ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

A Master's Thesis on:

MINIMIZATION OF COUPLING LOSS IN MICROSTRIP ANTENNA ARRAYS USING DEFECTED GROUND STRUCTURE & FREQUENCY SELECTIVE SURFACE

A thesis submitted in partial fulfillment of the requirements for

Master of Science in Communication Engineering

Submitted by

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Supervised by

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Leyla Ahmed

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Declaration

I hereby declare that the thesis entitled "Minimization of Coupling Loss in Microstrip Antenna Arrays Using Defected Ground Structure & Frequency Selective Surface" is my genuine work that has not been submitted earlier for award of any degree or fellowship to any other universities to the best of my knowledge and belief.

Declared by: Leyla Ahmed

Place: Addis Ababa, Ethiopia

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Acknowledgement

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Abstract

The performance of microstrip antenna arrays is greatly undermined by the excitation of space waves and surface waves which cause mutual coupling between microstrip antenna elements. Mutual coupling between antenna elements can affect the side lobe levels, beam position and frequency bandwidth of arrays. Mutual coupling through space waves are very strong if the array elements are very close to each other, and they can be suppressed by increasing the interelement spacing between the array elements. Defected ground structure (DGS) is a type of metamaterials designed at ground that is used to minimize the surface wave and prevents the degrading in performance of an antenna. Frequency Selective Surface (FSS) is also useful in miniaturization of a designed antenna.

In this thesis work, a ground plane is loaded with defected ground structure and frequency selective surface techniques to minimize the effect of coupling loss and to enhance the performance of the MSPA.

A rectangular-aperture coupled microstrip patch antenna is first designed for S-band application and 2x1 MSPA antenna array is formed by using the optimized design of the individual antenna for an inter element spacing λ/4 (where λ is the operating wave length of the antenna which is equal to 130.43mm). Then a simulation is carried out to measure the S11, S12, and other parameters of the antenna. Finally, DGS &FSS are applied on the antenna and the reduction in coupling loss is analyzed using HFSS Software.

The result of the study indicates, 2X1 rectangular micro strip patch antenna array inserting FSS at the ground plane were proposed for 2.3GHz which has an improved bandwidth of 71.8MHzand mutual coupling effect is -35.668dB when compared with an antenna array with DGS.

Key-Words: *Micro-Strip Antenna (MSA), Defected Ground Structure (DGS), Frequency Selective Surface (FSS*

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List of Abbreviation

CSRR	Complementary Split Ring Resonator
dB	Decibels
DGS	Defected Ground Structure
EBG	Electromagnetic Band Gap
EM	Electromagnetic
FSS	Frequency Selective Surface
GHz	Giga Hertz
HFSS	High Frequency Structure Simulator
HPBW	Half Power Beam Width
Lf	Length of Feed
Lp	Length of Patch
Ls	Stub Length
MHz	Mega Hertz
MSPA	Microstrip Patch Antenna
RADAR	Radio Detection and Ranging
RF	Radio Frequency
RL	Return Loss
S12	Coupling Loss
SR	Spiral Resonator
UC-EBG	Uni-Planar Electromagnetic Band Gap
VSWR	Voltage Standing Wave Ratio

Chapter One

Introduction

1.1. Background of Study

The growing popularity of wireless communication and multimedia services has raised the need for microstrip patch structures to be designed and implemented. In today's world of wireless communication technologies, the patch antenna is extremely significant. Microstrip antennas and arrays have become one of the most widely used antennas and arrays over the last 30 years for many applications ranging from satellite and wireless communication to military and biomedical applications.

The interest in these antennas and arrays comes directly from their advantages over other antennas such as low fabrication cost (especially for mass production), small volume, light weight, conformity to surface and easy integration with other microwave and solid-state devices. However, when a single microstrip antenna is considered, it mainly suffers from having a narrow bandwidth, low power handling capability and low gain [1]. Therefore, microstrip antenna arrays are preferred to improve the abovementioned performance merits. In spite of all the advantageous of microstrip antenna arrays, mutual coupling among the array elements which occurs as a result of space wave and surface wave, affects their operation and makes their design/analysis challenging.

When microstrip antenna arrays are considered, the mutual coupling among the array elements occurs as a result of space wave and surface wave. Space waves are usually stronger along the H-plane of the antennas and very strong if the array elements are close to each other. However, they die out quickly as the separation between array elements becomes larger. On the other hand, the surface waves are usually stronger along the E-plane of the antennas and weaker than that of space waves when the array elements are close to each other. However, they remain as the only coupling mechanism when the array elements are far away from each other.

1.2.Literature Review

In [2] a 2×2 micro-strip patch antenna array was designed, with three slots in three different positions with characteristic parameters of length (L), width (W) and thickness (t) on rectangular of patch antenna with operating frequency 5.25GHz. The proposed slots were to make this antenna small in size and suitable to handle easily. The resulted value of return loss was less than -25dB, VSWR less than 1.5 with a bandwidth of 180MHz and antenna gain of 13.88dB has been achieved. However the return loss value was not that much minimized.

In [3] Hsing-Yi Chen and Yu Tao, a wideband frequency selective surface (FSS) using one of the geometrical shape of FSS which is regular Jerusalem cross element integrated below U-slot patch antenna to improve gain, bandwidth, and return loss at operating frequency of 2.45 and 5.8GHz for Bluetooth and WLAN applications, here the gain is improved 28.3%.

In [4] the idea of this work was to use an UC-EBG structure which is placed on top of the antenna layer. The main objective was to reduce both the element separation and mutual coupling between the patch antennas, which in turn increases antenna directivity. An array of two patch antennas including a superstrate layer of the designed UC-EBG structures has been simulated. This structure reduces 10dB reduction in mutual coupling as well as reduction in array size. Even though these techniques can reduce mutual coupling up to 10dB, but they have some disadvantages compact and difficult to fabricate vias in EBG and cost expensive.

In [5] a metamaterial spiral resonator structure technique was used for reducing the mutual coupling between the elements of the microstrip array antenna. The parameters of the structure (length, width, spacing and the number of the rows) were studied. The proposed antenna with Spiral Resonator (SR) had the 5.5dB reduction of mutual coupling in comparison with the microstrip array antenna used alone. However the performance of the antenna is not improved as expected only mutual coupling was reduced.

In [6]S. Meliksah Yayan used a dumbbell shaped DGS to reduce mutual coupling between Probe-fed microstrip antennas at 5GHz. Although a considerable reduction in the mutual coupling has been achieved, the radiation patterns of that antenna are deteriorated due to a significant increase in the back lobe radiation. Hence, a reflector and a cavity combination are used to decrease the back lobe radiation to a certain level. And despite the achieved mutual coupling reduction between the microstrip antennas in the array environment, the far-zone radiation patterns related merits have not been improved.

In [7] a wide stop band frequency selective surface (FSS) integrated beneath micro strip patch antenna is presented, Wideband patch type FSS consists of four rectangular patches of different dimensions to give more than 7dB improvement in gain of the antenna, Characteristics of the proposed structure are simulated using HFSS. The FSS layer provides a wide stop band response with more than 10dB loss in the frequency range 6-8(GHz).

In [8] Muftah Asaadi, proposes a high gain and wide band high dense dielectric patch antenna using FSS superstrate for millimeter – wave applications, here two different FSS superstrates are used to enhance the gain up to 17.78dB and bandwidth 20% with radiation efficiency of 90% of the proposed antenna. The drawback here is that since the FSS layers increases the antenna size also increases there is a trade-off between antenna size and performance improvement.

From the literature review, it is clear that different mutual coupling reduction techniques have been done by many researchers. In this thesis DGS and FSS structures are selected for mutual coupling reduction and better antenna performance because of their simple structures and easy to model and design. It is noticed that using aperture coupled feeding technique in microstrip patch antenna array results better performance in bandwidth, return loss, gain directivity and antenna efficiency compared to the scenario where microstrip feed line and proximity coupled feed used.

1.3. Statement of the problem

It has been observed experimentally, in antenna arrays, grating lobes can be mitigated (or nullified) by keeping the inter-element spacing equal to half of the operating wave length. However, in designing antenna arrays for S-band applications (such as for Bluetooth, wireless networking (Wi-Fi), baby monitors, microwave ovens and other devices) in order to minimize the size of the antenna, it may be desired to keep the inter-element spacing below half of the operating wavelength. And also for operating frequencies above 4GHz, achieving an inter-element spacing of less than or equal to half of the operating wavelength is difficult. During which, in both cases, grating lobes are introduced because of mutual coupling which is created as a result of the excitation of surface wave, space wave, and near field overlapping of the array elements.

The coupling depends on the element separation and their orientation which causes scan blindness and forms blind spots. By increasing the element separation, mutual coupling can be lessened, but this would introduce undesirable grating lobes. Due to the power leakage through the dielectric substrate, the microstrip antenna mounted on the substrate can only radiate a small amount of power into free space. In order to improve antenna efficiency, propagation through the substrate should be prohibited. In this case, the antenna can radiate more in the direction of the main beam, thereby increasing its efficiency.

So, as a result of the excitation of surface wave, space wave and near field overlapping of the array elements the fields of one element couples mutually with the other which leads to element radiation pattern distortion, bigger side lobes and a mismatch between the elements and their feed.

1.4. Objectives

1.4.1 General Objective

The main objective of this thesis is to reduce the effect of mutual coupling between array of rectangular Microstrip antenna by using DGS and FSS.

1.4.2 Specific Objectives

- To design a rectangular Microstrip antenna resonating at 2.3GHz
- To model a rectangular 2×1 microstrip antenna array and evaluate the performance
- To design & simulate Rectangular MSPA array and analyze the performance of the Rectangular MSPA array in terms of return loss, radiation efficiency, directivity, gain, bandwidth & radiation pattern.
- To evaluate the performance of mutual coupling reduction techniques using DGS and FSS
- To analyze the simulated results of the antenna array with& without DGS and FSS; and quantify the reduction in Coupling loss and Return loss.
- Finally compare the simulated result between FSS & DGS techniques in terms of antenna parameters and mutual coupling effect.

1.5.Methodology

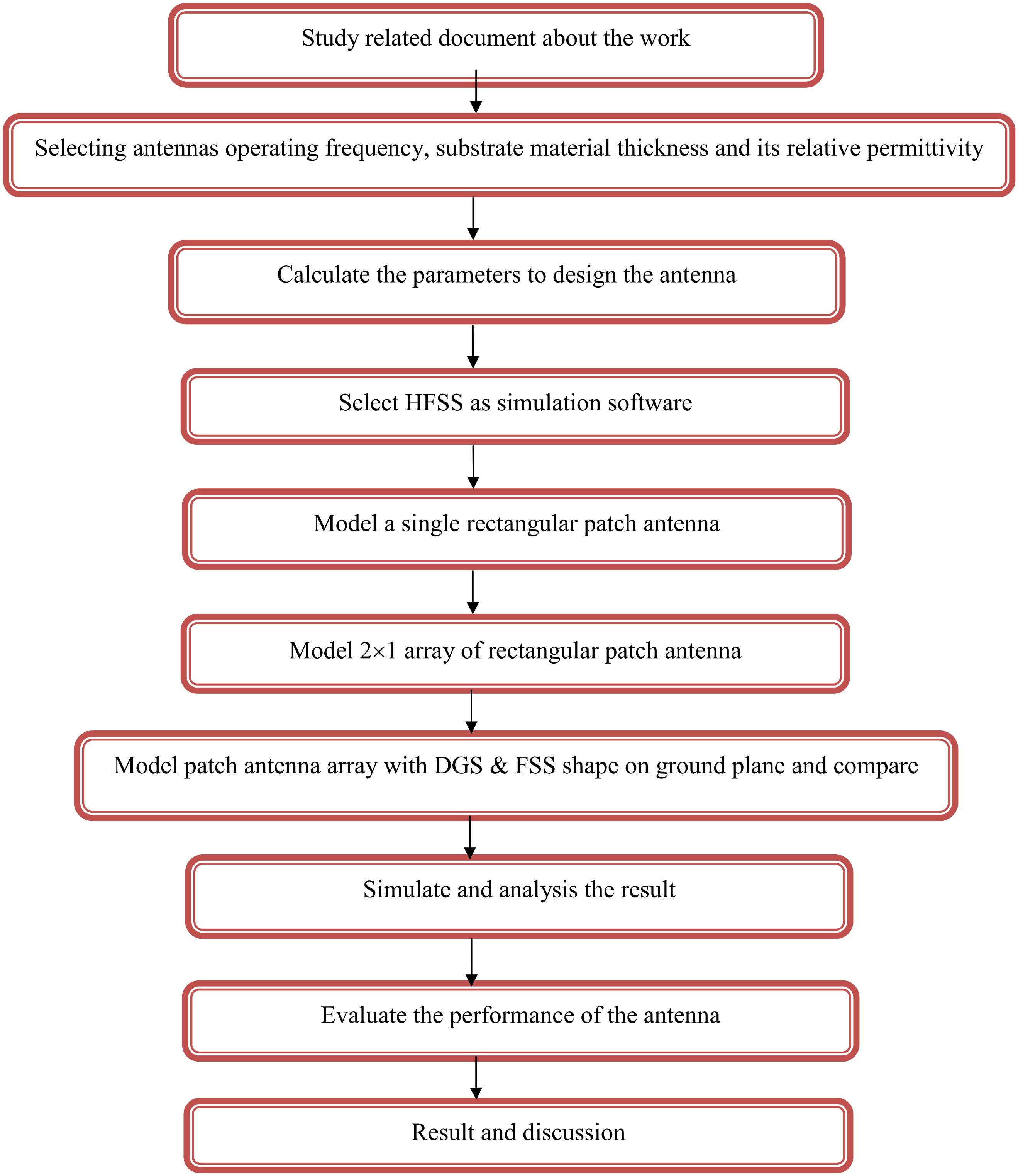


Figure 1. 1 Flow chart of methodology

1.6.Thesis Organization

This thesis work is divided into five chapters:

Chapter 1 Provides a brief introduction about micro strip patch antennas and their associated problems, other motivation for this thesis, Literature Review, Statement of problem, Objectives and Methodology.

Chapter 2 Gives details about basic concepts of micro strip patch antenna array, basic antenna parameters, feeding methods, Frequency Selective surfaces and Defected Ground Structure,

Chapter 3 Presents the procedures for the design of aperture coupled microstrip patch antenna, the procedure for setting up the simulation and design of the antenna in HFSS, and it also presents procedures for reducing coupling loss between array elements.

Chapter 4 Deals with the simulation results and discussion of the proposed design

Chapter-5 Draws conclusion and recommendation for future work

Chapter Two

Microstrip Patch Antenna Array, DGS & FSS

2.1. Introduction to Antenna

Antenna is a metallic device used to radiate or receive radio waves. In other words, antenna is a transitional region between guiding medium and free space that transmits or receives electromagnetic waves. It acts as a transducer which converts the electric signals into radio waves at the transmitting end and converts the radio waves back into electric current at receiving end [9].

The antenna carries a pulsating or alternating current that generates an EM field around the wire which varies in the same manner as the current does. Antenna plays very important role in the performance and consistency of any wireless communication system. Moreover, antennas find their applications in radios, television, RADAR, cell phones, wireless local area network, spacecraft communication and many other applications [9].

2.2. Antenna Parameters

As mentioned in [9], antenna parameters describe the performance of an antenna. During the design process of an antenna some design parameters like return loss, frequency band of operation, radiation patterns, gain, directivity and efficiency should be adjusted as required. Some of the parameters are discussed below and not all of them are necessary to describe antenna performance.

2.2.1. Antenna Gain

Gain is a parameter that measures the directional capability as well as efficiency of an antenna. Low-gain antennas emit radiation of approximately the same power in all directions, while high-gain antennas preferentially radiate in specific directions. Simply put, the antenna gain takes into account the directivity of the antenna and its effective performance. In particular, the directional gain or power gain of an antenna (in a given direction) is defined as the strength of the signal radiated by the antenna at any distance in a given direction divided by an intensity radiated at the same distance by the isotropic assumption without losses antenna. The radiation intensity corresponding to the isotropically radiated power is equal to the power accepted (input) by the antenna divided by 4π. This can be expressed as

$$Gain = 4\pi \frac{Radiaion\ intensity}{Total\ input\ acceped\ power} \tag{2.1}$$

2.2.2. Directivity

An antenna's directivity is defined as the ratio of the antenna's radiation intensity in one direction divided by the average radiation intensity in all directions. Since an antenna radiates power, the direction in which it radiates is extremely important.

The total power radiated by the antenna divided by 4πequals the average radiation intensity. A non-isotropic source's directivity is equal to the ratio of its radiation intensity in a given direction to that of an isotropic source [9].

$$D = \frac{4\pi u}{P_{rad}} \tag{2.2}$$

Where, U is the radiation intensity in (W/unit solid angle) and $P_{rad}$is total radiated power in (W), D is the directivity of antenna. If the direction is not specified the direction of maximum radiation intensity (maximum directivity) expressed as

$$D_{max} = D_0 = \frac{4\pi u_{max}}{P_{rad}} \tag{3.3}$$

2.2.3. Antenna Efficiency

The overall antenna efficiency $e_0$enables to account for the loss in the input terminal and the antenna structure.

$$e_0 = e_r e_c e_d \tag{4.4}$$

Where e_0 is the total efficiency,e_r is reflection mismatch, e_c is conduction efficiency,e_d is dielectric efficiency and e_{cd} is the antenna radiation efficiency. Usuallye_c and e_d are very difficult to compute, but they can be determined experimentally.

$$e_0 = e_r e_{cd} = e_{cd}(1 - \Gamma^2) \tag{5.5}$$

Γ is voltage reflection coefficient at the input terminals of the antenna Z_{in}= antenna input impedance, Z_0 = characteristic impedance of the transmission line.

$$\Gamma = \frac{z_{in} - z_0}{z_{in} + z_0} \tag{2.6}$$

2.2.4. Effective Area

Antennas collect power from the passing waves and send it to the terminals. The power provided to the terminals is the product of the incident wave's power density and the antenna's effective area.

$$P_d = SA_{eff} \tag{2.7}$$

Where $P_d$power is delivered to the terminal, S is the radiated power density and A_{eff} is effective area.

Effective area is physical area multiplied by aperture efficiency for an aperture antenna such as a horn, parabolic reflector, or flat-plate array. In general, material, distribution, and mismatch losses affect the effective area to physical area ratio.

2.2.5. Radiation Pattern

An antenna's radiation pattern is a plot of the antenna's far-field radiation qualities as a function of the spatial co-ordinates described by the elevation angle (θ) and azimuth angle (φ). It's a plot of the power radiated by an antenna per unit solid angle, which is nothing more than the radiation intensity. It is an extremely important parameter as it shows the antenna’s directivity as well as gain at various points in space. There are three typical radiation patterns used to characterize the radiation property of an antenna:

- **Isotropic:** An imaginary antenna that emits the same amount of radiation in all directions.
- **Directional:** A point antenna with the ability to transmit or receive EM energy more successfully in some of the directions than the others.
- **Omni-Directional:** In a given plane, having an essentially non-directional pattern and a directional pattern in any orthogonal plane.

2.2.6. Return Loss

It's a parameter that shows how much power is lost to the load and doesn't come back as a reflection. As a result, the RL is a parameter that indicates how well the transmitter and antenna have been matched. Simply put, it's an antenna's S11. The return loss curve of an antenna is a graph of S11 vs. frequency. For optimal performance, such graph must have a dip at the operating frequency and a minimum dB value at this frequency. This parameter is discovered to be crucial in adjusting the antenna size for a fixed operating frequency (say 2.3GHz).

Return loss is usually expressed as a ratio in decibels (dB);

$$RL(dB) = 10\log_{10}\frac{p_r}{p_i} \tag{2.8}$$

Where RL (dB) is the return loss in dB, Pi is the incident power and Pr is the reflected power. Since power is proportional to the square of the voltage for a constant impedance transmission line return loss is also given by,

$$RL(dB) = 10\log_{10}\frac{p_r}{p_i} = 20\log_{10}\frac{v_r}{v_i} = 20\log_{10}|\Gamma| \tag{2.9}$$

Where is the reflection coefficient and given by: $\Gamma = \frac{V_r}{V_i}$

For practical antenna design, the acceptable value of return loss is less than -10 dB to define the impedance bandwidth [9]. A return loss of -10dB implies 10% of the incident power is reflected back and 90% of the incident power is delivered to the antenna.

2.2.7. Voltage Standing Wave Ratio (VSWR)

VSWR is an important parameter considered during the installation of antennas. When an antenna is connected to the feed line, their impedance needs to be matched exactly so that the maximum energy transfer takes place. When the impedances of antenna and feed line do not match, some portion of electrical energy is not transferred from feed line to the antenna. This portion of energy, which is not transferred to antenna, reflects back to the transmitter.

Generally, The Voltage Standing Wave Ratio (VSWR) is an indication of the amount of mismatch between an antenna and the feed line connecting to it. The range of values for VSWR is from 1 to ∞. A VSWR value less than 2 is suitable for most antenna applications. The antenna can be described as having a good match. Therefore, when someone says that the antenna is poorly matched, means that the VSWR value exceeds 2 at a frequency of interest.

2.2.8. Beam width

An antenna's beam width is easily estimated from its 2D radiation pattern and is a critical parameter. The angular spacing of the half-power points of the radiated pattern is known as beam width. The following diagram illustrates how beam width is determined:

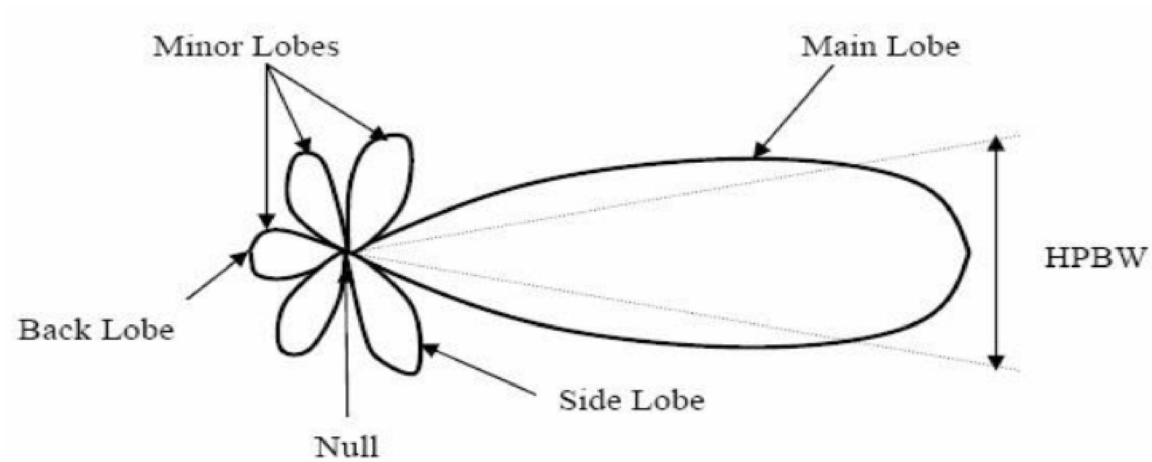


Figure 2. 1HPBW Determination Using Radiation Patterns [10]

2.2.9. Bandwidth and Efficiency

A general law for antennas states that the lowest achievable quality factor of an antenna is inversely related to the antenna volume [11]. The bandwidth increases with increasing patch substrate height, since the bandwidth is in inverse proportion to the quality factor. Another important substrate parameter that influences the bandwidth is the permittivity. Here, the absolute bandwidth of a patch antenna increases with decreasing substrate permittivity. In contrast to the bandwidth, the efficiency of a patch antenna decreases with increasing substrate height. And the efficiency increases with decreasing relative permittivity. In this thesis we will use a substrate height of 2.3 mm& a dielectric constant of 2.2.

2.3. Microstrip Patch Antenna

Micro strip antennas are extremely thin (0.01 to 0.05 free-space wavelength at 2.3GHz), printed antennas also have found many applications in military aircraft, missiles, rockets, and satellites.

Micro strip patch antennas have a low profile (low visibility), are conformable to planar and non-planar surfaces, are simple and inexpensive to manufacture using modern printed-circuit technology, and are very versatile in terms of resonant frequency, polarization, pattern, and impedance for a particular shape and mode. This makes the MSPA suitable for space craft, high-performance aircraft, satellite, and missile applications. Weight, cost, performance, ease of installation, and aerodynamic profile are constraints (required) [9].

There are a variety of substrates that can be utilized to make microstrip antennas, and their dielectric constants are typically in the range of $2.2 \leq \varepsilon_r \leq 12$ [9]. Thick substrates with dielectric constants at the bottom of the range are best for optimum antenna performance. Because they have a higher efficiency, a wider bandwidth, and loosely bound fields for radiation into space, but at the cost of a bigger element size. For microwave circuitry thin substrates with higher dielectric constants are preferred. Since they require tightly bound fields to reduce unwanted radiation and coupling, they result in smaller element sizes; however, they are less effective and have lower bandwidths due to their higher losses [12]. As a result, a compromise must be struck between antenna size and efficiency.

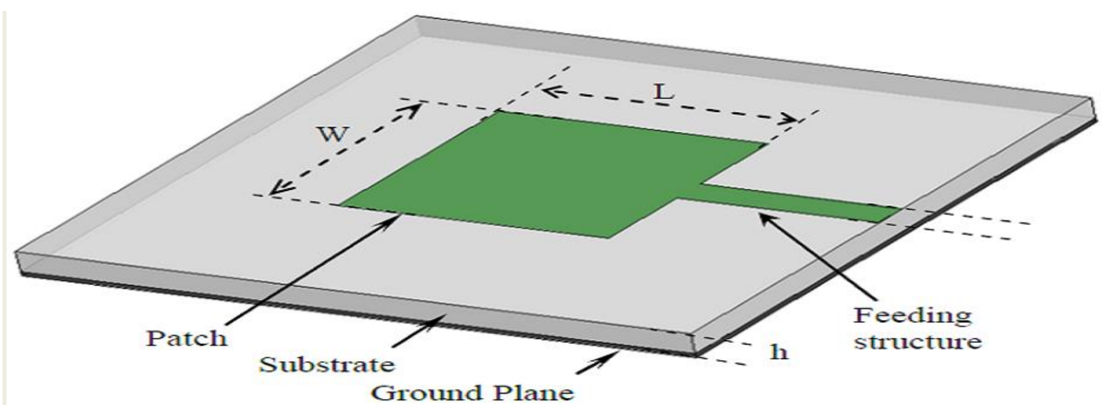


Figure 2. 2 Basic microstrip patch antenna [13]

A patch is usually made of conductive metals like copper or gold and can be manufactured into any shape. The ground plane is responsible for reflection of electromagnetic waves, and the substrate placed between the ground plane and patch decides the performance as well as size of the micro-strip antenna.Square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other shape can be used as a radiating patch. Figure 2.3 depicts these and additional examples. Because of their ease of analysis and production, as well as their appealing radiation characteristics, particularly low cross-polarization radiation, square, rectangular, dipole (strip), and circular are the most frequent. Micro strip dipoles are appealing because they have a broad bandwidth and take up less area, making them ideal for arrays. Single elements or arrays of micro strip antennas can achieve linear and circular polarizations. Scanning capabilities and higher directivities can also be achieved by using arrays of micro strip elements with single or multiple feeds [9].

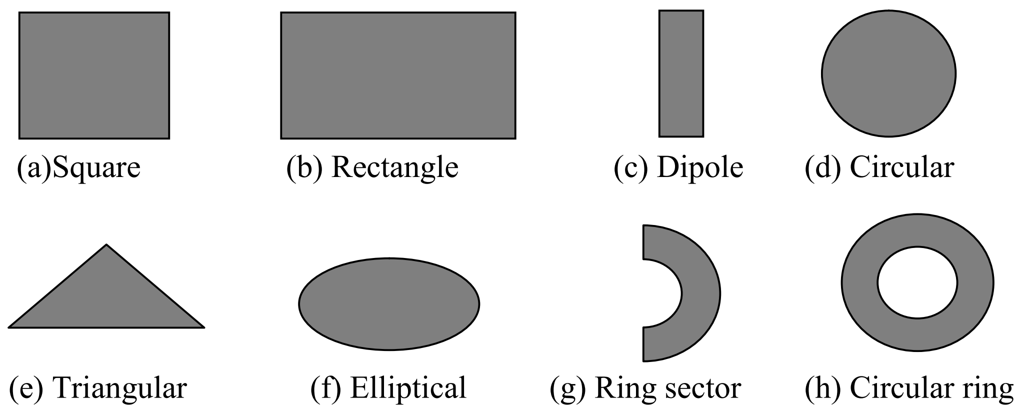


Figure 2. 3Representative shapes of Microstrip Patch Elements

On the dielectric substrate, the radiating patch and feed lines are normally photo etched. Antenna arrays, as well as their feeding networks, can be photo etched on the substrate. Through the use of basic photo etching processes, microstrip circuits enable a wide range of antennas.

A thick dielectric substrate with a low dielectric constant is ideal for improved antenna performance because it gives better efficiency, larger bandwidth, and better radiation. However, such a setup necessitates a larger antenna. Higher dielectric constants, which are less efficient and result in narrower bandwidth, are required to construct a tiny Micro strip patch antenna.

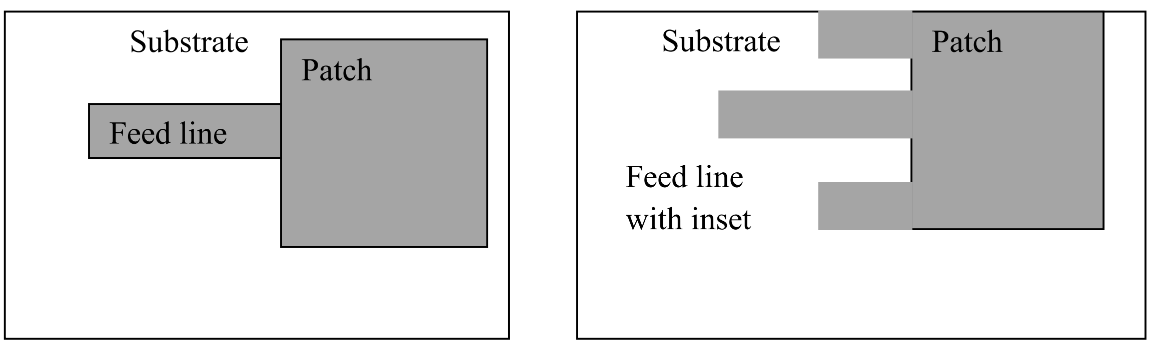
2.3.1. Feeding Techniques

A multitude of approaches can be used to feed micro strip patch antennas. These techniques are divided into two types: contacting and non-contacting. The RF power is delivered directly to the radiating patch using a connecting element such as a micro strip line in the contacting approach.

Electromagnetic field coupling is used in the non-contacting system to transfer power between the micro strip line and the radiating patch. The micro strip line, coaxial probe (both contacting schemes), aperture coupling, and proximity coupling (both non-contacting schemes) are the four most commonly utilized feed techniques [14].

I. Microstrip Line Feed

A conducting metal strip is directly attached to the edge of the microstrip patch in this feeding technique, as shown in Figure 2.31. The feeding line is smaller than the patch and could be edge feed or inset feed. In comparison to the patch, the feeding line is narrower and might be edge feed or inset feed. The antenna construction procedure is simplified in this feeding since both the feed and patch are etched on the same substrate to give a planar shape [15]. With inset micro-strip line feed, the level of input impedance may also be readily regulated. The inset cut in the patch's function is to match the feed line's impedance to the patch without the use of any extra matching elements.



(a) Edge Feed (b) Coplanar Feed

Figure 2.3. 1 Microstrip Feed Lines

I. Coaxial Probe Feed

Coaxial feed, often known as probe feed, is a common method of feeding Micro strip patch antennas. The coaxial connector's inner conductor extends through the dielectric and is attached to the radiating patch element, as shown in Figure 2.32, while the outer conductor is merely attached to the lower ground plane. The advantage of this category of feeding is that the feed can be placed at any desired location as per the requirement in the patch in mandate to match the input impedance. This feeding technique is easy to fabricate and has small unnecessary radiation. The main disadvantage of this technique is that it has a narrow bandwidth for thicker antenna substrates and is difficult to model thick coaxial feed substrates; additionally, a hole must be drilled in the substrate to touch the radiating patch, and the connector protrudes outside the ground plane, making it non-planar [16].

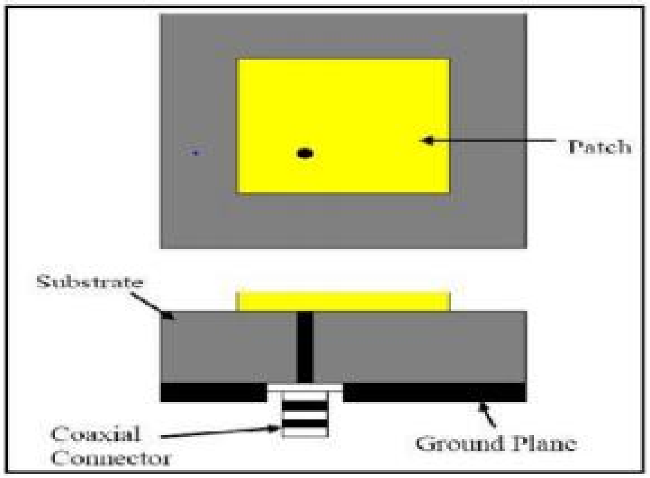


Figure 2.3. 2 Coaxial Feed [17]

II. Aperture Coupled Feed

The ground plane separates the microstrip feed line and the radiating patch in this sort of feeding approach, is shown in figure 2.3.3[18]. The spurious radiations are reduced by using this ground plane. A slot or an aperture in the ground plane completes the coupling (connection) between the feed line and the patch. Because of the symmetry of the design, the coupling aperture is frequently centered under the patch, resulting in lesser cross polarization.The shape, size, and position of the aperture impact the cost of coupling from the feed line to the patch [16].

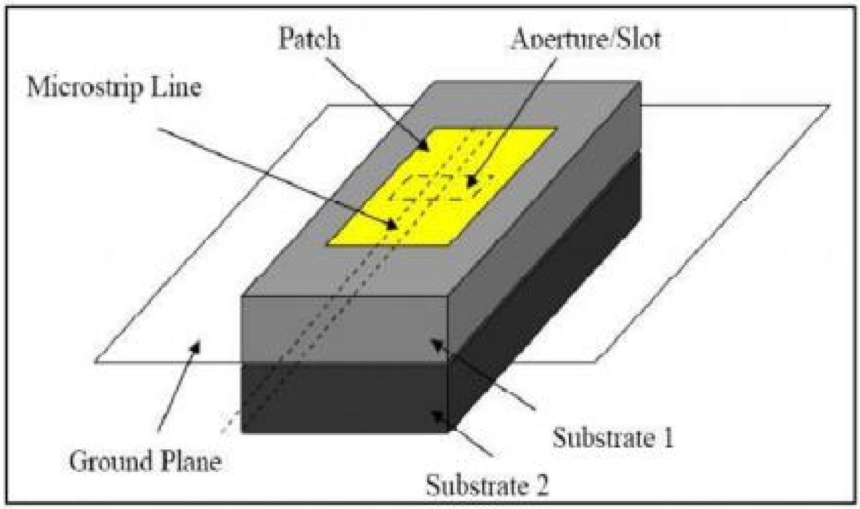


Figure 2.3. 3 Aperture coupled [17]

Typically, a high dielectric material is utilized for the upper (top) substrate and a low dielectric material is utilized for the bottom substrate to maximize the patch's radiations. The main downside of this feed method is that it is difficult to construct because to the many layers, which also adds to the antenna thickness.

III. Proximity Coupled Feed

Because this method of feeding is non-contact, it is also known as the electromagnetic coupling system. As can be seen in Figure 2.3.4. Between the two dielectric substrates, the feed line is sandwiched. The patch is printed on the upper dielectric substrate's top surface. The fundamental benefit of this feeding method is that it reduces spurious feed radiations while also providing extremely high bandwidth [9].

This approach also allows for the selection of two dielectric media, one for the patch and the other for the feed line, in order to optimize individual performance. Controlling the length of the feed line and the patch's width-to-line ratio can help with matching [16].

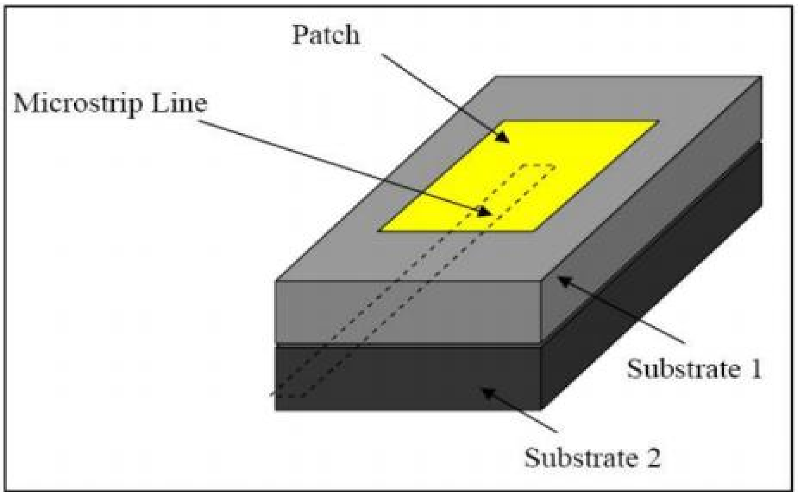


Figure 2.3. 4 Proximity coupling feed method [17]

A summary of all the feeding techniques discussed is presented in Table 2.1.

Characteristics	**Inset feed**	**Co-axial probe feed**	**Aperture coupled**	**Proximity coupled**
Configuration	Co-planar	Non-planar	Planar	Planar
Spurious feed radiation	More	More	More	More
Polarization purity	Poor	Poor	Excellent	Poor
Ease of fabrication	Easy	Soldering and drilling needed	Alignments required	Alignments required
Reliability	Better	Poor due to soldering	Good	Good
Impedance matching	Easy	Easy	Easy	Easy

Table 2. 1 Summarizes the characteristics of the four feeding technique

2.3.2. Methods of Analysis

The transmission line model, cavity model, and full wave model (which includes largely integral equations/Moment Method) are the most prominent models for the analysis of Micro strip patch antennas.

The transmission line model is the most basic of them all, and while it provides useful physical information, it is less precise. The cavity model is more accurate and provides better physical understanding, but it is also more complicated. Single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements, and coupling can all be treated using full wave models [9].

Transmission Line Model

The transmission-line concept essentially shows a microstrip antenna in two slots separated by a low-impedance transmission line of length L. The fields near the patch's boundaries are fringing because the patch's dimensions are finite along its length and width. The majority of the electric field lines are located in the substrate in Figure 2.4, whereas portions of others are located in the air. The emerging of these waves in air out of the substrate is known as the fringing effect.

As a result of these phenomena, the clear transverse electric- magnetic (TEM) mode of transmission cannot be supported by this transmission line model since the phase velocities in the substrate and the air substrate are different. The fringing fields between the patch edge and the ground plane are what cause the microstrip patch antenna to emit.

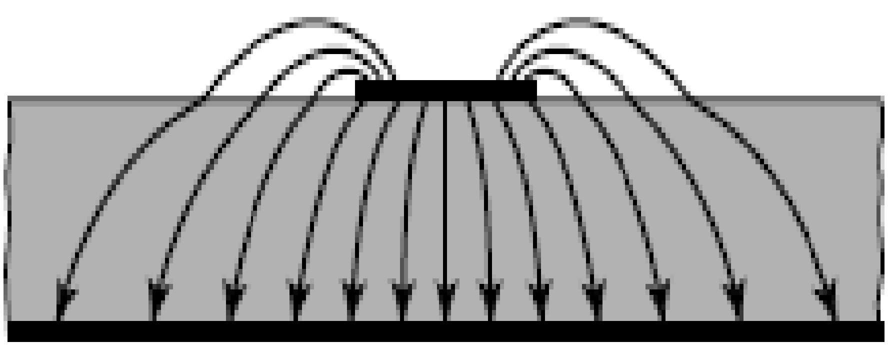


Figure 2. 4 Electric field lines [9]

To account for the fringing and wave propagation in the line, an effective dielectric constant (εreff) must be determined. Because the fringing fields surrounding the periphery of the patch are not restricted in the dielectric substrate but are also dispersed in the air, Ereff is slightly less than εr.The expression for Ereff is given as:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\left(\frac{\mathrm{h}}{\mathrm{w}}\right)\right]^{-\frac{1}{2}} \tag{2.10}$$

Where εreff is the effective dielectric constant, εr is the substrate's dielectric constant, h is the dielectric substrate's height, and W is the patch's width.

Electrically, the patch of the microstrip antenna appears larger than its actual dimensions due to fringing effects. Hence length, width and resonant frequency of the antenna changes from the original physical dimension value.

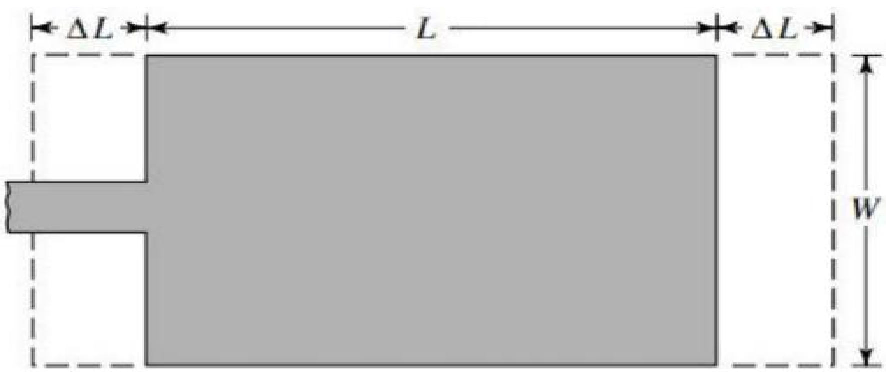


Figure 2. 5 Physical and effective length of MPA [9]

The patch's dimensions have been extended along its length by a distance L, which is a function of the effective dielectric constant and the width to height ratio (w/h), as shown in Figure 2.8 for the major E-plane (xy-plane). Where a popular and practical approximation relation for the normalized extension of the length is given by [9]:

$$\frac{\Delta L}{h} = \frac{0.412\left(\left(\varepsilon_{reff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)\right)}{\left(\left(\varepsilon_{reff} - 0.258\right)\left(\frac{w}{h} + 0.8\right)\right)} \tag{2.11}$$

Because the patch's length has been increased by ΔL on either side, the patch's effective length is now (L=λ/2 for dominant TM mode with no fringing):

$$L_{eff} = L + 2\Delta L \tag{2.12}$$

The resonance frequency for any TM_{mn} mode for a rectangular microstrip patch antenna is given by

$$(f_r)_{mn} = \frac{c}{\sqrt[2]{\varepsilon_{reff}}}\left[\left(\frac{m}{L_{eff}}\right)^2 + \left(\frac{n}{W_{eff}}\right)^2\right]^{\frac{1}{2}} \tag{2.13}$$

Where the letters 'n' and 'm' denote modes along the W and L respectively. The width W is calculated as follows for efficient radiation:

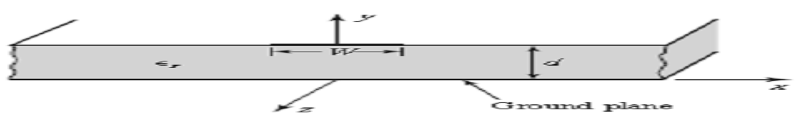
$$w_{eff} = \frac{c}{f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{2.14}$$

The speed of light in free space is denoted by the ‘C’.

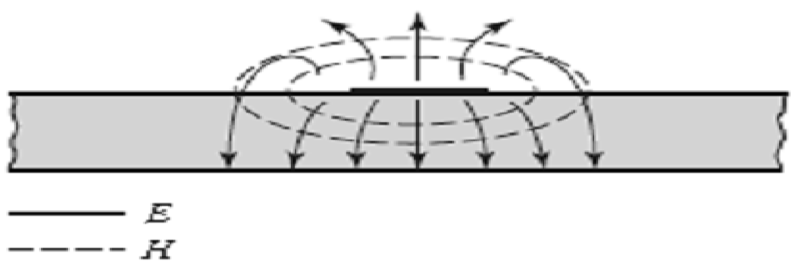
2.3.3. Microstrip Lines

Micro strip line is one of the most popular types of planar transmission lines primarily because it can be fabricated by photolithographic processes and is easily miniaturized and integrated with both passive and active microwave devices. [11].

The geometry of a micro strip line is shown in Figure 2.12. The behaviour and analysis of micro strip line is complicated due to the fact that a dielectric is present in between the micro strip and the ground plane; and because the dielectric does not fill the region above the strip. In this thesis a Micro strip line is used as a transmission line which will guide the EM-waves from the source and feed it to the patch antenna through the coupling aperture. And for the micro strip line to behave as a transmission line, the type of wave propagation needs to be TEM which is not possible in a micro strip line. This is because not all the fields are contained in the dielectric region between the strip and the ground plane; a fraction of the field lines are in the air-region above the substrate. In practice the dielectric substrate is electrically very thin ($d<<\lambda$) and so the fields are quasi-TEM.



(a) Geometry of Microstrip Transmission Line [19]



(b) Electric & Magnetic Field of Microstrip Transmission Line [9]

Figure 2. 6 Geometry & Electric & Magnetic Field of Microstrip Transmission Line

2.4. Mutual Coupling in Antenna Array

One of the basic characteristics of an antenna array appears when two or more elements are located near to each other and affect each other. The amount of coupling depends on the following:

- Radiation characteristics.
- Actual separation between elements.
- Relative orientation of elements.

The mutual coupling between two radiating elements depends upon the distance between them. If they are close to each other the mutual coupling will be greater. Thus, energy is transferred between elements and this is called mutual coupling. One can say that the electromagnetic coupling between the elements is mutual. Mutual coupling degrades not just the antenna efficiency, but it can alter the antenna's radiation pattern as well. This is one of the limitations involved in antenna array [20]. Mutual coupling reduces the antenna efficiency and performance of antennas in both the transmitting and receiving mode. Mutual coupling can be quantified by measuring the antenna isolation.

There are methods to reduce mutual coupling between radiating elements in antenna array systems and are described in the following subsection.

2.4.1. Electromagnetic Band gap (EBG) Structure

Electromagnetic band gap structure is man-made periodic elements that either prevents or let EM waves propagate in a specific frequency band for all polarization states and incident angles. It has a frequency range with very high surface impedances due to which the structure starts acting as a filter.

2.4.2. Split ring resonators (SRRs)/ Complimentary SRRs (CSRRs)

A single cell Split Ring Resonators (SRR) is an artificially created structure similar to metamaterials. The aim of SRR is to produce the desired -magnetic response in different types of metamaterials up to a frequency of 200 terahertz. SRRs consist of a pair of concentric metallic rings, having slits cut on opposite sides. SRR can be etched in the back side of the substrate, under the slots, to attain high magnetic coupling between the transmission line and the rings at resonance.

A SRR structure inserted between the patches to create a band gap in the operation frequency band of the antenna. By suppressing the surface wave, it provides a very low mutual coupling between array elements. In SRR the real part of magnetic permeability becomes positive below the resonant frequency, and above the resonant frequency, it becomes negative. This property can be used with the negative dielectric constant of another structure to produce negative refractive index materials. SRRs are used in MPA for size reduction, broad banding and multi banding.

2.4.3. Defected Ground Plane Structure (DGS)

Defected ground structure (DGS), increases the performance of the system in terms of return loss, gain, directivity and bandwidth by deliberately altering the ground plane metal of microstrip circuit. DGS is realized by intentionally etching off a normal shape (slot or defect) in the ground surface plane which is called as “defect or fault”. Several forms and sizes of the defect, interrupts the shielded distribution of the microstrip current in the plane of ground, that results in propagation of the electromagnetic (EM) waves through the layers of substrate. This disturbance also changes the line inductance and capacitance of a transmission line. In fact, any slightly defect etched in the microstrip's ground plane can enhance the effective capacitance and inductance. The defect's shape can be altered from a simple to a complex shape for better performance. Depending on the shape and configuration of the defects, the performance of microstrip system may be varied.

The defects can be single or multiple in the ground plane. The defects can be used to suppress the coupling (mutual) between the elements and to decrease the harmonics. Defected Ground Structure has become very popular in the area of microwave engineering which is used in many applications and developments. [21]

DGS has a simple structure and could be useful for designing microwave circuits including amplifiers, oscillators and filters. A DGS has the following properties and effects

- Increases effective permittivity.
- Increases effective capacitance and inductance of transmission line.
- Disturbs ground plane shielding areas.
- Size reduction for the component.

Classification of DGS Geometry

Various DGS geometries such as circular, spiral, square, rectangular, L-shaped, dumbbell, concentric ring, V-shaped and U-shaped, cross headed, hairpin DGS, arrow headed slot, hexagonal, cross shaped, slot etc. have been reported. The dumbbell shaped pattern of DGS is simple and easy to design. Hence in several microwave circuits the dumbbell shape of DGS pattern is mostly used. The geometry of the DGS consists of various shapes. These can be classified into periodic and unit cell DGS. Shapes like U&V shape, meander lines, slots with inter digital, quad spiral, DGS with complementary lines and cross shape are included under unit cell DGS. Dumbbell and its variations can be classified into square headed/ metal loaded square heads, circular headed, open loop, arrow headed [21].

2.4.4. Frequency Selective Surfaces

Frequency selective surface is a thin, repetitive surface that reflects, transmit or absorb electromagnetic fields depending on their frequency. Planar periodic structures with reflection and/or transmission properties as a function of frequency are known as FSSs. They operate as passive or active electromagnetic filters, selectively reflecting, or attenuating a desired frequency range. Frequency Selective Surface (FSS) structure has a phenomenon with high impedance surface that reflects the plane wave in-phase and suppresses surface wave.

FSS is a two – dimensional periodic array of metallic or aperture elements that can exhibit band-pass (non-radiating) or band- stop (radiating) response when excited by an electromagnetic wave at angle arbitrary to the plane of the arrays. A periodic array of aperture or patch components is referred to as an FSS. The aperture element FSS reflects low frequencies and transmits high frequencies (much like a high-pass filter), while the patch-element FSS transmits low frequencies and reflects high frequencies (much like a low-pass filter).

There are four major groups of FSS, as shown in Figure2.7. The first group includes the center connected or N-poles types for example single dipole, three-legged, anchor element, the Jerusalem cross and square spiral. Meanwhile, the loop types are categorized in group 2 for example three and four-legged loaded element, circular loops, square and hexagonal loops. Group 3 include Solid interior or plate types. Group 4 is combinations of groups 1, 2 &3.

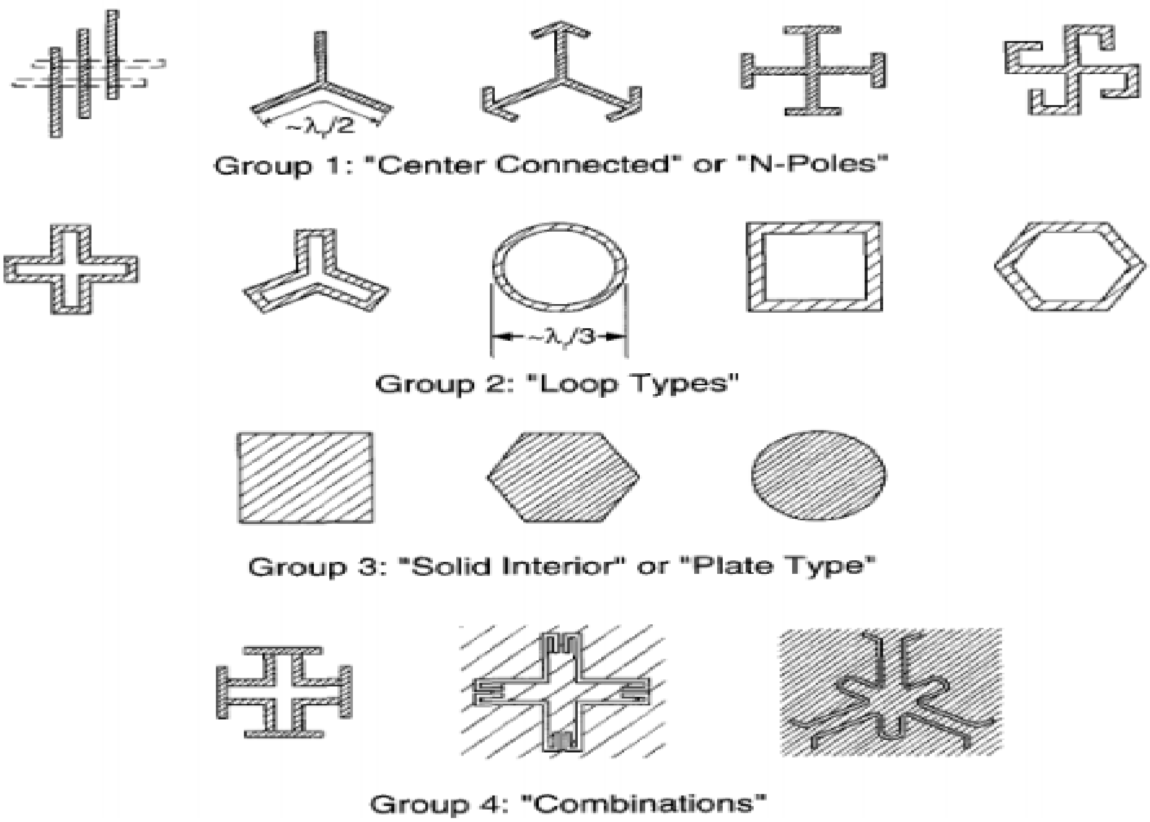
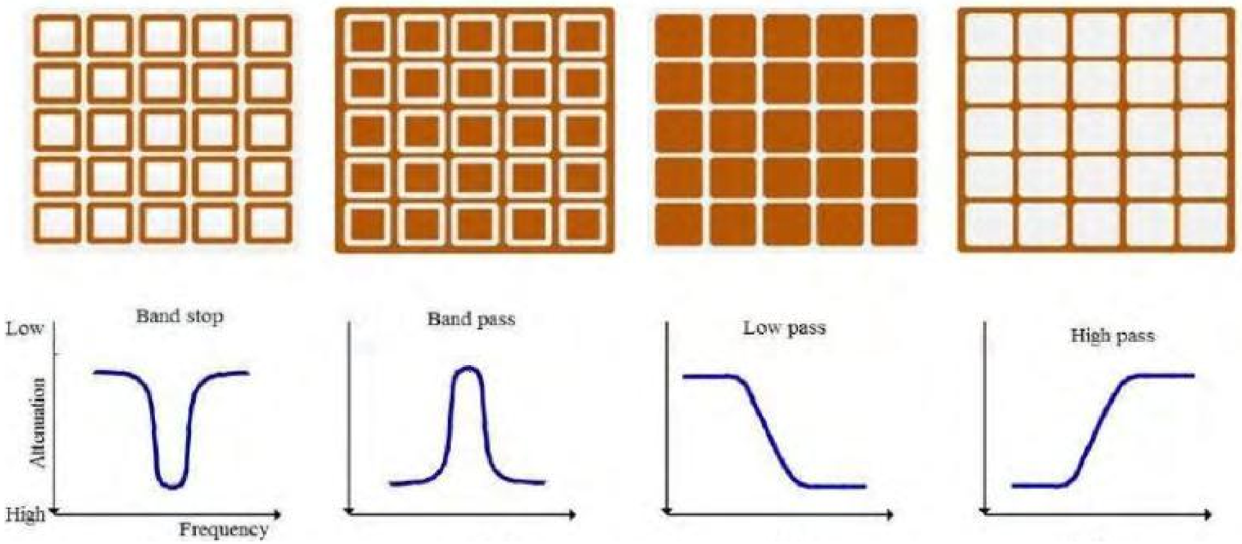


Figure 2. 7 Classification of FSS elements [22]

FSSs can be categorized into four type of filter which is band-stop, bandpass, low-pass and high-pass as shown in Figure 2.8. Filtering characteristics of EM mainly depends on the type and shape of the FSS elements.

If the elements are pure capacitive, it corresponds to a low-pass filter. Conversely, if the elements are pure inductive, a high-pass filters characteristics shows up. The size of patches in Figure 2.8(c) is greater than the size of the apertures, which results in a high capacitance and a negligible inductance as compared to the capacitance. In Figure 2.8(d) the same situation is present for the apertures against small patches which create an almost pure inductive medium.



(a) band stop (b) band pass (c) low pass (d) high pass

Figure 2. 8 Classification of FSS based on filtering characteristics [24]

These characteristics are modified by making the inter-element apertures between the patches comparable. In this way, FSS elements can be arranged in order to include both capacitive and inductive properties together. If patches are modified in this manner a band-stop filtering effect is observed; in which the array of conducting patches act as a band-stop filter, namely, rejecting waves at the patches resonant frequency but passing them at higher and lower frequencies. Similarly, due to the duality principle, apertures can be utilized in order to achieve band-pass performance. The periodic array of slots (or apertures) in a perfect conducting sheet act as a bandpass filter, namely, passing waves at the resonant frequency of the slots but rejecting them at higher and lower frequencies.

FSS Applications

Wireless communication systems, satellite communications, and radar cross section reduction are only a few of the application for FSSs. It is often used to reduce signal interference and serve as a filter signal. It only allows the necessary signals to pass through a given surface, thus reflecting unnecessary signals into the air. FSSs are important mechanism in antenna engineering because they can be used as filters, absorbers, and polarizers.

The Cryptologic Operation Center of Japanese Misawa Air Base, where the antennas are protected by spherical FSS radoms that shield the antennas from the impact of bad weather conditions, uses FSSs as radomes (short for “radar dome”) to protect the antennas from the weather conditions.

FSSs are also a component of low Observable (LO) technology, which is used to reduce the distance at which the equipment or even people can be detected. As a result, the military uses them to shield aircraft, ships, missiles and satellite in order to make them less visible to radar and preferably invisible. As a result, FSSs are interesting choice for reducing radar cross-section.

FSS can be used for microwave oven front doors. These surfaces operate by reflecting toxic electromagnetic emission from the microwave ovens while allowing visible light to pass through, ensuring that consumers can see the contents without being exposed to the emissions [25].

Chapter Three

Design and Simulation Setup

3.1. System Model

The proposed system is developed to operate aperture coupled antenna array for S-band applications with enhanced performance parameters and mitigation of mutual coupling. The overall flow of the proposed system is shown in Figure 3.1. The system starts by modeling single tuned aperture coupled antenna with better performance in terms of antenna parameters. Then designing antenna array and integrate with the shapes of DGS and FSS and comparing them. Finally the modeled systems in terms of antenna performance parameters. Hence return loss, bandwidth, VSWR, gain directivity and mutual coupling reduction is analyzed.

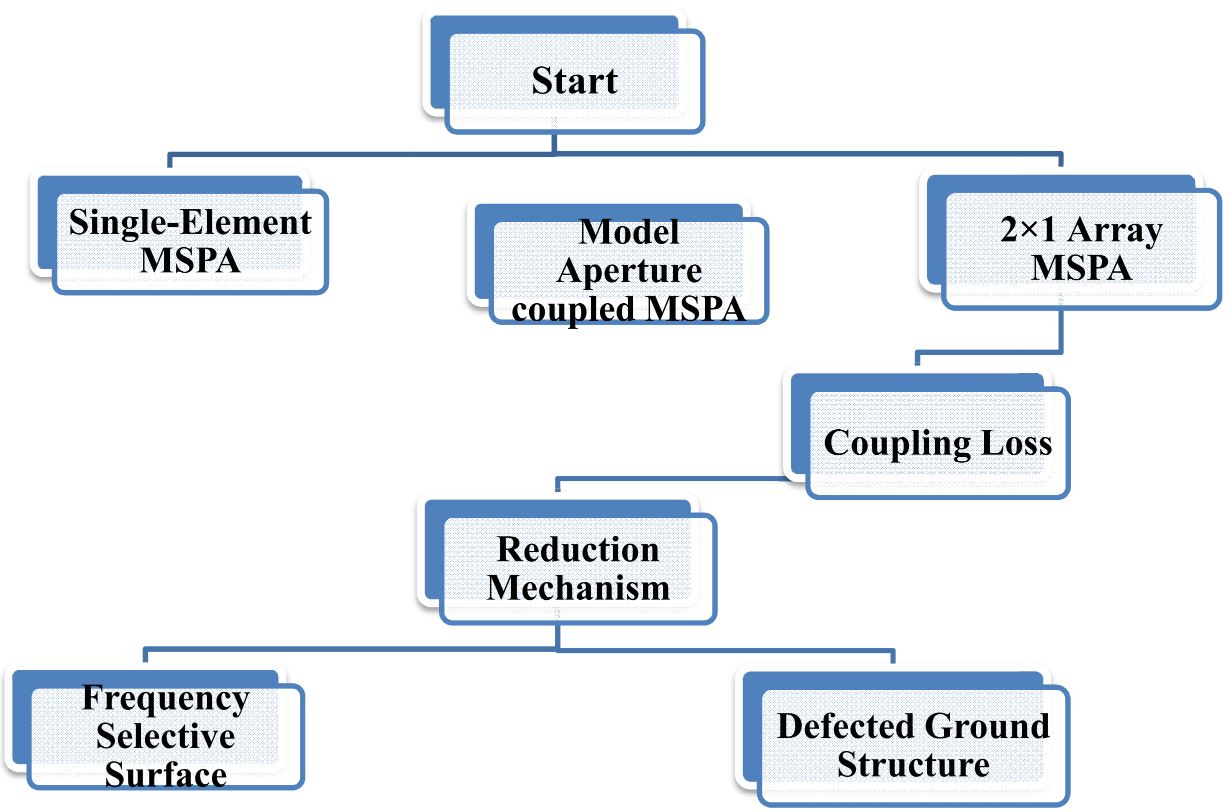


Figure 3. 1 System Model

3.2. Designing Single Element Aperture Coupled Microstrip Antenna

This section designs and simulates an aperture linked single element microstrip antenna that will be utilized as part of an antenna array that will be constructed later in this thesis. The focus of this section is to design a single element aperture coupled microstrip patch antenna, resonating at 2.3GHz which is used for S-band application.

No.	**Characteristics**	**Data**
1.	Polarization	Linear
2	Central Frequency (GHz)	2.3
3	Central Wavelength (mm)	130.43

Table 3. 1 Starting Data for Design

From Figure 3.2 the patch antenna substrate RT/Duroid 5880 is selected where dielectric constant (εr) is 2.2 and thickness (Hp) is 2.3mm. The feed line behaves like a transmission line designed to carry energy from a connector to the actual antenna and eventually launches guided waves. And it is a fact that in a transmission line guided waves become predominant when it is printed on an electrically thin substrate with large permittivity. So, for the microstrip feed line RT/Duroid 6006 is selected with dielectric constant 6.15.

3.3. Design Procedure and Summary of Design equations

Design of patch

Step 1: Patch Width (Wp)

The width of MPA is defined in equation 3.1

$$w_p = \frac{c}{2f_r\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{3.1}$$

Where$c$ = 3*10^{8}m/s, f_r= 2.3Gz and $\varepsilon_{r=}$2.2

$$w_p = 51.559\text{mm}$$

Step 2: Calculation of effective dielectric constant (ε_{rpeff})

$$\varepsilon_{rpeff} = \frac{\varepsilon_{rp} + 1}{2} + \frac{\varepsilon_{rp} - 1}{2}\left[1 + 12\left(\frac{h_p}{w_p}\right)\right]^{-\frac{1}{2}} \tag{3.2}$$

$$\varepsilon_{rpeff} = 2.11$$

Step 3: Calculation of effective length

$$L_{eff} = \frac{c}{2\mathrm{f_r}\sqrt{\boldsymbol{\varepsilon_{rpeff}}}} \tag{3.3}$$

$$L_{eff} = 44.89mm$$

Step 4: Calculation of length extension

$$\frac{\Delta L}{h_p} = \frac{0.412\left(\left(\varepsilon_{reff} + 0.3\right)\left(\frac{w_p}{h_p} + 0.264\right)\right)}{\left(\left(\varepsilon_{reff} - 0.258\right)\left(\frac{w_p}{h_p} + 0.8\right)\right)} \tag{3.4}$$

$$\Delta L = 0.844mm$$

Step 5: Calculation of actual length of patch (L_p):

$$L_p = L_{eff} - 2\Delta L \tag{3.5}$$

$$L_p = 43.202mm$$

Design of Feed

Step 6: Feed Length

In practice the length of the feed line is taken to be a little above the Free space wave length (i.e. $\lambda_0 = {}^{C_0}/_{f_r}$ = 130.43mm). As a starting point we have used a Feed length equal to the Effective guided wavelength of the antenna; which is found by using:

$$\lambda_{\mathrm{eff}} = \frac{\lambda_0}{\mathrm{sqrt}(\varepsilon_{\mathrm{eff}})} \tag{3.6}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1 + \frac{10h_p}{w_p})^{-0.5} \tag{3.7}$$

Where ε_{eff}, & λo are the effective relative permittivity of feed substrate and the free space wavelength

Step 7: Calculation of ground plane dimensions (Lg, Wg):

Only infinite ground planes are suitable for the transmission line model. However, a limited ground plane is required for practical considerations [2].The size of the ground plane must be greater than the patch dimensions by about six times the substrate thickness all around the periphery to achieve identical results for finite and infinite ground planes [24]. As a result, the ground plane dimensions for this design would be:

$$L_g = 6H_p + L_p = 57.002mm \tag{3.8}$$

$$W_g = 6H_p + W_p = 65.359mm \tag{3.9}$$

Where; Lg & Wg are the length and width of the ground plane respectively. And Hp, Lp, & Wp are the height of patch substrate, Length of patch, and width of patch respectively.

3.4. Modeling of Aperture Coupled MSPA

To perform a parametric study on the antenna it is necessary to understand the effect of dimensions and parameters of the antenna on its performance before tuning it to the desired performance level. Table 3.2 shows the initial dimensions and attributes of the planned linearly polarized aperture linked microstrip antenna.

Parameters	**Dimensions**
Resonant frequency	2.3GHz
Patch	Length (Lp) = 43.202mm, Width (Wp) = 51.559mm
Patch substrate RT/Duroid 5880	Thickness (Hp) = 2.3mm; Erp = 2.2
Aperture	Length (La) = 14mm ; Width (Wa) = 1.55
Feed substrate RT/Duroid 6006	Thickness (Hf) = 2.78mm ; Erf = 6.15;
Microstrip feed line	Length (Lf) = 70mm ; Z0 = 50 & (Wf) = 5mm

Table 3. 2 Calculated simulation parameters

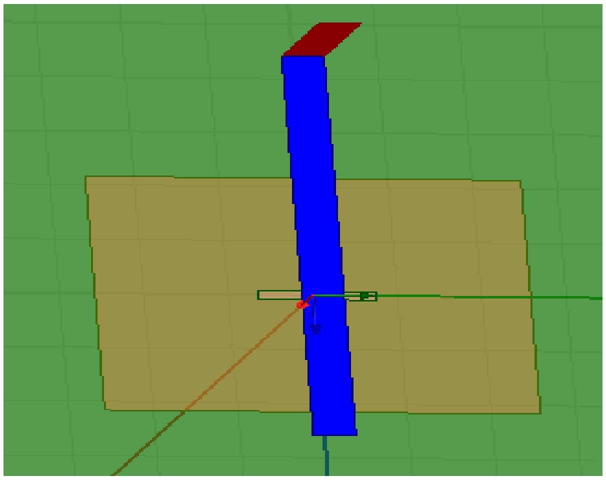


Figure 3. 2Aperture Coupled MSPA

3.5. Modeling of Tuned Aperture Coupled MSPA

The rectangular micro-strip patch antenna is modeled in HFSS by taking the dimensions designed in parametric sweep method. For better performance, the antenna dimensions are tuned with the help of HFSS and the tuned dimensions of the antenna are illustrated in Table 3.3. Based on the tuned design specifications given in Table 3.3, the modeled rectangular MPA is shown in Figure 3.3.

Antenna Element	**Tuned Dimensions of parameters**
Patch	Length (Lp) = 34.34mm, Width (Wp) = 31mm
Patch substrate	Thickness (Hp) = 2.3mm; relative permittivity = 2.2
Aperture (Slot)	Length (La) = 20mm ; Width (Wa) = 5mm
Feed substrate RT/Duroid 6006	Thickness (Hf) = 2.9mm; relative permittivity = 6.15
Micro strip feed line	Length (Lf) = 71mm; Z0 = 50 & Width (Wf) = 2.78mm

Table 3. 3 Tuned Simulation Parameters

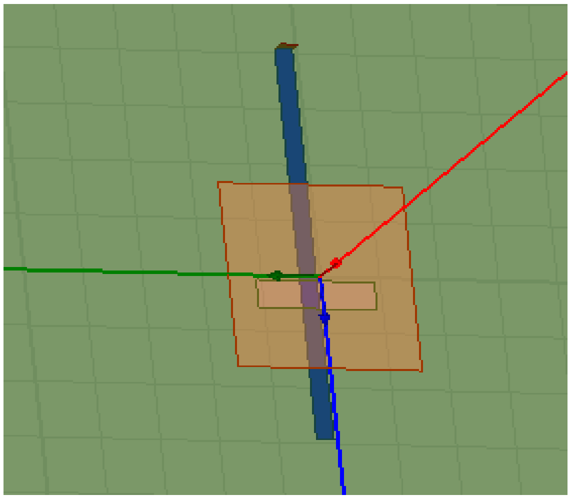


Figure 3. 3 Tuned MSPA

3.6. Modeling of 2X1 Array Design

The patch is designed as 2x1 arrays and is shown in Figure 3.3.With inter-element spacing of λ/4.

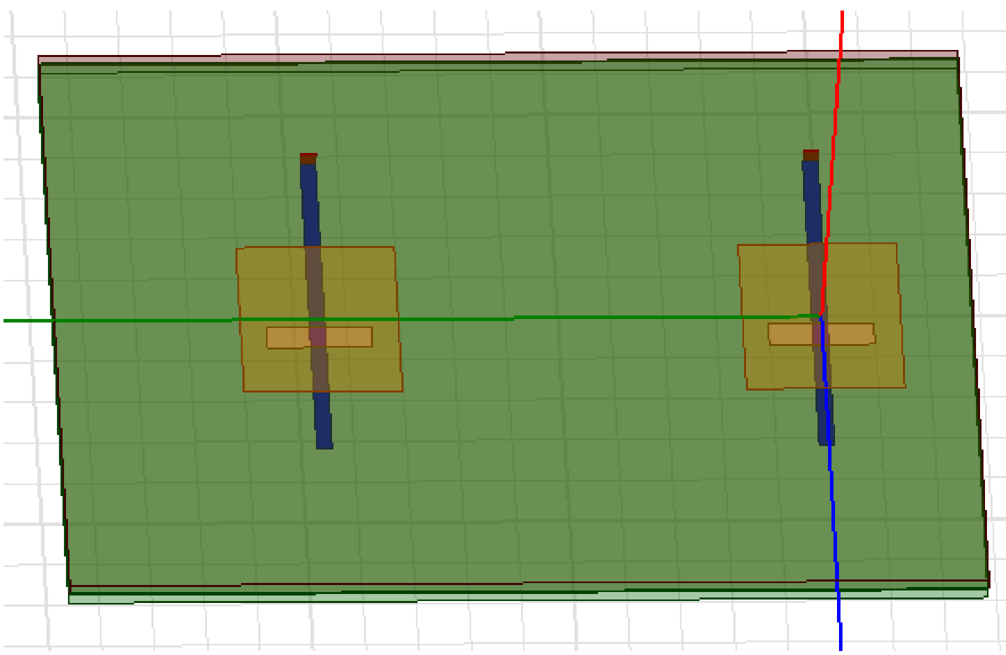


Figure 3. 4Geometrical Alignment of a two- element Patch Array

3.7. Modeling of Array with DGS & FSS

In this section a shape of DGS and FSS will be implemented and their performance evaluated to identify which then provide better performance in terms of mutual coupling reduction. The shape that is considered is: Square head dumbbell-shaped DGS and Square Loop FSS.

The performance evaluation of the listed shape of DGS and FSS on antenna array performance is evaluated in terms of return loss, bandwidth, VSWR, mutual coupling, radiation efficiency, gain and directivity.

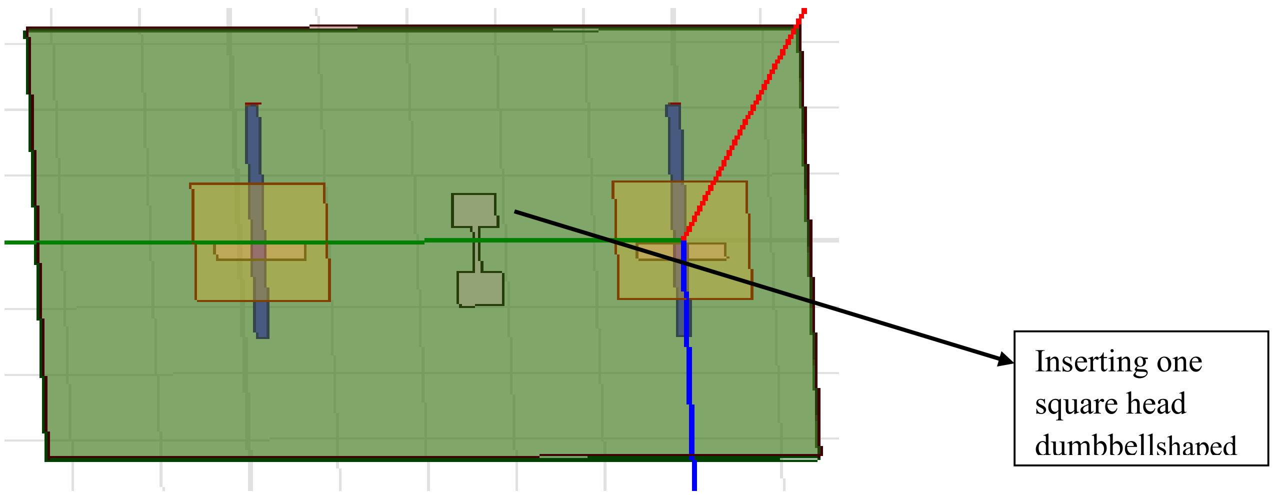


Figure 3. 52×1 MPA array with one dumbbell DGS between antenna elements

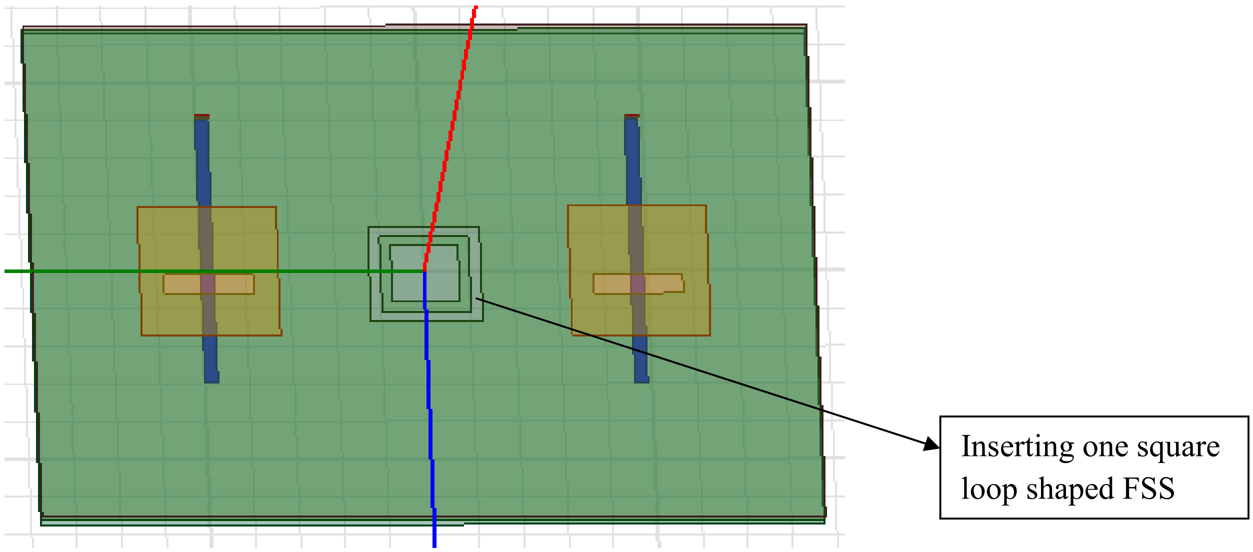


Figure 3. 62×1 MPA array with one square loop shaped FSS

3.8. Modeling of Array with 2-Square head dumbbell shaped DGS & 2-Square Loop shaped FSS

In this work two square head dumbbell of DGS and two square loops shaped FSS are modeled on the ground plane to reduce the mutual coupling and also improve antenna parameters.

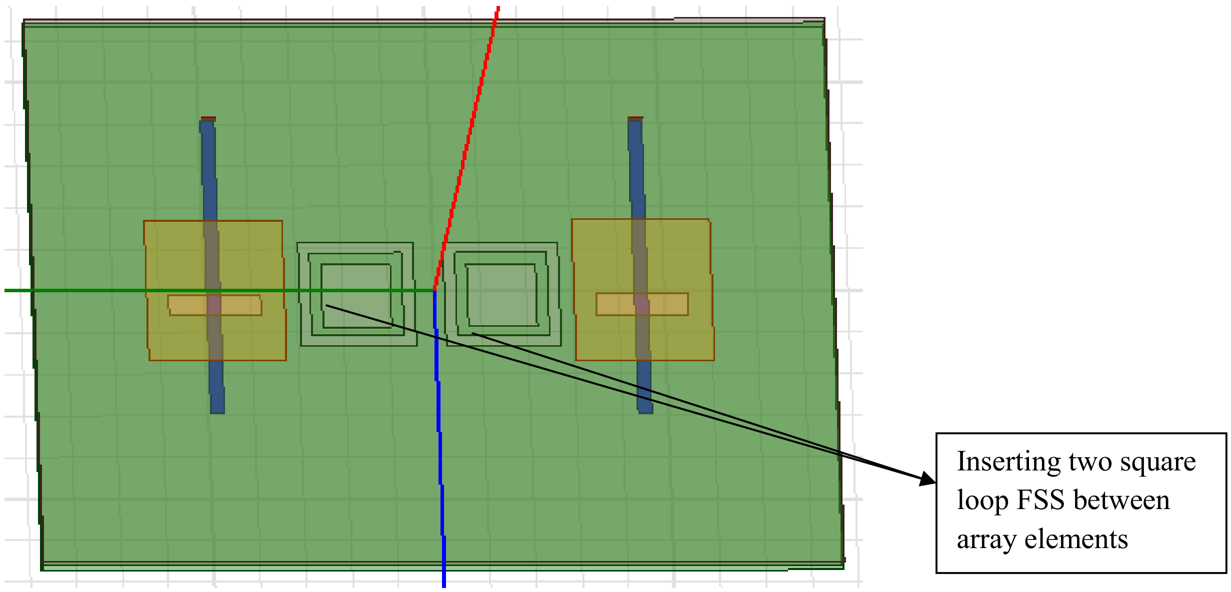


Figure 3. 72x1 MSPA array with two square loop shaped FSS

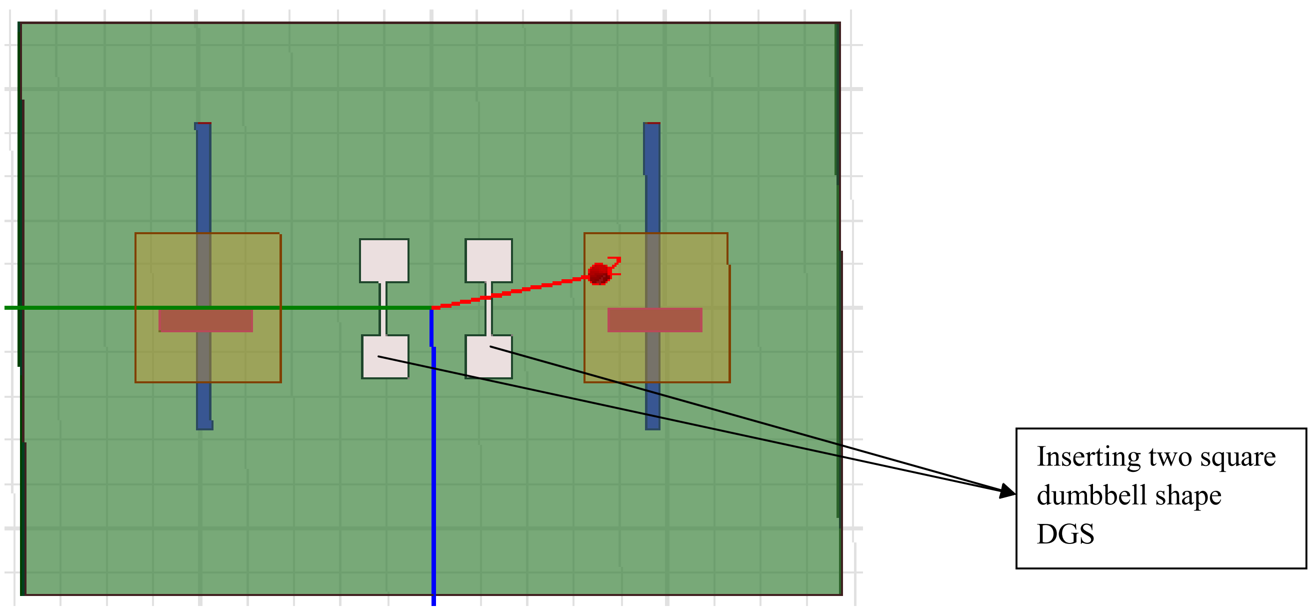


Figure 3. 82×1 MPA array with 2-dumbbell DGS in between antenna element

Chapter Four

Result and Discussion

4.1. Introduction

This section provides how the various parameters of the Aperture coupled microstrip patch antenna affect its performance. After tuning the dimension using optimetric on HFSS software, we will select the value of the particular parameter that gives the best performance.

4.2. Microstrip patch antenna

The rectangular shaped MPA array operating at 2.3GHz is designed using Rogers RT- Duroid 5880 substrate with ε_r= 2.2, RT- Duroid 6006 substrate with ε_r= 6.15 and height of dielectric substrate h=2.3mm. The model of a single microstrip patch antenna is shown in the Figure 4.1 and the feeding technique used is Aperture coupled feed.

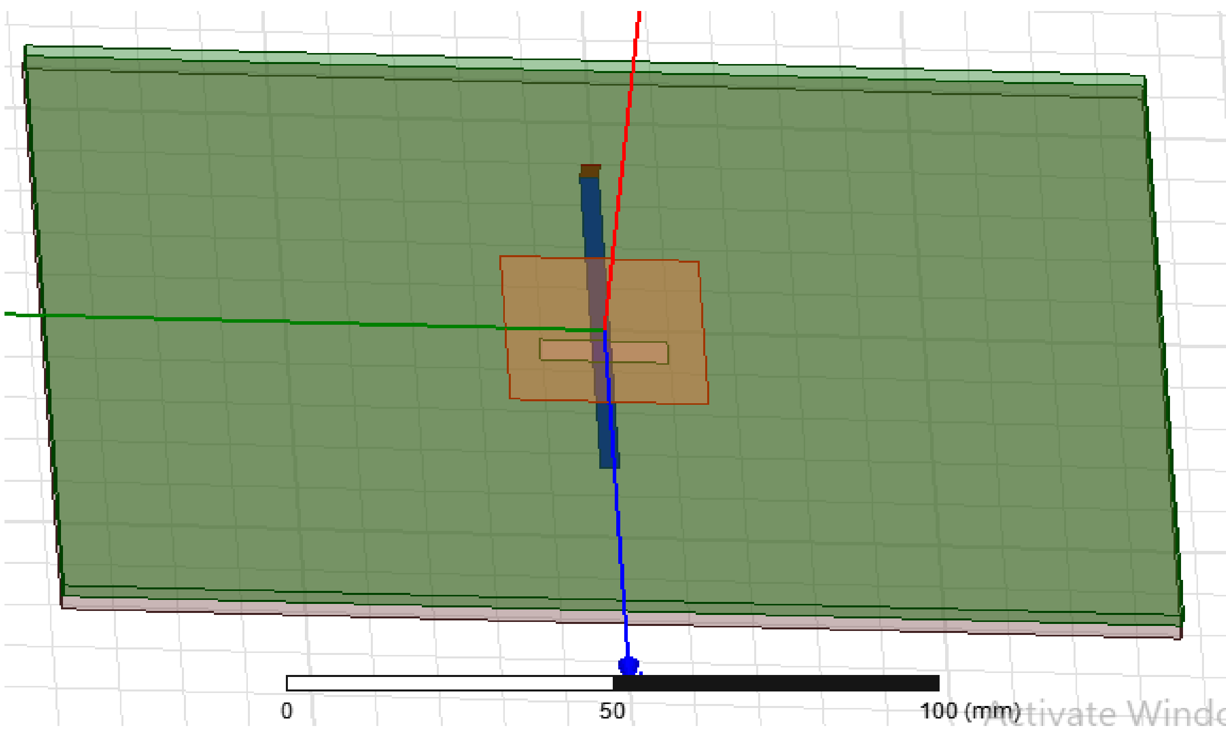
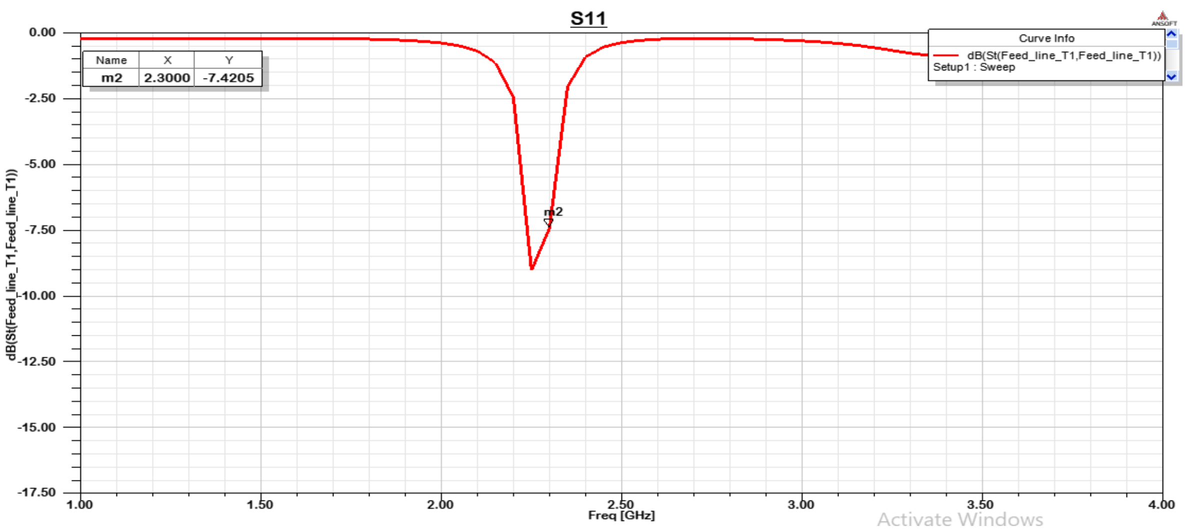


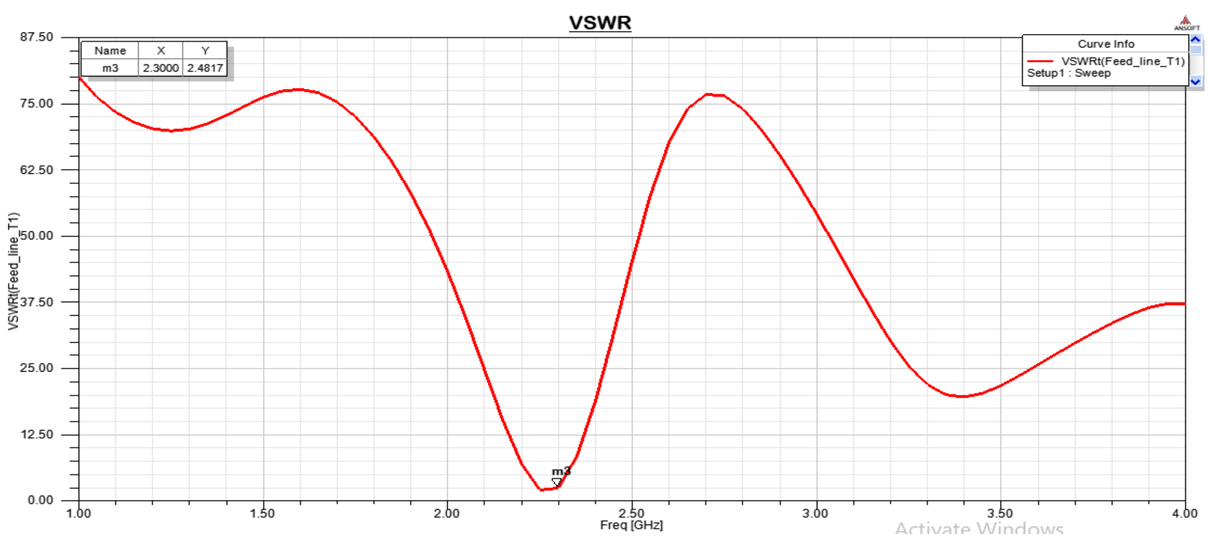
Figure 4. 1 Design of single rectangular MPA using aperture coupled feed

4.3. Simulation Result of Calculated Parameters in terms of return loss

Figure 4.2 it shows that the patch is not purely Resistive and most of the input power is being reflected because the value I found is -7.42dB. My aim here is to design an antenna that resonates at 2.3GHz with a return loss less than “-10dB” and VSWR less than “2” to ensure maximum power transfer. So, from the below figure the return loss and VSWR is not what I expected, so it is necessary to tune and optimize each dimensions of the antenna to get better result. Array antenna could be designed to overcome the problem.



(a) Return Loss



(b) VSWR

Figure 4. 2 Initial Simulation results of designed single MSPA Antenna

4.4. Result of Tuned MSPA

After using parametric sweep for each dimension of the antenna using the initial calculated parameters on Table 3.2, the result in terms of antenna parameters is indicated in Figure 4.3 which shows much more improved antenna performance

Effect of parameter calculations

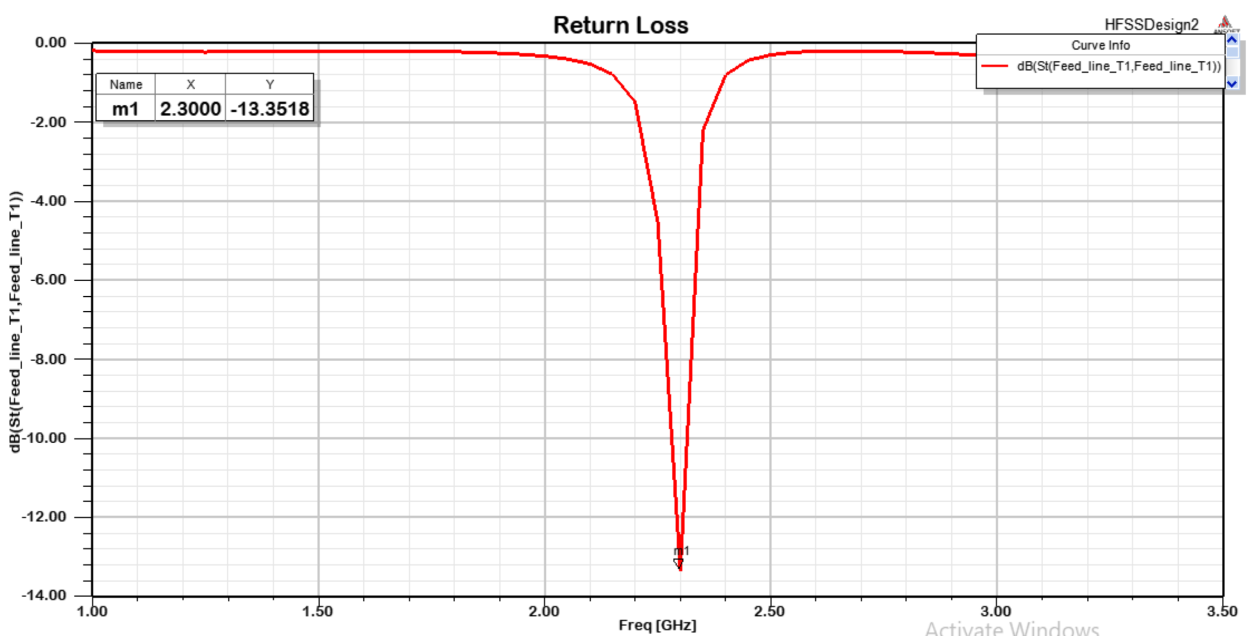
- **Effect of Patch Length**: By varying the patch length in order to improve the S11 &VSWR the result doesn't show that much improvement at the desired frequency because the patch length said to have an inverse relation with the resonant frequency though return loss and VSWR are better at with $L_P = 34.34$mm.
- **Effect of Patch width:** The increase in Patch width increases the return loss at first but starts to decrease it radically when increased further. This confirms that coupling is decreased between the patch and the feed as the Patch width is increased beyond a certain value. The VSWR is also affected in the same manner but the tuned dimension for good result show at $W_P = 31$mm.
- **Effect of the length of the Coupling Aperture:** The coupling slot behaves like an inductance and as the slot increase the inductance of the aperture increase, so the frequency shift is larger when the slot dimension increased but from the all simulated dimension the return loss is minimum when the slot is 20mm long.
- **Effect of the width of the coupling aperture:** The width of coupling slot affects the center frequency slightly as compared to the effect of the length of the slot has but from the result both return loss and VSWR are minimum for an aperture width of 5mm.
- **Effect of stub length:** Increasing the stub length decreases the amount of coupling and a very small stub length also decreases the coupling drastically which result in the current distribution below the slot cannot reach its maximum at the resonant frequency. Better antenna performance result shows at stub length of 27.52mm.
- **Effect of feed length:** The phase of input impedance can be changed by varying the feed length and its magnitude can be influenced by varying the patch length. The feed length has a relatively small impact on the Return loss. This is because it only affects the Phase of the input impedance and when the feed is long enough the field configuration becomes a quasi-TEM on the microstrip line. This means that no E- or H- field components are presented

along the direction of wave propagation. The return loss shows a significant improvement when the feed length is 70mm.

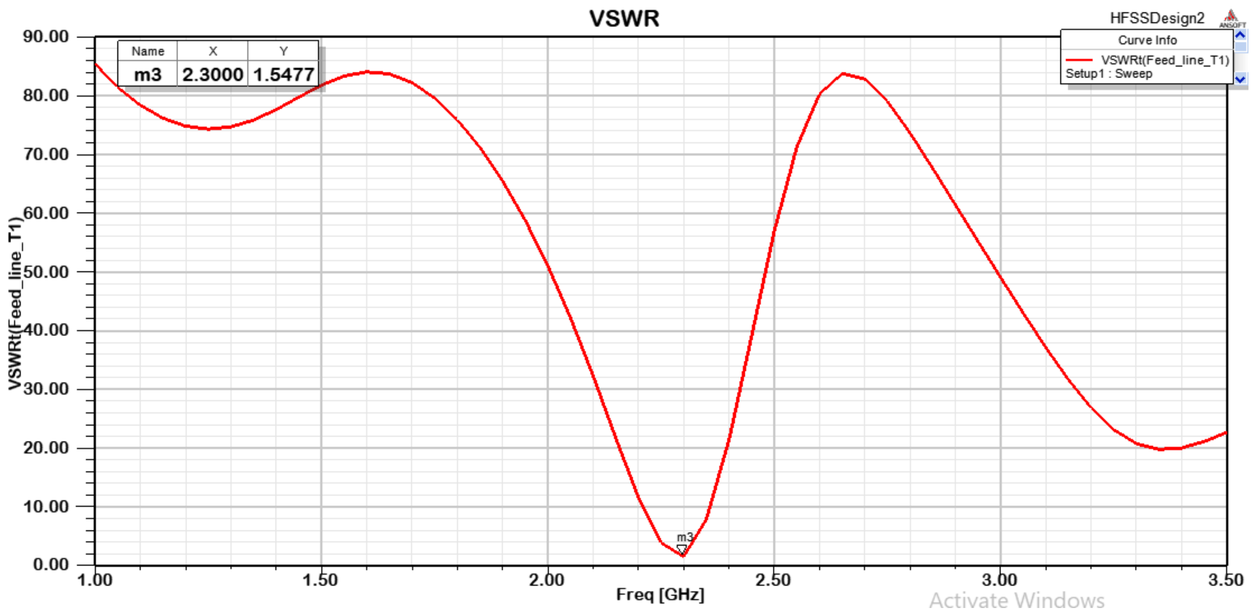
- **Effect of the ground plane**: The ground plane main purpose is to reinforce the radiation pattern toward the broadside by reflecting back fields that may spillover from the patch, and contain them inside the volume of the dielectric substrate. So, if the Area of the ground plane is not large enough than the area of the patch, the fields from the patch spill over and are not reflected back which disturbs the overall radiation pattern of the patch.

Return Loss: Return loss is the difference between forward and reflected power, in dB, generally measured at the input to the transmission line connected to the antenna. For maximum power transfer the return loss should be as small as possible. Figure 4.3 (a) shows the S11 (return loss) for a single MSPA antenna which resonates at 2.3GHz having value of -13.35dB.

The range of frequencies across which the return loss is less than -10dB is referred to as the antenna's bandwidth. The bandwidth of the proposed patch antenna is 33.3MHz. Figure 4.3 shows the simulation result for a single MSPA after tuning.

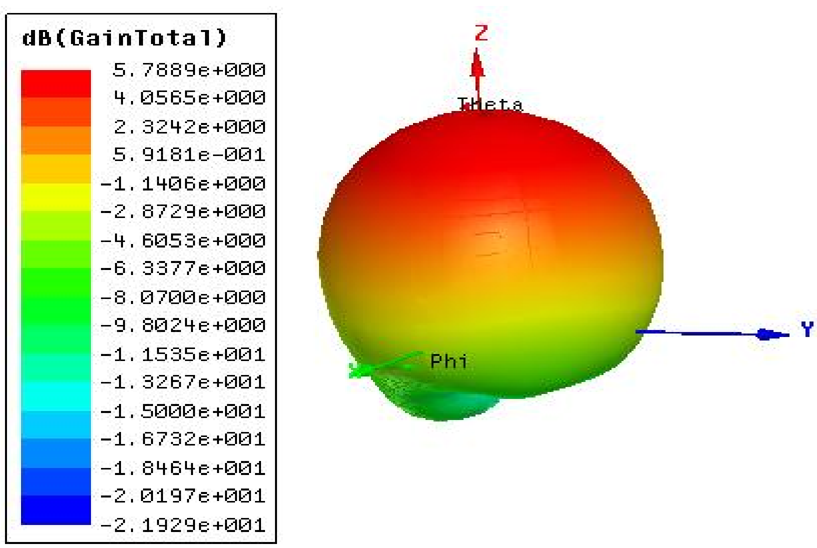


(a) Return Loss

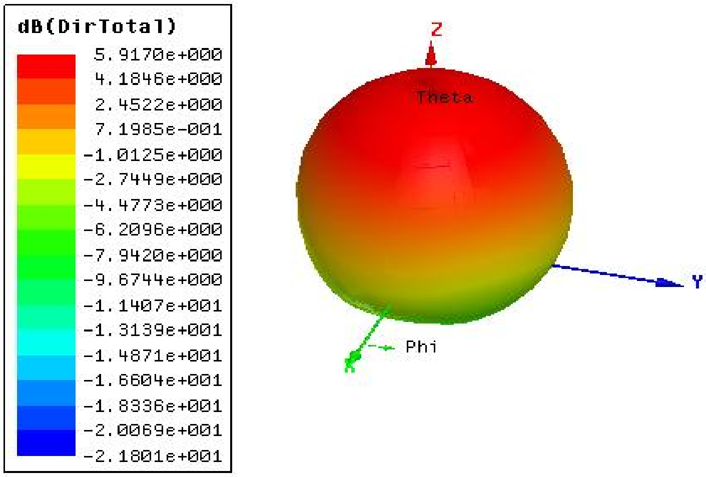


(b) VSWR

VSWR:VSWR is a measure of how much power is delivered to the antenna. This does not mean that the antenna radiates all the power it receives. When the VSWR value below two, the antenna is well-matched but does not necessarily mean the power delivered is also radiated. The VSWR plot for the designed antenna is shown in Figure 4.3 (b). The value of VSWR is 1.547 at resonating frequency.

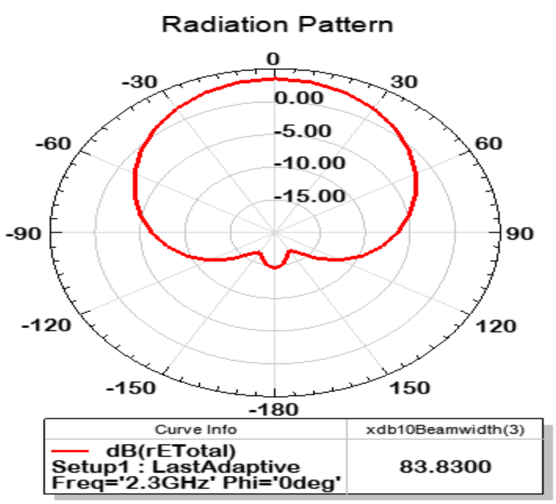


(c) Gain of a single MSPA



(d) Directivity of a single MSPA

Gain, Directivity and Efficiency: The main difference between gain and directivity is that the gain accounts the radiation pattern as well as the antenna losses but directivity does not account antenna losses. The achieved gain and directivity of single MSPAs are 5.789dB and 5.912dB respectively. The gain and directivity plot of the MPA is depicted in Figure 4.3(c) & (d). The efficiency obtained is 93.64% with beam width 83.83˚.



(e) Radiation pattern

Figure 4. 3 Simulation results of a designed single MSPA Antenna after tuning

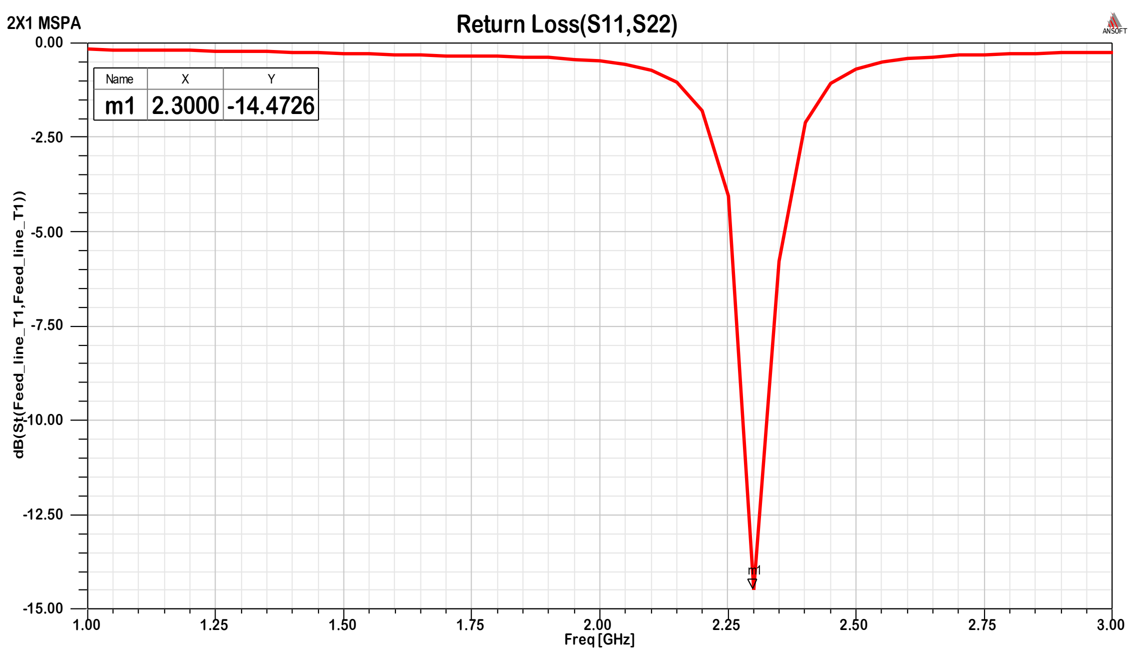
4.5. 2×1 Microstrip patch antenna array

The designed MPA is arranged as a 2×1 antenna array separated by a distance of λ/4. First, the performance of the conventional antenna array is evaluated without using DGS & FSS. Second, the mutual coupling reduction obtained by using DGS and FSS is presented.

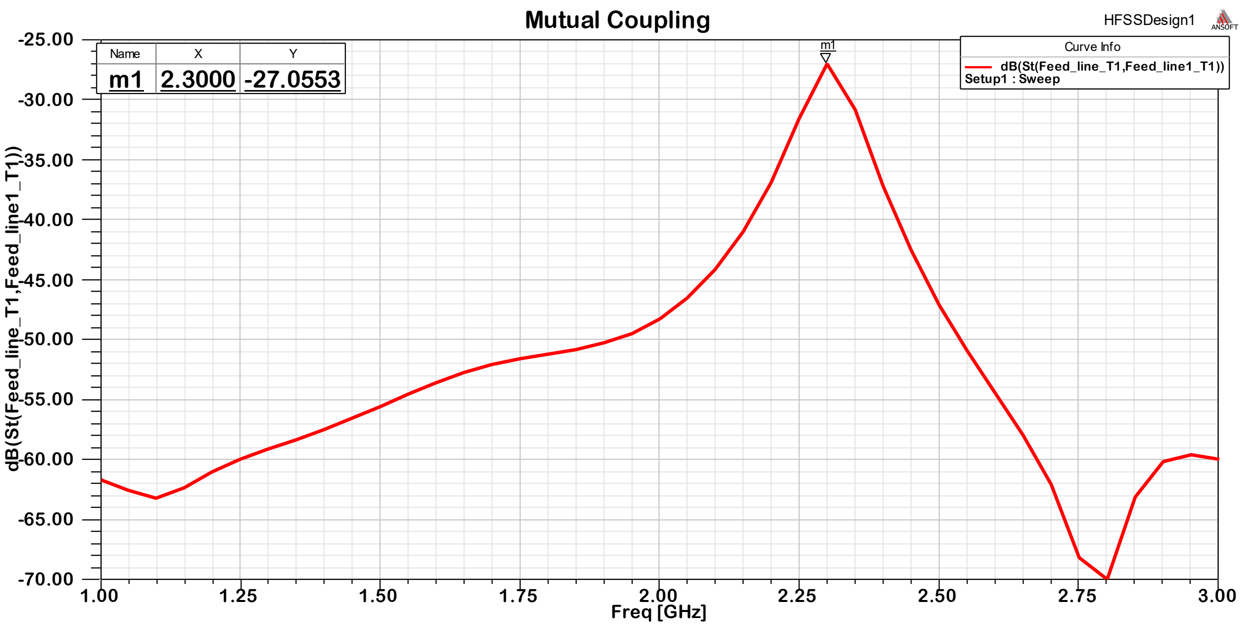
4.5.1. Conventional 2×1 MPA array

The designed MPA discussed in section 4.2 is arranged as a conventional 2×1 antenna array and its simulation result are shown in Figure 4.4. The distance of separation between the microstrip patch antenna elements is λ/4. Return loss, coupling loss, VSWR, gain, directivity and radiation pattern are shown in Figure 4.4.

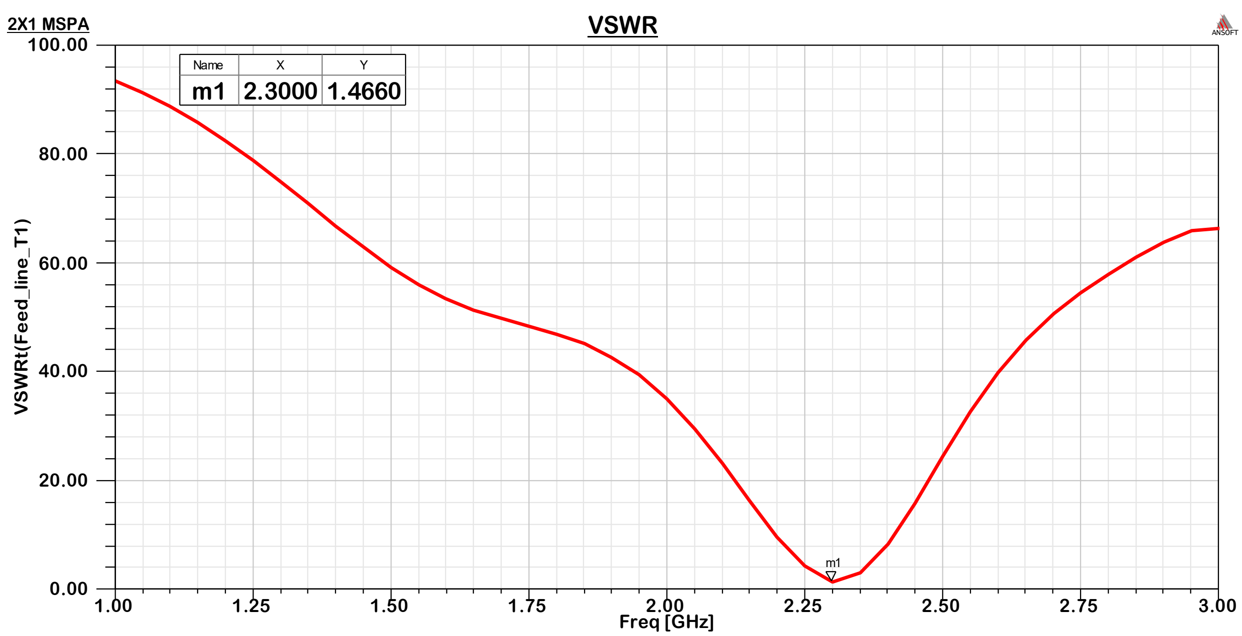
These results will be used as a reference for later simulations to analyze the reduction in mutual coupling.



(a) Return Loss of2×1 rectangular MSPA

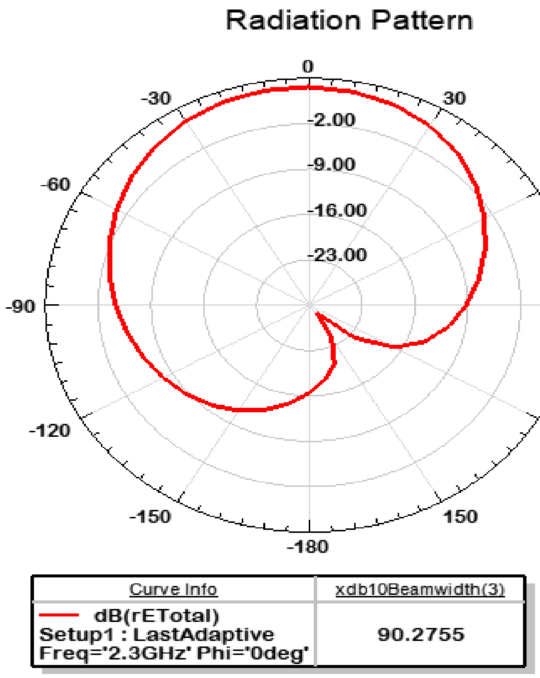


(b) Coupling Loss of2×1 rectangular MSPA



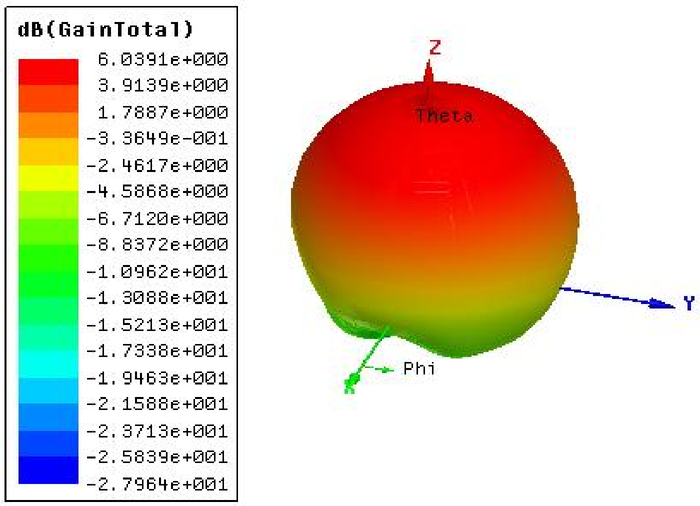
(c) VSWR of2×1 rectangular MSPA

The VSWR helps us to measure the amount of power that has been transmitted through the feed line. The value of VSWR must be in between 1&2.

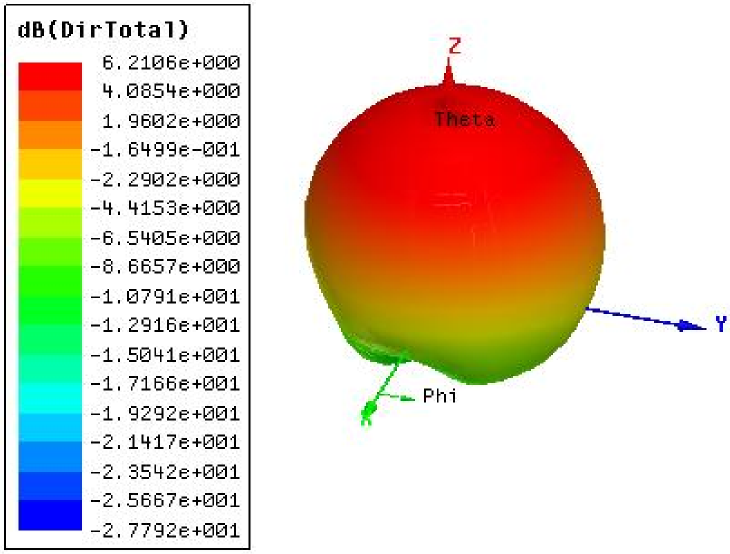


(d) Radiation Pattern of 2×1 rectangular MSPA

Gain and Directivity: - The gain and directivity plots are shown in Figure 4.4 (e) & (f) respectively. It is observed that the gain is 6.04dB and the directivity is 6.21dB.



(e) Gain of 2×1 rectangular MSPA



(f) Directivity of 2×1 rectangular MSPA

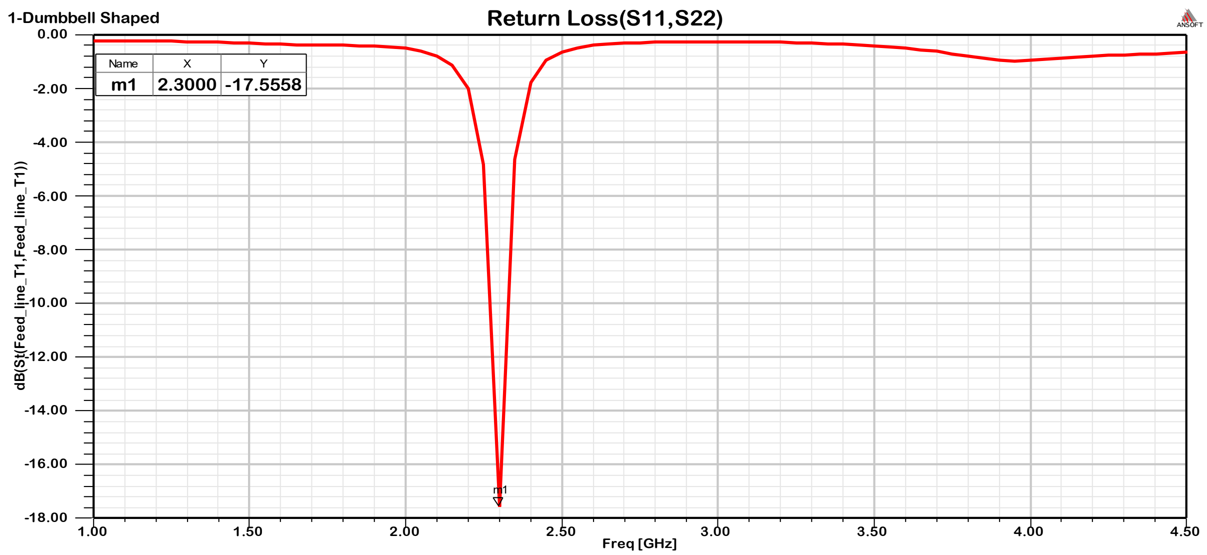
Figure 4. 4 Simulation results for 2 X1 MSPA Array

4.6. Array with DGS

In this section DGS dumbbell shape performance will be evaluated to identify which provide better performance in terms of mutual coupling reduction. The performance evaluation of shapes of DGS on antenna array performance is evaluated in terms of return loss, bandwidth, VSWR, mutual coupling, gain and directivity and radiation efficiency.

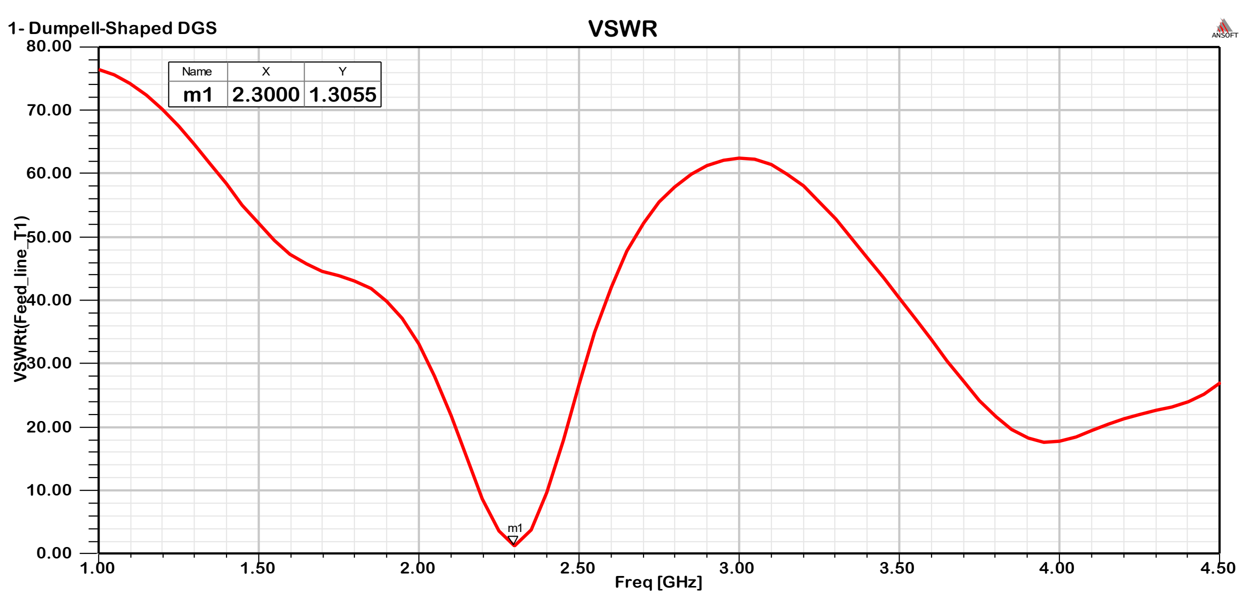
4.6.1. 2×1 MPA array with 1-square head dumbbell DGS between antenna elements

In between the designed 2×1 MPA array, a single dumbbell shape DGS is placed in between the patches, and its influence on antenna performance is evaluated are shown in Figure 4.5.

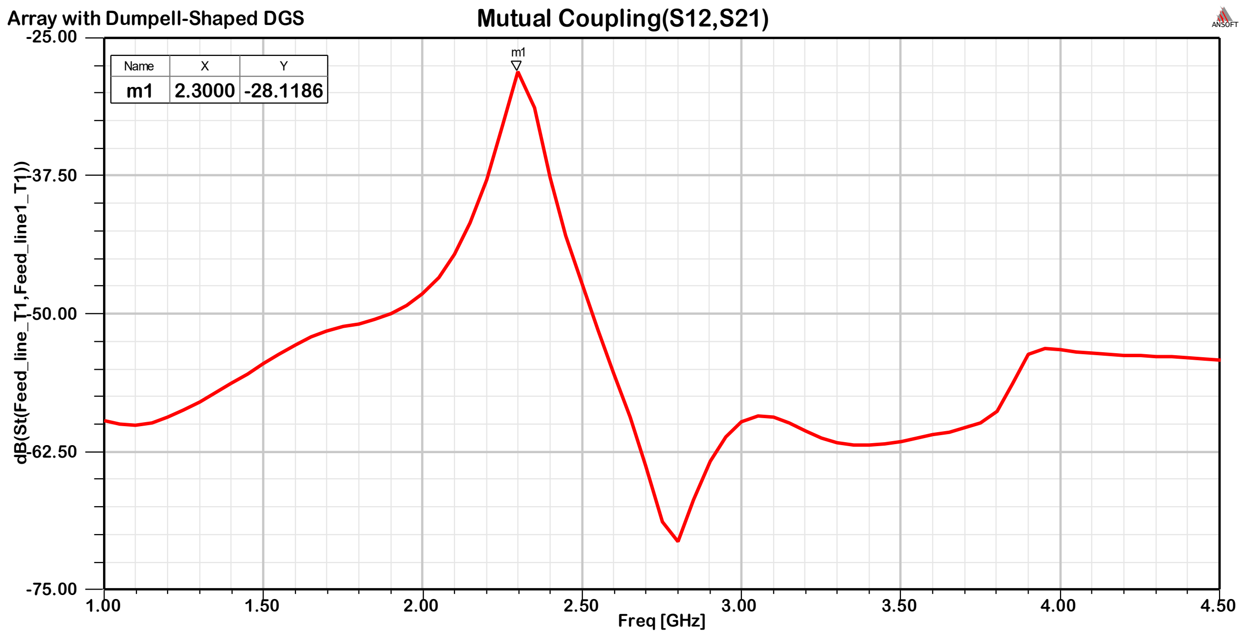


(a)Return loss (S11, S22) of 2×1 rectangular MPA array with single dumbbell DGS in between elements

Return Loss &Mutual coupling: - Figure 4.5 shows the return loss of designed patch antenna with one dumbbell shaped DGS (a).The return loss is increased from -13.15dB to -17.56dB with a bandwidth of 58.7MHz, indicating that the antenna performs well at the designed frequency with a radiation efficiency of 96.08 percent. Furthermore, the mutual coupling at 2.3GHz is reduced to -28.12dB from -27.83dB without DGS, indicating that the antenna performs well at the designed frequency with a radiation efficiency of 96.08 percent.

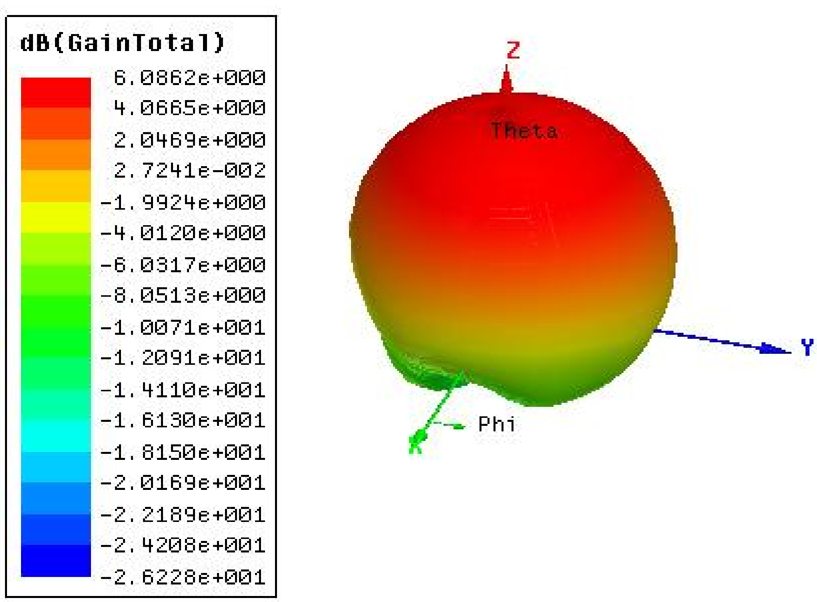


(b) VSWR of 2×1 rectangular MPA array with single dumbbell DGS in between elements

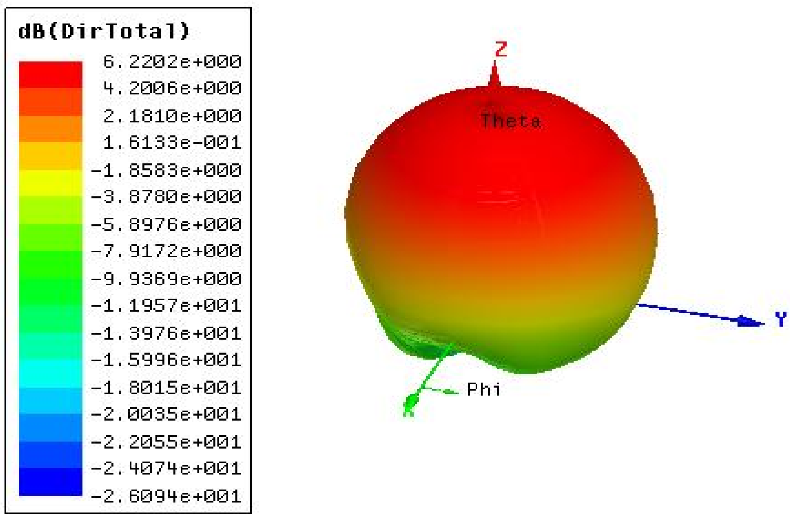


(c) Mutual coupling effect (S12, S21) of 2×1 rectangular MPA array with single dumbbell DGS in between element.

Gain and Directivity: The gain and directivity plots are shown in Figure 4.5 (d) & (e) respectively. It is observed that the gain is 6.086dB and directivity is 6.22dB

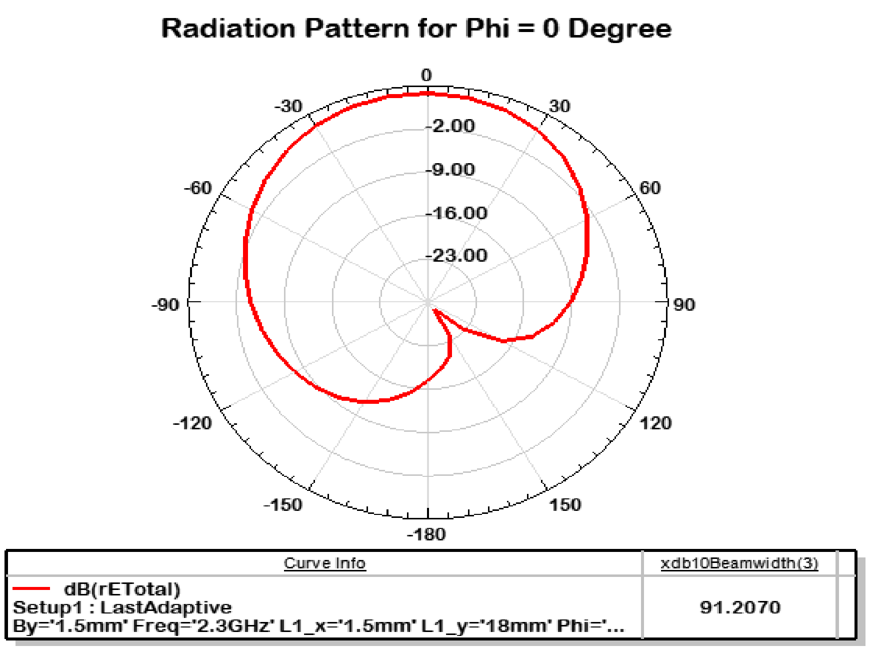


(d) Gain of 2×1 rectangular MSPA array with single dumbbell DGS



(e) Directivity of 2×1 rectangular MSPA array with single dumbbell DGS

Radiation pattern: - It is seen that the radiation is unidirectional broadside with BW of $90.88^0$and radiation efficiency is 96.08%.



(f) Radiation Pattern of 2×1 rectangular MPA array with single dumbbell DGS

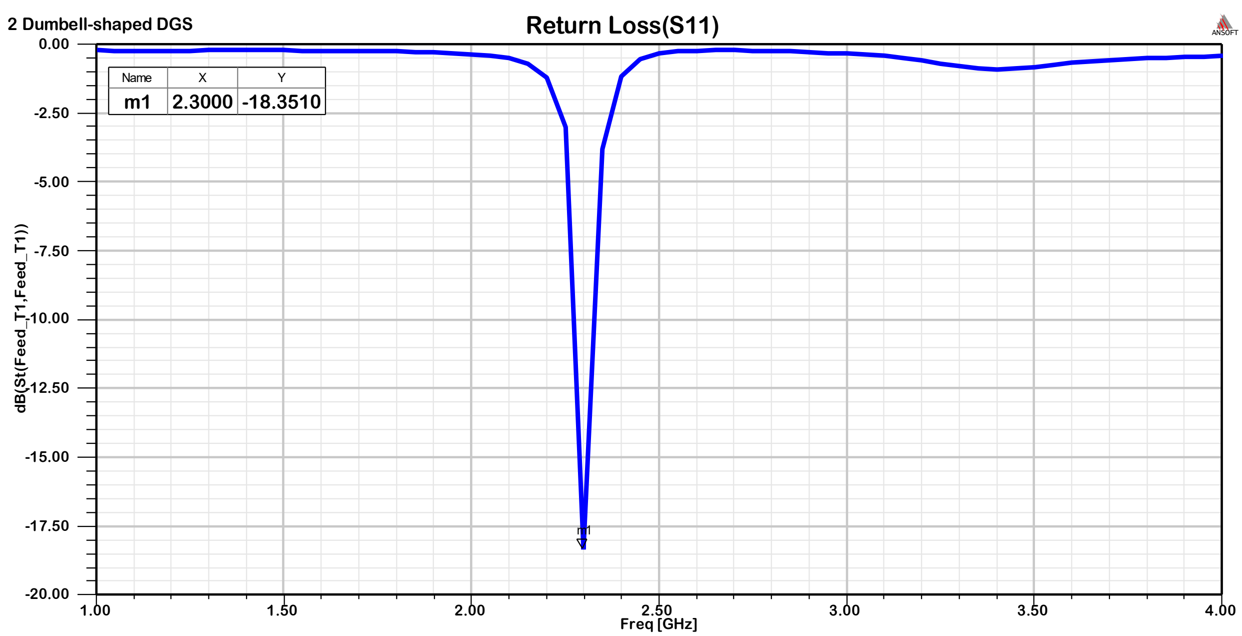
Figure 4. 5 Simulation results of 2X1 MSPA Array with single dumbbell shaped DGS in between elements

4.6.2. 2×1 MPA array with 2-dumbbell DGS between antenna elements

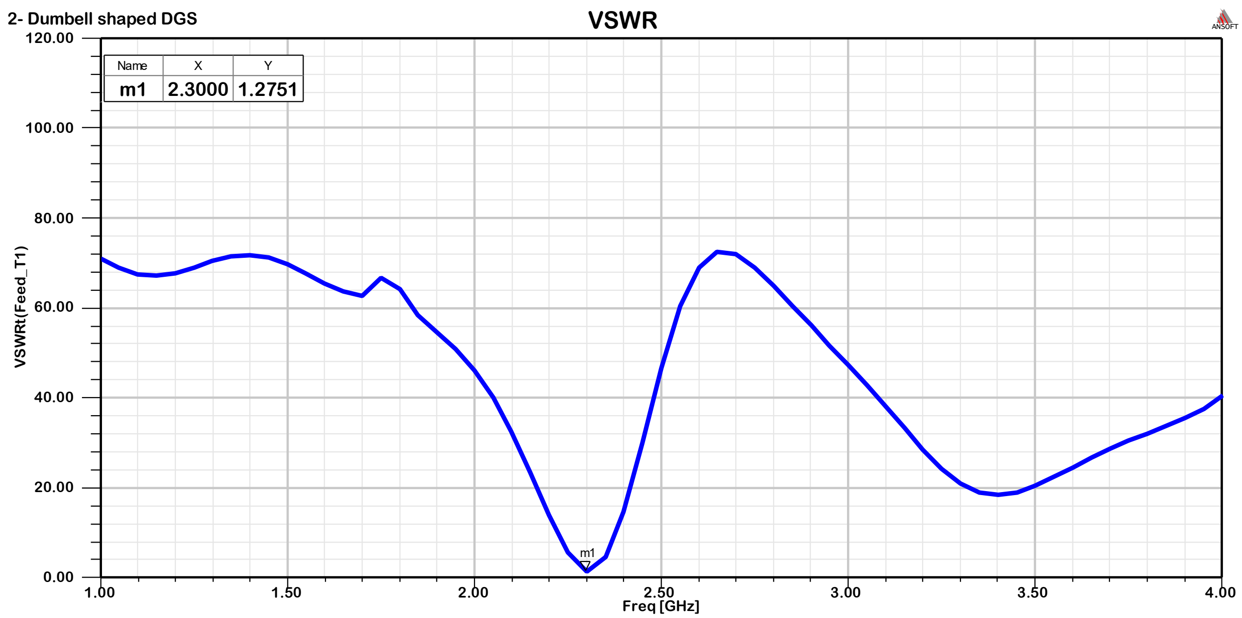
To understand the influence of number of DGS elements on mutual coupling reduction, DGS elements are increased from one to two and placed in between antenna elements as shown in Figure 3.7. The antenna performance is evaluated using the following metrics.

Return loss & Mutual Coupling: The return loss and mutual coupling effect of 2x1 arrays with 2-dumbbell shaped DGS was measured. The simulation showed that the antenna has a returning loss -18.35dB at operating frequency of 2.3GHz and mutual coupling effect is equal to -31.5123dB, as shown below.

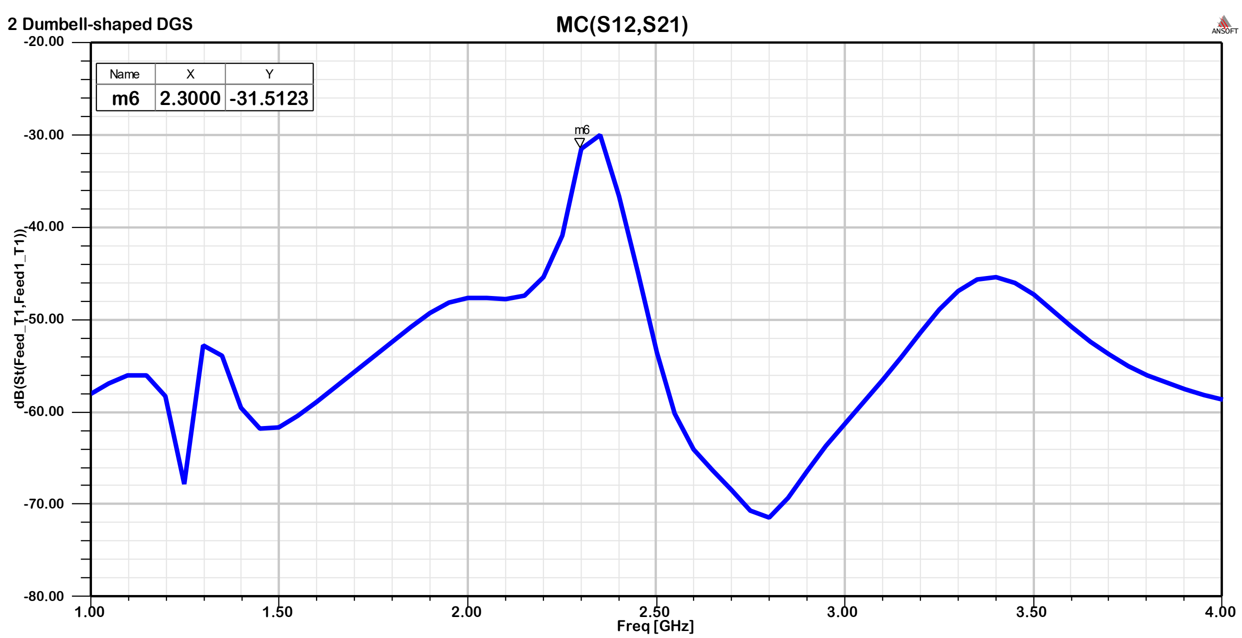
When comparing it to one element of DGS between antenna elements, the two-element uniform periodic DGS provide a better signal from the source to be more effectively delivered to the antenna.



(a)Return loss (S11, S22) of 2×1 MPA array with 2-dumpbell shaped DGS in between elements

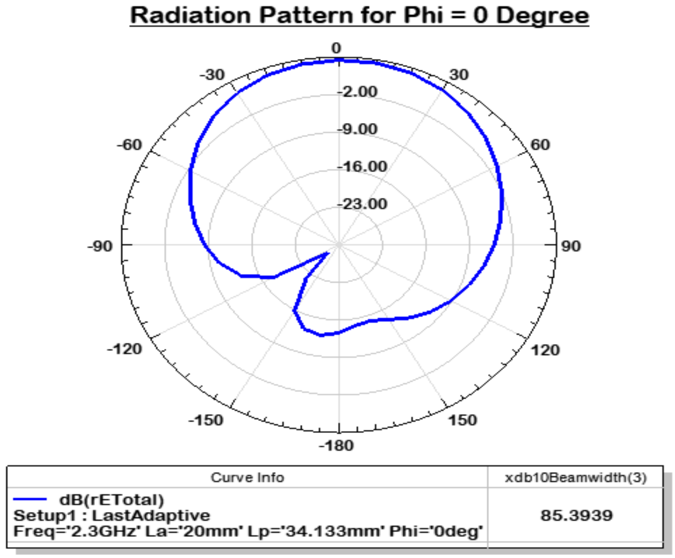


(b)VSWRof 2×1 MPA array with 2-dumpbell shaped DGS in between elements



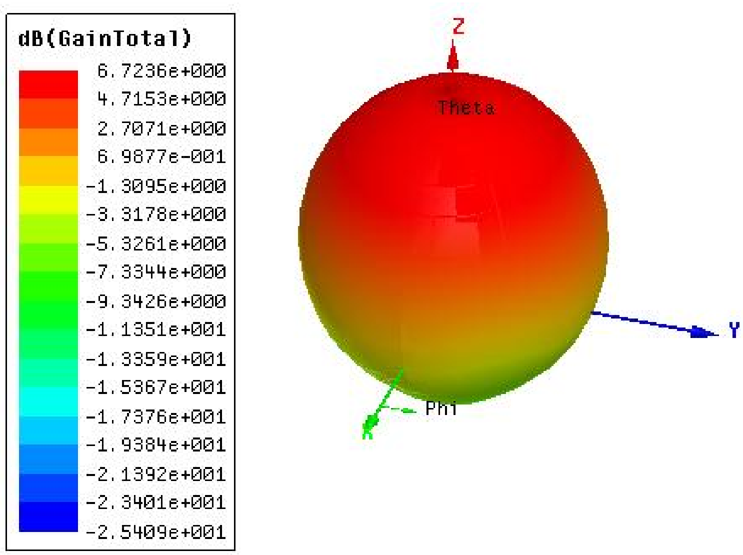
(c) Mutual coupling effect (S12, S21) of 2×1 rectangular MPA array with 2- dumbbell DGS in between element.

Radiation pattern: The radiation pattern plot of 2-dumbbells shaped DGS between antenna elements is shown in Figure 4.6 (d). It is seen that the radiation pattern plot at broadside unidirectional radiation pattern with85.39^0 and with 96.69% radiation efficiency.

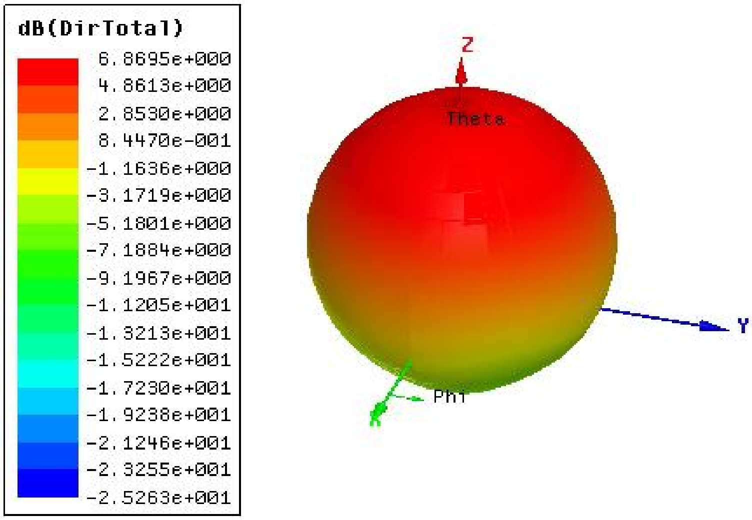


(d) Radiation Pattern of 2×1 rectangular MPA array with 2-dumbbell shaped DGS

Gain & Directivity: The gain and directivity plots for 2- element non-uniform periodic DGS between the antenna elements is shown in Figures 4.6 (e) & (f) respectively. The gain at 2.3GHz is 6.723dB and directivity of 6.869dB. As compared with the conventional 2×1 MPA array with one dumbbell shaped DGS a 0.673dB improvement in gain and 0.653dB in directivity is obtained.



(e) Gain of 2×1 rectangular MSPA array with 2-dumpbell shaped DGS



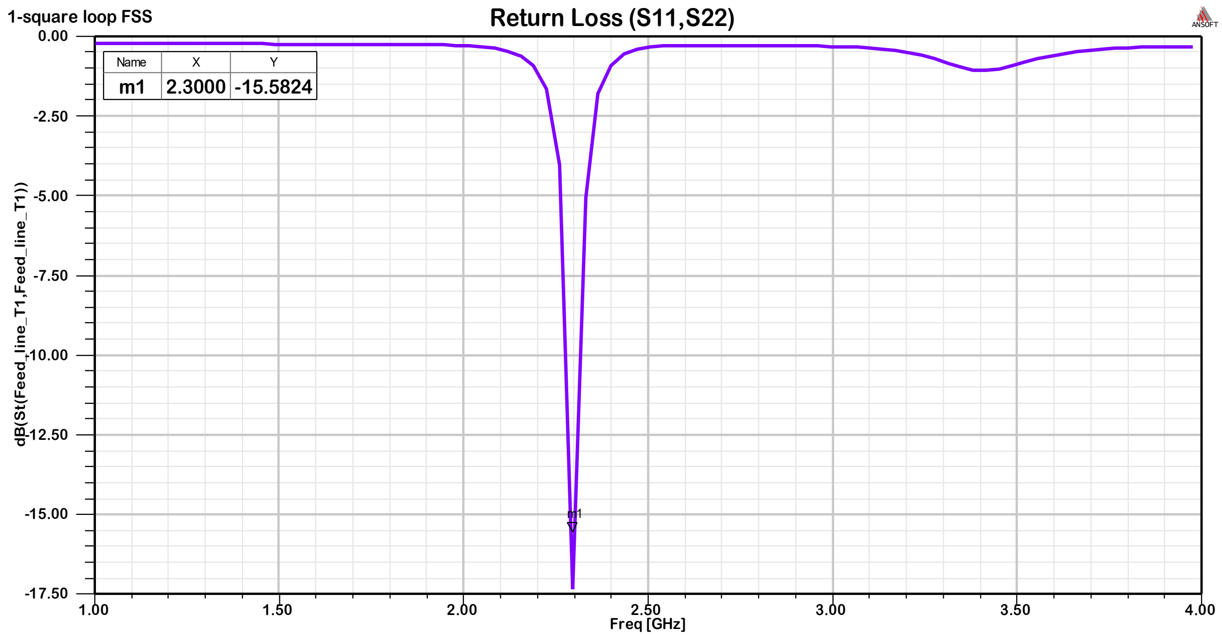
(f) Directivity of 2×1 rectangular MSPA array with 2-dumbbell shaped DGS

Figure 4. 6 Simulation results of 2×1 MPA array with 2-dumpbell shaped DGS in between elements

4.7. Array with FSS

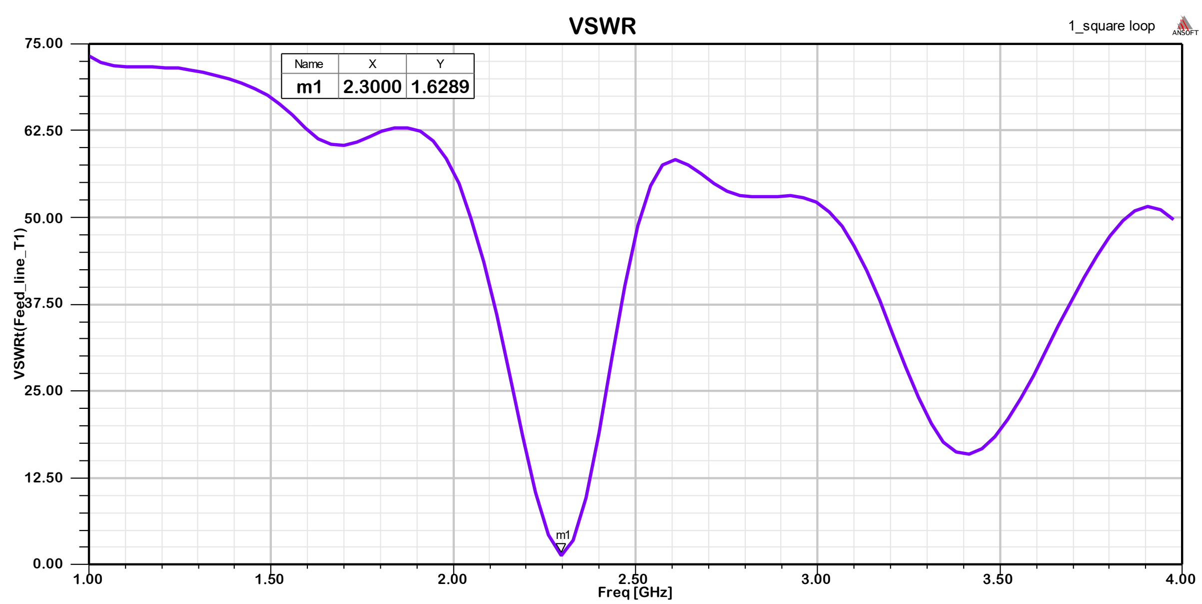
4.7.1. 2×1 MPA array with one –square loop shaped FSS

To improve the performance much better and to minimize mutual coupling, square loop shaped FSS is incorporated on the ground plane of the design MSPA and the performance is evaluated using return loss, VSWR, bandwidth, efficiency, gain and directivity.

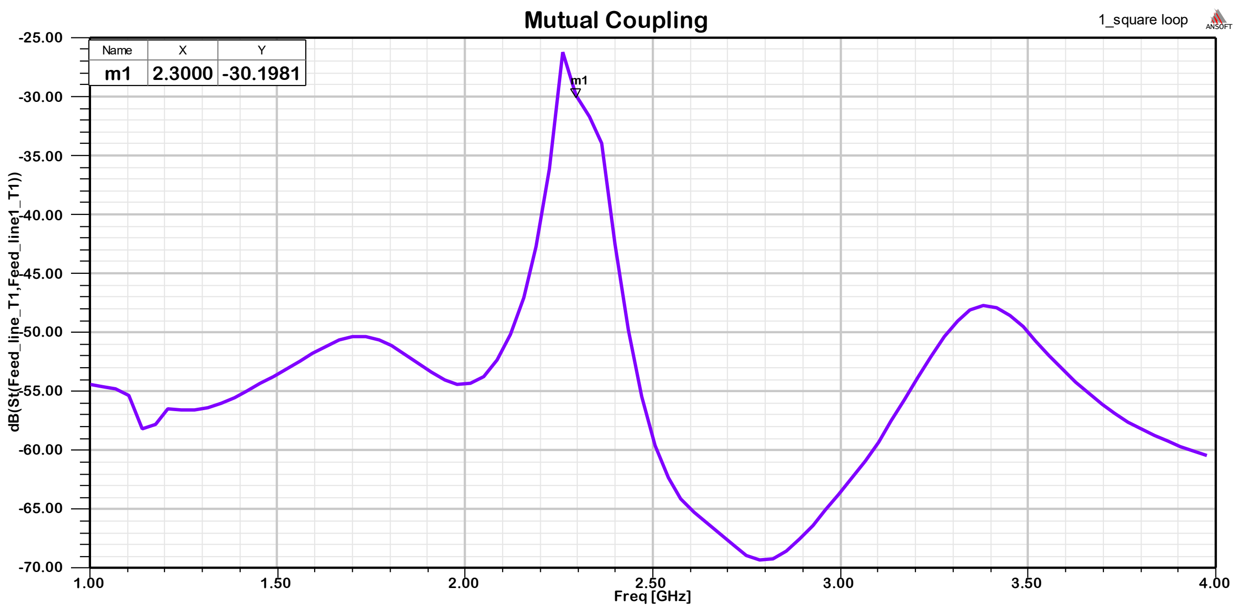


(a) Return Loss (S11,S22) of 2×1 MPA array with one square loop shaped FSS

Return Loss & Mutual coupling: in Figure4.7 (a) & (c) the simulation result of the return loss for one square loop shaped FSS is found -15.58dB and after integrating with one square loop the mutual coupling is -30.19dB with bandwidth of 40.1MHz.

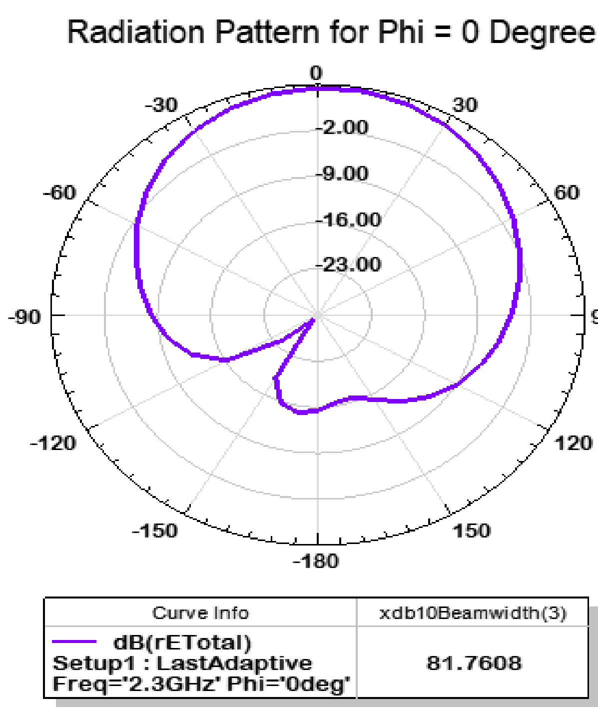


(b) VSWR of 2×1 MPA array with one square loop shaped FSS

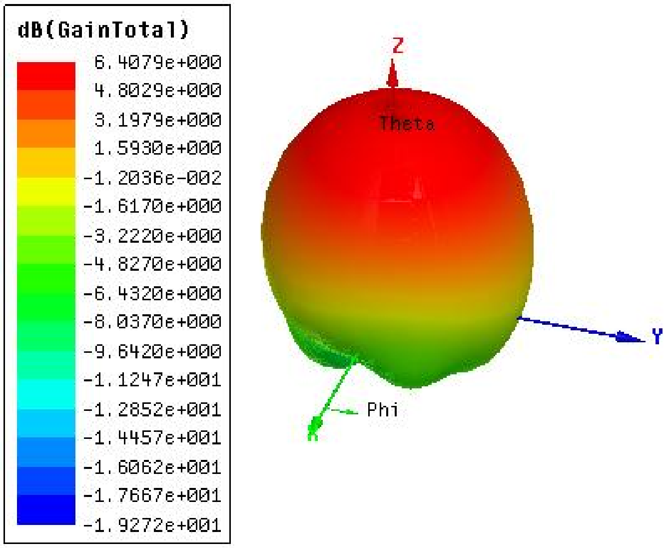


(c) Mutual coupling of2×1 MPA array with one square loop shaped FSS

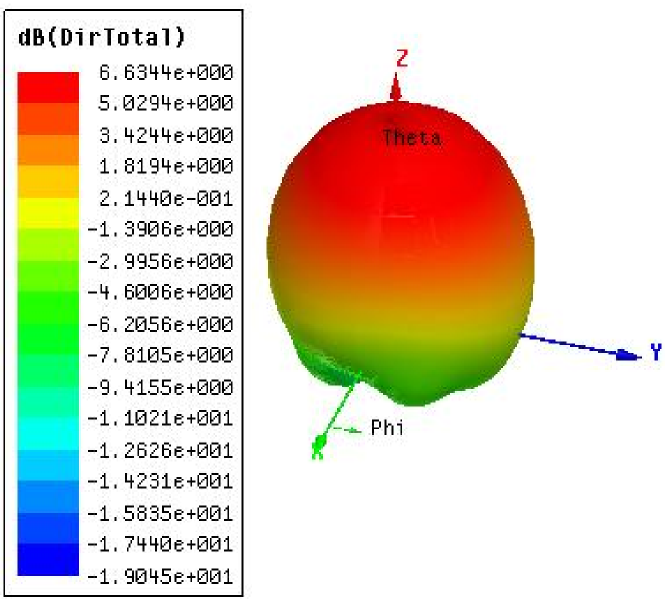
Radiation Pattern: From the radiation pattern diagram of figure 4.7 (d) the beam width of the designed antenna is 81.76^0 with radiation efficiency of 96.08%.



(d) Radiation pattern of 2×1 MPA array with one square loopshaped FSS



(e) Gain of 2×1 MPA array with one square loop shaped FSS



(f) Directivity of 2×1 MPA array with one square loop shaped FSS

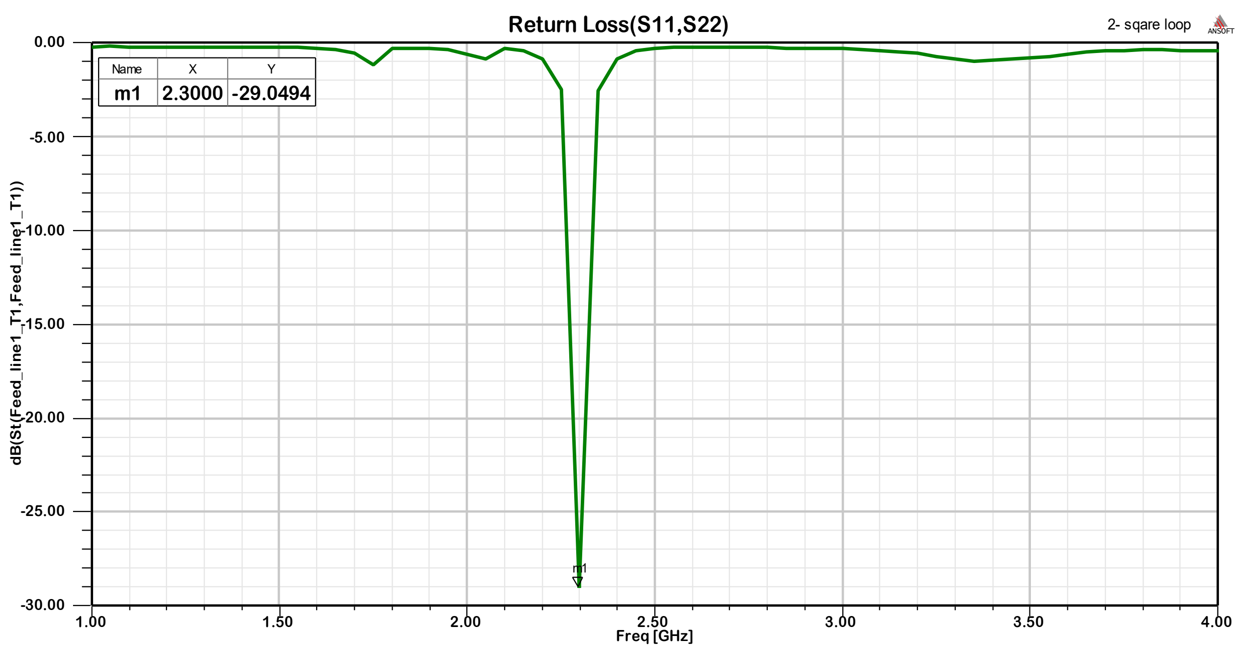
Figure 4. 7 Simulation results of 2x1 MSPA array with one square loop shaped FSS

4.7.2. 2×1 MPA array with two Square Loop shaped FSS

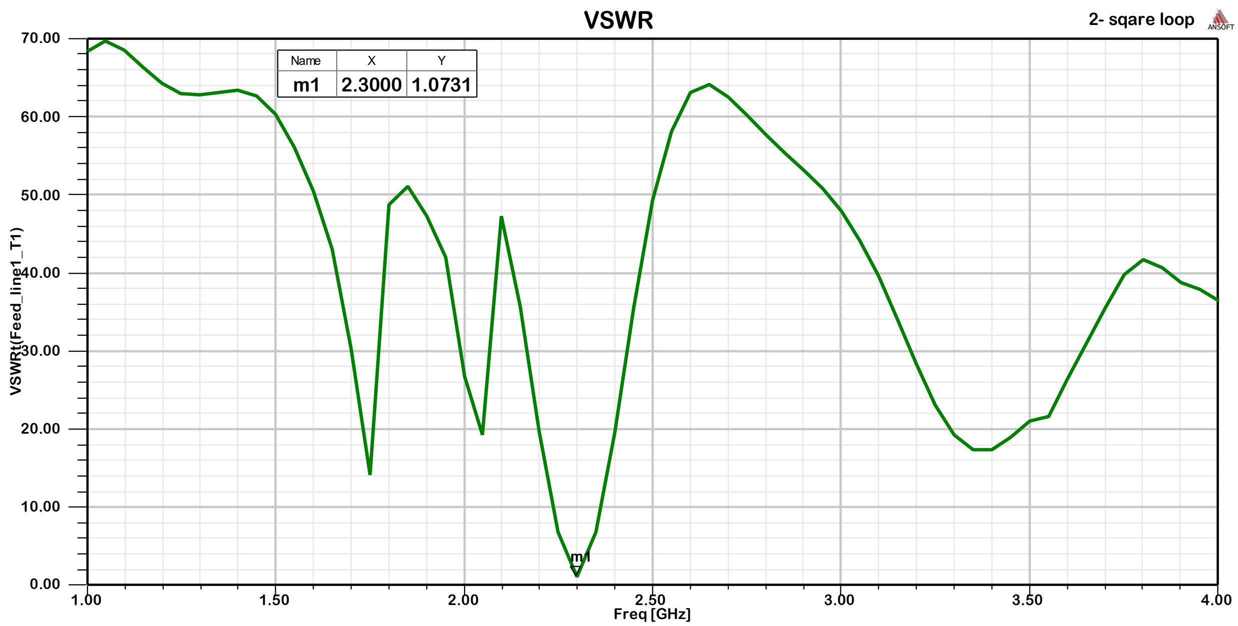
The simulation results of a 2×1array with two square loop FSS at the resonant frequency of 2.3GHz is shown in Figure 4.8. For the designed antenna the return loss, bandwidth, VSWR, gain, directivity and radiation pattern has been evaluated.

The effect of two FSS between antenna elements on mutual coupling effect is shown in Figure 4.8 (c) and it is observed that the mutual coupling at 2.3GHz is reduced to -35.886dB from -30.198dB using a single square loop FSS.

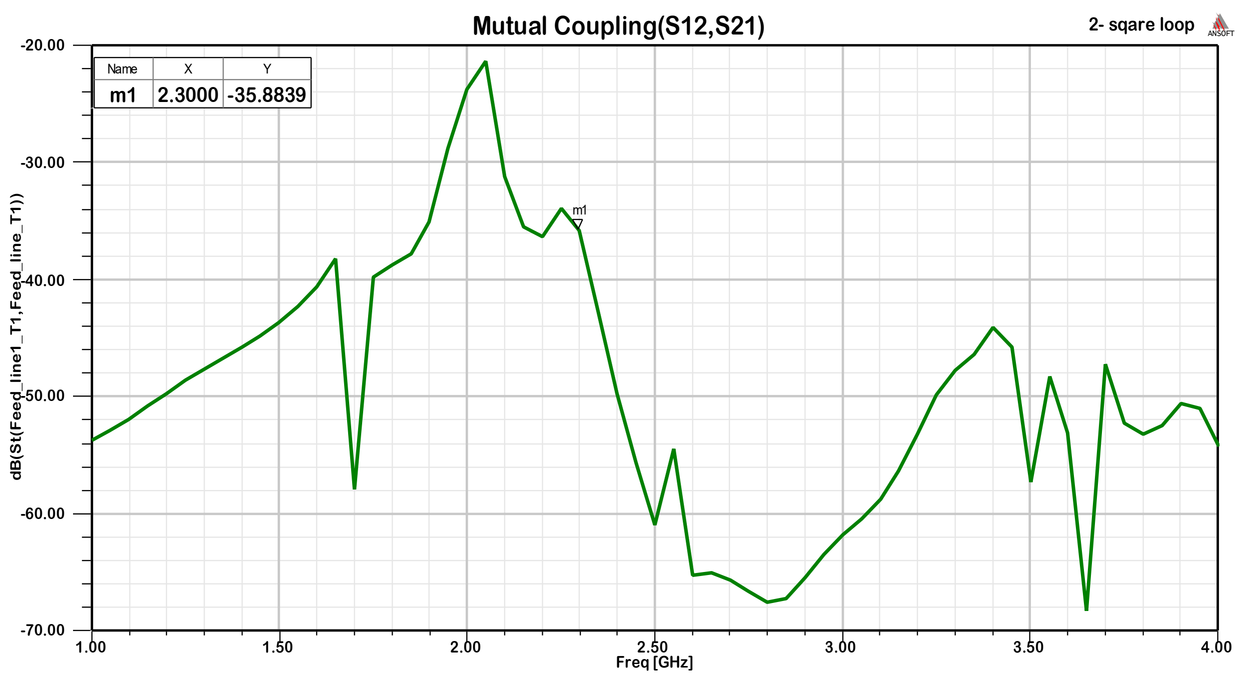
Radiation pattern: The radiation pattern plot shown in figure 4.8(d) exhibits unidirectional broadside radiation with BW of 89.6602^0 and radiation efficiency is 95.75%.



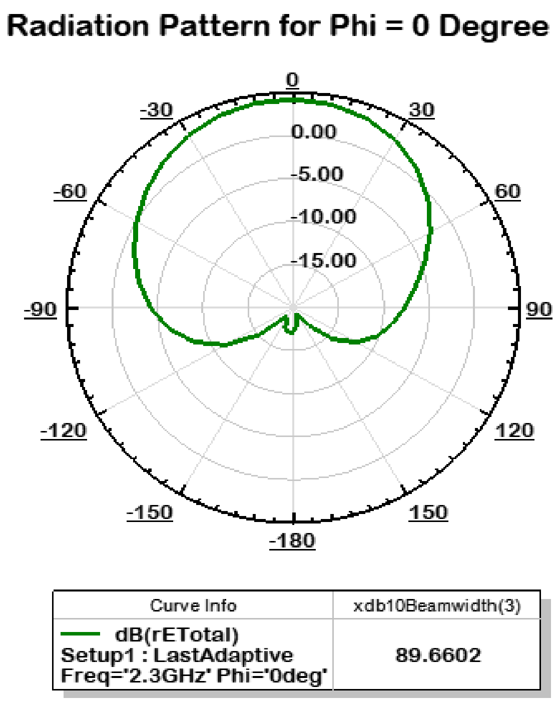
(a) Return Loss of 2x1 MSPA array with two square loopshaped FSS



(b) VSWR of 2×1 MPA array with two square loop shaped FSS

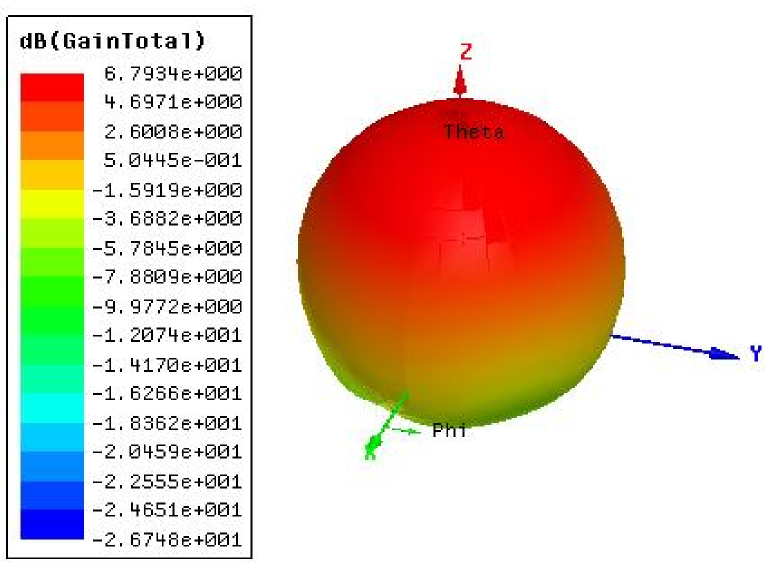


(c) Mutual coupling of2×1 MPA array with two square loopshaped FSS

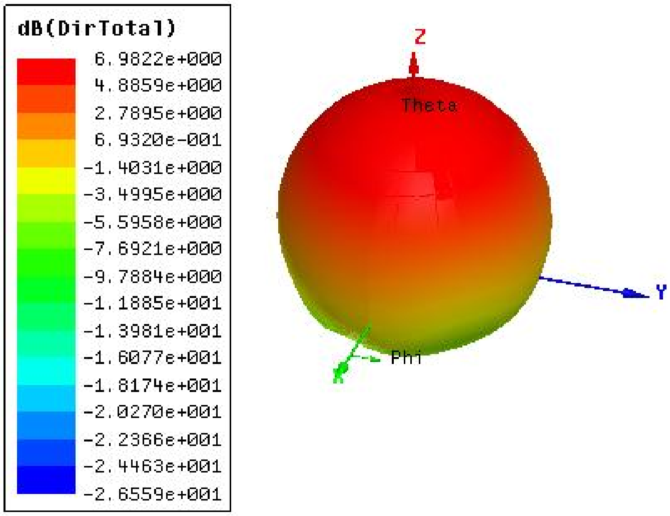


(d) Radiation pattern of 2×1 MPA array with two square loop shaped FSS

Gain & Directivity: The gain and directivity plots shown in Figure4.8 (e) & (f) represents that the gain is 6.7934dB for two square loop FSS between antenna elements and the directivity is 6.9822dB with bandwidth of 71.8MHz.



(e) Gain of 2×1 MPA array with two square loopshaped FSS



(f) Directivity of 2×1 MPA array with two square loop shaped FSS

Figure 4. 8 Results of 2x1 MSPA array with two square loop shaped FSS

The results of the proposed antenna and their simulation result are summarized in the following table.

	Return Loss (dB)	**VSWR**	**Mutual Coupling**	**Bandwidth (MHz)**	**Gain (dB)**	**Directivity (dB)**	**Efficiency (%)**
2 ×1 MSPA	-14.47	1.517	-27.056	46.5	6.04	6.21	94.12
One- Dumbbell Shaped DGS	-17.56	1.306	-28.118	58.6	6.080	6.216	96.08
Two-Dumbbell Shaped DGS	-18.35	1.275	-31.512	55.8	6.724	6.87	96.69
One- Square Loop FSS	-15.582	1.629	-30.198	40.1	6.402	6.634	95.26
Two- Square loop FSS	-29.049	1.073	-35.886	71.8	6.793	6.982	95.75

Table 4. 1 Performance comparison of designed antennas

As it is observed from Table 4.1 using two square loops shaped FSS between antenna array elements have better performance in terms of return loss, gain, VSWR and directivity with enhanced bandwidth (22.32%) compared with two square head dumbbell shaped DGS.

Chapter-Five

Conclusion and Future Work

5.1. Conclusion

The design simulation and analysis of aperture coupled micro strip antenna array using DGS and FSS has been discussed. A micro strip antenna which operates in the S-band frequency range has been designed with operating frequency at 2.3GHz. To measure the performance of the designed antenna, different antenna parameters have been used like return loss, VSWR, gain and bandwidth.

In this work, the aperture coupled MSPA has a return loss of -14.47dB with bandwidth of 46.5MHz at a resonant frequency of 2.3 GHz. The corresponding value for VSWR is 1.46 and gain of 6.04dB with 94.12% antenna efficiency. Following 2×1 micro strip antenna array with and without single and two square head dumbbell DGS and square loop FSS have been studied. Simulation results reflected that integrating DGS between two antennas due to the mutual coupling effect like gain, radiation efficiency and bandwidth are improved in some degree but is not satisfactory.

One of the aim of this thesis work is to use square loop shaped FSS which is chosen after comparing with square head dumbbell shaped DGS for showing a good performance result on antenna parameter to reduce mutual coupling between antenna array elements and get enhanced bandwidth. To minimize the mutual coupling between antenna elements first a single square head dumbbell shaped DGS on a ground plane has been integrated with an inter-element spacing of $\lambda/4$. From the simulation result, an antenna array integrated with square loop shaped FSS gives -35.886dB (32.636%) mutual coupling reduction when compared with an antenna array square head dumbbell shaped DGS. Beside these other parameters like VSWR, return loss, gain and efficiency are also improved. This work indicates that mutual coupling reduction can be achieved by using square loop shaped FSS in the expense of an increased back lobe radiation that may cause undesired multipath signal propagation and interference in RF systems.

At last, the proposed FSS can be used as a technique to reduce mutual coupling effect between antenna arrays at S-band frequency range. This S-band is used by airport surveillance radar for air traffic control, cordless phones, weather radar, surface ship radar and some communications satellites.

5.2. Recommendation for Future Work

The recommendations for future work are the following

- Use of slot, DGS and FSS of different geometrical configuration and their impact on mutual coupling reduction may be considered.
- Considering the combination of FSS & DGS by implementing on MPA array can be a wide scope for future studies.

References

[1] R. Garg, P. Bartia, I. Bahl, A. Ittipiboon.S, “Microstrip Antenna Design Handbook,” 2001.

[2] Kumar Ghosh, C. and Kumar Parui, “Design, Analysis and Optimization of A Slotted Microstrip Patch Antenna Array at Frequency 5.25 GHz for WLAN-SDMA System,” *International Journal on Electrical Engineering and Informatics*, 2010,2(2),pp.102- 112.

[3] Chen, H. and Tao, “Performance Improvement of a U-Slot Patch Antenna Using a Dual-Band Frequency Selective Surface with Modified Jerusalem Cross Elements,”*IEEE Transactions on Antennas and Propagation, 59*(9),Y. (2011), pp.3482-3486.

[4] H. S. Farahani, M. Veysi, M. Kamyab, and A. Tadjalli, “Mutual coupling reduction in patch antenna arrays using a UC-EBG superstrate,” *Antennas and Wireless Propagation Letters*, 2010, vol. 9, 57–59.

[5] Hamideh Kondori1, Mohammad Ali Mansouri-Birjandi2, Saeed Tavakoli3 “Reducing Mutual Coupling in Microstrip Array Antenna Using Metamaterial Spiral Resonator” *IJCSI International Journal of Computer Science Issues*,May 2012 Vol, 9, Issue 3, No 1, ISSN (Online): 1694-0814

[6] S. Meliksah Yayan, “Mutual Coupling Reduction in Microstrip Antennas Using Defected Ground Structures,” University of Bilkent, 2012.

[7] Das.P,Saha.S, “Design and analysis of frequency selective surface integrated microstrip patch antenna,”*International Conference on Opto-Electronics and Applied Optics (Optronix),* et al. (2017).

[8]. Asaadi.M, Afifi.I, and Sebak.A “High Gain and Wideband High Dense Dielectric Patch Antenna Using FSS Superstrate for Millimeter-Wave Applications,”*IEEE Access*,2018, 6, pp.43-50.

[9] C. A. Balanis, "Antenna Theory Analysis and Design", *John Wiley & Sons Inc.publication,*4th Edition, Hoboken, New Jersey: 2010.

[10] D. M. Pozar, “Microwave Engineering,” *John Wiley & Sons Inc*, 4th edition, 2012,

[11]. Alexander Kuchar, “Aperture Coupled Microstrip Patch Antenna Array”, March 15, 1996.

[12] L. I. William and Y. Rahmat-Samii, “Novel bi-polar planar near field measurement scanner at UCLA,” in *Int. IEEE/AP-S Symp. Dig.*, London, Ontario, Canada: June 1991.

[13] K. Carver and J. Mink, “Microstrip antenna technology,” *I EEE Trans. Antennas Propag.*, Jan. 1981, vol. 29, no. 1, pp. 2–24.

[14]. D. M. Pozar, “Microstrip Antennas,” *Proc. IEEE*, January 1992, Vol. 80, No. 1, pp. 79–81.

[15] G. Singh and J. Singh, "Comparative analysis of microstrip patch antenna with different feeding techniques," *IJCA,*2012,vol. 2, no. 7, pp. 18-22.

[16] R. Poisel, “Antenna system and electronic warfare applications,” *Artech house,*Canton street norwood: 2001

[17] C. A. Balanis, “Antenna Theory (Analysis and Design),”*John Wiley & Sons*, 2nd Edition.

[18] G. Kumar and K. P. Ray, “Broadband microstrip antennas,” *Artech house Inc.,*Norwood: 2003.

[19] D. M. Pozar, “Microwave Engineering,” *John Wiley & Sons, Inc*, 4th edition, 2012.

[20] A. Habashi, J. Nourinia, and C. Ghobadi, “Mutual coupling reduction between very closely spaced patch antennas using low-profile folded split-ring resonators (FSRRs),”*IEEE Antennas and Wireless Propagation Letters*, Oct. 2011, vol. 10, pp. 862–865,.

[21] L. H. Weng, Y.-C. Guo, X.-W. Shi, and X.-Q. Chen, “An Overview on Defected Ground Structure,” *Progress in Electromagnetics Research B*,2008, vol. 7, pp. 173–189.

[22] Sarabandi.K, & Behdad.N, “A Frequency Selective Surface with Miniaturized Elements,” *IEEE Transactions on Antennas and Propagation,* 2007,55(5),pp.1239-1245.

[23] J.T. Murugan, T.R.S. Kumar, P. Salil and C. Venkatesh, “Dual Frequency Selective Transparent Front Doors for Microwave Oven with different opening areas,”*PIER letters*, 2015, Vol.52, 11-16.

[24] Norshahida Bint Mohd saidi, “Design of Dual Band Frequency Selective Surface,” Malaysia Melaka : University Teknikal, 2015.

[25] B.A. Munk, “Frequency Selective Surfaces,” *Theory and Design*, Wiley, New York: 2000