INVESTIGATION OF ELECTROMAGNETIC BAND GAP STRUCTURES FOR MICRO STRIP PATCH ANTENNA

A Dissertation submitted in partial fulfillment for the Degree of

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In

Nano Science and Technology

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CERTIFICATE

I, **Manoj Singh Chauhan**, Roll No. **2K12/NST/09** student of M. Tech. (**Nano Science and Technology**), hereby declare that the dissertation/project titled "**Investigation of electromagnetic band gap structures for micro strip patch antenna** " under the supervision **Prof. Suresh C. Sharma**, H.O.D., Department of Applied Physics, Delhi Technological University in partial fulfillment of the requirement for the award of the degree of Master of Technology has not been submitted elsewhere for the award of any Degree.

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Manoj Singh Chauhan

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ABSTRACT

The main objective of this dissertation **"Investigation of Electromagnetic Band Gap Structures for Micro Strip patch Antenna"** is to design and simulate the various electromagnetic band gap (EBG) structure in order to investigate their frequency band gap region and reflection phase characteristic for micro strip antenna parameter improvement. Range of frequency region at which wave cannot propagate in the material is known as frequency band gap region and variation in phase of a reflected wave is produced by a surface determined by the reflection phase property.

Two dimensional mushroom-like EBG structures have been investigated in this dissertation. The equivalent LC circuit of EBG structure acts as two dimensional electric filter to block the flow of wave. Frequency band gap property is investigated by dispersion diagram, scattering parameter method and reflection phase property is investigated by wave guide method.

Electromagnetic Interference (EMI) is a source of noise problems in electronic devices. The EMI is attributed to coupling between sources of radiation and components placed in the same media such as substrate or chassis. This coupling can be either through conducting currents or through radiation. The radiation of electromagnetic (EM) fields is supported by surface currents. Thus, minimization of these surface currents is considered a major and critical step to suppress EMI. In this dissertation, A novel EBG strategy is presented to confine surface currents in antenna substrate. Traditional use of lossy materials and absorbers suffers from considerable disadvantages including mechanical and thermal reliability leading to limited life time, cost, volume, and weight. Here, a new method of EM noise suppression is introduced into micro strip patch antennas using mushroom-type EBG structures. These structures are suitable for suppressing surface currents within a frequency band denoted as the band gap. The effectiveness of the EBG as an EMI suppresser is demonstrated using numerical simulations CST Software. Applications of EBG structure in micro strip antennas are investigated, in which surface wave of micro strip antenna substrate is suppressed by dual layer of EBG around the micro strip patch. Significant improvement in return loss and bandwidth has been achieved.

EBG structure also exhibit property of artificial magnetic conductor (AMC) in a certain frequency range. Phase of reflected wave do not change in this frequency region. PEC ground plane in micro strip antenna gives 180 degree phase shift, which rise the disadvantage of distractive interference between incident wave and reflected wave of micro strip antenna .When PEC ground plane is replaced by AMC ground plane, it gives the constructed interference. Micro strip antenna with AMC ground plane has been investigated. Significant improvement in return loss has been achieved of micro strip antenna.

Keywords: Electromagnetic Band Gap structure, Artificial magnetic conductor plane, Return Loss, Micro strip Patch antenna.

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LIST OF SYMBOLS

f - Frequency

λ - Wavelength

Γ - Reflection Coefficient

S_{11} - Return Loss

η – efficiency

K - Wave number

E - Electric Field

H - Magnetic Field

D - Electric Flux Density

B - Magnetic Flux Density

ρ - Charge Density

S - Poynting Vector

P_0- Power Flow

ε - Permittivity

μ - Permeability

ε_r- Relative Permittivity

μ_r- Relative Permeability

n - Refractive Index

c - Speed of Light

ω - Radian Frequency

k - Complex wave number

f - Frequency

λ - Wavelength

Z - Impedance

S_{11}- Return Loss

S_{21} – Insertion Loss

LIST OF ABBREVIATION

AMC -Artificial magnetic conductor

EBG -Electromagnetic bandagap

FDTD -Finite difference time domain

PBG- Photonic bandagap

PBC –Periodic boundary condition

CHAPTER 1

OVERVIEW AND BACKGROUND RESEARCH

1.1 Introduction

The Electromagnetic Band Gap (EBG) terminology has been suggested based on the photonic band-gap (PBG) phenomenon in optics that are realized by periodical structures. The EBG materials provide frequency bands or also can called band gaps or stop bands inside which waves cannot propagate in the materials [1]. Electromagnetic Band Gap structure is known as objects that prevent the propagation of the electromagnetic waves in a specified band of frequency for all angles and for all polarization state.

1.2 The Scope of Research

Objective of this project are to design an EBG structure that can suppress surface waves in the substrate and improve the parameter of the micro strip antenna. These structures reduce the mutual coupling between the antenna array element and increase isolation between the different radiation elements on a common ground plane. These structures also show the filter characteristic which is useful in many microwave devices. EBG structures are integrated with micro strip patch antenna and confine the surface wave in substrate. EBG structure also shows the zero reflection phase property, which is also useful in micro strip antenna as an artificial magnetic conductor (AMC). Therefore integration of EBG structure with micro strip antenna gives significant improvement in antenna parameter.

1.3 Literature Overview

The progress of electromagnetic (EBG) structures, since their invention in the 1987 in the optical domain, has not followed a series pattern of development; on the contrary, it followed parallel enhancement and improvement through the innovation of different structures and patterns. Each structure proved to have certain advantages making it suitable for specific applications. This overview is focused on the most famous structures and their applications. Since the invention of photonic band gap (PBG) structures in 1989, they were totally designed for optical applications till the publication of a paper by Brown et al., proposing the building of a planar antenna on photonic crystal substrate in 1993 [2]. This paper was a break through as it transferred the idea of PBG structures [3]from the optical domain to the microwave and millimeter wave bands. It stated the advantages of using EBG in three main applications which were (1) planar antennas, (2) delay lines, and (3) nonreciprocal devices.

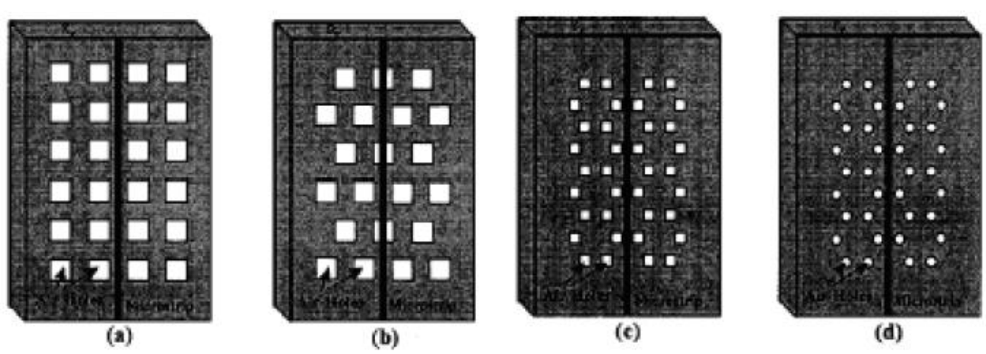

Figure.1.1. Several EBG structures for microstrip circuits: (a) Square-lattice, squarehole, (b) Triangular-lattice, square-hole, (c) Honeycomb-lattice, square-hole, (d) Honeycomb-lattice, circular-hole [2].

The photonic crystal is well suited for this class of applications because of the absence of propagation in the bandgap and because of the nature of the dispersion curves at frequencies above and below the band gap. In 1997, Qian, Radistic and Itoh produced a paper which is still considered one of the literature items in the PBG structures [3]. They reported the first comprehensive investigation of synthesized dielectric materials which possess distinctive stop bands for micro strip lines. They performed the first full-wave, comprehensive study of a category of EBG structures which are suitable for microstrip-based circuits and antennas. Four types of these EBG structures had been simulated using FDTD. Figure 1.1 shows the four types of EBG structures. The EBG holes were drilled through the dielectric substrate, and a conductive tape was applied in the ground plane of the micro strip line.

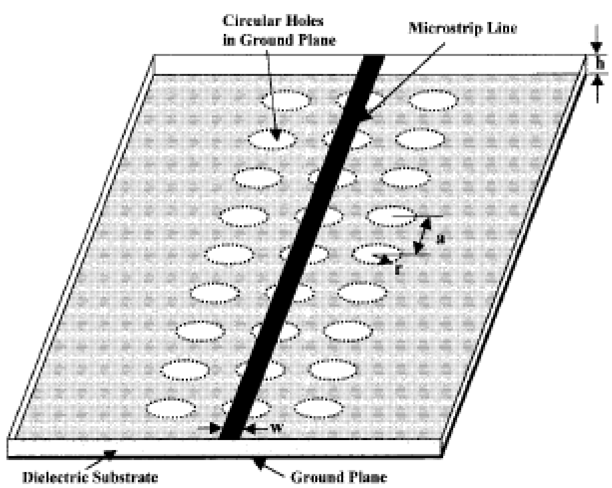

Figure1.2: Three-dimensional view of a proposed EBG structure.

In February, 1998, the same group, Radisic et al. proposed a two-dimensional (2-D) EBG structure for micro strip lines [4], in which a periodic 2-D pattern consisting of circles was etched in the ground plane of microstrip line. The main advantage of this structure is that no drilling through the substrate was required. Three EBG circuits were fabricated with different circle radii to determine the optimum dimensions. Figure1.2 shows the proposed (2-D) EBG structure. The paper provided no analysis for the proposed structure as all the responses were fabricated and measured.

Surface Wave

A surface wave is one that propagates along an interface between two different media without radiation, such radiation being construed to mean energy converted from the surface wave field to some other form [3]. In surface waves, there have electric and magnetic field components, which are excited by different sources. In order to suppress surface wave propagation, there were some techniques which can be use, such as special antenna designs, micromachining the substrate and employing electromagnetic band gap structure. The lack of availability of direct methods for investigating surface waves is becomes a problem in solving the suppression surface wave [2].

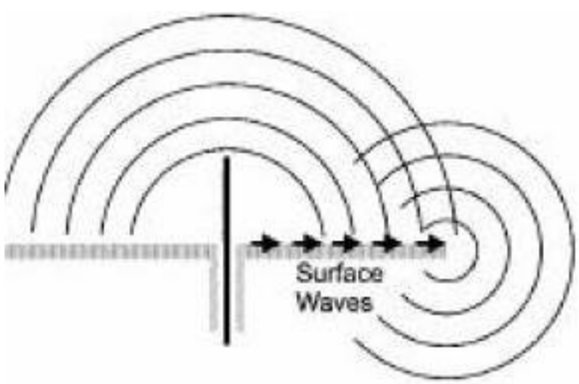

Figure1.3: surface wave generation

EBGs could be used to improve the efficiency of antennas [4], due to the suppression of surface and substrate waves, which are the predominant loss mechanisms. Furthermore, the EBGs can function as an artificial magnetic conductor (AMC) at a certain EM wavelength [5]. A metal surface, as an approximation of a perfect electric conductor (PEC), has a voltage wave reflection coefficient of -1, which causes a reflection and a phase shift of 180 degrees to the incident EM wave. With an artificial magnetic conductor, as an approximation to a perfect magnetic conductor (PMC), there is an in-phase reflection. Due to destructive interference, the PEC is undesirable as a ground plane for micro strip antennas. Having a PMC with a voltage wave reflection coefficient of +1 underneath a micro strip antenna increases the antenna's efficiency. While the drawback of the reflection coefficient of a PEC can be offset by a spacing of $\lambda / 4$ between the antenna and the ground plane [6], the problem of surface waves still persist for PEC ground planes. Another advantage of EBGs is the integration of components. Usually the required high dielectric constant of the substrate needed for a high level of integration would be detrimental for microstrip antennas. However, by using an EBG, the antenna could be shielded from the substrate, enabling it to be integrated with other components on the same substrate . Similarly, EBGs can be utilised to reduce crosstalk between neighbouring components on a chip . The radiation pattern of antennas can be changed with EBG structures . Some research has been carried out on altering waveguides via EBGs [7]. Another important point about EBGs is the idea of introducing defects into the structure in order to tweak its properties, similar to doping of semiconductors [5]. EBG structures could be used to enhance other radio frequency (RF) applications like attenuators, cavity resonators, filters, etc.

1.4 Methodology

This project was start with background study of basic concept of electromagnetic band gap structure. All was done guidance by the reference journal, articles and books that related to this project. After understand the concepts, project move on varies modeling technique which is related to the analysis of EBG structure. Modeling technique required good understand of boundary condition according to the simulated parameter. Frequency band gap and artificial magnetic conductor are major properties of EBG structure which is utilized in characterization of EBG structure. According to these two properties, EBG integrated with micro strip antenna. All parameters simulated by CST MWS 2010 with transient and Eigen mode solver.

1.5 Outlines of Thesis

The outlines of the thesis are as follows:

Chapter 1: It provides the introduction of electromagnetic band gap structure, scope of work, literature over view and methodology.

Chapter 2: It covers the literature review on the electromagnetic band gap structure, Types of EBG Structure, EBG Properties, characterization of EBG structure, micro strip antenna design and their property

Chapter 3: It contains the design and analysis of EBG structure , different method of frequency band gap and zero reflection phase measurement setup.

Chapter 4: It chapter contains the design of micro strip antenna with EBG structure. In first design EBG structure is integrated with substrate and in second design EBg structure act as an artificial ground plane.

Chapter 5: It contains conclusion and future work of this project.

CHAPTER 2

ELECTROMAGNETIC BAND GAP STRUCTURE

2.1 Introduction

Electromagnetic bandgap (EBG) structures are periodic structures that initially evolved in the optical domain by the name of photonic band gap (PBG) structures in the late 1980’s [8]. EBG structures may be implemented in different ways; either by etching gaps in the metal of the ground plane [9], or the signal line, or by drilling periodic holes in the dielectric [8]. These periodic structures have very interesting features which make them very promising candidates to a number of applications [10]. EBG structures allow the propagation of electromagnetic waves in certain frequency bands and forbid them in other bands known as bandgap. This first property used in many applications for the suppression of higher order harmonics and undesirable pass bands. The second feature of these structures is that they increase the effective inductance and capacitance of the line, supporting slow-wave propagation. On the other hand, contradicting all slow-wave technologies, EBG structures do not suffer from excess losses in the passbands; on the contrary, such structures might give better insertion and return loss values due to their ability to suppress surface waves. Surface waves are caused by the multiple reflections of electromagnetic waves between the ground plane and the air-dielectric interface. They are the source of two basic problems in many systems. First problem is the leakage of energy through leaky waves and end-fire radiation. The second problem is the spurious coupling between circuit components and antenna elements. These problems cause an overall reduction in the system efficiency, limit the bandwidth, and limit the applicable frequency range of microstrip systems [10]. Finally, we may summarize the advantages of EBG structures into seven main points:

1. Easy fabrication.

2. Low cost.

3. Compatibility with standard circuit technologies.

4. Ability of these structures to introduce distinctive stopbands

5. Slow-wave effect which is very important for size reduction.

6. Low attenuation in the passband.

7. Suppression of surface waves.

EBG reflector stop certain band of frequency and pass reaming band of frequency.whereas metal reflector stop complete band of frequency as shown in figure 2.1.

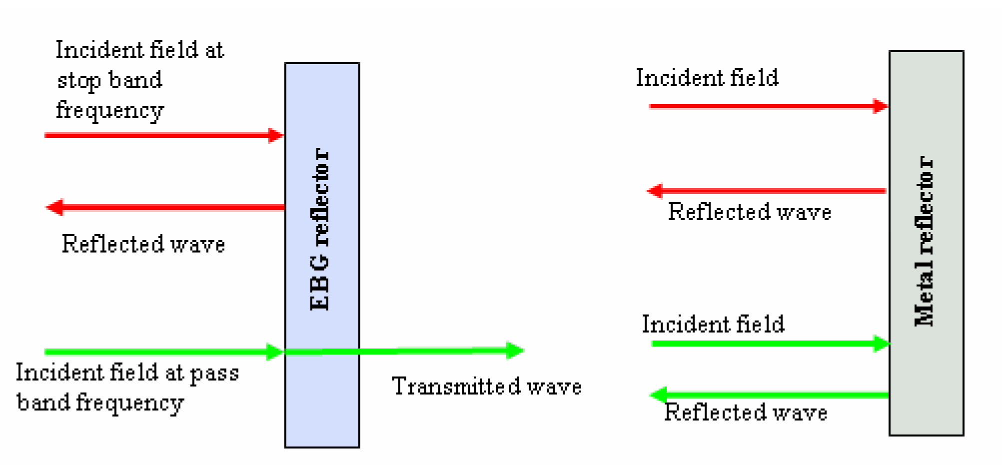

Figure 2.1: Diagram illustrating the application of EBG as a mirror and its comparison with a metal reflector.

A photonic crystal essentially behaves much like a band-stop filter, rejecting the propagation of energy over a fixed band of frequencies. However, once a defect is introduced such that it disrupts the periodicity in the crystal, an area to localize or “trap” electromagnetic energy is established. In this region, a pass-band response is created. This ability to confine and guide electromagnetic energy has several practical applications at microwave frequencies as filters, couplers, and especially antennas. This rather simple concept of placing defects in a photonic crystal structure introduces a new methodology in the design of microstrip (patch) antennas. The idea is to design a patch antenna on a 2D photonic crystal substrate, where the patch becomes the “defect” in the crystal structure. crystal arrays of cylindrical air holes are patterned into the dielectric substrate of the patch antenna. By not patterning the area under the patch, a defect is established in the photonic crystal, localizing the EM fields. Surface waves along the XY plane of the patch are forbidden from forming due to the periodicity of the photonic crystal in that plane. This prevention of surface waves improves operational bandwidth and directivity, while reducing side-lobes and coupling, which are common concerns in micro strip antenna designs [11]. Using these concepts, a photonic crystal patch antenna was developed.

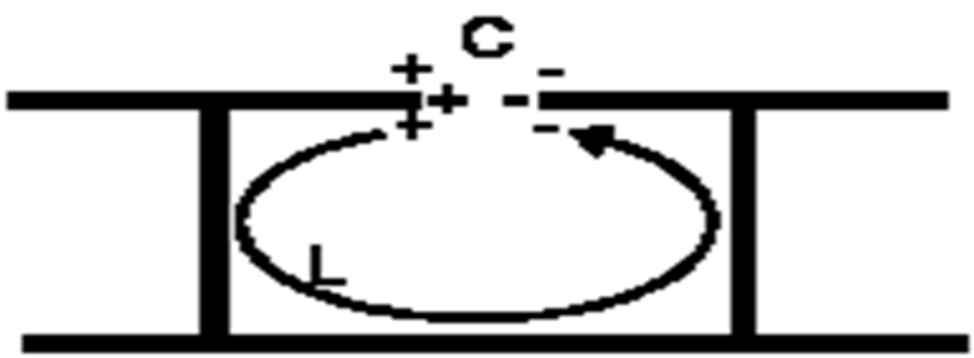

Figure 2.2: Origin of the equivalent circuit elements

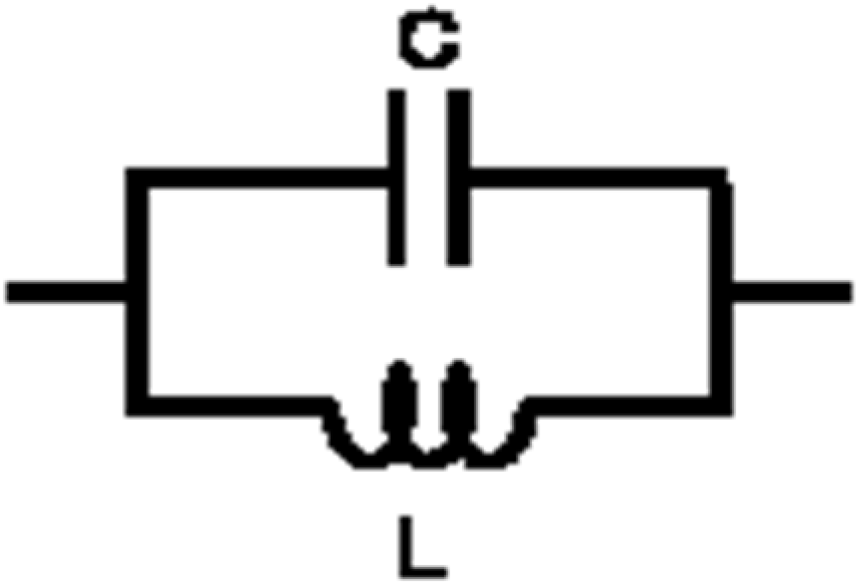

Figure 2.3: Equivalent circuit model for the high-impedance surface

$$f_c = \frac{1}{2\pi\sqrt{LC}} \tag{2.1}$$

The frequency band gap of EBGs is directly related to the geometrical parameters and material parameters of the host medium. The EBG structures are essentially electrically-small resonators. Within the band gap where they provide wave suppression, their size is much smaller than the wavelength. Analytical formulation of a precise relationship between the effective bandwidth (bandgap) and the geometrical and material parameters is difficult. It is very difficult to calculate bandgap with the help of analytical expressions or accurate circuit models to give a reasonably accurate prediction of the bandgap. Therefore, and until a highly accurate closed-form analytic expression is developed, the stop band of an EBG structure may be generated directly or indirectly using numerical simulation tools.

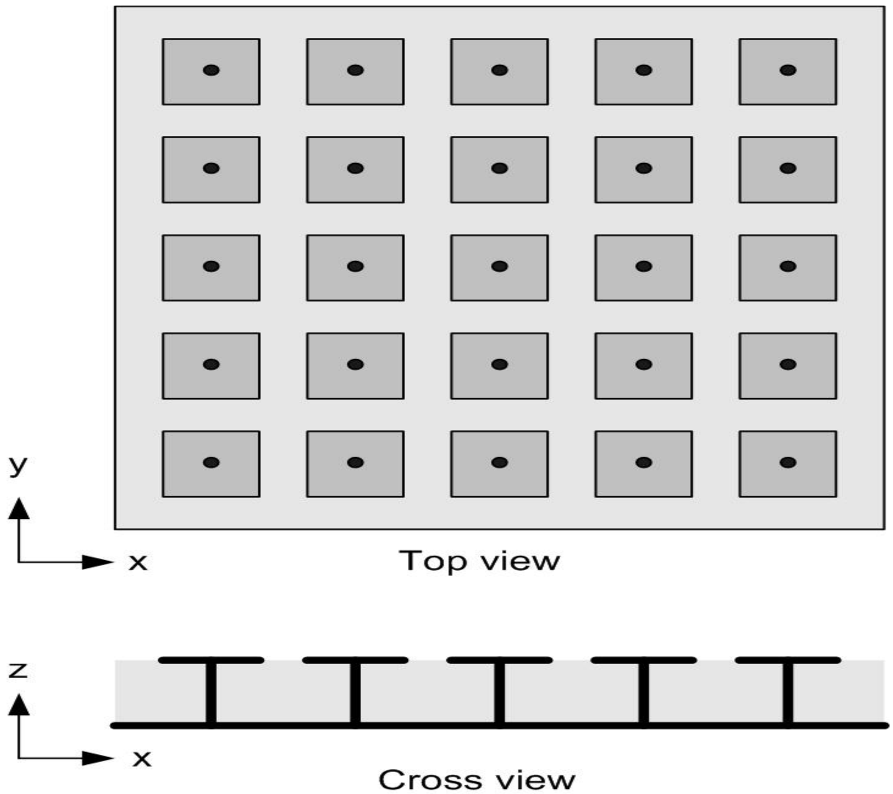

Figure 2.4: A mushroom like EBG structure top and cross view

2.2 Types of EBG Structure

EBG structures are periodic in nature, which may be realized by drilling, cuffing, and etching on the metal or dielectric substrates. They may be formed in the ground plane or over the substrate. On the basis of dimensions EBG structures are categorised as one dimensional (1-D), two dimensional (2-D), and three dimensional (3-D) periodic structures that satisfies Bragg's conditions, i.e., inter-cell separation (period) is close to half guided wavelength ($\lambda g/2$). They are capable of forbidding electromagnetic propagation in either all or selected directions [12].

2.2.1 3-D EBG Crystals

In the beginning a 3D EBG was designed only. A successful attempt to obtain a 3D periodic dielectric structure was made in Iowa State University (ISU) . It was called the woodpile structure as shown in the figure2.5 . Three dimensional EBG crystals have periodicity along all the three dimensions and the remarkable feature is that these systems can have complete band gaps, therefore that propagation states are not allowed in any direction [13].

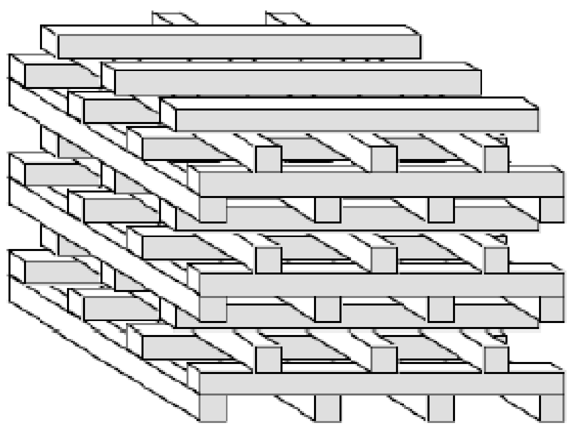

Figure 2.5: Three dimensional EBG Structures

Although, a perfect 3-D EBG structure is required to block all waves in all directions, but then these structures are difficult to fabricate and integrate. From literature, we learned that 2-D EBG could be even more valuable. 2-D EBG structures are easy to fabricate and are capable of maintaining a similar control on the wave propagation in the structure as the 3-D structure.

2.2.2 2-D EBG Crystals

These crystals have periodicity in two dimensions and are homogeneous along the third direction, or we can say that, all variations happen in the two dimensions, whereas everything is constant along the third dimension, thereby propagation is allowed along one axis of the crystal [14]. These 2-D EBG structures have substantial advantages in terms of compactness, stability, and fabrication, which make them more attractive for microwave devices.

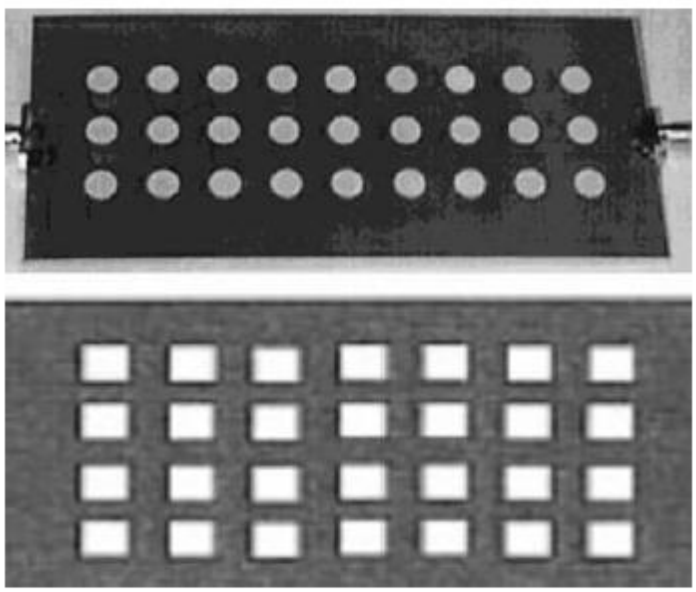

Figure 2.6: Two dimensional EBG structures

One of the greatest advances in the development of these 2-D EBG structures in microwave range has been their implementation in micro strip technology.

2.2.3 1-D EBG Crystals

One dimensional EBG structures can also be implemented in micro strip technology. 1-D EBG structures have periodicity of two different media along one direction only. These basic crystals exhibit three important phenomena: photonic band gaps, localized modes, and surface states. However, as the index contrast is only along one direction, the band gaps and bound states are limited to that direction. Nevertheless, these simple structures show most of the features of 2-D and 3-D EBG crystals.

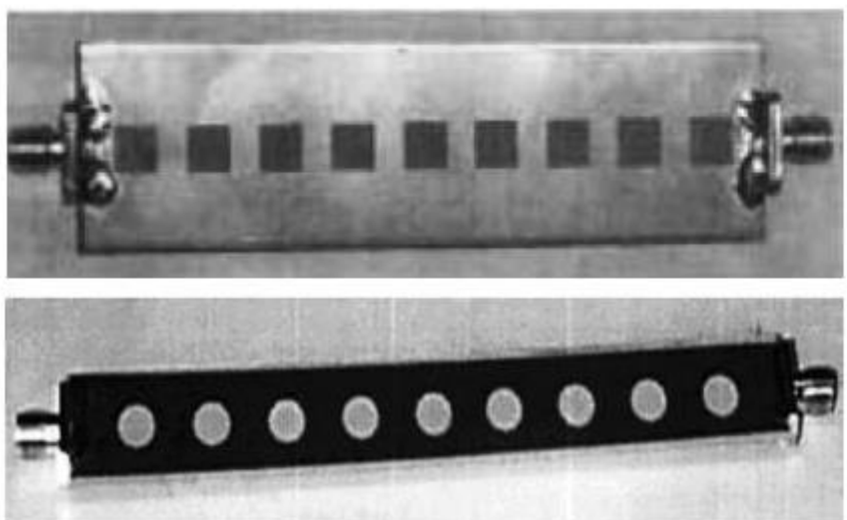

Figure 2.7: One dimensional EBG structure

2.3 Characterization of EBG Structures

The frequency bandgap of EBGs is directly related to the geometrical parameters and material parameters of the host medium. The EBG structures are essentially electricall small resonators. Within the bandgap where they provide wave suppression, their size is much smaller than the wavelength. Analytical formulation of a precise relationship between the effective bandwidth (bandgap) and the geometrical and material parameters is difficult. In [15], the authors have obtained circuit models for EBGs embedded in power planes. However, for the cases of EBG structures used in open systems, as in this study, we could not find any analytical expressions or accurate circuit models to give a reasonably accurate prediction of the bandgap. Therefore, and until a highly accurate closed-form analytic expression is developed, the stop band of an EBG structure may be generated directly or indirectly using numerical simulation tools. There are different numerical techniques to extract the frequency stop band of a structure which vary in complexity and efficiency. Using the scattering parameters (S-parameters) to characterize the bandgap is the most direct method while the dispersion diagram [16] is the indirect one.

2.3.1. Scattering Parameters

In this method the bandgap can be specified by extracting the S-parameters numerically between two ports placed across the EBG structure as shown in Figure 2.8. For this purpose full-wave EM simulators such as Ansoft HFSS (or CST) can be used.EBG structure with specific bandgap can be designed using this method by trial and error procedure. This method is the most direct one because not only it characterizes the location of the bandgap, the bandwidth, and the center frequency but also, it provides the attenuation level of the signal at different frequencies.

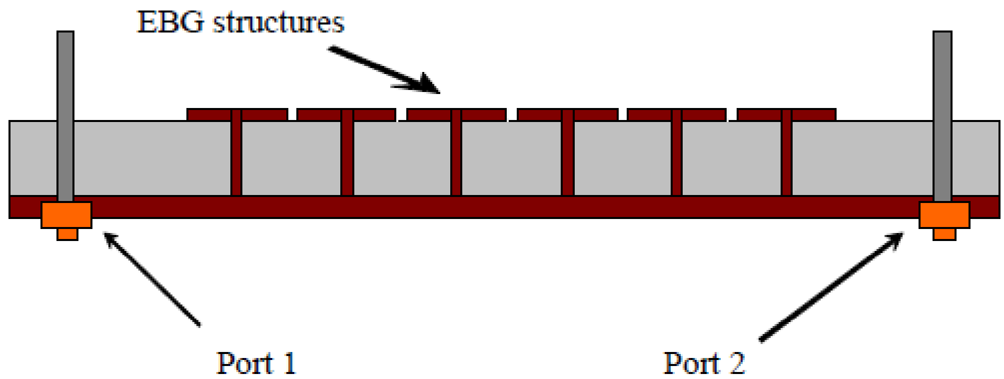

Figure 2.8: A schematic showing the simulation setup used to extract the bandgap of an EBG structure using scattering parameters

2.3.2. Dispersion Diagram

In Dispersion diagram method, the bandgap is specified by extracting the dispersion diagram which describes the propagation characteristics of an infinitely periodic structure composed of EBG patches. Dispersion diagram is numerically extracted using fullwave solver, by considering a single patch (unit cell) and applying periodic boundary condition (PBC) on the sides of the cell to mimic the presence of the cell in a inifinite array of periodic structure, and absorbing boundary condition (ABC) or perfectly matched layer (PML) on the top open wall as shown in Figure 2.9(a) . Dispersion diagrams show the relationship between wave numbers and frequency. These diagrams present the propagating modes and the bandgaps that can potentially exist between such modes (in a periodic structure at a given frequency of operation, many modes propagating in different directions may be excited) . Brillouin, in his theory of wave propagation in periodic structures, states that for any periodic structure there are certain vectors in the unit cell of the periodic structure that constitute a boundary region of propagation called irreducible Brillouin zone. According to that theory, deriving the propagating modes in the direction of these vectors suffices to cover all possible directions of wave propagation within the lattice. Therefore, the problem of deriving the propagating modes excited at a certain frequency reduces to finding such modes only in the directions of the vectors of the irreducible Brillouin zone. For the type of structure considered in this work, the border of the irreducible zone is illustrated in Figure 2.9 (b) and it consists of the direction pointing from Γ to X, from X to M and from M back to Γ.

Therefore, in light of Brillouin theory, a dispersion diagram will consist of three regions. In each region, we consider the paropagation wave vector β which is translated into a phase shift between the sides of the unit cell shown in Figure 2.9 (a). This translation allows the derivation of dispersion diagram using traditional eigenmode solver based on full-wave analysis. In these simulations, the structure of unit cell and the required phase shifts (shown as Phase 1 and Phase 2 in Figure 2.9 (a)) are given to the simulator. The simulator calculates the frequencies of propagating waves that would generate such phase shifts. For a wave propagating in the x-direction with no y variation, Phase 1 is varied between 0 and 1800 and Phase 2 is kept constant at zero degree. This corresponds to the Γ to X direction. The X to M direction corresponds to Phase 1 being constant and equal to 1800 and Phase 2 varying from 0 and 180o. This represents the second region in the dispersion diagram. The third region is represented by the M to Γ direction in which both phases are equal and changing from 180o back to 0. For wave propagation in free space, as there is no dispersion, the diagram constitutes of straight lines in the first and third regions and a quadratic graph in the second region. The following equation shows the frequency phase relationship for wave propagation in free space:

$$f(\beta d) = \begin{cases} \dfrac{c}{2\pi d}(\beta_1 d) & \Gamma - \mathrm{X} : (0 \le \beta_1 d \le \pi \quad \beta_2 d = 0) \\ \dfrac{c}{2\pi d}\sqrt{\pi^2 + (\beta_2 d)^2} & \mathrm{X} - \mathrm{M} : (0 \le \beta_2 d \le \pi \quad \beta_1 d = \pi) \\ \dfrac{c\sqrt{2}}{2\pi d}(\beta_1 d) & \mathrm{M} - \Gamma : (0 \le \beta_1 d \le \pi \quad \beta_2 d = \beta_1 d) \end{cases} \tag{2.2}$$

where $d = a + g$ is the size of unit cell (periodicity length), c is the speed of light in free space, $\beta 1 = \beta x$ and $\beta 2 = \beta y$ are the wave numbers in the Γ-X and the X-M directions. With the presence of EBG structures, the surface becomes dispersive; therefore the frequency-phase relationship of propagating modes will not be the same as in free space. A gap between the upper limit of any propagating mode and the intersection of the free space propagation line with the next propagating mode represents a region in which the surfaces do not support any propagation.

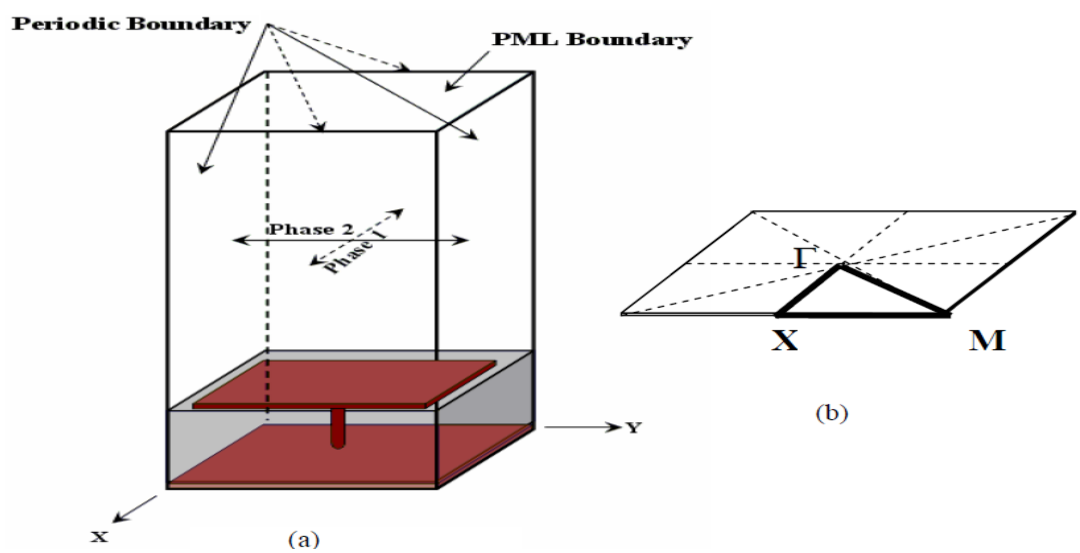

Figure 2.9: (a) Computational domain containing single cell.

(b) The irreducible Brillouin zone triangle.

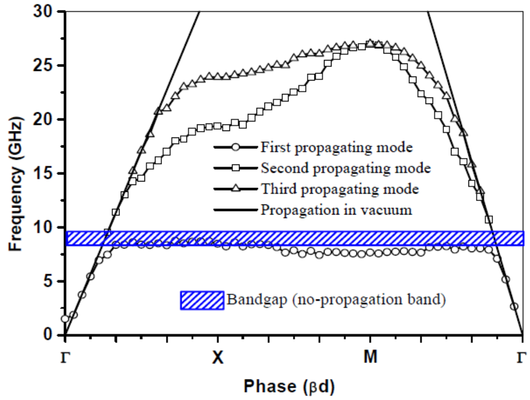

Figure 2.10: Dispersion diagram for the EBG structure

2.4 Compression between PEC Ground Plane and EBG Ground Plane

2.4.1 Perfect Electric Conductor as Ground Plane

The perfect electric conductor (PEC) is a theoretical material having infinite conductivity σ (S/m). It turns out that conducting material such as copper (typically 6×107 S/m) although having finite conductivity can be approximated as a PEC. A flat copper sheet has been used in numerous antenna designs as a reflector or a ground plane [18]. The conducting ground plane reflects an incident electromagnetic wave. Given the correct position of the antennas radiating element/s the use of a ground plane has two advantages. One it may improve the antenna gain by up to 3dB and two, it shields a body underneath's the ground plane. The amount of gain increase and shielding depends on the ground plane size [19].

While a simple conducting surface has these desirable properties, it also exhibits one undesirable property of inverting the phase of the reflected wave for antenna applications. As the electric field inside a perfect conductor is zero the boundary condition at the metal/air interface forces the tangential electric field at the surface to be zero. When an electromagnetic wave is incident on a conductor, the reflected wave undergoes a phase reversal to satisfy boundary conditions of electric field node and magnetic field antinode

[20]. Unfortunately, antennas do not operate efficiently if positioned very close and parallel above a PEC ground plane. By image theory [21] the parallel electric source placed very close above the PEC surface will generate negative image currents on the PEC surface. The image currents in the conductive sheet cancel the currents in the antenna resulting in reduced radiation efficiency. This phenomenon can also be explained by considering the phase shift that occurs as incident wave propagates and than reflects back from the PEC and finally adding with the incident wave to form an interference pattern on the front side of the radiator. This sequence of operation is shown in Figure 2.11 for a $\lambda / 4$ distance between the radiator and PEC ground plane. When an electromagnetic wave travels a distance of $\lambda / 4$ it undergoes a phase change of 90 degrees.

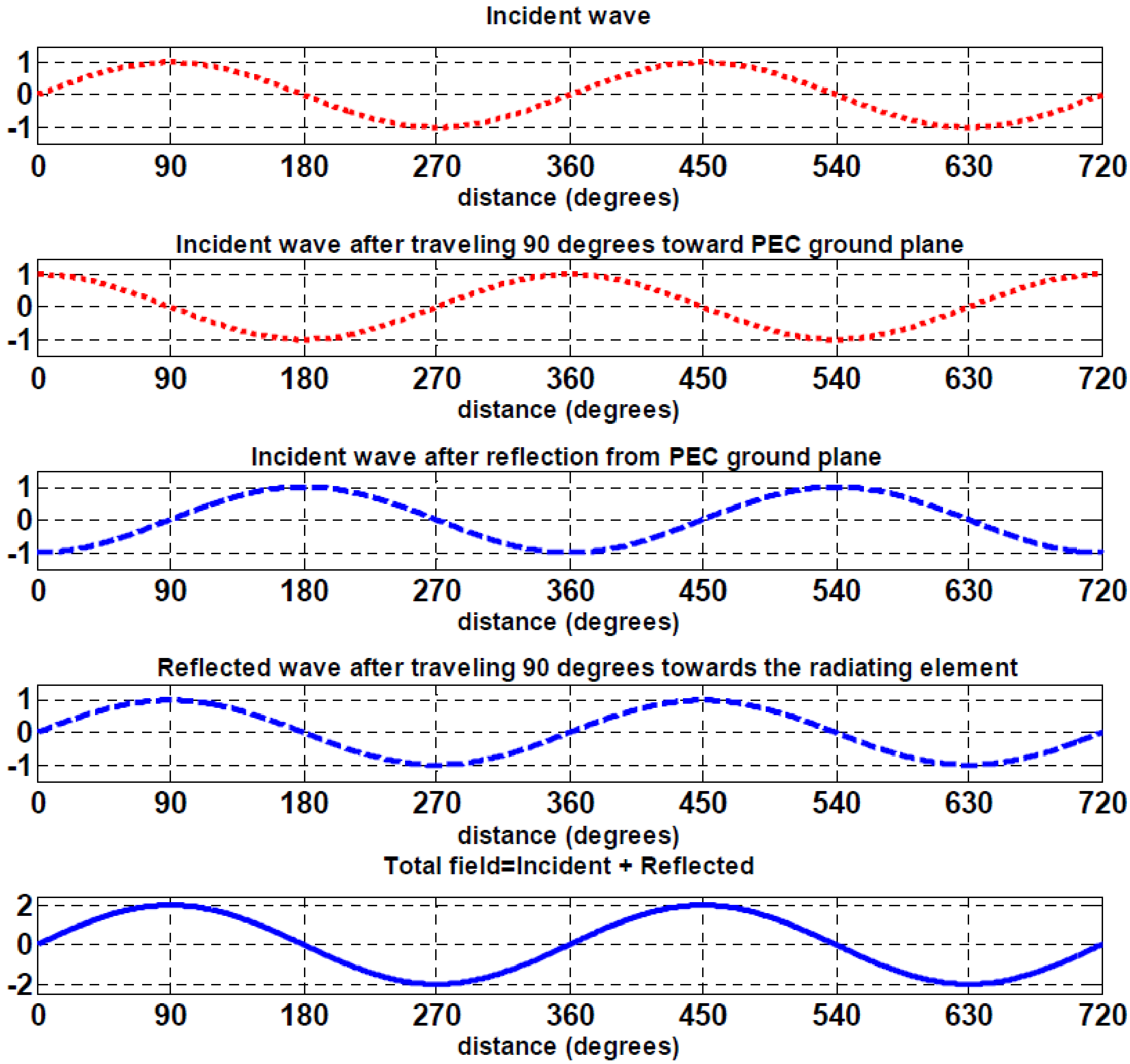

Figure 2.11: Phase changes of incident wave for a λ/4 spacing between the radiator and PEC ground Plane

When it impinges the PEC ground plane, it is reflected back and undergoes further 180 degrees phase change. It than travels towards the radiator by travelling λ / 4 distance again and in the process its phase changes by further 90 degrees. Now as shown in Figure 2.8 this wave and the incident wave are in phase. They add up constructively in the forward direction. However if this spacing of λ / 4 is not there, the reflected will be 180 degrees out of phase with the incident wave and destructive interference will take place accordingly. This destructive interference phenomenon is shown in Figure 2.12 for a dipole antenna placed horizontally and very close to a PEC ground plane. Due to destructive interference between reflected waves and original waves emitted directly by the radiating element, the antenna is effectively shorted out by the metal surface and radiation efficiency is reduced significantly.

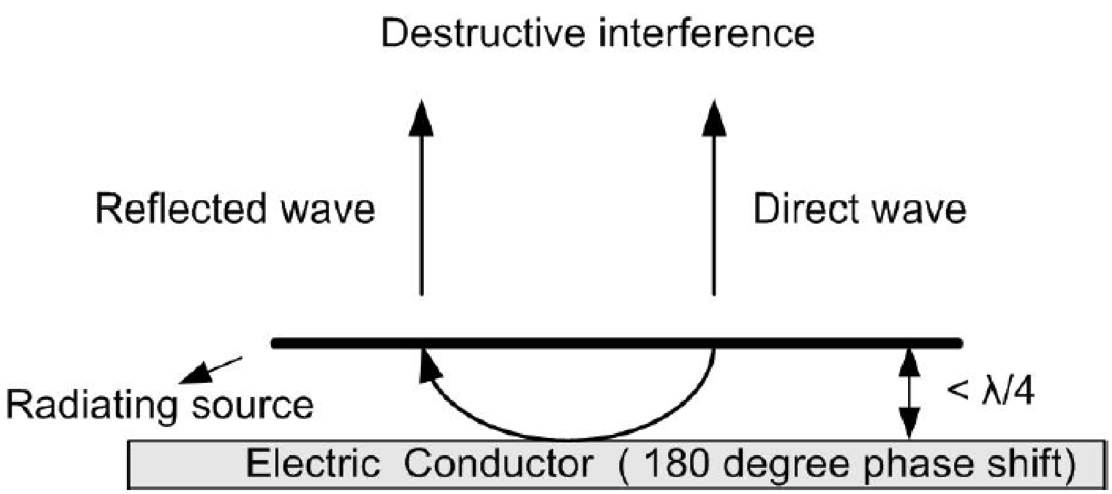

Figure 2.12: A Radiating element lying parallel and close to electric conductor

This problem can be solved by separating the radiating element from the ground plane by at least one quarter of operating wavelength as explained in Figure 2.11. This situation is depicted in Figure 2.13, the total round trip phase shift from the radiating element, to the conductor surface and back to the element equals one complete cycle. Therefore, the two waves will be in phase and will interfere constructively. In this way the antenna will radiate efficiently even when placed close to the electric conductor. However the entire structure requires a minimum thickness of λ/4 which limits its applications in low profile antenna designs. The low profile design usually refers to the antenna structure whose overall height is less than one tenth of a wavelength at the operating frequency. Therefore this minimum thickness requirement is the limitation in reducing the antenna profile and also in achieving broadband design as quarter wavelength separation only exists at a certain frequency range.

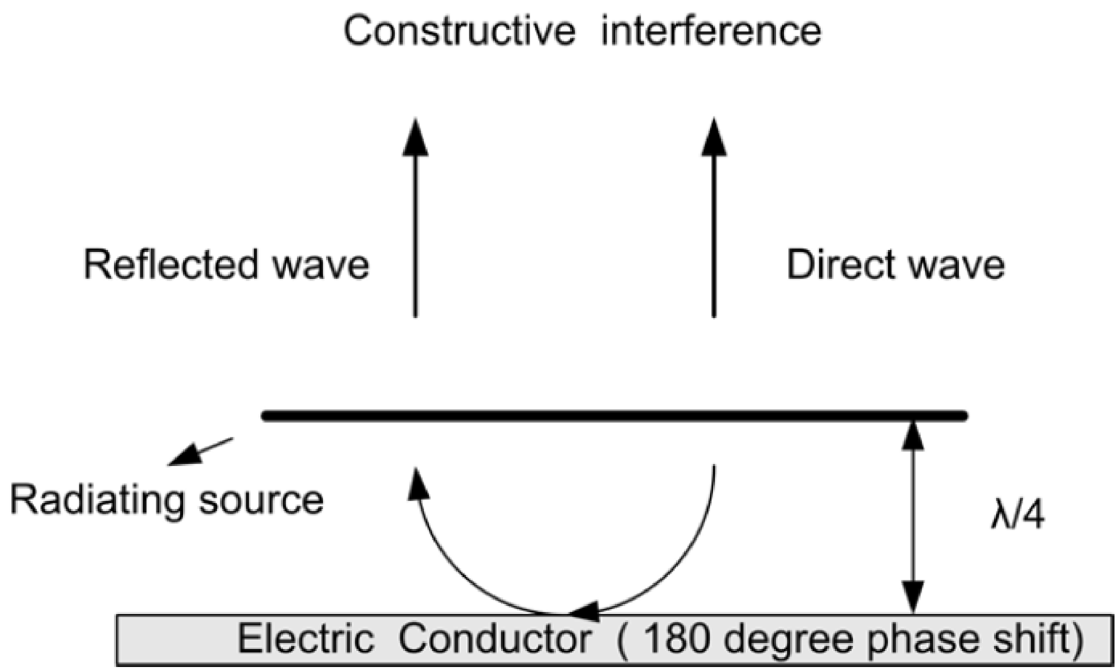

Figure 2.13: Radiating element separated by ¼ wavelength from the electric conductor

Another property of conductor surfaces is that they support surface waves [21]. These are propagating electromagnetic waves that are bound to the interface between conductor and free space. When an antenna operates close to a metal sheet, it will radiate plane waves into free space; however it will also induce surface currents that will propagate along the conducting sheet. If the conductor is smooth and infinite in extent, the surface currents will not radiate into free space and would result only as slight reduction in radiation efficiency. In a real situation, the conducting ground plane is always finite in size and not perfectly smooth.

So these surface currents will propagate until they reach a discontinuity like an edge or corner. They will radiate and interfere with the antenna radiation. The combined radiation from the antenna and different parts of the conducting ground plane will form series of lobes and nulls at various angles which will be seen as ripples in the far field radiation pattern [22]. In addition part of the surface currents will also radiate on the back side of the ground plane, decreasing Front-to-back ratio. Moreover when multiple antennas share the same ground plane to form an array, surface currents in addition to free space coupling also cause unwanted mutual coupling among them [22]. This may cause scan blindness in phased arrays.

2.4.2 Perfect Magnetic Conductor as Ground Plane

In contrast to a PEC, the Perfect Magnetic Conductor (PMC) will generate in phase image currents when a horizontal electric source is placed above it. This image current will reinforce the antenna current and increase the radiation efficiency of antenna. Because the reflected wave has no phase shift on reflection from PMC surface, the $\lambda/4$ minimum distance is no longer needed. The in phase reflected waves and the waves radiating directly from the source will combine constructively as shown in Figure 2-4. This helps to significantly reduce the antenna profile. However, unfortunately no natural material hasbeen found to realize such a magnetic conductive surface.

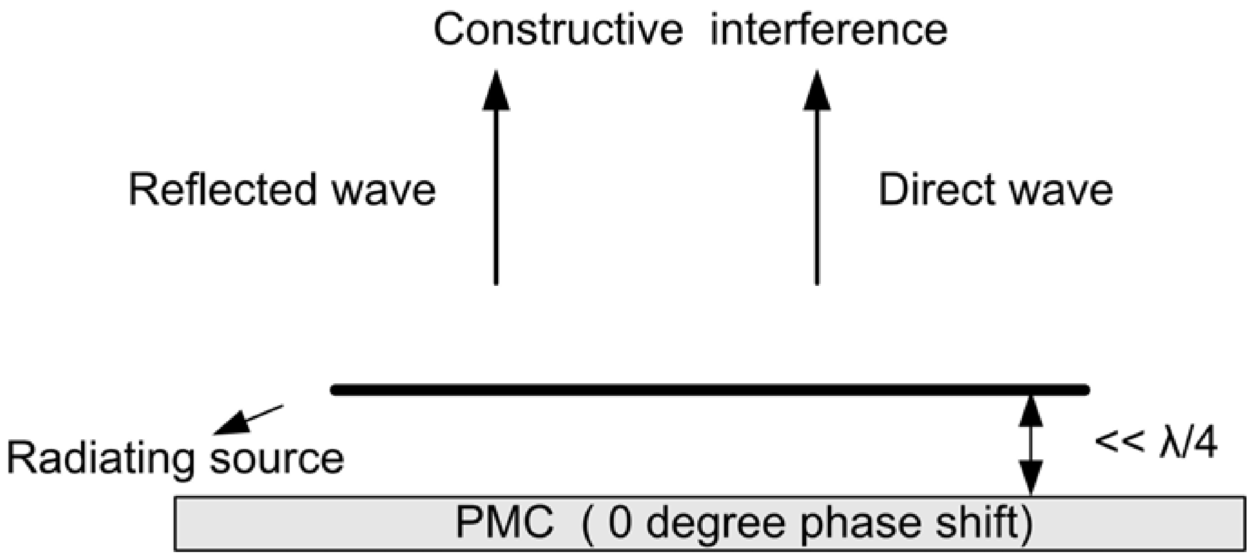

Figure 2.14: A radiating source lying parallel above PMC ground plane

Much effort was therefore devoted to realise a PMC like surface artificially. In the next section the artificially engineered electromagnetic band gap structure has been design that can mimic PMC behavior and has many interesting applications in antenna and microwave field.

2.5 Micro Strip Patch Antenna Design

A patch antenna is a type of radio antenna with a low profile, which can be mounted on a flat surface. It consists of a flat rectangular sheet or "patch" of metal, mounted over a larger sheet of metal called a ground plane. Patch antennas are simple to fabricate and easy to modify and customize. The two metal sheets together form a resonant piece of micro strip transmission line with a length of approximately one-half wavelength of the radio waves. The radiation mechanism arises from discontinuities at each truncated edge of the micro strip transmission line. The radiation at the edges causes the antenna to act slightly larger electrically than its physical dimensions, so in order for the antenna to be resonant, a length of micro strip transmission line slightly shorter than one-half a wavelength at the frequency is used. A patch antenna is usually constructed on a dielectric substrate, using the same materials and lithography processes used to make printed circuit boards.

Major operational disadvantage of micro strip antennas are their low efficiency, low power high Q (sometime in excess of 100), poor scan performance, spurious feed radiation and very narrow bandwidth, which is typically only a fraction of a percent or at most few percentage.

2.6 Antenna Properties

There are some important parameters need to be considered that characterize all antenna designs. There are the radiation pattern, return loss, gain, bandwidth, VSWR, half – power beamwidth and antenna efficiency.

2.6.1 Radiation pattern

The radiation pattern of an antenna is generally its most basic requirement because it determines the distribution of radiated energy in space. Radiation pattern is defined as the power radiated or received by an antenna in a function of the angular position and radial distance from the antenna [19]. It describes how the antenna directs the energy it radiates. The Figure 2.15 below shows a 3D representation of the radiation from an antenna (top) and one form of radiation pattern (bottom). The pattern consists of a main lobe and several minor lobes. With all antennas (except monopoles and dipoles), side lobe and backlobes can be obtained, and they are always undesirable because they represent wasted energy for transmitting antennas and potential noise sources for receiving antennas.

2.6.2 Return Loss

Return loss is a convenient way to characterize the input and output signal sources. Return loss can be defined in dB as follow:

$$\text{Return loss} = 20\log|\Gamma| \text{ (dB)} \tag{2.1}$$

Where,

$$\Gamma = \frac{V^-}{V^+} = \frac{ZL - Z0}{ZL + Z0} \tag{2.2}$$

$|\Gamma| = \text{reflection coefficient}$

$V^- = \text{the reflected voltage}$

$V^+ = \text{the incident voltage}$

Zo = characteristic impedance

Z_L = load impedance

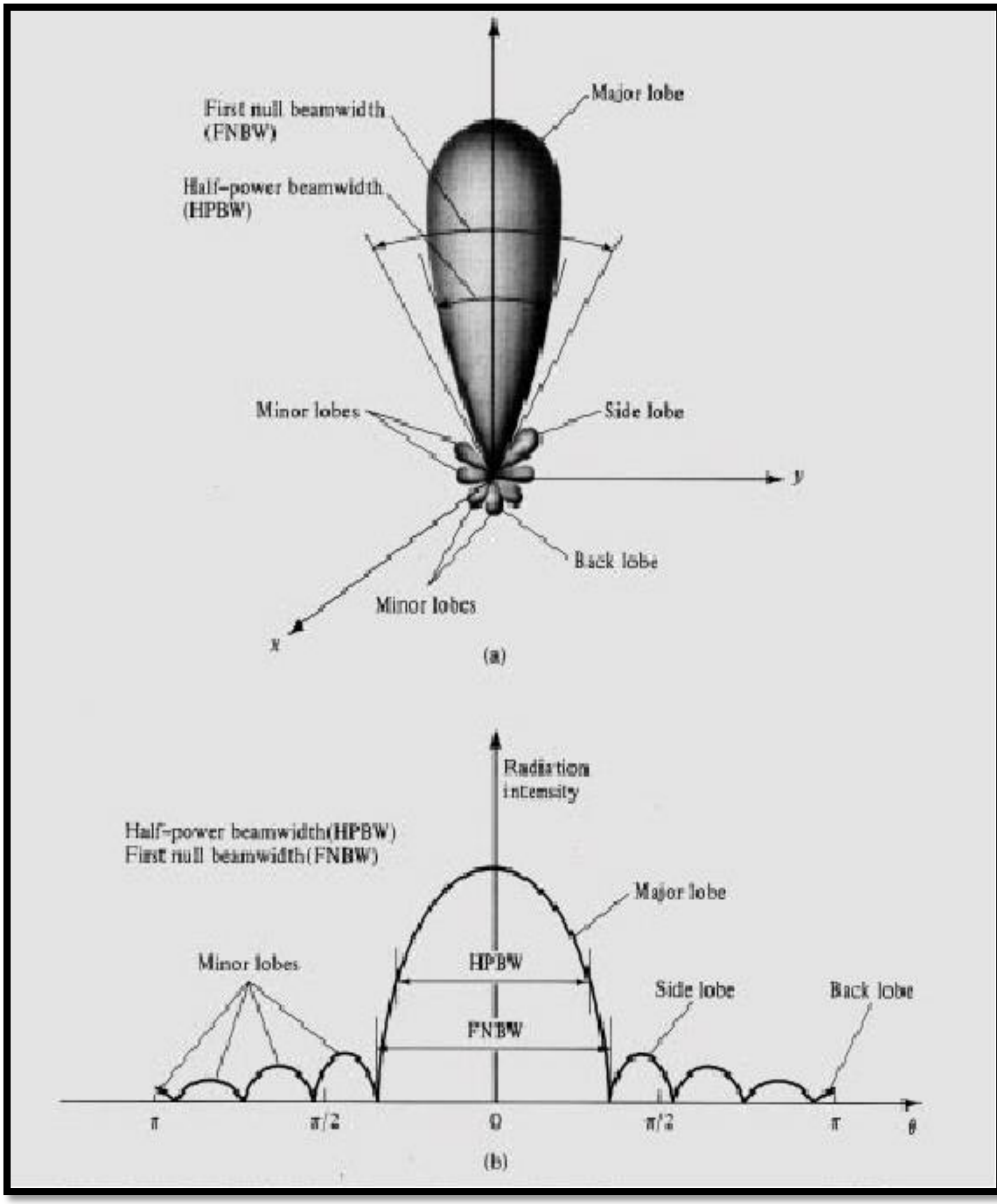

Figure 2.15: 3D representation of a radiation pattern.

2.6.3 Gain

The antenna gain describes the antenna's ability to radiate power in a certain direction when connected to a power source. Gain is usually calculated in the direction of maximum radiation. Gain is given by referencing the antenna under test against a standard antenna. This is technically known as the gain transfer technique. The two most common reference antennas are the isotropic antenna and the resonant half-wave dipole antenna. The isotropic antenna radiates equally well in "all" directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas. An antenna gain of 2 (3 dB) compared to an isotropic antenna would be written as 3 dBi. Here dBi means that the directivity D is measured compared to an isotropic antenna. The resonant half-wave dipole can be a useful standard for comparing to other antennas at one frequency or over a very narrow band of frequencies. To compare the dipole to an antenna over a range of frequencies requires an adjustable dipole or a number of dipoles of different lengths. An antenna gain of 1 (0 dB) compared to a dipole antenna would be written as 0 dBd. dBd is used when the directivity is referring to the directivity of a dipole antenna. Gain can be obtained by using Equation 2.3 [18]:

$$G = \eta \times D \qquad (2.3)$$

Where,

η = efficiency

D = directivity

2.6.4 Half Power Beam width

In plane containing the direction of the maximum of a beam, the angle between the directions in which the radiation intensity is one half the maximum value of the beam. In this design, the Azimuth must be <100 and the Zenith <100.

2.6.5 VSWR

The VSWR (ratio of maximum voltage to the minimum voltage along the line) expresses the degree of match between the transmission line and the antenna. When the VSWR is 1 to 1 (1:1) the match is perfect and all the energy is transferred to the antenna prior to be radiated [18]. By definition VSWR can never be less than 1.

2.6.6 Efficiency

Efficiency is used to expresses the ratio of the total power radiated by an antenna (and the power dissipated in the antenna structure as heat) to the net power accepted by the antenna from the connected transmitter.

2.6.7 Bandwidth

The bandwidth of the patch is defined as the frequency range over which it is matched with that of the feed line within specified limits. In other words, the frequency range over which the antenna will perform satisfactorily. The bandwidth of the antenna is usually defined by the acceptable standing wave ratio (SWR) value over the concerned frequency range. To calculate bandwidth, 1.5:1 ratio will be used. Bandwidth can be defined as:

$\mathrm{Bandwidth} = \frac{\mathrm{SWR}-1}{\mathrm{Q}\sqrt{\mathrm{SWR}}}$: Where Q is the quality factor (2.4)

$$\mathrm{VSWR} = \mathrm{S} = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad (2.5)$$

And

$$\Gamma = \frac{V^-}{V^+} = \frac{ZL-Z0}{ZL+Z0} \tag{2.6}$$

Where Γ = Reflection Coefficient

2.7 Feeding Techniques

Antennas have radiating element on upper side of a dielectric substrate. To make it radiate properly the accurate feeding is a compulsion. Since the accurate feeding of any radiating element plays vital role in maximal power transfer from source to the radiating element resulting in the lower efficiency of antenna under observation. The point of feeding, and length or width of the feed-line should be adjusted by optimization process.

2.7.1 Coaxial Probe Feed

Coaxial probe feeding is a specific feeding technique in which the radiating element is fed by the direct connection of an inner conductor of the coaxial cable. The substrate cylinder of the cable is exposed to the substrate designed and the outer most shielding is connected directly to the ground. In case of coaxial feed, a hole equal to the size of the substrate cylinder is made inside the substrate material through which the inner conductor and substrate cylinders are passed. Then from the other end of the cable, the input power is delivered to excite the antenna. This feeding technique is taken as the most accepted one because by using this technique, relatively higher bandwidth can be achieved.

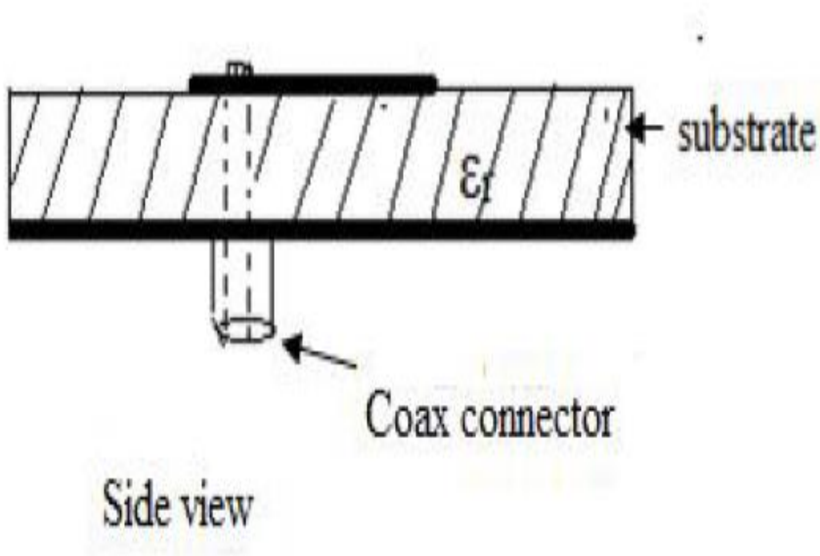

Figure 2.16: Coaxial Probe Feed

2.7.2 Microstrip Feed

The excitation of microstrip antenna by microstrip line appears to be quite sophisticated and seems natural because by using this feeding method both the patch antenna and the feed-line can be fabricated simultaneously. When a microstrip line is excited by an electrical signal, it starts acting as a radiating element itself and thus these radiations couple with the radiations of patch. This mutual coupling let the antenna to behave in another mode instead of its actual design mode. This phenomenon disrupts the impedance matching of the source and load and thus results in a narrower bandwidth.

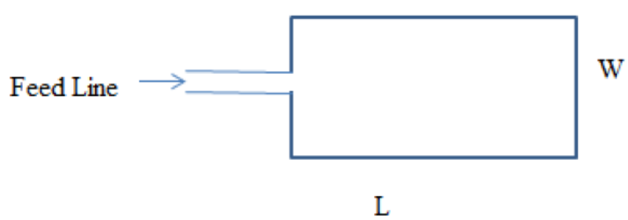

Figure 2.17: Microstrip Feed

2.7.3 Electromagnetically Coupled Microstrip Feed

This feeding method is the non-contacting feeding method. In this technique the patch antenna is electromagnetically coupled with the radiations emitting from the microstrip feed line in the lower substrate. Basically in this method, the patch antenna is placed on an upper substrate and on the lower substrate the microstrip line is placed with an open end. The first end of the underneath lying microstrip line is fed by electrical signal. The radiations emitting from this feed-line cast their effect on the upper lying patch which couples with the incoming radiations and starts radiating. The coupling between microstrip and patch is capacitive in nature. This method is excellent to achieve relatively larger bandwidth. For this feeding method the microstrip feed-line should be placed on a thinner lower substrate. However this requires high level of accuracy and is more complex during its fabrication process.

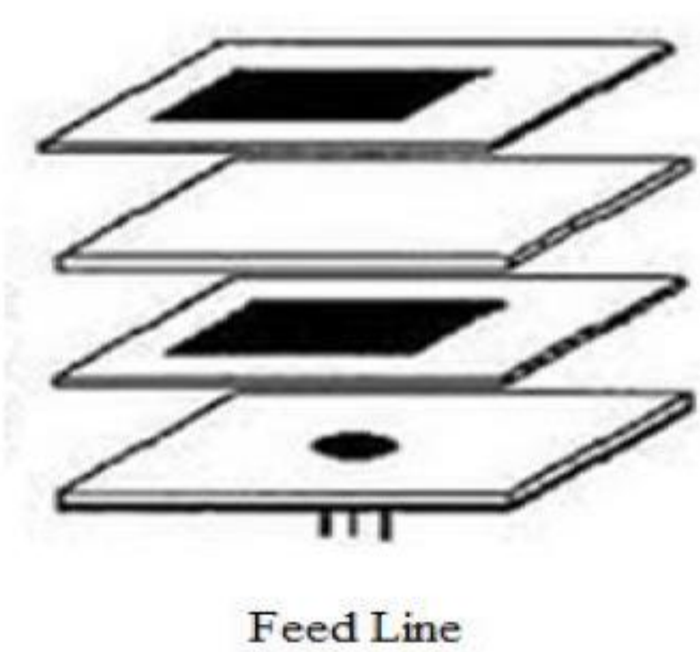

Figure 2.18: Electromagnetically coupled microstrip feed

2.7.4 Aperture Coupled Microstrip Feed

This feeding method provides dramatically wider bandwidth and provides a good shielding to the radiating patch from the radiation emitting from the feed structure. In this technique a common ground is used to separate two substrates placed back to back. A microstrip line is electromagnetically coupled to the patch through a slot in common ground. The slot shape and size can vary and is used to improve the bandwidth. To optimize the feed and the radiation functions, the substrate parameters are chosen independently. The radiations from the open end of the feed-line do not interfere with the radiating patch because of the shielding effect of common ground. Due to the non-disruption of the radiation functions, the polarization purity is guaranteed in this feeding method.

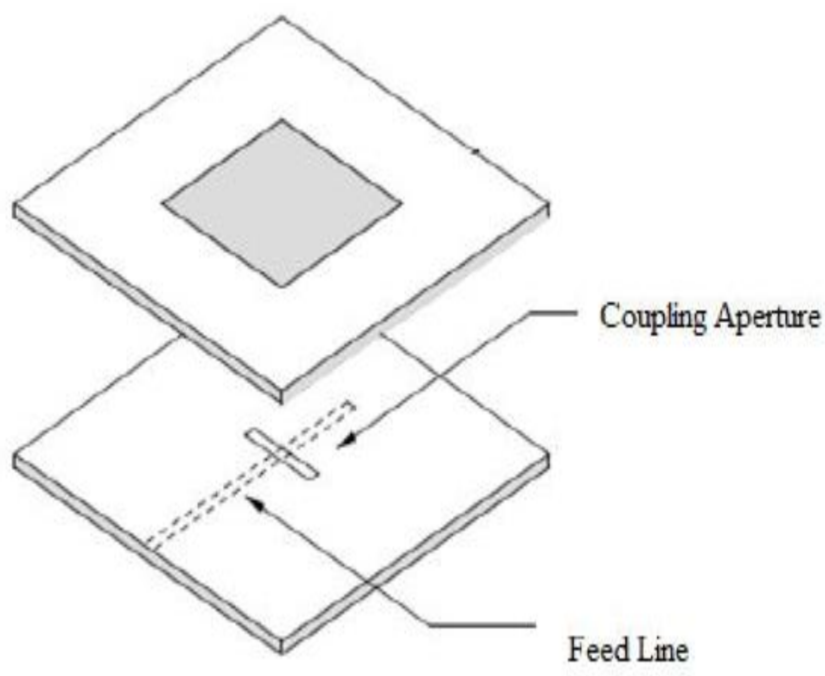

Figure 2.19: Aperture Coupled Micro-strip Feed

2.7.5 Coplanar Waveguide Feeding

In this feeding method two ground planes are placed on both sides of the feeding which are on the top of the dielectric medium; the ground planes and connectors are all on the same plane that is called CPW feeding. An advantage of a CPW feed is that the radiation from the feed structure is negligible because the coplanar waveguide is excited in the odd mode of the coupled slot line. Due to this mode the equivalent magnetic current on both CPW slots radiate almost out of phase, contributing negligibly to the feed radiation thus purity in the polarization is promised.

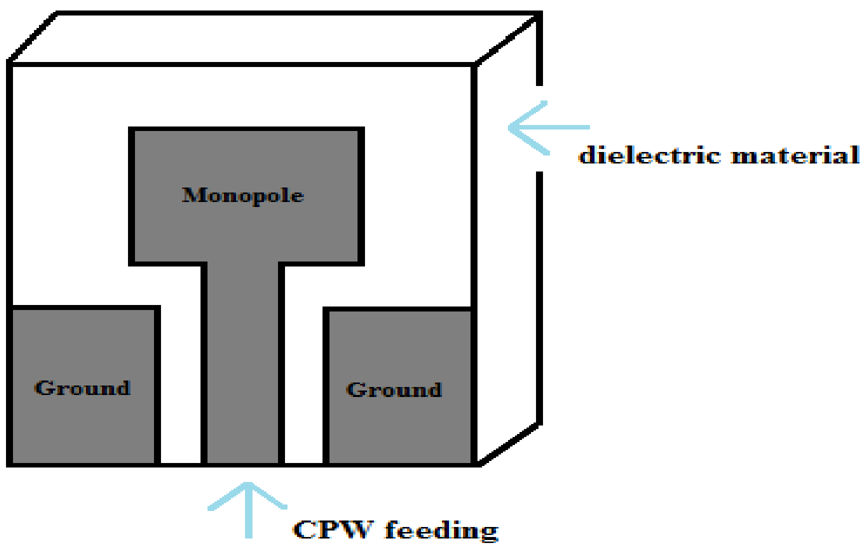

Figure 2.20: CPW Feeding Technique

CHAPTER 3

DESIGN AND ANALYSIS OF EBG STRUCTURE

3.1 Introduction

There are no exact analytical formulas that relate the structural parameters of the EBG structures to the frequency stop band. Therefore, our goal here is to determine the effect of varying the EBG parameters on the width of the bandgap and its lower and upper frequency limits based on direct numerical simulation using CST MWS. There are some ways to analysis these structures as describe below:

Band gap property (1) Dispersion analysis (2) Trasssmission coficient

Reflection phase property (1) Wave guide method

3.2 Spiral EBG Design

The mushroom-like electromagnetic band gap (EBG) structure printed on the one side of the FR4 lossy substrate and the ground plane is located on the other side of the substrate with bias ground. Front view and side view of the proposed configuration are shown in figure 3.1 and 3.2. The proposed design of mushroom-like electromagnetic band gap structure is constructed in rectangular spiral shape as shown in table 1.

Table 3.1: Dimensions of spiral EBG structure

Layer	Ground	Substrate	Strip1	Strip2	Wire
Material	PEC	FR-4(lossy)	PEC	PEC	PEC
Dimension (mm)	20×20	20×20	2×4	As show in figure.1	h=1.676 r=.1

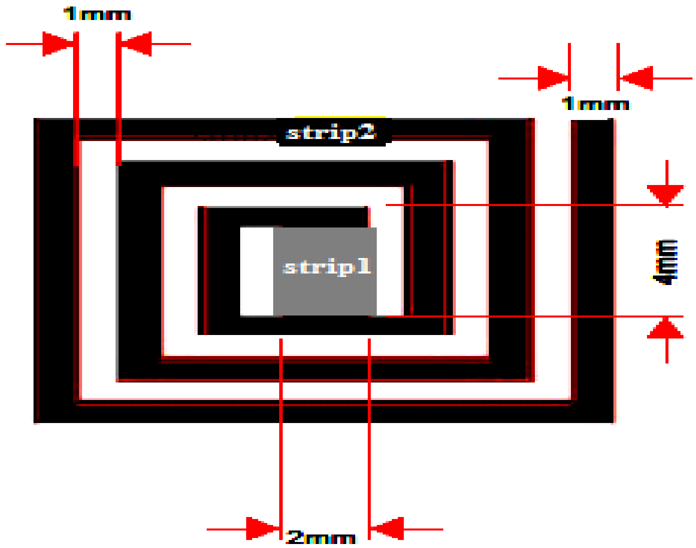

Figure 3.1: Front view of EBG unit cell

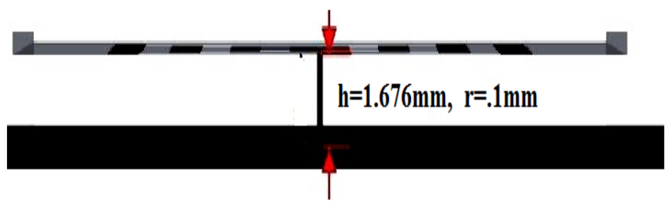

Figure 3.2: Side view of EBG unit cell

3.2.1 Dispersion Analysis

The frequency band gap of EBGs is directly related to the geometrical parameters and material parameters of the host medium. The band gap is specified by extracting the dispersion diagram which describes the propagation characteristics of an infinitely periodic structure composed of EBG patches as describe in chapter 2. Dispersion diagram is numerically extracted using full wave by considering unit cell and applying periodic boundary condition (PBC) on the sides of the cell and electric boundary condition at the top and bottom of the unit cell as shown in Figure 3.3. Parameter sweep analysis setup is shown in figure 3.4.

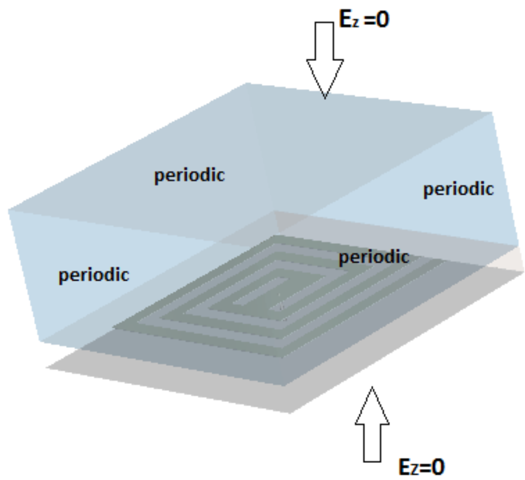

Figure 3.3: Boundary Condition

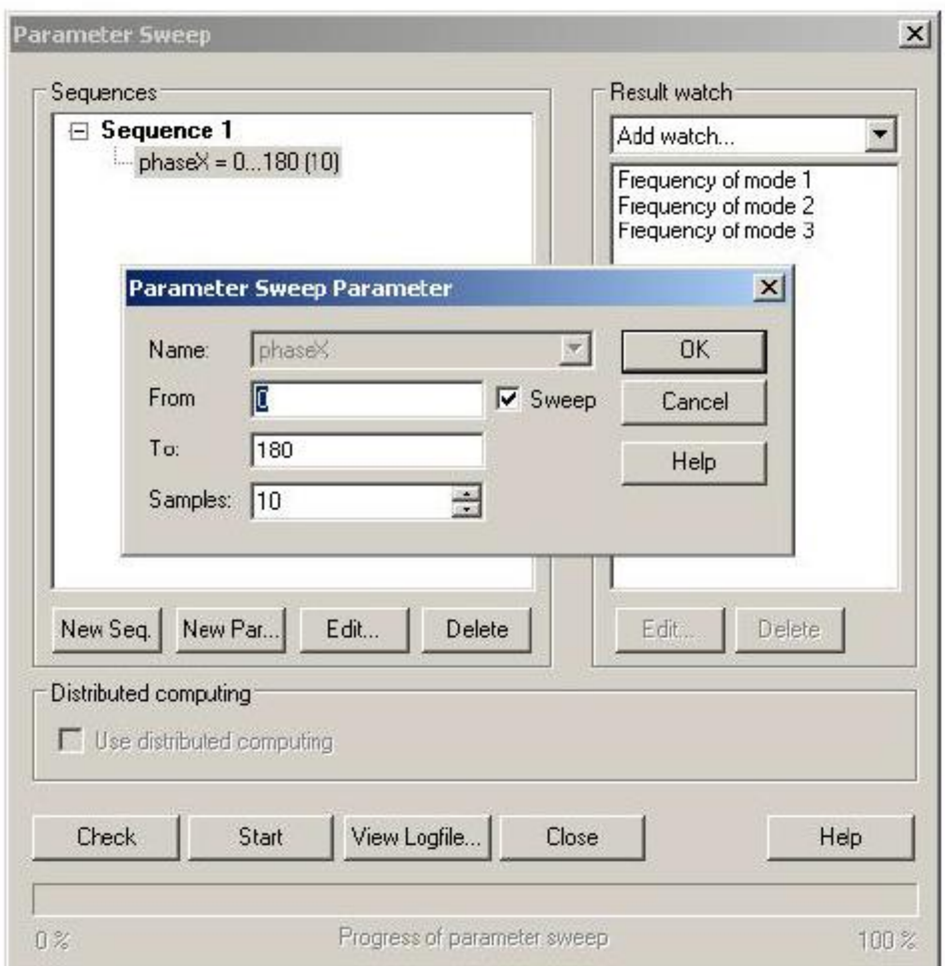

Figure 3.4: Parameter sweep analysis setup

A structure with a forbidden frequency band (no electromagnetic wave propagation is possible), can be fully characterized by its dispersion diagram. The dispersion diagram is a graphical representation of the wave vector in dependence on frequency and gives us information about the position of pass-bands and stop-bands in the frequency spectrum.

According to that theory, a dispersion diagram consist of three regions[4]. To characterize the behavior of the wave as it propagates through the structure, we assume a propagation constant of $k = k_x x + k_y y$. The computational domain and the boundary setup for extracting the dispersion diagram for the EBG unit cell are shown in Figure 3.3. three parameter sweep has been assign for complete modeling of dispersion diagram as shown in table 3.2

Table 3.2: Parameter of three region of dispersion

	Γ ⇨ X	X ⇨ M	M ⇨ Γ
P_x	0 to 180deg	0 to 180deg	0 to 180deg
P_y	0deg	180drg	0 to 180deg

3.2.2 Dispersion result

Mushroom-like electromagnetic band gap (EBG) structure is simulated according to the theory of Brillouin zone of three region as described in table 2. Simulation is done with eigenmode solver of CST Microsoft studio10. Dispersion result of each region shows 7.5GHz band gap (from 7.49GHz to14.94GHz) is shown in figure 3.5, figure 3.6 and figure

3.7. Dispersion result of first region is shown in figure 3.6, which shows 7.5GHz wide band between the mode 2 and mode 3.

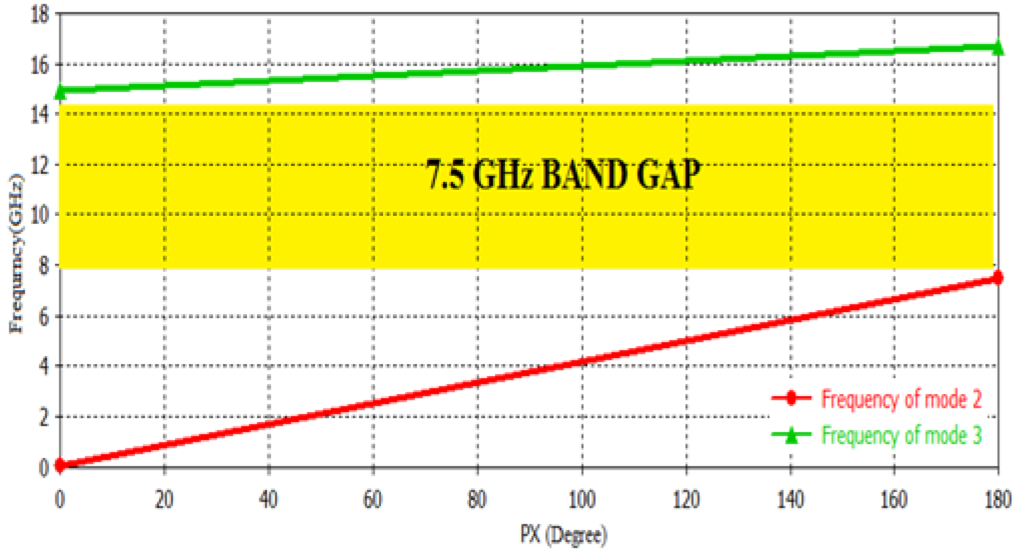

Figure 3.5: Dispersion analysis result for ⌈ to X sweep of Brillouin zone

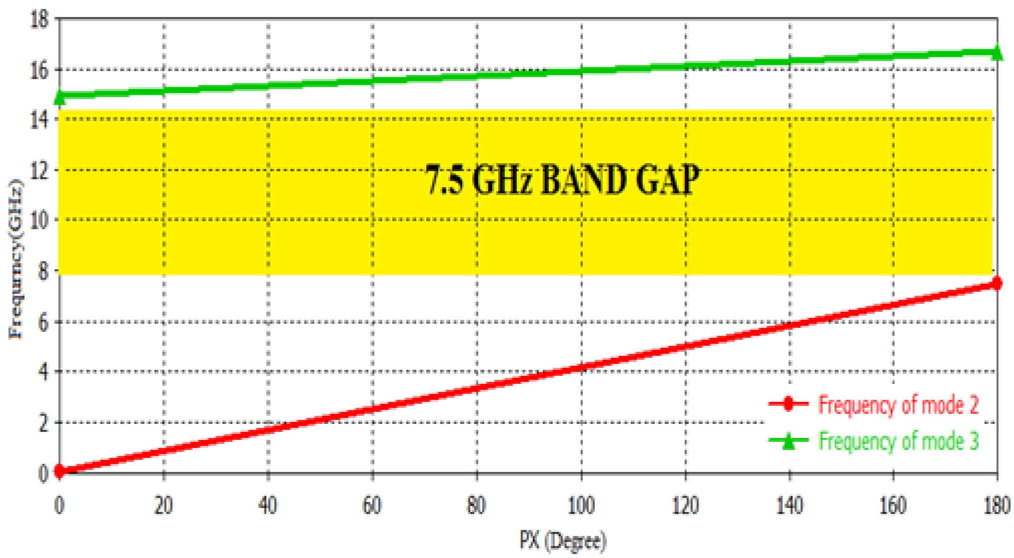

Figure 3.6: Dispersion analysis result for X to M sweep of Brillouin zone

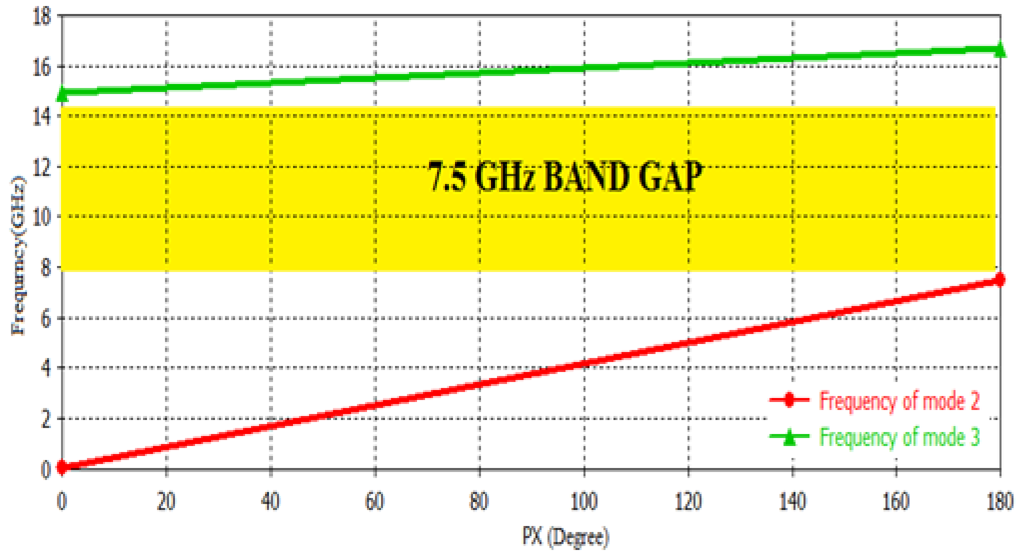

Figure 3.7: Dispersion analysis result for M to ɼ sweep of Brillouin zone

3.3 Band Gap Measurement through Transmission Coefficient (S21)

3.3.1 Microstrip line EBG Ground plane

To analyze the bandgap characteristics of the proposed EBG structure, the suspended microstrip line method [5] is used, as shown in Figure 3.5. In contrast to the classical microstrip the suspended microstrip structure shows strong coupling nature and eliminates the effect of parasitic propagation, which helps to achieve the desired characteristics . The EBG structure is built on a commonly available, inexpensive, 1.6mm thick FR4 substrate with a relative permittivity of 4.4 and a tangent loss of 0.0027. A thin microstrip line of 2.4mm with 50 ohm characteristic impedance is printed on the opposite layer of the dielectric material and connected with two waveguide port on both sides of the micro strip to measure the transmission characteristics.

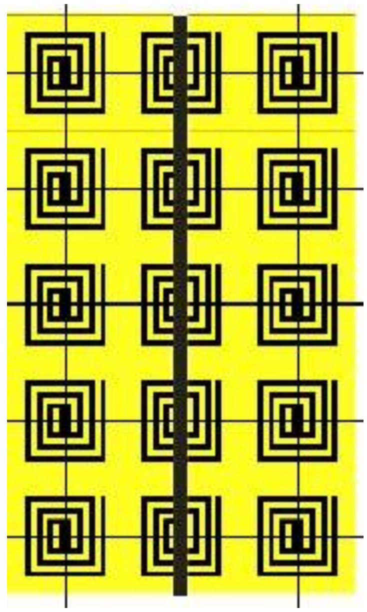

Figure 3.8: 5×3Array of proposed unit cell with microstripline

3.3.2 Micro Strip Line Result

To verify the accuracy of the Dispersion diagram bandgap, a microstrip line method is used [5-6]. A 3× 5 array of the EBG cell, which is mounted on a grounded dielectric slab, is connected with 50- micro strip lines at both ends. This array acts as a filter in which the transmission coefficient *S*21 of the structure used to determine the frequency ranges of the band gap. The band gap bandwidth defined with *S*21 is below-20 dB. Simulated S- parameter result of micro strip line with EBG ground plane is shown in Figure 3.9. In this result transmission coefficient S21 of micro strip line (without EBG) denote attenuate while same structure simulated with EBG ground plane instead of PEC ground, shows high attenuation in the wide band range. It maximum attenuate up to -88db at 10.13 GHz.

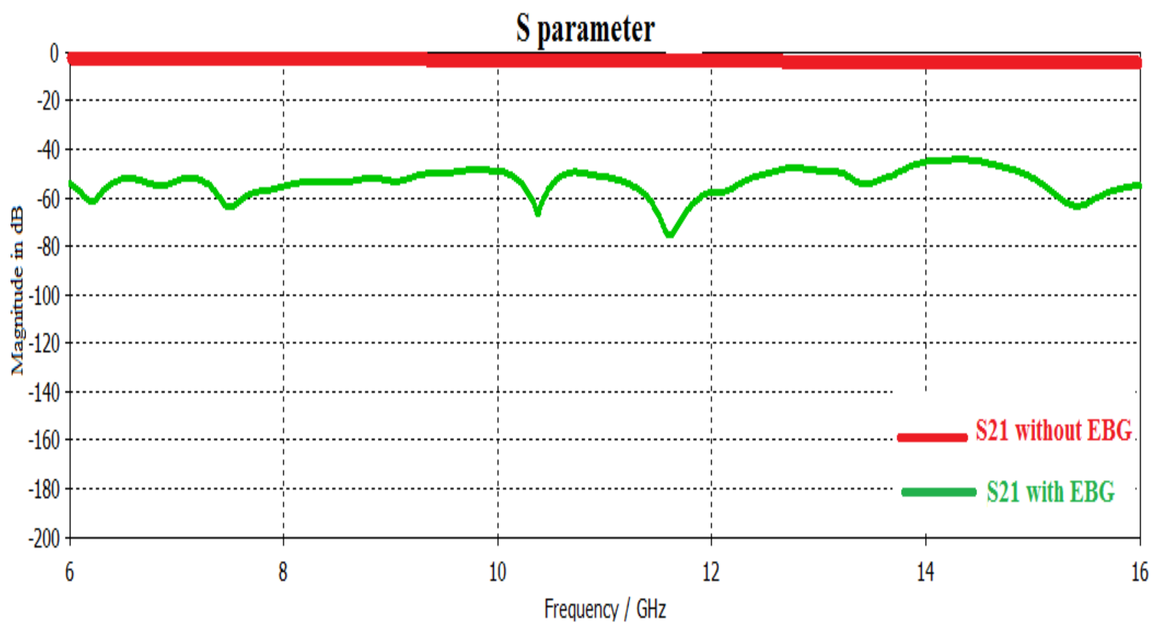

Figure 3.9: Comparison of transmission coefficient

3.4 Square EBG Design

The mushroom-like electromagnetic band gap (EBG) structure printed on the one side of the FR4 lossy substrate and the ground plane is located on the other side of the substrate with bias ground. The proposed design of mushroom-like electromagnetic band gap structure is constructed in alternative square shape with symmetric slot as shown in Figure 3.10 and Figure 3.11. Dimension of proposed structure in presented in Table1.

Table 3.3

Dimensions of spiral EBG layers

Layer	Ground	Substrate	Cylinder	Slots
Material	PEC	FR-4 (lossy)	PEC	vacuum
Dimension (mm)	7.5×7.5	7.5×7.5	h=1.676 r=.1	As show in Figure 3

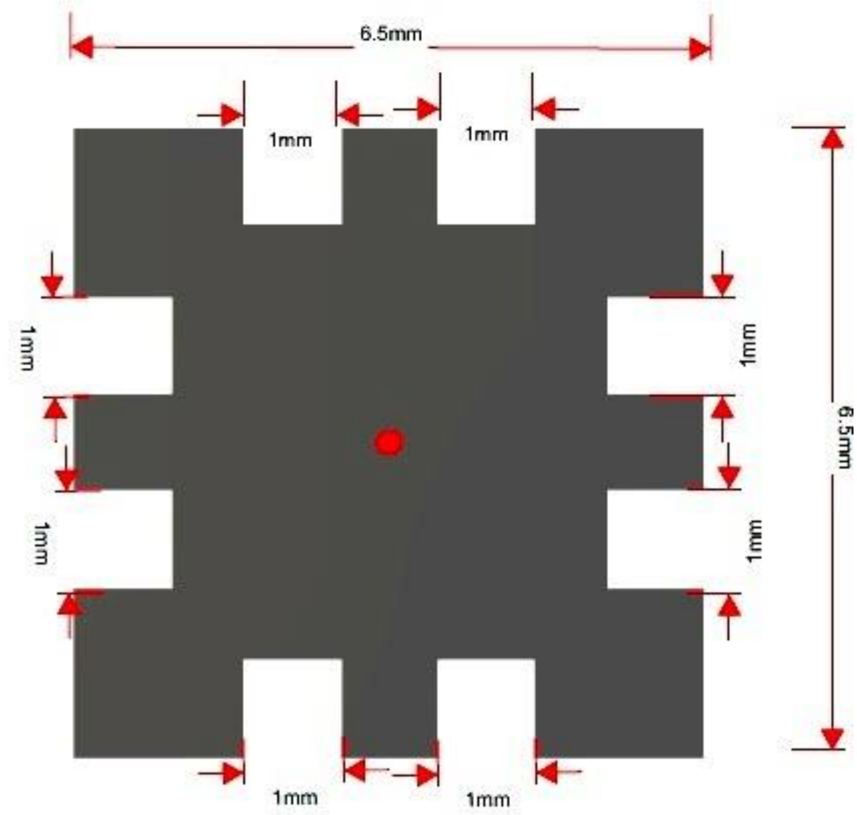

Figure 3.10: Front view of EBG unit cell

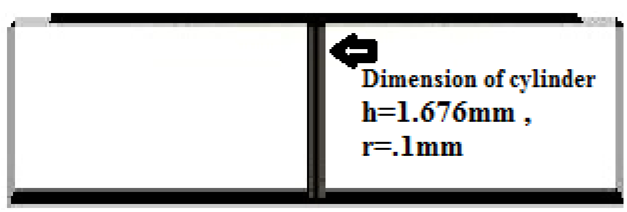

Figure 3.11: Side view of EBG unit cell

3.4.1 Band Gap Analysis

The frequency band gap of EBGs is directly related to the geometrical parameters and material parameters of the host medium. The band gap is specified by magnitude of transmission coefficient (S21) using full wave simulator CST MWS, which describes the propagation characteristics of an EBG structure. Performance of 2×4 EBG array has been investigated by two port method [1] as shown in Figure 3.12. Band gap of 2×4 EBG array is simulated by introducing port on each side of EBG array. Proposed array exhibit two band gap region as shown in Figure 3.12. First band gap region (BG1) spread over the frequency range 0 – 4 GHz and second band gap region spread over the frequency range 7.2 - 11.2 GHz. Due to above characteristics proposed array is also referred as dual band EBG array. Band gap result of 2×4 EBG array is shown in figure 3.13.

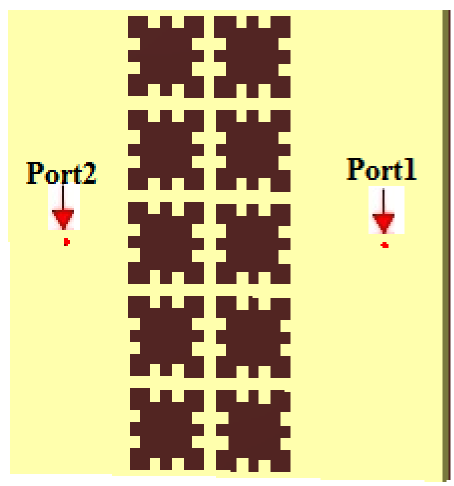

Figure 3.12: Band gap measurement set up

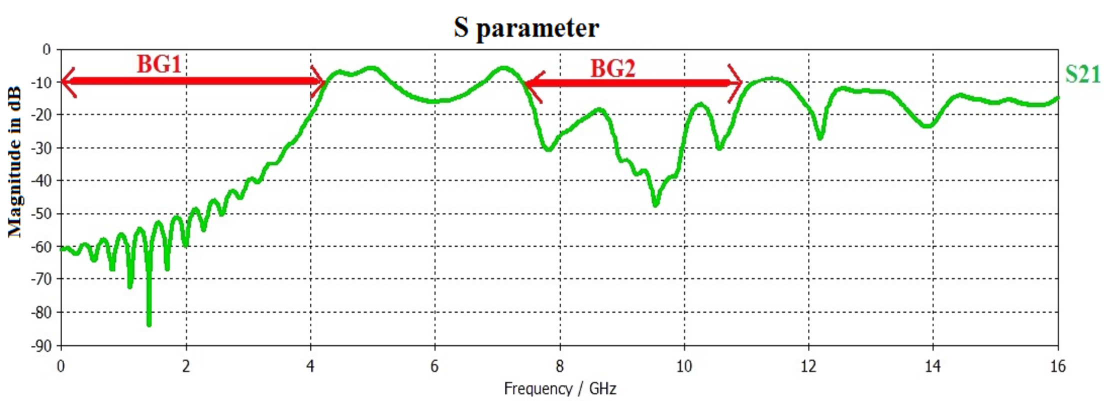

Figure 3.13: Band gap result of 2×4 EBG array

3.4.2 Reflection Phase Analysis

The reflection properties of a structure can be obtained by computing its reflection diagram, which is the graphical representation of the frequency dependence of the phase shift between the incident and reflected wave. The commercial finite difference time domain (FDTD) solver CST Microwave Studio (CST MWS) is used for reflection phase computation of the considered structures. In order to measure the reflection phase of unit cell , waveguide port with Perfect Electric and Perfect Magnetic boundary conditions on the opposite side walls of unit cell is used to simulate plane wave incidence. Boundary condition for reflection phase measurement is shown in figure 3.14. Boundary condition representation on CST and deembeding (to shift the reference plane of wave guide port) of wave guide port are shown in figure 3.15 and figure 3.16.

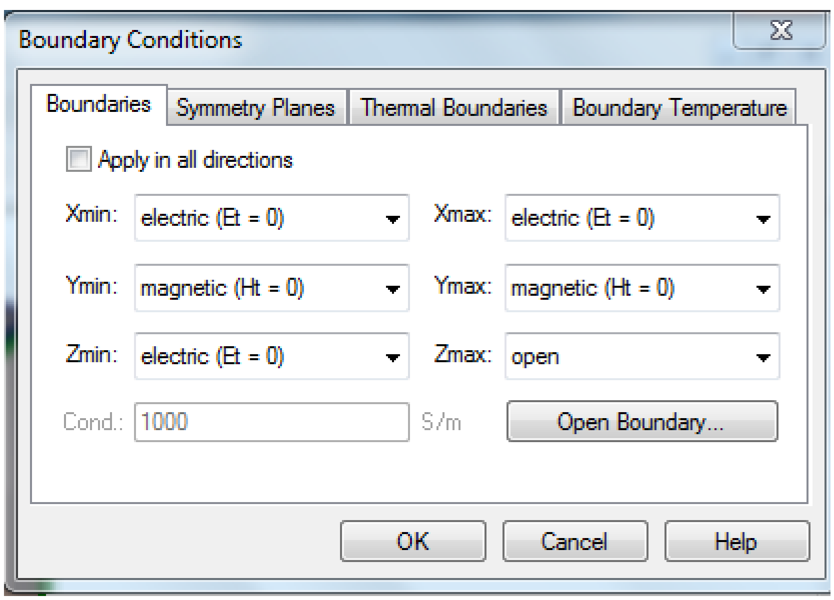

Figure 3.14: Boundary condition for reflection phase measurement

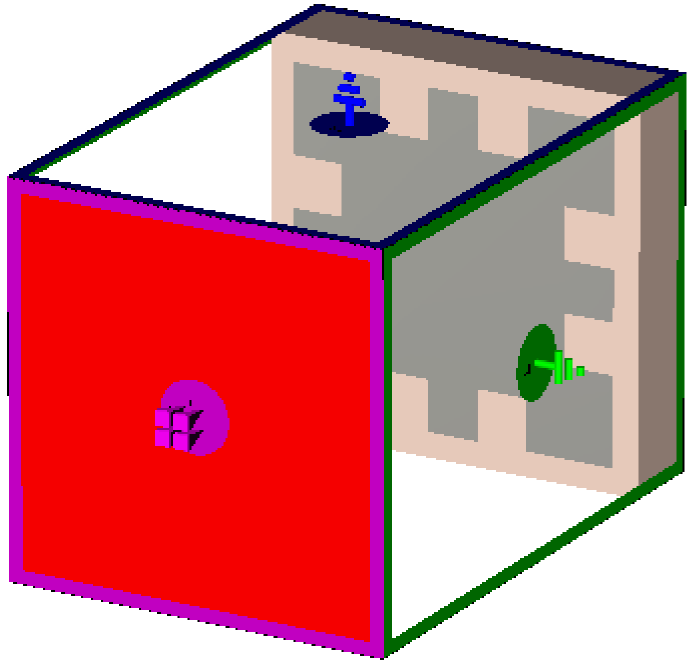

Figure 3.15: Boundary condition representation on CST

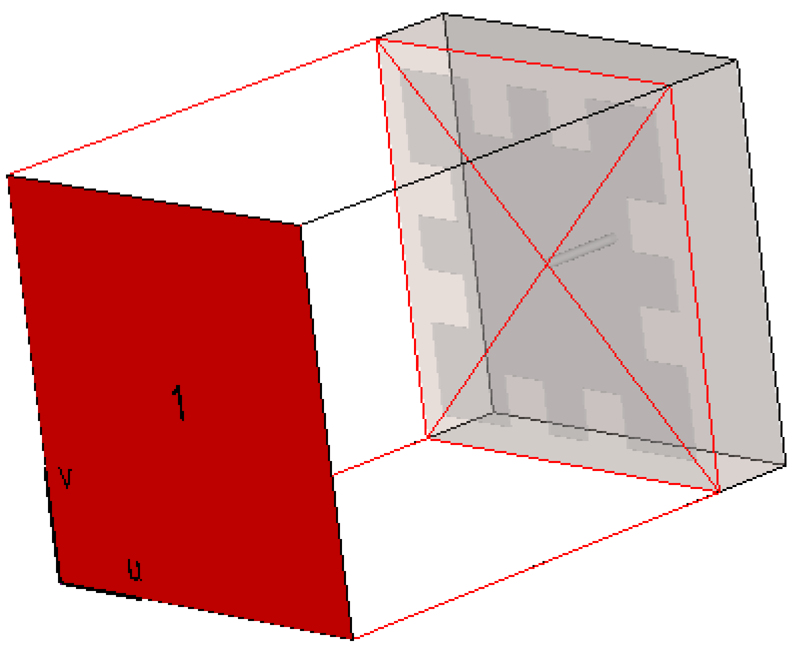

Figure 3.16: Deembeding of wave guide port

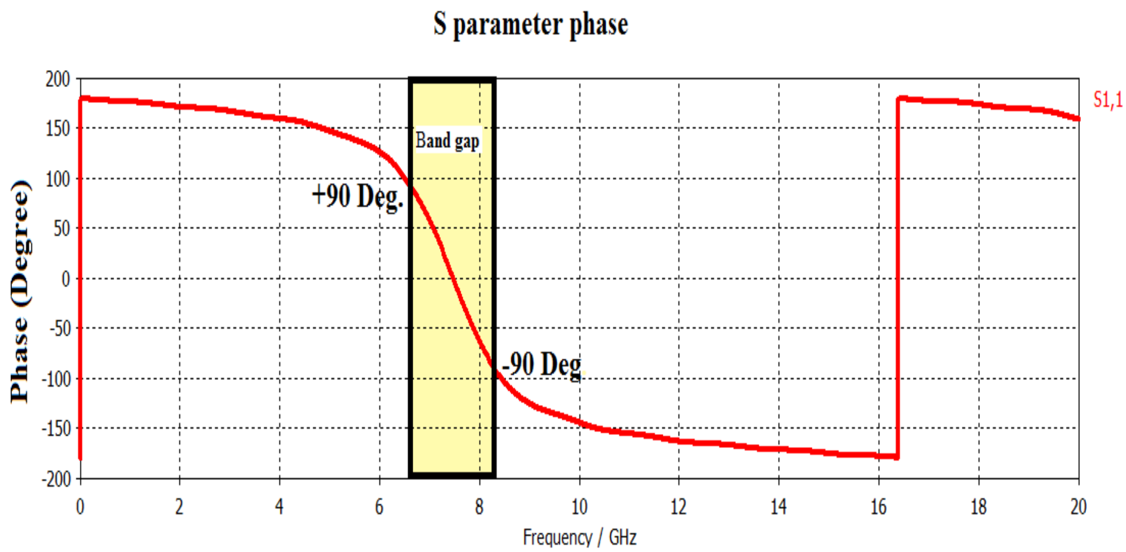

Figure 3.17: Reflection phase result of EBG structure

3.4.3 Result

As can be seen from figure 3.17 the reflection coefficient phase of AMC surface varies with frequency from +180° to -180°. At low and high frequencies the EBG surface exhibits a phase similar to a PEC that is 180 °. For this design the reflection coefficient phase crosses zero degrees at 7.5GHz which is the AMC resonant frequency. The useful bandwidth of an AMC surface has been defined as the range ±90°. Proposed EBG design gives 6.6GHz to 8.3GHz AMC band width within range of $+90^0$ to -90^0 . The usefulness criteria is that within this bandwidth the reflected wave is more in phase than out of phase with the incident wave (constructive for radiating elements in the interface). Outside this frequency range the reflected waves are mostly out of phase with the incident waves and from the known literature survey it has no useful applications for antenna and microwave devices.

3.5 Conclusion

Two design of mushroom like EBG structure has been analysised in this dissertation. First design of EBG structure is constructed in spiral shap which shows the 7.5 GHz wide band gap to confine the surface wave. But this structure do not shows the reflection phase characteristics. Second design of EBG structure in square shape with alternative square slot, which shows two band gap to confine the surface wave and reflection phase characteristics. First band gap occurs in 0 to 4 GHz and second band gap occurs in the range of 7.2Ghz to 11.2GHz. Both band gap confine surface wave in their region. These band gap highly attenuate electromagnetic wave in their band gap region. Reflection phase property of second EBG design has been analysised, which gives zero phase crossing frequency in 7.5GHz. and produces 1.7GHz band (6.6 GHz to 8.3GHz) . Proposed EBG design act as artificial magnetic conductor and produce constructive interference between incident and reflected wave in their band.

CHAPTER 4

ANTENNA DESIGN WITH EBG STRUCTURE

4.1 Introduction

The conventional half-wavelength size is relatively large in modern portable communication devices. Various approaches have been proposed, such as using shorting pins, cutting slots, and designing meandering microstrip lines. Increasing the dielectric constant of the substrate is also a simple and effective way in reducing the antenna size. Applications of MPAs on high dielectric constant substrate are of growing interest due to their compact size and conformability with monolithic microwave integrated circuits (MMIC). However, there are several drawbacks with the use of high dielectric constant substrate, namely, narrow bandwidth, low radiation efficiency, and poor radiation patterns, which result from strong surface waves excited in the substrate. The narrow bandwidth can be expanded by increasing the substrate thickness, which, however, will launch stronger surface waves. As a result, the radiation efficiency and patterns of the antenna are further degraded. To overcome the drawbacks of using the thick and high dielectric constant substrate, several methods have been proposed to manipulate the antenna substrate.

4.2 Microstrip Parch Antenna Design at 2.0 GHz

Formulae for designing microstip patch antenna is given below.

The resonance frequency for the (1, 0) mode is given by

$$f_o = \frac{C}{2Le\,\sqrt{\varepsilon_r}} \tag{4.1}$$

Where, C is the speed of light in vacuum. To account for the fringing of the cavity fields at the edges of the patch, the length, the effective length Le is chosen as:

$$Le = L + 2\Delta L \quad (4.2)$$

The Hammerstad formula for the fringing extension is

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{eff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+0.8\right)} \quad (4.3)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{W}}}\right) \quad (4.4)$$

Width of metallic patch (w)

$$w = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (4.5)$$

Where,

ε_{reff} = Effective dielectric constant,

ε_r= Dielectric constant of substrate,

h = Height of dielectric substrate and

w = Width of the patch

Table: 4.1

Rectangular Microstrip Patch Antenna Specifications for design I

	Dimensions	Unit
Dielectric Constant (ε_r)	4.3	-
Loss Tangent ($\tan\partial$)	0.02	-
Thickness (h)	1.6	mm
Operating Frequency	1.96	GHz
Length (L)	35.4	mm
Width (W)	45.6	mm
Cut Width	5	mm
Cut Depth	8.5	mm
Path Length	28.8	mm
Width Of Feed	2.4	mm

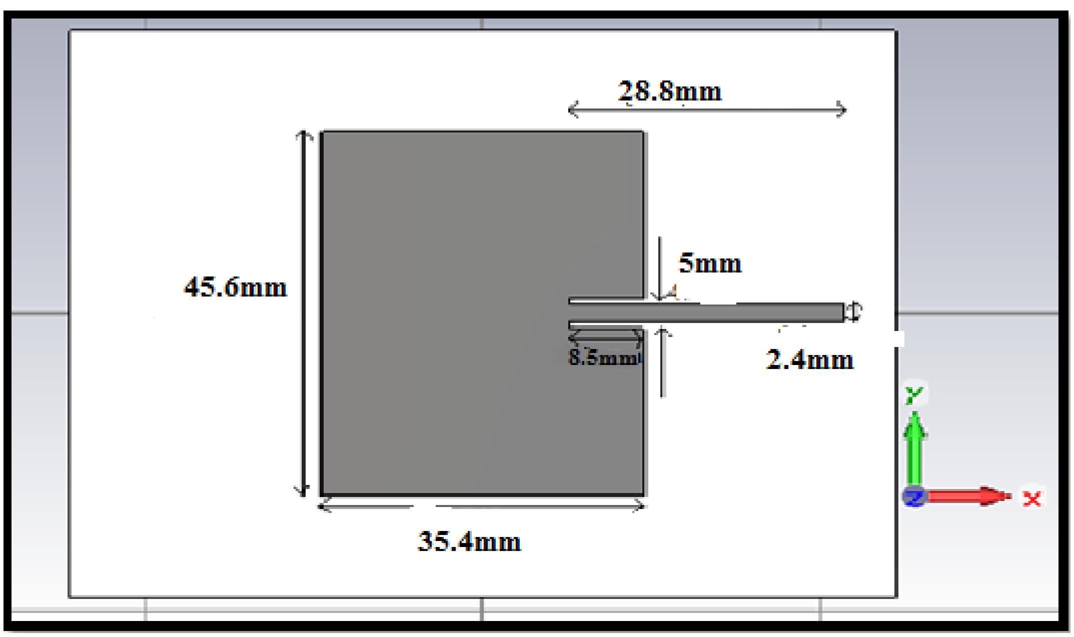

Figure 4.1: Front view of micro strip patch antenna

Result

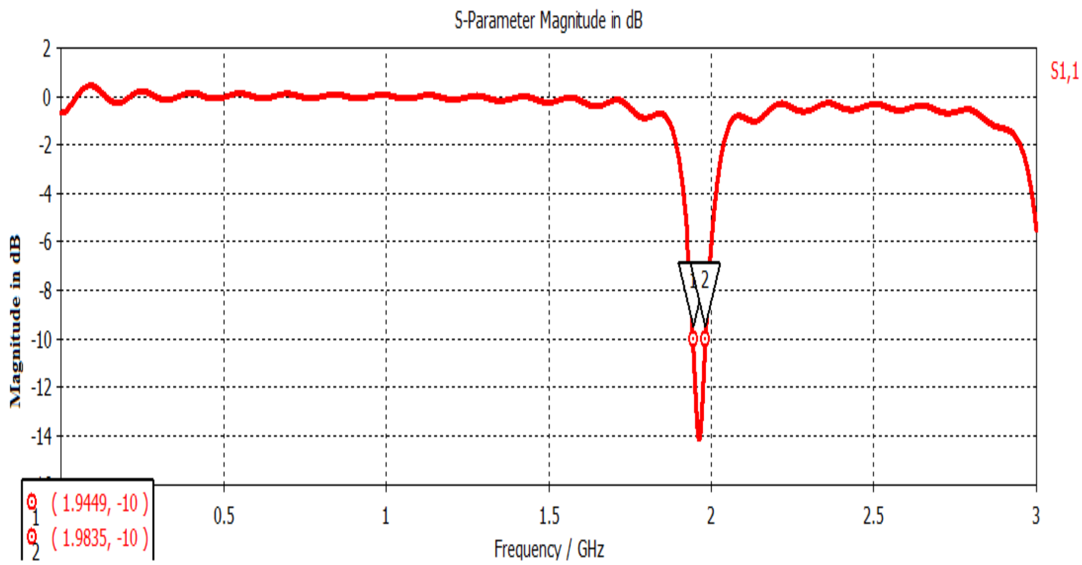

Figure 4.2: Return loss of simple microstrip antenna

4.3 Surface wave

Surface waves are excited on microstrip antenna when the substrate ϵr > 1. Besides end radiation, surface waves give rise to coupling between various elements of an antenna. Surface waves are launched into the substrate at an elevation angle θ lying between π / 2 and sin-1 ($1/\sqrt{\epsilon r}$). These waves are incident on the ground plane at this angle, get the reflected from there, then meet the dielectric-air interface, which also reflect them. Following this zig-zag path, they finally reach the boundaries of the microstrip structure where they are reflected back and diffracted by the edges giving rise to end-fire radiation . On other way in the boundary, if there is any other antenna in proximity, the surface wave can become coupled into it. Surface waves will decay as r 1/ ε so that coupling also decreases away from the point of excitation. Surface wave are TM and TE modes of the substrate. These modes are characterized by waves attenuating in the transverse direction (normal to the antenna plane) and having a real propagation constant above the cut-off frequency. The phase velocity of the surface waves is strongly dependent on the substrate parameters h and ϵr. Figure 4.3 shows the propagation of the surface wave in microstrip antenna .

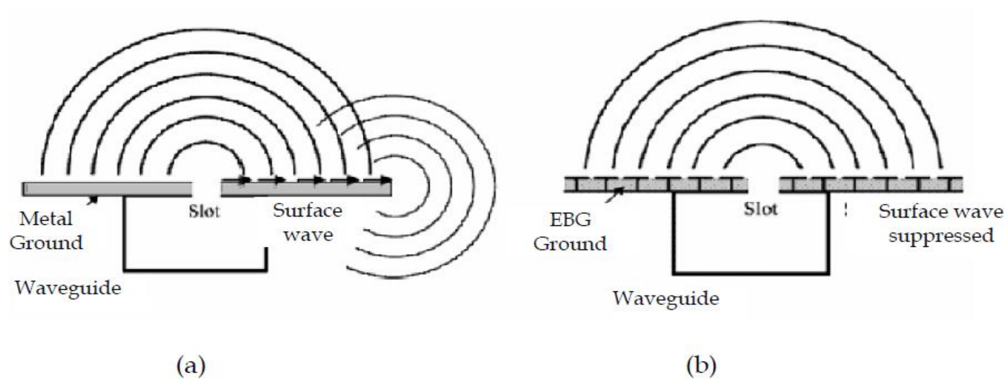

Figure 4.3: (a) The substrate without EBG structure, (b) with EBG structure.

Surface wave propagation is a serious problem in microstrip antennas. It reduces antenna efficiency and gain, limits bandwidth, increases end-fire radiation, increases crosspolarization levels, and limits the applicable frequency range of microstrip antennas. Two solutions to the surface wave problem are available now. One of the approaches is based on the micromachining technology in which part of the substrate beneath the radiating element is removed to realize a low dielectric constant environment for the antenna. In this case the power loss through surface wave excitation is reduced and coupling of power to the space wave is enhanced. The second technique relies on electromagnetic band-gap structure (EBG) engineering. In this case, the substrate is periodically loaded so that the surface wave dispersion diagram presents a forbidden frequency range (stop-band or band-gap) about the antenna operating frequency. Because the surface waves cannot propagate along the substrate, an increase amount of radiating power couples to the space waves. Also, other surface wave coupling effects like mutual coupling between array elements and interference with onboard systems are now absent .

4.4 Designing of patch antenna with EBG substrate

Surface waves are by-products in many antenna designs. It directs electromagnetic wave propagation along the ground plane instead of radiation into free space, consequently reduce the antenna efficiency and return loss. The diffraction of surface waves increases the back lobe radiations, which may deteriorate the signal to noise ratio in wireless communication. To confine the surface wave ,substrate is intregreted with EBG structure as shown in figure 4.4.

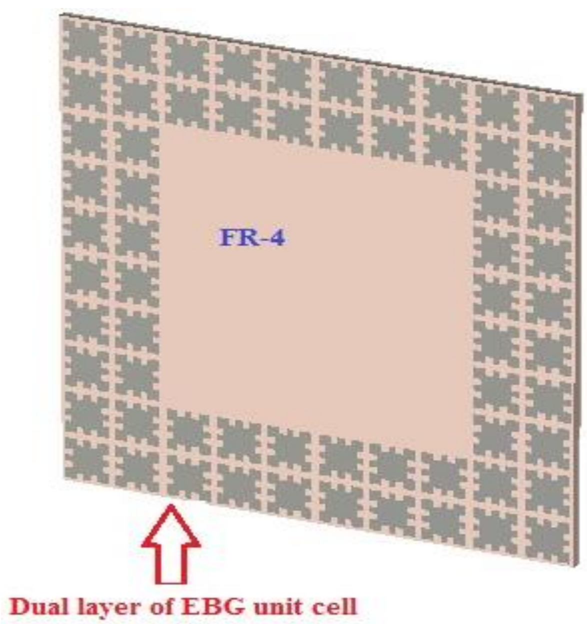

Figure 4.4: FR-4substrate with EBG structure

EBG structure is used to surround a microstrip antenna to increase the return loss and bandwidth as shown in figure 4.5.

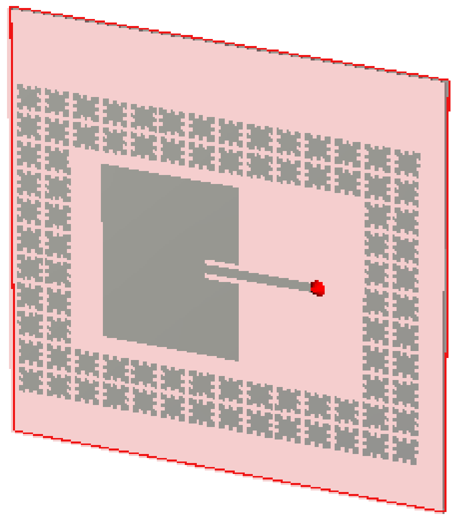

Figure 4.5: Micro strip antenna with EBG structure

Result

Simple micro strip antenna with PEC ground plane and FR4 substrate has been simulated on CST MWS. Return loss and Bandwidth of conventional rectangular micro strip patch antenna is shown in figure 4.2. According to this figure 4.2 , return loss and bandwidth are -14dB & 35MHz respectively. To enhance the characteristics of conventional micro strip antenna, it is surrounding by dual layer of EBG structure as shown in figure 4.5 and simulated . EBG layer provide improvement in return loss and bandwidth as shown in figure 4.6. According to result, return loss reached at -25dB and bandwidth reached at 45MHz.

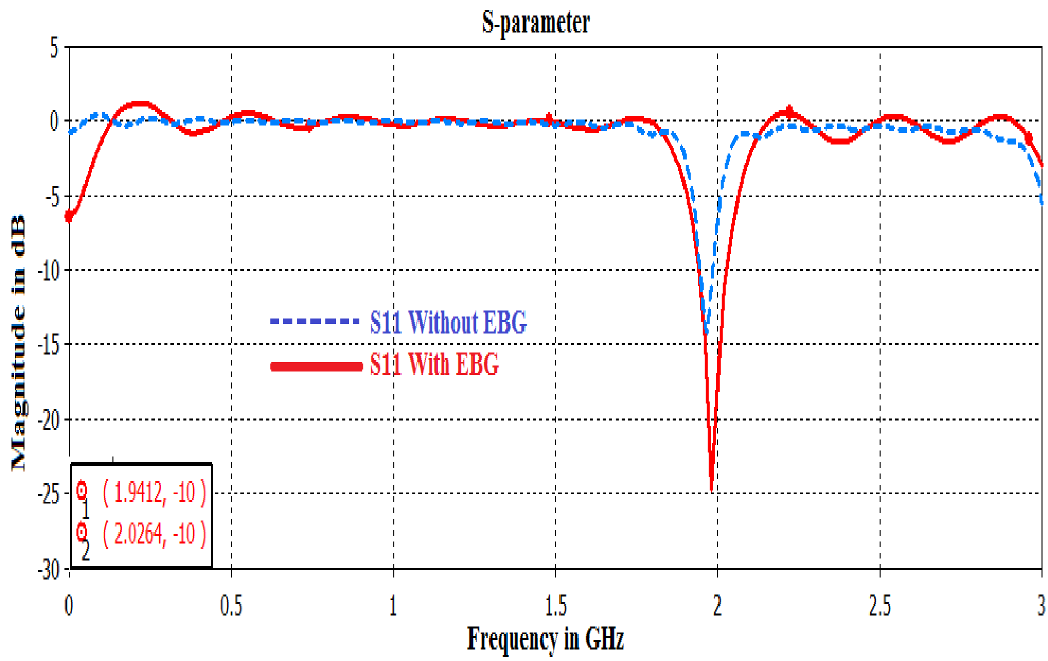

Figure 4.6: Comparison of return loss with and without EBG

4.5 Designing of Patch Antenna with Artificial Magnetic Ground Plane

4.5.1 Design of Simple Microstrip Patch Antenna at 8.0GHz

The Rectangular Microstrip Patch Antenna is designed on FR-4 (Lossy) substrate. According to the formula the parameter specifications of rectangular microstrip patch antenna are mentioned in Table: 4.1.2

Table: 4.2

Rectangular Micro strip Patch Antenna Specifications for design II

Parameters	Dimensions	Unit
Dielectric Constant (ε_r)	4.3	-
Loss Tangent ($\tan\partial$)	0.02	-
Thickness (h)	1.6	mm
Operating Frequency	8.0	GHz
Length (L)	8.37	mm
Width (W)	11.518	mm

Cut Width	5	mm
Cut Depth	8.56	mm
Path Length	8.56	mm
Width Of Feed	1.685	mm

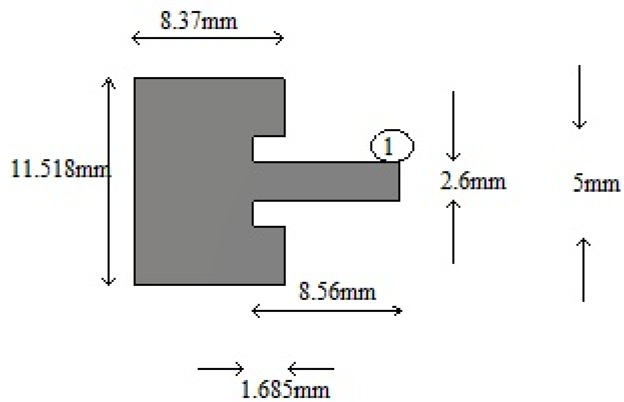

Figure 4.7: front view of micro strip antenna at 8.0 GHz

Result

Simple micro strip antenna with PEC ground plane and FR4 substrate has been simulated on CST MWS. Micro strip antenna resonates at 8.0GHz frequency and return loss reaches at -12dB.

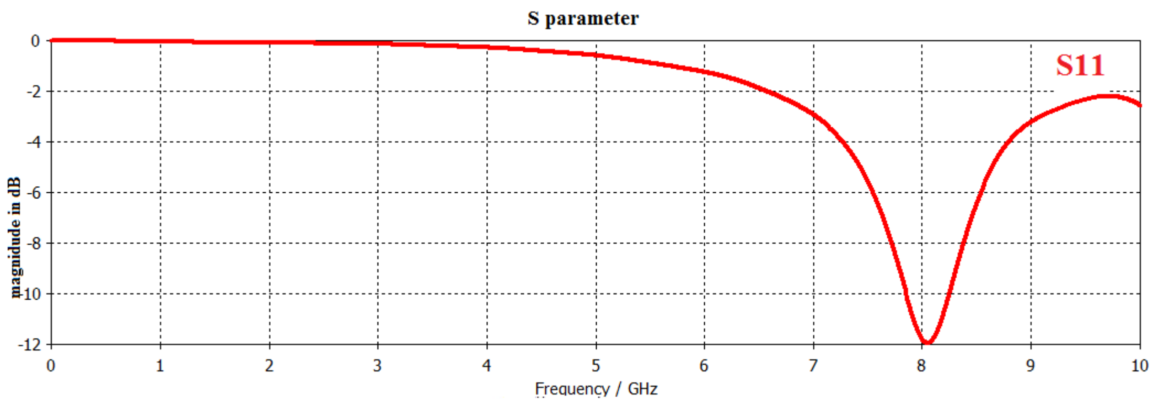

Figure 4.8: Result of return loss of micro strip antenna at 8.0 GHz

4.5.2 Artificial magnetic conductor (AMC) plane

Artificial magnetic ground plane has been constructed with FR-4 substrate over PEC plane.FR-4 substrate is integrated with periodic EBG unit cell as shown in figure4.9.Depending upon substrate Dimension , 3×4 unit cell has been consider in proposed substrate .To avoid the shorting between the EBG unit cell and exiting port , one of the EBG unit cell may remove. In proposed structure, one of the middle EBG unit cell has been removed.

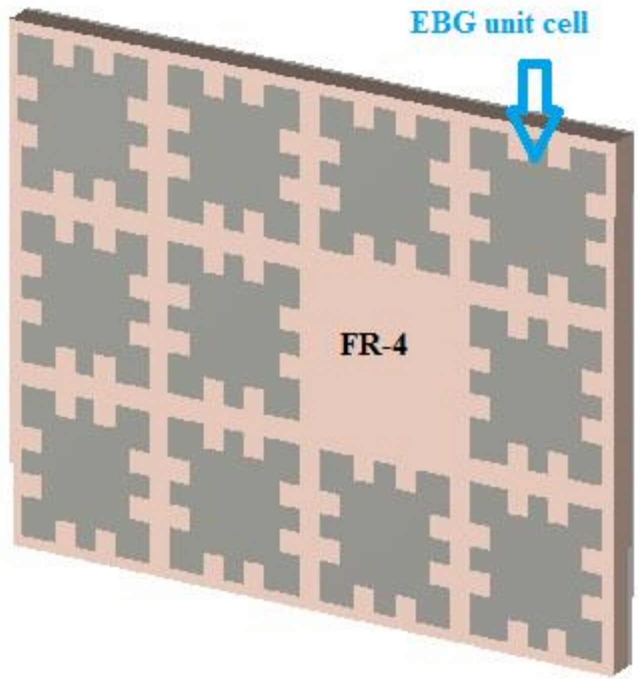

Figure 4.9: Artificial magnetic ground plane

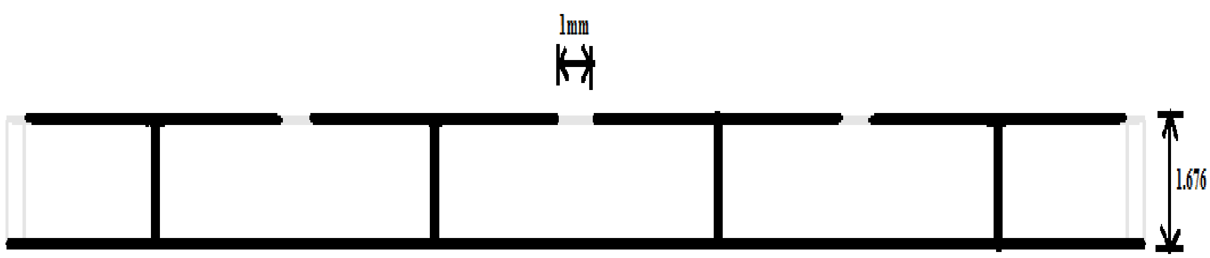

Figure 4.10: Side view of artificial magnetic ground plane

4.5.3 Micro strip antenna over AMC ground plane

Microstrip patch antenna over is constructed as simple microstrip antenna except PEC ground plane replace by artificial magnetic ground plane. Therefore two layer of FR-4 dielectric exist in design. first layer exist in artificial magnetic ground plane and second layer exist over the artificial magnetic ground plane then patch of simple microstip antenna is placed over the second dielectric as shown in Figure 4.11.

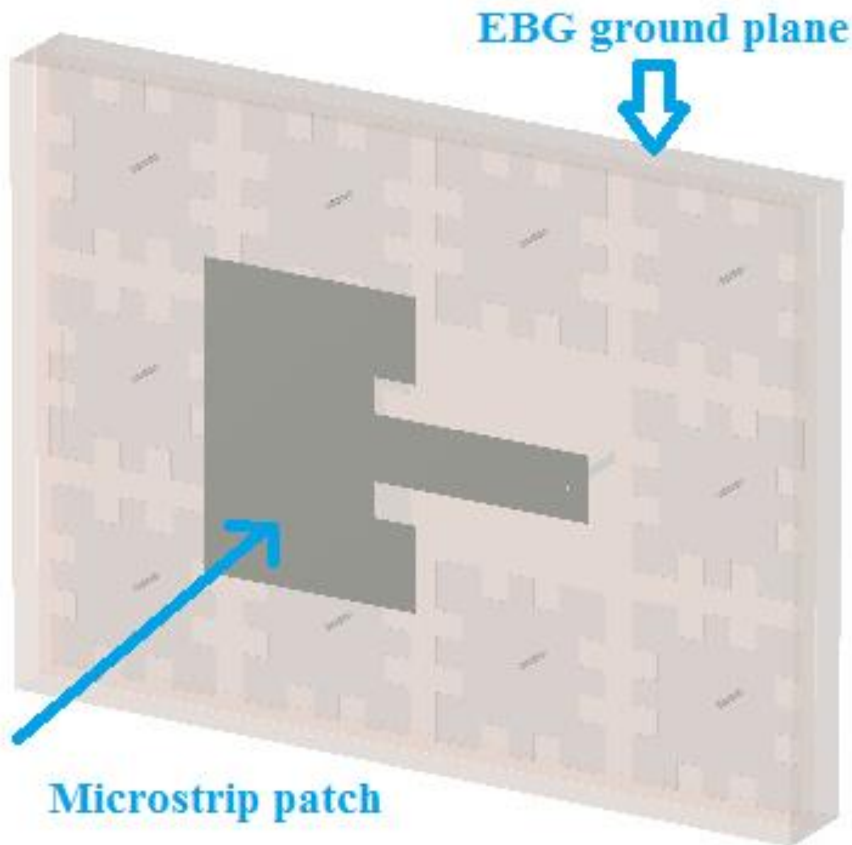

Figure 4.11: Microstrip patch antenna with artificial magnetic ground plane

4.5.4 Result

Simple micro strip antenna with PEC ground plane and FR4 substrate has been simulated on CST MWS. Return loss of simple rectangular micro strip patch antenna is shown in figure4.8. According to this figure , return loss is -12dB. To enhance the characteristics of simple micro strip antenna, it is placed over the artificial ground plane as shown in figure 4.11 and simulated . Artificial magnetic ground provide improvement in return loss as shown in figure4.12. According to result, return loss reached at -39dB.

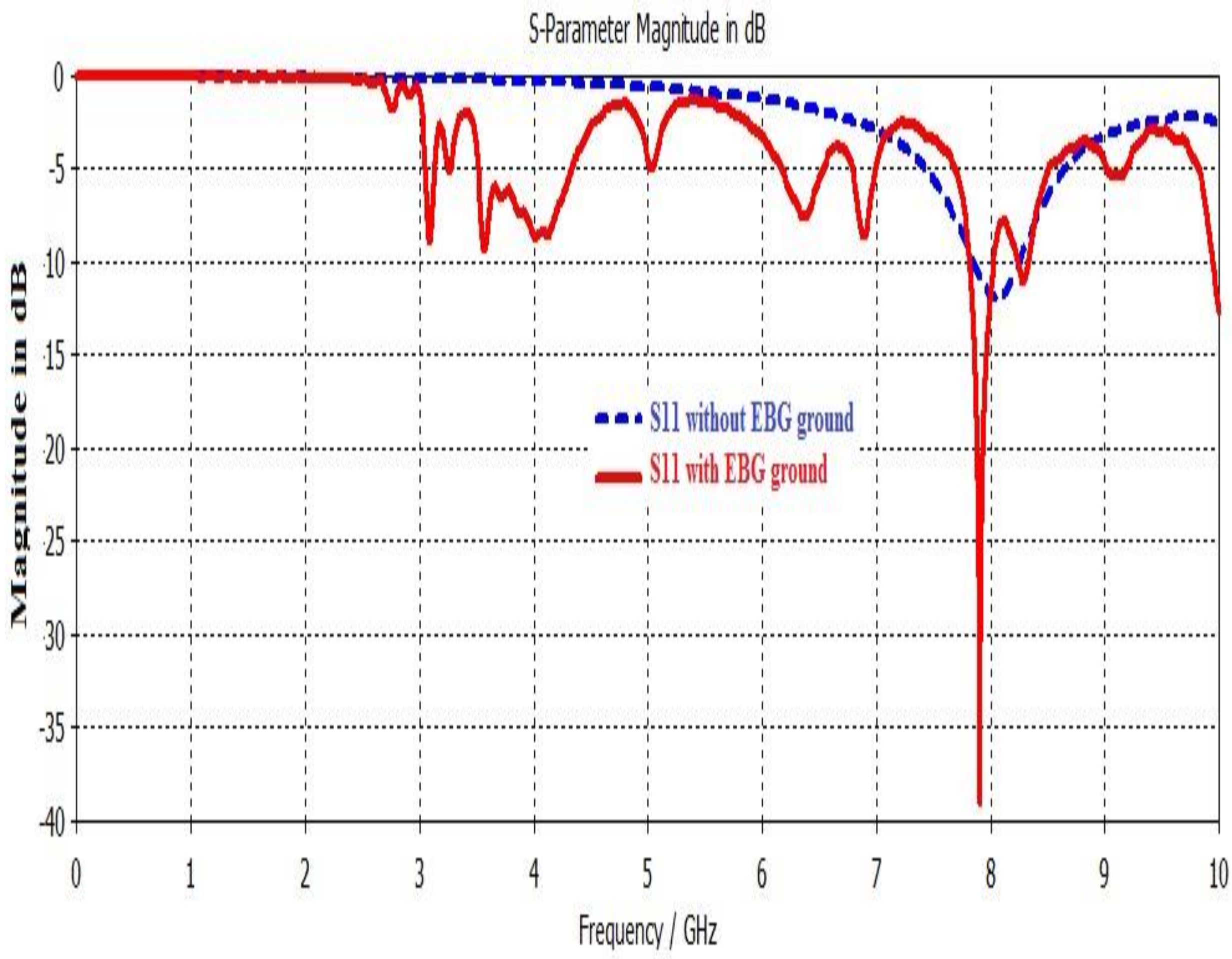

Figure 4.12: Comprision graph of return loss with and without EBG ground plane

4.6 Conclusion

Microstrip patch antenna with EBG structure has been investigated in this chapter. Initially simple microstrip patch antenna has been designed and simulated .According to their resonant frequency ,EBG structure has been designed. EBG structure mainly used to confine surface wave and as a artificial magnetic ground plane.

Micro strip patch antenna at 2GHz has been design and simulated. Return loss reaches -14dB & bandwidth is 35MHz. Without changing the position and Dimension of Micro strip antenna , substrate is surrounded by EBG layer, and simulated then return loss and bandwidth is increase and reaches up to -25dB & 45GHz.

Micro strip patch antenna at 8.0GHz has been designed and simulated. Return loss reaches -12dB. Without changing the position and Dimension of Micro strip antenna , PEC ground is replaced by artificial magnetic ground plane , and simulated then return loss is increase and reaches up to -39dB.

CHAPTER 5

CONCLUSION AND FUTURE WORK

Conclusion of work has been presented, and future work also suggested for improving the performance of EBG structure in micro strip patch antenna

5.1 CONCLUSION

In present work, Electromagnetic band gap structure has been investigated for micro strip patch antenna parameter improvement. Mushroom-like EBG structures are constructed in spiral shape and square shape. EBG structure constructed in spiral shape exhibits 7.5GHz wide frequency band gap in which surface wave cannot propagate. Second EBG structure contracted in square shape exhibits two frequency bands from 0GHz to 4GHz and 7.2GHZ to 11.2GHz. Square EBG design exhibits not only frequency band gap but it also shows a reflection phase property. It provides zero reflection phase at 7.5GHz and band gap from 6.6GHz to 8.3GHz between $+90^0$ to -90^0 phase shift. Surface wave reduction and reflection phase property of EBG structure is verified by their application in micro strip antenna. Mushroom-like square EBG structure is used in micro strip antenna. When substrate of micro strip antenna surrounded by EBG structure, it gives significant improvement in return loss and bandwidth. Improvement occurs due to surface wave reduction. Zero Reflection phase property provide artificial magnetic conductor nature within the certain frequency band. When PEC ground replace by EBG structure artificial magnetic ground plane, it gives significant change in return loss.

5.2 Future Scope

EBG structure finds their application in microwave devices such as antenna. It is necessary that frequency band gap of EBG structure must be centered around the resonance frequency of the microwave devices. There is no exact formula for dimension of EBG structure corresponding with particular formula. Therefore band gap of EBG structure is achieved by hit-n-trial method. Sometimes, When EBG structure is integrated with antenna, it shifts the frequency band of response a little bit. In the future work these two problem can be overcome by improving the modeling techniques of EBG structure.

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