Design and Simulation of Microstrip Patch Array Antenna for Polarization Diversity

Major Project Report

Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology

In

Electronics & Communication Engineering

(Communication Engineering)

By

Dilip D. Chakravarti

(09MECC02)

Department of Electronics & Communication Engineering

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Nirma University

Ahmedabad-382 481

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Under the Guidance of

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Declaration

This is to certify that

i) The thesis comprises my original work towards the degree of Master of Technology in Communication Engineering at Nirma University and has not been submitted elsewhere for a degree.

ii) Due acknowledgement has been made in the text to all other material used.

Dilip D. Chakravarti

Certificate

This is to certify that the Major Project entitled **"Design and Simulation of Microstrip Patch Array Antenna for Polarization Diversity"** submitted by **Dilip D. Chakravarti (09MECC02)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Communication Engineering of Nirma University, Ahmedabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of our knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Abstract

With the rapid growth of wireless communication, the antennas with polarization diversity performance are widely studied and adopted, especially using Microstrip patch antenna. In the urban or indoor environments, the radio wave will propagate through complicated reflections or scattering process.In order to reduce signal fading caused by multipath effects, diversity techniques are applied to the antenna system at the receiving site. Such type of antenna is particularly suitable for mitigating fading in multi-path propagation environments.

The proposed design of inset-fed microstrip patch array antenna work in the ISM band with 2.4 GHz center frequency. A design of the broadband dual-polarized microstrip antennas is proposed by using inset feed technique but slant at desired rotation. Here, +45° and -45° rotation is provided to the patch geometry, which gives dual polarization.

First, the design parameters for single element of rectangular patch antenna have been calculated from the transmission line model equation and extended the antenna design into the array geometry. Single element +45° and -45° ,+45° 1×2 patch array, -45° 1×2 patch array and ±45° 1×2 patch array geometry have been design and simulated using FR4 (ϵ_r=4.7) and RT/DUROID 5880 (ϵ_r=2.2). From the simulation results, it is found that the RT/DUROID 5880 has very low loss compare to FR4.

Further to meet the high gain and directivity demand ±45° 1×4 and ±45° 2×2 patch array antenna has been design and simulated. Bandwidth is improvised by increasing height of the substrate, increasing substrate height of 6.35 mm, 9% bandwidth has been achieved at the operating frequency range.

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Last, but not the least, no words are enough to acknowledge constant support and sacrifices of my family members.

- Dilip D. Chakravarti

09MECC02

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Chapter 1

Introduction

Wireless communication is one of the most vibrant areas in the field of communication today. With the rapid progress of wireless communication, the antennas with polarization diversity performance are widely studied and adopted, especially using Microstrip patch antenna. Due to the advantage of mobility, there are many applications in wireless local area networks (WLAN) at 2.4 GHz. For these applications, multipath effects are the common reception problems in dynamic, complex electromagnetic environments.

In the urban or indoor environments, the radio wave will propagate through complicated reflections or scattering process. The polarization of radio wave may change significantly. In order to effectively receive the communication signal, a polarization diversity antenna for wireless communication applications such as Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMax), Satellite Digital Multimedia Broadcasting (SDMB) may become an important requirement.

In order to reduce signal fading caused by multipath effects, diversity techniques are therefore applied to the antenna system at the receiving site. Such type of antenna is particularly suitable for mitigating fading in multi-path propagation environments. The channel capacity improvements are widely studied with proven advantages when adopting antennas with polarization diversity. Therefore, antennas with dual polarizations, wide bandwidth, good port isolation and compact dimension are highly desirable for modern wireless communication applications. Several antenna designs providing polarization diversity have been designed and their characteristics were published in recent papers [1], [2], [3]. This includes designs based on dipoles , patch antennas , slot radiators and loop antennas.

The microstrip Patch antenna offers three excellent advantages relative to other types of antennas; low weight, low profile with conformability and low manufacturing cost and mechanically robust when they are mounted on rigid surface. Their narrow bandwidths, however, have been one of the most noticeable limitations hindering their wider applications [4].

For polarization Diversity antenna Dual-polarization is desired. In practices, a dual-polarized microstrip antenna can be realized by feeding the rectangular microstrip patch at two orthogonal edges, through edge feed or probe feed, which excites TM_{01}-and TM_{10} -mode with orthogonal polarizations [5] , [6].

The most reported technique for achieving dual polarization is using different feed mechanisms such as aperture coupling a single patch with crossed narrow slots or two offset narrow slots. This technique requires a relatively complicated feed arrangement or a complex multiplayer construction to reduce the coupling between the two feed lines and therefore adds complexity to the fabrication process [6] , [7].

All the reported technique shows that to produce Dual-Polarization, the design requires two orthogonal feed lines. Whereas propose technique requires only one feed line to patch element with desire rotation. Here +45° and -45° rotation is provided to the geometry which reduces complexity to the fabrication process [8].

In Practical Wireless application, the desired signals in communications are always appeared in an uncertain polarization way, so dual slant ±45° polarization are appreciated for its advantages over vertically/horizontally polarized antennas [2].

Single element geometry is not much efficient to produce good Gain and Directivity, parameter but array geometry is used to produce high Gain and Directivity value. 1×2, 1×4 and 2×2 patch array antenna geometry is fulfill the Gain, Directivity and

Bandwidth requirement.

1.1 Literature Survey

Several Microstrip Patch antenna have been reported and analyzed to address polarization diversity in literature [3], [9], [10], [6] , [7].

In practices, a dual-polarized microstrip antenna can be realized by feeding the rectangular microstrip patch at two orthogonal edges, through edge feed or probe feed, which excites TM_{01}-and TM_{10} -mode with orthogonal polarizations.

LJ du Toit et al. [5], have reported low cost, dual polarized linear array of microstrip patch antenna. The antenna is a linear array of square microstrip patches excited by a coplanar corporate feed network. The feed network has two ports and allows independent radiation of orthogonal linearly polarized far-field. Here the diagonals of each square patch are aligned with the principle planes of the array. Consequently the two port feed network, which allows essentially independent excitation of the two dominant, degenerate patch modes, will cause far-field which are orthogonally and linearly polarized at angles of $\pm 45°$ to the principle planes. For low manufacturing cost a coplanar feed network was used ie. a single layer array.

Bjorn Lindmark et al. [6], have reported aperture coupled patch geometry for dual-polarization. Authors reported single layer feed where one channel feeds a single slot centered under the patch whereas the other channel feeds two separate slots placed near the edges of the patch. Author propose a technique to reduce the symmetry to only one principal plane which turns out to be sufficient for high isolation and low cross-polarization. The advantage is that only one layer of feed network is needed, with no air-bridges required. In addition the aperture position is centered under the patch.

S. K. Padhi et al. [7],have reported technique for achieving dual polarization is using different feed mechanisms such as aperture coupling a single patch with crossed narrow slots or two offset narrow slots or C-shaped coupling slot. The antenna uses a novel configuration of symmetric and asymmetric coupling slots.This technique requires a relatively complicated feed arrangement or a complex multiplayer construction to reduce the coupling between the two feed lines and therefore adds complexity to the fabrication process [6] , [11].

Yahya Rahmat-Samii et al. [12], have reported novel design of a microstrip patch antenna with switchable slots (PASS) is proposed to achieve circular polarization diversity. Two orthogonal slots are incorporated into the patch and two pin diodes are utilized to switch the slots on and off. By turning the diodes on or off, this antenna can radiate with either right hand circular polarization (RHCP) or left hand circular polarization (LHCP) using the same feeding probe.

Jung-han Kim et al. [13], have reported novel design, annular ring slot antenna with circular polarization diversity. The proposed antenna consists of a ring slot with tuning stubs. Four PIN diodes are attached to achieve circular polarization diversity. By switching the diodes on or off, the proposed antenna can be operated either RHCP(Right Hand Circular Polarization) mode or LHCP(Left Hand Circular Polarization) mode.

Though, these schemes for polarization diversity give an optimum result, its complexity increases with respect to structure and manufacturing process.

M. S. R. Mohd Shah et al. [8], have reported a technique for polarization diversity uses single layer substrate to maintain simplicity in structure without using dual feed for dual polarization. In this technique, +45° and -45° rotation is provided to the patch geometry from the 50 ohm feed line, which reduces complexity to the fabrication process. In this article, FR4 is used as Substrate. ReturnLoss and VSWR shows good agreement for impedance matching but Gain of particular patch antenna is low.

M. S. R. Mohd Shah et al. [1], have carry forward their work from [8] and try to improve the Gain parameter by array application. So, to improve the Gain, 1x4 and 2x2 patch array antenna design has been proposed. Simulation and measurement results shows good match.

Aurangzeb Hayat Awan et al. [14] have reported the design of single microstrip patch antenna at 2.5 GHz, simulated with different kind of substrate materials. Subsequent to the selection of the most desirable substrate based on simulated results, a design of 8 element microstrip patch antenna array at X-band (10 GHz) design and a comparison of simulated and experimental results have been discussed. Using three types of substrate materials FR4, GML1000 and RT/Duroid 5880, the single patch simulated and experimental results are compared in conclusion. Results shows that the low loss RT/Duroid is the most desirable for satellite and ground terminal antennas application.

1.2 Motivation

All the reported techniques show good agreement with the simulated and measured results. In polarization diversity scheme, Dual feed with multilayer stack structure along with various shapes of slot is used for dual polarization. Various multilayer technique adds complexity in design and manufacturing process.

Motivation comes from the reported techniques to design such a microstrip patch array antenna which has single layer substrate along with simple feed mechanism. Also major interest from the array antenna design is to obtain high gain, wide impedance bandwidth and cost effective design for polarization diversity.

1.3 Problem Statement

The main objective of this project work is to design single layer substrate patch array antenna with high Gain and Bandwidth for polarization diversity in wireless communication application such as WLAN.

1.4 Thesis Organization

The rest of the thesis is organized as follows.

Chapter 1 describes, the breif introduction of requirement of Polarization diversity in wireless communication and reported techniques for Dual Polarization produced in patch antenna and array geometry and about antenna design software HFSS.

Chapter 2 describes, Basic configuration of microstrip patch antenna and its radiation characteristics, feeding techniques and analysis model and antenna properties like Polarization, ReturnLoss, VSWR, Radiation Pattern, Bandwidth. This chapter also explains array characteristics like Pattern Multiplication, Sidelobes, etc.

Chapter 3 describes, the concept of Transmission Line Model for Inset-Fed patch antenna design. This chapter also shows single element Inset-Fed +45° and -45° Microstrip Patch Antenna design and their simulation results. The concepts of Quarter-Wave Transformer for impedance matching and design of Power Divider for 1×2 patch array antenna with simulation result is shown.This chapter also shows +45° , -45° and ±45° 1×2 patch array antenna design and simulation results. At the end of chapter, simulation results have been summarized and remarks has been made.

Chapter 4 describes, the single element Inset-Fed +45° and -45° patch antenna design using substrate RT/Duroid 5880 (ϵ_r=2.2). Power Divider for 1×2 patch array antenna has been design and simulated. This chapter also includes +45° , -45° and ±45° 1×2 patch array antenna design and simulation results. At the end of chapter, simulation results of all the designs have been summarized and remarks has been made.

Chapter 5 describes, the design and simulation results of Power Divider for 1×4 patch array antenna using substrate RT/Duroid 5880 (ϵ_r=2.2). Further, 1×4 ±45°

and 2×2 ±45° patch array antenna design and simulation results have been shown. At the end of chapter, simulation results of 1×4 ±45° and 2×2 ±45° patch array antenna summarized with previous chapter's results.

Chapter 6 describes, the various bandwidth enhancement method. Single element Inset-Fed +45° and -45° patch antenna using substrate RT/Duroid 5880 (ϵ_r=2.2) with height of 6.35 mm have been design and simulated. Further Simulation results and designs of 1×2, 1×4, 2×2 patch array antenna have been shown. At the end of chapter, simulation results of all the designs have been summarized and remarks has been made.

Chapter 7 describes, the final conclusion of project work and future scope.

Chapter 2

Overview of Microstrip Patch Antenna

2.1 Introduction

Microstrip line were first proposed in 1953 and were increasingly used in the late 1960s and 1970s to realize circuits, generally called Microwave Integrated circuit (MICs).Although radiation leakage which occurs in MICs is most unwanted in circuits, the design of microstrip patch antenna had already been suggested in 1953. A patent was issued in France in 1955 in the names of Gutton and Baissinot.

More than 20 years after the original suggestion was made, the first actual microstrip antenna appeared in 1974. The first practical antennas were developed by Howell and Munson. Considerable interest in microstrip antenna developed, with a first major specialists' meeting held in Las Cruces, New Mexico 1979; a steady flow of publication and several technical books followed.

Microstrip antennas appeared as a product of microstrip circuits which by then had become a mature technology. Their design and realization took advantages of the techniques developed for microstrip circuits and used microstrip circuits substrates.

2.2 Basic Configuration of Microstrip patch Antenna

Considering most basic form, a microstrip patch antenna consists of a rectangular patch on one side of a dielectric substrate, which has a ground plane on the other side as shown in Figure 2.1.

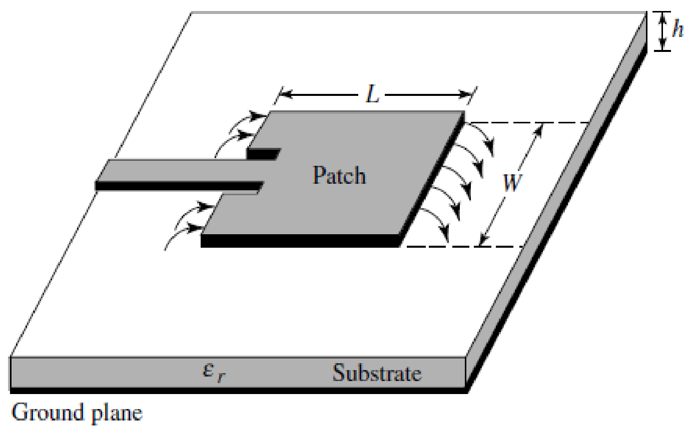

Figure 2.1: Basic Configuration of Microstrip Patch Antenna

The patch is generally made up of conducting material such as copper or gold and can be take any possible shapes.The radiating patch and the feed lines are usually photoetched on the dielectric substrate

The geometry of the patch is selected depending upon the required specification.The principle geometries are shown in Figure 2.2.

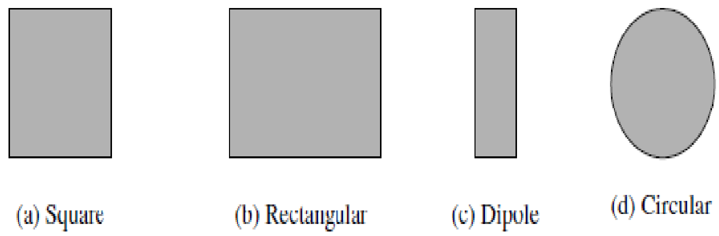

Figure 2.2: Principle Geometry of Patch Elements

2.3 Advantages and Limitation of Microstrip Patch Antenna

Microstrip patch antennas have many advantages. Some of them are light weight, low volume and thin profile configuration.

The rest of the advantages are listed below.

a. Since Microstrip patch antennas are low profile, the fabrication cost is comparatively less.

b. Many patch geometries are available to design patch antenna. Therefore, flexibility to design is very high.

c. Generation of Dual frequency and Dual polarization is easy in this case. Large numbers of geometries are available to generate dual frequency as well as dual polarization antenna.

d. Microstrip patch antennas can support both, linear as well as circular polarization.

e. Multiband operation is possible with Microstrip patch antennas.

f. Microstrip patch antenna can also be integrated with Microwave Integrated Circuits.

g. They can easily conform to a curved surface of a vehicle or product.

Although Microstrip patch antenna has many advantages, but it has come limitations like narrow bandwidth, low gain etc.

Some of the limitations are listed as follows.

a. Microstrip patch antennas have very narrow bandwidth. Commonly, with single layer substrate, 2.5 % bandwidth can be achieved and with multilayer substrate, 30 % bandwidth can be achieved.

b. Inherently, Microstrip patch antennas provide low gain and low efficiency.

c. They have relatively poor radiation efficiency.

d. Microstrip patch antennas consist of conductor as well as dielectric. Therefore, conductor and dielectric losses come into picture.

e. Since Microstrip patch antennas are less in size, it is very difficult to keep polarization purity up to certain level.

f. From some specific height of substrate, the surface wave phenomenon become predominant and losses due to surface wave excitation become high.

g. Microstrip patch antennas use the dielectric materials which are sensitive to environmental factors like temperatures, humidity.

2.4 Application of Microstrip Patch Antenna

Although, Microstrip patch antennas have numbers of limitations, they are widely used nowadays, mainly because of their low weight, low volume and thin profile.

Some of the applications of microstrip patch antenna are discussed below.

(1) Because of conformal property of microstrip patch antennas, they are widely used in Aircraft application. They are mainly built with Communication and Navigation Altimeters.

(2) Array of Microstrip patch antennas is created and it is used in RADAR system.

(3) Because microstrip patch antenna posses the property of low profile and low volume, they are widely used in mobile handsets and many handheld wireless devices like Bluetooth, GPS.

(4) Microstrip patch antennas can be used for the feed of the reflector antennas.

These are very few applications of microstrip patch antennas. There are lots of other applications in which Microstrip patch antennas are widely used.

2.5 Radiation Mechanism of Microstrip Patch Antenna

To make any antenna radiate, we have to keep its one of its dimensions as $\lambda/2$, if the antenna is resonating structure. For travelling wave type antenna or for frequency independent antenna like spiral, log periodic antenna,the $\lambda/2$ condition is not required.

Here,the microstrip patch antenna is modeled as cavity; hence it has the property of resonance. The length of the microstrip patch antenna is kept as $\lambda/2$, so that we have half cycle variation in that dimension. These edges are not responsible for radiation in Microstrip Patch Antenna, but the remaining two edges are responsible for radiation in patch antenna.

Here, as shown in Figure 2.3, because of air dielectric boundary, Microstrip line has the fringing field made up of E and H field lines. Hence, the field which propagates in the Microstrip line is not purely TEM but it is quasi TEM.The same case is applied to the patch antenna. The fringing field in patch antenna in length-wise cut section

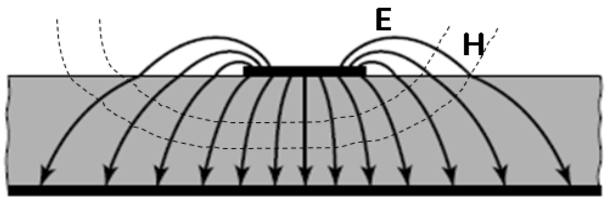

Figure 2.3: E and H Field Variation in Microstrip Line

is shown in top view of Figure 2.6.Because of this fringing field, effective length of the patch is increased and increased length is called Extended length ($\triangle L$).

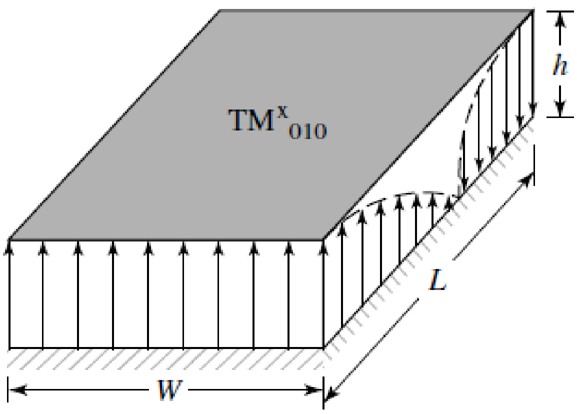

Figure 2.4: Half Cycle Variation along Length of Patch Antenna

Here, as we can see, at both ends of lengths, the E field direction is reverse for half cycle variation in length. Hence, if we take resultant E field pattern of this field distribution, the horizontal component of both the side are added whereas vertical component are equal in magnitude but opposite in direction, therefore they

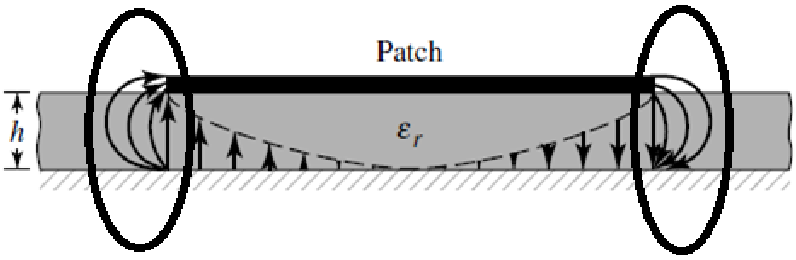

Figure 2.5: Fringing Field in Patch Antenna

are cancelled.

Therefore, E field variation in the patch antenna can be shown in side view of Figure 2.6.

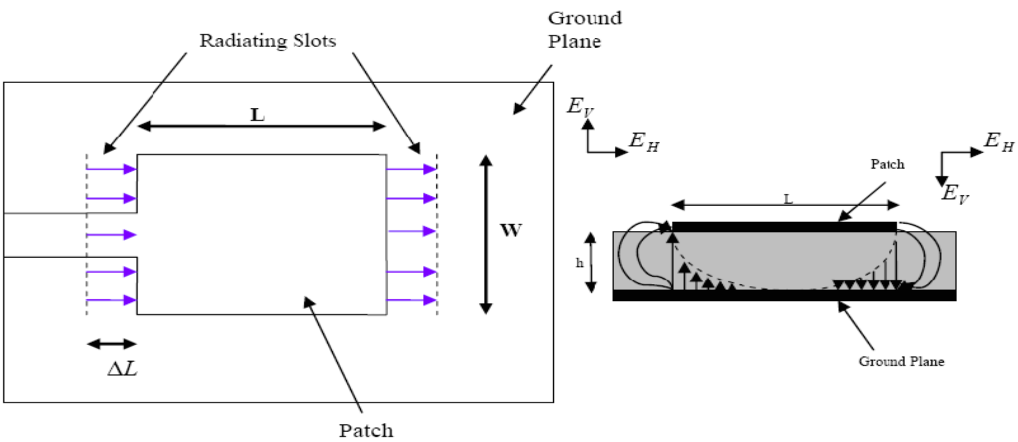

Figure 2.6: E Field Variation on Patch Antenna (Top View and Side View)

The co-ordinate axis is selected such that the length is along the x direction, width is along the y direction and the height is along the z direction.

Since E field is in horizontal direction, the propagation of EM waves is occurred in Z direction (Z direction is coming out f pages). Therefore, we can have broadside pattern. Similar explanation is given for two half cycle variation in patch. In this case, we have the farfield pattern of the patch antenna.

The half cycle variation along length generates TM_{10} mode in patch antenna, similarly, two half variation along length generates TM_{20} mode and so on [4].

The Edges which are responsible for the radiation are called Radiating Edges and others are Non-radiating Edges.

2.6 Patch Antenna Feeding Techniques

Different types of feed Mechanisms are available for Microstrip Patch Antenna. In, the broad way, they can be classified as [15]

2.6.1 Direct Feed Mechanism

(1) Coaxial Probe Feed

(2) Microstrip Line Edge Feed

(3) Microstrip Line Inset Feed

(4) Microstrip Line Gap Coupled Feed

2.6.2 Indirect Feed Mechanism

(1) Aperture Coupled Feed

(2) Electromagnetically coupled Feed

Direct Feed Mechanism

(1) Coaxial Probe Feed

The very basic mechanism to feed the microstrip patch antenna is to use of Coaxial Probe. The center conductor of the coaxial probe is extended to the patch and outer conductor is shorted to the ground plane of the patch antenna. The structure of the coaxial feed microstrip patch antenna is shown in Figure 2.7.

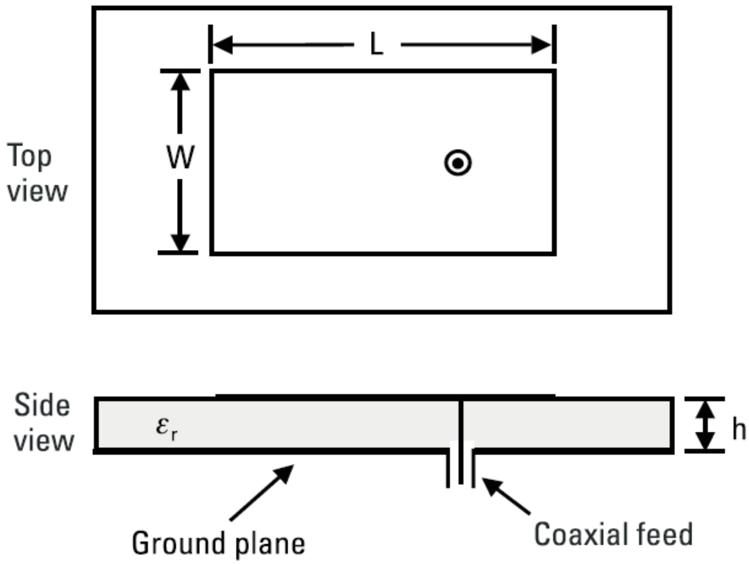

Figure 2.7: Co-axial Feed of Microstrip Patch Antenna

The major advantage of this type of feed mechanism is ease of fabrication and it can be placed at any desired location inside the patch in order to meet the impedance matching requirement.

The variation of Voltage, Current and Impedance on Patch Antenna is shown in below Figure 2.8. Since, the impedance is varying with the length; the position of the probe is set in such way so that there is perfect impedance matching.

The major disadvantage of this feed mechanism is that a hole has to be drilled in the substrate which causes the problem in impedance matching in fabrication of Antenna. Another disadvantage of probe fed technique is that the probe impedance comes into picture if the length of extended center is comparatively more. This problem become more predominant when, in order to improve the

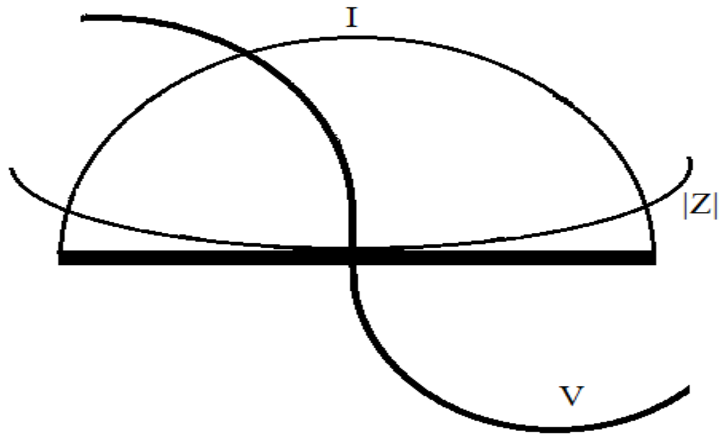

Figure 2.8: V, I and Z Variation along the length of the Patch

bandwidth of the antenna, we increase the substrate thickness which cause in increment in extended center conductor length.

The equivalent circuit for Coaxial Probe Fed Microstrip Patch Antenna can be shown in below figure 2.9.

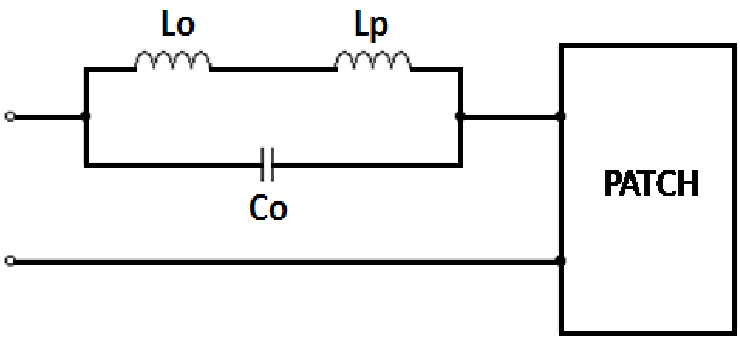

Figure 2.9: Equivalent Circuit of Coaxial Probe Fed Patch Antenna

Another disadvantage is that this mechanism provide narrow bandwidth and it is difficult to model specially for thick substrate ($h > 0.02\lambda$).

(2) Microstrip Line Edge Feed Mechanism

One of the simplest methods to feed the Patch Antenna is Microstrip line Feed. In this mechanism, the Patch Antenna is fed to any edge (radiating edge or Non-radiating edge) by Microstrip Line. The configuration is shown in Figure 2.10.

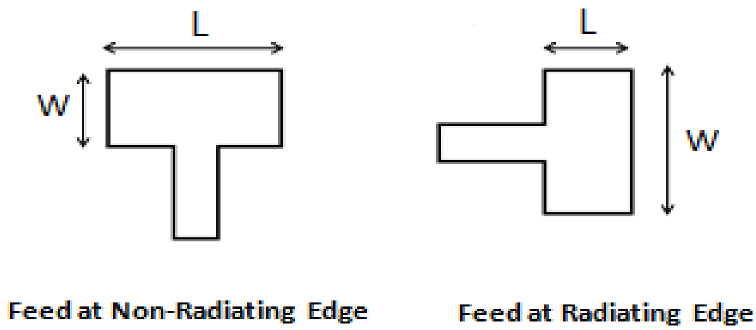

Figure 2.10: Microstrip Line Edge Feed patch Geometries

This type of excitation technique has an advantage that it can be fabricated on same substrate. Although, it appears to be a general choice, it has some limitation.

In this case, major problem is of impedance matching. The edge impedance of Microstrip Patch Antenna is very high compared to 50 ohms impedance of feed line. Therefore, external impedance matching circuits (like quarter wave transformer) is used between patch and 50 ohms impedance line. The impedance matching circuits also results in spurious radiation. Another limitation is that microstrip line blocks radiation from the portion of the patch with which it is in contact resulting in reduced radiation. This problem become predominant when the patch antenna is design for very high frequencies (millimeter-wave frequencies) where the microstrip line and patch width become comparable.

The equivalent circuit for microstrip line Fed Patch Antenna is shown in Figure 2.11.

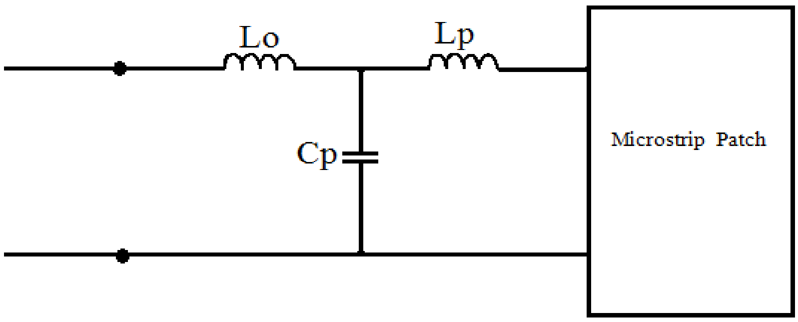

Figure 2.11: Equivalent Circuit of Microstrip Line Feed

(3) Microstrip Line Inset Feed

In order to remove one of the limitations of Microstrip Line Edges Feeding techniques, Microstrip line Inset Feeding Technique comes into picture.The configuration of Microstrip Line Inset Fed Patch Antenna is shown in Figure 2.12.

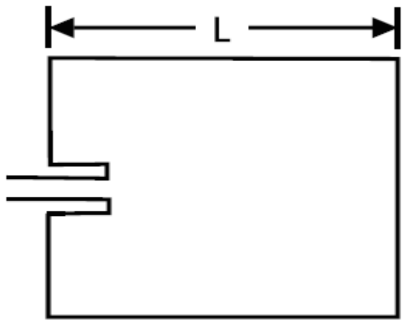

Figure 2.12: Microstrip Line Inset Fed Patch Geometry

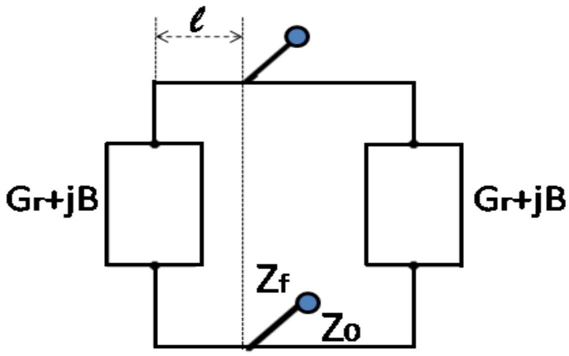

Figure 2.13: Equivalent Circuit of Microstrip Line Inset Fed Patch

As shown in Figure 2.12, the microstrip line is inset into patch. The feed position is selected such that the input impedance of the antenna is 50Ω.

This type of techniques has advantages like easy to design and fabricate. But, it has the problem of spurious radiation cause by the microstrip lines.

Generally, inset fed is used at the non radiating edges and cross polarization radiation is optimized by choosing the proper W/L ratio which is ideally 1.5. Inset fed is used widely in the integrated microstrip antenna.

The equivalent circuit for this type of feed mechanism is shown in Figure 2.13.

(4) Microstrip Line Gap Coupled Feed

The problem of impedance matching can be avoided by using the gap between the edge of the patch antenna and 50 ohms impedance Microstrip Line. The configuration for such type of feed mechanism is shown in Figure 2.14.

In this case, the gap should narrow for efficient coupling of power which introduces high capacitances in the structure. The limitation of this type of technique is that a narrow gap size will limit the power handling capability of the antenna. Moreover, the open end of the microstrip feed gives rise to the spurious radiation.

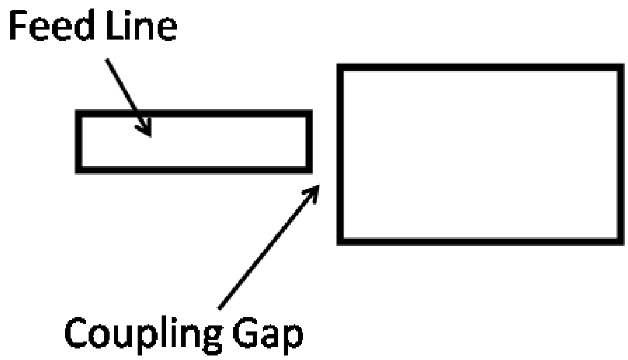

Figure 2.14: Microstrip Line Gap Coupled Fed Patch Geometry

The equivalent circuit of Gap Coupled Fed technique is shown in Figure 2.15.

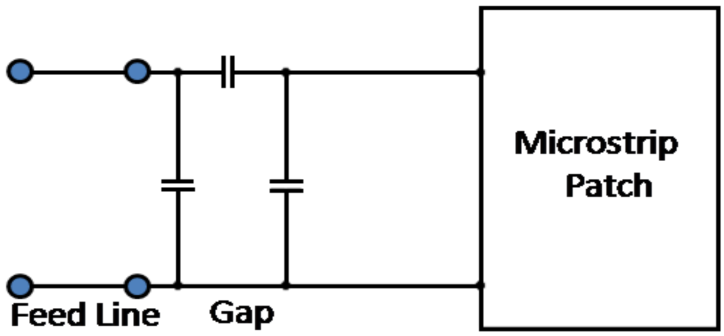

Figure 2.15: Equivalent Circuit of Microstrip Line Gap Coupled Feed

Indirect Feed Mechanism

(1) Aperture Coupled Feed

Direct feed mechanism have disadvantage of having narrow bandwidth. There are some of the techniques which can improve the bandwidth of the patch antenna and Aperture Coupled Feed is one of them. The configuration of Aperture coupled fed patch antenna is shown in Figure 2.16.

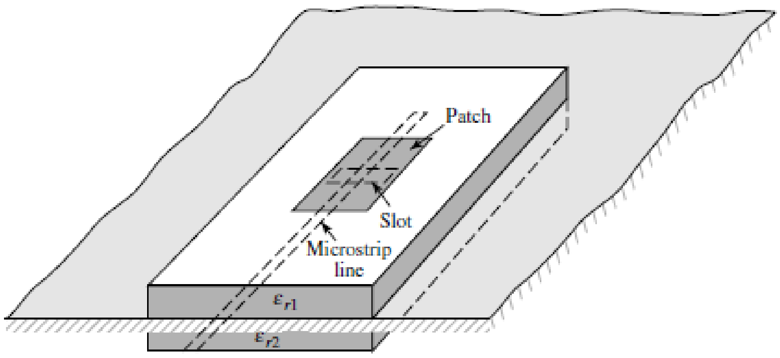

Figure 2.16: Aperture Coupled Feed Patch Antenna

As shown in above Figure 2.16, it uses two substrates by a common ground plane. A microstrip feed line on the lower substrate is electromagnetically coupled to the patch through slot aperture in the common ground plane. The slot can be of any shape and size depending upon the application. For an example, for linear polarized antenna, crossed slot is used.

Generally, the substrate selected for feed line has the high dielectric constant and thin height so that optimum coupling can be possible between the feed line and slot. The substrate selected for patch has low dielectric constant and thick in height so that the gain of the antenna can be improved.

The major advantage of this type of feed mechanism is wide bandwidth. Therefore, Aperture Coupled feed is mainly used in Ultrawide band application of patch antenna. Another advantage is that, radiation from the open end of the feed line does not interfere with the radiation pattern of the patch because of shielding effect of ground. This causes improvement in polarization purity.

The disadvantage of this feed is that, structure become complex, hence it is difficult to fabricate. Moreover, in this type of structure, number of layer increases which create difficulty in the optimizing the result. In addition, Aperture Coupled fed antenna is comparatively difficult to analyze.

The equivalent circuit of the aperture coupled fed microstrip patch antenna is shown in Figure 2.17.

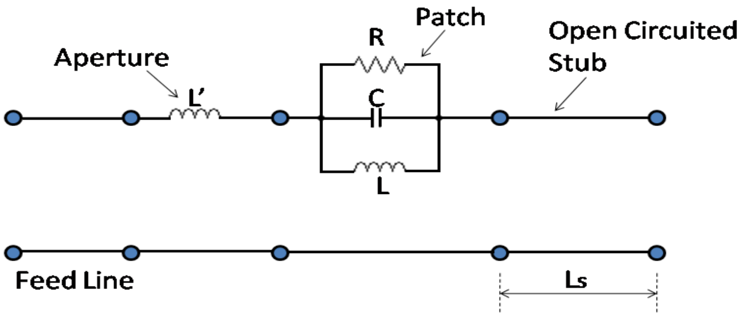

Figure 2.17: Equivalent Circuit of Aperture Coupled Feed Mechanism

(2) Electromagnetically coupled Feed

Another technique to improve the bandwidth of patch antenna is electromagnetically Coupled Feed Mechanism. The configuration of such type of feed mechanism is shown in Figure 2.18.

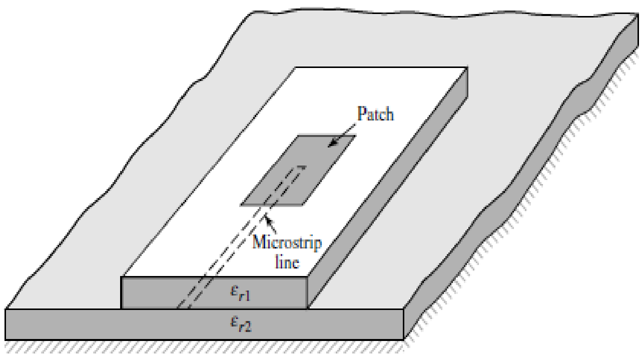

Figure 2.18: Electromagnetically coupled Microstrip Patch Antenna

It is a two layer structure with the microstrip line on the lower layer and the patch antenna on the upper layer. The feed line terminates in open end. The dielectric selected for the feed line has high dielectric constant in order to reduce the spurious radiation from the feed line.

The advantage of such type of feed is improvement in bandwidth. Another advantage is that, no soldering or drilling of a hole is required in this case.

The disadvantage is that, the structure become complex, hence it is slightly more difficult to fabricate. Here, the accurate alignment between patch and feed line required.

The equivalent circuit for EM coupled fed Microstrip Patch antenna is shown in Figure 2.19.

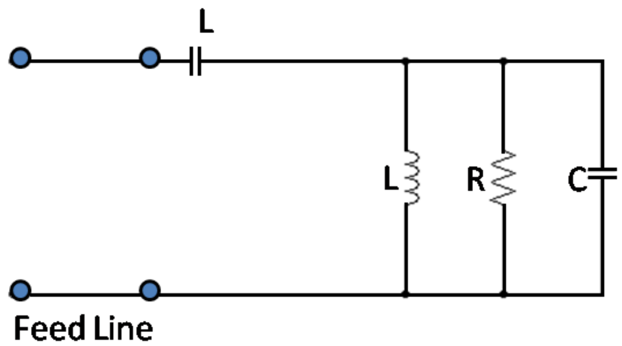

Figure 2.19: Equivalent circuit of EM coupled Microstrip Patch Antenna

2.7 Analytical Models for Microstrip Patch Antenna

There are some of the models which are used to analyze the microstrip patch antenna. Mainly three models are widely used which are, Transmission Line Model [15] , Cavity Model [4], and Full Wave Model (which includes Method of Moments, Finite Element Method and Finite Difference Time Domain Method [16]).

2.7.1 Transmission Line Model

The transmission line model was the first technique employed to analyze a rectangular microstrip antenna by Munson in 1974. In this model, the interior region of the patch antenna is modeled as a section of transmission line. The characteristic impedance Z_o and propagation constant β for the lines are determined by the patch size and substrate parameters.

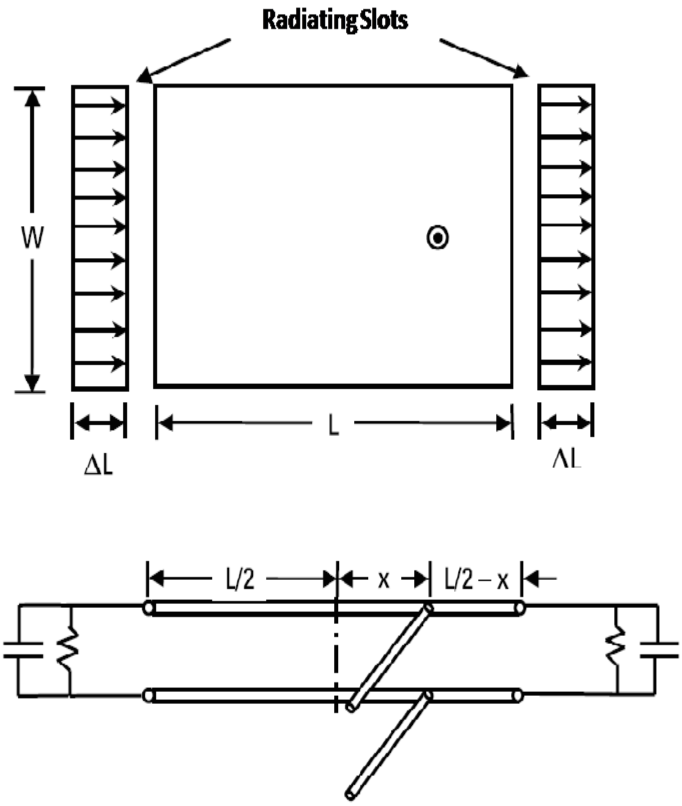

Figure 2.20: Transmission Line Model for Microstrip Patch Antenna

Consider a rectangular patch of dimensions $L \times W$.The periphery of this patch is described by four walls/edges at X=0, L and Y=0, W. The four edges of the patch are classified as radiating type or non-radiating type depending on the field variation along their length. The classification is based on the observation that a radiating edge is associated with slow field variation along the edge, such that there is an almost complete cancellation of the radiated power from the edge. For TM_{10} mode in patch, the edge at X=0, L are radiating types because the electric field is uniform along these edges. The walls at Y=0, W are non-radiating types because of half wave variation of the field along these edges. Based on this history, the equivalent circuit of the rectangular patch antenna can be shown as follows in Figure 2.20 [16].

2.7.2 Cavity Model

In cavity model, the interior region of the dielectric substrate is modeled as a cavity bounded by electric walls on the top and bottom. The basis for this assumption is the following observations for the substrate (h << λ).

Since, the substrate is thin; the field in the interior region does not vary much in the Z direction, i.e. normal to the patch.

The electric field is Z directed only, and magnetic field has only the transverse component H_X and H_Y in the region bounded by the patch metallization and the ground plane.

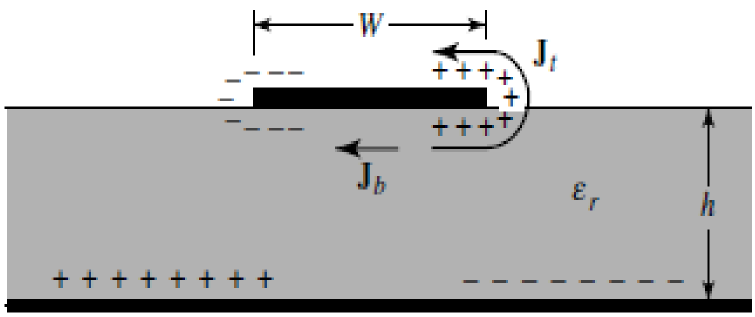

Figure 2.21: Charge Distribution and Current Density

Consider Figure 2.21, when the microstrip patch is provided power, a charge distribution is seen on the upper and lower surfaces of the patch and at the bottom of the ground plane. This charge distribution is controlled by two mechanisms - an attractive mechanism and a repulsive mechanism. The attractive mechanism is between the corresponding opposite charges on the bottom side of the patch and the ground plane, which tends to maintain the charge concentration on the bottom of the patch. The repulsive mechanism is between like charges on the bottom surface of the patch, which tends to push some charges from the bottom of the patch, around its edges, to its top surface. The movement of these charges creates corresponding current densities Jb and Jt , at the bottom and top surfaces of the patch, respectively, as shown in Figure 2.21. Since for most practical microstrip the height-to-width ratio is very small, the attractive mechanism dominates and most of the charge concentration and current flow remain underneath the patch. Small amount of current would flow on the surface of the patch and as the height-to-width ratio further decreases, the current flow on the top surface of the patch would be almost zero equal to zero, which ideally would not create any tangential magnetic field components to the edges of the patch. This would allow the four side walls to be modeled as perfect magnetic conducting surfaces which ideally would not disturb the magnetic field and, in turn, the electric field distributions beneath the patch [4].

2.7.3 Full wave Model

Full wave numerical techniques can provide analysis of microstrip antennas in which the effects like space wave radiation, surface wave loss and coupling, fringing fields, mutual coupling between the edges do not have to be modelled.These features are all integrated in numerical analysis techniques [16]. Some of the widely used numerical techniques are listed below:

(1) Method of Moment

In the MoM, the surface currents are used to model the microstrip patch, and volume polarization currents in the dielectric slab are used to model the fields in the dielectric slab. An integral equation is formulated for the unknown currents on the microstrip patches and the feed lines and their images in the ground plane. This method takes into account the fringing fields outside the physical boundary of the two-dimensional patch, thus providing a more exact solution.

(2) Finite Element Method

The FEM, unlike the MoM, is suitable for volumetric configurations. In this method, the region of interest is divided into any number of finite surfaces or volume elements depending upon the planar or volumetric structures to be analyzed. These discretized units, generally referred to as finite elements, can be any well-defined geometrical shapes such as triangular elements for planar configurations and tetrahedral and prismatic elements for three-dimensional configurations, which are suitable even for curved geometry. It involves the integration of certain basis functions over the entire conducting patch, which is divided into a number of subsections. The problem of solving wave equations with inhomogeneous boundary conditions is tackled by decomposing it into two boundary value problems, one with Laplace's equation with an inhomogeneous boundary and the other corresponding to an inhomogeneous wave equation with a homogeneous boundary condition.

(3) Finite Difference Time Domain Method

The FDTD method is well-suited for MSAs, as it can conveniently model numerous structural inhomogenities encountered in these configurations. It can also predict the response of the MSA over the wide BW with a single simulation. In this technique, spatial as well as time grid for the electric and magnetic fields are generated over which the solution is required. The spatial discretizations along three Cartesian coordinates are taken to be same. The E cell edges are aligned with the boundary of the configuration and H-fields are assumed to be located at the center of each E cell. Each cell contains information about material characteristics. The cells containing the sources are excited with a suitable excitation function, which propagates along the structure. The discretized time variations of the fields are determined at desired locations. Using a line integral of the electric field, the voltage across the two locations can be obtained. The current is computed by a loop integral of the magnetic field surrounding the conductor, where the Fourier transform yields a frequency response.

(4) Spectral Domain Technique

In the SDT, a two-dimensional Fourier transform along the two orthogonal directions of the patch in the plane of substrate is employed. Boundary conditions are applied in Fourier transform plane. The current distribution on the conducting patch is expanded in terms of chosen basis functions, and the resulting matrix equation is solved to evaluate the electric current distribution on the conducting patch and the equivalent magnetic current distribution on the surrounding substrate surface. The various parameters of the antennas are then evaluated.

2.8 Antenna Parameter

There are some important parameters need to be considered that characterize all antenna designs. These are the ReturnLoss, VSWR, Gain ,Bandwidth , Radiation Pattern.

2.8.1 ReturnLoss

ReturnLoss is a measure of the effectiveness of power delivery from a transmission line to a load such as an antenna.If the power incident on the antenna-under-test (AUT) is P_{in} and the power reflected back to the source is P_{ref} , the degree of mismatch between the incident and reflected power in the travelling waves is given by the ratio P_{in}/P_{ref}.The higher this power ratio is, the better the load and line are matched.

ReturnLoss is expressed in dB. ReturnLoss is defined,

$$RL = 10\log_{10}\left(\frac{P_{in}}{P_{ref}}\right) dB \tag{2.1}$$

ReturnLoss is also defined as,

$$RL = -20\log|\Gamma| dB \tag{2.2}$$

2.8.2 VSWR

VSWR is defined as the ratio of maximum to minimum voltage on the transmission line and is given by,

$$VSWR = \frac{V_{max}}{V_{min}} \tag{2.3}$$

The VSWR 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.

By definition, VSWR can never be less than 1.Most suitable value of VSWR for microstrip antenna is 2:1.

2.8.3 Gain

The ratio of the radiation intensity, in a given direction,to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically.

$$Gain = 4\Pi\left(\frac{U(\theta,\phi)}{P_{in}(Lossless\ Isotropic\ Source)}\right) \tag{2.4}$$

where, U(θ,ϕ) = Radiation Intensity

2.8.4 Bandwidth

The bandwidth of an antenna is defined as the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard [4].

The Bandwidth of the antenna is usually defined by the acceptable standing wave ratio (SWR) value over the concerned frequency range.To calculate bandwidth, 2:1 ratio will be used. Bandwidth can be defined as,

$$Bandwidth = \frac{VSWR - 1}{Q\sqrt{VSWR}} \tag{2.5}$$

where Q = Quality Factor

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{2.6}$$

Bandwidth(%) can also be find out,

$$Bandwidth(\%) = \frac{F_h - F_l}{F_c} \times 100 \tag{2.7}$$

where, F_h is the upper frequency, F_l is the lower frequency and F_c is the centre frequency.

2.8.5 Radiation Pattern

An antenna radiation pattern or antenna pattern is defined as [4], " a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates.In most cases, the radiation pattern is determined in the farfield region and is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization ".

A major lobe (also called main beam) is defined as the radiation lobe containing the direction of maximum radiation. In Figure 2.22 the major lobe is pointing in the

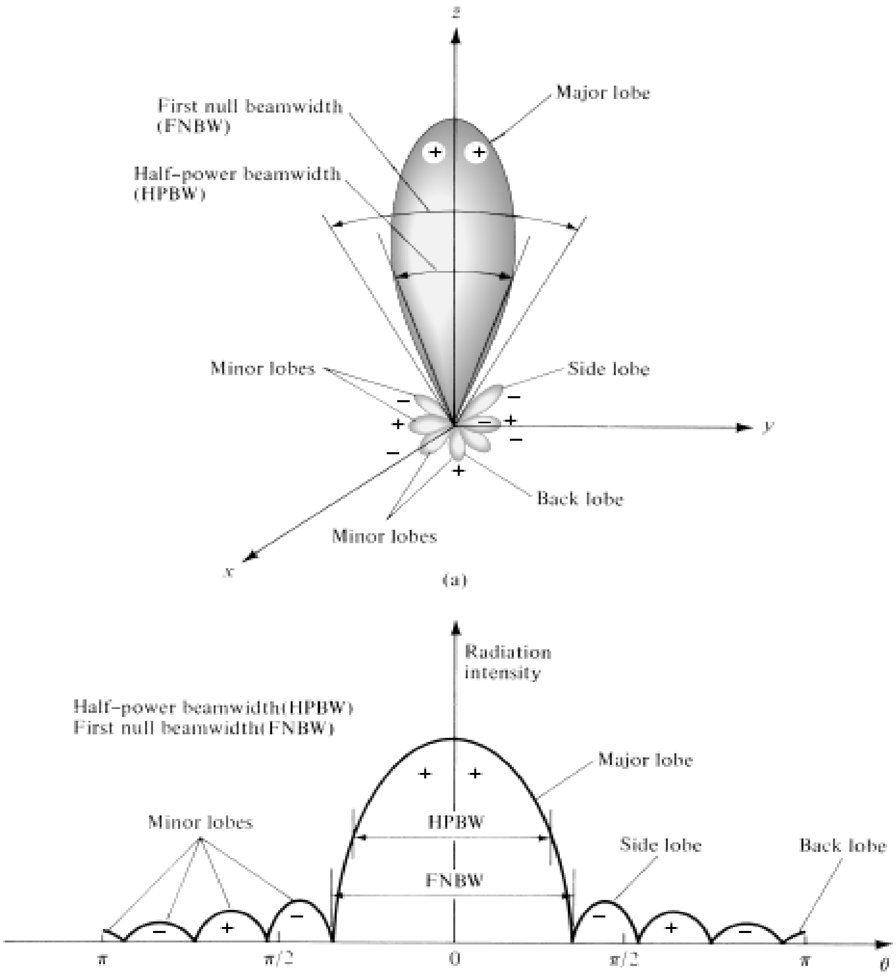

Figure 2.22: Radiation lobes and beamwidths of an antenna pattern.

$\theta = 0$ direction. In some antennas, such as split-beam antennas, there may exist more than one major lobe. A minor lobe is any lobe except a major lobe. In Figures 2.22 all the lobes with the exception of the major lobe can be classified as minor lobes.

A side lobe is "a radiation lobe in any direction other than the intended lobe." (Usually a side lobe is adjacent to the main lobe and occupies the hemisphere in the direction of the mainbeam.) A back lobe is "a radiation lobe whose axis makes an angle of approximately 180° with respect to the beam of an antenna." Usually it refers to a minor lobe that occupies the hemisphere in a direction opposite to that of the major (main) lobe.

Minor lobes usually represent radiation in undesired directions, and they should be minimized. Side lobes are normally the largest of the minor lobes. The level of minor lobes is usually expressed as a ratio of the power density in the lobe in question to that of the major lobe. This ratio is often termed the side lobe ratio or side lobe level. Side lobe levels of -20 dB or smaller are usually not desirable in most applications.

2.8.6 Polarization

Depending on the geometry of an antenna, it can produce different polarization. Some antennas are very simple, while other exhibit quite sophisticated shapes. For actual applications, signals that have either linear or circular polarization are required. Elliptical polarization results from geometrical or electrical imperfection.

Linearly Polarized Antenna

The basic antenna that provides a linear polarization is the Dipole. The wave radiated by a dipole has an electric field directed along its length. All the antennas made by combining dipoles or their variations. Usually, microstrip antennas of rectangular, circular, annular or triangular shapes can be considered to be modified forms of dipole antennas, which provide a linear polarization.

The polarization quality of an antenna is given by the ratio of the desired linearly polarized component (copolar) to that of the unwanted one (crosspolar). For microstrip antennas, ratios are typically in the range of 20-30 dB.

Circularly Polarized Antenna

Circularly polarized antennas can be divided into two main types. In type 1 circularly polarized antennas, the circular polarization is a direct result of the physical aspect of the antenna, which generally has the shape of a spiral or helix. Type 2 circularly polarized antennas consists of a dual polarized antenna(with two orthogonally polarized linear elements), where the two ports are fed in phase quadrature(same amplitude and 90° phase shift). These antennas can produce circular polarization in both sense of rotation (Right Hand Circularly Polarization-RHCP, Left Hand Circularly Polarization-LHCP) as well as possible elliptical and linear polarizations. Circularly polarized microstrip patch antennas fall into this category: two resonant modes of the patch radiate with orthogonal polarization and an adequate excitation provide 90° phase shift.

Axial ratio R is given by,

$$R = 20log\,(b/a)\,dB \tag{2.8}$$

$b =$ major axis length

$a =$ minor axis length;

is used to characterized the degree of a circularly polarized antenna in achieving the circular polarization.

2.9 Arrays

The radiation characteristics of single-element antenna were discussed.Usually the radiation pattern of a single element is relatively wide, and each element provides low values of Gain and Directivity.[17]

For purpose of point-to-point and point-to-multipoint communication, it is desirable for the antenna to have a specific shape of radiation pattern such as a narrow beam shape in certain direction and little radiation in other directions in the case of point-to-point communication. Such a pattern cannot be obtained by using a single microstrip patch antenna. However by means an array of antennas, it is possible to obtain a pattern that is highly directive in one direction. Moreover, the beamwidth can in principle be made as narrow as one wish by increasing the number of elements in array.

In many applications it is necessary to design antennas with very directive characteristics (very high gain) to meet the demands of long distance communication. This can only be accomplished by increasing the electrical size of the antenna.

Enlarging the dimensions of single elements often leads to more directive characteristics. Another way to enlarge the dimensions of the antenna, without necessarily increasing the size of the individual elements, is to form an assembly of radiating elements in an electrical and geometrical configuration. This new antenna, formed by multielement, is referred to as an array. [18]

In most cases, the elements of an array are identical.This is not necessary, but it is often convenient, simpler, and more practical. The individual elements of an array may be of any form (wires, apertures, etc.).

The total field of the array is determined by the vector addition of the fields radiated by the individual elements. This assumes that the current in each element is the same as that of the isolated element (neglecting coupling). This is usually not the case and depends on the separation between the elements. To provide very directive patterns, it is necessary that the fields from the elements of the array interfere constructively (add) in the desired directions and interfere destructively (cancel each other) in the remaining space.Ideally this can be accomplished, but practically it is only approached.

In an array of identical elements, there are at least five controls that can be used to shape the overall pattern of the antenna.[4] These are :

(1) The geometrical configuration of the overall array (linear, circular, rectangular, spherical, etc.)

(2) The relative displacement between the elements

(3) The excitation amplitude of the individual elements

(4) The excitation phase of the individual elements

(5) The relative pattern of the individual elements

2.10 Array Characteristics

The elements that make up an array are usually of the same type are similarly oriented.There are two common configurations of array: linear array and planar array. A linear array is one in which the terminals of the individual antennas lie along a straight line while the individual antennas of a planar one lie on a common plane.

In this section, the basic characteristics of linear and planar arrays are briefly Covered.Such parameters as radiation pattern, Beamwidth, Directivity, Bandwidth, Side lobe and Mutual coupling.

2.10.1 Pattern Multiplication

Pattern multiplication is an important result which simplifies the analysis of radiation pattern of an array, assuming that the elements are identical in all senses. The array pattern can be decomposed of an element factor and array factor. The element factor is contributed by the single element while the array factor is affected by the array structure like number of elements, the inter-element spacing, and the amplitude and phases of the excitation currents. Since the individual pattern is a known quantity, the study of the array factor yields all the information about the properties of an array.

the far-zone field of a uniform array of identical elements is equal to the product of the field of a single element, at a selected reference point (usually the origin), and the array factor of that array. That is,

$$E(total) = [E(single\ element\ at\ reference\ point)] \times [array\ factor] \tag{2.9}$$

This is referred to as pattern multiplication for arrays of identical elements.

Each array has its own array factor. The array factor, in general, is a function of the number of elements, their geometrical arrangement, their relative magnitudes, their relative phases, and their spacings. The array factor will be of simpler form if the elements have identical amplitudes, phases, and spacings. Since the array factor does not depend on the directional characteristics of the radiating elements themselves, it can be formulated by replacing the actual elements with isotropic (point) sources. Once the array factor has been derived using the point-source array, the total field of the actual array is obtained by the use of Equation 2.9 Each point-source is assumed to have the amplitude, phase, and location of the corresponding element it is replacing.

2.10.2 Front-to-Back Ratio

Front-to-back ration is a measure of the maximum directivity of an antenna to its directivity in a specified rearward direction. The Front-to-Back Ratio is a parameter used in describing directional radiation patterns for antennas.

2.10.3 Array Factor

Array Factor is defined as the radiation pattern of an array antenna when each array element is considered to radiate isotropically.

2.11 Summary

At starting introduction of Microstrip Patch Antena and its Radiation Characteristics has been discussed in section 2.1 and 2.5 respectively. Later feeding techniques and antenna analysis model like Transmission Line Model and Cavity Model have been briefly explained in section 2.6 followed by the antenna parameter and array characteristics in section 2.8 and 2.10 respectively.

Chapter 3

Patch Array Antenna Design Using FR4

In previous Chapter ,the basic details of Microstrip Patch Antenna and Arrays is discussed. Return-Loss, Gain, Directivity, Polarization and Radiation efficiency are very important parameter to design Microstrip Patch Array Antenna. In this chapter,Transmission line model is used to design Microstrip Patch Antenna for simplicity. Inset feeding technique is used to design a single element patch and results obtained from the simulation are demonstrated. For Dual-Polarization, $1{\times}2$ $\pm 45°$ Patch Array Antenna is designed and simulation results are demonstrated.

3.1 Transmission Line Model for Inset Fed Microstrip Patch Antenna Design

The inset-fed microstrip antenna provides a method of impedance control with a planar feed configuration.[19]

For a probe-fed rectangular microstrip antenna,the relationship between the resonant input resistance and feed position has been theoretically and experimentally follow a $\cos^2$ variation [20]. Previous work found that for an inset-fed patch, a higher-order cosine function fit the experimental data better [20]. A more recent study proposed a modified shifted $\sin^2$ form that well characterizes probe-fed patches with a notch [19]. When the patch is fed with an inset microstrip line, the resistance dependence becomes proportional to the fourth power of the cosine $\cos^4$,although no theoretical justification was given for this result [21].

Patch can be feed from the edge by using an inset microstrip line as shown in Figure 3.1. where the gap on either side of the microstrip line equals its width [19].

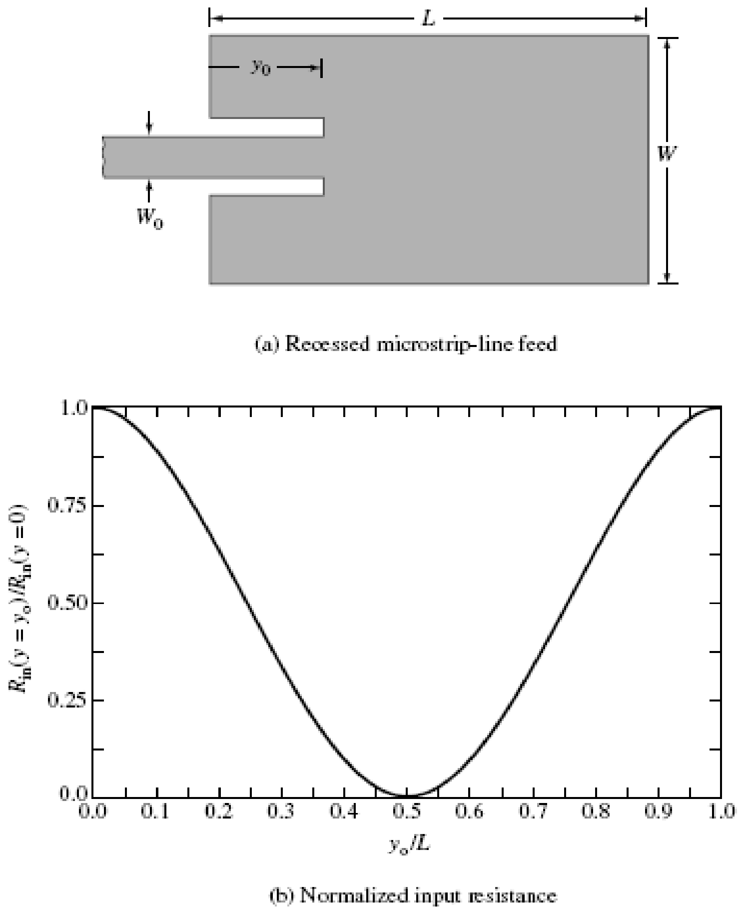

Figure 3.1: Inset-Fed Patch Antenna

However, the inset feed introduces a physical notch, which in turn introduces a junction capacitance. The physical notch and its corresponding junction capacitance influence slightly the resonance frequency, which typically may vary by about 1% [20].

It is apparent from Equation 3.1 and Figure 3.1(b) that the maximum value occurs at the edge of the slot ($y_0 = 0$) where the voltage is maximum and the current is minimum; typical values are in the 150-300 ohms.[4] The minimum value (zero) occurs at the center of the patch ($y_0 = L/2$) where the voltage is zero and the current is maximum. As the inset feed point moves from the edge toward the center of the patch the resonant input impedance decreases monotonically and reaches zero at the center. When the value of the inset feed point approaches the center of the patch ($y_0 = L/2$), the $\cos^4$ (y_0/L) function varies very rapidly; therefore the input resistance also changes rapidly with the position of the feed point. To maintain very accurate values, a close tolerance must be preserved.

$$R_i(y = y_0) = R_e(y = 0)\cos^4\left(\frac{\Pi y_0}{L}\right) \tag{3.1}$$

Above Equation 3.1 is an approximate solution because at $y = 0$, the resistance remains finite. We locate the feed from the equation using a radian angle measure [18]:

$$y_0 = \frac{L}{\Pi}\cos^{-1}\left(\frac{R_i}{R_e}\right)^{1/4} \tag{3.2}$$

Location of the feed can also be find out using curve fit formula to achieve 50Ω input impedance for the commonly used thin dielectric substrates [22].

$$\begin{aligned} y_0 \quad = \quad & 10^4\left[0.001699\epsilon_r^7 + 0.13761\epsilon_r^7 - 6.1783\epsilon_r^7 + 93.187\epsilon_r^4 - 682.69\epsilon_r^4\right. \\ & \left. +2561.9\epsilon_r^2 - 4043\epsilon_r + 6697\right]\left(\frac{L}{2}\right) \end{aligned} \tag{3.3}$$

Feed line Width Calculation,

for condition $\frac{W_0}{h} \leq 1$

$$Z_c = \frac{60}{\sqrt{\epsilon_{eff}}}\ln\left[\frac{8h}{W_0} + \frac{W_0}{4h}\right] \tag{3.4}$$

and

for condition $\frac{W_0}{h} > 1$

$$Z_c = \frac{120\Pi}{\sqrt{\epsilon_{eff}}\left[\frac{W_0}{h} + 1.393 + 0.667\ln\left(\frac{W_0}{h} + 1.444\right)\right]} \tag{3.5}$$

where, W_0 = Feed line width

h = Height of the substrate

Z_c = Characteristics impedance

$\sqrt{\epsilon_{eff}}$ = Effective dielectric constant

The three essential parameters for the design of a rectangular Microstrip Patch Antenna is :

(1) Frequency of operation (f_r)

(2) Dielectric constant of the substrate (ϵ_r)

(3) Height of dielectric substrate (h)

Design equation of a rectangular patch antenna is shown below from Equation 3.6 to 3.10.

For an efficient radiator, a practical width that leads to good radiation efficiencies

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{3.6}$$

Where,

$\frac{1}{\sqrt{\mu_0\epsilon_0}}$ = C ; Free-space velocity of light.

Effective dielectric constant of microstrip patch antenna

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\sqrt{1 + 12\frac{h}{W}} \tag{3.7}$$

Where,

ϵ_r = Substrate's dielectric constant

W = Width of the Patch

h = Height of the Patch

Extension of the Length (ΔL) can be find out by,

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{reff} + 0.3)}{(\epsilon_{reff} - 0.258)} \frac{\left(\frac{W}{h} + 0.264\right)}{\left(\frac{W}{h} + 0.8\right)} \tag{3.8}$$

Actual length can be find out by,

$$L = \frac{1}{2f_r\sqrt{\epsilon_{reff}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L \tag{3.9}$$

Effective length of the patch,

$$L_e = L + 2\Delta L \tag{3.10}$$

Parameter to design a patch antenna taken into the consideration is shown in Table 6.2.

Table 3.1: Parameters for The Patch Antenna Design

Parameter	Parameter Description	Parameter value
f_r	Frequency of operation	2.4GHz
ϵ_r	Dielectric Constant	4.7
h	Height of substrate	1.6mm

Parameter of the single element patch antenna can be calculate based upon above Equations 3.1 to 3.10 is shown in Table 3.2.

Table 3.2: Design Specification of Inset-Fed Patch Antenna

Parameter	Parameter Description	Parameter value(mm)
L	Length of the Patch antenna	28.2894
W	Width of the Patch antenna	34.0180
S	Slot cut for inset	6.3787
Y_0	Inset distance from the edge of the patch	8.1034

3.2 +45° Inset-Fed Patch Antenna Design

3.2.1 Design and Simulation Results

Design of +45° Inset-Fed Patch Antenna is shown in Figure.3.2. Design of +45° Inset-Fed Patch Antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 76.34 mm x 105 mm. In the single element antenna design, patch is fed through inset feeding technique. 50 ohm feed line is inserted to the patch for matching 50 ohm impedance of patch element. +45° rotation is given to the inset-fed patch antenna from other 50 ohm impedance line. Concept behind to provide +45° rotation of the patch element is for generation of Dual-Polarization in array antenna design.

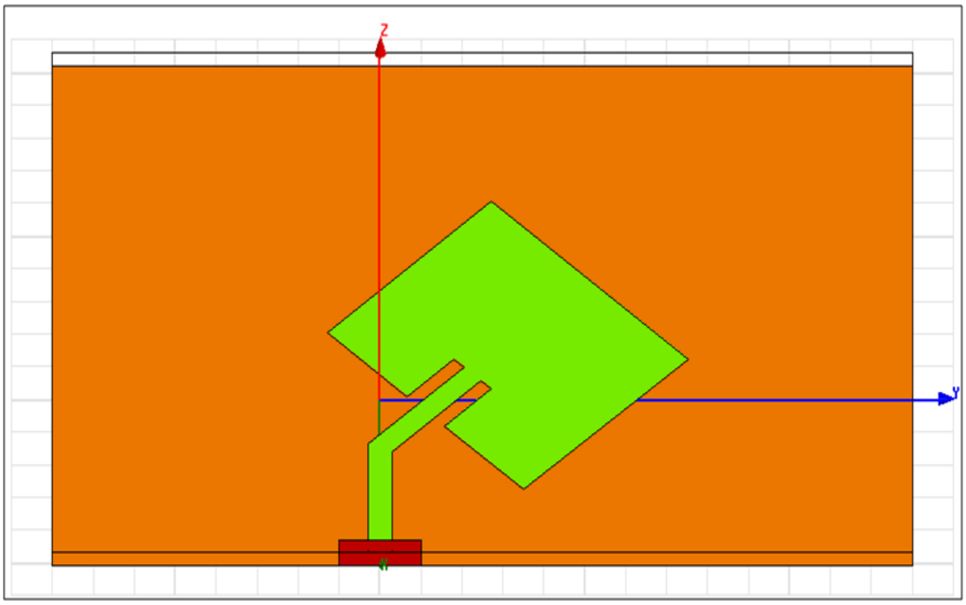

Figure 3.2: +45° Inset Fed Patch Antenna Design

Simulation results of +45° Inset-Fed Patch Antenna is shown below. Simulation result of ReturnLoss plot shows that S_{11} = -30.05 dB at 2.37 GHz.

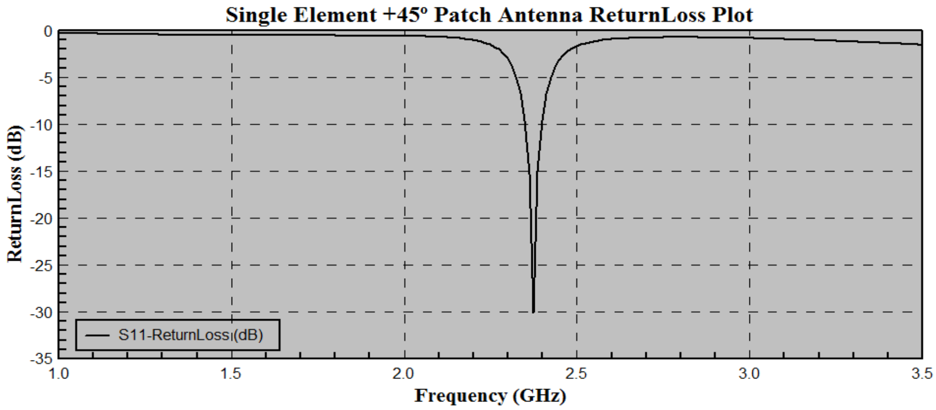

Figure 3.3: ReturnLoss (S_{11}) Plot of Inset Fed +45° Patch Design

Simulation result of VSWR plot shows that VSWR = 1.06 at 2.37 GHz.

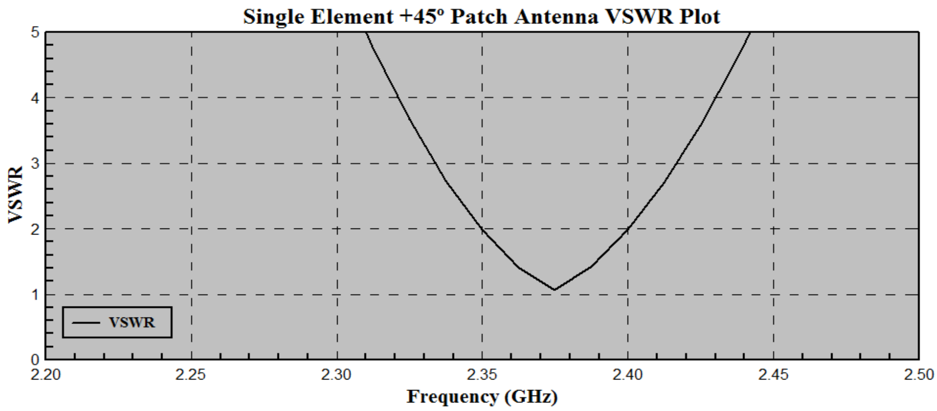

Figure 3.4: VSWR Plot of Inset Fed +45° Patch Design

Simulation result of Gain plot shows that Gain = 2.94 dB in Figure 3.5.

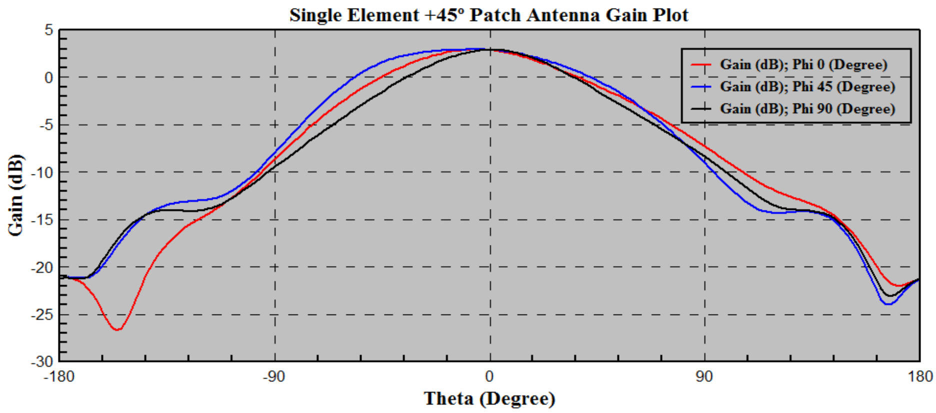

Figure 3.5: Gain Plot of Inset Fed +45° Patch Design

Simulation result of Directivity plot shows that Directivity = 7.09 dB in Figure 3.6.

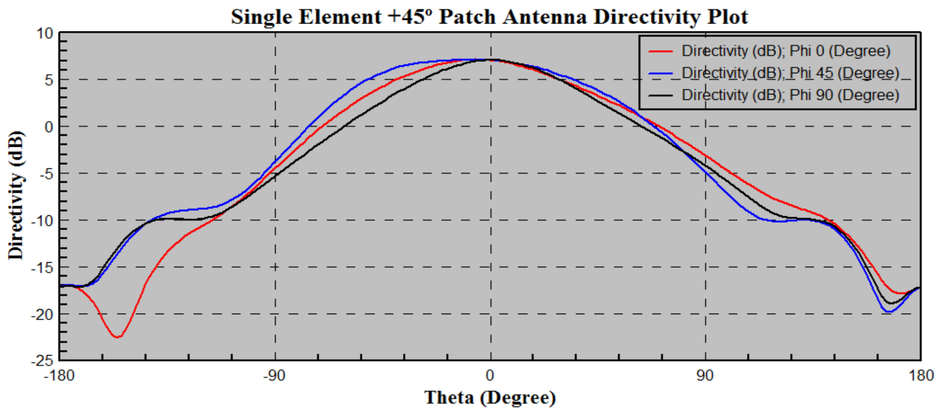

Figure 3.6: Directivity Plot of Inset Fed +45° Patch Design

Simulation result of Radiation Pattern plot shows in Figure 3.7

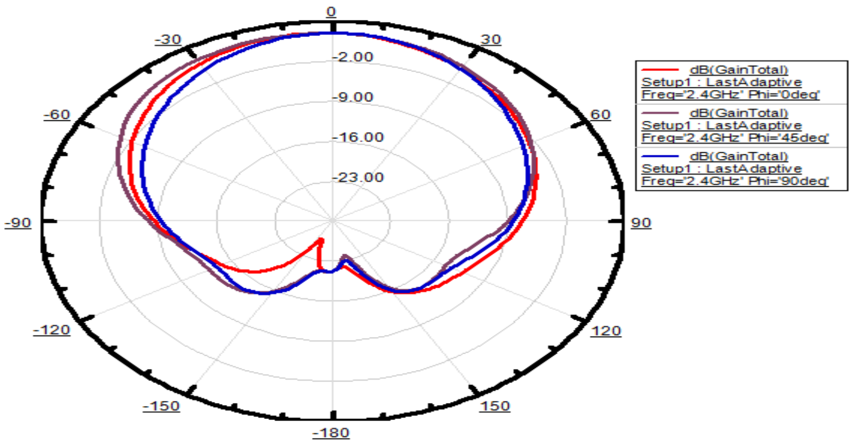

Figure 3.7: Radiation Pattern Plot of Inset Fed +45° Patch Design

3.3 -45° Inset-Fed Patch Antenna Design

3.3.1 Design and Simulation Results

Design of -45° Inset-Fed Patch Antenna is shown in Figure 3.3. Design of -45° Inset-Fed patch antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 76.34 mm x 105 mm. In the,-45° Inset-Fed patch Antenna design opposite rotation or slant is provided to the antenna compare to the +45° Inset-Fed patch Antenna design.

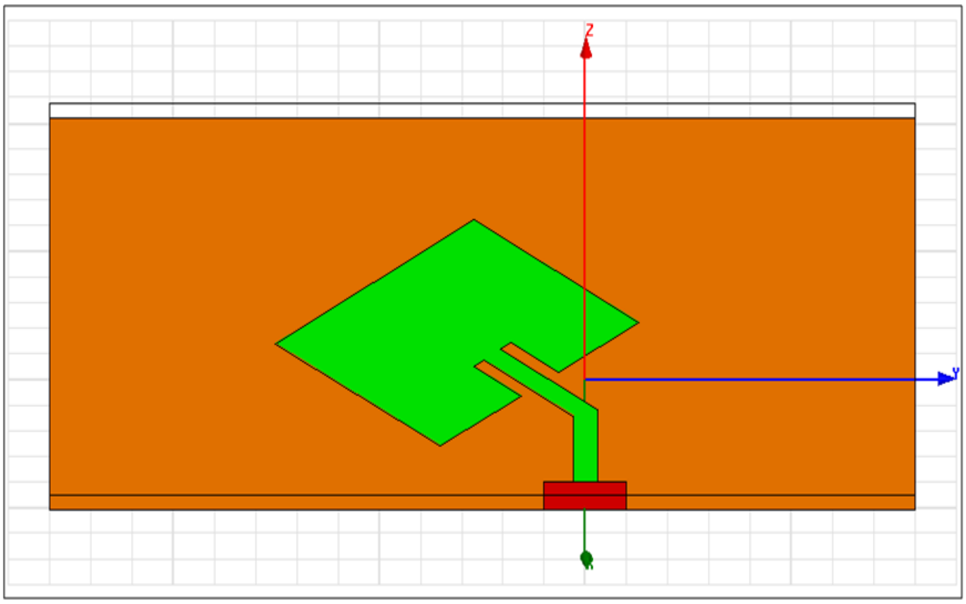

Figure 3.8: -45° Inset Fed Patch Antenna Design

Simulation results of -45° Inset-Fed Patch Antenna is shown below. Simulation result of ReturnLoss plot shows that S_{11} = -18.87 dB at 2.38 GHz.

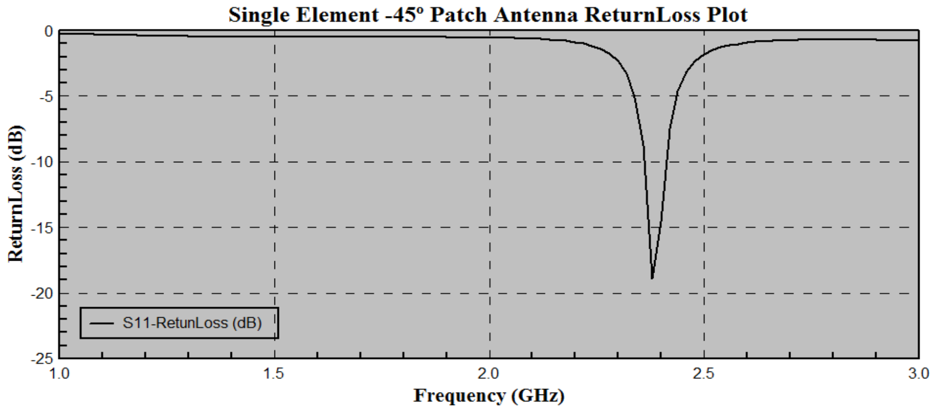

Figure 3.9: ReturnLoss (S_{11}) Plot of Inset Fed -45° Patch Design

Simulation result of VSWR plot shows that VSWR = 1.25 at 2.38 GHz.

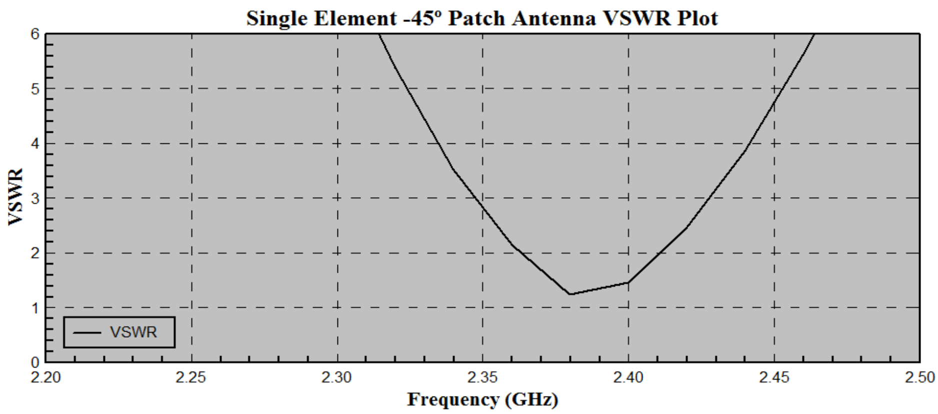

Figure 3.10: VSWR Plot of Inset Fed -45° Patch Design

Simulation result of Gain plot shows that Gain = 3.09 dB in Figure 3.11.

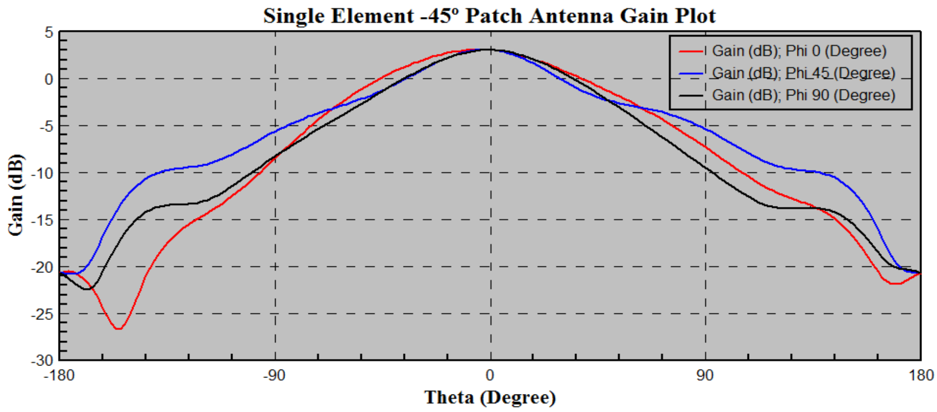

Figure 3.11: Gain Plot of Inset Fed -45° Patch Design

Simulation results of Directivity plot shows that Directivity = 7.18 dB in Fig..

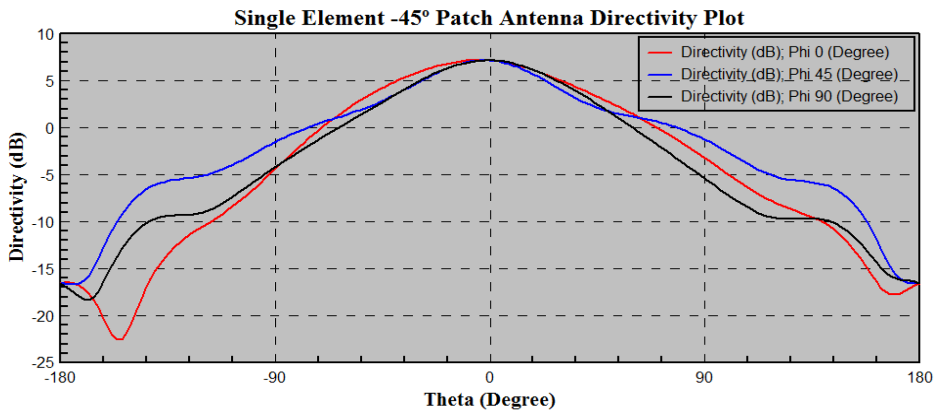

Figure 3.12: Directivity Plot of Inset Fed -45° Patch Design

Simulation result of Radiation Pattern plot shows in Figure 3.13

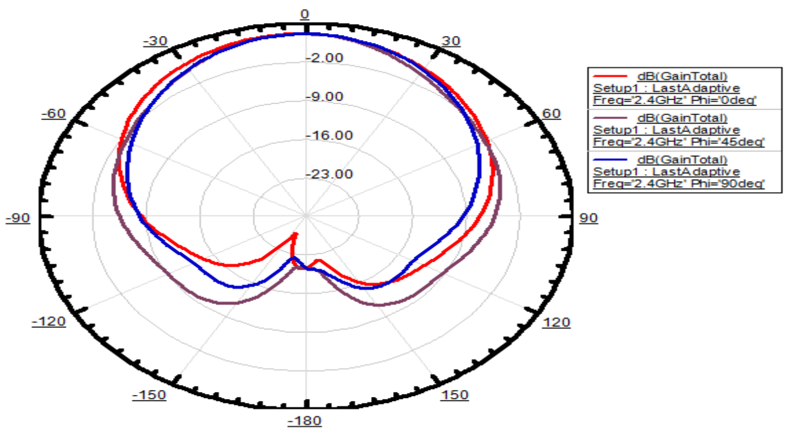

Figure 3.13: Radiation Pattern Plot of Inset Fed -45° Patch Design

3.4 1×2 Patch Array Antenna Feed Network Design

In the design of 1×2 patch array antenna each element of an array antenna should be feed through feed line and for that Feed network is required. Feed network is designed with striplines.

A parallel or corporate feed configuration was used to build up the arrays. Transmission line is used to feed the patch elements parallely in parallel feed configuration. The transmission lines were divided into two branches according to the number of patch elements. The quarter-wave transformer impedance matching technique was applied to divide the power equally to all patches.

3.4.1 1×2 Power Divider design

Power dividers are passive microwave components widely used for power division and power combining in a microstrip patch array antenna. In power division, an input signal is divided by the coupler into two (or more) signals of less power. Power dividers are often of the equal-division (3 dB) type, but unequal power division ratios are also possible. Here, The design requirements is equal power division.

This 3-port power divider network has one input and two output port.The scattering matrix of a 3-port network has nine independent elements.

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \tag{3.11}$$

If the component is passive and contain no anisotropic material, then it must be reciprocal and its [S] matrix must be symmetric ($S_{ij} = S_{ji}$). Usually, to avoid power loss, we would like to have a junction that is lossless and matched at all ports.

If all ports are matched, then S_{ii}=0, and if the network is reciprocal the scattering matrix of Equation 3.11 reduces to

$$S = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{21} & 0 & S_{23} \\ S_{31} & S_{32} & 0 \end{bmatrix} \tag{3.12}$$

Now if the network is lossless, the energy conversation requires that the scattering matrix be unitary, which leads to the following condition:

$$|S_{12}|^2 + |S_{13}|^2 = 1 \tag{3.13}$$

$$|S_{12}|^2 + |S_{23}|^2 = 1 \tag{3.14}$$

$$|S_{13}|^2 + |S_{23}|^2 = 1 \tag{3.15}$$

$$S_{13}^{*}S_{23} = 0 \tag{3.16}$$

$$S_{23}^{*}S_{12} = 0 \tag{3.17}$$

$$S_{12}^{*}S_{13} = 0 \tag{3.18}$$

From Equation 3.16 to 3.18 shows that at least two of the three parameter (S_{12}, S_{13}, S_{23}) must be zero.But this condition will always be inconsistent with one of Equations 3.13 to 3.15, implying that a 3-port network cannot be lossless, reciprocal and matched at all ports. If any one of these condition is relaxed, then a physically realizable device is possible.

Design contains T-Junction power divider with Quarter-wave transformer. Quarter-wave transformer is useful and practical circuit for impedance matching and also provides a simple transmission line circuit that further illustrate the properties of standing waves on a matched line [23].

3.4.2 Quarter-Wave Transformer

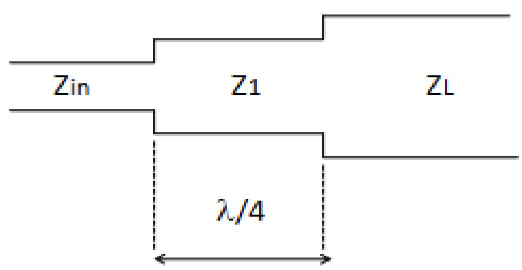

Figure 3.14: Quarter-wavelength Transformer

Figure 3.14 shows Quarter-Wave transformer. The load impedance Z_L and the input feedline impedance Z_{in} are both real. These two components are connected with a lossless piece of transmission line of characteristic impedance Z_1 and length $\lambda/4$. It is desired to match the load to the Z_{in} line, by using the $\lambda/4$ piece of line and so make $\Gamma = 0$ looking into the $\lambda/4$ matching section.

$$Z_1 = \sqrt{Z_{in} Z_L} \tag{3.19}$$

For the 1x2 patch array antenna, power divider design is developed. Parallel feed Quarter Wave-transformer is used to match the impedance. Main transmission line of power divider is of 50Ω. To make an equal power division 50Ω line is parallely divided into 100Ω line (100|| 100 =50). To match the 100Ω line into the 50Ω line Quarter Wave transformer is used of 70.71Ω.

$$Z_1 = 70.71 = \sqrt{100 \times 50} \tag{3.20}$$

3.4.3 Power Divider Design for 1×2 Patch Array Antenna

For power divider design, transmission line impedance value required to be converted in physical length and width dimensions. Length and Width of transmission line is shown in Table 3.3.

Table 3.3: Design Parameter of Power Divider Transmission Line

Impedance (Ω)	Length (mm)	Width(mm)
50	16.5671	2.87872
70.71	17.0633	1.4839
100	17.5478	0.6146

Length and Width calculation procedure of Transmission line is shown in Appendix A. Based on calculated dimensions Power Divider for 1×2 Patch Array Geometry has been designed and Simulated.Design of power Divider is Shown in Fig. 3.15.

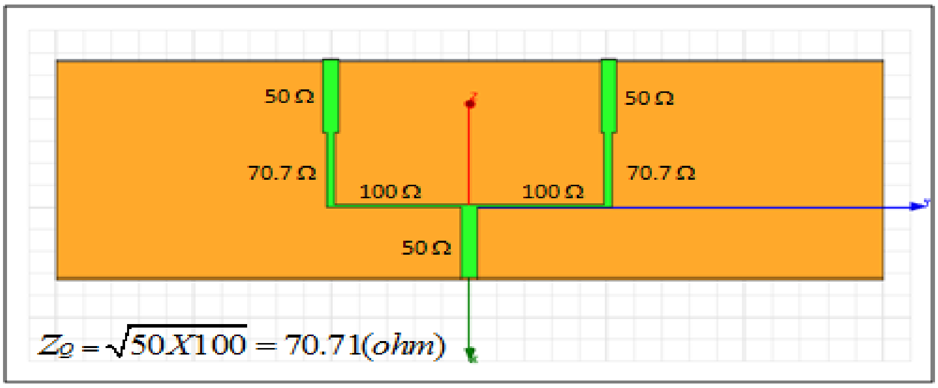

Figure 3.15: Power Divider Design for 1×2 Patch Array

3.4.4 Simulation Result

Simulation result shows that S_{11} parameter is -31.36 dB at 2.38 GHz and S_{21} and S_{31} is -3.6 dB at 2.38 GHz. Insertion Loss (S-parameter) S_{21} and S_{31} shows that 3-dB down power at both the port, is equal.

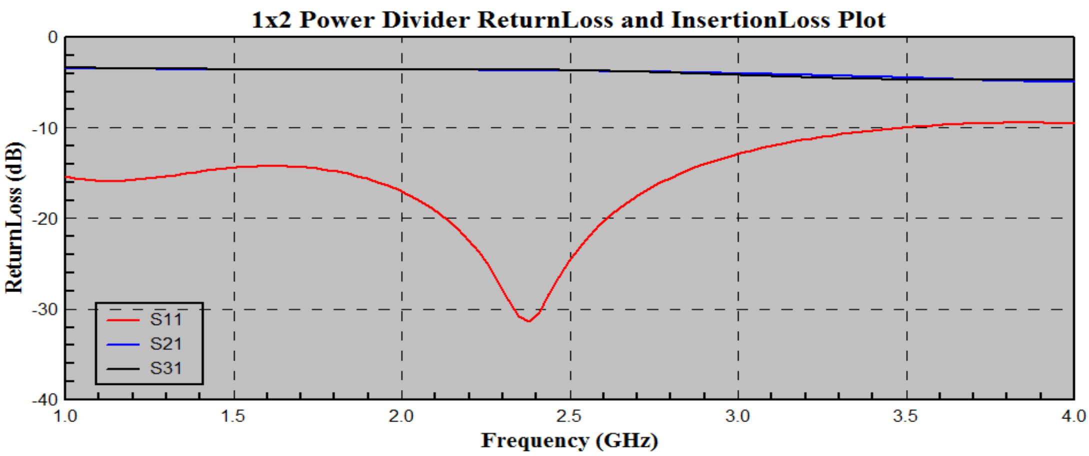

Figure 3.16: ReturnLoss (S_{11}) and Insertion Loss(S_{21},S_{31}) of Power Divider

3.5 1×2 Patch Array Antenna Design

single element +45° and -45° patch antenna is used to make an array for 1×2 Patch Array configuration. 1×2 patch array antenna design is simulated and obtained results were demonstrated.

3.5.1 Geometry of +45° 1×2 Patch Array Antenna Design

Geometry of +45° 1×2 patch array antenna is shown in Figure 3.17. Design of +45° 1×2 patch array antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 140 mm x 200 mm. 50Ω Inset-fed Patch antenna element is +45° rotated from the 50Ω output line of power divider. Input power is transferred from the main feed line through the quarter-wave transformer and to the patch.

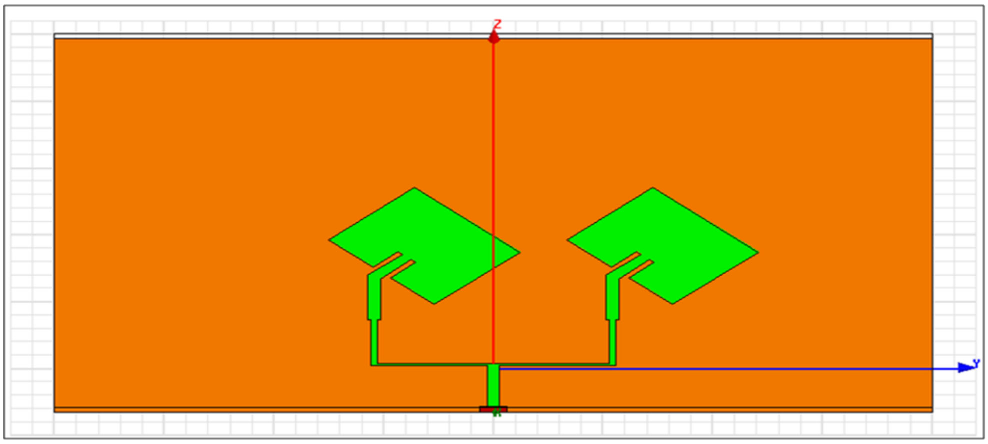

Figure 3.17: +45° 1×2 Patch Array Geometry

3.5.2 Simulation Results of +45° 1×2 Array Antenna

Simulation results of +45° 1×2 Array Antenna geometry are shown below from Figure 3.18 to 3.22. Simulation results contain the plot of ReturnLoss, VSWR, Gain, Directivity and radiation pattern.

Figure 3.18 shows simulation result of ReturnLoss characteristics of +45° 1×2 array configurations. The antenna design gives Return Loss of -16.80 dB at 2.4 GHz. Bandwidth is obtained 3.04% with reference of -10 dB Return Loss.

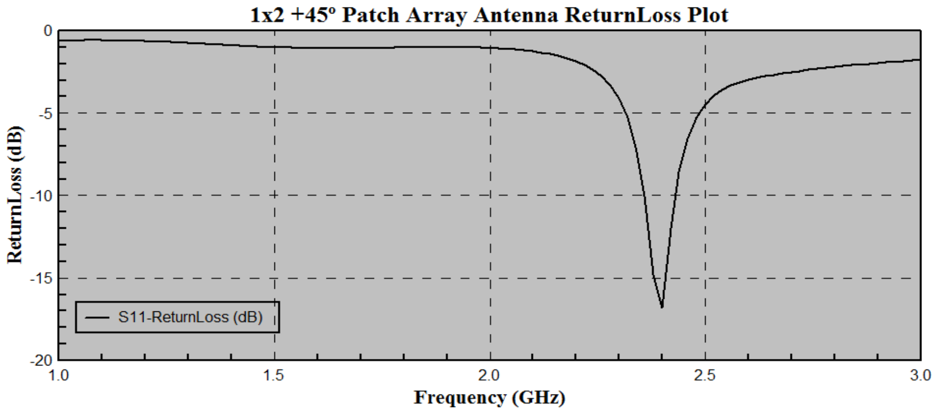

Figure 3.18: ReturnLoss (S_{11}) Plot of +45° 1×2 Patch Array Design

Figure 3.19 shows simulation result of VSWR characteristics of +45° 1×2 array configurations. +45° 1×2 array configurations gives VSWR of 1.33 at 2.4 GHz.

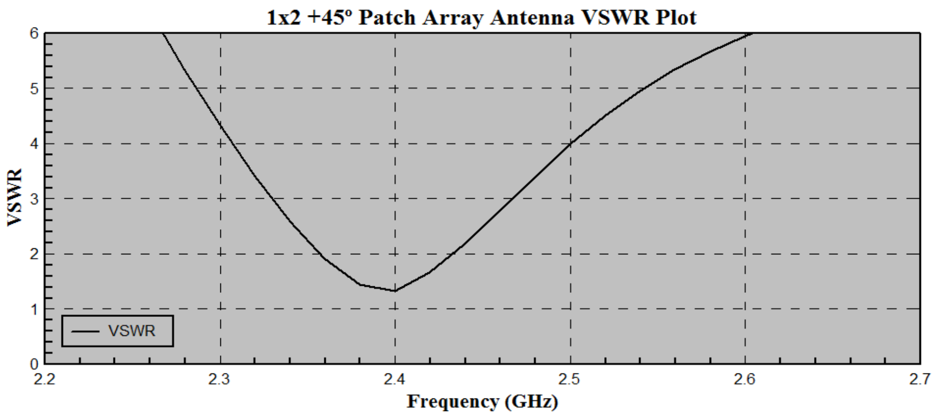

Figure 3.19: VSWR Plot of +45° 1×2 Patch Array Design

Figure 3.20 shows simulation result of Gain characteristics of +45° 1×2 array configurations. +45° 1×2 array configuration gives Gain of 5.59 dB.

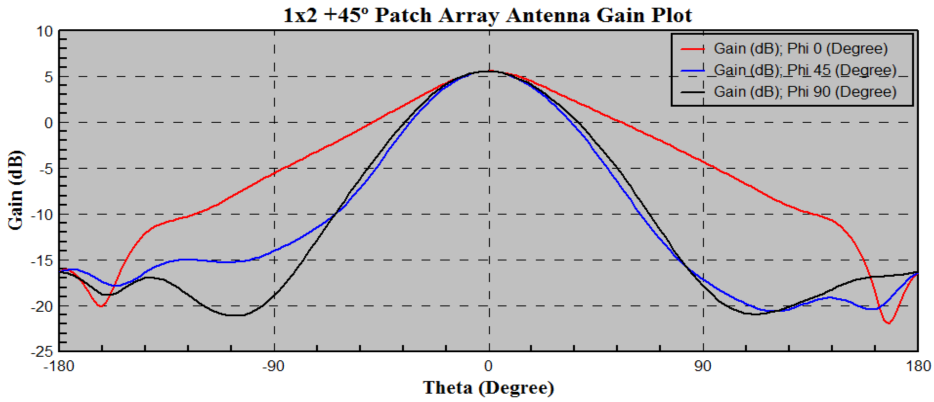

Figure 3.20: Gain Plot of +45° 1×2 Patch Array Design

Figure 3.21 shows simulation result of Directivity of 45° 1×2 array configurations. +45° 1×2 array configurations gives Directivity of 9.42 dB.

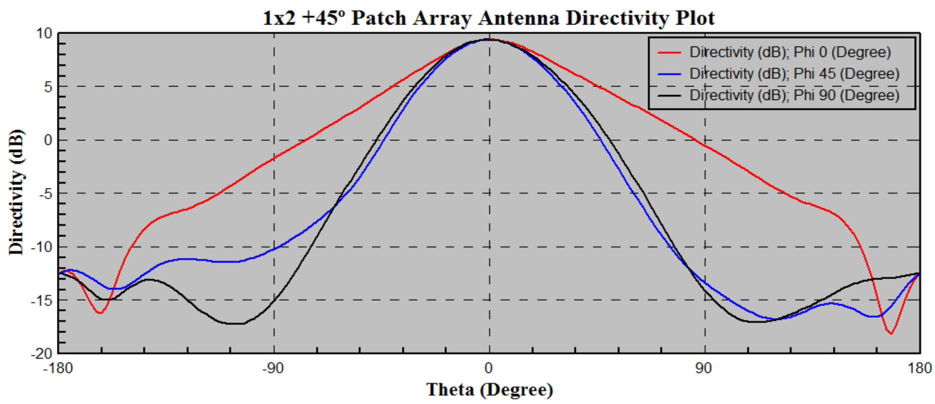

Figure 3.21: Directivity Plot of +45° 1×2 Patch Array Design

Figure 3.22 shows simulation result of Radiation Pattern of +45° 1×2 array configurations.

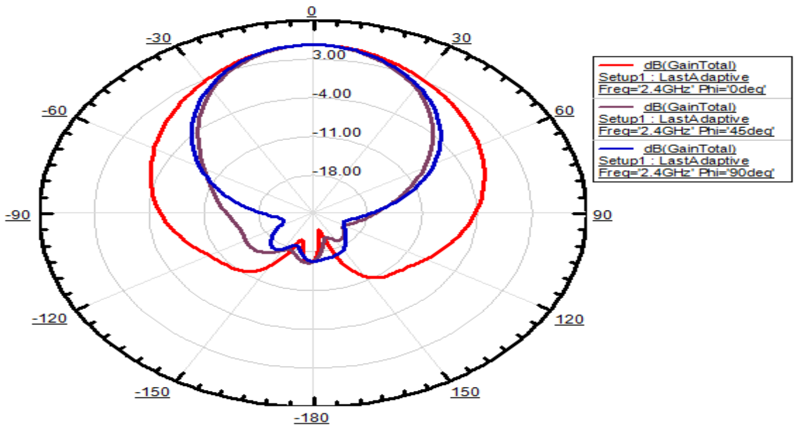

Figure 3.22: Radiation Pattern of +45° 1×2 Patch Array Design

3.5.3 Geometry of -45° 1×2 Patch Array Antenna Design

Geometry of -45° 1×2 patch array antenna is shown in Figure 3.23. Design of -45° 1×2 patch array antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 140 mm x 200 mm. In the design of -45° 1×2 patch array geometry everything is same as +45° 1×2 patch array geometry except the inset-fed patch element. Rotation or slant of the inset-fed patch is given opposite to the +45° 1×2 patch array geometry. Patch array antenna dimensions are given in table 3.2 and 3.4.3.

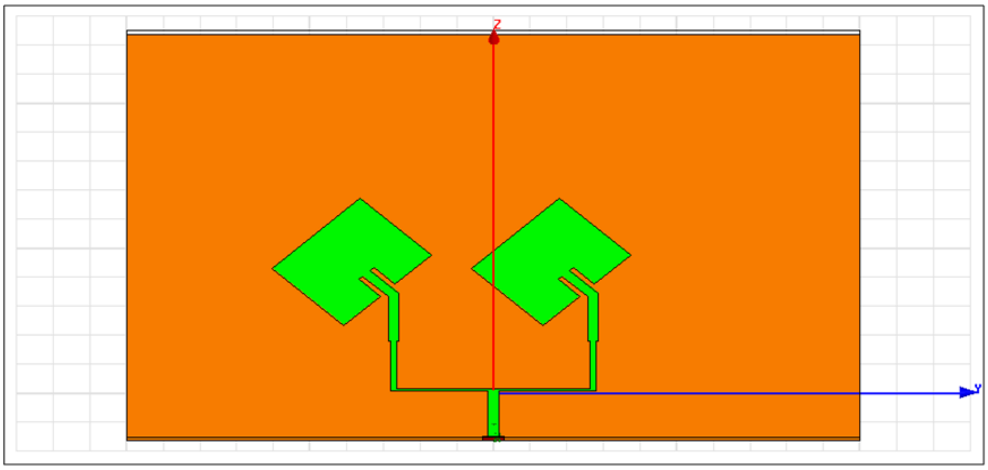

Figure 3.23: -45° 1×2 Patch Array Geometry

3.5.4 Simulation Result of -45° 1×2 array antenna

Figure 3.24 shows simulation result of ReturnLoss characteristics of -45° 1×2 array configurations. The antenna gives Return Loss of -17.63 dB at 2.4 GHz. Bandwidth is obtained 3.0% with reference of -10 dB Return Loss.

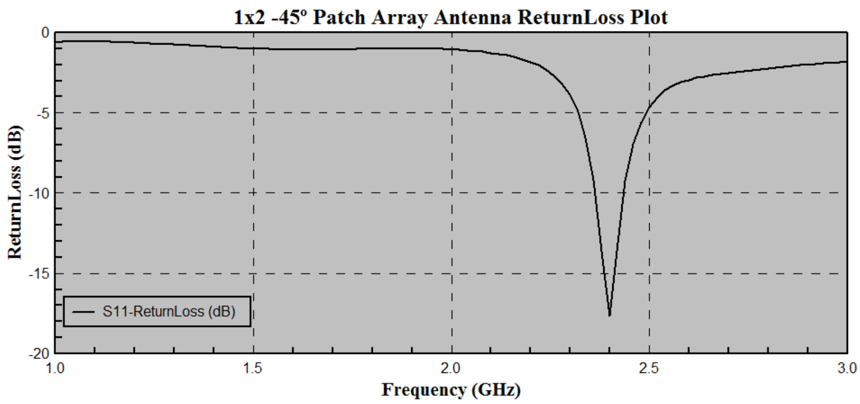

Figure 3.24: ReturnLoss (S_{11}) Plot of -45° 1×2 Patch Array Design

Figure 3.25 shows simulation result of VSWR characteristics of -45° 1×2 array configurations.-45° 1×2 array configurations gives VSWR of 1.30 at 2.4 GHz.

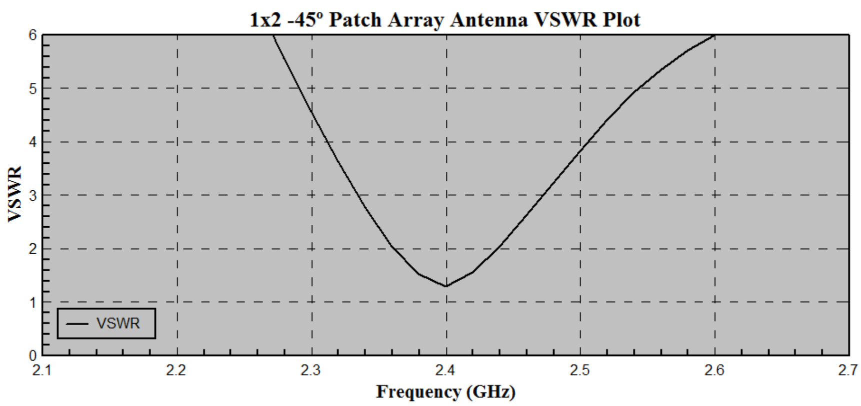

Figure 3.25: VSWR Plot of -45° 1×2 Patch Array Design

Figure 3.26 shows simulation result of Gain characteristics of -45° 1×2 array configurations. -45° 1×2 array configurations gives Gain of 5.60 dB.

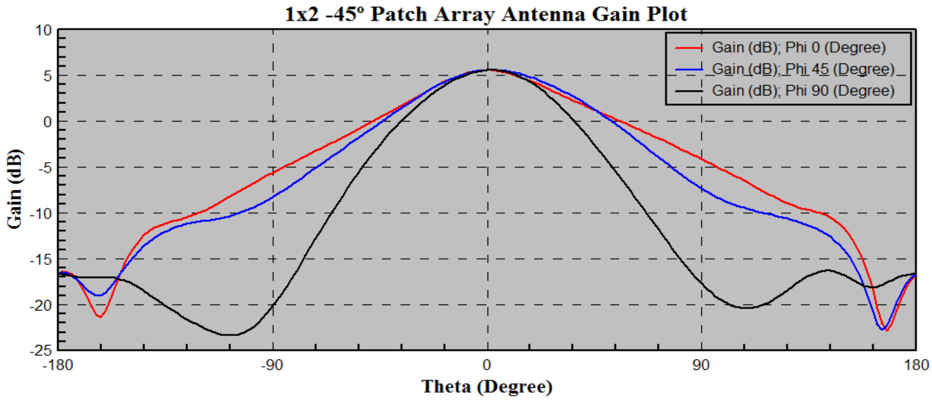

Figure 3.26: Gain Plot -45° 1×2 Patch Array Design

Figure 3.27 shows simulation result of Directivity of -45° 1×2 array configurations. -45° 1×2 array configurations gives Directivity of 9.43 dB.

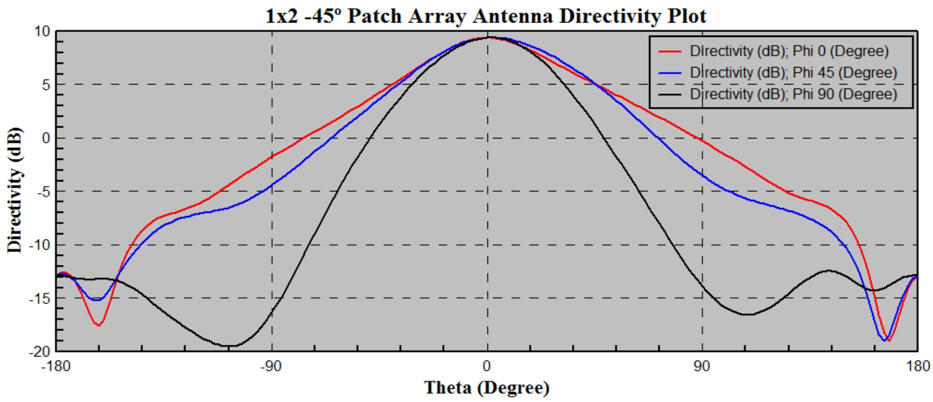

Figure 3.27: Directivity Plot of -45° 1×2 Patch Array Design

Figure 3.28 shows simulation result of Radiation Pattern of -45° 1×2 array configurations.

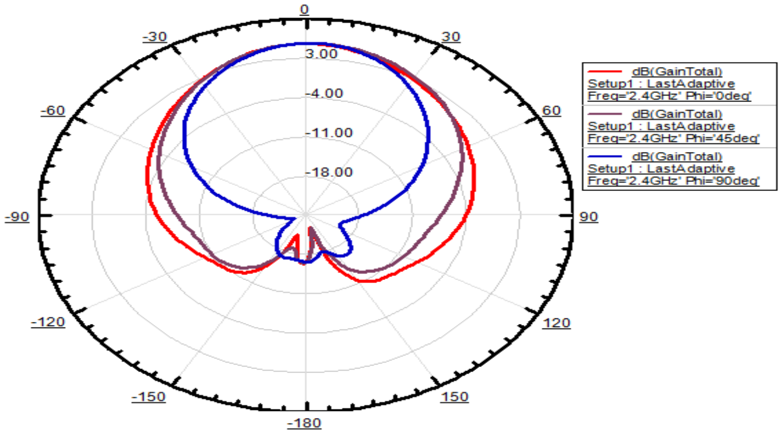

Figure 3.28: Radiation Pattern of -45° 1×2 Patch Array Design

3.5.5 Geometry of ±45° 1×2 Patch Array Antenna Design

Geometry of ±45° 1×2 array antenna configuration is shown in 3.29. Design of ±45° 1×2 array antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 100 mm x 150 mm. In the design of ±45° 1×2 array antenna, one inset-fed patch antenna is rotated or slanted at +45° whereas other element of 1×2 patch array geometry is rotated or slanted at -45°. Patch array antenna dimensions are given in table 3.2 and 3.4.3.

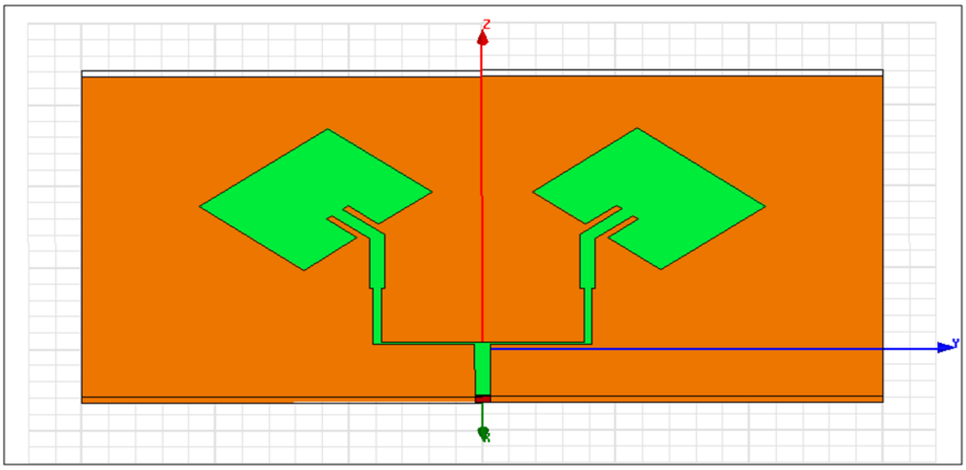

Figure 3.29: ±45° 1×2 Patch Array Geometry

3.5.6 Simulation Result of ±45° 1×2 array antenna

Figure 3.30 shows simulation result of Return Loss characteristics of ±45° 1×2 array configurations. The antenna gives Return Loss of -27.41 dB at 2.4 GHz. Bandwidth is obtained 2.9% with reference of -10 dB Return Loss.

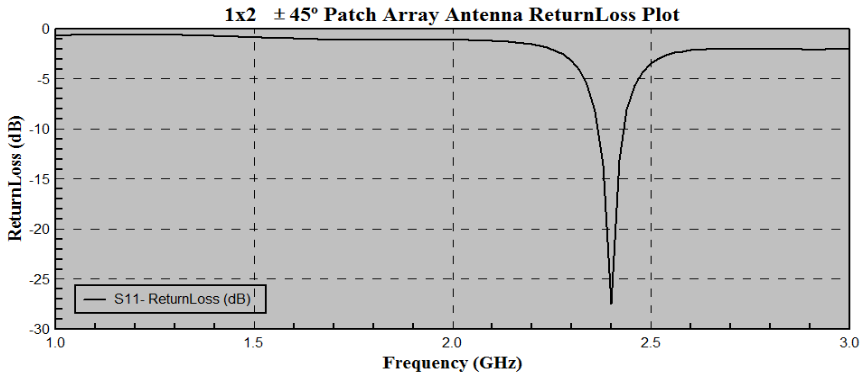

Figure 3.30: ReturnLoss (S_{11}) Plot of ±45° 1×2 Patch Array Design

Figure 3.31 shows simulation result of VSWR characteristics of ±45° 1×2 array configurations. ±45° 1×2 array configurations gives VSWR of 1.08 at 2.4 GHz.

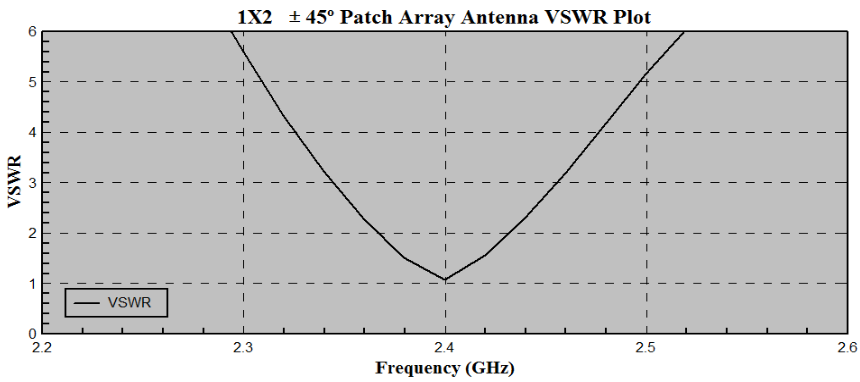

Figure 3.31: VSWR Plot of ±45° 1×2 Patch Array Design

Figure 3.32 shows simulation result of Gain characteristics of ±45° 1×2 array configurations. ±45° 1×2 array configuration gives Gain of 1.79 dB.

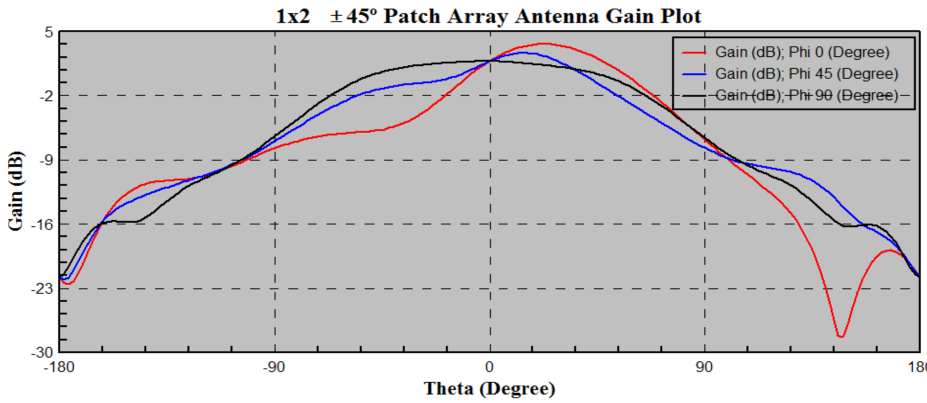

Figure 3.32: Gain Plot of ±45° 1×2 Patch Array Design

Figure 3.33 shows simulation results of Directivity of ±45° 1×2 array configurations. ±45° 1×2 array configurations gives Directivity of 5.82 dB.

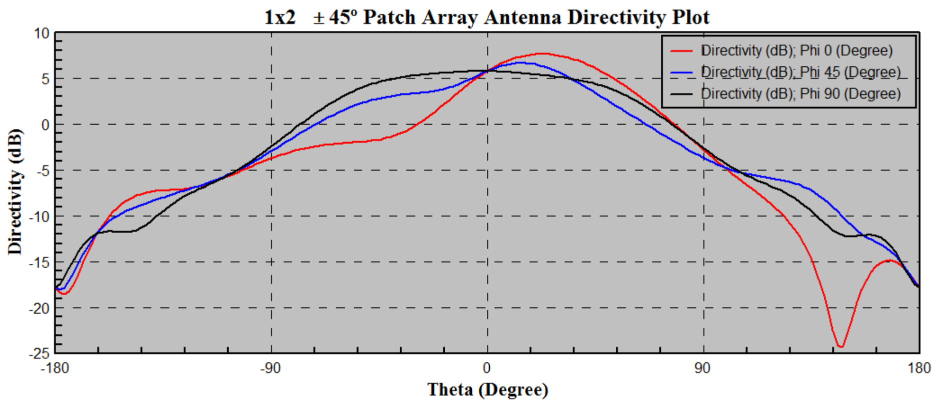

Figure 3.33: Directivity Plot of ±45° 1×2 Patch Array Design

Figure 3.34 shows simulation result of Radiation Pattern of ±45° 1×2 array configurations.

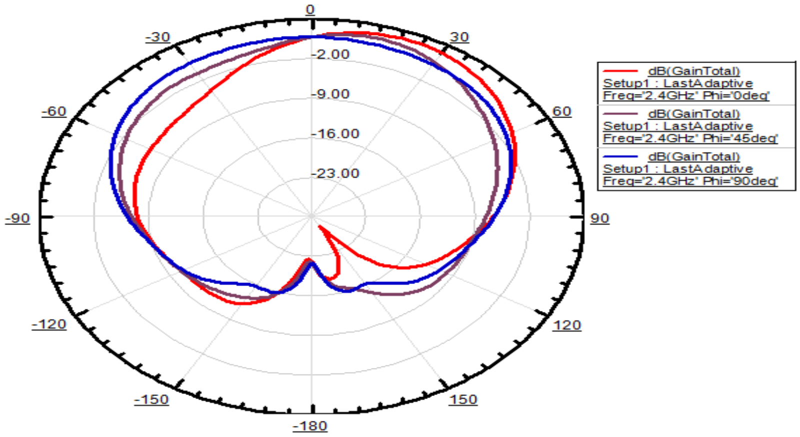

Figure 3.34: Radiation Pattern of ±45° 1×2 Patch Array Design

3.6 Summary of Simulation Results

All the designs of patch array antenna results are summarized in below Table 3.4 .

Table 3.4: Summary of Simulation Results

Antenna Design	**ReturnLoss (dB)**	**VSWR**	**Gain (dB)**	**Directivity (dB)**	**BW (MHz)/(%)**
Single Element +45°	-30.05	1.06	2.94	7.09	50.3/2.15
Single Element -45°	-18.87	1.25	3.09	7.18	48.3/2.12
1x2 +45° **Patch Array Antenna**	-16.80	1.33	5.59	9.42	71.6/3.04
1x2 -45° **Patch Array Antenna**	-17.63	1.30	5.60	9.43	72.1/3
1x2 ±45° **Patch Array Antenna**	-27.41	1.08	1.79	5.82	65.4/2.9

From the Table 3.4, it is evidence that the proposed patch array antenna has very good impedance matching and VSWR. But impedance bandwidth is low which is not desired for 2.4 GHz ISM(Industrial,Scientific and Medical) band applicaton such as WLAN. Gain and Directivity also shows major seperation in between. This major difference is due to the substrate material FR4 (ϵ_r=4.7) used in the antenna design.

3.7 Summary

In this chapter, Transmission Line Model for Inset Fed Microstrip Patch Antenna Design and 50Ω Inset-Fed location for transmission line feeding is explained in section 3.1. Based on the study, +45° Inset-Fed patch antenna design and -45° Inset-Fed patch antenna design and its simulation results is shown in section 3.2 and 3.3. Section 3.4.1 shows the design concept of power divider for parallel feed configuration with quarter-wave transformer. Section 3.4.4 also exhibits power divider design and simulation result for 1×2 patch array geometry. For +45°, -45°, ±45° 1×2 Patch Array Design is shown in section 3.5 with their simulation results.

Chapter 4

Patch Array Antenna Using RT/Duroid 5880

In the previous chapters 3, Design and Simulation of single element and 1×2 patch array antenna using FR4 (ϵ_r=4.7) substrate has been demonstrated. This chapter is dedicated to the design of single element and 1×2 patch array antenna using RT/Duroid 5880 (ϵ_r=2.2). At the end of this chapter, array antenna results obtained from simulation for two substrate (FR4 and RT/Duroid 5880) has been comapred.

4.1 +45° Inset-Fed Patch Antenna Design

As shown in chapter 3, single element +45° patch antenna, single element -45° patch antenna and 1×2 patch array antenna has been designed and simulated using FR4 (ϵ_r=4.7) substrate. Simulation results shows very low Gain due to the substrate material loss. RT/Duroid 5880 compensate losses and improve Gain of the antenna design. This step has been considered from the reference article [14].

4.1.1 Design and Simulation Results

Parameter of the single element patch antenna is shown in Table 4.1. Design parameter of antenna has been calculated from the equations 3.1 to 3.10 given in the Chapter 3.

Table 4.1: Design Specification of Inset-Fed Patch Antenna

Parameter	Parameter Description	Parameter value(mm)
L	Length of the Patch antenna	40.7484
W	Width of the Patch antenna	49.4104
S	Slot cut for inset	11.3385
Y_0	Inset distance from the edge of the patch	11.3127
Lg	Length of the Groundplane	85.9484
Wg	Width of the Groundplane	134.0104

Design of +45° Inset-Fed Patch Antenna is shown in Figure.4.1. Design of +45° Inset-Fed Patch Antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 85.94 mm x 134.01 mm.

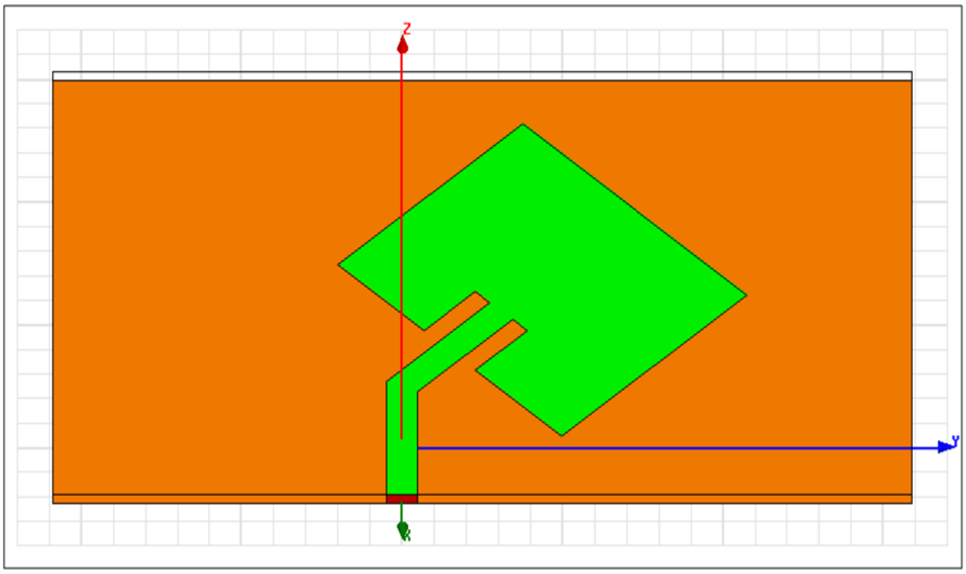

Figure 4.1: +45° Inset Fed Patch Antenna Design

Simulation results of +45° Inset-Fed Patch Antenna is shown below. Simulation result of ReturnLoss plot shows that S_{11} = -21.01 dB at 2.39 GHz. Bandwidth is obtained 1.37% with reference of -10 dB Return Loss.

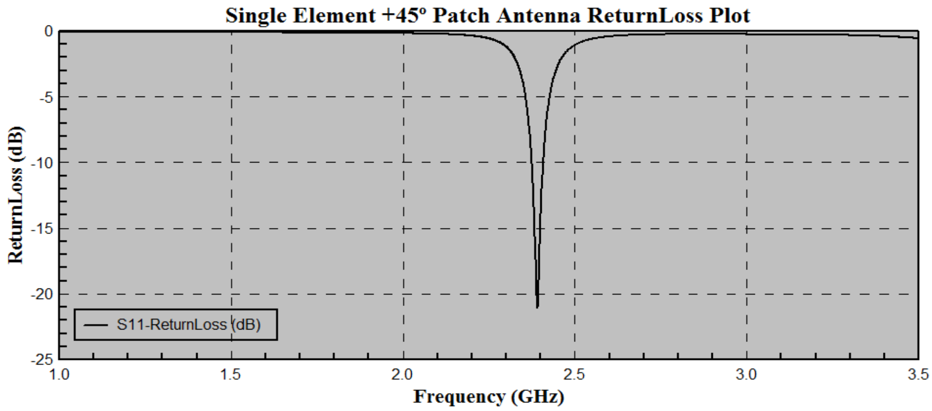

Figure 4.2: ReturnLoss (S_{11}) Plot of Inset Fed +45° Patch Design

Simulation result of VSWR plot shows that VSWR = 1.19 at 2.39 GHz.

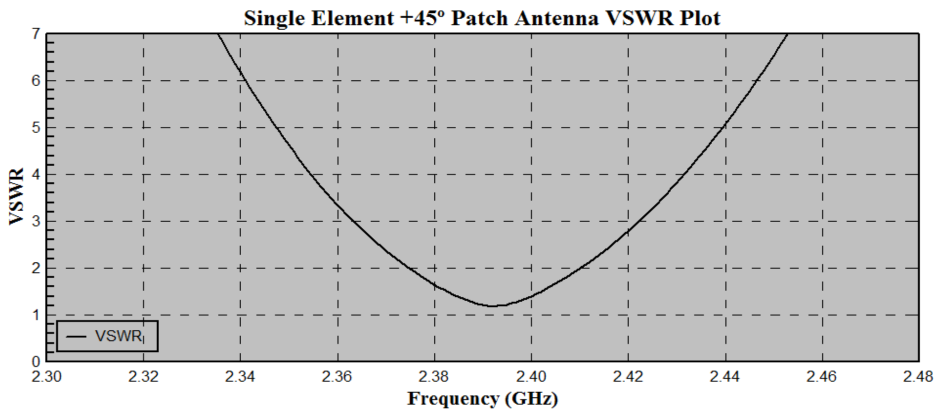

Figure 4.3: VSWR Plot of Inset Fed +45° Patch Design

Simulation result of Gain plot shows that Gain = 7.61 dB in Figure 4.4.

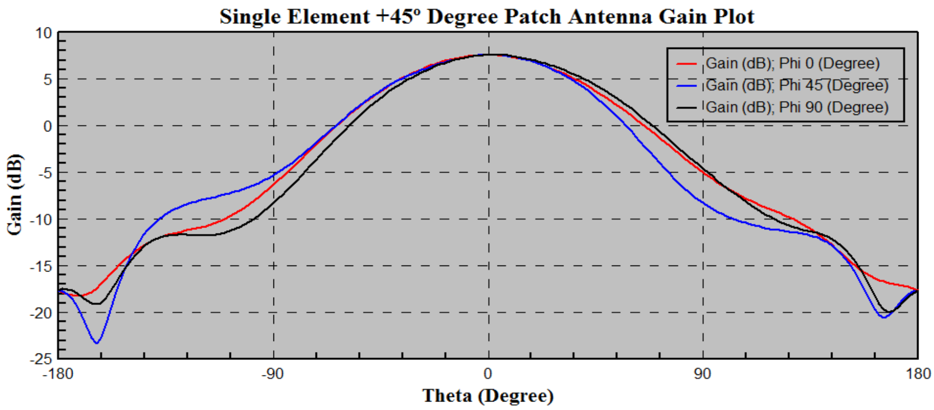

Figure 4.4: Gain Plot of Inset Fed +45° Patch Design

Simulation result of Directivity plot shows that Directivity = 7.71 dB in Figure 4.5.

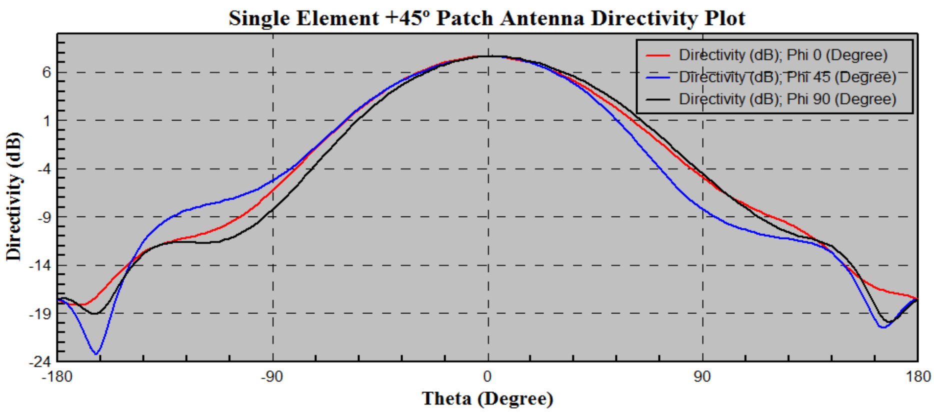

Figure 4.5: Directivity Plot of Inset Fed +45° Patch Design

Simulation result of Radiation Pattern plot shows in Figure 4.6

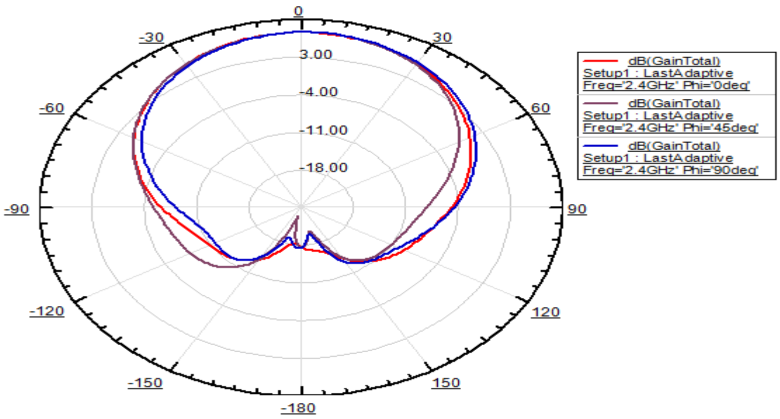

Figure 4.6: Radiation Pattern Plot of Inset Fed +45° Patch Design

4.2 -45° Inset-Fed Patch Antenna Design

4.2.1 Design and Simulation Results

Design of -45° Inset-Fed Patch Antenna is shown in Figure 4.2. Design of -45° Inset-Fed Patch Antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 85.94 mm x 131.04 mm. Other dimensions of the patch antenna is given in Table. 4.1 .

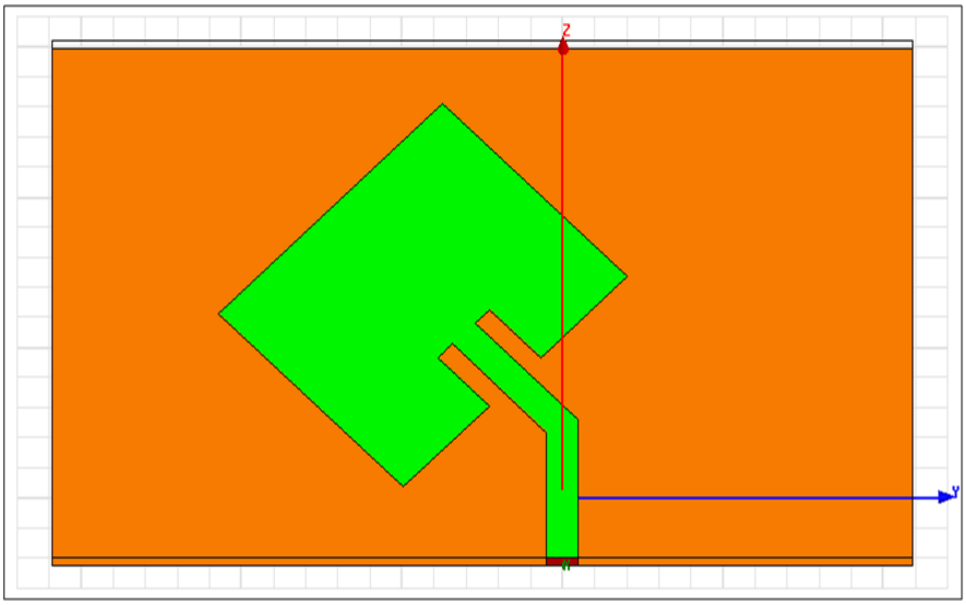

Figure 4.7: -45° Inset Fed Patch Antenna Design

Simulation results of -45° Inset-Fed Patch Antenna is shown below. Simulation result of ReturnLoss plot shows that S_{11} = -21.57 dB at 2.39 GHz. Bandwidth is obtained 1.38% with reference of -10 dB Return Loss.

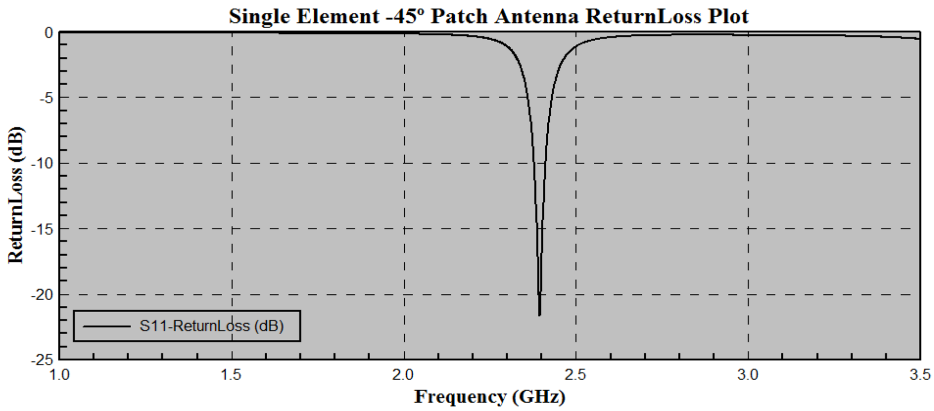

Figure 4.8: ReturnLoss (S_{11}) Plot of Inset Fed -45° Patch Design

Simulation result of VSWR plot shows that VSWR = 1.18 at 2.39 GHz.

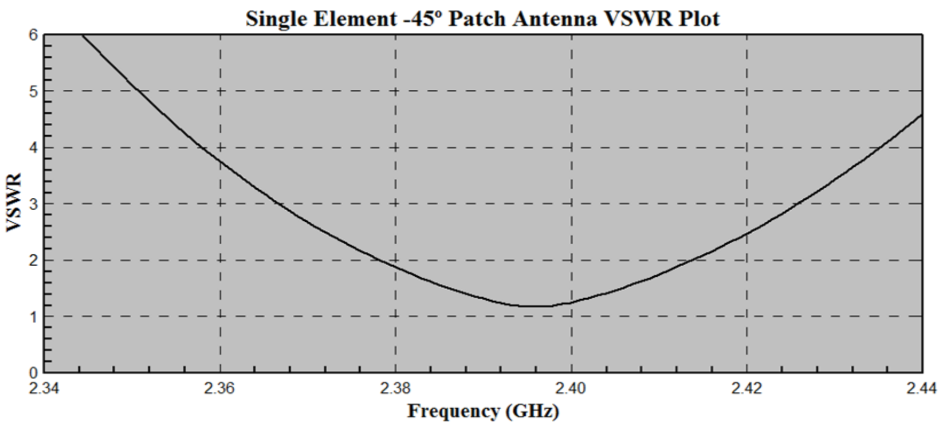

Figure 4.9: VSWR Plot of Inset Fed -45° Patch Design

Simulation result of Gain plot shows that Gain = 7.74 dB in Figure 4.10.

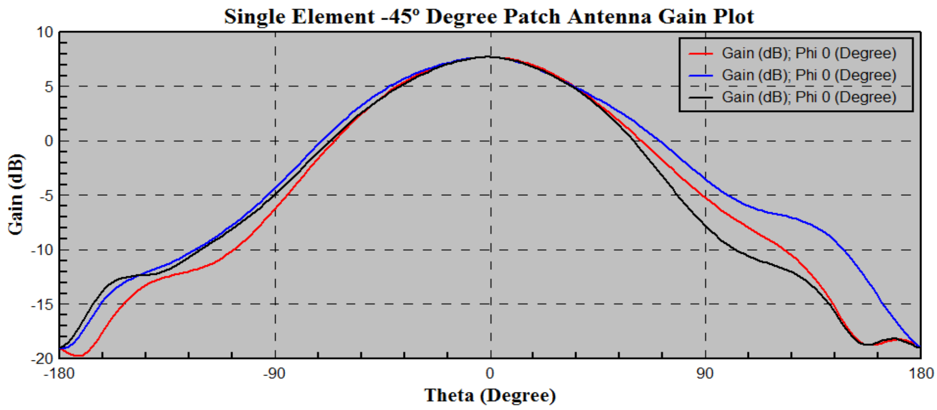

Figure 4.10: Gain Plot of Inset Fed -45° Patch Design

Simulation results of Directivity plot shows that Directivity = 7.87 dB in Figure 4.11.

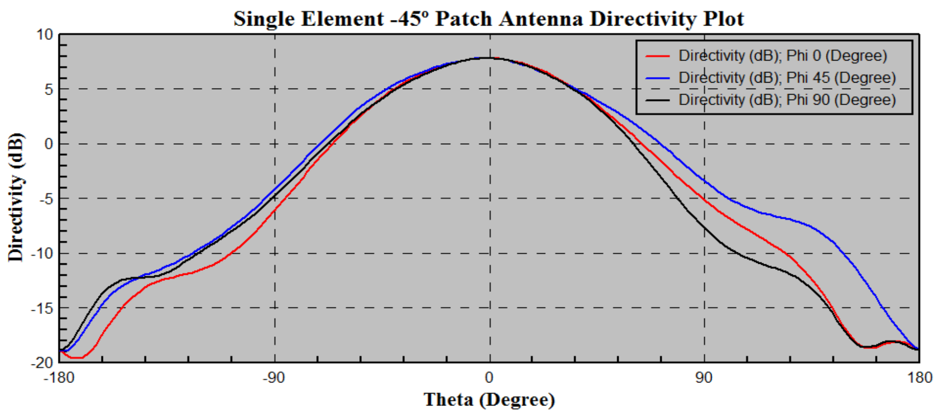

Figure 4.11: Directivity Plot of Inset Fed -45° Patch Design

Simulation result of Radiation Pattern plot shows in Figure 4.6

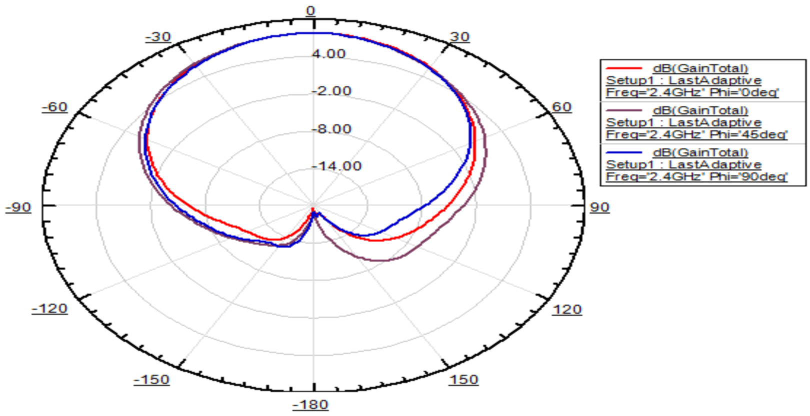

Figure 4.12: Radiation Pattern Plot of Inset Fed -45° Patch Design

4.3 1×2 Patch Array Antenna Feed Network Design

Length and Width calculation procedure of Transmission line is shown in Appendix A. Length and Width of transmission line is shown in Table 4.2.

Table 4.2: Design Parameter of Power Divider Transmission Line

Impedance (Ω)	Length (mm)	Width(mm)
50	22.8449	4.8373
70.71	23.1959	2.7752
100	23.5667	1.4072

Based on calculated dimensions Power Divider for 1×2 Patch Array Geometry has been designed and Simulated.Design of Power Divider is Shown in Figure 4.13.

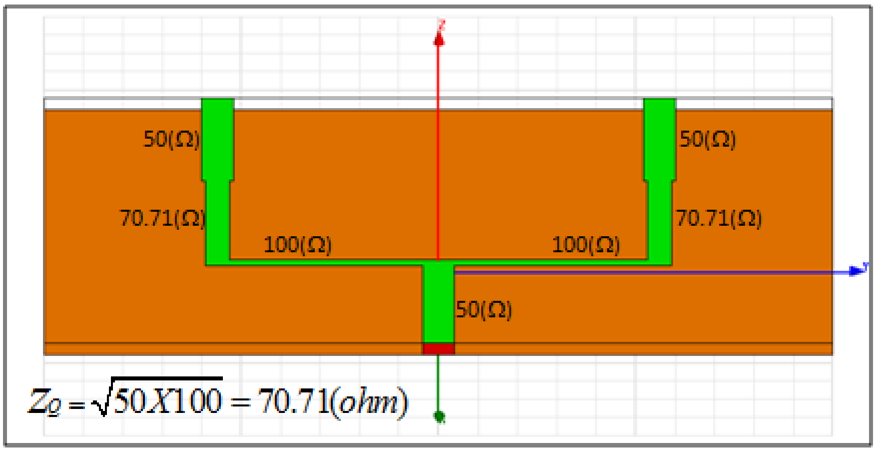

Figure 4.13: Power Divider Design for 1×2 Patch Array

Simulation result shows that S_{11} parameter is -47.28 dB at 2.4 GHz and S_{21} and S_{31} is -3.00 dB at 2.4 GHz. Insertion Loss (S-parameter) S_{21} and S_{31} shows that 3-dB down power at both the port, is equal. Means, power is equally divided in both the output port from input port.

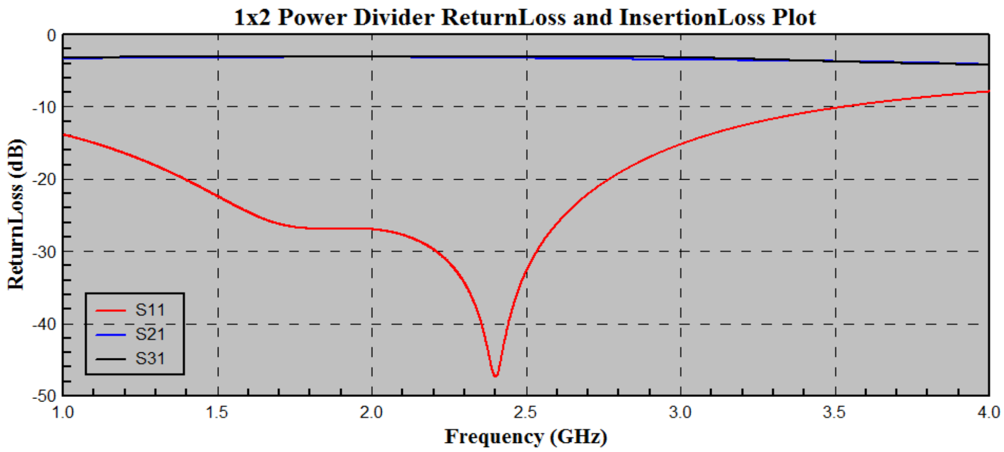

Figure 4.14: ReturnLoss (S_{11}) and Insertion Loss(S_{21},S_{31}) of Power Divider

4.4 1×2 Patch Array Antenna Design

4.4.1 Geometry of +45° 1×2 Patch Array Antenna Design

Geometry of +45° 1×2 patch array antenna is shown in Figure 4.15. Design of +45° 1×2 patch array antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 135 mm x 240 mm.

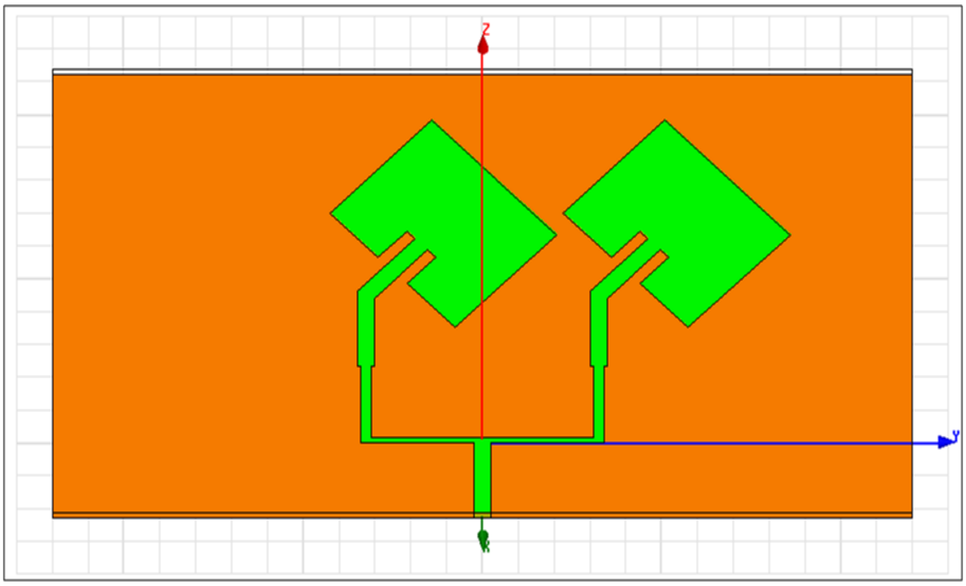

Figure 4.15: +45° 1×2 Patch Array Geometry

4.4.2 Simulation Results of +45° 1×2 Array Antenna

Simulation results of +45° 1×2 Array Antenna geometry are shown below from Figure 4.16 to 4.20. Simulation results contain the plot of ReturnLoss, VSWR, Gain, Directivity and radiation pattern.

Figure 4.16 shows simulation result of ReturnLoss characteristics of +45° 1×2 array configuration. The antenna design gives Return Loss of -18.87 dB at 2.36 GHz. Bandwidth is obtained 1.76% with reference of -10 dB Return Loss.

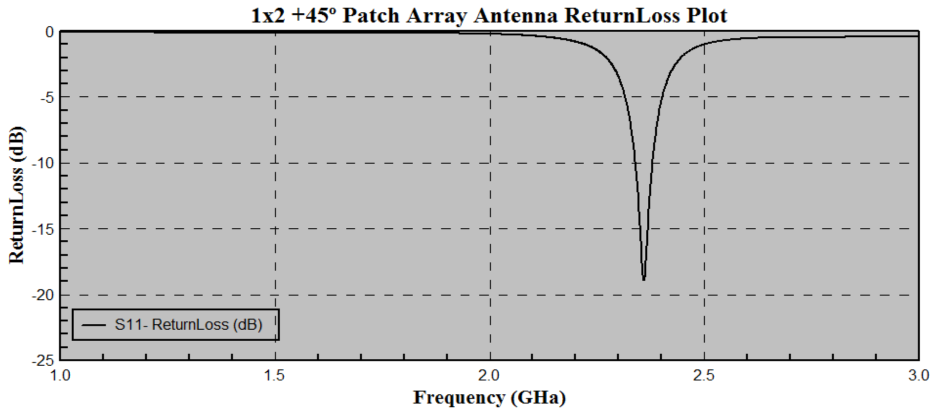

Figure 4.16: ReturnLoss (S_{11}) Plot of +45° 1×2 Patch Array Design

Figure 4.17 shows simulation result of VSWR characteristics of +45° 1×2 array configuration. +45° 1×2 array configuration gives VSWR of 1.25 at 2.36 GHz.

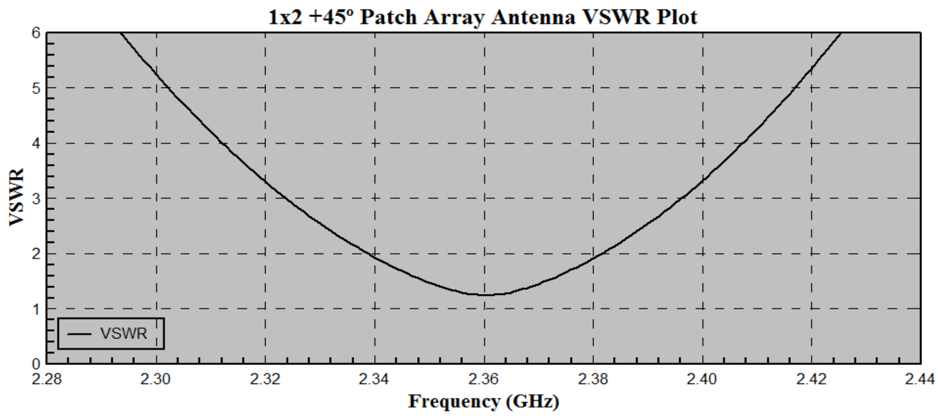

Figure 4.17: VSWR Plot of +45° 1×2 Patch Array Design

Figure 4.18 shows simulation result of Gain characteristics of +45° 1×2 array configurations. +45° 1×2 array configuration gives Gain of 10.10 dB.

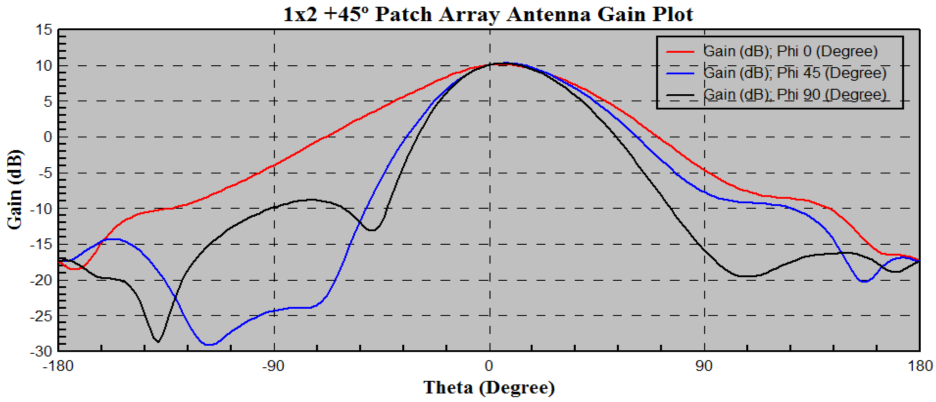

Figure 4.18: Gain Plot of +45° 1×2 Patch Array Design

Figure 4.19 shows simulation result of Directivity of +45° 1×2 array configuration. +45° 1×2 array configuration gives Directivity of 10.22 dB.

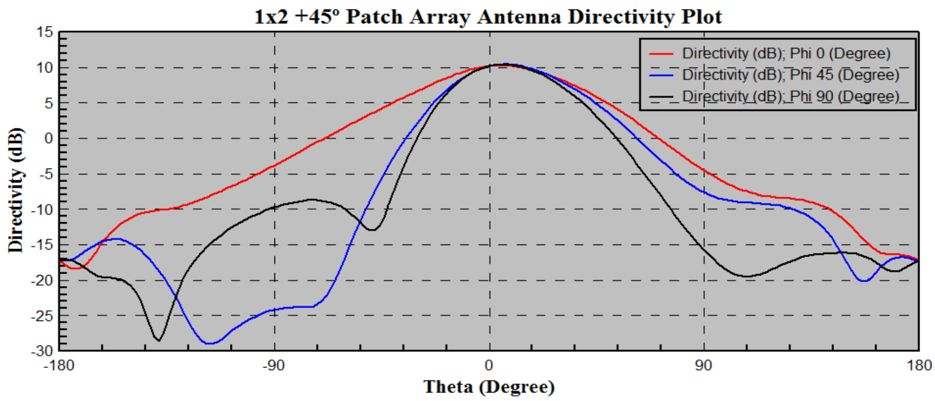

Figure 4.19: Directivity Plot of +45° 1×2 Patch Array Design

Figure 4.20 shows simulation result of Radiation Pattern of 1×2 +45° array configuration.

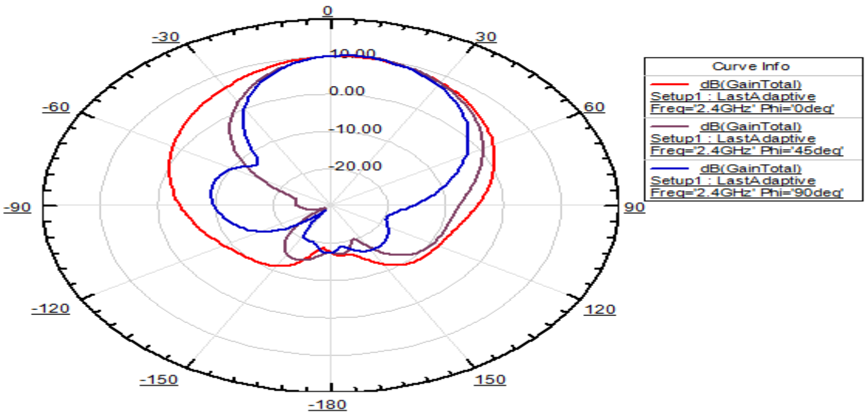

Figure 4.20: Radiation Pattern of +45° 1×2 Patch Array Design

4.4.3 Geometry of -45° 1×2 Patch Array Antenna Design

Geometry of 1×2 -45° patch array antenna is shown in Figure 4.21. Design of a 1×2 -45° patch array antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 135 mm x 240 mm.

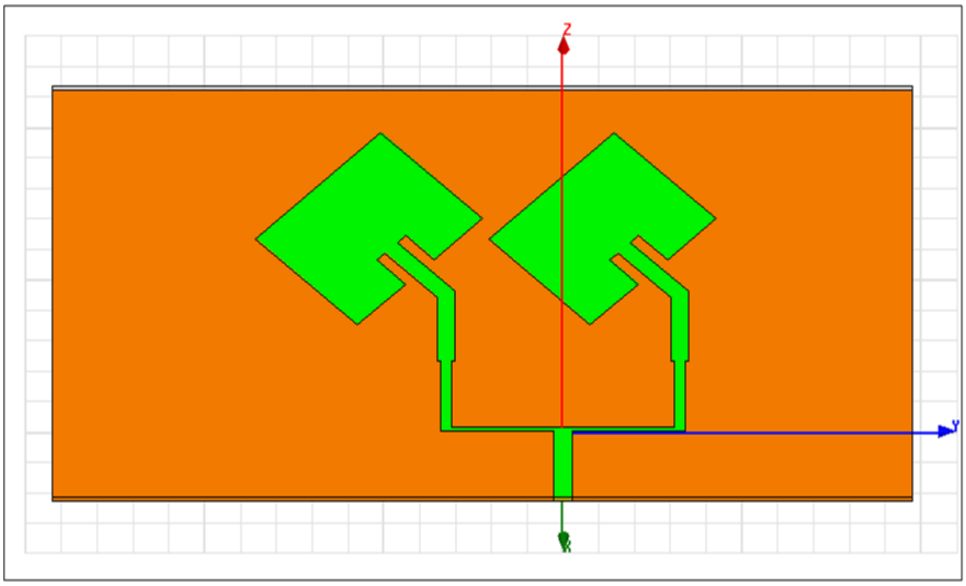

Figure 4.21: -45° 1×2 Patch Array Geometry

4.4.4 Simulation Result of -45° 1×2 Array Antenna

Figure 4.22 shows simulation result of ReturnLoss characteristics of -45° 1×2 array configuration. The antenna gives Return Loss of -23.86 dB at 2.38 GHz. Bandwidth is obtained 1.66% with reference of -10 dB Return Loss.

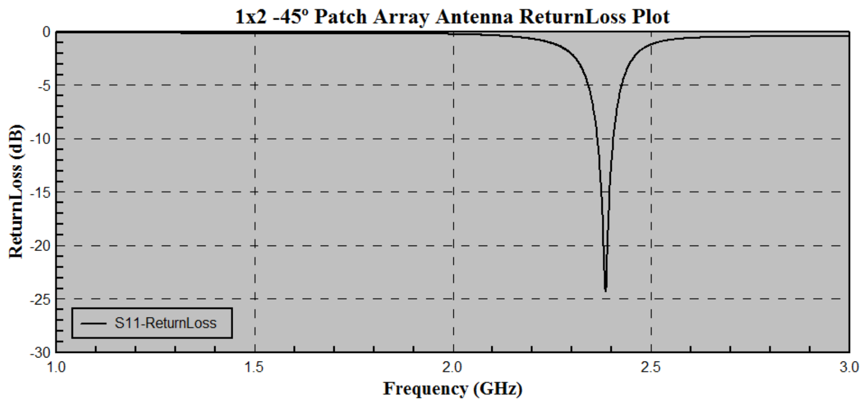

Figure 4.22: ReturnLoss (S_{11}) Plot of -45° 1×2 Patch Array Design

Figure 4.23 shows simulation result of VSWR characteristics of -45° 1×2 array configuration. -45° 1×2 array configuration gives VSWR of 1.13 at 2.38 GHz.

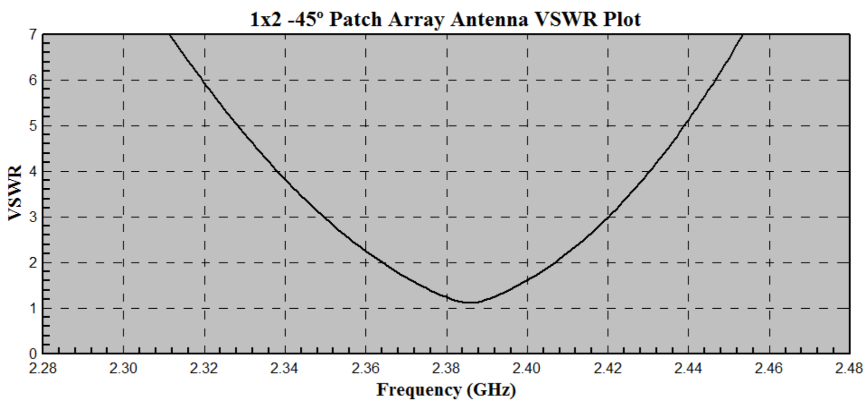

Figure 4.23: VSWR Plot of -45° 1×2 Patch Array Design

Figure 4.24 shows simulation result of Gain characteristics of -45° 1×2 array configuration. -45° 1×2 array configuration gives Gain of 10.26 dB.

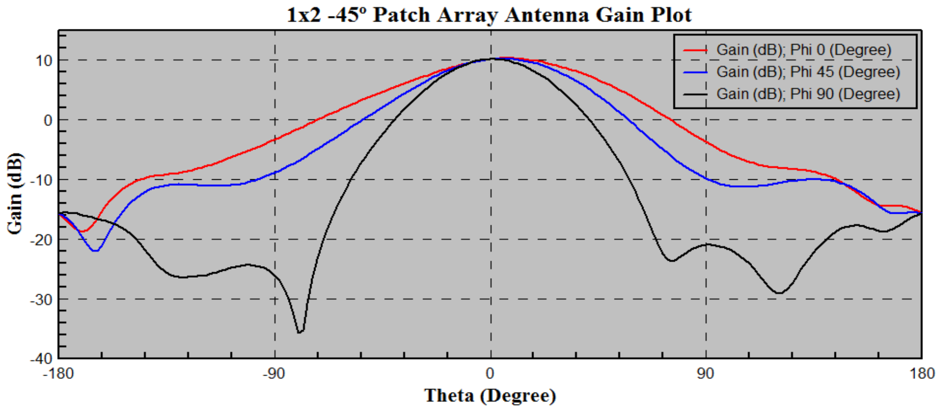

Figure 4.24: Gain Plot of -45° 1×2 Patch Array Design

Figure 4.25 shows simulation result of Directivity of -45° 1×2 array configuration. -45° 1×2 array configuration gives Directivity of 10.36 dB.

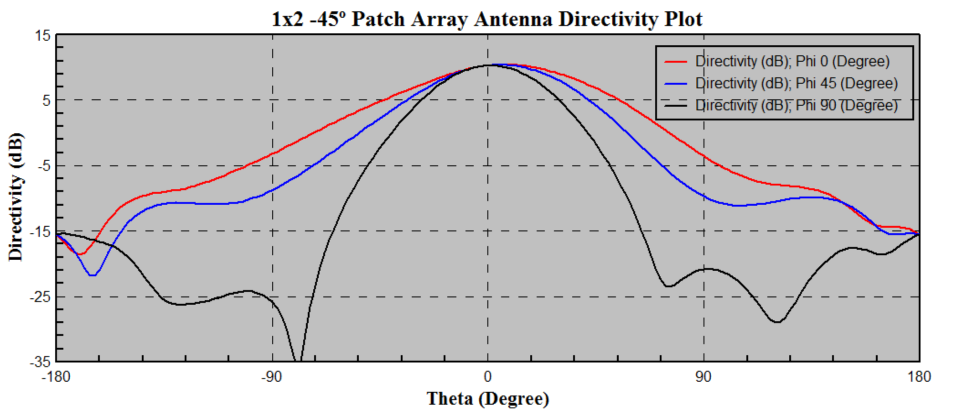

Figure 4.25: Directivity Plot of -45° 1×2 Patch Array Design

Figure 4.26 shows simulation result of Radiation Pattern of -45° 1×2 array configuration.

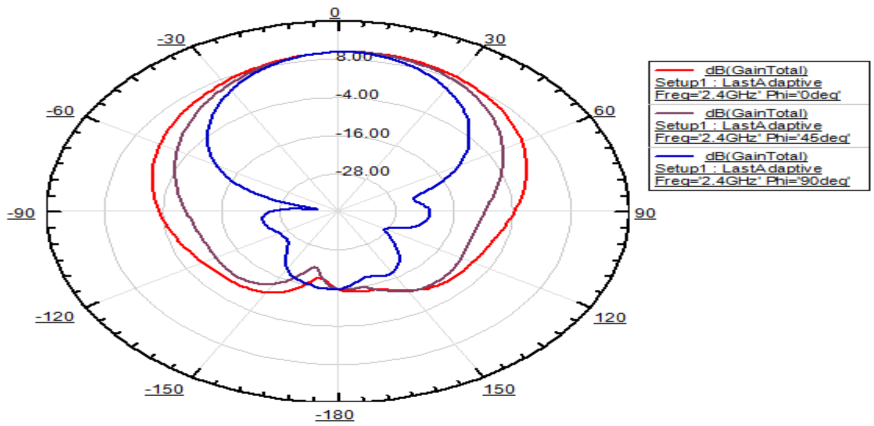

Figure 4.26: Radiation Pattern of -45° 1×2 Patch Array Design

4.4.5 Geometry of $\pm45°$ 1×2 Patch Array Antenna Design

Geometry of $\pm45°$ 1×2 array antenna configuration is shown in 4.27. Design of $\pm45°$ 1×2 array antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 130 mm x 200 mm.

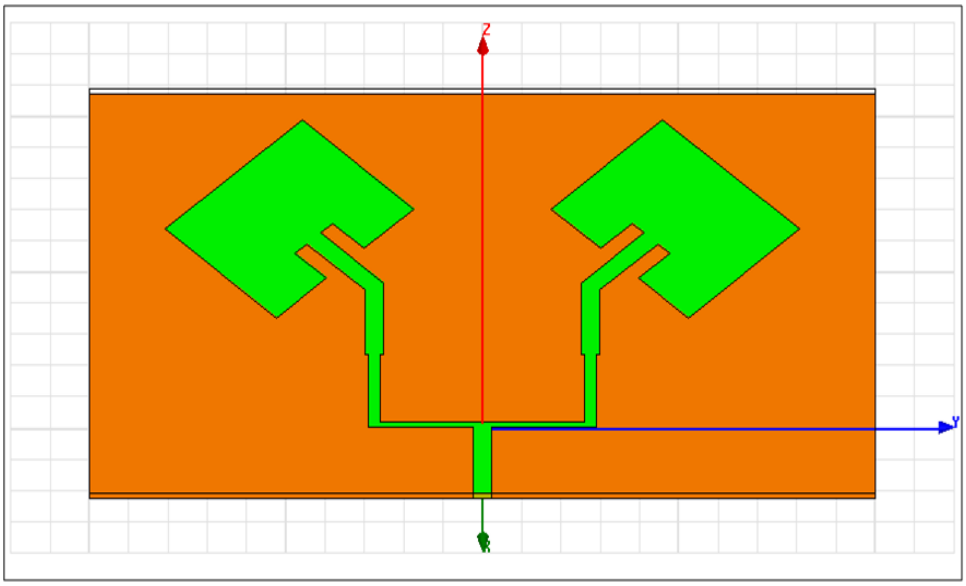

Figure 4.27: $\pm45°$ 1×2 Patch Array Geometry

4.4.6 Simulation Result of ±45° 1×2 Array Antenna

Figure 4.28 shows simulation result of Return Loss characteristics of ±45° 1×2 array configuration. The antenna gives Return Loss of -22.36 dB at 2.35 GHz. Bandwidth is obtained 1.41% with reference of -10 dB Return Loss.

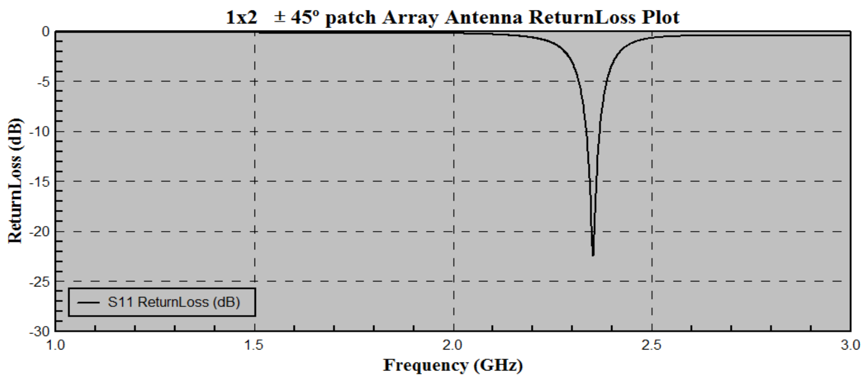

Figure 4.28: ReturnLoss (S_{11}) Plot of ±45° 1×2 Patch Array Design

Figure 4.29 shows simulation result of VSWR characteristics of ±45° 1×2 array configuration. ±45° 1×2 array configuration gives VSWR of 1.16 at 2.35 GHz.

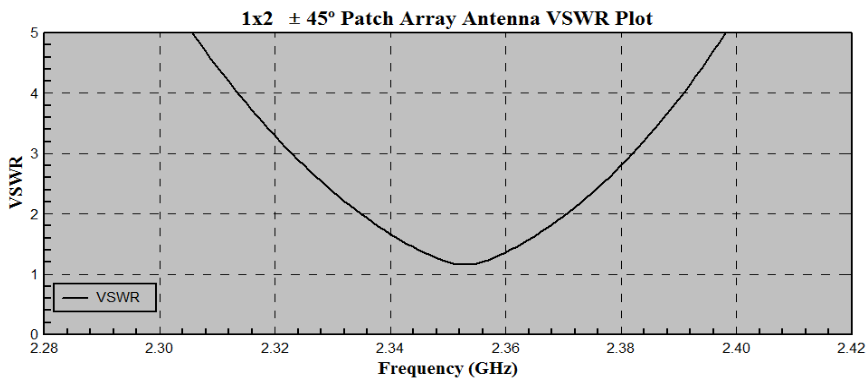

Figure 4.29: VSWR Plot of ±45° 1×2 Patch Array Design

Figure 4.30 shows simulation result of Gain characteristics of ±45° 1×2 array configuration. ±45° 1×2 array configuration gives Gain of 8.51 dB.

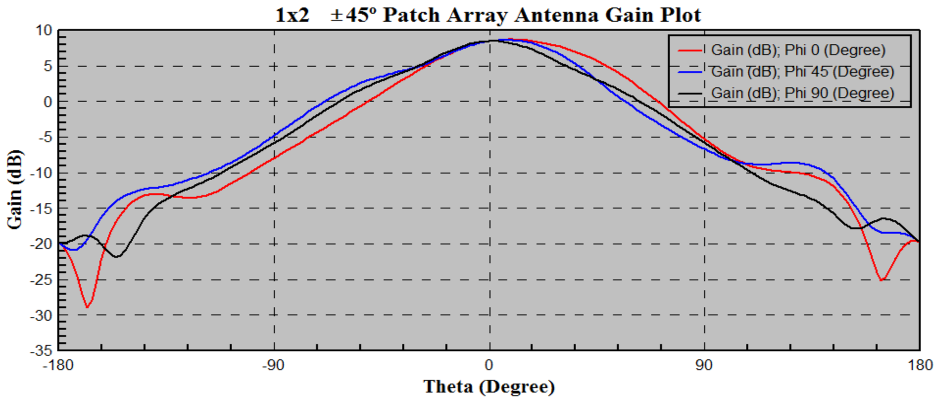

Figure 4.30: Gain Plot of ±45° 1×2 Patch Array Design

Figure 4.31 shows simulation results of Directivity of ±45° 1×2 array configurations. ±45° 1×2 array configuration gives Directivity of 8.70 dB.

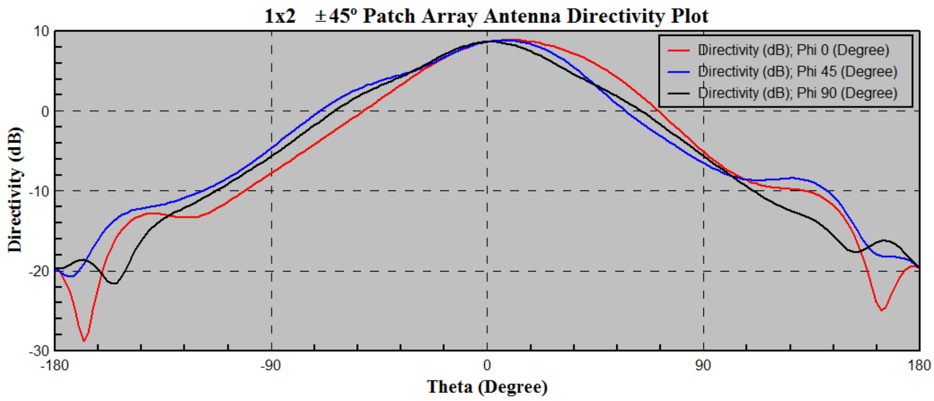

Figure 4.31: Directivity Plot of ±45° 1×2 Patch Array Design

Figure 4.32 shows simulation result of Radiation Pattern of ±45° 1×2 array configuration.

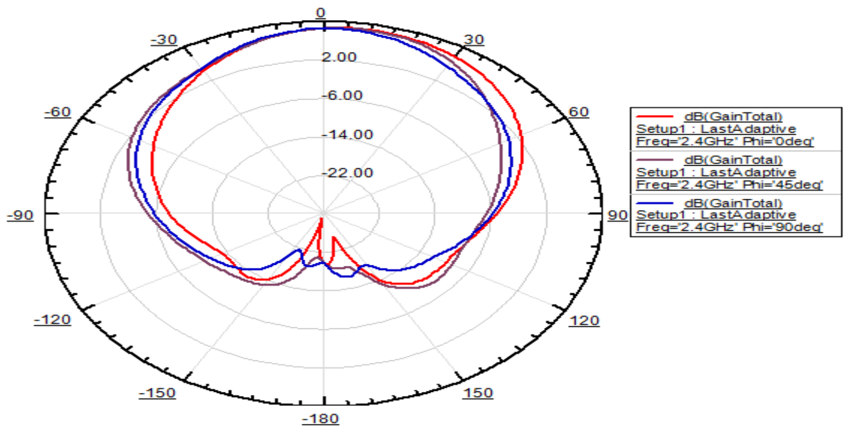

Figure 4.32: Radiation Pattern of ±45° 1×2 Patch Array Design

4.5 Summary of Simulation Results

All the designs of patch array antenna results are summarized in below Table 4.3 .

Table 4.3: Summary of Antenna Design Simulation Results

Antenna Design	**ReturnLoss (dB)**	**VSWR**	**Gain (dB)**	**Directivity (dB)**	**BW (MHz)/(%)**
Single Element +45°	-21.01	1.19	7.61	7.71	33/1.37
Single Element -45°	-21.57	1.18	7.74	7.87	33.2/1.38
+45° **1x2 Patch Array Antenna**	-18.87	1.25	10.10	10.22	39.7/1.76
-45° **1x2 Patch Array Antenna**	-23.86	1.13	10.26	10.36	39.8/1.66
±45° **1x2 Patch Array Antenna**	-22.36	1.16	8.51	8.70	33.3/1.41

From the Table 4.3, it is evidence that the proposed patch array antenna has very good impedance matching and VSWR. Gain and Directivity of the proposed array antenna has been improved by replacing substrate. Duroid 5880 (ϵ_r=2.2) has shown very low loss compare to FR4 (ϵ_r=4.7). It is clearly understood from Table 3.4 and Table 4.3. But impedance bandwidth is low which is not desired for 2.4 GHz ISM(Industrial,Scientific and Medical) band applicaton such as WLAN.

4.6 Summary

In this chapter, Based on the study of Transmission Line Model , +45° Inset-Fed patch antenna design and -45° Inset-Fed patch antenna design and its simulation results is shown in section 4.1 and 4.2. power divider design and simulation result for

1×2 patch array geometry is shown in section 4.3. For $+45°$, $-45°$, $\pm 45°$ $1{\times}2$ Patch Array Design is shown in section 4.4 with their simulation results.

Chapter 5

1×4 and 2×2 Patch Array Antenna Design

In the previous chapters 4, Design and Simulation of single element and 1×2 patch array antenna using RT/Duroid (ϵ_r=2.2) substrate has been demonstrated. This chapter is dedicated to the design and simulation of 1×4 and 2×2 patch array antenna using RT/Duroid 5880 (ϵ_r=2.2). At the end of this chapter, array antenna results obtained from simulation are summarized.

5.1 1×4 Patch Array Antenna Feed Network Design

Length and Width calculation procedure of Transmission line is shown in Appendix A. Dimensinos of Length and Width of transmission line is shown in Table 5.1.

Table 5.1: Design Parameter of Power Divider Transmission Line

Impedance (Ω)	Length (mm)	Width(mm)
50	22.8449	4.8373
70.71	23.1959	2.7752
100	23.5667	1.4072

Based on calculated dimensions Power Divider for 1×4 Patch Array Geometry has been designed and Simulated.Design of power Divider is Shown in Figure 5.1.

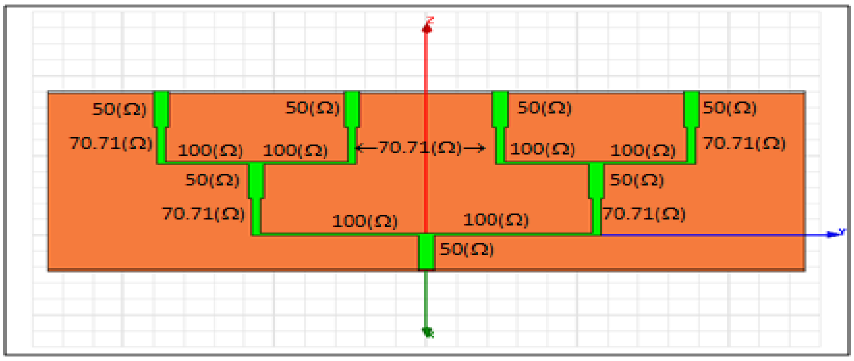

Figure 5.1: Power Divider Design for 1×4 Patch Array

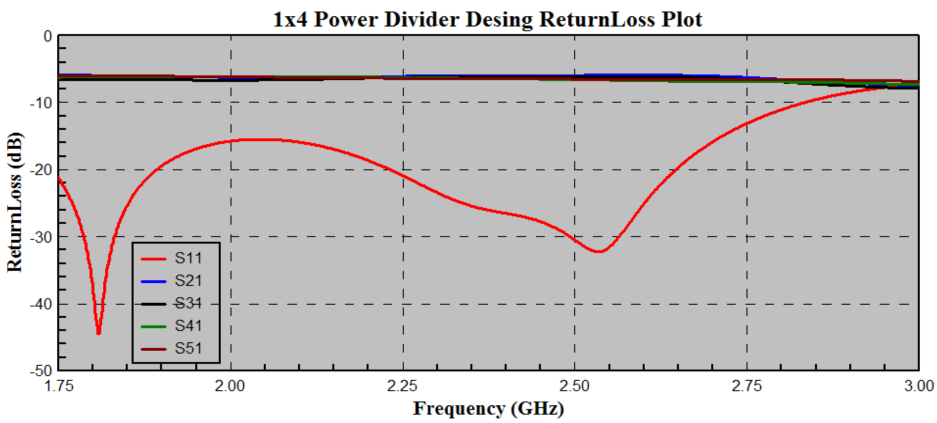

Figure 5.2: ReturnLoss (S_{11}) and Insertion Losses of 1×4 Power Divider

Simulation of 1×4 power divider is shown in Figure. 5.2. Simulation result shows that S_{11} parameter is -47.28 dB at 2.4 GHz and S_{21}, S_{31}, S_{41}, S_{51} are -5.93, -6.04, -6.38, -6.41 at 2.4 GHz respectively. Insertion Loss (S-parameter) S_{21}, S_{31}, S_{41}, S_{51} shows nearly 6-dB down power at all four the ports. Means, power is equally divided in all four output ports from input port.

5.2 1×4 Patch Array Antenna Design

5.2.1 Geometry of ±45° 1×4 Patch Array Antenna Design

Geometry of ±45° 1×4 patch array antenna is shown in Figure 5.3. Design of ±45° 1×4 patch array antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 181.99 mm x 300 mm.

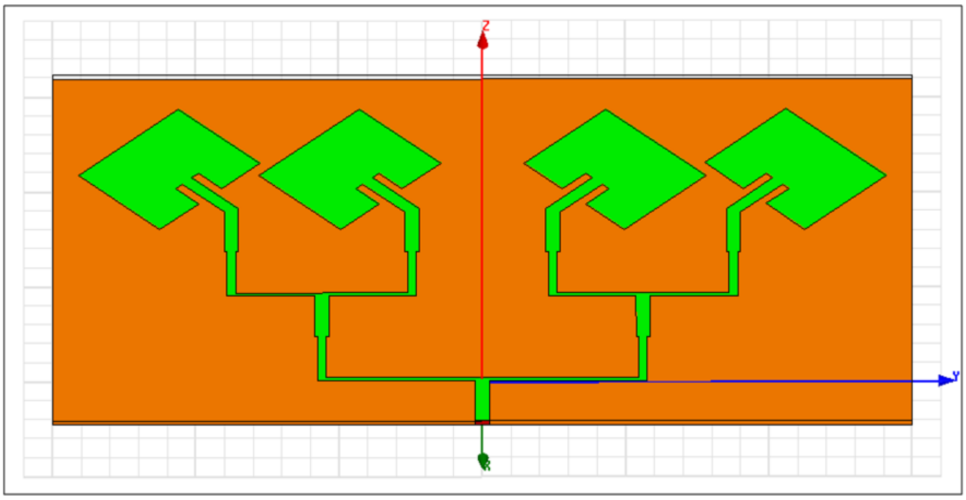

Figure 5.3: ±45° 1×4 Patch Array Geometry

5.2.2 Simulation Results of ±45° 1×4 Array Antenna

Figure 5.4 shows simulation result of ReturnLoss characteristics of ±45° 1×4 array configuration. The antenna design gives Return Loss of -34.28 dB at 2.21 GHz.

Bandwidth is obtained 1.43% with reference of -10 dB Return Loss.

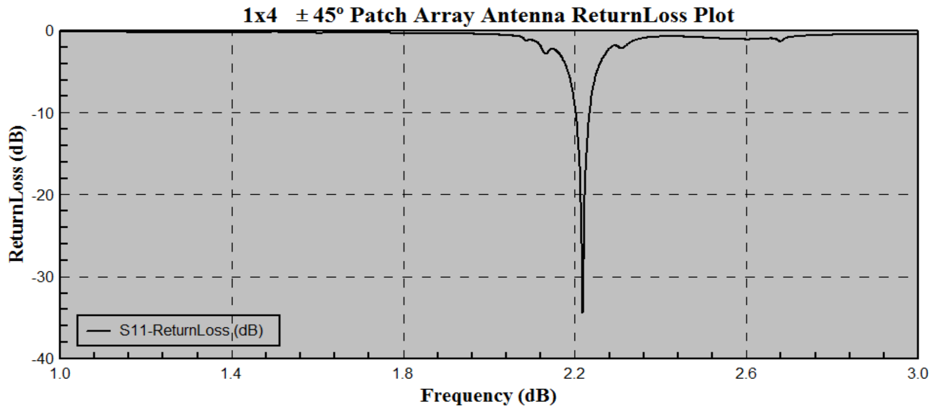

Figure 5.4: ReturnLoss (S_{11}) Plot of ±45° 1×4 Patch Array Design

Figure 5.5 shows simulation result of VSWR characteristics of ±45° 1×4 array configuration. 1×4 ±45° array configuration gives VSWR of 1.03 at 2.21 GHz.

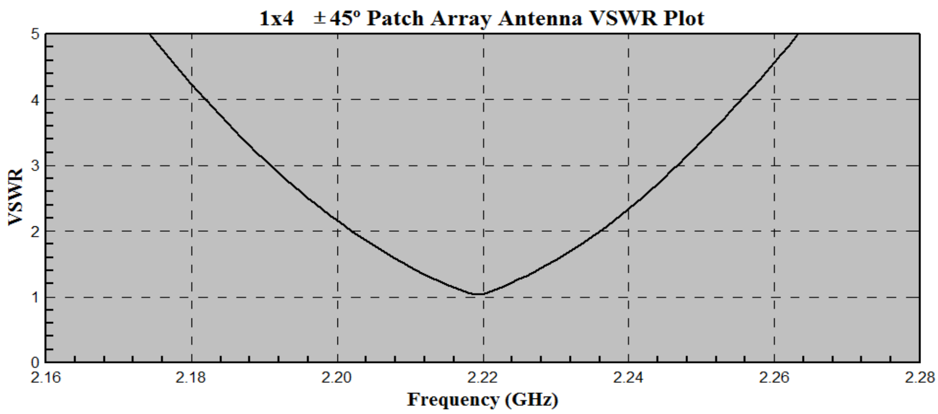

Figure 5.5: VSWR Plot of ±45° 1×4 Patch Array Design

Figure 5.6 shows simulation result of Gain characteristics of ±45° 1×4 array configuration. ±45° 1×4 array configuration gives Gain of 12.86 dB.

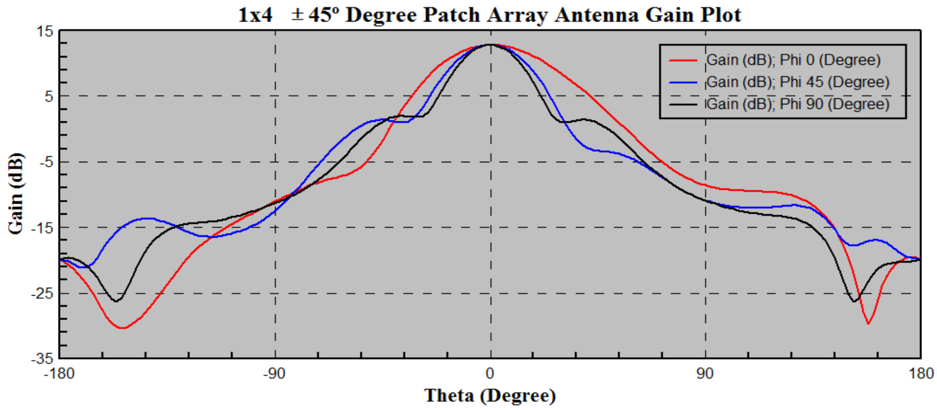

Figure 5.6: Gain Plot of ±45° 1×2 Patch Array Design

Figure 5.7 shows simulation results of Directivity of ±45° 1×4 array configuration. ±45° 1×4 array configuration gives Directivity of 13.56 dB.

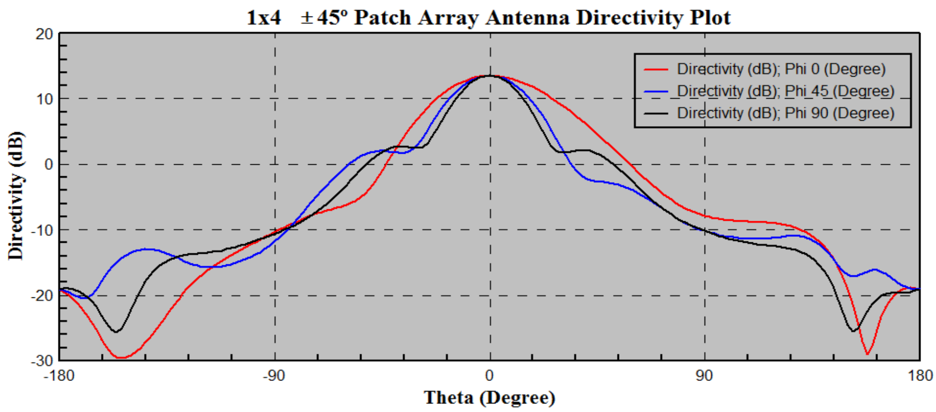

Figure 5.7: Directivity Plot of ±45° 1×4 Patch Array Design

Figure 3.34 shows simulation result of Radiation Pattern of ±45° 1×4 array configuration.

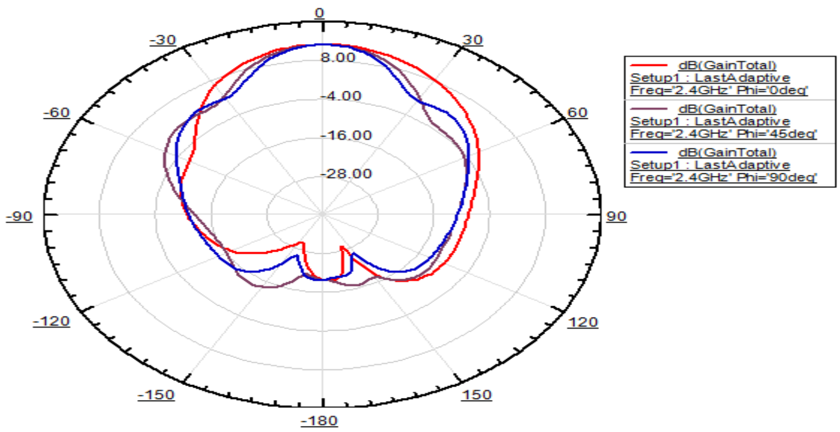

Figure 5.8: Radiation Pattern of ±45° 1×4 Patch Array Design

5.3 2×2 Patch Array Antenna Design

5.3.1 Geometry of ±45° 2×2 Patch Array Antenna Design

Geometry of ±45° 2×2 patch array antenna is shown in Figure 5.9. Design of ±45° 2×2 patch array antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 264.83 mm x 200 mm.

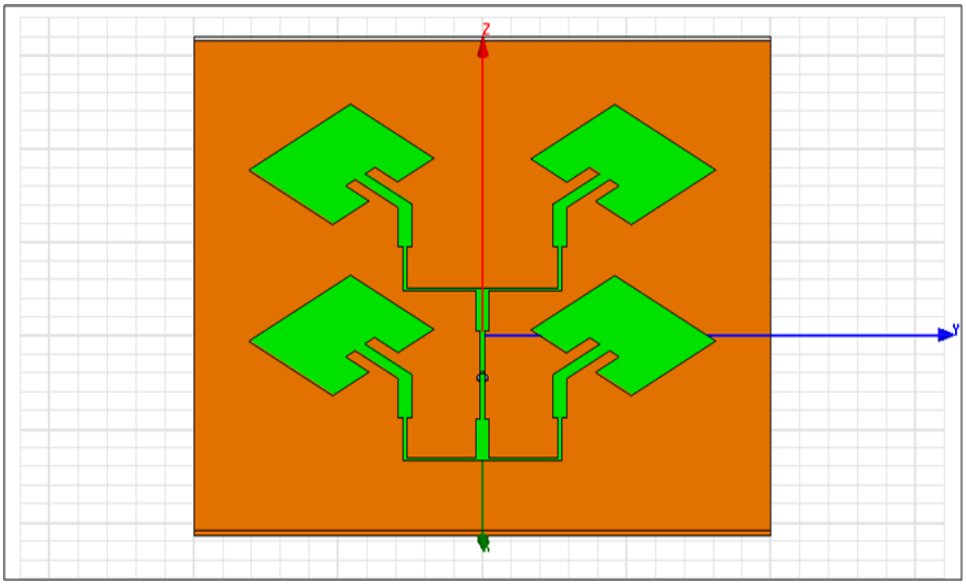

Figure 5.9: ±45° 2×2 Patch Array Geometry

5.3.2 Simulation Results of ±45° 2×2 Array Antenna

Simulation results of ±45° 2×2 Array Antenna geometry are shown below from Figure 5.10 to 5.14. Simulation results contain the plot of ReturnLoss, VSWR, Gain, Directivity and radiation pattern.

Figure 5.10 shows simulation result of ReturnLoss characteristics of ±45° 2×2 array configuration. The antenna design gives Return Loss of -20.43 dB at 2.19 GHz. Bandwidth is obtained 1.27% with reference of -10 dB Return Loss.

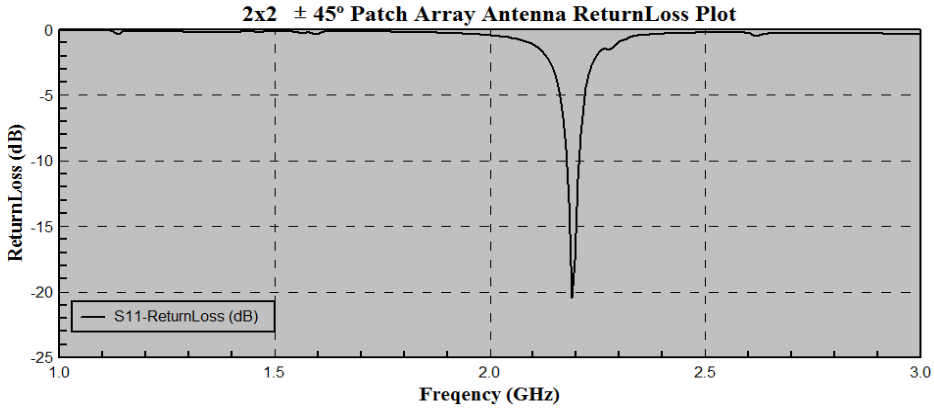

Figure 5.10: ReturnLoss (S_{11}) Plot of ±45° 2×2 Patch Array Design

Figure 5.11 shows simulation result of VSWR characteristics of ±45° 2×2 array configuration. ±45° 2×2 array configuration gives VSWR of 1.21 at 2.19 GHz.

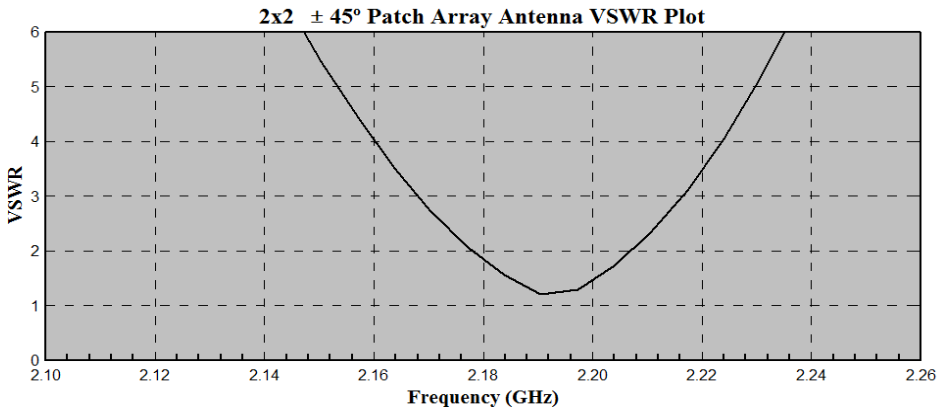

Figure 5.11: VSWR Plot of ±45° 2×2 Patch Array Design

Figure 5.12 shows simulation result of Gain characteristics of ±45° 2×2 array configuration. ±45° 2×2 array configuration gives Gain of 12.61 dB.

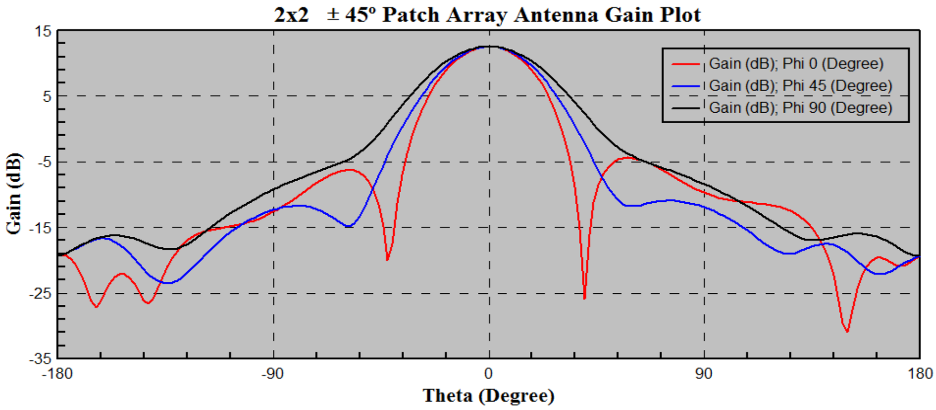

Figure 5.12: Gain Plot of ±45° 2×2 Patch Array Design

Figure 5.13 shows simulation results of Directivity of ±45° 2×2 array configurations. ±45° 2×2 array configuration gives Directivity of 13.70 dB.

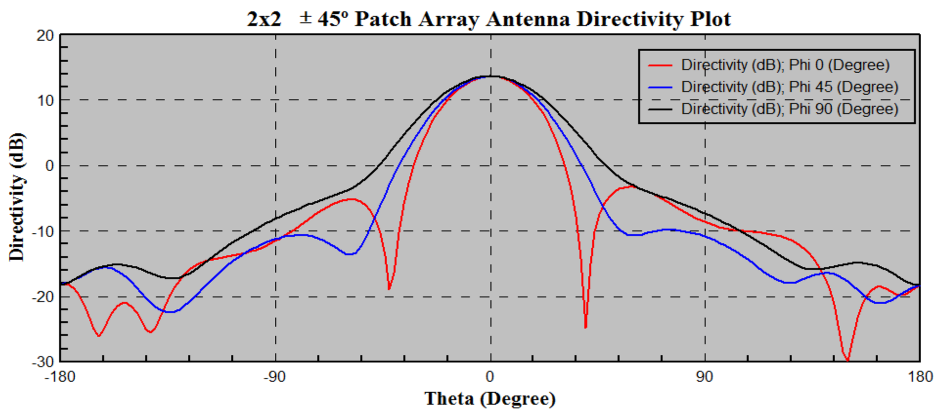

Figure 5.13: Directivity Plot of ±45° 2×2 Patch Array Design

Figure 5.14 shows simulation result of Radiation Pattern of ±45° 2×2 array configuration.

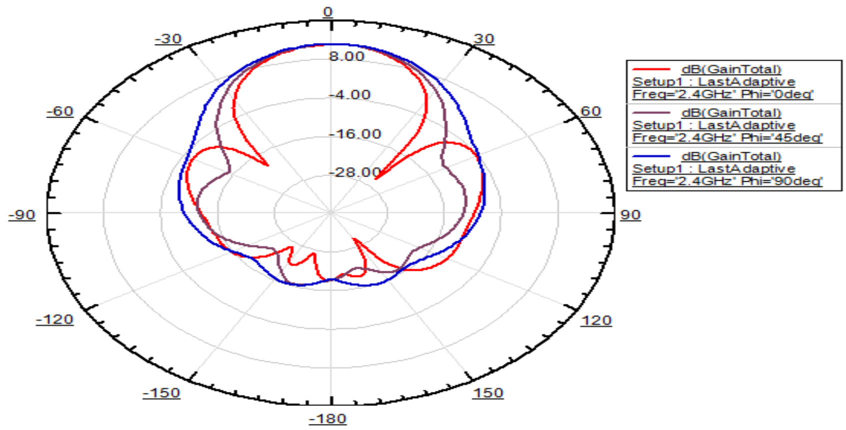

Figure 5.14: Radiation Pattern of ±45° 2×2 Patch Array Design

5.4 Summary of Simulation Results

All the designs of patch array antenna results are summarized in below Table 5.2 .

Table 5.2: Summary of Simulation Results

Antenna Design	**ReturnLoss (dB)**	**VSWR**	**Gain (dB)**	**Directivity (dB)**	**BW (MHz)/(%)**
Single Element +45°	-21.01	1.19	7.61	7.71	33/1.37
Single Element **-**45°	-21.57	1.18	7.74	7.87	33.2/1.38
1x2 +45° **Patch Array Antenna**	-18.87	1.25	10.10	10.22	39.7/1.76
1x2 **-**45° **Patch Array Antenna**	-23.86	1.13	10.26	10.36	39.8/1.66
1x2 ±45° **Patch Array Antenna**	-22.36	1.16	8.51	8.70	33.3/1.41
1x4 ±45° **Patch Array Antenna**	”<u>-34.28</u>”	”<u>1.03</u>”	”<u>12.86</u>”	”<u>13.56</u>”	”<u>31.8</u>/<u>1.43</u>”
2x2 ±45° **Patch Array Antenna**	”<u>-20.43</u>”	”<u>1.21</u>”	”<u>12.61</u>”	”<u>13.70</u>”	”<u>27.9</u>/<u>1.27</u>”

(”_”)Indicate present chapter’s results

From the Table 5.2, it is evidence that the proposed design of 1×4 ±45° and 2×2 ±45° patch array antenna have very good impedance matching and VSWR. Gain and Directivity of the proposed array antenna has been improved by increasing patch element into the array design. But impedance bandwidth is low which is not desired for 2.4 GHz ISM(Industrial,Scientific and Medical) band application such as WLAN.

5.5 Summary

In this chapter, 1×4 patch array antenna feed network design with simulation results shown in section 5.1. 1×4 patch array antenna design and simulation results are shown in section 5.2 and 5.2.2 respectively. 2×2 patch array antenna design and simulation results are shown in section 5.3 and 5.3.2 respectively. All the results from chapter 4 and 5 are summarized in section 5.4.

Chapter 6

BW Enhanced Design for Patch Array Antenna

6.1 Introduction

In the previous chapter, single element +45° and -45°, 1×2 +45°, 1×2 -45°, and 1×2 ±45° dual polarized patch array antenna, 1×4 ±45° dual polarized patch array antenna and 2×2 ±45° dual polarized patch array antenna have been design using substrate material Duroid 5880.

As the element increases in the array antenna design, antenna shows good Gain and Directivity properties. But these all designs have a low BW parameter. With gain and Directivity, Bandwidth of the array antenna is also an important parameter. Various bandwidth enhancement method have been reported in literature.
Bandwidth enhancement methods are listed below:

(1) BW can be increase based on feeding techniques
    (1.1) Aperture Coupling Method
    (1.2) Proximity Coupling Method

Detail information of above two methods have been given in section 2.6 of chapter 2.

Wide bandwidth is the major advantage of above two methods. Therefore both the methods are used in Ultra wide-band application of patch antenna.

This method increases the overall height of the antenna but the size in the planar direction remains the same as that of the single-patch antenna. Thus, these multilayer configurations are suitable as array elements [16].

In, aperture-coupled MSAs configuration consists of two resonant patches that are slightly different in size, with lower patch fed by microstrip line through a resonant slot in the common ground plane. The basic feature of this configuration is that each of the three resonator, two patches and the aperture, has its own impedance loop. There is also mutual coupling among three resonators. The resonator parameters are also adjustable to bring the impedance loop closer to each other. The substrate thickness and dielectric constant between the resonators is also varied to adjust the mutual coupling between them resulting in a wide bandwidth.

Another advantage is that, radiation from the open end of the feed line does not interfere with the radiation pattern of the patch because of shielding effect of ground in aperture Coupling.

Unlike the aperture couple configuration the bottom patch can be fed by a coaxial probe or by a microstrip line. The upper patch is proximity coupled to the excited bottom patch. The size of the upper patch is slightly different from that of the lower patch to obtain slightly different resonance frequency. Although the offset patch gives rise to a wider bandwidth the structural asymmetry gives rise to the beam squint in the E-plane.[15]

The disadvantage of above described method is that, the structure become complex. Here, the accurate alignment between feed line and patch required.Hence it is slightly more difficult to fabricate.

(2) BW can be enhanced by Multilayer Stacking Technique

In stacked multiresonator technique, multiple patches are taken in the bottom layer and a single patch is taken on the top layer. Alternatively, a single patch is placed in the bottom layer, and multiple patches are taken in the top layer. This is followed by multiple patches in both the bottom and the top layers. A single patch With four stacked patches yields broad BW with a high gain.

The bottom patch can be excited either by a microstrip line or a coaxial feed or through electromagnetic or aperture coupling. The method of excitation influences the bottom patch characteristics and does not significantly affect the performance of the stacked patches. However, by this technique high BW is achieved.

(3) BW can be increase by Slot Techniques

Various Slots method, i.e. U-Slot, W-Slot, E-Slot, H-Slot for bandwidth enhancement have been reported in literature [9], [24] , [25], [26] , [27] , [28] , [29] , [30] , [31] , [32], [33].

If the resonance frequencies of the slot and the patch are close to each other, then broad BW could be obtained [16]. The frequency and Q of the resonances can be independently controlled by adjusting their length and width. However, care must be taken so that the polarization of the radiated field of the slot and the patch are similar, so that the pattern remains stable over the VSWR BW.

(4) BW can be enhanced by increasing Substrate Height

Bandwidth, Quality factor and Efficiency are antenna figures-of-merit, which are interrelated, and there is no complete freedom to independently optimize each one.

Therefore there is always a trade-off between them in arriving at an optimum antenna performance. Often, however, there is a desire to optimize one of them while reducing the performance of the other.

The quality factor is a figure-of-merit that is representative of the antenna losses. Typically there are radiation, conduction (ohmic), dielectric and surface wave losses. Therefore the total quality factor Q_t is influenced by all of these losses and it is generally written as,

$$\frac{1}{Q_t} = \frac{1}{Q_{rad}} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_{sw}} \tag{6.1}$$

Where,

Q_t = total quality factor

Q_{rad} = quality factor due to radiation losses

Q_c = quality factor due to conduction (ohmic) losses

Q_d = quality factor due to dielectric losses

Q_{sw} = quality factor due to surface waves

There are approximate formulas to represent the quality factors of the various losses. These can be expressed as,

$$\frac{1}{Q_c} = h\sqrt{\Pi f \mu \sigma} \tag{6.2}$$

$$\frac{1}{Q_d} = \frac{1}{\tan\delta} \tag{6.3}$$

$$\frac{1}{Q_{rad}} = \frac{2\omega\epsilon_r}{\frac{hG_t}{l}}K \tag{6.4}$$

where, tan δ is the loss tangent of the substrate material, σ is the conductivity of the conductors associated with the patch and ground plane, $\frac{G_t}{l}$ is the total conductance per unit length of the radiating aperture.

Q_{rad} is inversely proportional to the height of the substrate, and for very thin substrates is usually the dominant factor.

The fractional bandwidth of the antenna is inversely proportional to the Q_t of the antenna, and it is defined by

$$\frac{\Delta f}{f_0} = \frac{1}{Q_t} \tag{6.5}$$

However above equation 6.5 may not be as useful because as it does not take into account impedance matching at the input terminals of the antenna. A more meaningful definition of the fractional bandwidth is over a band of frequencies where the VSWR at the input terminals is equal to or less than a desired maximum value, assuming that the VSWR is unity at the design frequency.

A modified form of equation 6.5 that takes into account the impedance matching is

$$\frac{\Delta f}{f_0} = \frac{VSWR - 1}{Q_t \sqrt{VSWR}} \tag{6.6}$$

So, equation from 6.2 to 6.6 shows that as the height of the substrate increases, quality factor decreases along with increase in impedance bandwidth.

6.2 Improved BW Single Element Design

To make an array antenna design simpler single layer substrate concept is more useful. In previous chapter, single layer substrate Duroid 5880 of a height 1.57 mm is used. But, the array design has a bandwidth of very few MHZ, which is not required bandwidth for wireless application such as WLAN.

One way to improve the bandwidth of an array antenna with single layer substrate is to increase the height of the substrate. Here, the single element +45° and -45° antenna is design with the Duroid 5880 having height of 6.35 mm.

Table 6.1: Parameters for The Patch Antenna Design

Parameter	Parameter Description	Parameter value
f_r	Frequency of Operation	2.4 GHz
ϵ_r	Dielectric Constant	2.2
h	Height of Substrate	6.35 mm

Table 6.2: Design Specification of Improved BW Single Element Patch antenna

Parameter	Parameter Description	Parameter value(mm)
L	Length of the Patch antenna	37.96
W	Width of the Patch antenna	49.41
S	Slot cut for Inset	12.55
Y_0	Inset distance from the edge of the patch	10.57

6.2.1 Geometry of +45° Inset-Fed Patch Antenna Design for Improved BW

Design of +45° Inset-Fed Patch Antenna is shown in Figure.6.1. Design of +45° Inset-Fed Patch Antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 100 mm x 120 mm.

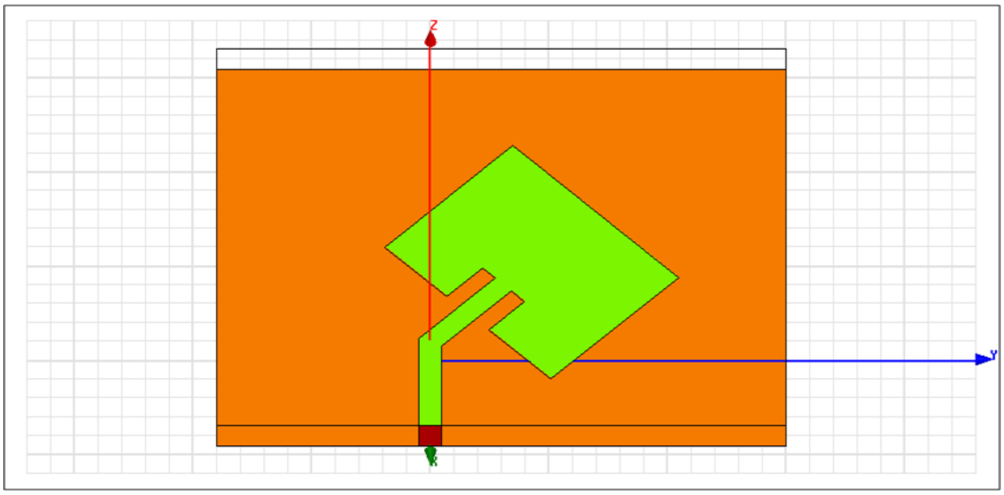

Figure 6.1: +45° Inset Fed Patch Antenna Design

6.2.2 Simulation Results of +45° Inset-Fed Patch Antenna for Improved BW

Simulation results of +45° Inset-Fed Patch Antenna geometry for Improved BW are shown below from Figure 6.2 to 6.6.

Simulation result of ReturnLoss plot shows that S_{11} = -18.51 dB at 2.40 GHz. Bandwidth is obtained 7.4 % with reference of -10 dB Return Loss.

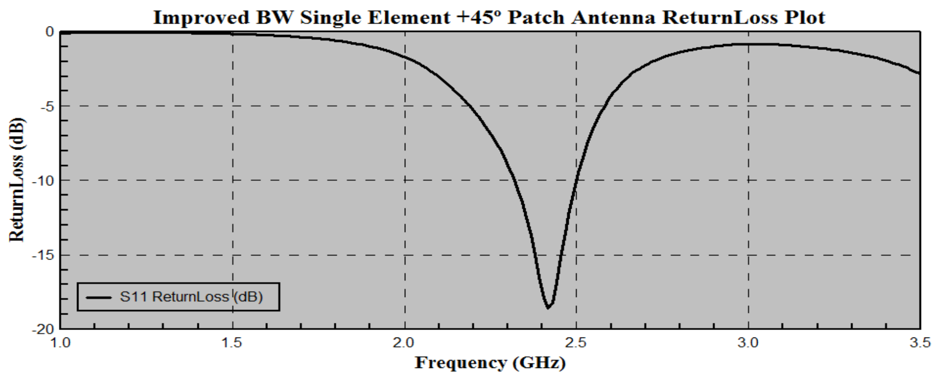

Figure 6.2: ReturnLoss (S_{11}) Plot of Inset Fed +45° Patch Design

Simulation result of VSWR plot shows that VSWR = 1.29 at 2.40 GHz.

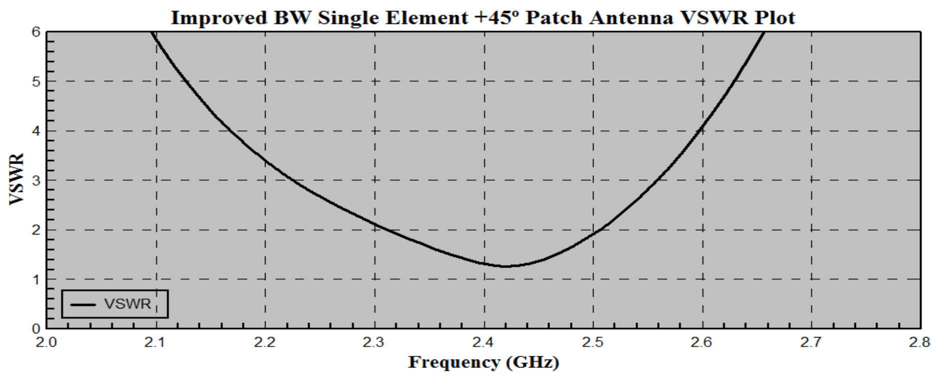

Figure 6.3: VSWR Plot of Inset Fed +45° Patch Design

Simulation result of Gain plot shows that Gain = 7.24 dB in Figure 6.4.

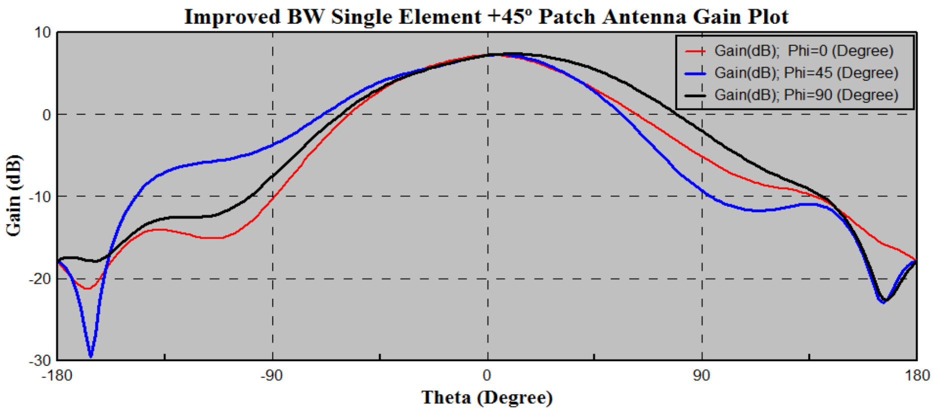

Figure 6.4: Gain Plot of Inset Fed +45° Patch Design

Simulation result of Directivity plot shows that Directivity = 7.35 dB in Figure 6.5.

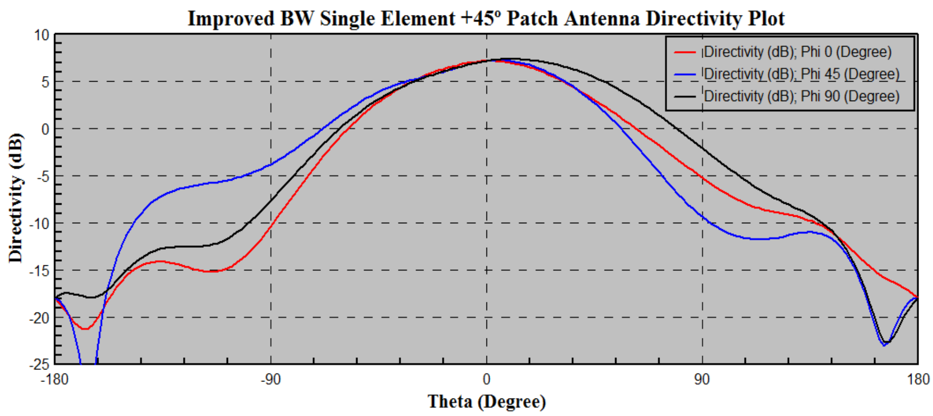

Figure 6.5: Directivity Plot of Inset Fed +45° Patch Design

Simulation result of Radiation Pattern plot shows in Figure 6.6

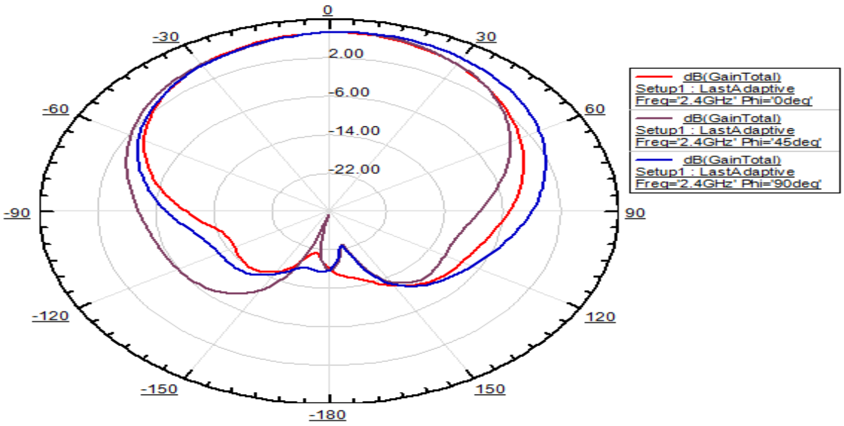

Figure 6.6: Radiation Pattern of Inset Fed +45° Patch Design

6.2.3 Geometry of -45° Inset-Fed Patch Antenna Design for Improved BW

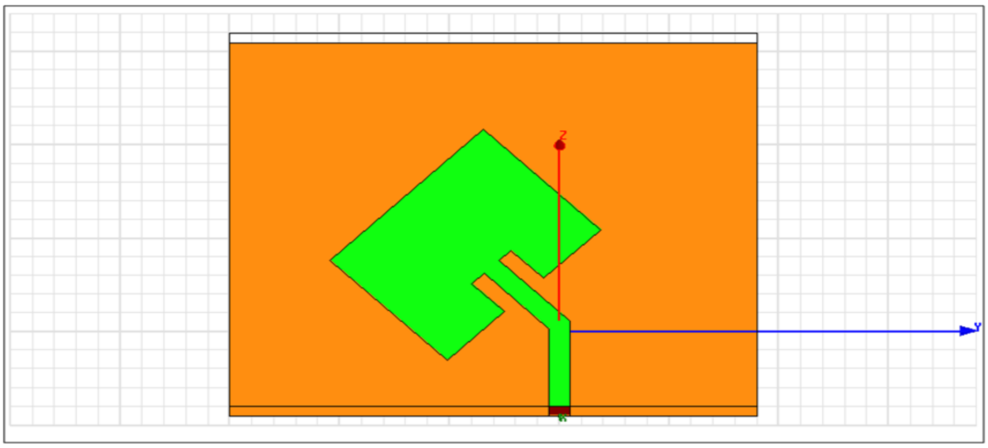

Figure 6.7: -45° Inset Fed Patch Antenna Design

6.2.4 Simulation Results of -45° Inset-Fed Patch Antenna for Improved BW

Simulation result of ReturnLoss plot shows that S_{11} = -18.29 dB at 2.40 GHz. Bandwidth is obtained 7.42 % with reference of -10 dB Return Loss.

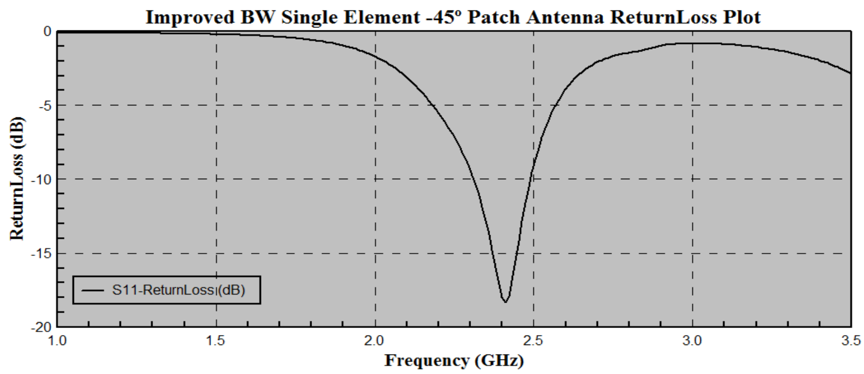

Figure 6.8: ReturnLoss (S_{11}) Plot of Inset Fed -45° Patch Design

Simulation result of VSWR plot shows that VSWR = 1.27 at 2.40 GHz.

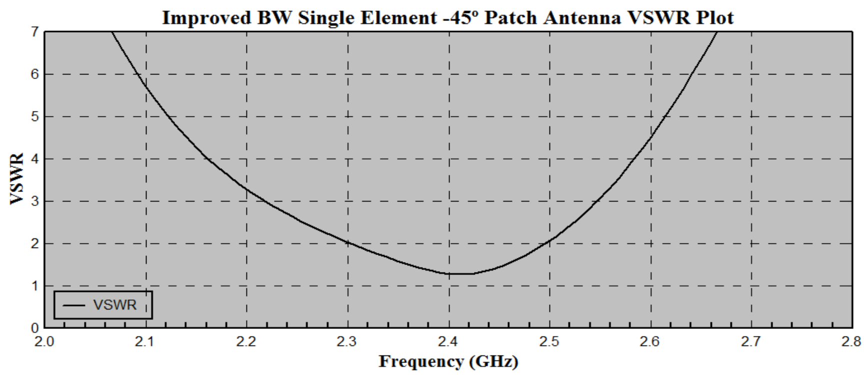

Figure 6.9: VSWR Plot of Inset Fed -45° Patch Design

Simulation result of Gain plot shows that Gain = 7.14 dB in Figure 6.10.

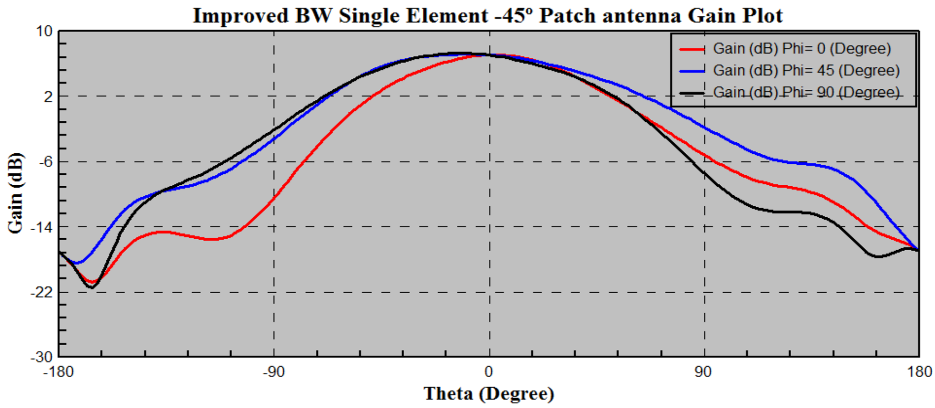

Figure 6.10: Gain Plot of Inset Fed -45° Patch Design

Simulation result of Directivity plot shows that Directivity = 7.22 dB in Figure 6.11.

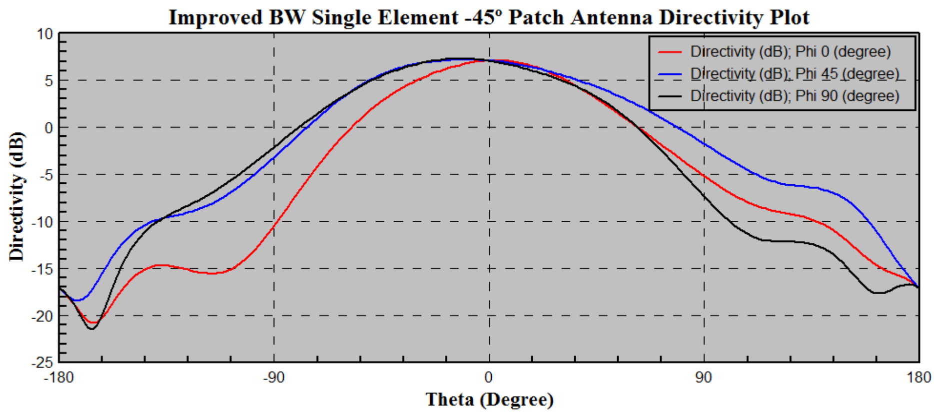

Figure 6.11: Directivity Plot of Inset Fed -45° Patch Design

Simulation result of Radiation Pattern plot shows in Figure 6.12

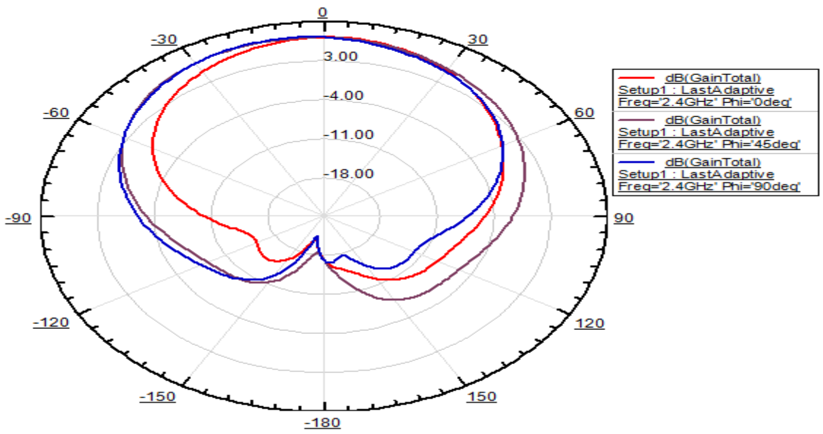

Figure 6.12: Radiation Pattern of Inset Fed -45° Patch Design

6.3 1×2 Patch Array Antenna Design for Improved BW

Parameter of the 1×2 patch array antenna is shown in Table 6.3.

Table 6.3: Design Specification of Improved BW 1×2 Patch Array Antenna

Parameter	Parameter Description	Parameter value (mm)
L	Length of the Patch antenna	35.8484
W	Width of the Patch antenna	49.4105
S	Slot cut for Inset	14.04
Y_0	Inset distance from the edge of the patch	10.68
Lg	Length of the Groundplane	150
Wg	Width of the Groundplane	200

6.3.1 Geometry of +45° 1×2 Inset-Fed Patch Array Antenna Design for Improved BW

Geometry of +45° 1×2 patch array antenna is shown in Figure 6.13. Design of +45° 1×2 patch array antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 150 mm x 200 mm.

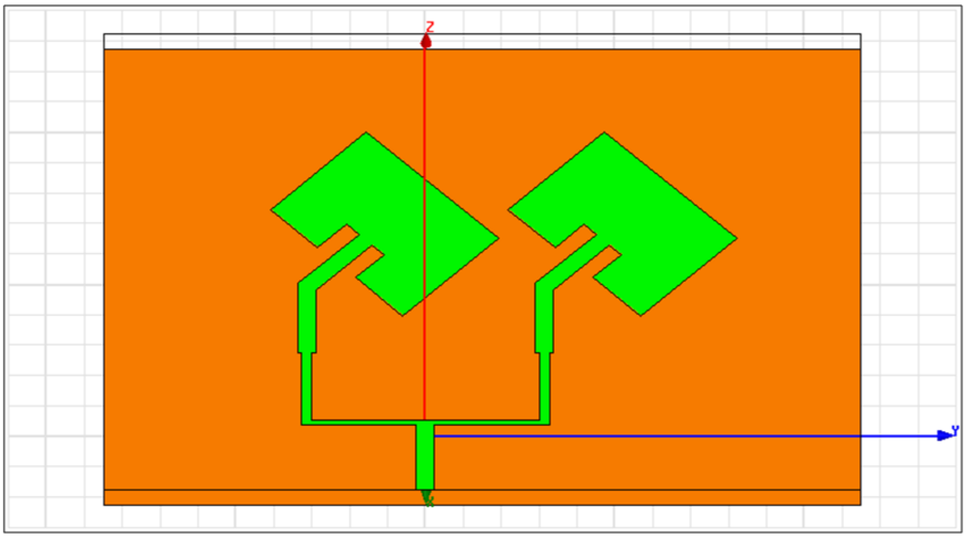

Figure 6.13: +45° 1×2 Patch Array Geometry

6.3.2 Simulation Results of +45° 1×2 Inset-Fed Patch Array Antenna for Improved BW

Figure 6.14 shows simulation result of ReturnLoss characteristics of +45° 1×2 array configuration. The antenna design gives Return Loss of -25.96 dB at 2.40 GHz. Bandwidth is obtained 9.76% with reference of -10 dB Return Loss.

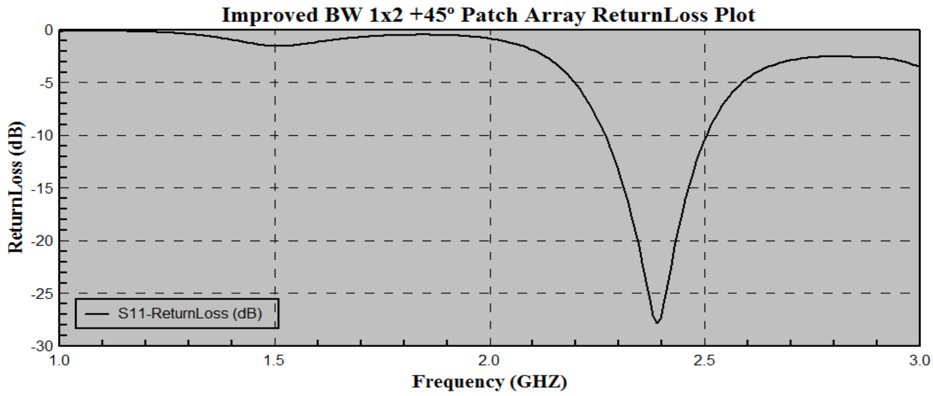

Figure 6.14: ReturnLoss (S_{11}) Plot of +45° 1×2 Patch Array Design

Simulation result of VSWR plot shows that VSWR = 1.10 at 2.40 GHz.

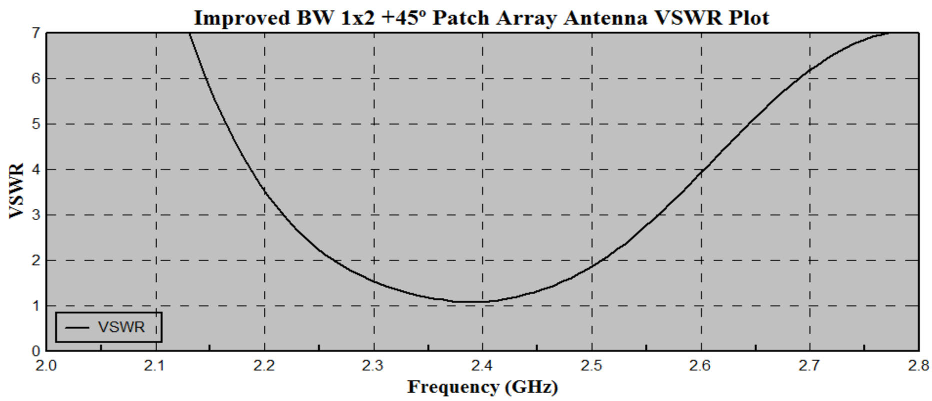

Figure 6.15: VSWR Plot of +45° 1×2 Patch Array Design

Simulation result of Gain plot shows that Gain = 8.69 dB in Figure 6.16.

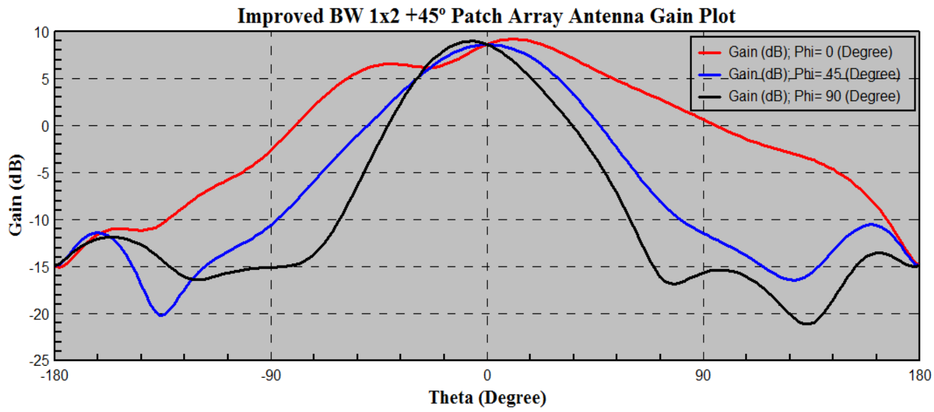

Figure 6.16: Gain Plot of +45° 1×2 Patch Array Design

Simulation result of Directivity plot shows that Directivity = 8.72 dB in Figure 6.17.

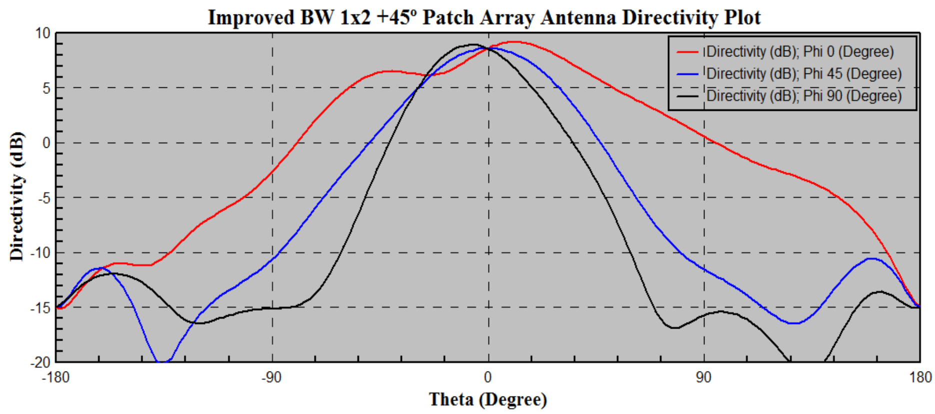

Figure 6.17: Directivity Plot of +45° 1×2 Patch Array Design

Simulation result of Radiation Pattern plot shows in Figure 6.18.

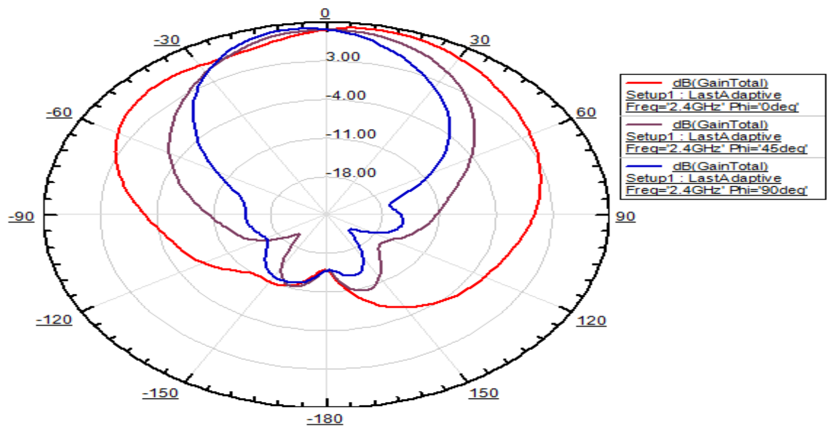

Figure 6.18: Radiation Pattern of +45° 1×2 Patch Array Design

6.3.3 Geometry of -45° 1×2 Inset-Fed Patch Array Antenna Design for Improved BW

Geometry of -45° 1×2 patch array antenna is shown in Figure 6.19.Design of -45° 1×2 patch array antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 150 mm x 200 mm.

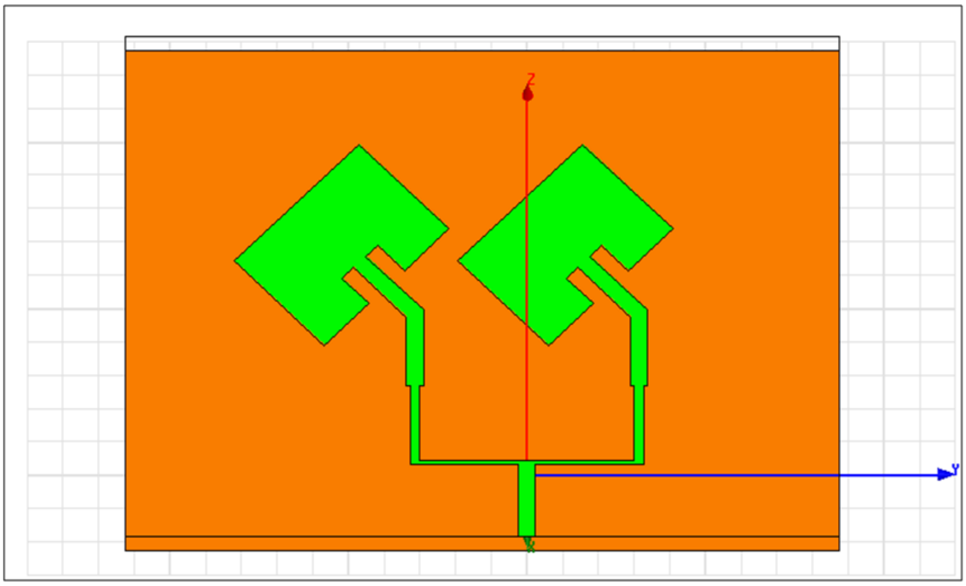

Figure 6.19: -45° 1×2 Patch Array Geometry

6.3.4 Simulation Results of -45° 1×2 Inset-Fed Patch Array Antenna for Improved BW

Figure 6.20 shows simulation result of ReturnLoss characteristics of -45° 1×2 array configuration. The antenna design gives Return Loss of -22.95 dB at 2.40 GHz. Bandwidth is obtained 9.76% with reference of -10 dB Return Loss.

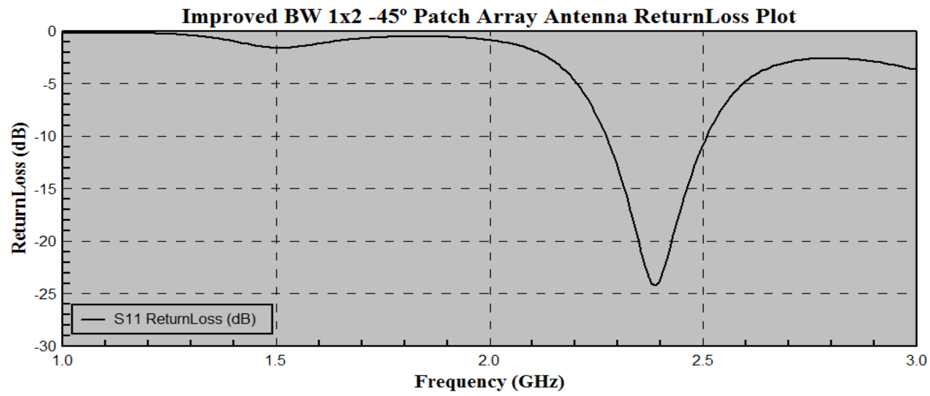

Figure 6.20: ReturnLoss (S_{11}) Plot of -45° 1×2 Patch Array Design

Simulation result of VSWR plot shows that VSWR = 1.15 at 2.40 GHz.

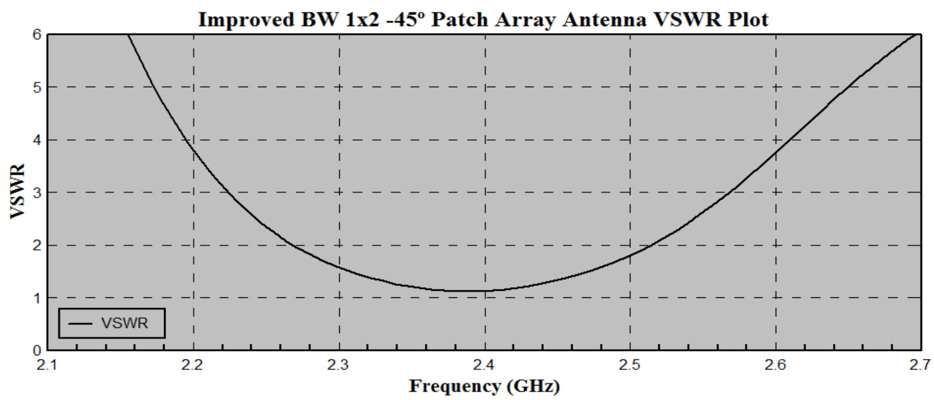

Figure 6.21: VSWR Plot of -45° 1×2 Patch Array Design

Simulation result of Gain plot shows that Gain = 8.51 dB in Figure 6.22.

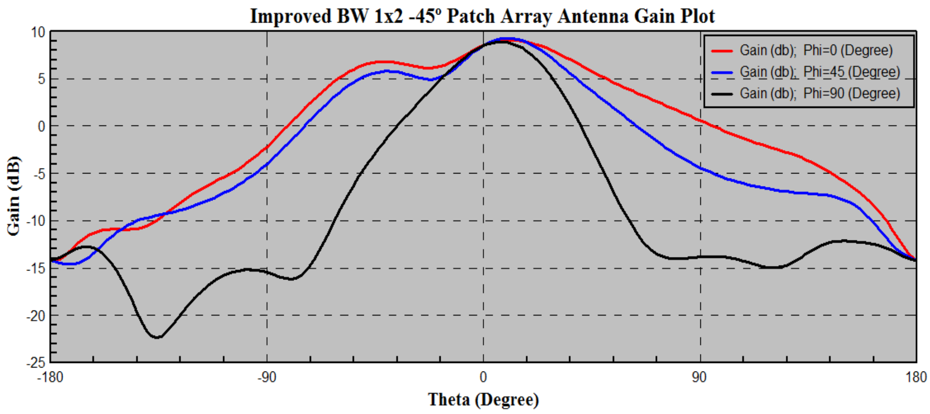

Figure 6.22: Gain Plot of -45° 1×2 Patch Array Design

Simulation result of Directivity plot shows that Directivity = 8.59 dB in Figure 6.23.

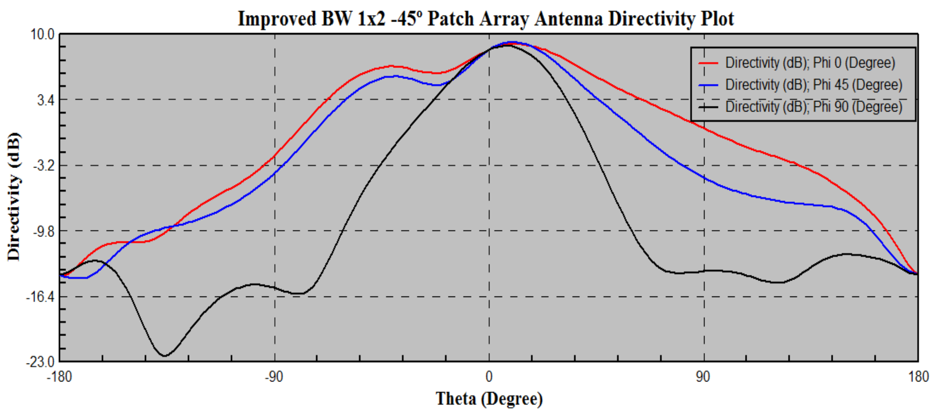

Figure 6.23: Directivity Plot of -45° 1×2 Patch Array Design

Simulation result of Radiation Pattern plot shows in Figure 6.24.

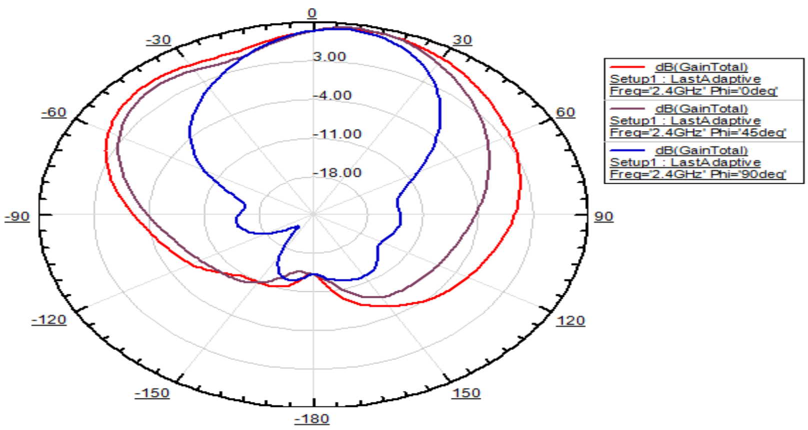

Figure 6.24: Radiation Pattern of -45° 1×2 Patch Array Design

6.3.5 Geometry of ±45° 1×2 Inset-Fed Patch Array Antenna Design for Improved BW

Geometry of ±45° 1×2 patch array antenna is shown in Figure 6.25. Design of ±45° 1×2 patch array antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 150 mm x 225 mm.

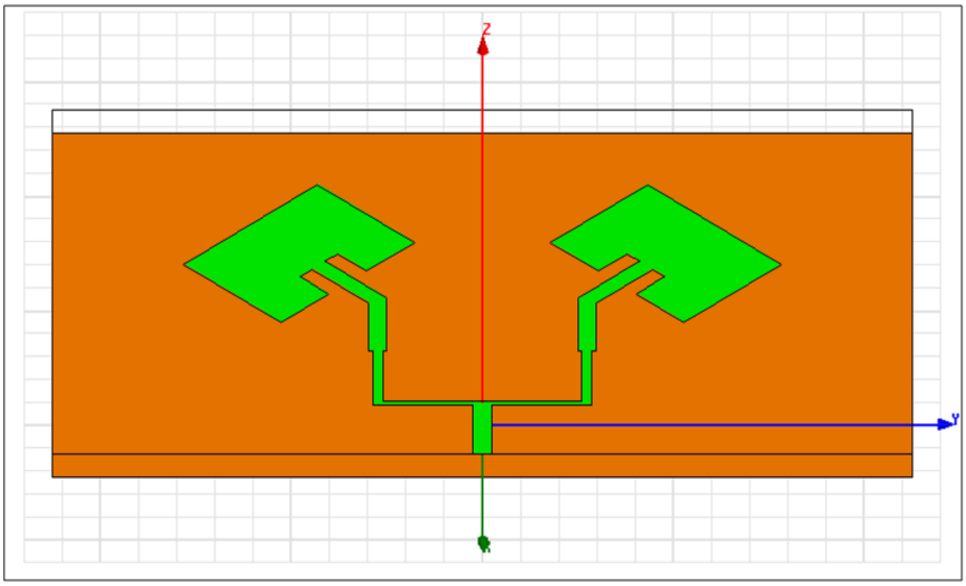

Figure 6.25: ±45° 1×2 Patch Array Geometry

6.3.6 Simulation Results of ±45° 1×2 Inset-Fed Patch Array Antenna for Improved BW

Figure 6.26 shows simulation result of ReturnLoss characteristics of ±45° 1×2 patch array configuration. The antenna design gives ReturnLoss of -17.96 dB at 2.40 GHz. Bandwidth is obtained 8.12% with reference of -10 dB Return Loss.

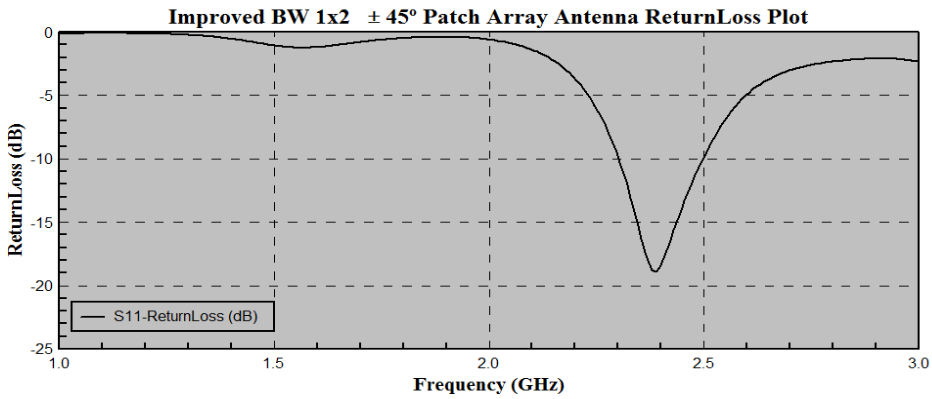

Figure 6.26: ReturnLoss (S_{11}) Plot of ±45° 1×2 Patch Array Design

Simulation result of VSWR plot shows that VSWR = 1.28 at 2.40 GHz.

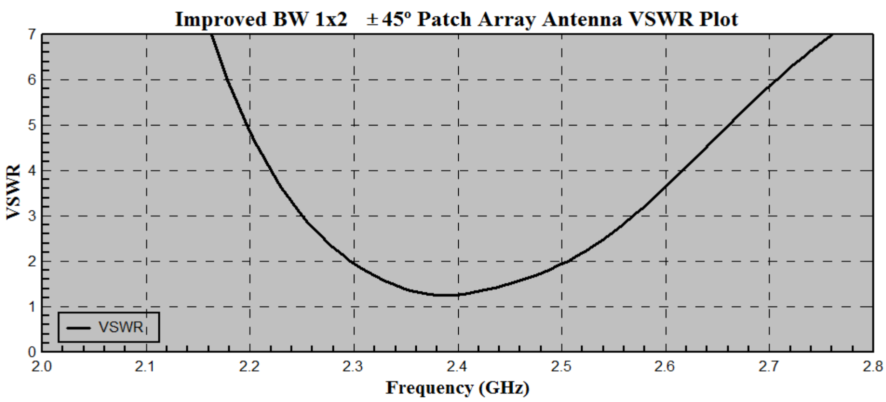

Figure 6.27: VSWR Plot of ±45° 1×2 Patch Array Design

Simulation result of Gain plot shows that Gain = 5.53 dB in Figure 6.28.

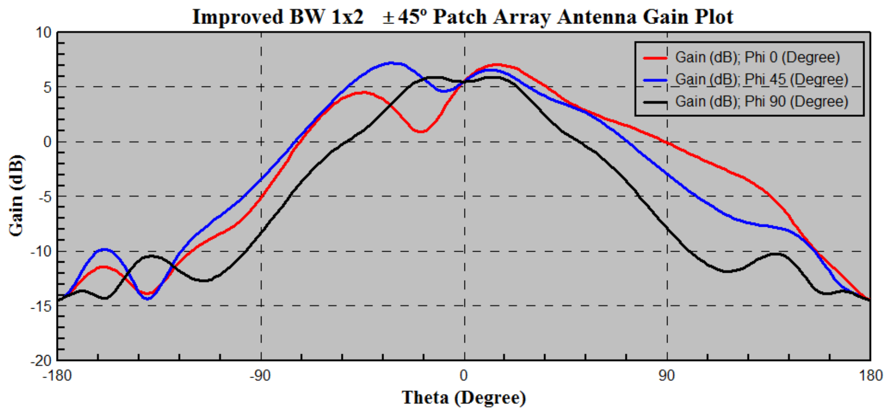

Figure 6.28: Gain Plot of ±45° 1×2 Patch Array Design

Simulation result of Directivity plot shows that Directivity = 5.65 dB in Figure 6.29.

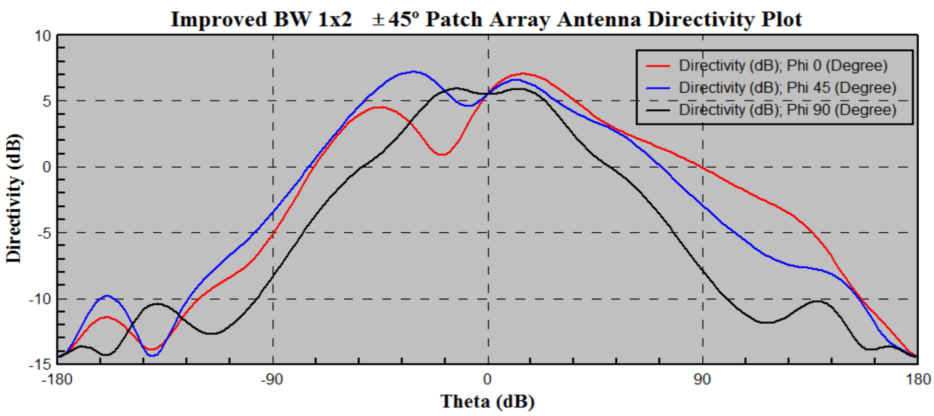

Figure 6.29: Directivity Plot of ±45° 1×2 Patch Array Design

Simulation result of Radiation Pattern plot shows in Figure 6.30.

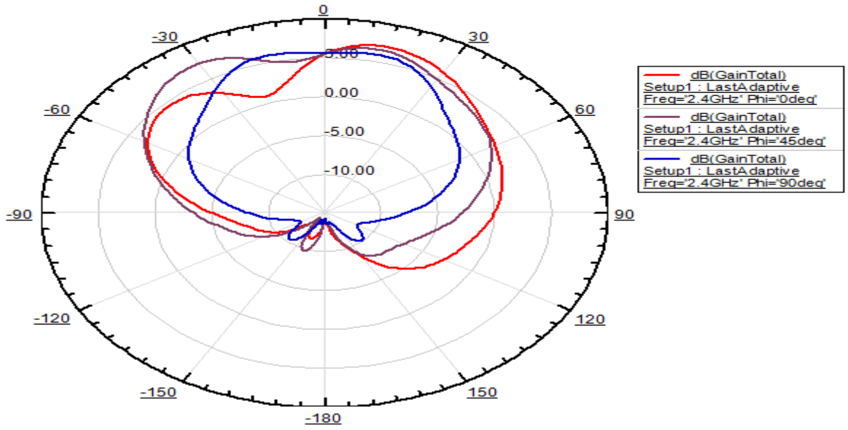

Figure 6.30: Radiation Pattern of ±45° 1×2 Patch Array Design

6.4 1×4 Patch Array Antenna Design for Improved BW

Parameter of the ±45° 1×4 patch array antenna is shown in Table 6.4.

Table 6.4: Design Specification of Improved BW 1×4 ±45° patch array antenna

Parameter	Parameter Description	Parameter value (mm)
L	Length of the Patch antenna	36.3484
W	Width of the Patch antenna	49.4105
S	Slot cut for Inset	13.80
Y_0	Inset distance from the edge of the patch	10.68
Lg	Length of the Groundplane	180
Wg	Width of the Groundplane	300

6.4.1 Geometry of ±45° 1×4 Inset-Fed Patch Array Antenna Design for Improved BW

Geometry of ±45° 1×4 patch array antenna is shown in Figure 6.31. Desing of ±45° 1×4 patch array antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 180 mm x 300 mm.

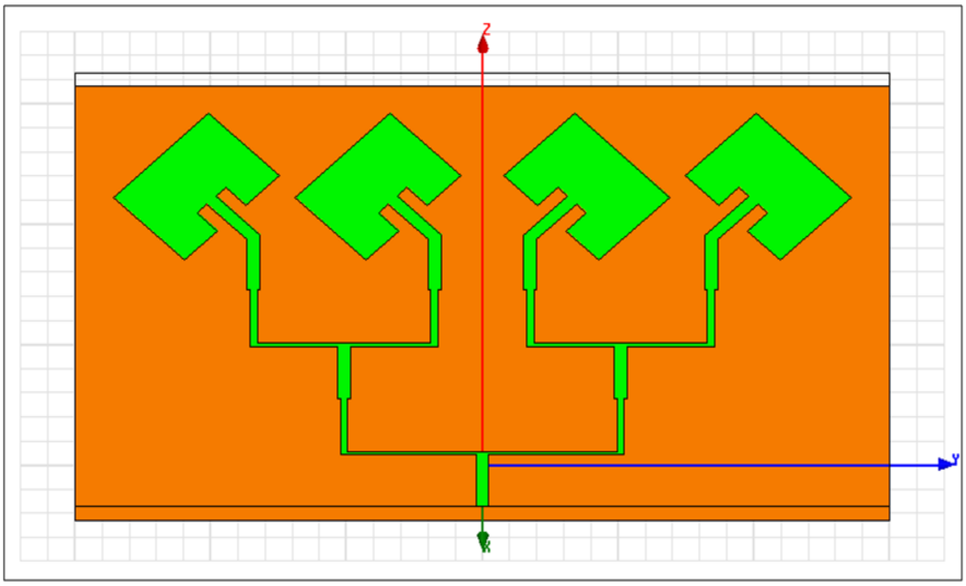

Figure 6.31: ±45° 1×4 Patch Array Geometry

6.4.2 Simulation Results of ±45° 1×4 Inset-Fed Patch Array Antenna for Improved BW

Figure 6.32 shows simulation result of ReturnLoss characteristics of ±45° 1×4 array configuration. The antenna design gives ReturnLoss of -23.56 dB at 2.32 GHz. Bandwidth is obtained 9.91% with reference of -10 dB Return Loss.

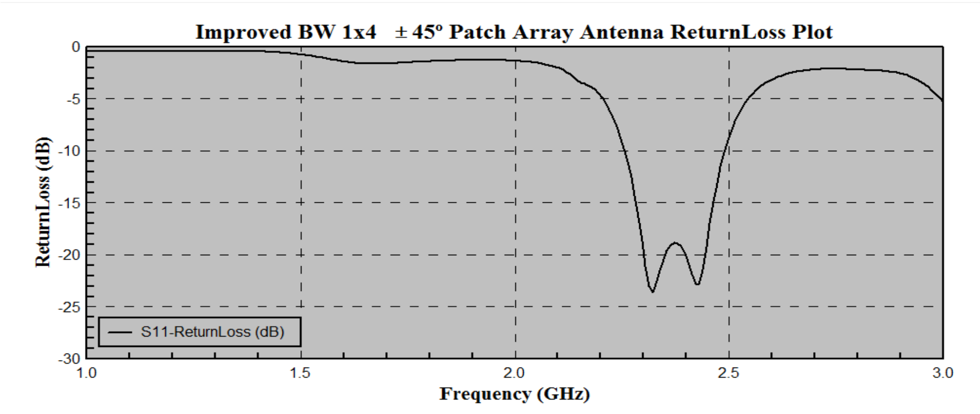

Figure 6.32: ReturnLoss (S_{11}) Plot of ±45° 1×4 Patch Array Design

Simulation result of VSWR plot shows that VSWR = 1.14 at 2.32 GHz.

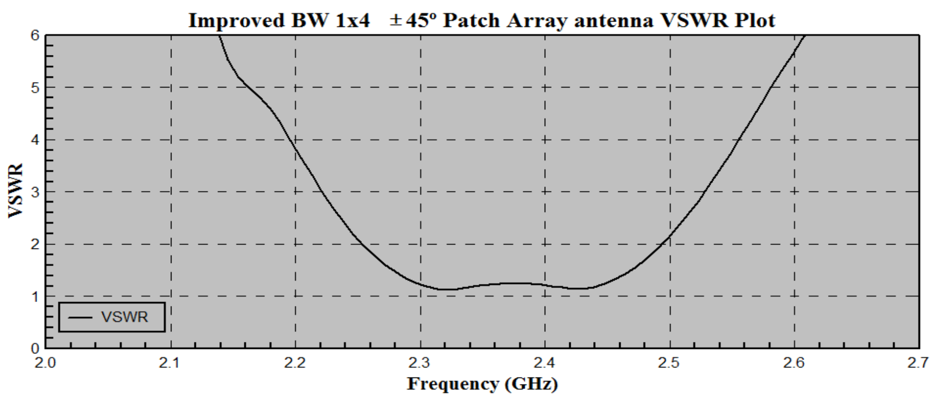

Figure 6.33: VSWR Plot of ±45° 1×4 Patch Array Design

Simulation result of Gain plot shows that Gain = 8.12 dB in Figure 6.34.

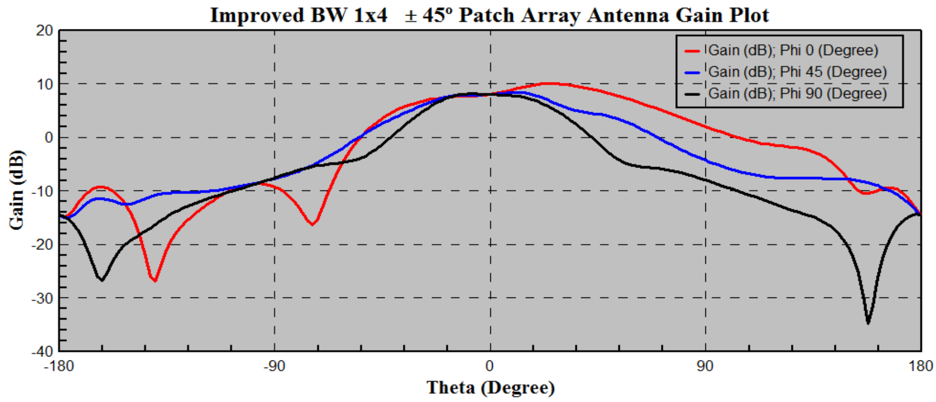

Figure 6.34: Gain Plot of ±45° 1×4 Patch Array Design

Simulation result of Directivity plot shows that Directivity = 8.19 dB in Figure 6.35.

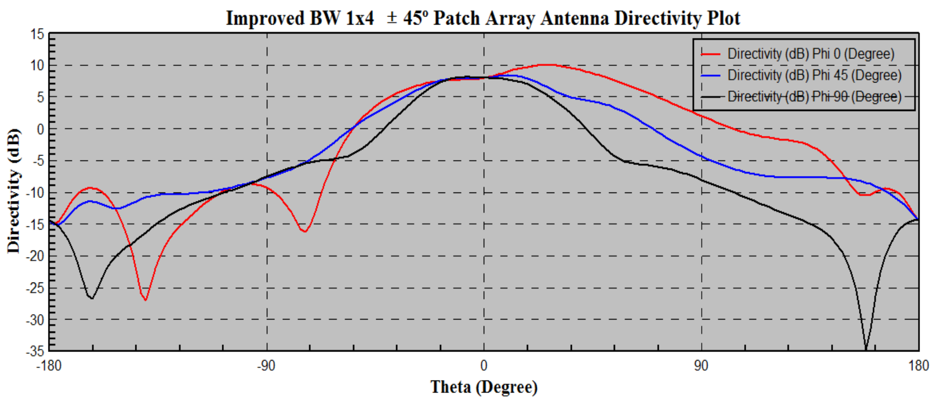

Figure 6.35: Directivity Plot of ±45° 1×4 Patch Array Design

Simulation result of Radiation Pattern plot shows in Figure 6.36.

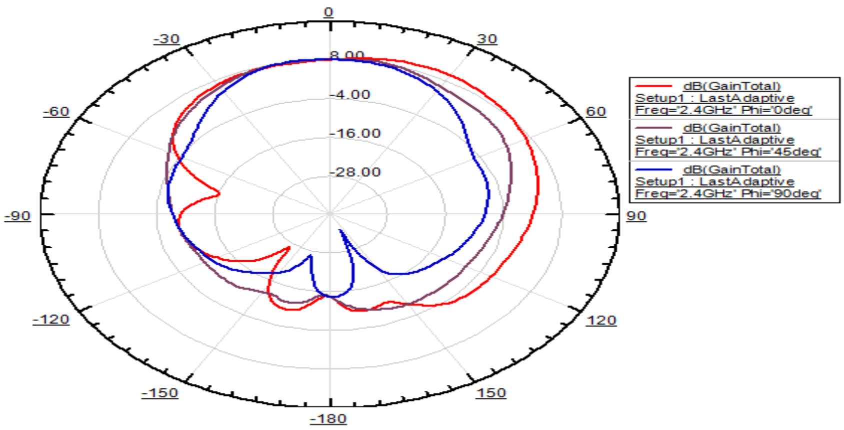

Figure 6.36: Radiation Pattern of ±45° 1×4 Patch Array Design

6.5 2×2 Patch Antenna Array Design for Improved BW

Parameter of the ±45° 2×2 patch array antenna is shown in Table 6.5.

Table 6.5: Design Specification of Improved BW 2×2 ±45° patch array antenna

Parameter	Parameter Description	Parameter value (mm)
L	Length of the Patch antenna	36.3484
W	Width of the Patch antenna	49.4104
S	Slot cut for Inset	11.31
Y_0	Inset distance from the edge of the patch	14.04
Lg	Length of the Groundplane	264.83
Wg	Width of the Groundplane	300

6.5.1 Geometry of ±45° 2×2 Inset-Fed Patch Array Antenna Design for Improved BW

Geometry of ±45° 2×2 patch array antenna is shown in Figure 6.37. Design of ±45° 2×2 patch array antenna is developed by considering the finite groundplane and dimensions of finite groundplane is 264.83 mm x 300 mm.

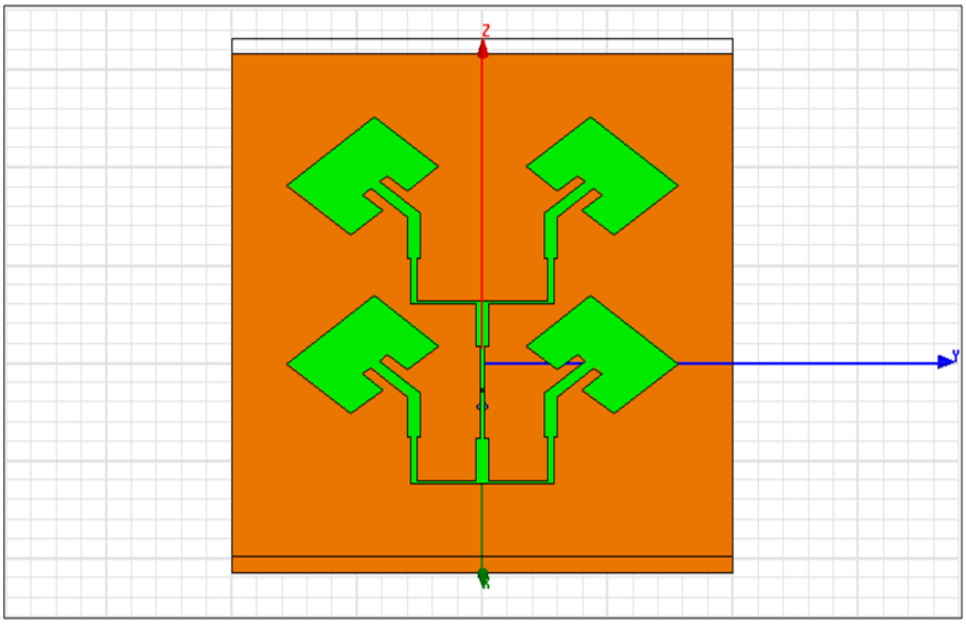

Figure 6.37: ±45° 2×2 Patch Array Geometry

6.5.2 Simulation Results of ±45° 2×2 Inset-Fed Patch Array Antenna for Improved BW

Figure 6.38 shows simulation result of ReturnLoss characteristics of ±45° 2×2 patch array configuration. The antenna design gives ReturnLoss of -34.64 dB at 2.4 GHz. Bandwidth is obtained 9.0% with reference of -10 dB Return Loss.

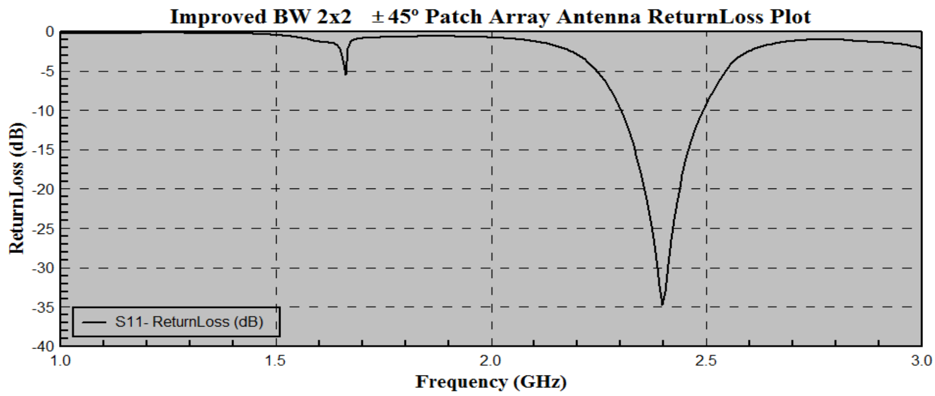

Figure 6.38: ReturnLoss (S_{11}) Plot of ±45° 2×2 Patch Array Design

Simulation result of VSWR plot shows that VSWR = 1.14 at 2.32 GHz.

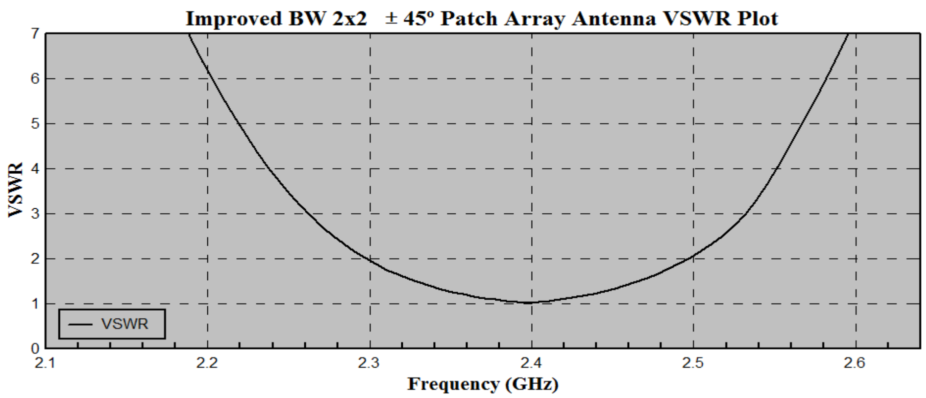

Figure 6.39: VSWR Plot of ±45° 2×2 Patch Array Design

Simulation result of Gain plot shows that Gain = 10.04 dB in Figure 6.40.

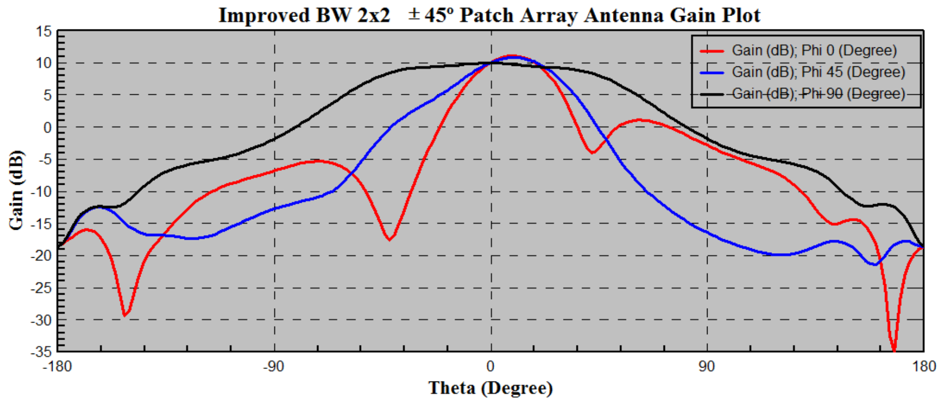

Figure 6.40: Gain Plot of ±45° 2×2 Patch Array Design

Simulation result of Directivity plot shows that Directivity = 10.09 dB in Figure 6.41.

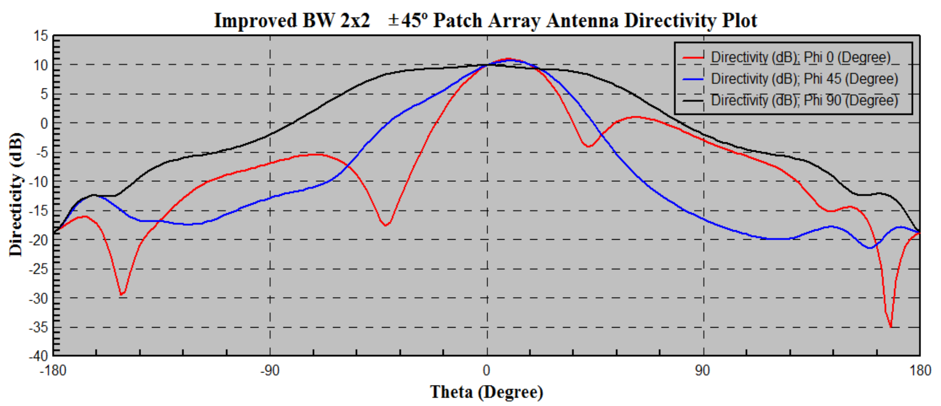

Figure 6.41: Directivity Plot of ±45° 2×2 Patch Array Design

Simulation result of Radiation Pattern plot shows in Figure 6.42.

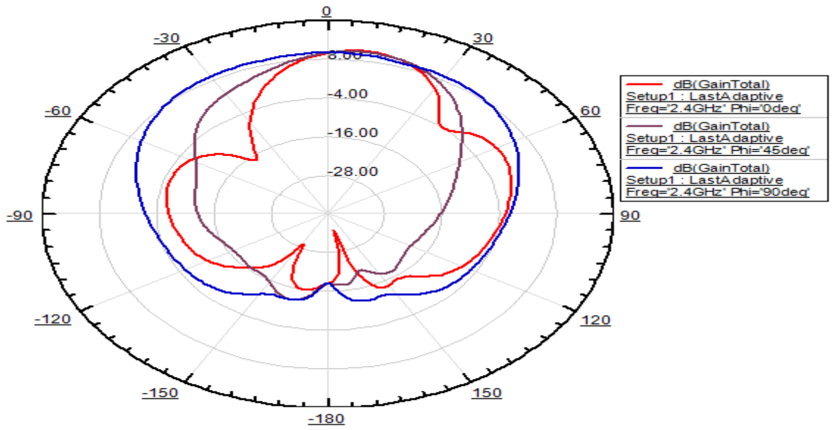

Figure 6.42: Radiation Pattern of ±45° 2×2 Patch Array Design

6.6 Summary of Simulation Results

All the designs of patch array antenna results are summarized in below Table 6.6 .

Table 6.6: Summary of Simulation Results

Antenna Design	**ReturnLoss (dB)**	**VSWR**	**Gain (dB)**	**Directivity (dB)**	**BW (MHz)/(%)**
Single Element +45°	-18.51	1.29	7.24	7.34	177/7.4
Single Element -45°	-18.29	1.27	7.14	7.22	177/7.42
1x2 +45° **Patch Array Antenna**	-25.96	1.15	8.69	8.72	234/9.76
1x2 -45° **Patch Array Antenna**	-17.96	1.28	8.51	8.70	234/9.76
1x2 ±45° **Patch Array Antenna**	-22.36	1.16	5.53	5.54	195/8.12
1x4 ±45° **Patch Array Antenna**	-23.56	1.14	8.12	8.19	233/9.91
2x2 ±45° **Patch Array Antenna**	-34.64	1.14	10.04	10.09	190/9.0

From the Table 6.6, it is evidence that the proposed patch array antenna has very good impedance matching and VSWR. Impedance bandwidth has been improved up to the 9% in all the array antenna design.It is also found that the gain has been reduced in all the patch antenna array design compare to the array antenna design shown in Table 5.2 , chapter 5. Though, 10 dB gain is achieved in 2×2 ±45° patch array antenna.

6.7 Summary

In this chapter, Various bandwidth enhancement method have been discussed in section 6.1. Single element +45° and -45° patch antenna design with simulation results have been shown in section 6.2. Improved BW Inset-Fed 1×2 patch array antenna design and simualtion results have been shown in section 6.3. Improved BW Inset-Fed 1×4 and 2×2 patch array antenna design and simulation results have been shown in section 6.4 and 6.5 respectively. All the improved bandwidth design and their simulation results have been summarized in section 6.6.

Chapter 7

Conclusion and Future Work

7.1 Conclusion

Microstrip patch antenna oriented at +45° and -45° was proposed to obtain dual polarization for polarization diversity application. The antennas were operated at resonant frequency, around 2.4 GHz with optimum VSWR and ReturnLoss.

The ReturnLoss, VSWR , Gain, Directivity and radiation pattern have been observed for single element +45° and -45° , 1×2 dual-polarized microstrip patch array antenna using substrate material FR4 (ϵ_r=4.7) and Duroid 5880 (ϵ_r=2.2).Gain and Directivity of proposed designs has shown good results using RT/Duroid 5880 (ϵ_r=2.2) compared to FR4 (ϵ_r=4.7).

Gain and Directivity of 1×4 and 2×2 patch array antenna, meet the requirement of wireless application. Bandwidth requirement of the antenna design is fulfill by increasing the height of the substrate by which 9% bandwidth is achieved in array design. Whole 2.4 GHz ISM band has been covered but gain is slightly reduced due to surface-wave excitation.

With the simplicity of single feed line, feed network and single layer substrate structure; proposed antenna design is a good candidate for polarization diversity in many wireless communications.

7.2 Future Work

Miniaturization of proposed single layer substrate array antenna design can be carried out with desired antenna parameters such as VSWR, ReturnLoss, Gain, Directivity and Bandwidth, to meet the demand for 2.4 GHz ISM band applications.

Appendix A

Formulas for Microstrip Transmission Line

The numerical methods for the characterizations of a microstrip line involve extensive computations. But close form expressions are available that have accuracies compatible with various types of errors such as tolerances in microstrip parameters (ϵ_r, h and W) and measurement errors.

For a given characteristics impedance Z_0 and dielectric constant ϵ_r, the $\frac{W}{d}$ ratio can be found as

For $\frac{W}{d} < 2$

$$\frac{W}{d} = \frac{8e^A}{e^{2A} - 2} \tag{A.1}$$

For $\frac{W}{d} > 2$

$$\frac{W}{d} = \frac{2}{\Pi}[B - 1 - \ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r}(\ln(B - 1) + 0.39 - \frac{0.61}{\epsilon_r})] \tag{A.2}$$

Where,

$$A = \frac{Z_0}{60}\sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1}(0.23 + \frac{0.11}{\epsilon_r}) \tag{A.3}$$

$$B = \frac{377\Pi}{2Z_0\sqrt{\epsilon_r}} \tag{A.4}$$

The effective dielectric constant of a microstrip line is given approximately by

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12\frac{d}{W}}} \tag{A.5}$$

The line length L is found as

$\phi = \beta\ L = \sqrt{\epsilon_e}\ k_0\ L$

so,

$$L = \frac{\phi(\frac{\Pi}{180^\circ})}{\sqrt{\epsilon_e}k_0} \tag{A.6}$$

From above formulas characteristics impedance of microstrip transmission line can be converted into its physical dimensions.

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