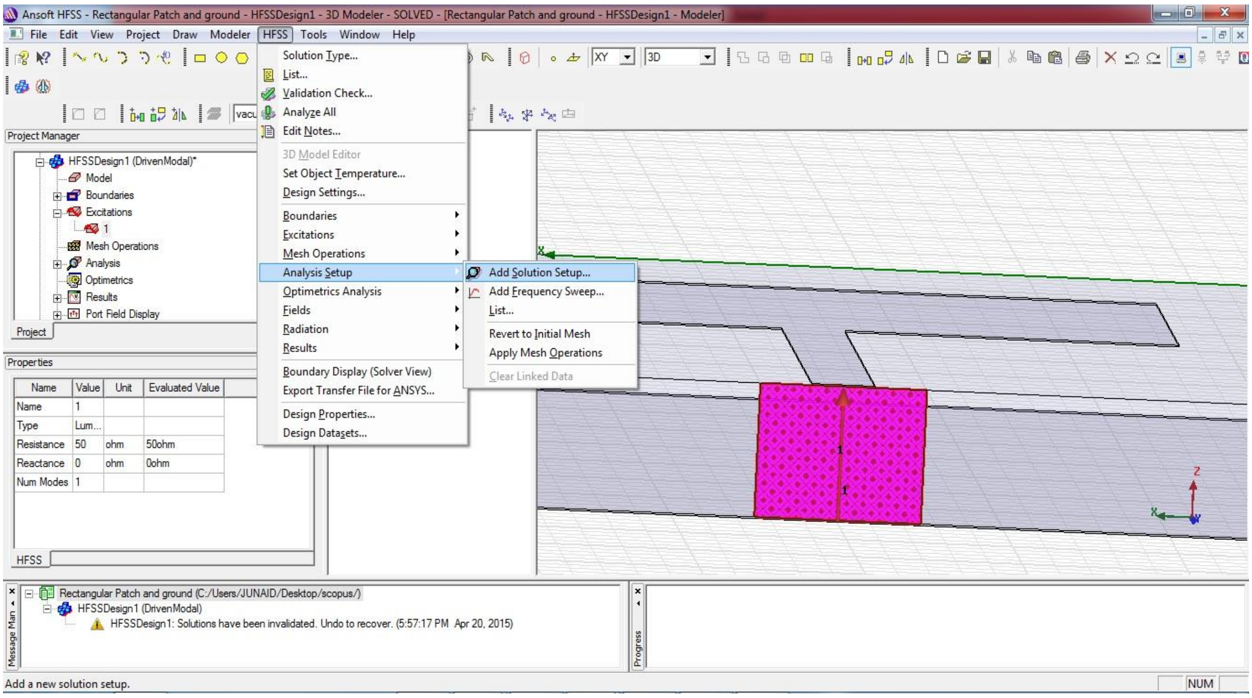


Figure 5.12: Snapshot Showing how to Add Solution Setup

On selecting the add solution setup the solution setup window opens from where from the solution frequency is assigned as 5 GHz as shown in figure 5.13.

To generate the solution over the range of frequencies, it is necessary to add a frequency sweep which can be accomplished by selecting a HFSS menu where from the analysis set up is selected and the add frequency sweep can be selected which opens up window of edit sweep where the sweep type is selected. The start frequency, stop frequency and the step size between them can be assigned from this window as shown in figure 5.14.

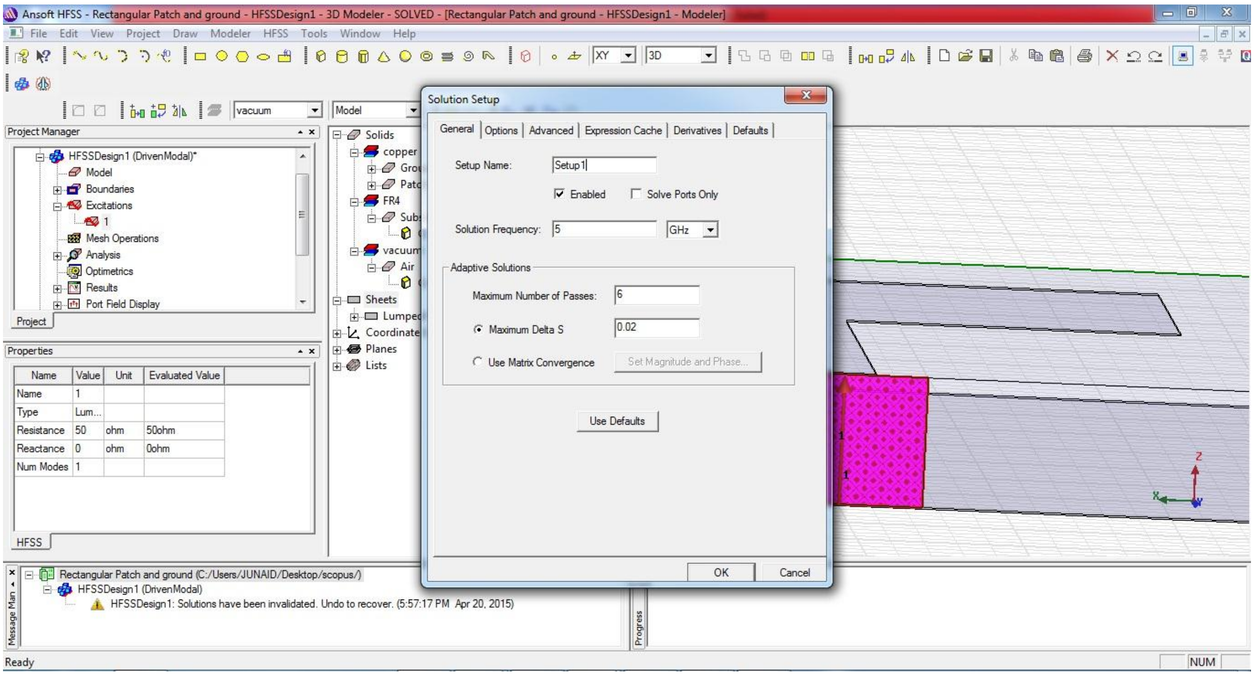


Figure 5.13: Snapshot of Solution Setup Window

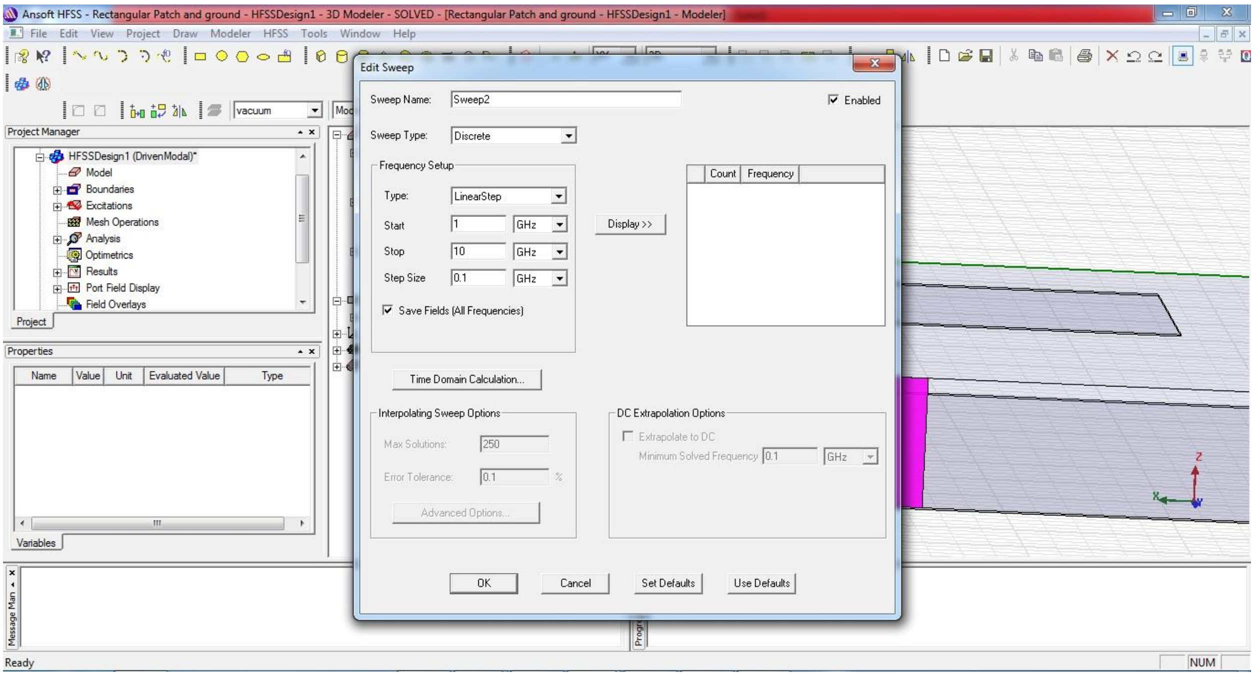


Figure 5.14: Snapshot of Frequency Sweep Window

For obtaining the far-field radiation patterns, the infinite sphere is presented by using the HFSS menu where from the radiation is selected which opens up into far-field setup where from the infinite sphere can be added as shown in figure 5.15. On selecting the infinite sphere window of far field radiation sphere setup is opened up as shown in figure 5.16.

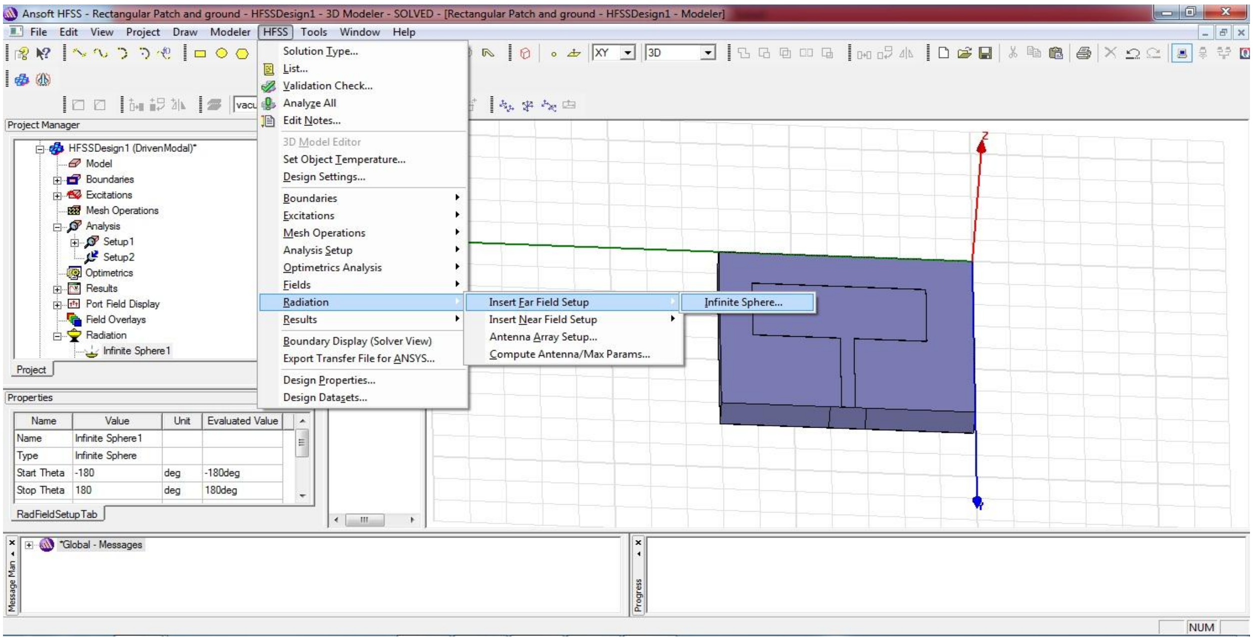


Figure 5.15: Snapshot Showing how to Insert Far-Field Setup

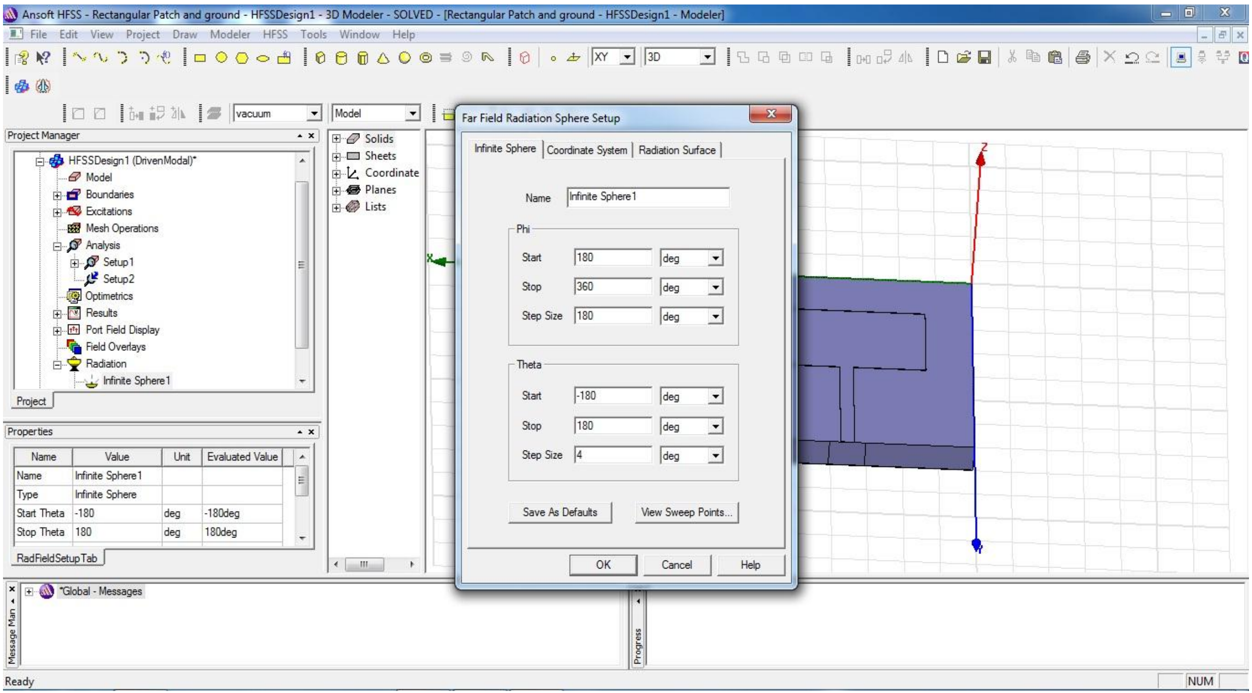


Figure 5.16: Snapshot for Far-Field Radiation Sphere Window

5.2.5.5 SIMULATION RUNNING

The validation check of the model is performed before running the simulation which can be checked by using validation check option in the HFSS menu. The validation check window is shown in the figure 5.17.

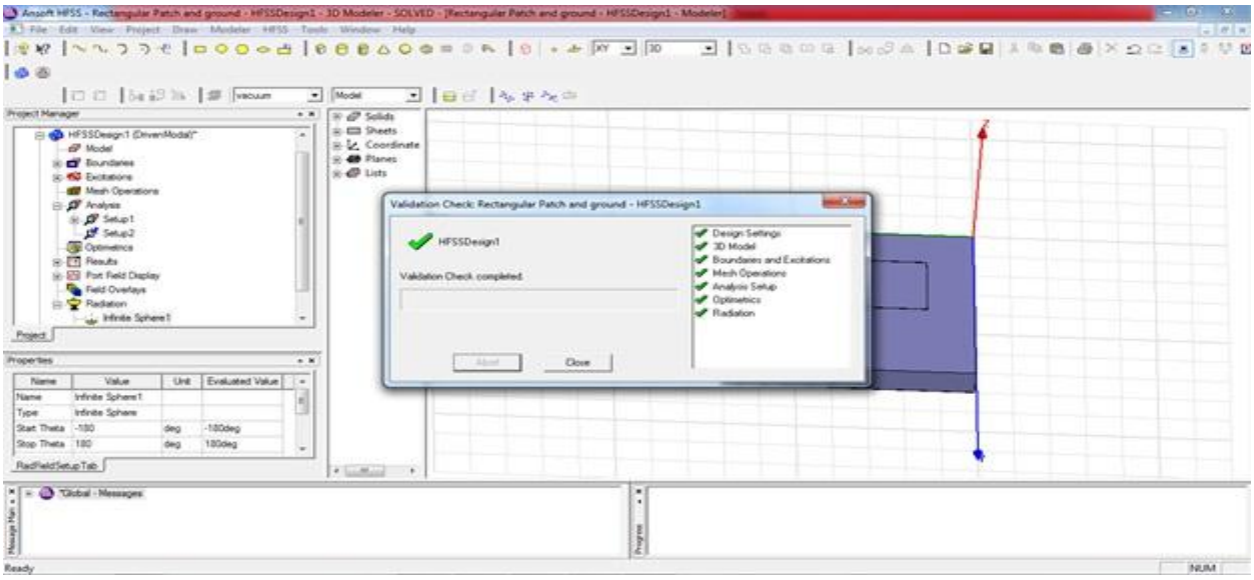


Figure 5.17: Snapshot for the Validation Check

Now the simulation process is started by using the Analyze all option in HFSS menu. The 3D field solutions inside the structure are now computed using HFSS tool.

5.3 RECTANGULAR PATCH WITH REDUCED GROUND PLANE

After designing of the rectangular patch with reduced ground plane, the shape of the ground was reduced to half rectangle. The process of designing and simulation of the antenna is same as described in the section 5.2 and 5.3 but there is change in the dimensions of the ground which are given in table 5.2. The corresponding antenna is operated at the frequency of 5.0 GHz.

Width of the substrate	**Length of the substrate**	**Width of the Ground plane**	**Length of the Ground Plane**	**Width of the Patch**	**Length of the Patch**	**Width of the Feed line**	**length of the Feed line**
35 mm	35 mm	35 mm	15 mm	12 mm	24 mm	1.9 mm	16mm

Table 5.2: Dimensions of the Rectangular Patch with Reduced Rectangular Ground Plane

5.3.1 ANTENNA GEOMETRY

The geometry of the corresponding antenna is shown in the figure 5.18:

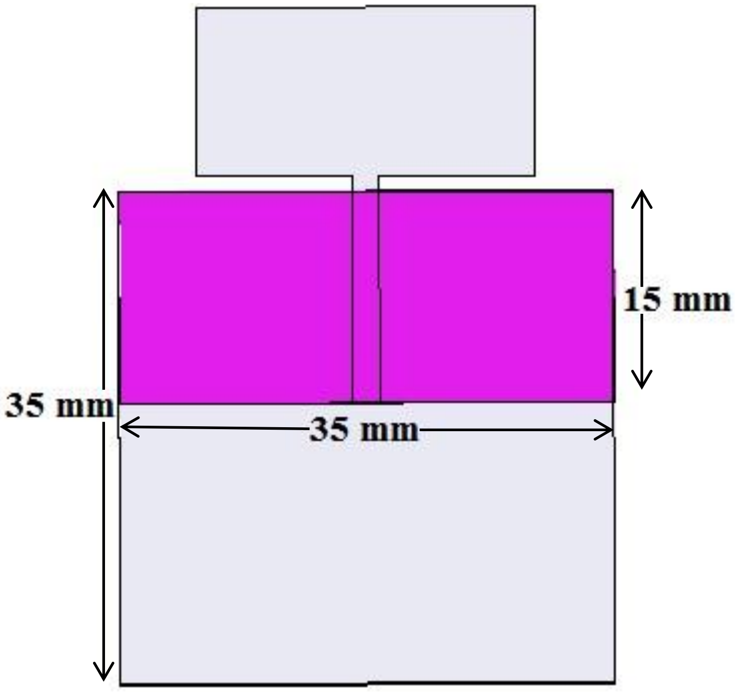


Figure 5.18: Rectangular Microstrip Patch Antenna with reduced Ground Plane

The 3D view of the antenna of the antenna is shown in figure 5.19.

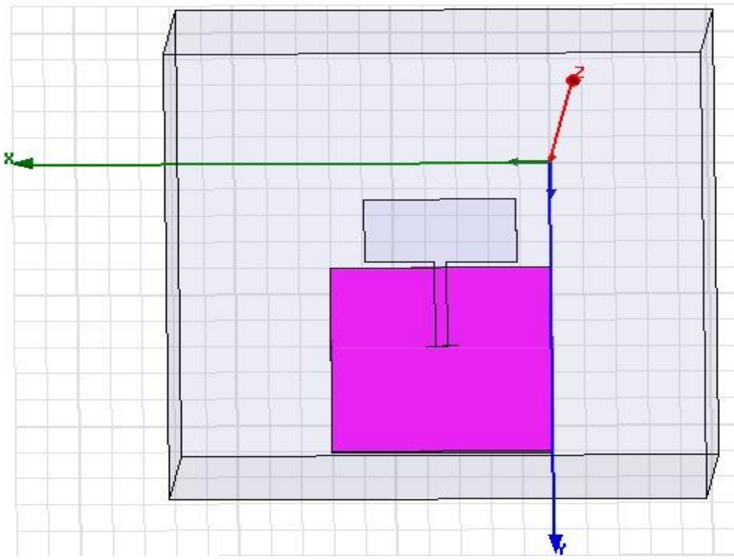


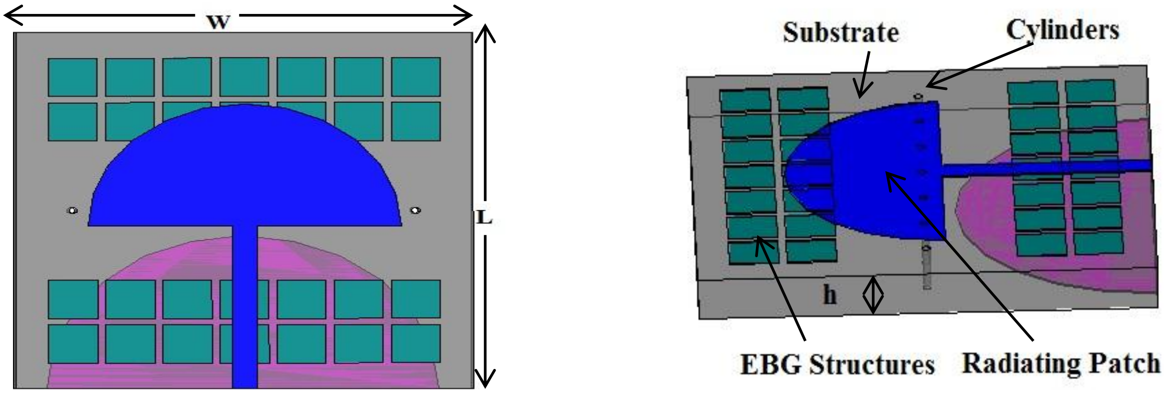
Figure 5.19: 3D View of the Rectangular Microstrip Patch Antenna

5.4 SEMICIRCULAR PATCH SURROUNDED BY EBG STRUCTURES

After designing and simulating of the previous two cases of antennas, the shape of the both radiating element and ground plane is changed to semicircular shape (Umbrella Shaped) and later on the EBG structures are implemented on the substrate. The antenna is operated at the frequency of 5.0 GHz. The designing and simulation process of the antenna is carried out by using HFSS tool which is described in detail.

5.4.1 ANTENNA GEOMETRY

The geometry of the proposed patch antenna in both top view and side view is shown in figure 5.20.



(a) Top View (b) Side View

Figure 5.20: Microstrip Patch Antenna Surrounded with EBG Structures

The pink color region in both the figures 5.20 (a) and (b) shows the ground plane. There is the semicircular shaped patch placed on the grounded dielectric substrate at the height of 0.5 mm. The thickness of the dielectric substrate is denoted by 'h' and the substrate has a dielectric constant which is denoted by ε_r .

5.4.2 SELECTION OF SUBSTRATE

The first step in designing any type of the antenna is to select the type of substrate which has appropriate thickness and loss tangent. Thicker substrates are mechanically strong substrates which increase the radiated power, improve the impedance bandwidth and have low conductor losses but it increases the weight, dielectric losses and surface wave losses [1].

The dielectric constant plays (ε_r) plays the similar role to that of the substrate thickness. There are the many substrates available which are used for the designing of the microstrip antenna whose dielectric constant range generally vary between 2.2 to 12. The substrates which are generally thicker and whose dielectric constant usually lies in the lower end of the range are used because they offer better efficiency and superior bandwidth but they tend to increase the size of the radiating element. The substrates having high loss tangent reduce the efficiency of the antenna due to increase in the dielectric losses.

Considering all these factors, the FR4 dielectric substrate material is chosen whose dielectric constant is 4.7 and loss tangent is 0.02.

5.4.3 DIMENSIONS OF THE PATCH ANTENNA

For the designing of the semicircular patch antenna, the same methodology which was used in designing of rectangular patch antenna is also used here. The length and width of the substrate is taken as 35 mm and 35 mm respectively at the height of 3.2 mm. The radius of the patch is taken as 12 mm and that of ground plane is taken as 15 mm as shown in figure 6.2. The length and width of the microstrip feed line is taken as 16 mm and 1.9 mm respectively.

The feeding technique which was used to feed the power to the patch in the rectangular microstrip patch antenna is also used here. The width of the microstrip feed is usually much smaller as compared to the patch. The feed is attached with the lumped port from which the input power is given. The feed is designed with the characteristic impedance of 50 Ω.

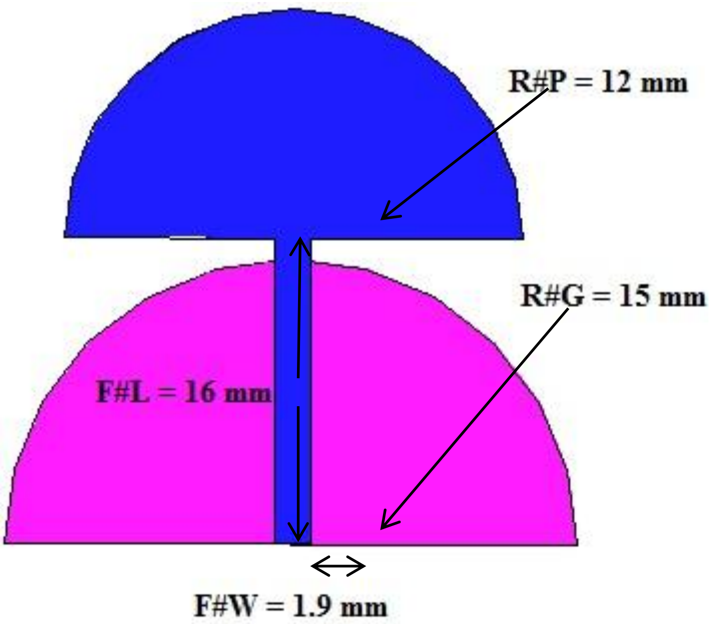


Figure 5.21: Semicircular Microstrip Patch Antenna

The length and width of the microstrip feed line is taken as 16 mm and 1.9 mm. respectively as shown in figure 6.21 above. The dimension of the semicircular microstrip patch antenna operated at the frequency of 5.0 GHz is given in the table 6.1.

Width of the Substrate	Length of the Substrate	Height of the Substrate	Radius of the Patch	Radius of the Ground Plane	Width of the Feed line	Length of the Feed line
35 mm	35 mm	3.2 mm	12 mm	15 mm	1.9 mm	16mm

Table 5.3: Dimensions of Semicircular Microstrip Patch Antenna

5.4.4 DESIGN METHODOLOGY FOR EBG STRUCTURES

The properties of the electromagnetic band gap structures can be determined by their physical dimensions. There are four parameters which affect the performance of the EBG structures [3] which are as:

- Patch Width (P#W).
- Gap Width (g).
- Substrate Thickness (h).
- Permittivity of Substrates (ε_r).

5.4.4.1 PATCH WIDTH EFFECT

The patch width has an important role in determining the resonant frequency. The patch width varies from 0.04 λ_g to 0.20 λ_g [2]. The capcitance increases with increase in the width of the patch which results in reduction of frequency which inturn reduces bandwidth. The capictance can be calculated by[3]:

$$C = \frac{W\varepsilon_o(1+\varepsilon_r)}{\Pi}\cosh^{-1}\left(\frac{W+g}{g}\right) \tag{6.1}$$

5.4.4.2 GAP WIDTH EFFECT

The coupling between the EBG structures is controlled by the gap between the EBG patch units. The gap width can be changed from 0.01 λ_g to 0.12 λ_g [2]. The variation of the gap width has the opposite effect as that of patch width. When the gap width is increased the capacitance is decreased which wider bandwidth as inductance increases. The inductance can be calculated by [3]:

$$L = \mu h \tag{6.2}$$

Where μ is the permeability.

5.4.4.3 SUBSTRATE THICKNESS EFFECT

The thickness of the substrate has the same effect as that of the patch width effect. If the substrate thickness is increased it results in the increase in the bandwidth because the increase in the inductance as reported in [3].

5.4.4.4 SUBSTRATE PERMITTIVITY EFFECT:

As reported in [3], the bandwidth becomes narrow when the high permitivity substrates are used buut it reduces the size of EBG cells.

Using the parametrs which were desribed above the dimensions which were calculated for designing of EBG cells is shown in table 6.1 as below.

Width of the Patch (P#W)	**Length of the Patch (P#L)**	**Gap between two EBG cells (g)**	**Substrate Permitivity**
3.75 mm	3.75 mm	0.625 mm	FR4 (4.7)

Table 5.4: Dimensions of the EBG Cells

The structure of the unit EBG cell is shown in the figure 5.22 as:

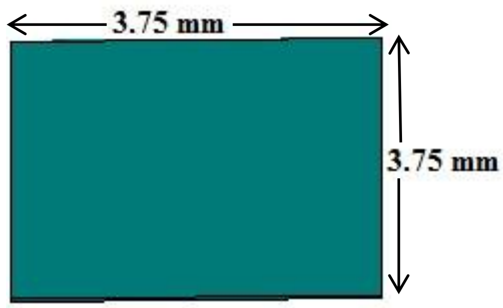


Figure 5.22: Dimension of the Unit EBG Cell

The structure of EBG Structures which were designed as shown in figure 5.23.

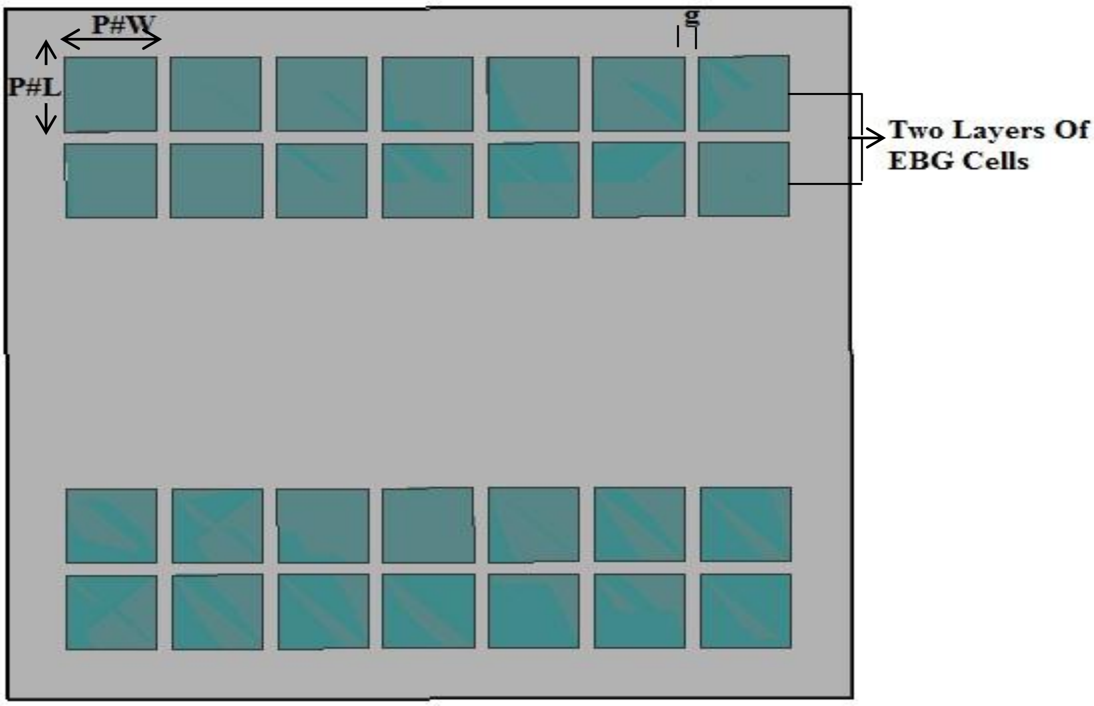


Figure 5.23: Designed EBG Structures

5.4.5 DETAILS OF SIMULATION

This section describes the process of designing the semicircular microstrip patch antenna surrounded by EBG structures for the simulation. The Ansoft HFSS v.12 is used simulation of antenna.

5.4.5.1 DRAWING

Before drawing the model of antenna, it is necessary to select the solution type from the available types and unit which is to be used in designing of the antenna. In this antenna the driven terminal solution type is been selected and the unit which has been selected is millimeter (mm). The driven terminal solution type is usually used for computing the terminal based S-parameter of passive, high frequency structures. After selecting the solution type and the unit, the grid plane is selected as XY plane and the antenna geometry is modeled using the available objects in the in the Draw menu as shown in figure 5.2.

Now to draw the substrate the box object is selected from the draw menu. The dimensions of the substrate are given in the table 5.3 and these dimensions are put into corresponding fields as shown in figure 5.24.

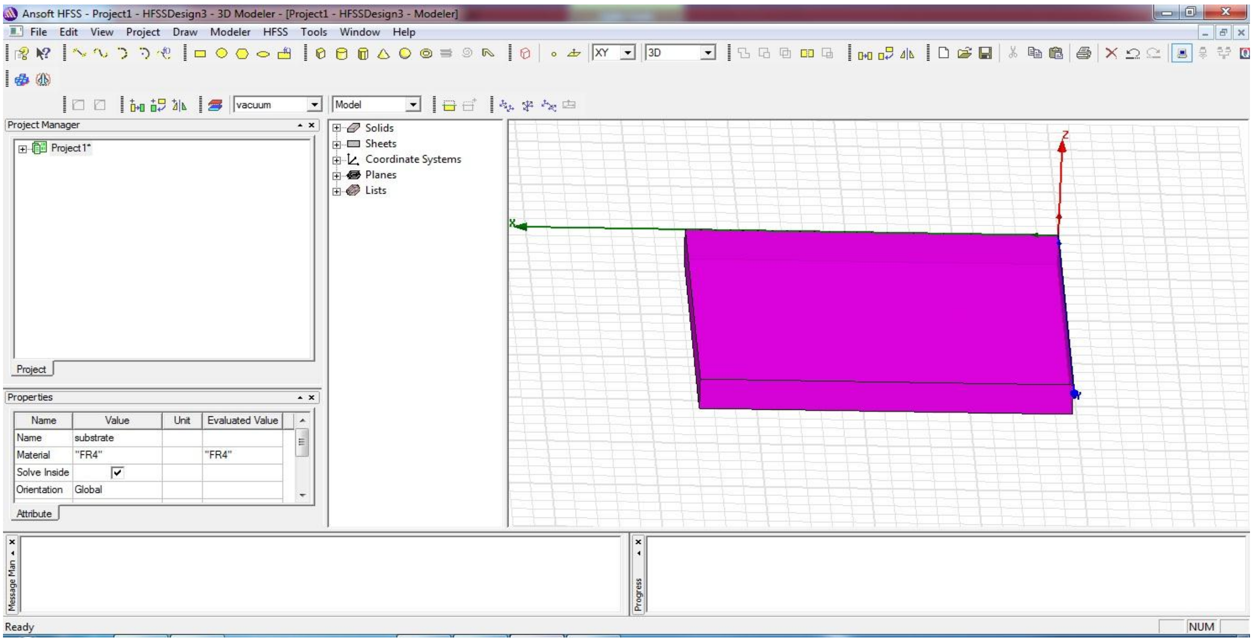


Figure 5.24: Snapshot of the Substrate

After drawing the substrate, it is required to draw the ground which is semicircular in shape. For drawing the semicircular shape first the circle is drawn of radius 15 mm and rectangle of dimensions 35 mm$\times$15 mm and then this rectangle is subtracted from the portion of the circle so as to achieve the semicircular shape as shown in figure 5.25 and figure 5.26

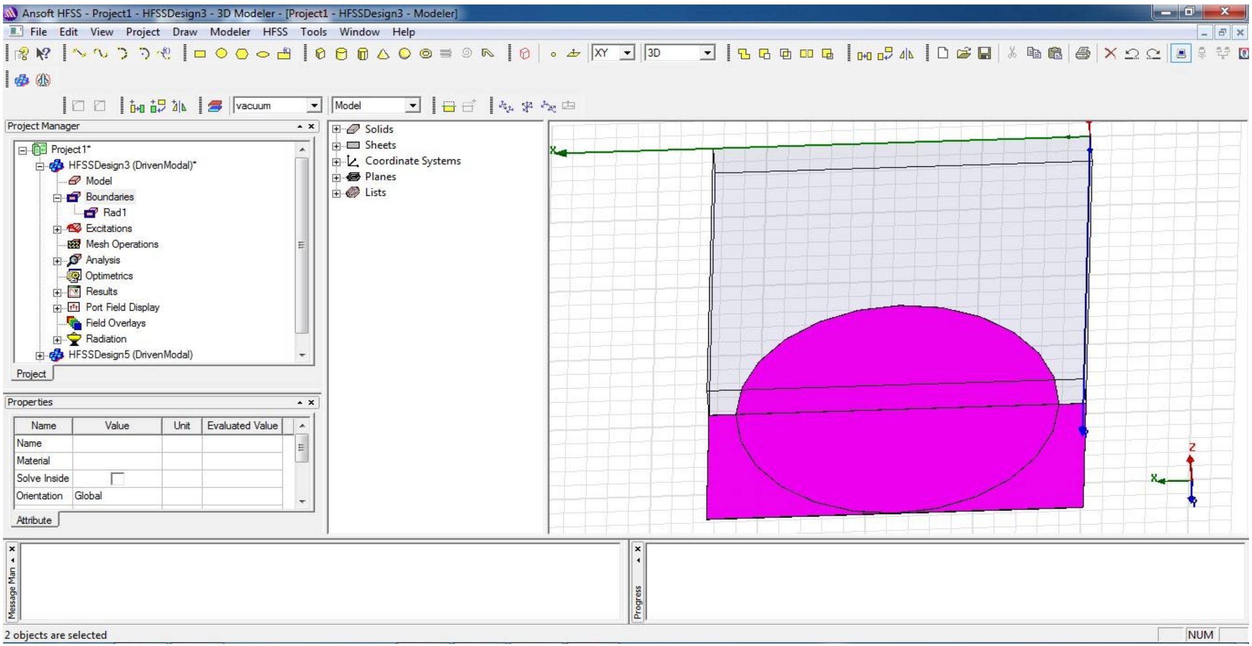


Figure 5.25: Snapshot Showing the Circle and Rectangle Drawn below Substrate

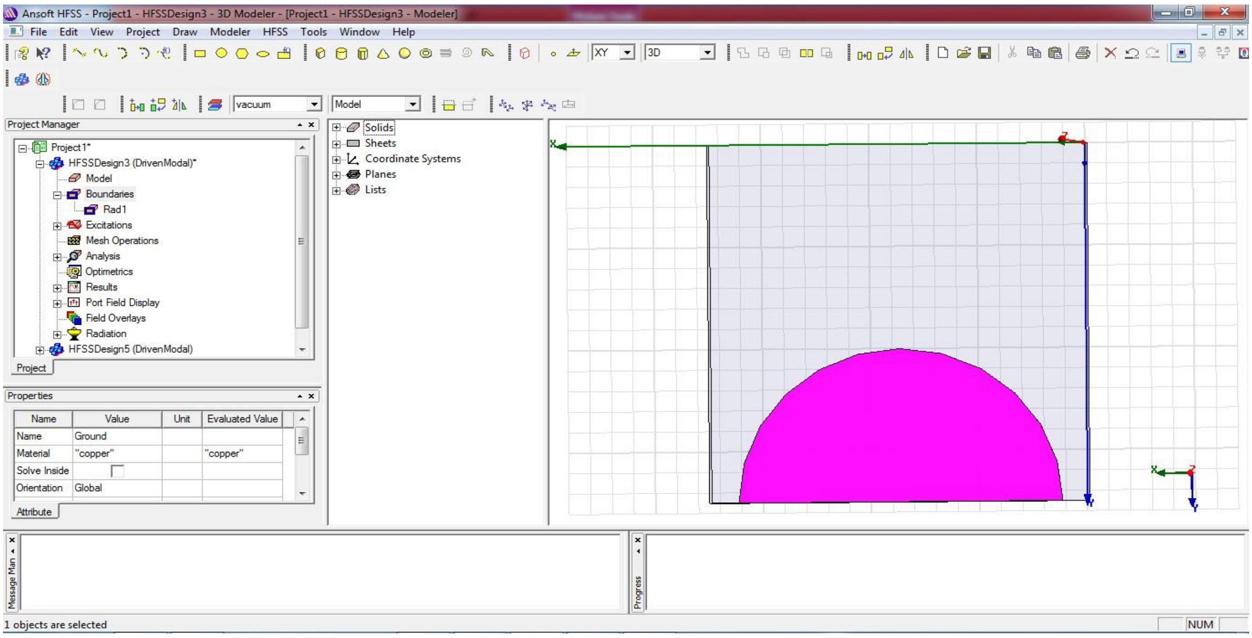


Figure 5.26: Snapshot showing the Ground after Subtraction of Rectangle from Circle

After drawing ground plane, the umbrella shaped radiated patch is drawn which can be achieved by drawing the circle first of radius 12 mm and the rectangle of dimensions 35 mm $\times$ 15 mm and then the rectangle is subtracted from the circle to obtain the semicircular shape as shown in figure 5.27.

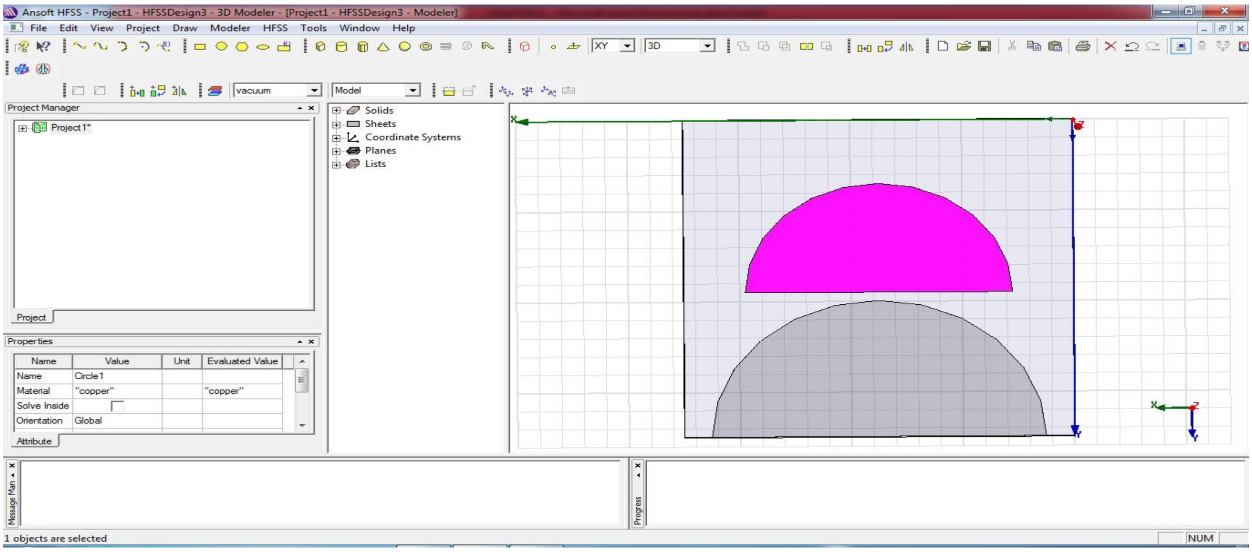


Figure 5.27: Snapshot showing the Radiating patch after Subtraction of Rectangle from Circle

After the patch is drawn, microstrip feed line is drawn of dimensions 16 mm $\times$ 1.9 mm and this microstrip feed line is united with the radiating patch by using the Boolean option in the modular menu as shown in figure 5.28.

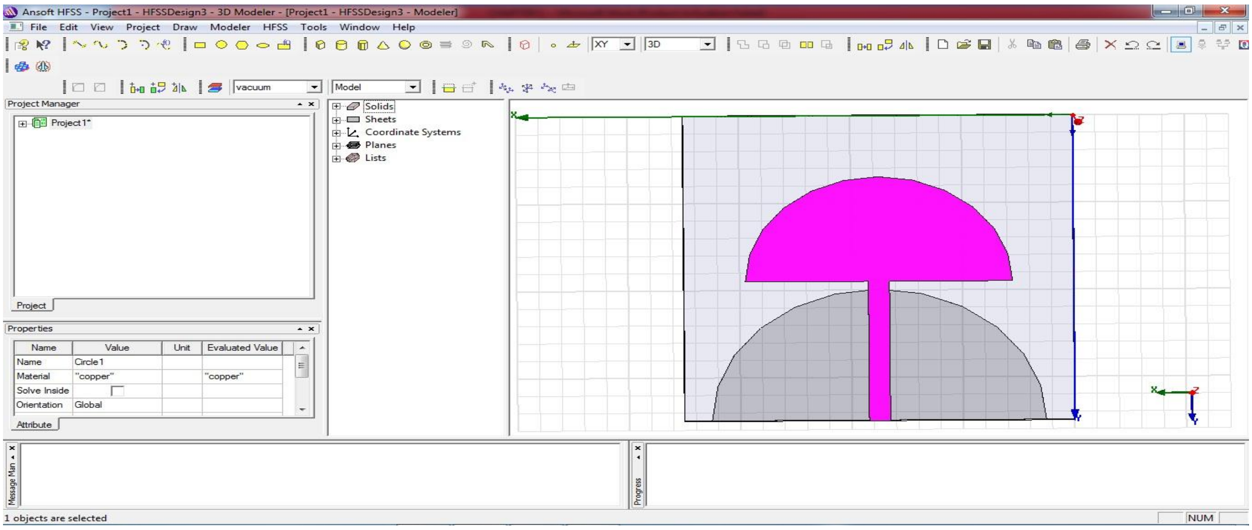


Figure 5.28: Snapshot Showing the Radiating Patch United with Microstrip Feed Line

Now the EBG structures are drawn by the selecting the box in the draw menu of dimensions as shown in table 5.4. The similar structures are drawn on the each side of radiating patch in the form of array with the gap of 0.625 mm between two EBG cells as shown in figure 5.29.

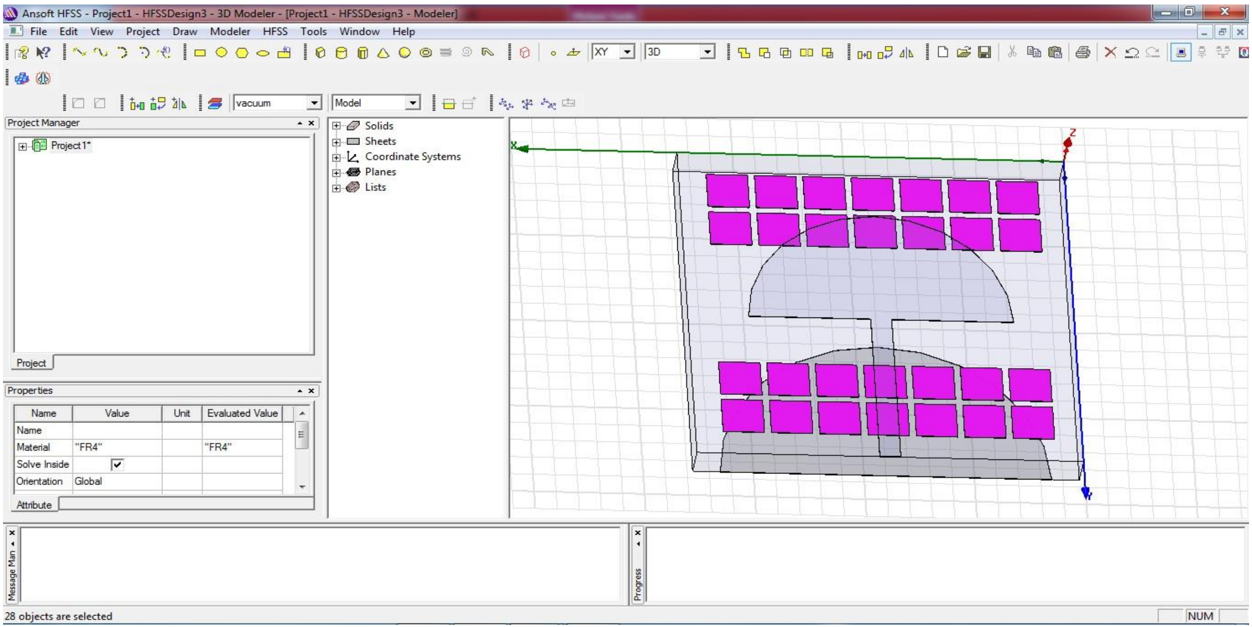


Figure 5.29: Snapshot of EBG Structures Drawn on the each sides of the Radiating Patch

In order to avoid the mutual coupling between the two layers of EBG structures on the each side of array the cylinders are drilled in the substrate of radius 0.3 mm as shown in figure 5.30.

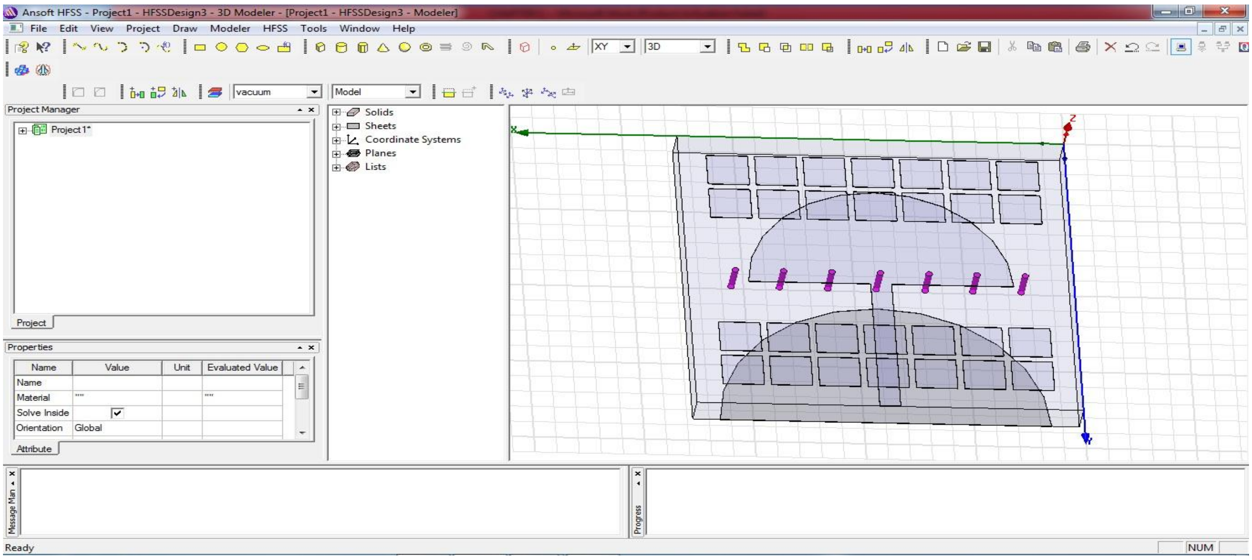


Figure 5.30: Snapshot Showing the Cylinders Drilled into the Substrate

In order to excite the antenna the lump port is drawn by drawing the rectangle of dimensions 5 mm $\times$3.25 mm and is shown in figure 5.31.

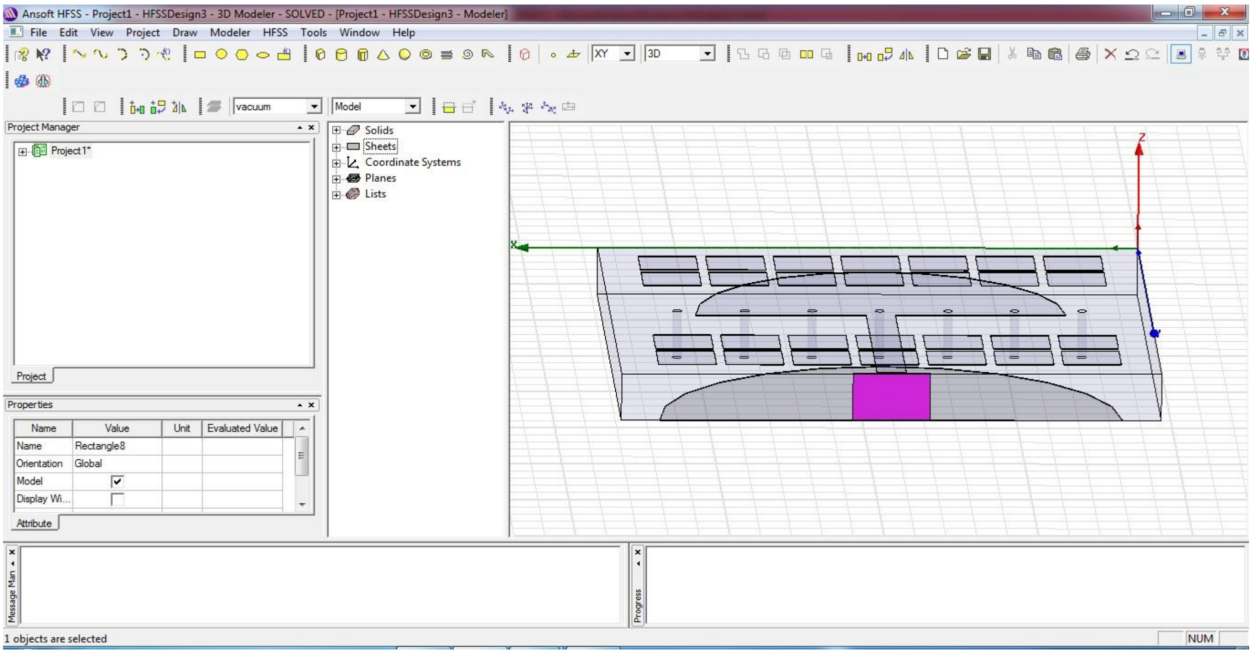


Figure 5.31: Snapshot Showing the Lump Port in Color Portion

In order to perform far field calculations HFSS needs an object that is assigned a radiation boundary so box is drawn from the draw menu of HFSS and this box is called the air box. The 3D view of the microstrip patch antenna surrounded by EBG structures is shown in figure 5.32.

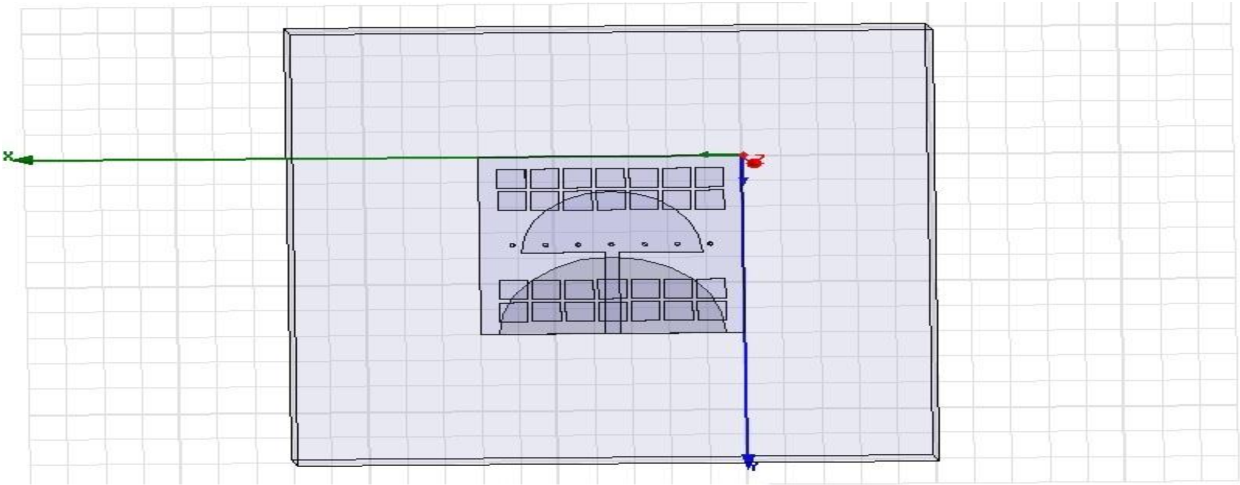


Figure 5.32: Snapshot Showing the 3D view of the Microstrip Antenna Surrounded by EBG Structures

5.4.5.2 ASSIGNING MATERIALS

After completing the drawing the model of the antenna it is necessary to assign the material properties to the objects. This can be achieved by selecting the object and then using the assign material in the modular menu of HFSS, by selecting assign material the select definition window opens up where the material of our type as shown in figure 5.33. The substrate is assigned the FR4 material having the relative permittivity of 4.7 with dielectric loss tangent of 0.02.

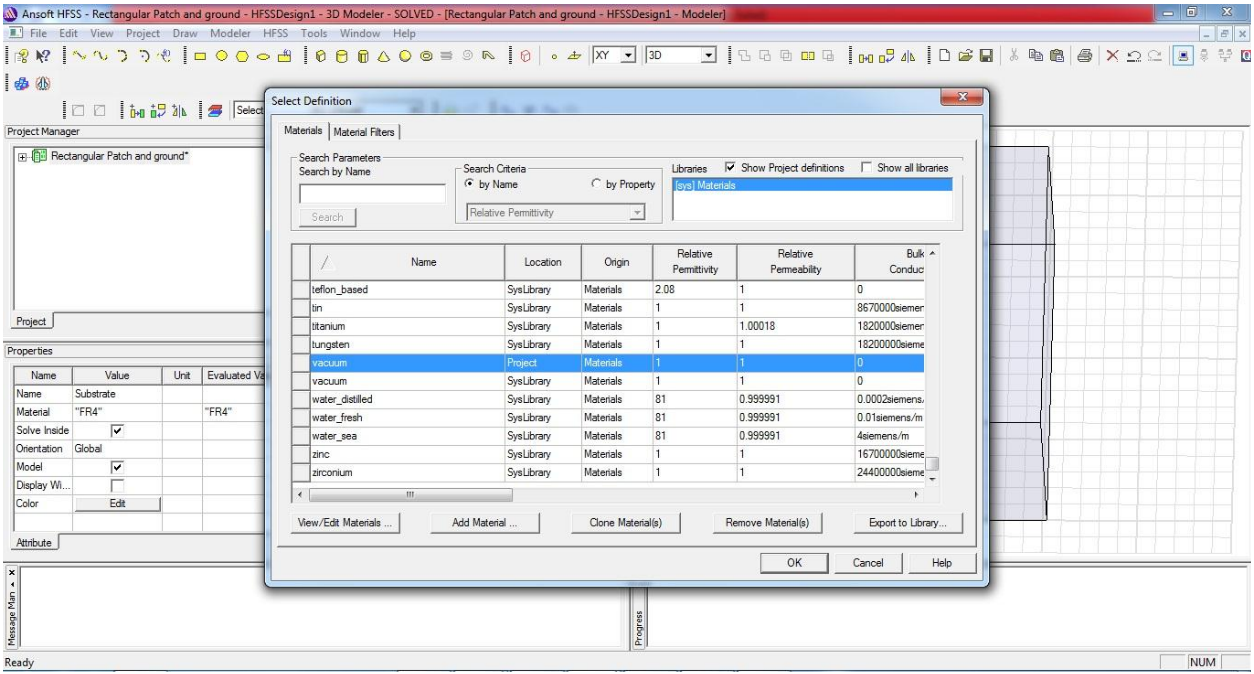


Figure 5.33: Snapshot of the Select Definition Window

After assigning the material to the substrate, similarly the material is assigned for the ground and feed line which is assigned as Copper having the relative permittivity of 1. Further the EBG structures are assigned the same material which was assigned to the substrate. The box which was drawn around the antenna for performing far field calculations is known as air box which is assigned a material vacuum having permittivity and permeability of 1.

The next step in the process for setting up the simulation is to assign the boundary conditions to the surfaces, radiation to the air box and excitation to the lump port.

5.4.5.3 ASSIGNING BOUNDARIES AND EXCITATIONS

As described in section 5.2.5.3, boundary conditions state the field performance at the edges of the problem region and the object interfaces. The boundaries are assigned to the surfaces of the objects by selecting the surface of the object and then the boundaries are assigned from the HFSS menu which opens up assign on selecting assign we can assign the boundaries to the surfaces. The ground plane and the patch are assigned the perfect E boundaries because these are perfectly conducting surfaces. The air box is then assigned a radiation which can be assigned from the same HFSS menu.

The excitation to the lump port is given by selecting the lump port then the excitation is assigned from the same HFSS menu from which excitation is selected which opens up assign from which lump port is selected as described in 5.2.5.3.

On selecting the lump port the lump port mode window opens from which integration line is drawn when integration line is drawn correctly the lump port mode window again opens automatically and shows the integration line is defined. After the integration line is defined the lump port mode window fallows the lump port post processing window which needs the assigning of impedance. The impedance assigned to the port is 50 Ω. The boundary assigned to the radiating patch is shown in the figure 6.34.

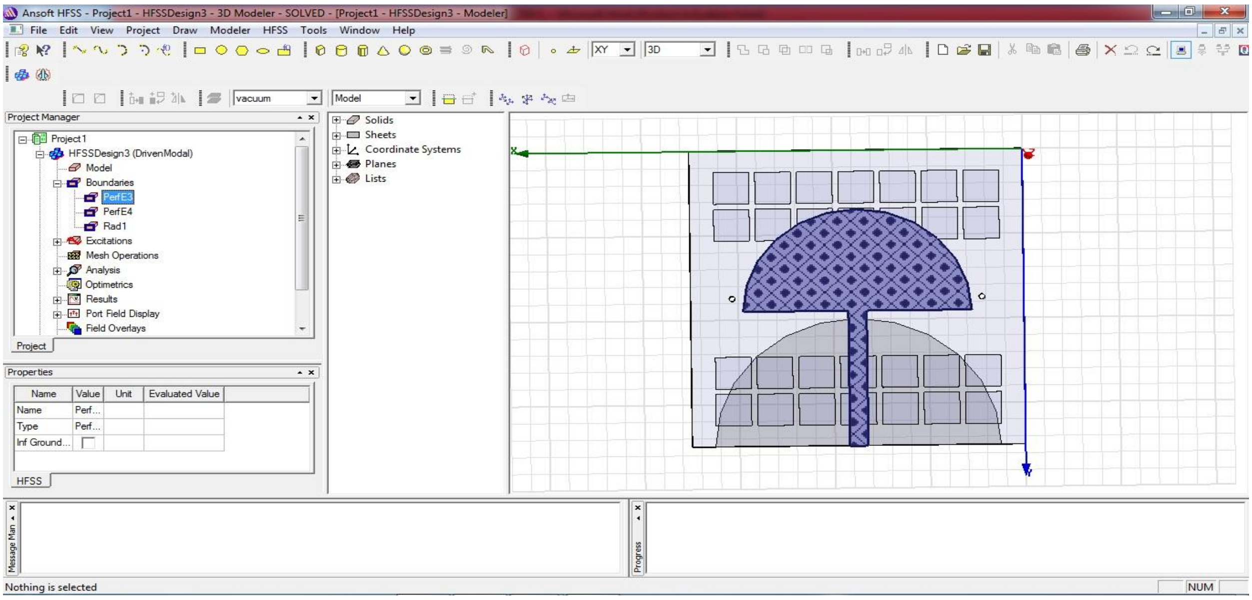


Figure 6.34: Snapshot showing the Boundary Assigned to the Radiating Patch of the Antenna

5.4.5.4 SIMULATION RUNNING

The validation check of the model is performed before running the simulation which can be checked by using validation check option in the HFSS menu. The validation check window is shown in the figure 6.35.

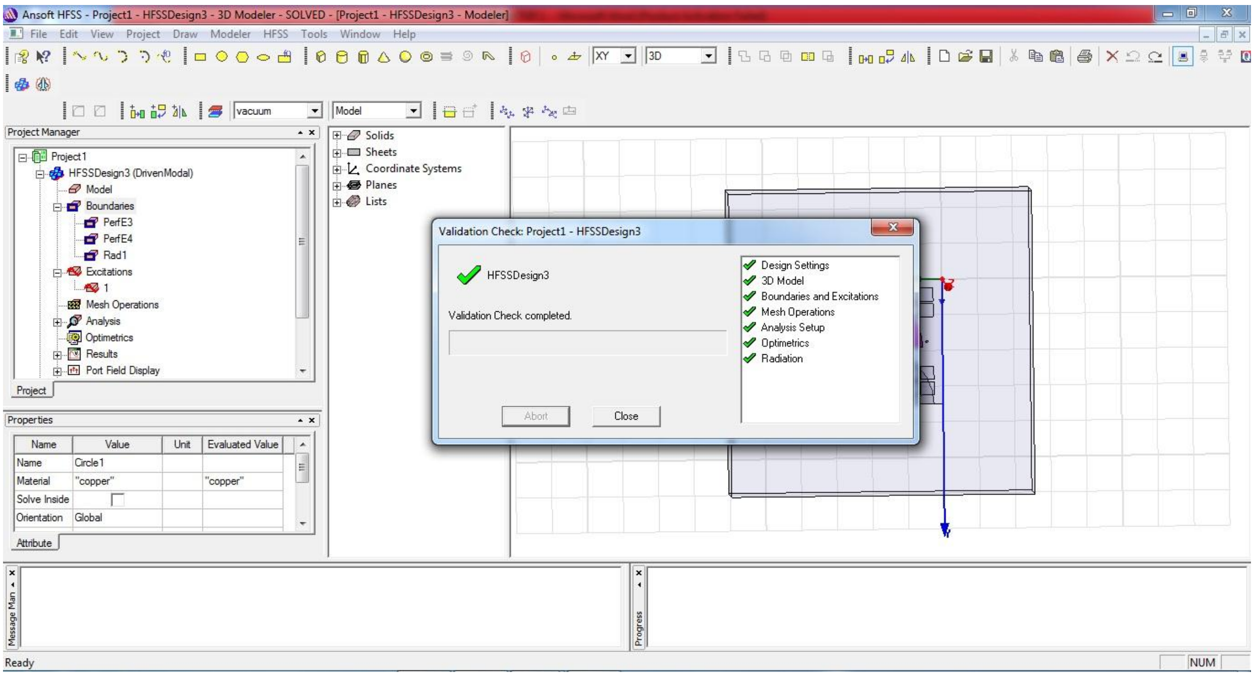


Figure 6.35: Snapshot showing the Validation Check

Now the simulation process is started by using the Analyze all option in HFSS menu. The 3D field solutions inside the structure are now computed using HFSS tool.

SUMMARY

In this chapter, the designing and simulation of various types of microstrip patch antenna operating at 5 GHz is been performed. The procedure used for calculating the various dimensions of the antenna has been also discussed. The antenna designing methodology for EBG structures is also been discussed. Furthermore the implementation of the design using HFSS tool is also described in detail.

CHAPTER 6

RESULTS AND DISCUSSIONS

In the previous chapter, the process of designing and simulating of the various types of microstrip antennas was discussed in detail. After the structures are validated and the simulation process comes to end, the results can be are obtained which are discussed in detail.

Following are the terms which need to be understood before discussing the results obtained.

6.1 S11 PARAMETER

At microwave frequencies the problem exists when we try to measure voltages and currents because direct measurements usually involve the magnitude and phase of wave in a given direction. Thus equivalent voltages, currents and related impendences become somewhat of an abstraction when dealing with high frequency networks. So at microwave frequencies the logical variables used are travelling waves with associated powers, rather than total voltages and currents. These logical variables are known as S-Parameters.

6.2 BANDWIDTH

The range of frequencies over which the antenna can operate correctly is known as the bandwidth of the antenna.
The impedance bandwidth of the antenna is calculated at by:

$$BW = f_h - f_l \qquad (6.1)$$

In terms of percentage the bandwidth is given by:

$$BW = \frac{f_h - f_l}{f_c} \times 100 \qquad (6.2)$$

Where f_h = Highest frequency f_l = Lowest frequency f_c = Center frequency.

6.3 VSWR

VSWR (Voltage Standing Wave Ratio) is the function of the reflection coefficient which describes the power redirected from the antenna. If the reflection coefficient is given by Γ, the VSWR is defined by:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad (6.3)$$

The VSWR is always real and positive number for antennas. Smaller the value of VSWR is better the antenna is matched with the transmission line and more power is delivered to antenna. For the ideal antenna VSWR is 1.0 that is no power is reflected.

6.4 RADIATION PATTERN

The radiation pattern defines the relative strength of the radiated field in several directions from the antenna. It is usually measured in the far-field region. 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.

6.5 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.

Following are the results which were obtained after simulating the different types of microstrip antennas.

6.6 RECTANGULAR PATCH WITH RECTANGULAR GROUND PLANE

The results can be displayed and analyzed only after the completion of the solution by HFSS. After completion of the solution by HFSS for rectangular patch with rectangular ground type of microstrip antenna at the operating frequency of 5.0 GHz, the results are been obtained which are been discussed.

- **S11 Parameter**

The S11 parameter can be generated by selecting the results from HFSS menu were from create terminal solution data report can be selected.

The S11 parameter of the rectangular microstrip patch antenna is shown in the figure 6.1. It can be seen from the figure that the operating frequency of the antenna is 5.0 GHz. The value of the return loss at this frequency is -12.1225 dB.

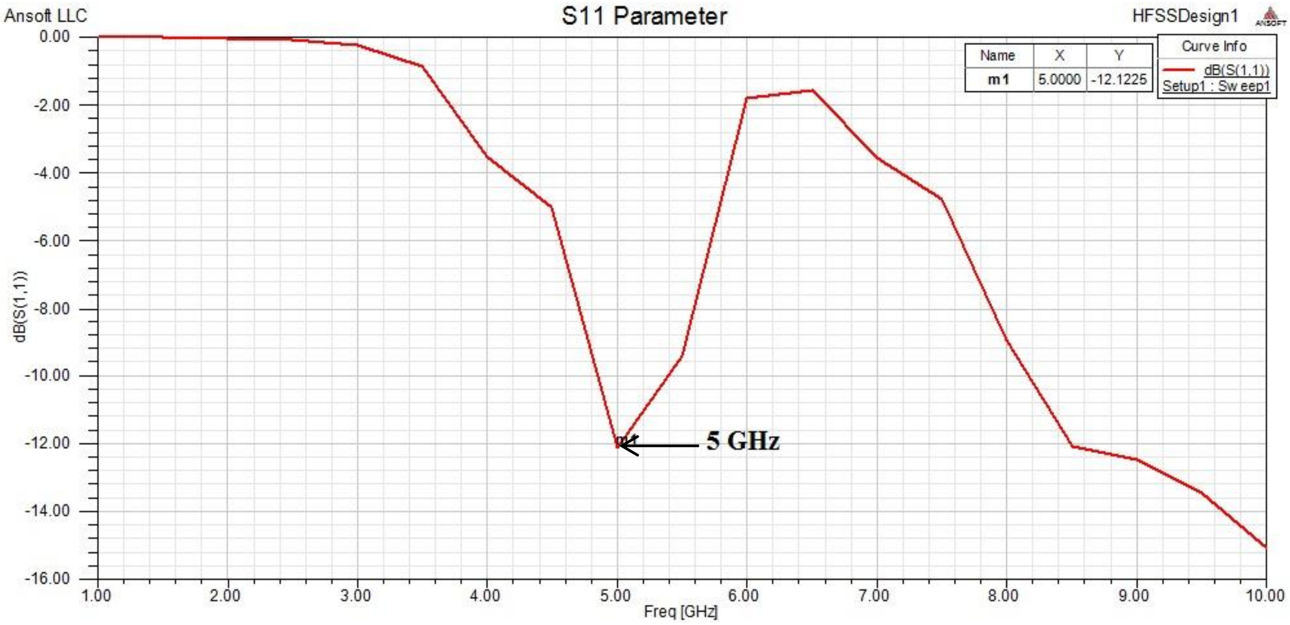


Figure 6.1: S11 Parameter of Rectanglar Patch with Rectangular Ground

- **Bandwidth**

The impedance bandwidth of the antenna was calculated at -10 dB of the return loss by the help of the equations 6.1 and 6.2. The bandwidth of the antenna at -10 dB was found to be 0.55 GHz and the percentage bandwidth was found to be 11.00 %.

- **VSWR**

The simulated VSWR plot of the antenna is shown in figure 6.2. It can be seen from the figure that the value of VSWR at operating frequency is 1.6584.

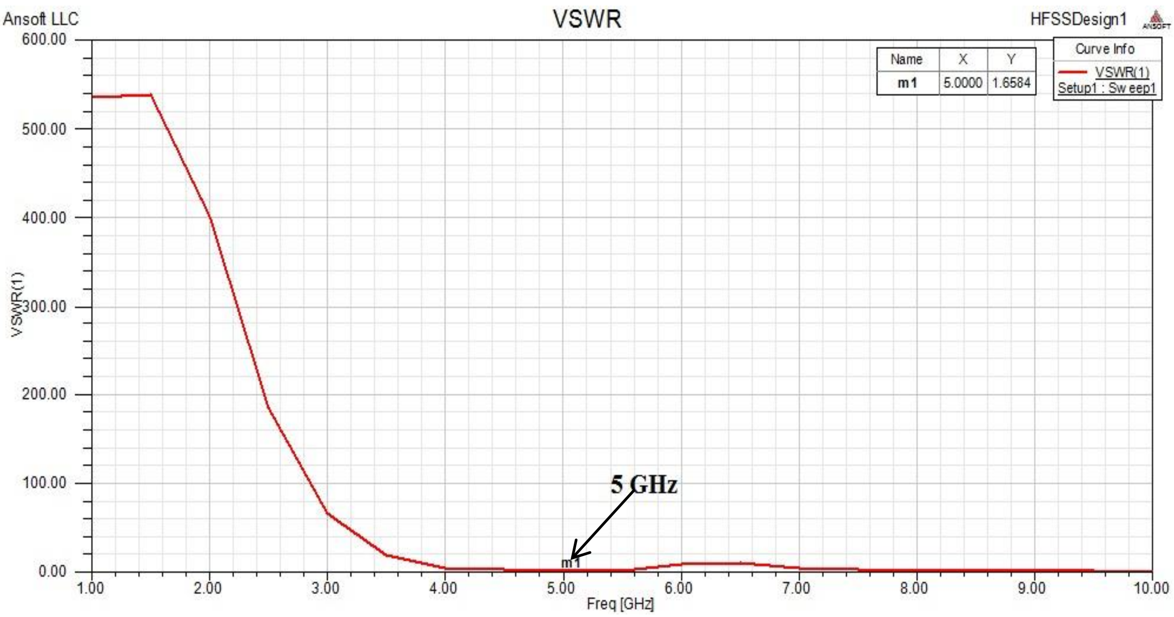


Figure 6.2: VSWR of Rectanglar Patch with Rectangular Ground

- **Radiation Pattern**

The far field radiation pattern of the antenna at 5.0 GHz is shown in the figure 6.3.

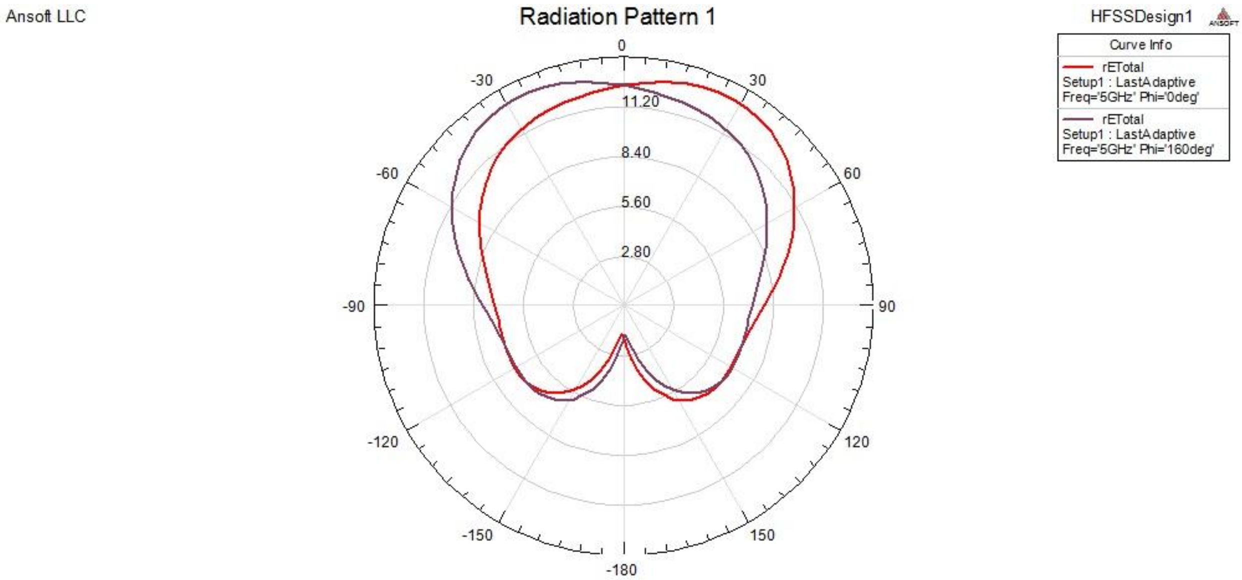


Figure 6.3: Radiation Pattern of the Rectangular patch antenna with Rectangular Ground

It can be clearly seen that the antenna suffers from the narrow bandwidth. For an antenna to operate in ultra-wide band it should have bandwidth greater than 2.0 GHz. Also the antenna has very high VSWR of 1.65

6.7 RECTANGULAR PATCH WITH REDUCED RECTANGULAR GROUND PLANE

The results which were obtained for the rectangular patch with reduced rectangular ground plane as discussed below.

- **S11 Parameter**

The S11 parameter of the rectangular microstrip patch antenna with reduced ground plane is shown in the figure 6.4. The value of the return loss at the frequency of 5.0 GHz is -14.00 dB

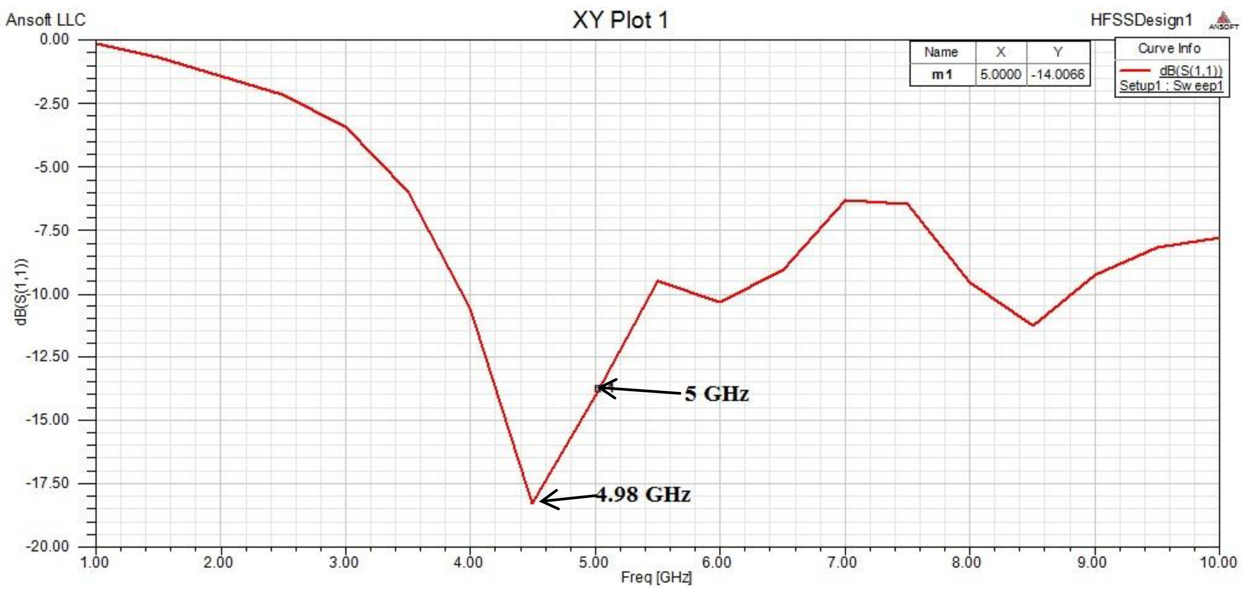


Figure 6.4: S11 Parameter of Microstrip Patch Antenna with Reduced Ground Plane

- **Bandwidth**

The bandwidth of the antenna at -10 dB was found to be 1.5 GHz and the percentage bandwidth was found to be 30.00 % at frequency of 4.98 GHz.

It can be clearly seen from the figure 6.4 that the frequency shifted to the left of the operating frequency.

- **VSWR**

The simulated VSWR plot of the antenna is shown in figure 6.5. It can be seen from the figure that the value of VSWR at operating frequency is 1.5.

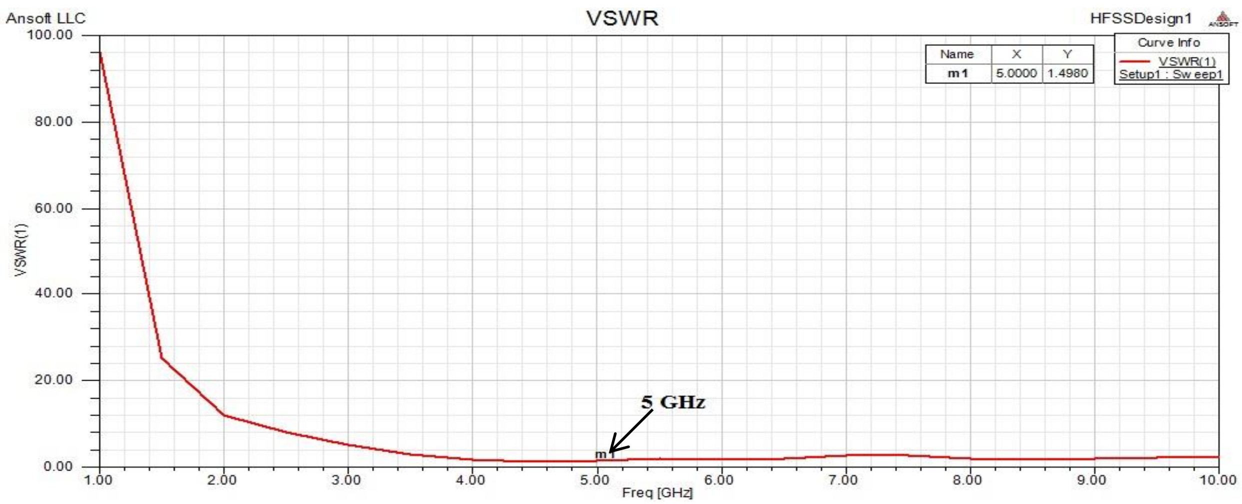


Figure 6.5: VSWR of Microstrip Patch antenna with Reduced Ground Plane

- **Radiation Pattern**

The far field radiation pattern of the antenna at 5.0 GHz is shown in the figure 6.6.

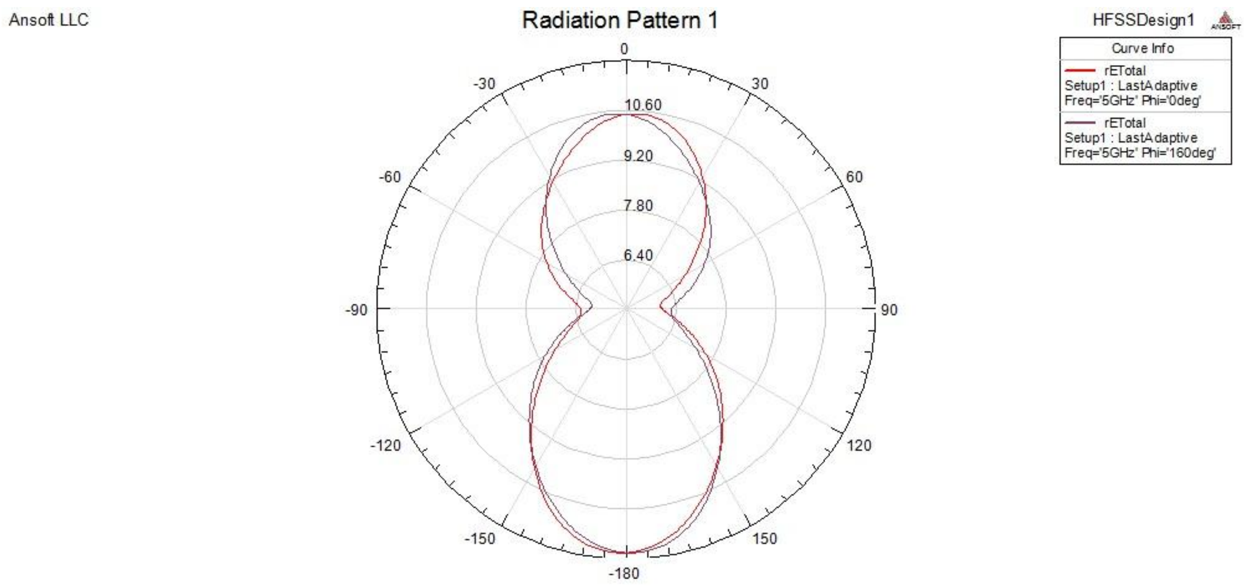


Figure 6.6: Radiation Pattern of the Microstrip Patch Antenna with Reduced Ground Plane

- **Gain**

The 3D gain polar plot of the antenna resulted in 3.3171 dB and is shown in the figure 6.7.

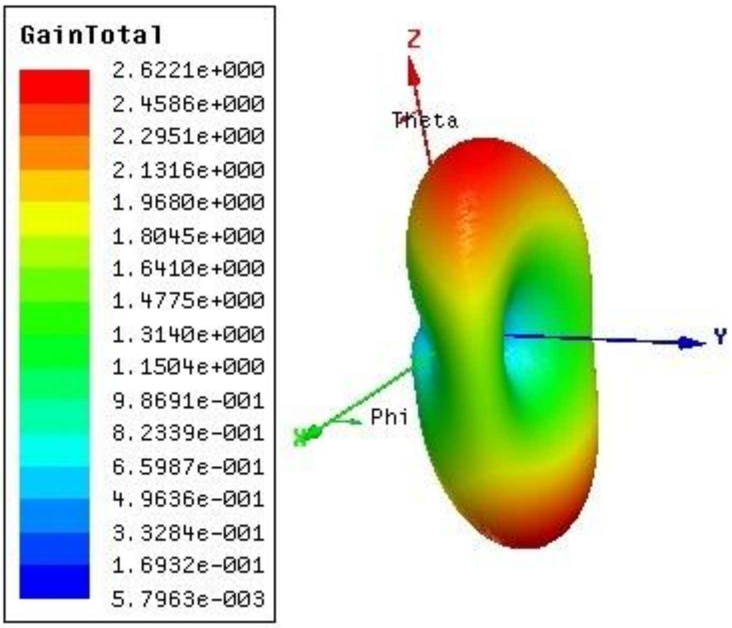


Figure 6.7: Gain of the Microstrip Patch Antenna with Reduced Ground Plane

This type of antenna has a good bandwidth as compared to the previous antenna but still it has not the bandwidth that is required for antenna to operate in ultra-wide band also the VSWR of the antenna is not some good. The value of VSWR is approximately 1.5.

6.8 SEMICIRCULAR PATCH SURROUNDED BY EBG STRUCTURES

After completion of the solution by HFSS for the microstrip antenna which is surrounded by EBG structures at an operating frequency of 5.0 GHz, the results are been obtained which are been discussed below.

- **S11 Parameter**

The S11 parameter of the designed antenna is shown in the figure 6.8. It can be seen from the figure that the operating frequency of the antenna is 5.0 GHz. The value of the return loss at this frequency is -23.3495 dB.

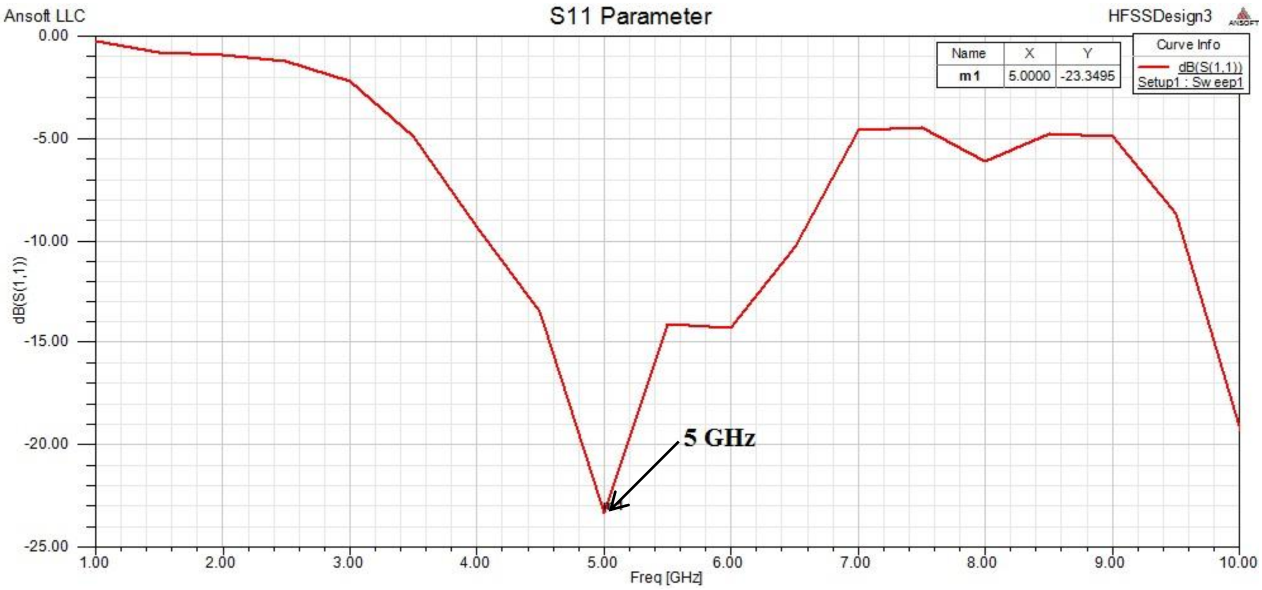


Figure 6.8: S11 Parameter of the Microstrip Patch Antenna Surrounded by EBG Structures

- **Bandwidth**

The impedance bandwidth of the antenna was calculated at -10 dB of the return loss by the help of the equations 6.1 and 6.2. The bandwidth of the antenna at -10 dB was found to be 2.55 GHz and the percentage bandwidth was found to be 50.00 %.

- **VSWR**

The simulated VSWR plot of the antenna is shown in figure 6.9. It can be seen from the figure that the value of VSWR at operating frequency is 1.1.

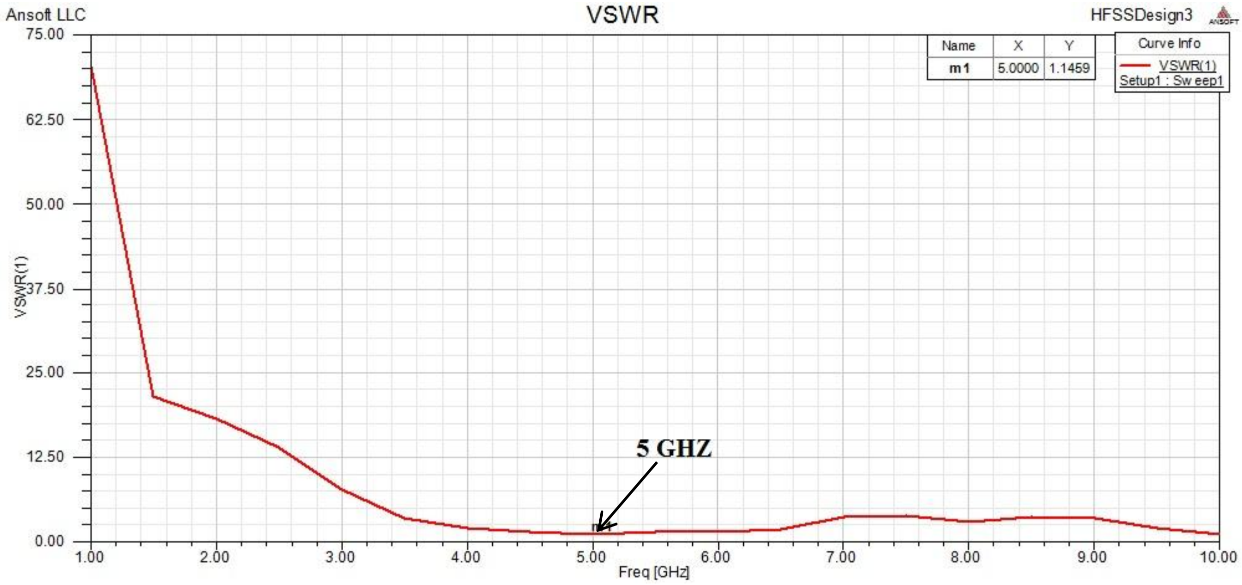


Figure 6.9: VSWR of the Microstrip Patch Antenna Surrounded by EBG Structures

- **Radiation Pattern**

The far field radiation pattern of the antenna at 5.0 GHz is shown in the figure 6.10.

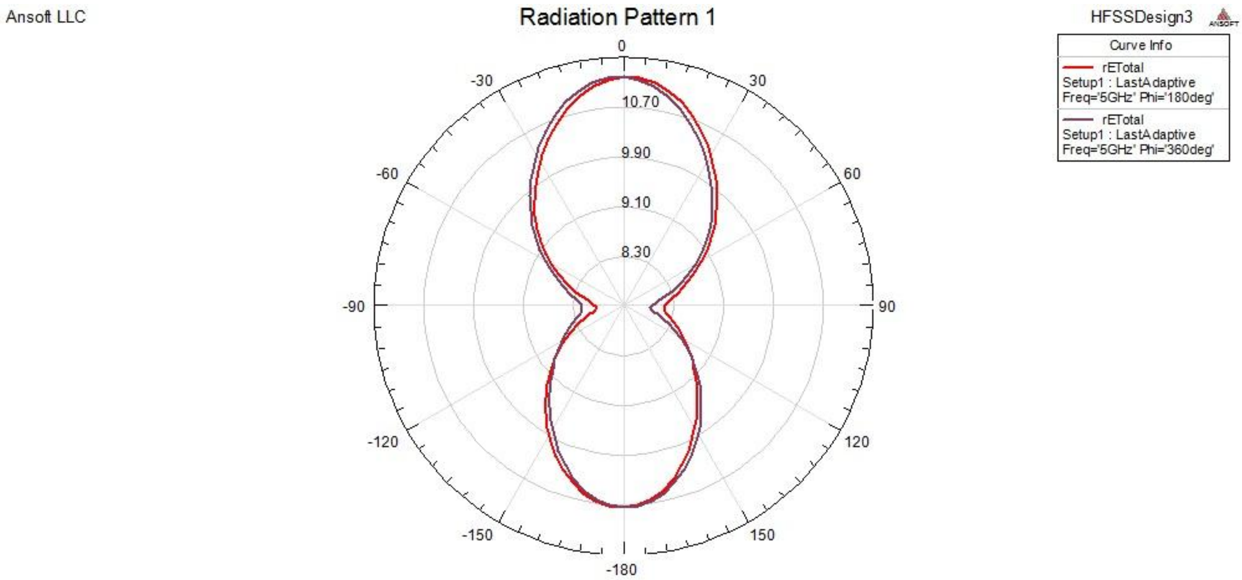


Figure 6.10: Radiation Pattern of the Microstrip Patch Antenna Surrounded by EBG Structures

- **Gain**

The 3D gain polar plot of the antenna resulted in 3.3171 dB and is shown in the figure 6.11.

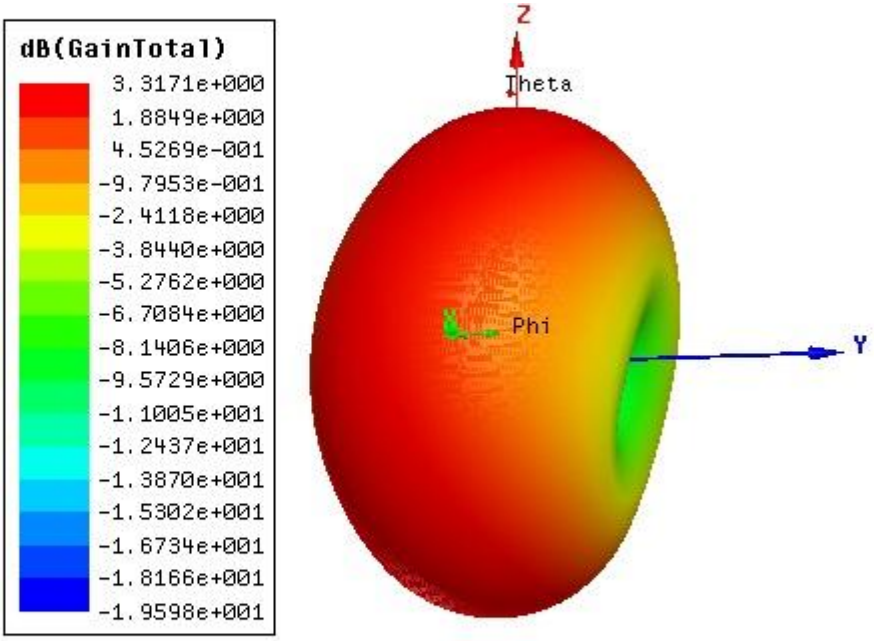


Figure 6.11: Gain of the Microstrip Patch Antenna Surrounded by EBG Structures

It can be clearly seen that the antenna has the wide bandwidth of 2.5 GHz with good return loss and VSWR. The antenna has the sufficient bandwidth to operate in the Ultra-wide band.

6.7 COMPARISON OF RESULTS

The table 6.1 below shows the comparison of results for three types of the antennas which have been simulated.

Antenna Type	S11	VSWR	Bandwidth	Percentage bandwidth
Rectangalur Patch with Rectangular Ground Plane	-12.1225 dB	1.65	0.55 GHz	11.00%
Rectangalur Patch with Reduced Ground Plane	-14.00 dB	1.5	1.5 GHz	30.00%
Microstrip Patch Antenna surrounded by EBG Structures	-23.3495 dB	1.14	2.5 GHz	50.00%

Table 6.1: Comparison between the results obtained for the different structures of Microstrip Antennas.

It can be seen that the bandwidth of the antenna that is surrounded by the EBG structures corresponds to the Ultra-wide bandwidth. This is because there are the two effects which enhance and degredage the bandwidth of the antenna one is the parastic effect and another is the cavity effect. The EBG cells which are placed near the radiating edges of the radiator result in the parasitic effect. The cavity effect comes into the picture as EBG cells reflect back some part of energy that circulates into the substrate as act as reflecting walls around the antenna. This parasitic effect is responsible for enhancing the bandwidth of antenna while as cavity effect degrades the bandwidth of the antenna. Parasitic effect becomes dominant when there are the few rows of EBG which surround the antenna as the number of rows is increased the cavity effect dominates which result in degredation of the bandwidth as more energy circulates along the substrate.

CHAPTER 7

CONCLUSION AND FUTURE WORK

7.1 CONCLUSION

This thesis describes about the enhancement of bandwidth in the microstrip antennas by using EBG structures. The ANSOFT HFSS tool is used to design and simulate the designs of the antennas. The novelty in this approach is shape of the structures and cylinders which drilled inside the substrate to cancel out the mutual coupling between them. The different types of antennas are designed to enhance the bandwidth of the microstrip antenna and it is found that the antenna which was surrounded by the EBG structures is having the wide bandwidth. The fractional bandwidth around the center frequency is achieved to be equal to 50% with a very good return loss of -23.3495. It can also be seen that the VSWR is also improved from 1.65 to 1.1. Also, the radiation pattern and the gain of the antenna was obtained at the frequency of 10 GHz which is been reported.

7.2 APPLICATIONS

Following are the applications where the microstrip antenna using EBG structures can be used.

7.2.1 HIGH DATA RATE

The demand for the high multimedia applications are increasing day by day which requires an new methods to utilze the avialble bandwidth. As this demand increases, this antenna has the property which can fill the available bandwidth. The devices which are used for high resolution vedio access need to have high data rates, this antenna can be used in these devices to increse the data rates.

7.2.2 POSITION LOCATION AND TRACKING

For the applications where it is used to locate a patient at critical condition, tracking of cars i-e for active RF tracking and positioning application this anteena will offer an advantage in multi path resistance and low power requirements for RFIDs.

7.2.3 RADARS

The antenna can be used in the radar applications where the high range accarucy in measurements, target recognition, increase in detection probability for some targets and where the detection of slow moving targets is required.

7.2.4 MILITARY APPLICATIONS

The antenna can be used in the devices which are used by the military such as intrusion detection radars, terrain mapping, obstacle detection and precision geolocation systems.

7.3 FUTURE WORK

This thesis describes the technique of enhancing the bandwidth of antenna using EBG structures. There are also the different methods which can be used to improve the bandwidth of the antenna such as using low dielectric substrates, using of various impedance matching and feeding techniques and the use of slot antenna geometry. The other characteristics of the antenna can also be improved by using different feeding techniques such as coaxial and aperture coupling feeds.

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