Project Report

On

A RECONFIGURABLE PATCH ANTENNA WITH EBG STRUCTURE

Submitted in partial fulfillment of

the requirements for the award of the degree of

Master of Technology

in

Microwave and Optical Communication Engineering

Submitted by

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CANDIDATE'S DECLARATION

I, **Khushbu Sharma, Roll No. 2K16/MOC/05** student of M.Tech (Microwave and Optical Communication), hereby declare that the project Dissertation titled ***"A RECONFIGURABLE PATCH ANTENNA WITH EBG STRUCTURE"*** which is submitted by me to the Department of Electronics and Communication and Department of Applied Physics, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or any other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled ***" A RECONFIGURABLE PATCH ANTENNA WITH EBG STRUCTURE"*** which is submitted by **Khushbu Sharma, Roll No. 2K16/MOC/05** [Electronics and Communication], Delhi Technological University, Delhi in partial fulfillment of requirement for the award of the degree of Master of Technology in Microwave and Optical Communication Engineering, is a record of the project work carried out by the students under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

Microstrip antennas are widely used in wireless communications because of their compatibility, low profile, low power consumption and low cost. The capability to select the frequency is essential for diverse missions and this is achieved by a Reconfigurable Antenna. Resonant frequency of an antenna is changed by reconfiguring its geometrical structure. To achieve reconfigurability RF switching devices such as PIN diodes , photoconductive switches, micro-electromechanical system (MEMS) switches and FETs can be used.

Electromagnetic Bandgap (EBG) Structures that are those structures in which each element follows periodicity. Hence using EBG structures in a conventional patch antenna increase bandwidth and provide better suppression of harmonics .

This major project combines these two structures designing a reconfigurable patch antenna with EBG structure in which PIN diodes are used as switch as they provide fast switching speeds, reasonably high current handling capabilities, reliability and ease of modelling.

First of all the phase reflection diagram for a unit cell of proposed EBG is shown, after that bandgap of full EBG structure is shown using suspended transmission line method. Different EBG structures' bandgaps are also compared. Then the EBG structure is combined with a reconfigurable patch antenna and simulation results are presented in terms of return loss, VSWR and radiation pattern. A comparison between simulated results for reconfigurable antenna with and without EBG structures for return loss and radiation pattern is also provided. All the above simulations are carried out by CST STUDIO SUITE 2014.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my project supervisor, Dr. N. Jayanthi, for her supervision, invaluable guidance, motivation and support throughout the extent of the project. I have benefitted immensely from her wealth of knowledge.

I extend my gratitude to my university, Delhi Technological University (formerly Delhi College of Engineering) for giving me the opportunity to carry out this project.

This opportunity will be a significant milestone in my career development. I will strive to use the gained skills and knowledge in the best possible way, and I will continue to work on their improvement, in order to attain desired career objectives.

Khushbu Sharma
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CHAPTER 1

INTRODUCTION

In this chapter we will see why patch antennas are so important in the modern communication environment, merits, demerits of patch antenna, ways to reduce those demerits and what are EBG structures and frequency reconfigurable antennas.

As the technology evolves, the need for high speed data transmission and better and faster communication also increases. Antennas are an integral part of wireless communication system, so the antennas having higher bandwidth and higher gain are required but in many applications an antenna having low profile and smaller size is required such as in satellite applications, missiles, radars and aircrafts. For this purpose, microstrip patch antenna is one of our best options as they –

- Are low profile
- smaller in size than many antennas
- are rather inexpensive
- mechanically robust
- easy to manufacture
- versatile in terms of resonant frequency, polarization, radiation pattern, impedance and possible geometries
- conformable to most surfaces

But they suffer from many demerits as well-

- they can handle only small amount of power
- have narrow bandwidth and higher Q
- smaller gain than required in many applications
- Polarization purity is poor
- Spurious radiation at feed
- Poor scan performance
- Low efficiency

Apart from that they also suffer from surface waves which decrease efficiency of patch antenna and degenerate the radiating characteristics of patch antenna [1].

One way to decrease the surface waves, to increase bandwidth, increase efficiency and improve radiation characteristics is use of EBG structures.

EBG structures are an arrangement of periodic cells that provide a bandgap in frequency and act as high impedance surface in that bandgap.

Frequency reconfigurable antennas are the antennas that can switch between different frequency based on the reconfigurability mechanism in that antenna.
EBG structure can also be used with a frequency reconfigurable antenna to improve its performance.

CHAPTER 2

In this chapter we will get to know what are the basic characteristics of patch antenna, what are surface waves and its impact on antenna performance, some of patch antenna's feeding methods and how it is analyzed using transmission line and cavity models.

PATCH ANTENNA

2.1 BASIC CHARACTERISTICS

Microstrip patch antenna consists of a ground plane of metal, a substrate above the ground and metallic patch above the substrate which radiates. Thickness of metallic patch is very small ($t \ll \lambda_0$), where t is thickness of patch and λ_0 is the free space wavelength.
Thickness of substrate $h \ll \lambda_0$ and typically $0.003\ \lambda_0 < h < 0.05\ \lambda_0$

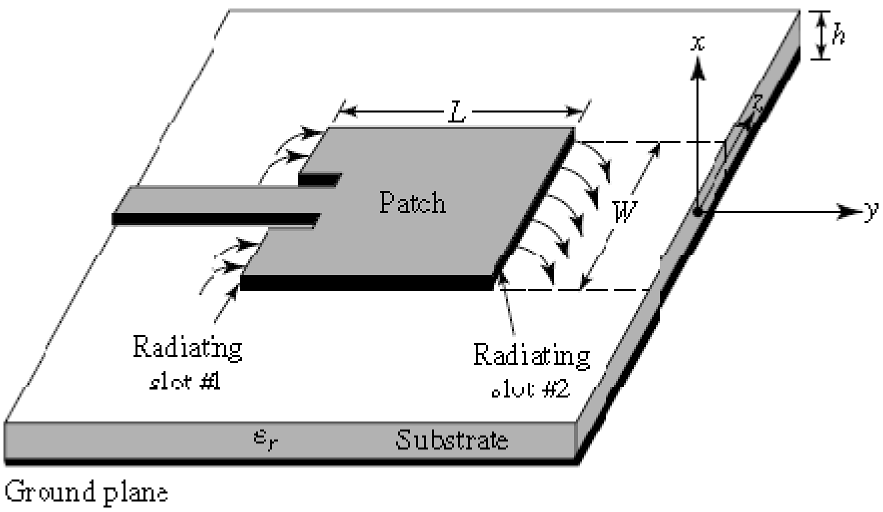


Fig. 2.1 Microstrip Patch Antenna[2]

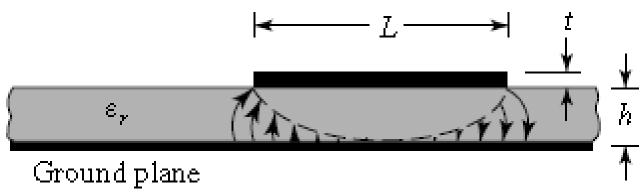


Fig. 2.2 Side View of Patch Antenna[2]

Where L is length of patch above substrate and W is the width of patch. L affects the resonant frequency of the patch antenna and W affects the bandwidth of patch antenna. Typically $\lambda_0/3 < L < \lambda_0/2$. The dieletric constant of substrate is given by ε_r. the value of ε_r is usually between 2.2 and 12.

Higher dielectric constant of substrate results in tightly bound fields that are suitable for microwave circuits(with small h), for the purpose of radiation we require that fields are loosely bound with antenna and to accomplish that we need low dielectric constant and thick substrate. But as the substrate thickness increases, surface waves also increase and it results in increased size of the antenna which is undesirable for many applications. So there is tradeoff between the antenna performance and its size.

Usually patch is designed for broadside radiation by properly choosing the mode of excitation but it can also be configured in such a way that it radiates in end-fire manner.

2.2 WAYS TO MITIGATE THE DISADVANTAGES

As we saw earlier the disadvantages that the patch antennas faces are narrow BW, small gain, surface wave propagation and low efficiency. There are many ways in which we can deal with this situation.

One way to increase the efficiency and BW of patch antenna is increasing the thickness of substrate h and decrease dielectric constant of the substrate ε_r but it results in increment in surface waves as well. By using cavities we can reduce surface waves.

To increase the bandwidth we can introduce many slots having different resonant frequencies, it makes the antenna broadband. In [3], A slot antenna for ultra wideband applications has been proposed and it is achieved by the introduction of slots in the patch antenna.

In a similar way different patches having different frequencies can be stacked together to form a wideband antenna. In [4], a broadband stacked patch antenna has been achieved using different radiating patches. In this antenna a maximum BW of 60.2% can be obtained.

Another way which is gaining increasing popularity is the use of metamaterials particularly the use of EBG structures in the vicinity of patch antenna or in place of ground. They suppress the surface waves and increases efficiency as well as BW[5].

Another way to increase the bandwidth is proving impedance matching by using stubs and using coplanar patch. Inset feed can also be used to give impedance matching.
Ferrite composition also provides larger BW but is expensive.

2.3 TYPE OF PATCH ANTENNAS

Patch antennas are available in many geometries such as rectangular, square, circular, elliptical, dipole, bowtie etc. out of theses rectangular, square and circular are most popular as they are easiest to fabricate and easy to analyze as well.

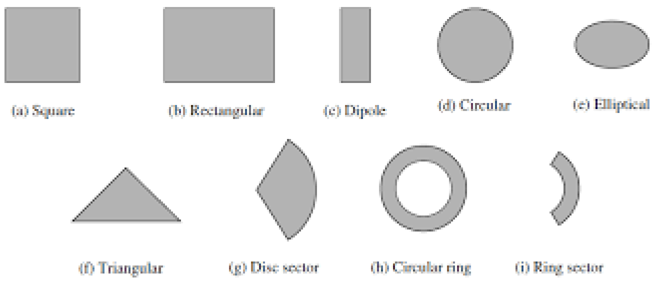


Fig. 2.3 Types of Patch Antennas based on geometry [1]

2.4 DIFFERENT FEED MECHANISMS OF PATCH ANTENNA

Patch antenna can be fed mainly in four ways-

2.4.1 Coaxial probe

It is one of the most popular methods to feed the patch antenna. In this type of feed method, outer conductor of coax cable is joined with the ground plane of antenna and the inner conductor is connected to the radiating patch above the substrate.

The impedance matching is easy and it provides low amount of spurious feed radiation but to model it to analyze patch antenna is very difficult and it offers narrow BW. It also adds an inductive reactance in input impedance of patch antenna. The value of input impedance increases as the radius of probe deceases but it affects antenna performance [4].

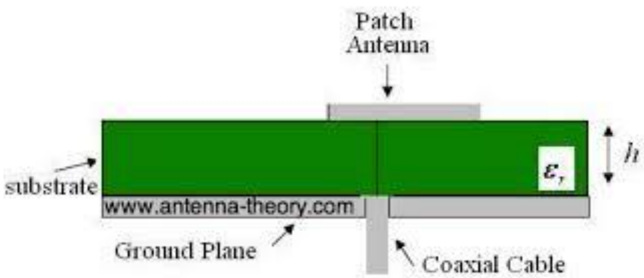


Fig. 2.4 Coax cable fed patch antenna[6]

2.4.2 Microstrip Line

In this type of feeding mechanism, a microstrip line is used to feed the patch in the same plane above the substrate, the width of microstrip line is much smaller than the width of radiating patch. The advantages include ease of modelling, fabricating and matching with the input impedance of patch antenna by varying the position of microstrip line. But if the thickness of substrate increases then the surface waves and spurious feed radiation through it are increased as well. One more disadvantage is that it limits the BW of patch antenna and provides narrow band. If we use microstrip of smaller input impedance than patch antennas then they can be very easily matched using quarter wave transformer microstrip line.

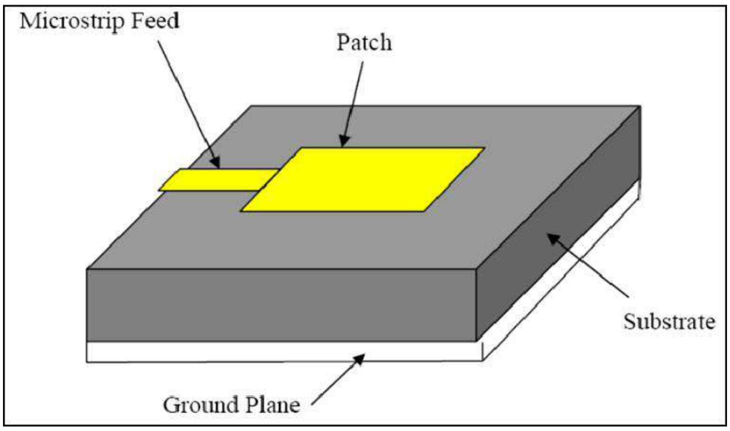


Fig 2.5 Microstrip fed Patch Antenna[7]

Due to the asymmetries which are inherently present, it produces cross polarization due to higher modes generation.

2.4.3 Aperture coupling

This type of feeding consists of two substrates and ground plane is placed between them. Microstrip line that feeds the patch is present on the lower side of lower substrate and ground plane has a slot in it so that it can couple the energy to the patch. The advantage of this mechanism is that feeding line and radiating patch can be optimized in an independent manner.
Advantages also include modeling ease and spurious feed radiation that is moderate.
Disadvantage is that it is very difficult to model and provides narrow BW.

Ground between the two substrate provides isolation to them and decrease spurious feed radiation.
The lower substrate has higher dielectric constant whereas upper one has lower dielectric constant[8].

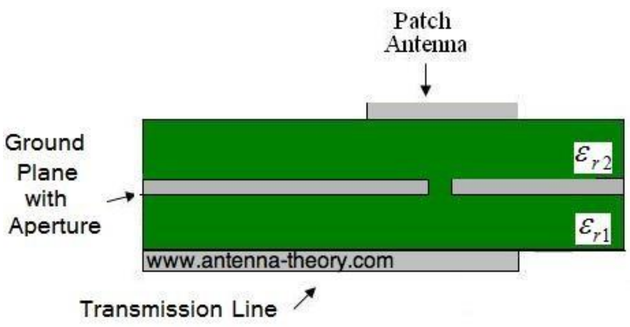


Fig. 2.6 Aperture coupled antenna[6]

2.4.4 Proximity Coupling

Advantages include low spurious feed radiation and provides largest BW among the four feeding mechanisms discussed here but fabricating it is difficult.

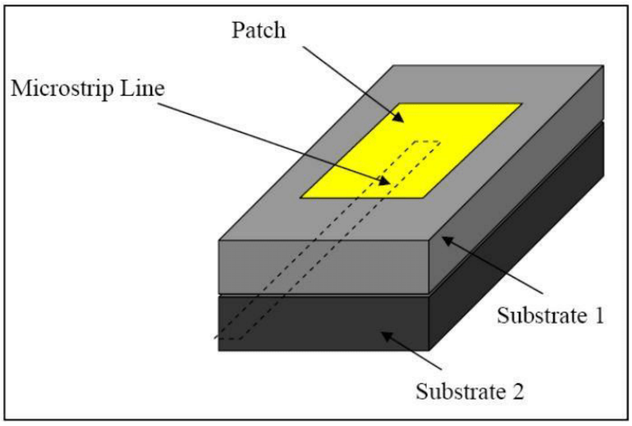


Fig. 2.7 Proximity coupled Patch Antenna[7]

In this feeding type, instead of ground plane the fedding strip line is placed between two substrates. It can be matched by varying width of strip line and width to line ratio of patch.

2.4.5 Coplanar Waveguide Feed (CPW)

In this feeding method, three conductors are placed in the same plane and the central conductor carries the current. This scheme is very popular because it offers large BW and can be integrated in MMIC structures. It is simple to fabricate.

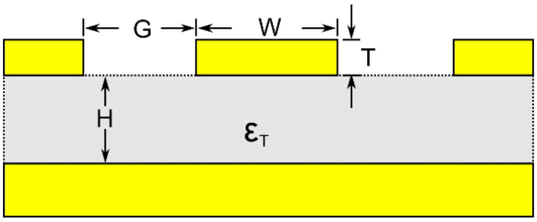


Fig 2.8 Coplanar Waveguide Feed

2.5 ANALYSIS OF MICROSTRIP PATCH ANTENNA(MPA)

There are mainly three ways to analyze the behavior of MPA-

- Transmission Line Model
- Cavity Model
- Full Wave Method

Easiest of these is transmission line model but it is not that accurate while predicting the behavior of MPA. Cavity model is more accurate but it is complex as well. Full wave method is most accurate but it has most complexity of all the methods.

2.5.1 Transmission Line Model

In this model the patch is represented by two slots that are at a distance of L from each other, where L is the length of patch. These slots have width of W and height of h, where W is width of patch and h is the thickness of substrate.

In this model MPA is shown as two slots that have low impedance transmission line of length L between them.

Due to fringing in MPA, electrically it appears to be larger than it physically is.

$$L_{eff}=L+2\Delta L$$

Where L_{eff} is effectective length of patch, L is physical length and ΔL is increment in length of patch on each side due to fringing effect.

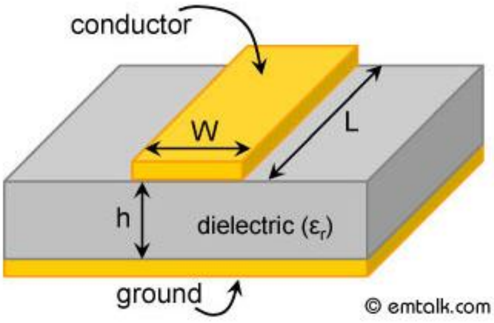


Fig.2.9 Transmission Line Model of MPA[9]

For dominant TM_{010} mode resonant frequency is given by(without taking fringing into account)

$$(f_r)_{010}=v_0/2L\sqrt{\varepsilon r}$$

After taking fringing into consideration

$$(f_r)_{010}=v_0/2(L+\Delta L)\sqrt{\varepsilon reff}\sqrt{\varepsilon r}$$

Where ε_{reff} is effective dielectric constant.

2.5.1.1 Fringing in MPA

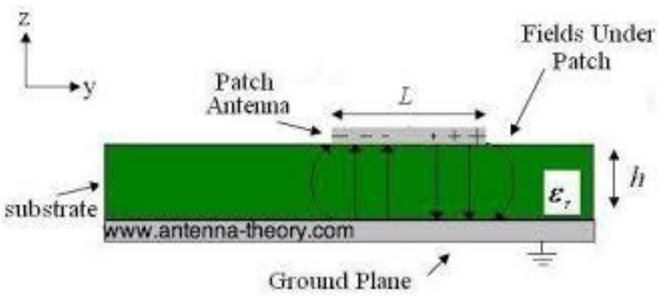


Fig. 2.10 Fringing in MPA[6]

Due to finite length and width of MPA, fields at the edges of antenna are curved, some are in air and some are in the substrate. It is called fringing and due to it antenna appears to be electrically larger, so L becomes less than half wavelength. It affects resonant frequency of MPA. It can be controlled by varying L,W,h and dielectric constant of substrate. If L/h>>1 then fringing effect is less.

There are two medias, one is substrate and the other is air in which field is present, they can be modelled by a single homogenous material having dielectric constant ε_{reff}..

ε_{reff} accounts for fringing and wave propagation in transmission line. It is more than 1(dielectric constant of air) and less than dielectric constant of the substrate. When dielectric constant of substrate is much larger than 1 then effective dielectric constant becomes closer to it.

$$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1 + \frac{12h}{W}\right]$$

2.5.2 Cavity Model

MPAs are like cavities that have been loaded by a dielectric and they exhibit higher order resonance. Upper and lower conductor of MPA are treated as electric walls and remaining faces are treated as magnetic walls.

When MPA is energized, the charge distribution is as shown-

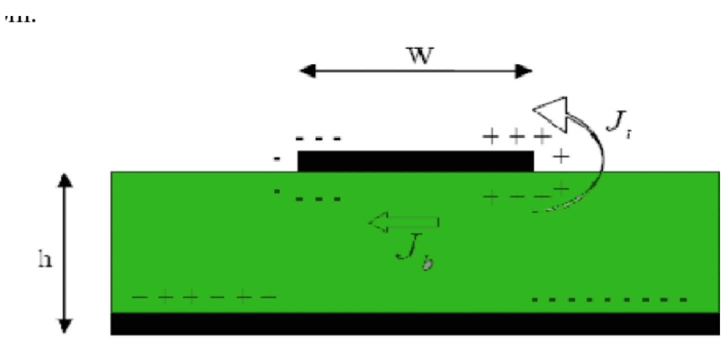


Fig. 2.11 Charge Distribution in MPA[10]

When h/w<<1 then most of charge concentration and flow of current is below patch.

Field configuration in MPA is shown below-

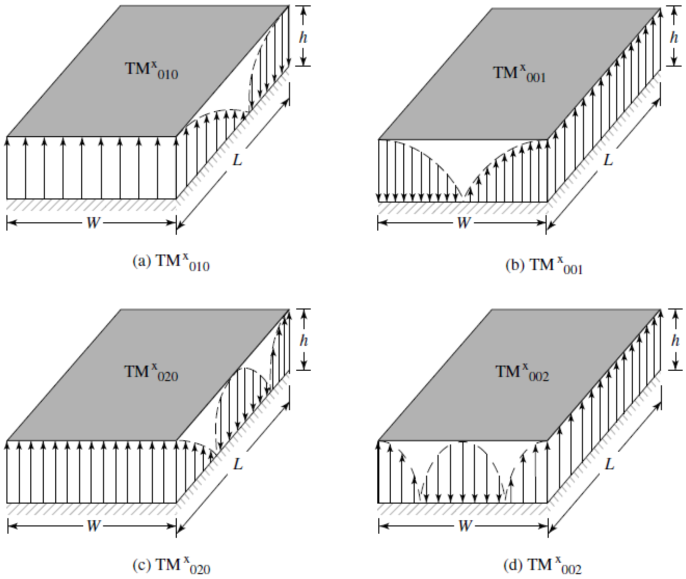


Fig. 2.12 Field Distribution for different modes in MPA

Resonant frequency is given by $f_r = \frac{v}{2}\sqrt{(\frac{m}{h})^2 + (\frac{n}{L})^2 + (\frac{p}{W})^2}$

For dominant mode TM_{010}, $f_r = v_0/2L\sqrt{\varepsilon r}$

Four side walls of MPA act as slots that radiate.

Directivity of MPA is given as-

$D = 8.2$ dB when $W << \lambda_0$

$8(W/\lambda_0)$ when $W << \lambda_0$

CHAPTER 3

SURFACE WAVES IN MICROSTRIP PATCH ANTENNAS

In this chapter we will see what are surface waves, what are the factors that affect it , what is its impact in MPA performance and how it can be reduced.

3.1 SURFACE WAVES IN MPA

Surface waves are the waves that propagate along ground plane. When $\varepsilon_r>1$, surface waves are indusced in MPA. Surface waves are reflected from ground plane after they are incident on it at an angle, then they are reflected from dielectric-air boundary so the propagate in a zig-zag manner and by the boundaries of MPA they are again reflected and are diffaracted by the edges of antenna hence providing end-fire radiation.

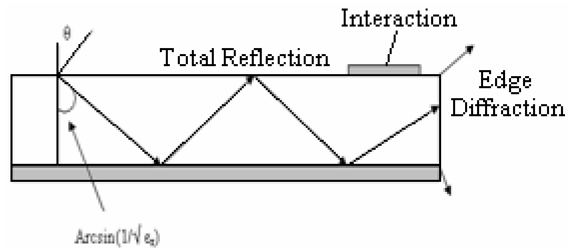


Fig. 3.1 Surface Waves in MPA[11]

3.2 FACTORS AFFECTING SURFACE WAVES

Cutoff frequency for surface waves id given by

$$f_c = \frac{nc}{4h\sqrt{\varepsilon r-1}}$$

where n is the order of surface wave mode, hence surface waves cannot be removed completely as for TM_0 mode, the cutoff frequency is 0[12].

In MPA if h increases then surface waves also increase.
If $h \ll \lambda_0/10$, then surface waves in MPA are insignificant.

3.3 SURFACE WAVES IMPACT ON ANTENNA PERFORMANCE

As we saw earlier, surface waves become the reason for end-fire radiation from the antenna edges. This radiation takes away some portion of input power that was meant for radiation into space hence efficiency of antenna is compromised, it results in back lobes as well as in side lobes in radiation pattern hence radiation pattern is degraded. Surface waves also contribute to increased cross polarization levels and limitation on BW.

Due to side lobes and back lobes present in radiation pattern signal to noise ratio in communication system is also decreased. Surface waves also contribute to the coupling between antenna elements in an antenna array which results in blind scanning angle in case of phased array systems [13].

3.4 WAYS TO REDUCE SURFACE WAVES

As we saw if the h is very small then surface waves become negligible. They can also be reduced using EBG structures in MPA as EBG structures block propagation of surface waves.

CHAPTER 4

RECONFIGURABLE ANTENNAS

In this chapter we will see what reconfigurable antenna are, why are they needed, their types, and switching mechanisms used to achieve reconfigurability.

4.1 RECONFIGURABLE ANTENNAS AND THEIR NEED

In modern communication system and in many applications, we require antennas that can work on multiple frequencies providing good gain, hence multiband antennas are used so often now-a-days. They cater to our need very well but often there is interference in adjacent frequency bands in multiband antennas and they radiate at all bands including the desired band simultaneously.

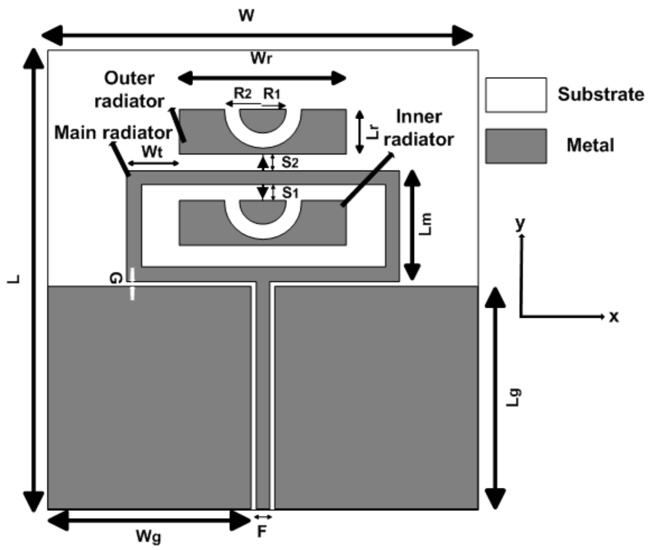


Fig. 4.1 A frequency reconfigurable antenna using switches [14]

Reconfigurable antennas solve these problems as they operate on a single band at a time so there is no interference between bands. They can change their geometries so that they could switch states according to surroundings. It also helps in making antennas compact as now the filters will not be needed to filter out undesired band.

Frequency reconfigurable antennas are often chosen used as they can switch between different frequencies without affecting gain. They also result in miniaturization of antenna and provide cost effective solution to our needs [14].

4.2 TYPES OF RECONFIGURABLE ANTENNAS

As of now mainly there are three types of reconfigurable antennas-

- Frequency reconfigurable
- Radiation pattern reconfigurable
- Polarization reconfigurable

A combination of any of these can also be reconfigured [15-18].

4.3 SWITCHING MECHANISM

By changing the radiating fields in effective aperture of antenna, reconfigurability is achieved. It is usually achieved by altering the current distribution or by changing the radiating elements of antenna. This can change functionality of antenna and make it suitable for various wireless applications.

Reconfigurability requires that good gain and stable radiation pattern are provided at all states of antenna.

Switching between different states in a reconfigurable antenna can be achieved by

- Electrical switches
- Optical switches
- Mechanical switches
- Material change

Electrical switches include PIN diodes, varactor diodes etc. they use these switches to manipulate the design of the antenna. Usually some part of antennas is connected to remaining part by a switch and this wistch if ON connects it to antenna and if OFF, disconnect it from the rest of antenna. Hence as the size of antenna element changes, resonant frequency also changes. PIN diodes are fast having switching speed in range of nanoseconds. Varactor diodes changes their capacitance as the applied voltage is changed, changed capacitance provides change in resonant frequency [15][18][19].

Optical switches are photoconductive, when laser beam is incident on them they conduct. In [20], a frequency reconfigurable antenna which is optically pumped.

RF-MEMS are also used in frequency reconfigurable antennas, they are based on the mechanical movements of these switches. They provide high isolation and require very low power. Switching speed is in the range of microseconds [17].

CHAPTER 5

ELECTROMAGNTIC BANDGAP STARUCTURES(EBG)

In this chapter we will see what are EBG structures, how do they work, what are their types and what are their applications.

5.1 EBG STRUCTURES

EBG structures are a type of metamaterials. Metamaterials are that artificial materials which are originally not found in nature, rather they are constructed using periodicity of elements which is less than half wavelength, so they behave as a new material having different properties as field considers that to be property of a material itself. Such a materials allows free control of permittivity and permeability of material. We can construct materials having negative refractive index(permittivity $\varepsilon<0$, permeability $\mu<0$) by using metamaterials(Such materials are not present in nature). Using them we can have left handed materials in which th electromagnetic waves propagate backward. Coming to their applications, they can be used to bend light passing through them and creating invisibility cloak.

EBG structures are also made up of a periodic arrangement of unit cells consisting of metal and dielectric or just dielectric. They are called so because they provide a bandgap in the frequency response i.e. electromagnetic waves of certain frequency passing through them is blocked and is not able to propagate, so prevent or assist electromagnetic waves through them for all incident angles and polarization states. This bandgap depends upon the periodicity of EBG structure. Due to their property of being able to control electromagnetic waves passing through them, they are useful for a variety of applications. They can be fabricated using conventional techniques and PCB materials.

EBG structures can either be placed in place of ground plane or can be used around the patch to suppress surface waves.[22]

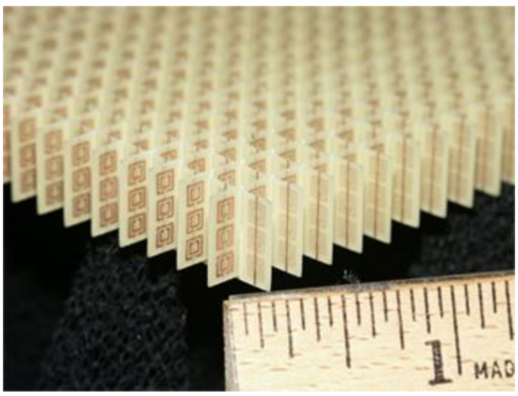


Fig. 5.1 Split Ring Resonator based metamaterial[21]

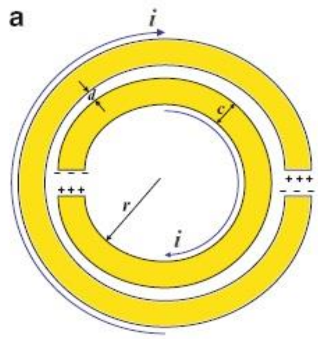


Fig. 5.2 Split Ring Resonator[21]

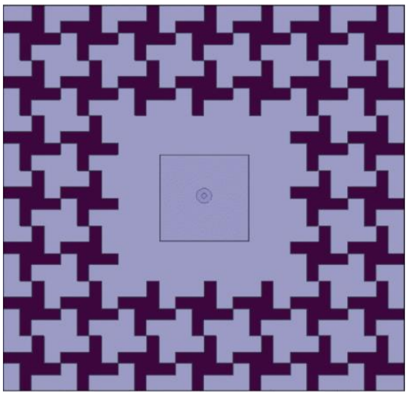


Fig. 5.3 MPA with two rows of EBG structures[22]

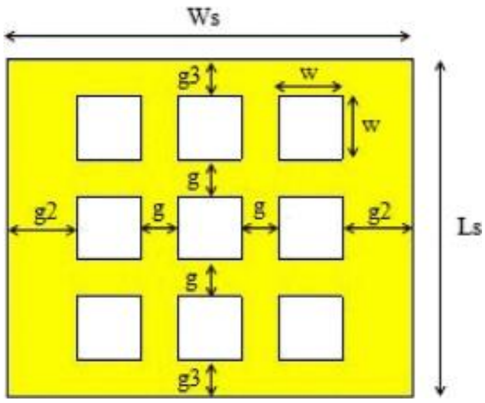


Fig.5.4 EBG structures[23]

EBG structures are developed after the similar periodic structures in photonic applications i.e. Photonic Bandgap Structures.

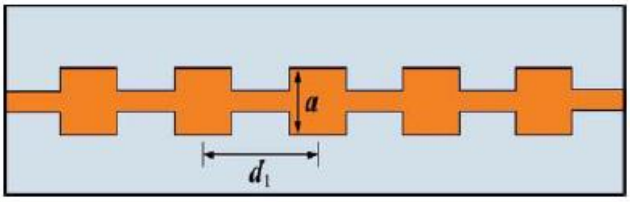


Fig. 5.5 Another example of EBG[24]

By photonic crystal theory EBG exhibit bandgap when the below condition is satisfied-

$$\beta . d_1 = \pi$$

Where d_1 is the distance between elements and $\beta = \frac{2\pi}{\lambda g}$ where $\lambda_g = \frac{c}{f0\sqrt{\varepsilon eff}}$

Where β is guided wavenumber of substrate, λ_g is guided wavelength, f_0 denotes the stopband central frequency, c speed of light in free space, εeff effective permittivity.

So $d_1 = \lambda_g/2$, hence for EBG the periodicity of elements should be half wavelength of the bandgap frequency, this increases the size of antenna but different EBG structures such as fork like EBG, Rabbet spiral EBG of smaller size can also be used for blocking same frequency thus providing compactness compared to mushroom EBG design. a decides the controls the BW and suppression level in stopband.

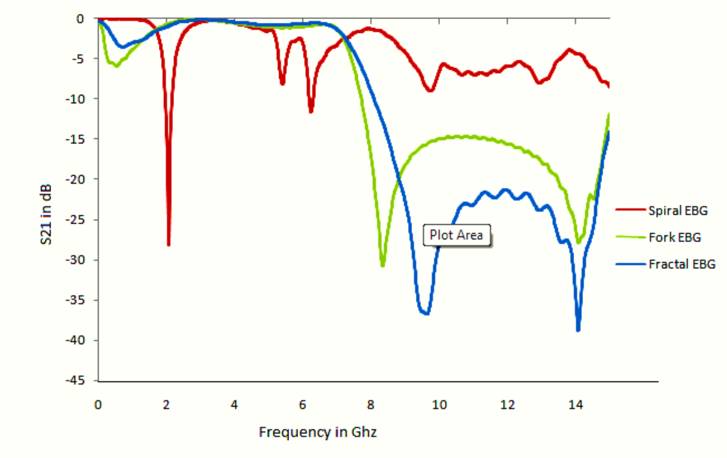


Fig. 5.6 Bandgap of some EBG structures[25]

As we increase the order of EBG structures, attenuation level and selectivity improve but the size of structure also increase and with increasing order there are ripples in passband which can be minimized using Chebyshev tapered EBG.

Periodicity of unit cells is also utilized in Artificial Magnetic Conductor(AMC) to provide miniaturization to antennas. When an electromagnetic wave is reflected by perfect electric conductor(PEC), reflection coefficient Γ is -1 hence to achieve combination of incident and reflected waves in same phase the distance between patch and ground should be about quarter wavelength but in the case of perfect magnetic conductor(PMC) it is +1 so wave is reflected without any phase shift so this distance between antennas and ground can be very small. AMC is the surface exhibiting properties of PMC within its bandgap. In case of AMC, the phase of image and original current is same hence it can be utilized as reflectors in antennas. They also suppress surface waves in their bandgap and outside this bandgap behavior is same as PEC. The cavity that forms between periodic structure and ground plane resonates hence it absorbs energy of incident wave at resonance and then reradiates this energy. When AMC is place beneath the antenna ir redistributes the image current in such a way that mutual impedance between antenna and its image is minimized. Hence, it can be used to increase BW. Phase reflection diagram of AMC is shown below-

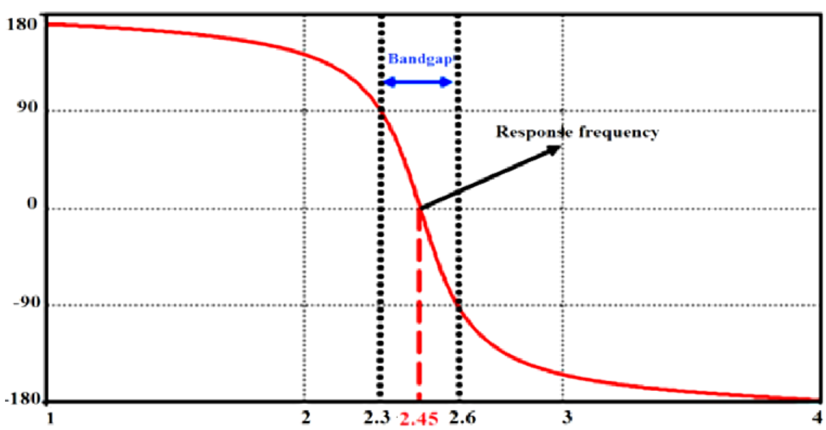


Fig. 5.7 Reflection phase diagram of AMC unit cell[26]

On the either side of central frequency of this diagram, BW of AMC is defined in range of $+90^0$ to -90^0 in whiv. Here we are referring to AMC as a type of EBG structures.

EBG structures can also be arranged in the same plane of radiating patch, that also exhibits the property of surface waves suppression and increased gain and efficiency. Even holes can be drilled in the substrate of antenna to obtain same performance. EBG shows high impedance in its bandgap.

5.2 WORKING OF EBG STRUCTURES

A typical EBG structure unit cell consists of patch, dielectric, ground and a via between patch and ground and it can be considered to be equivalent to a lumped LC circuit where inductance L results from current flow through via and edges of patch and capacitance C stems from the gap between different unit cells.

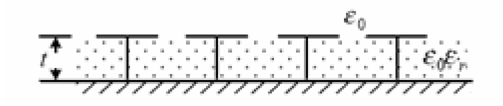


Fig. 5.8 EBG structure side view[27]

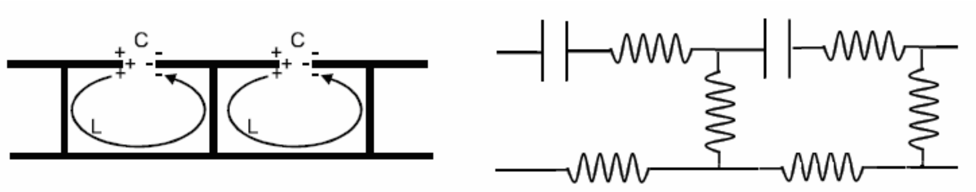


Fig. 5.9 EBG cells and their equivalent circuit[27]

Impedance of this parallel circuit is given by-

$$Z = \frac{j\omega L}{1-\omega^2 LC}$$

At resonant frequency $\omega = \frac{1}{\sqrt{LC}}$ this tends to a very large value hence suppressing surface waves and providing bandgap.

$$C = \frac{W\varepsilon 0(1+\varepsilon r)}{\pi}\cos^{-1}\left(\frac{W+g}{g}\right)$$

$$L = 2*10^{-7}h\left[\ln\left(\frac{2h}{r}\right) + 0.5\left(\frac{2r}{h}\right) - 0.75\right]$$

Where, g is gap between the elements and r is via radius.

Thus, EBG work as a filter passing or blocking EM waves of different frequencies.

5.3 TYPES OF EBG STRUCTURES

Broadly there are three types of EBG structures-

- One dimensional
- Two dimensional
- Three dimensional

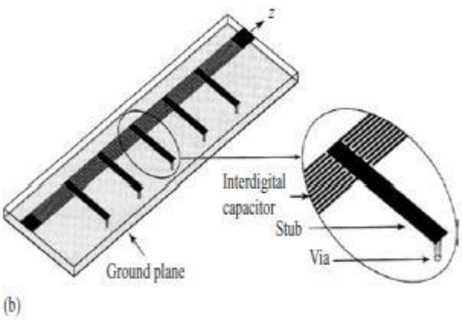


Fig. 5.10 1D EBG Structures[28]

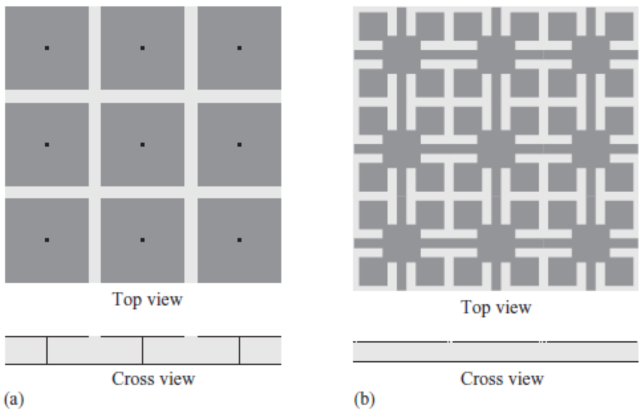


Fig.5.11 2D EBG Structures[28]

There are many shapes in 2D EBGs as spiral EBG, fork like EBG, hexagonal EBG[28], cross hair type EBG and swastika type EBG in single band and hexagonal patch with double C slot EBG, square patch having a disconnected loop slot EBG and fractal type EBG in dual band[13]. They can be planar having no vias or can have vias.

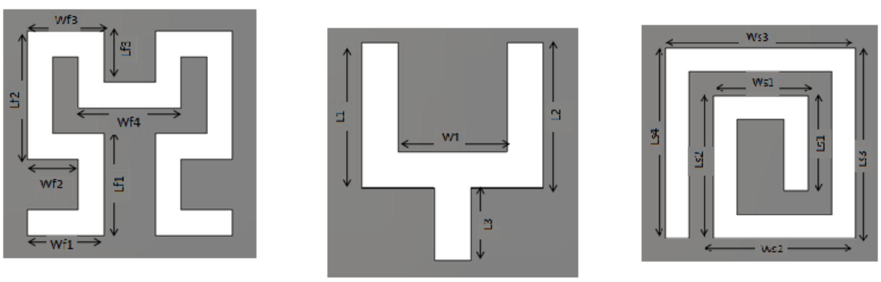


Fig. 5.12 Fractal, Fork like and Spiral EBG unit cells[25]

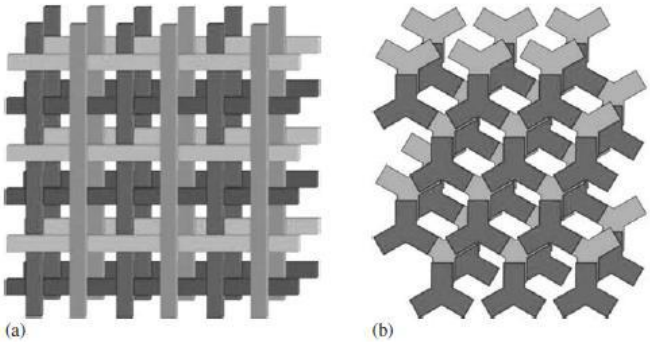


Fig. 5.13 3D EBG structures[28]

5.4 APPLICATIONS OF EBG STRUCTURES

There are many applications of EBG structures as

- Surface wave suppression
- Noise reduction in multilayer PCBs
- Reduction of EMI in high speed circuits
- Reduction in coupling between antenna array elements
- Increasing efficiency of MPA
- Increasing gain of MPA
- Increasing BW of MPA[29][30]
- Reducing size of antennas
- Can also be used to achieve reconfigurability using switches[31]
- Reduction in specific absorption rate
- Reduction in side and back lobes thus improving radiation pattern of MPA

In [32], EBG structure at 60GHz has been designed which reduced mutual coupling of elements in array. In [33], overall improvement in antenna performance is observed using EBG. As they reduce the backward radiation from MPA they are used to reduce the absorption of radiation by human body and at the same time provide better efficiency and BW than conventional MPA[34]. In [35], EBG structures are used with patch antenna for passive development of radio frequency identification so that they can be used to identify the objects in warehousing, service logistics etc.

CHAPTER 6

A RECONFIGURABLE PATCH ANTENNA WITH EBG STRUCTURES

In this chapter we will see the design of a reconfigurable patch antenna, phase reflection diagram of a unit cell of EBG structure, bandgap of an EBG structure using suspended transmission line method, comparison of bandgap among different dual band EBG structures, how this EBG structure is combined with reconfigurable patch antenna beneath patch as well as surrounding the patch and how this affects the performance of reconfigurable patch antenna.

6.1 RECONFIGURABLE PATCH ANTENNA

A simple patch antenna can be designed at a resonant frequency after selecting a substrate having dielectric constant ε_r and deciding the thickness of substrate h. For low surface waves it is generally $h<<\lambda_0/10$ where λ_0 is free space wavelength.

Then dimension of MPA are given by

$$W = \frac{c}{2f\sqrt{\frac{\varepsilon r+1}{2}}}$$

$$L = \frac{c}{2f\sqrt{\varepsilon reff}} - 2\Delta L$$

Where W is width of patch and L is length.
ε_{eff} is effective dielectric constant and is given by-

$$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1 + \frac{12h}{W}\right]$$

ΔL is extension in electrical length of antenna from physical length and is given by-

$$\Delta L = 0.412h\,\frac{(\varepsilon eff+0.3)(\frac{W}{h}+0.264)}{(\varepsilon reff-0.258)(\frac{W}{h}+0.8)}$$

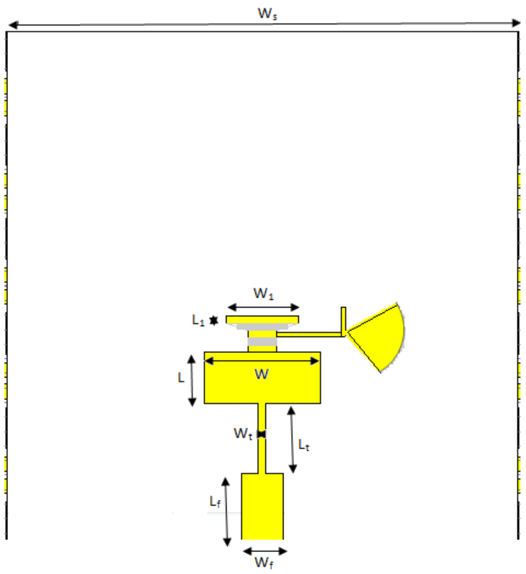
A reconfigurable patch antenna is taken here as it works on two resonant frequencies. The resonant frequencies that the antenna is working on are 8.5 GHz and 18.5 GHz. 8.5 and 18.5 GHz bands come under Super High Frequency(SHF) bands. 8.5GHz is part of X band and is useful for space research operations.18.5GHz is part of K band and is useful for satellite applications.

In this reconfigurable patch antenna PIN diode has been used as a switch. When this PIN diode is ON(forward biased) then the current floes from main patch to the second patch and as the size of antenna is bigger smaller resonant frequency is observed but when PIN diode if OFF(reverse biased), the second patch is effectively disconnected from main patch due to high impedance of diode and size of antenna is smaller hence higher resonant frequency is achieved.

To provide RF/DC isolation inductor at DC biasing side and capacitors at feed lines are used. Here we have simulated PIN diode by presence and absence of a metallic strip between the two patches, this model is approximate and resonance in actual scenario might differ but this effect can be reduced by properly biasing PIN diodes[31]. Alternatively PIN diode in ON state can also be denoted by series inductor and resistor(3.5 Ω) and in OFF state a capacitor in parallel with resistor (3KΩ) is also present but the model using metal strip is easier to simulate and more accurate[36][37].

6.1.1 Reconfigurable patch antenna

The reconfigurable patch antenna is designed as below-



Parameters	In mm
W_s	35
W	8
L	3.48
W_t	0.531
L_t	4.869
W_f	2.917
L_f	4.611
h	1.5
t	0.035

Fig. 6.1 Reconfigurable patch antenna **Table 6.1** Dimensions of Reconfigurable Patch antenna

PIN diode in this antenna has been biased using radial stub that works as inductor and capacitor is used to block DC signal from interfering with RF signal.

6.1.2 Reconfigurable patch antenna when PIN diode is ON

When the PIN diode is biased using DC signal then main patch is connected to the second patch and here biasing circuit has not been taken into account as it does not change the current distribution in patch antenna. PIN diode is simulated using a copper strip.

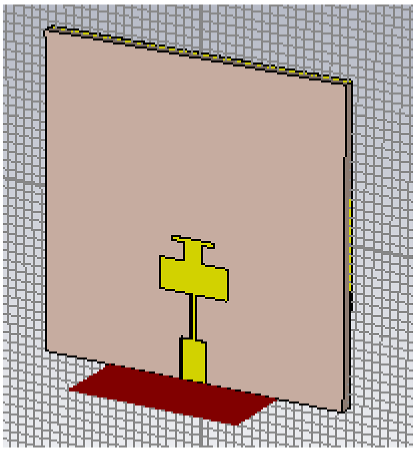


Fig. 6.2 Patch antenna when switch is ON

Return loss vs frequency plot obtained after the simulation is as below-

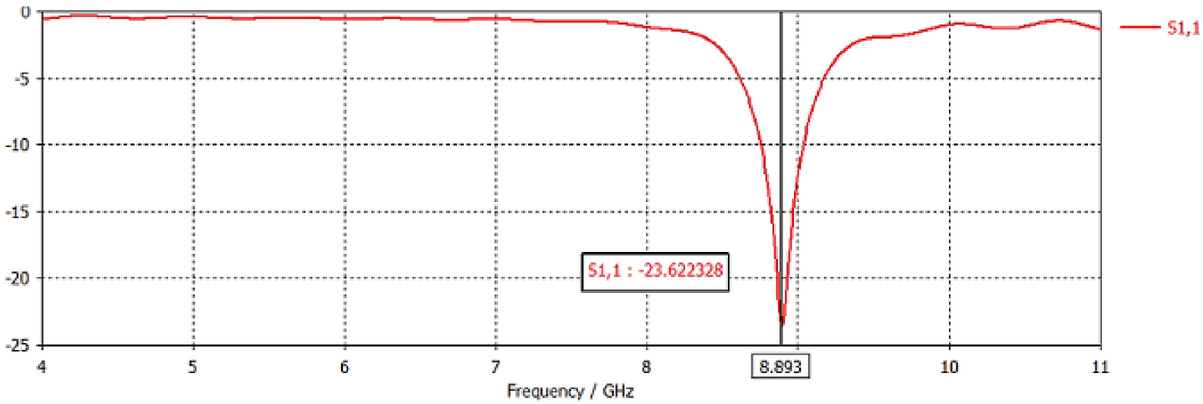


Fig 6.3 Return loss plot

We can see that resonant frequency is 8.89GHz and return loss at this frequency is -23.6dB. BW is from 8.75 to 9.03GHz.

VSWR vs frequency plot is as shown below-

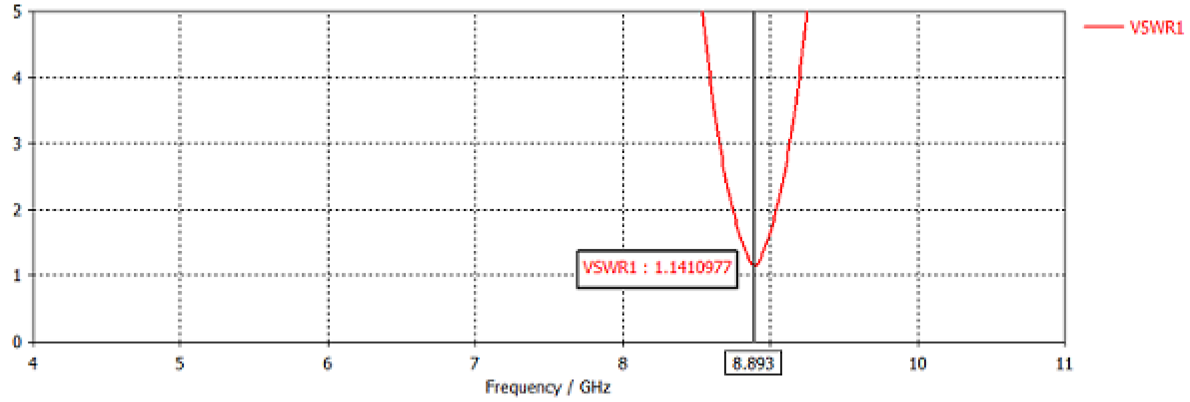


Fig. 6.4 VSWR plot

For frequency 8.74 to 9.04GHz, VSWR is less than 2.

Far field plot at 8.8 GHz-

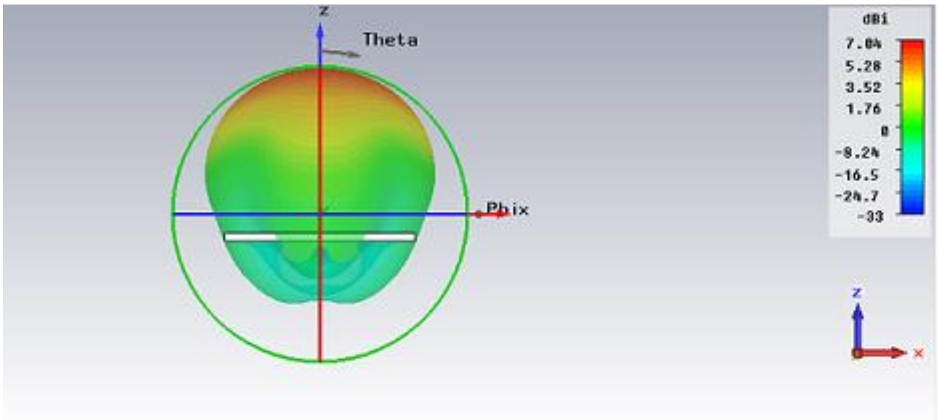


Fig. 6.5 Far field at 8.8 GHz

Current distribution on patch antenna-

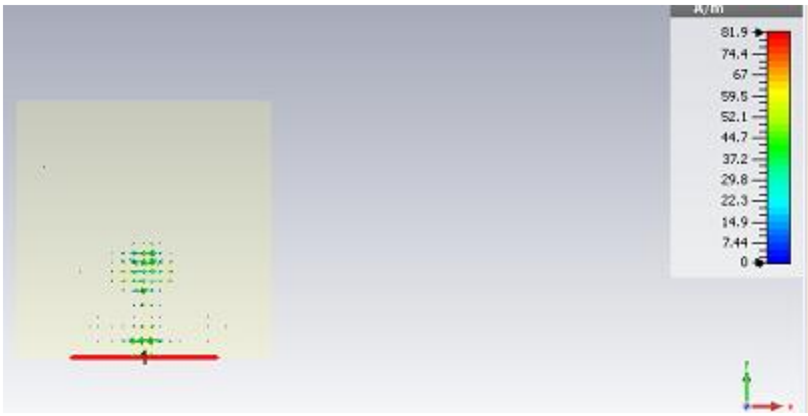


Fig. 6.6 Surface Current distribution at 8.8 GHz

Radiation pattern-

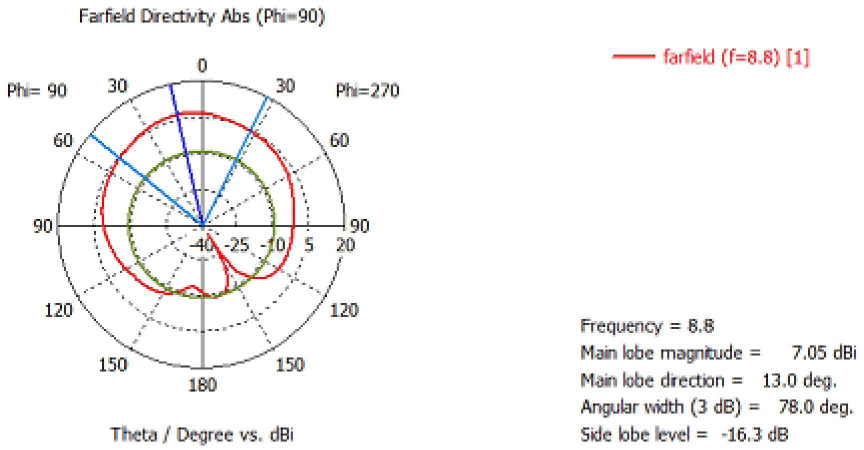


Fig. 6.7 Radiation pattern at 8.8 GHz

6.1.3 Reconfigurable patch antenna when PIN diode is OFF

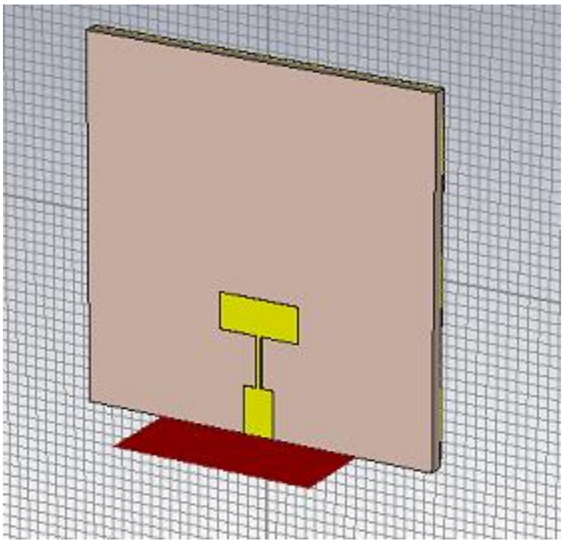


Fig. 6.8 Patch antenna when switch is OFF

Return loss vs frequency plot for the above antenna is as shown-

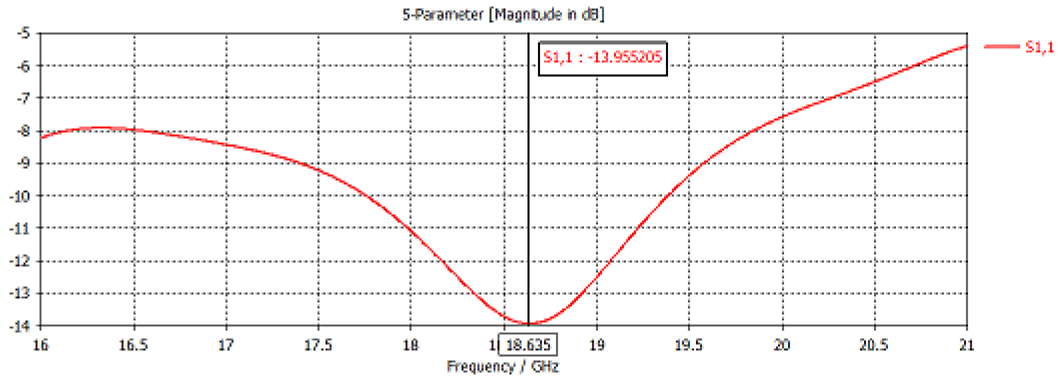


Fig. 6.9 Return loss plot

VSWR vs frequency plot is as shown below-

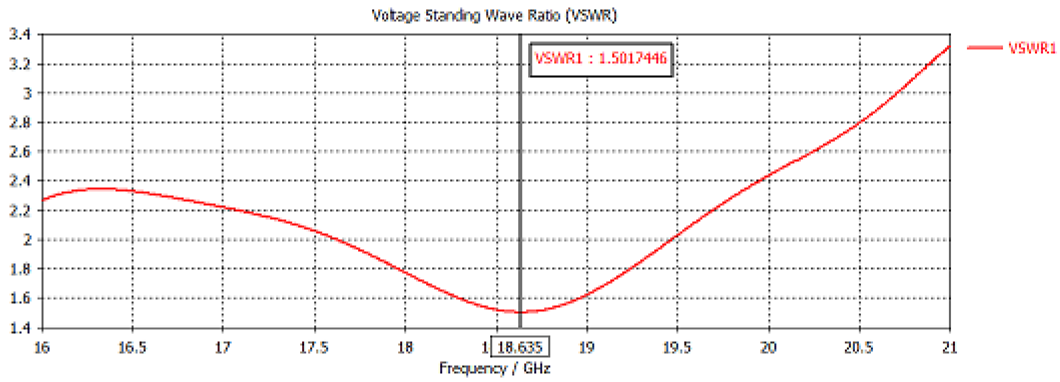


Fig. 6.10 VSWR plot

Far field plot of patch antenna at 18.6 GHz-

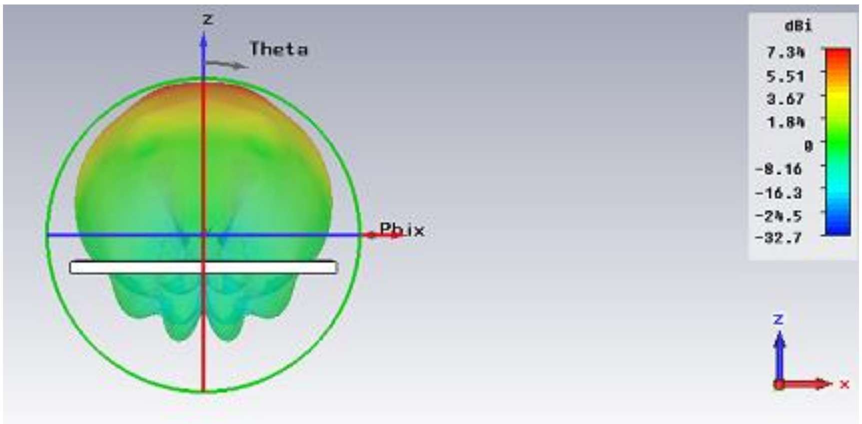


Fig. 6.11 Far field plot at 18.6 GHz

Current distribution in patch antenna-

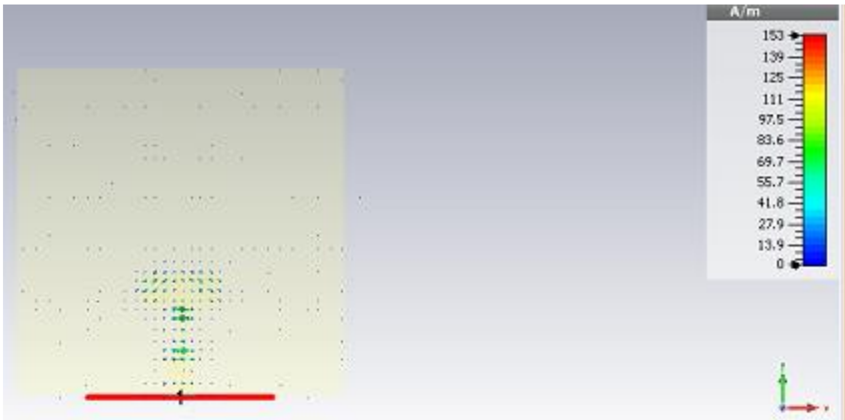


Fig. 6.12 Surface Current distribution at 18.5 GHz

Radiation pattern at 18.6 GHz-

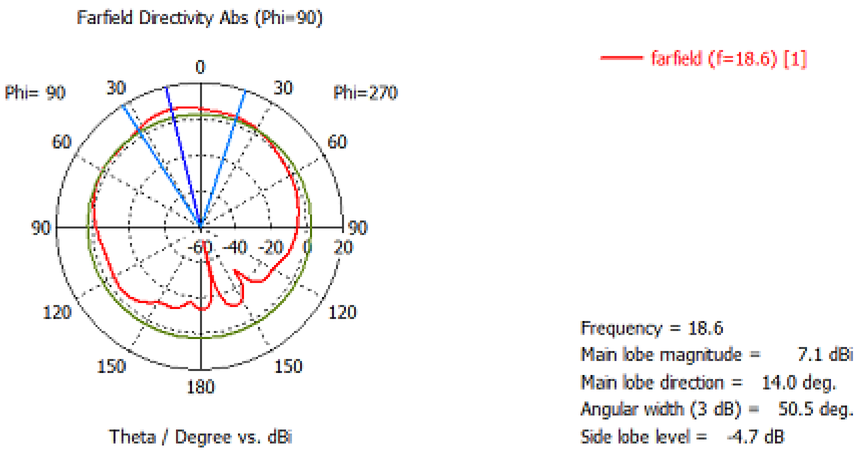


Fig. 6.13 Radiation pattern

6.2 EBG UNIT CELL AND ITS PHASE REFLECTION DIAGRAM

The unit cell of used dual band EBG structure is shown below-

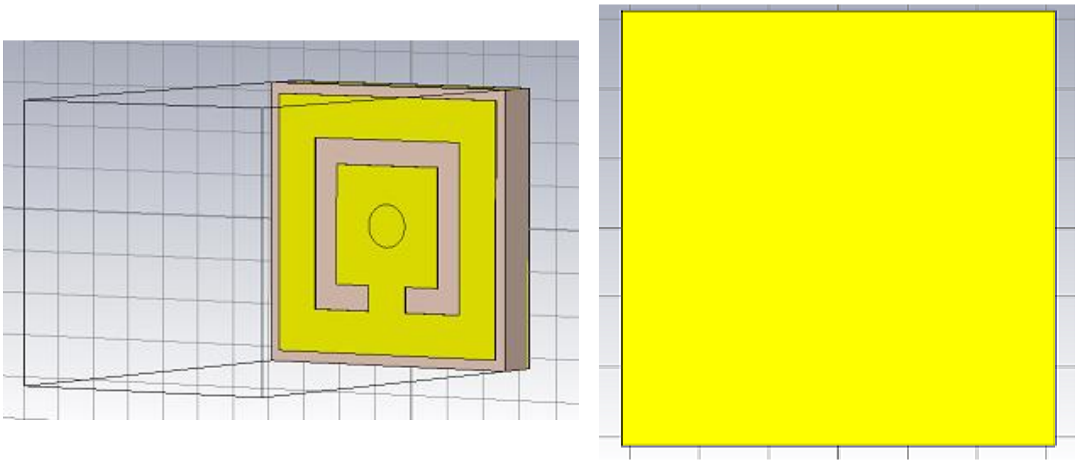


Fig. 6.14 Unit cell of EBG structure and its back view

The substrate used is FR-4 having dielectric constant 4.3 and for metal copper has been used.

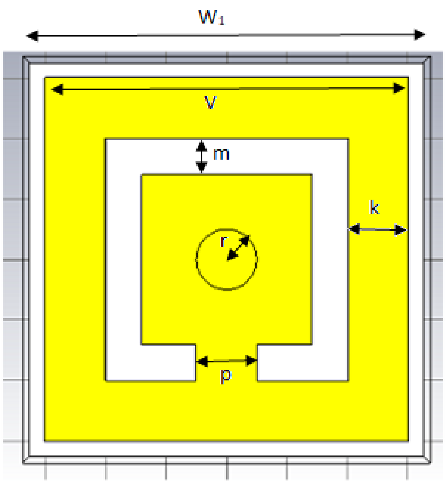


Fig. 6.15 Unit cell

Dimensions of unit cell of EBG	In mm
h	1
t	0.035
W_1	6.5
V	6
r	0.5
p	1
m	0.6
k	1

Table 6.2 Dimensions of unit cell of EBG

Its phase reflection diagram is obtained using CST STUDIO SUITE by using floquet ports and periodic boundary along the side walls of unit cell, open for top surface and electric for bottom surface. As we can see there are two frequency bands having $+90^0$ to -90^0 phase.

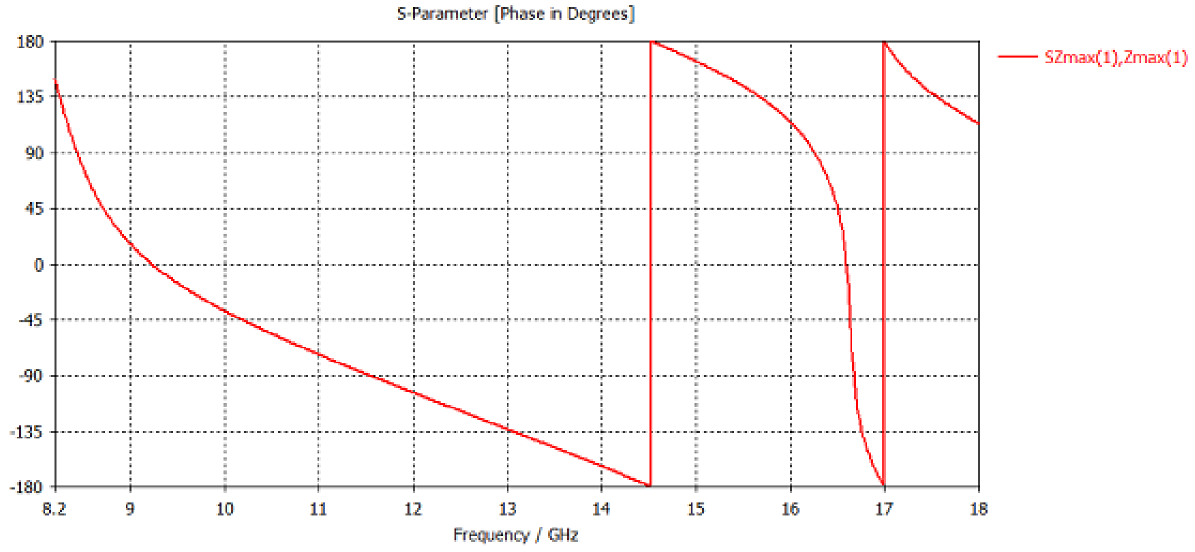


Fig. 6.16 Phase reflection diagram of EBG

6.3 EBG STRUCTURE AND ITS BANDGAP

A 6×6 array of EBG structure has been used and the bandgap of this structure is obtained by using suspended microstrip line over the EBG structure. S_{21} indicates the bandgap in EBG structure.

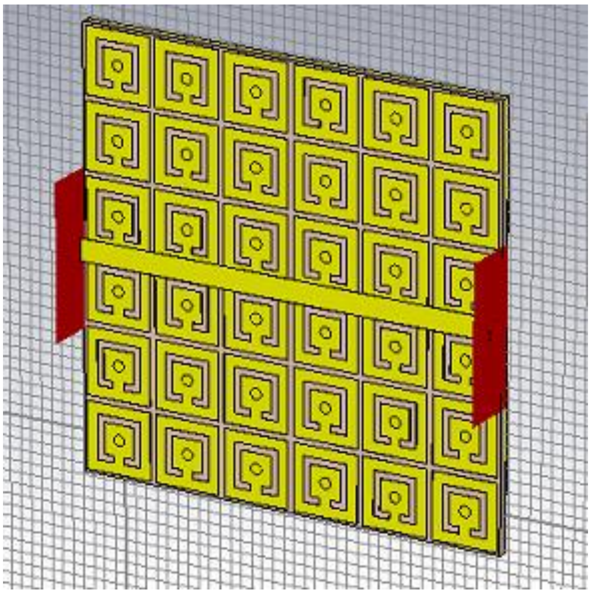


Fig. 6.17 EBG structure with suspended strip

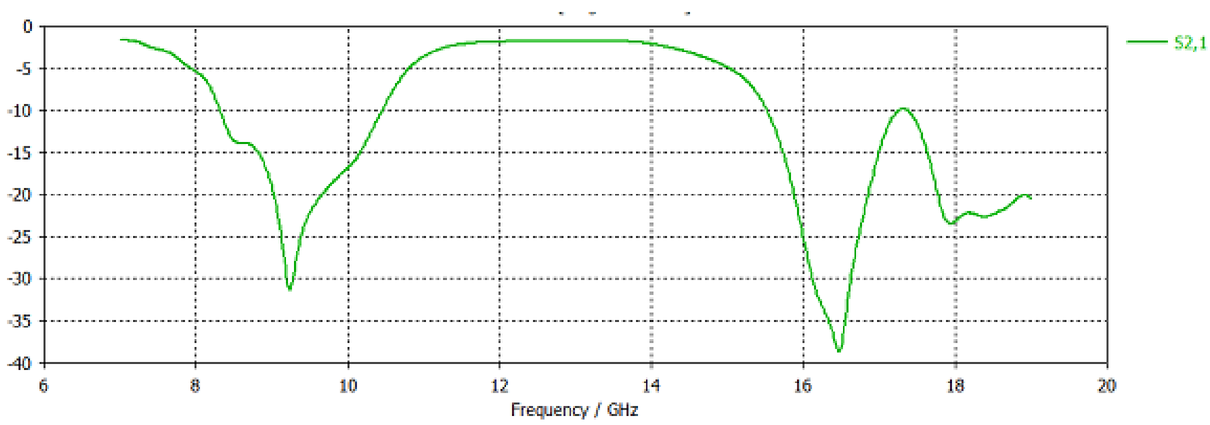


Fig. 6.18 Bandgap of EBG structure

Here we can see that two bandgaps are provided by this structure centred at 9.2 GHz(8.3 GHz to 10.4 GHz) and 16.47 GHz(15.5 GHz to 17.2 GHz).

6.4 COMPARISON IN BANDGAP OF DIFFERENT EBG STRUCTURES

In this section different EBG structures have been compared-

Here the above EBG structure having 6×6 and 8×8 array have been compared and we can see that as the size of array increases, transmission from one port to other decreases and lower bandgap frequency shifts to a higher value.

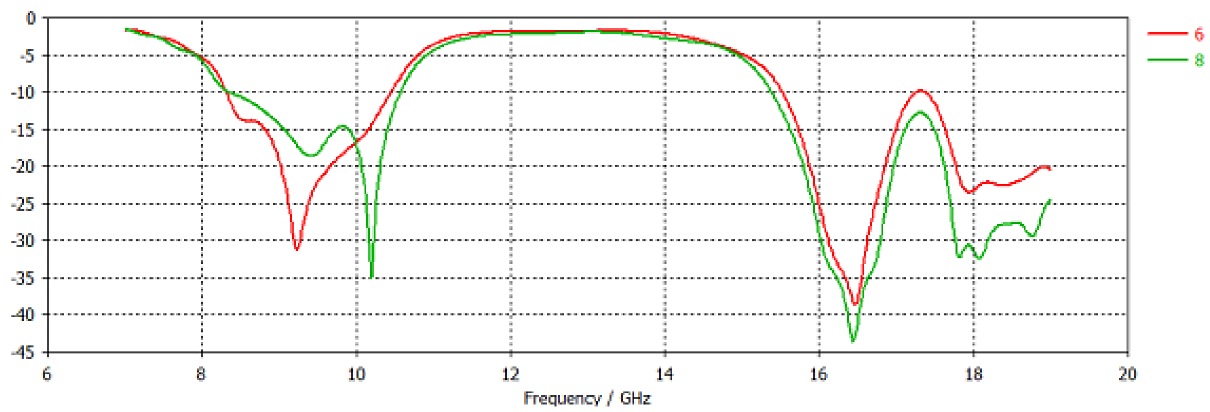


Fig. 6.19 EBG comparison for array size

Here the width of slot inside the square is varied and we can see that as the width decreases the upper bandgap frequency shifts to a lower value.

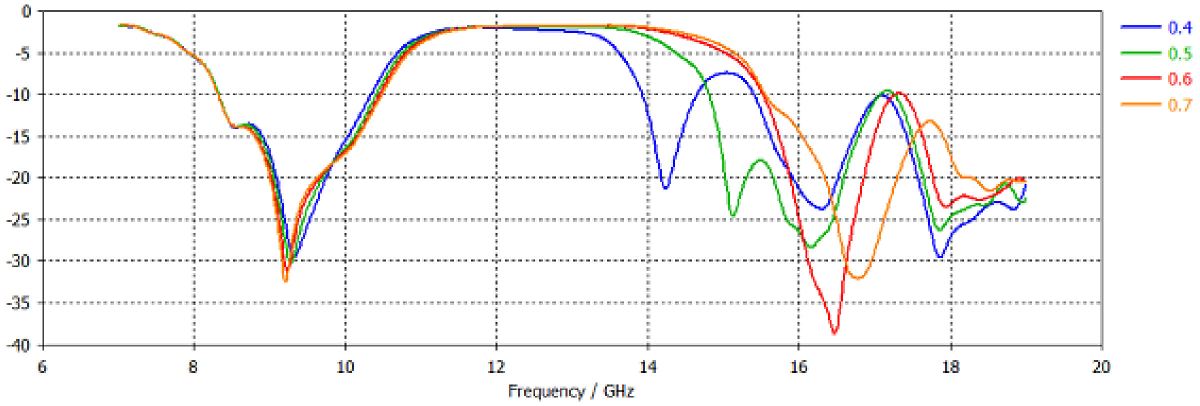


Fig. 6.20 EBG comparison for slot width

Here circular slot with and without via and double C slot inside the square patch are compared-

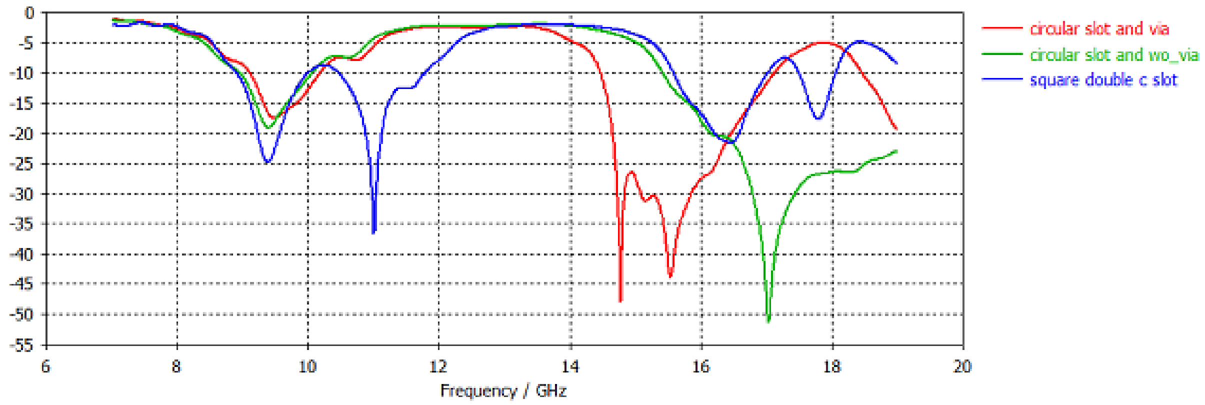


Fig. 6.21 Comparison of EBG with different slots

Here the square patch with and without disconnected loop type slot and with and without square slot have been compared-

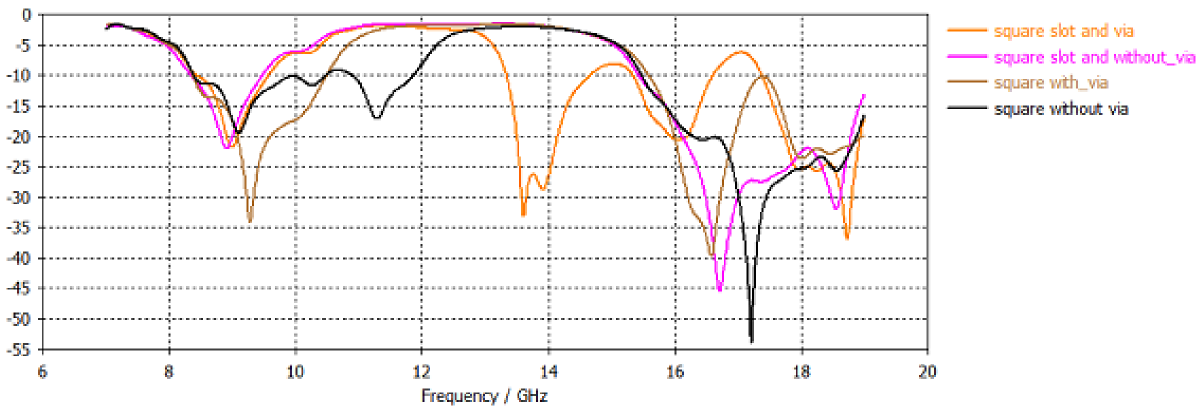


Fig. 6.22 Comparison of EBG with different slots

6.5 RECONFIGURABLE PATCH ANTENNA WITH EBG STRUCTURE

In this section the ground plane of reconfigurable patch antenna has been replaced with the EBG structure shown above with 6×6 array of square type EBG having disconnected loop type slot and connected to ground by via.

6.5.1 when switch is ON

Here the patch antenna with EBG structure as ground has been shown-

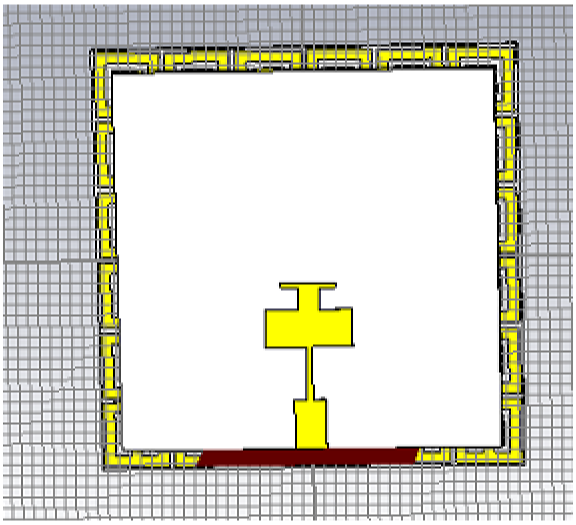


Fig. 6.23 Patch with EBG when switch is ON

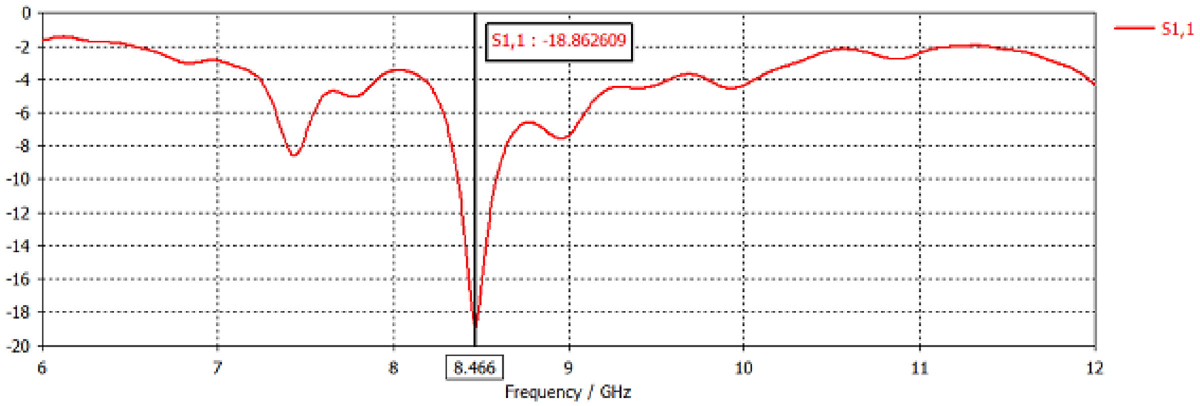


Fig. 6.24 Return loss plot

By the return loss plot we can see that BW is from 8.3 to 8.65 GHz, resonant frequency is 8.466 GHz and return loss at this frequency is -18.86dB. the frequency has decreased due to increased capacitance due to EBG structure.

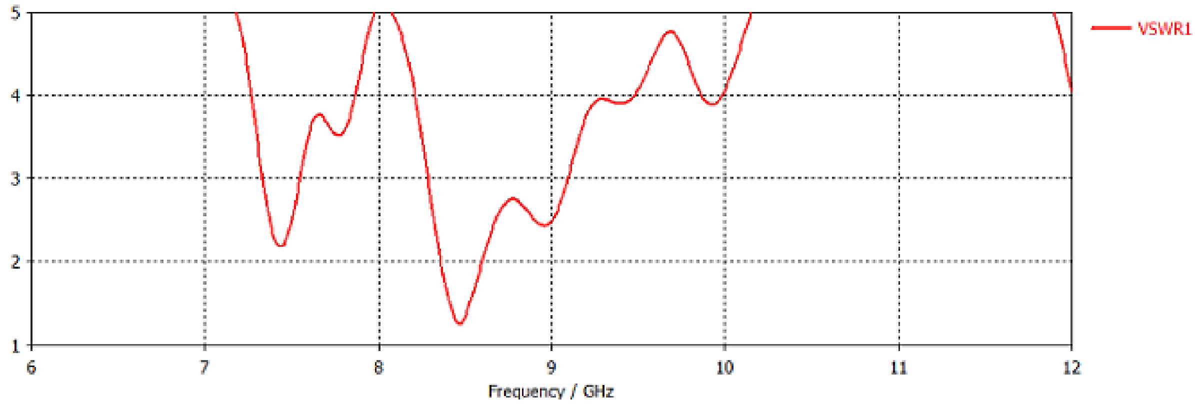


Fig. 6.25 VSWR plot

VSWR is less than 2 for 8.3 to 8.66 GHz.

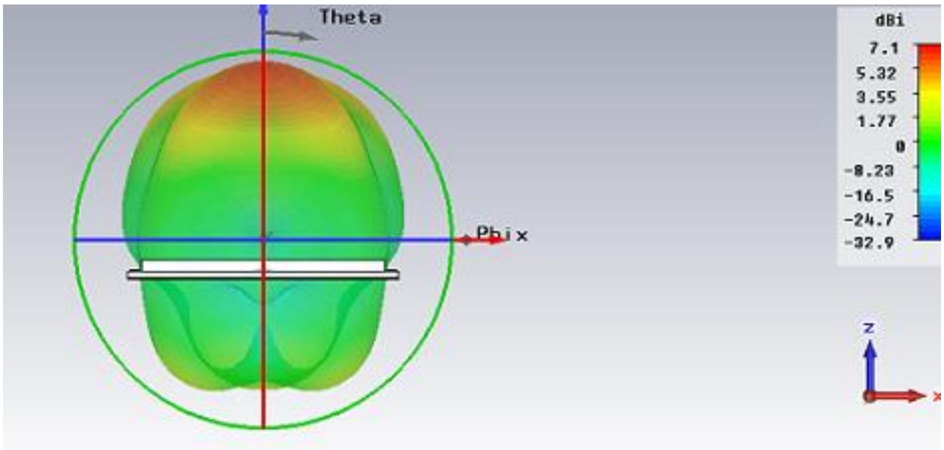


Fig. 6.26 Far field plot

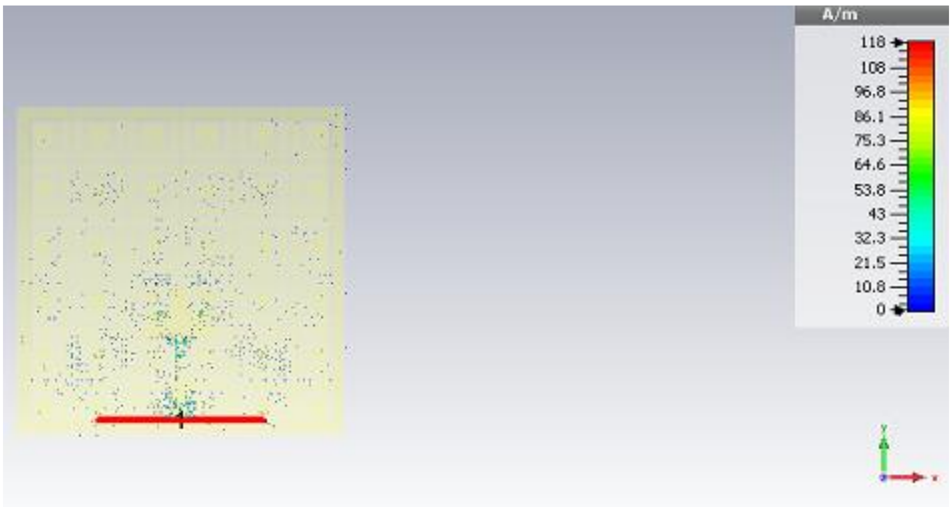


Fig. 6.27 Surface current distribution at patch antenna

We can see that surface current distribution in patch antenna with EBG structure is less than without EBG structure.

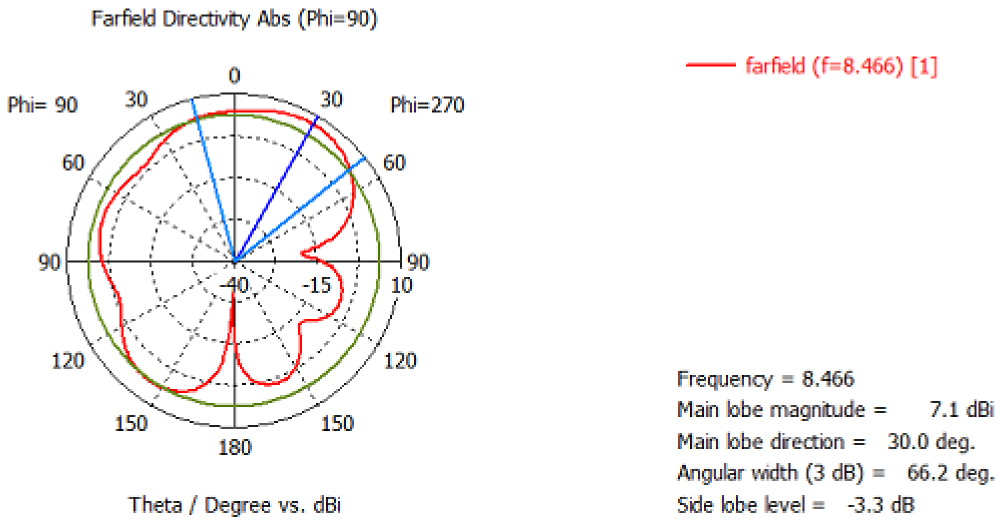


Fig. 6.28 Radiation pattern

6.5.2 When switch is OFF

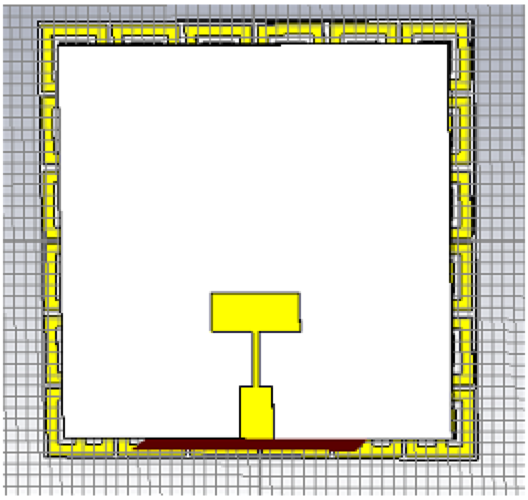


Fig. 6.29 Reconfigurable patch antenna with EBG when switch is OFF

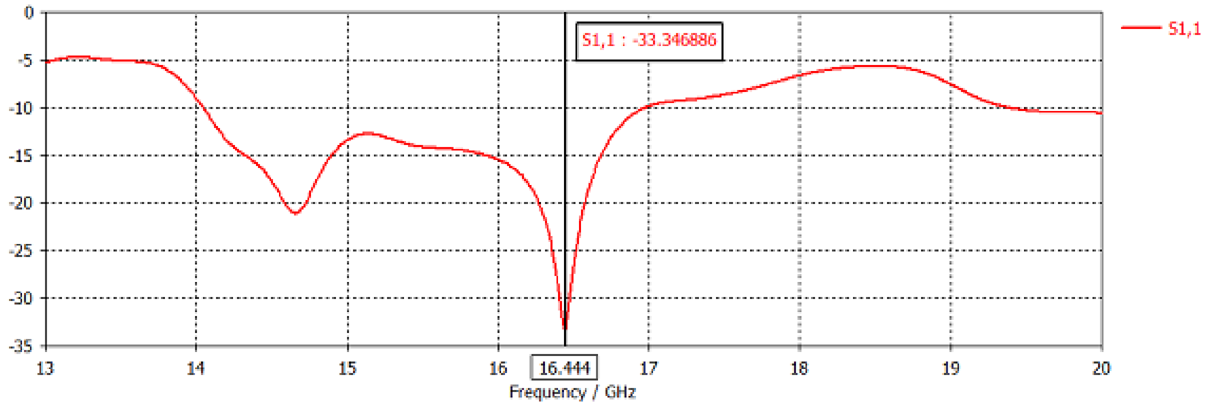


Fig. 6.30 Return loss plot

Resonant frequency is 16.44 GHz and return loss at this frequency is -33.34 dB. BW is 14 to 16.9 GHz. Hence we can see that by using EBG structure BW has increased and return loss is decreased.

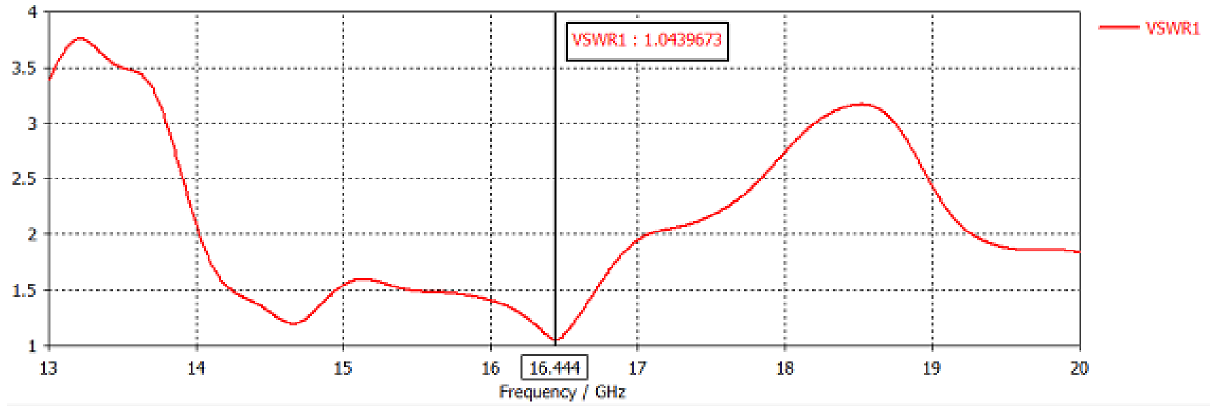


Fig. 6.31 VSWR plot

VSWR is less than 2 for 14 to 17 GHz by the above plot.

Far field plot at 16.5 GHz-

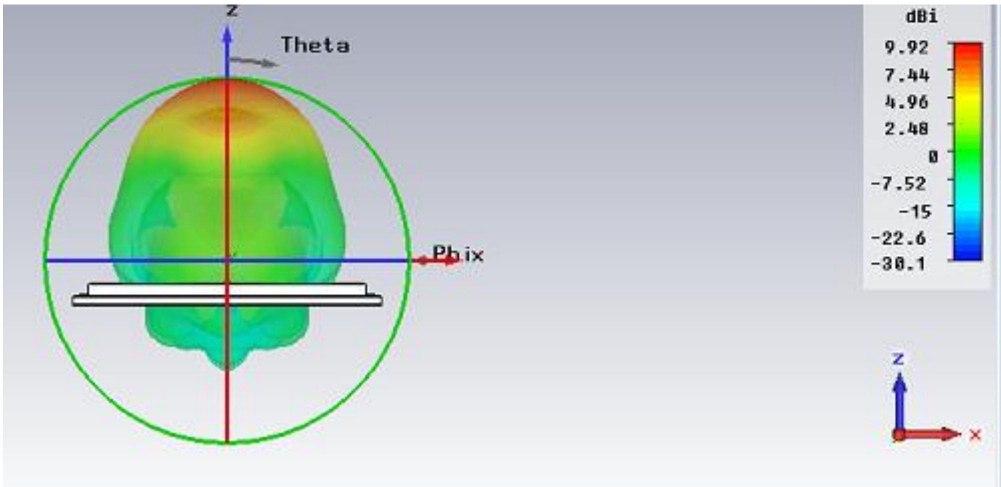


Fig. 6.32 Far field plot

Surface current distribution at patch antenna at 16.5 GHz-

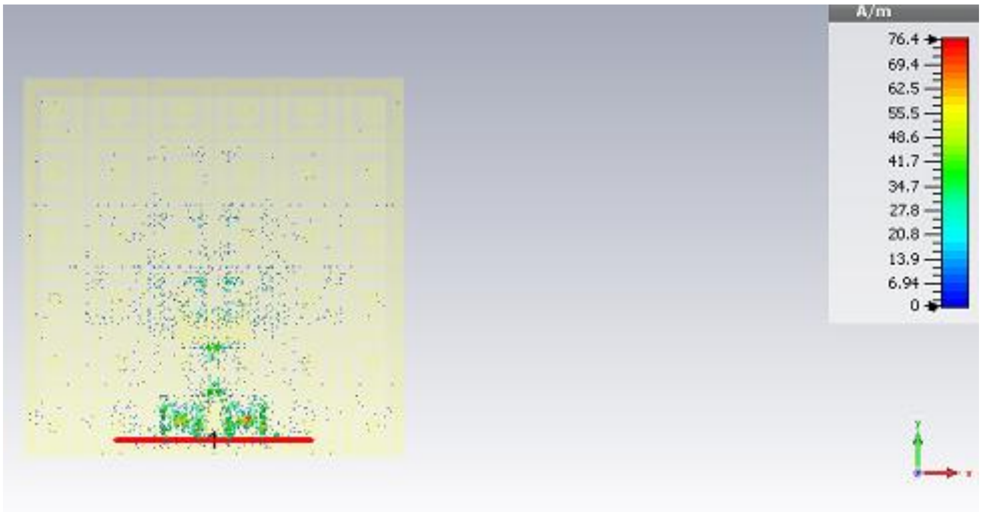


Fig. 6.33 Surface current distribution

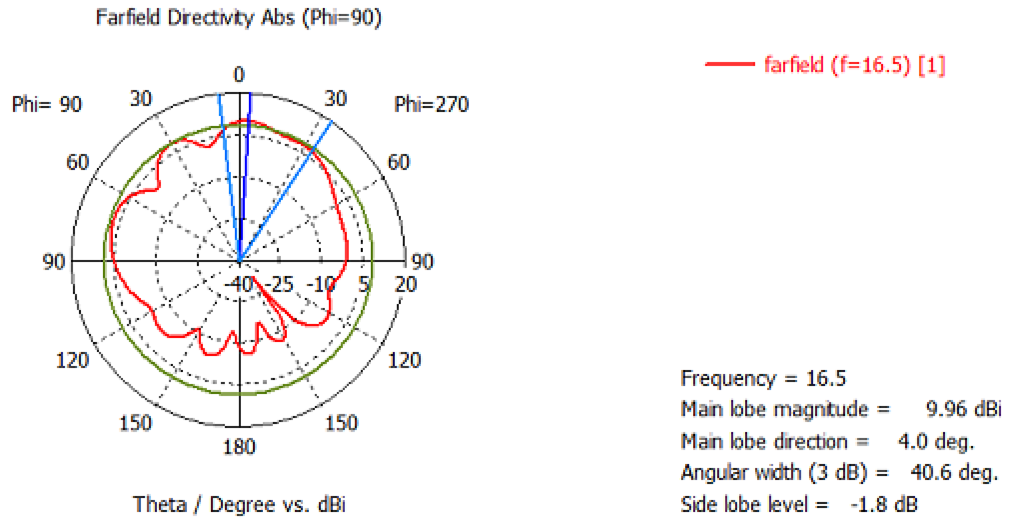


Fig. 6.34 Radiation pattern at 16.5 GHz

6.6 RECONFIGURABLE PATCH ANTENNA WITH EBG AROUND PATCH

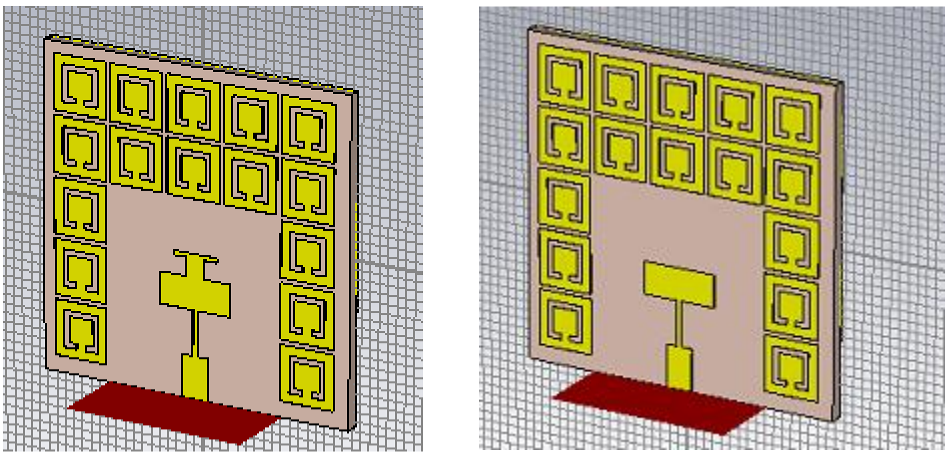
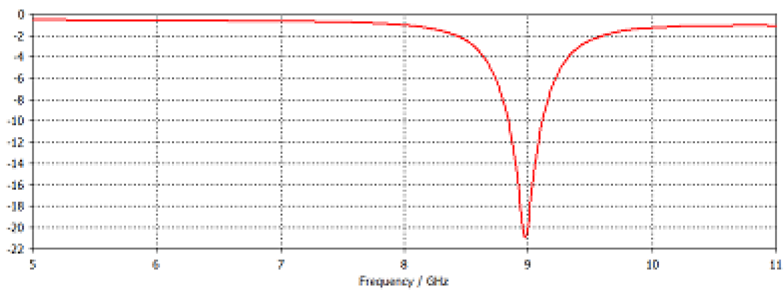


Fig. 6.35 Reconfigurable patch antenna with EBG around patch when switch is ON and OFF



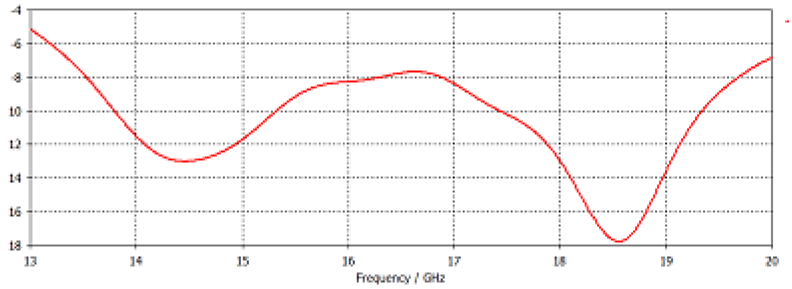


Fig. 6.36 Return loss plot for switch ON and OFF

Here when switch is ON then resonant frequency is 8.98 GHz and return loss at this frequency is -21dB, BW is from 8.8 to 9.11 GHz. When the switch is off then we have two bands, higher one having less return loss which is -17.8 at 18.5 GHz.

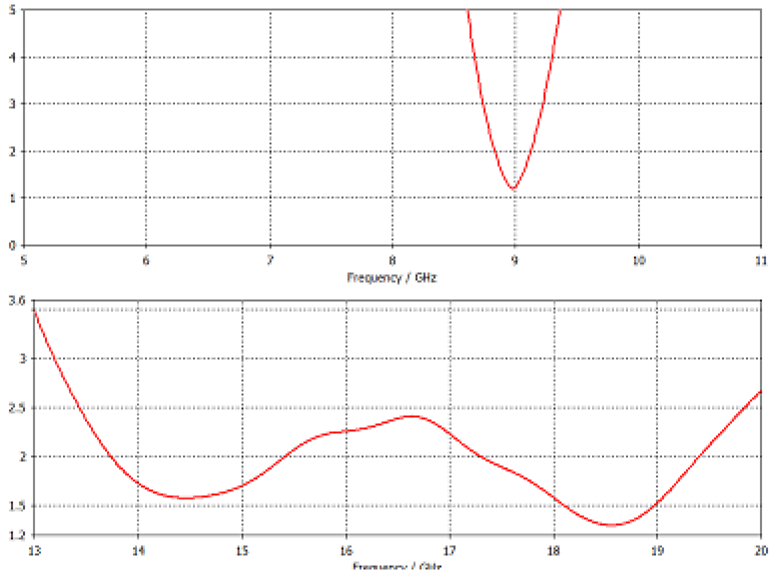
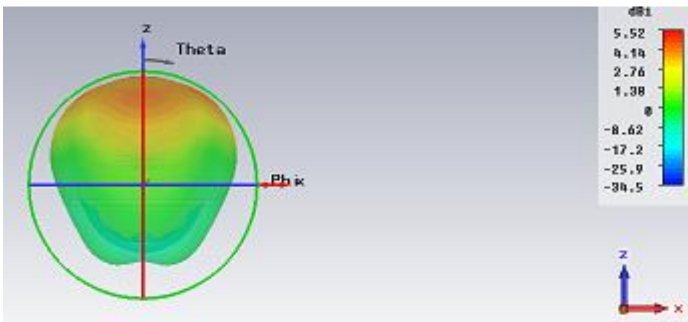


Fig. 6.37VSWR plot for switch ON and OFF

When switch is ON then for 8.8 to 9.12 VSWR is less than 2 but when switch is OFF then from 13.79 to 15.3 and from 17.43 to 19.33 VSWR is less than 2.



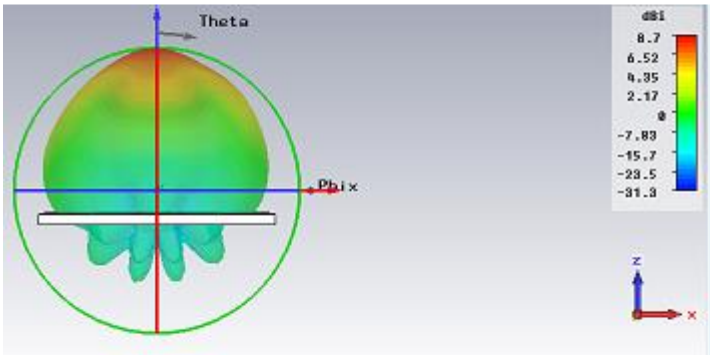


Fig. 6.38 Far field for switch ON at 8.9 GHz and for switch OFF at 18.5 GHz

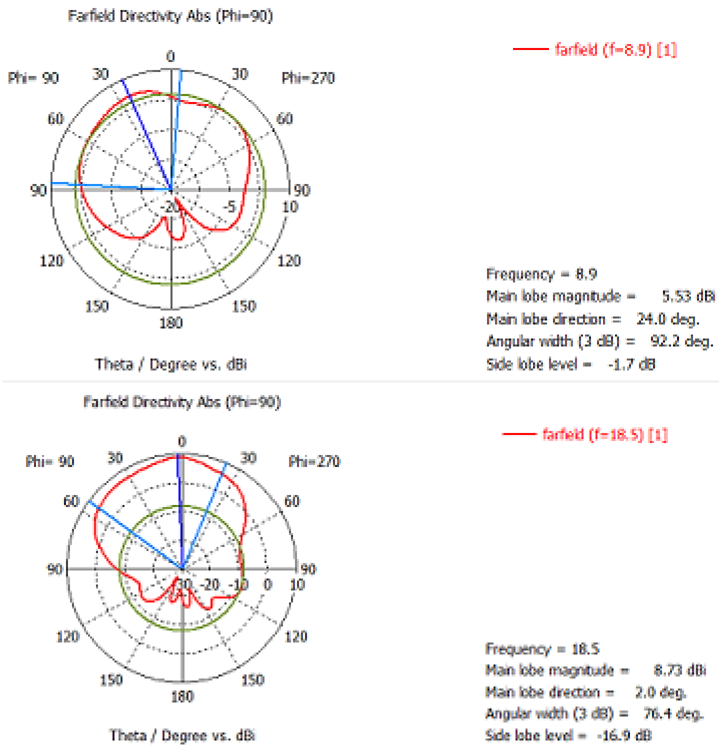


Fig. 6.39 Radiation pattern for switch ON at 8.9 GHz and for switch OFF at 18.5 GHz

CHAPTER 7

CONCLUSION

By looking at the above resukys we can conclude that adding EBG structure to an antenna whether as a substitute to ground(AMC) or around patch can increase BW, decrese return loss, suppress surface waves, reduce noise.

Here the switch used is electrical which is controlled manually but for modern antenna systems FGPA controlled reconfigurable patch antennas are also being used where rather than being controlled manually, the reconfigurability of antenna is controlled by softwares. Using the EBG structure with such an antenna can improve its performance.

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