Comprehensive Journal of Science
Volume (10), Issue (38), (Dec, 2025)
ISSN: 3014-6266

مجلة العلوم الشاملة
المجلد (10) العدد 38 ديسمبر 2025
ردمد: 3014-6266

Design of 2 Elements Rectangular Microstrip Patch Antenna for 2.40 GHz Using HFSS

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تاريخ الاستلام:2025/8/13 –تاريخ المراجعة: 2025/9/14 – تاريخ القبول: 2025/11/14 – تاريخ للنشر : 12/6/ 2025

Abstract

In this paper, aims to design and simulate a rectangular microstrip patch antenna with a two-element array operating at 2.4 GHz using HFSS software. Microstrip patch antennas are essential components in wireless communication systems, known for their small size and high efficiency but suffer from limited bandwidth and low gain. The study focuses on improving the antenna's performance by converting it into a two-element array to enhance gain and improve radiation patterns.

The antenna design was simulated using HFSS software, evaluating key parameters such as radiation patterns, gain, and return loss. The results showed that the two-element array provides significant improvements over a single patch antenna, particularly in terms of gain and radiation efficiency. The research recommends future studies on larger array designs or different feeding techniques for further performance enhancement..

Keywords — High Frequency Structure Simulator (HFSS), The Internet of Things (IOT) The Industrial, Scientific and Medical (ISM) .

Introduction

Recently, there has been a lot of interest in the shrinking and integration of various telecommunication equipment functions. These devices encompass mobile communication systems, smart phones, tablets, wireless Internet devices, and other everyday gadgets.

The components of the mobile device must be small and able to operate on several frequencies and functions in order to meet this criteria. One such component is the antenna, which has to fit inside the device's body, be smaller than the gadget, and be able to function at several mobile communication system frequencies that are used by a single, so-called smart device.

There are several reasons why microstrip antennas are so popular. First off, microstrip antennas are ideal for integrated microwave and millimeter-wave circuit components because of their straightforward construction and compatibility with printed circuit boards. They can be produced affordably through the use of a straightforward lithographic process. Second, compared to conventional mm-wave designs, they are lighter and have a lower profile, which makes them more appropriate for mobile environments.

However printed antennas on high-permittivity substrates are well documented for their exited surface wave, which lead to narrow bandwidth, limited radiation efficiency, low gain, and undesired coupling between the various elements in array configuration. Which limits their application in broadband modules, and they cannot be applied at millimeter wave frequencies compact size and high performance can be achieved by integrating the patch antenna on the low dielectric constant material with thick substrate.

Printed antennas are widely employed as single elements and in arrays. Microstrip antennas are ideal for arrays due to their low profile, light weight, conformability, and low production cost.

Planar microstrip array antennas are widely used in radar and telecommunication systems. Antenna arrays are used to increase directivity and gain, scan an antenna's beam, and improve a variety of other functions that would be difficult to achieve with a single-element antenna alone.

The primary drawback of microstrip is that it can only radiate efficiently across a restricted band of frequencies and cannot operate at the high power levels of coaxial lines, waveguides, or even strip lines. Now with new inventions and the developing technology the use of wireless modernized devices is increasing day by day. Antennas are the most important part of any wireless devices which provide the wireless transmission and reception of electromagnetic signals and play an essential role in modern telecommunications.

The newest wireless technologies, like the Internet of Things (IOT) and 5G networks, are the means of bringing in a new era of sophisticated connection. Antennas must adapt and meet the ever-increasing needs as demand for faster data rates, dependable communication lines, and compact high-performance transceivers surges.

Modern antennas shall have small size, low-profile and high bandwidth, while the radiation pattern and gain should also be sufficient. Because of its low profile, low cost of production, light weight, and several advantages over conventional antennas, the microstrip patch antenna is frequently employed in these devices. For wireless devices, an antenna's compact size, durability, and affordability are essential.

Among their many uses, microstrip antennas are employed to synthesize patterns that are impossible to accomplish with a single element. They are also utilized to boost directivity, scan the beam of an antenna system, and carry out a number of additional tasks that would be challenging with a single element. As the elements can be fed by a single line or several lines in a feed network configuration, in this project, we developed the antenna's performance using an array.

Work on antennas started many years ago, The first well-known satisfactory antenna experiment was conducted by the German physicist Heinrich Rudolf Hertz (1857–1894), an Antenna can be defined according to IEEE Standard as “That part of a transmitting or receiving system that is designed to radiate or to receive electromagnetic waves.” In other words, the antenna serves as a bridge between free space and a guiding device, as shown in Fig 1.1. An antenna plays a very important role in a radio system, transmitting and receiving radio waves. It is designed to transform guided electromagnetic waves present in a waveguide, feeder cable or transmission line into radiating free space waves, and vice versa, by reciprocity, collects power from passing electromagnetic waves [1] [2].

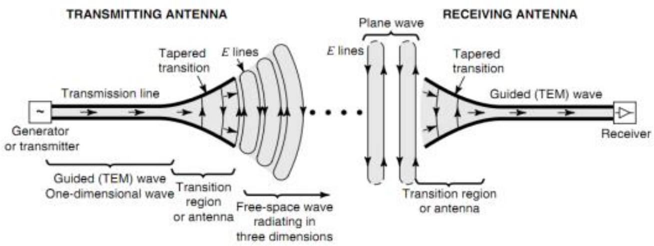


Fig 1.1: Antenna transmitting and receiving structure.

With the advances in telecommunication, the requirement for compact antenna has increased significantly. In mobile communication, the requirement for smaller antennas is quite large, so significant developments are carried out to design compact, minimal weight, low profile antennas for both academic and industrial communities of telecommunication. This technology used in to design microstrip patch antennas. Many varieties in designing are possible with microstrip antenna.

First this chapter will introduce antennas fundamentals, types, application of it is type and parameters, afterwards microstrip antennas advantages and disadvantages will be discussed, and their feeding techniques methods of analysis and application will be introduced.

I. Antenna Types

There are several types of antennas each type has his advantages and disadvantages and work well in a specific application area, this section will discuss the forms of some antenna types.

1. Wire Antenna

Since wire antennas are ubiquitous and can be found practically anywhere in cars, buildings, ships, airplanes, and spacecraft-the general public is familiar with them. There are many different forms of wire antennas, like the helix, loop, and straight wire (dipole) depicted in Fig 1.2. Loop antennas are not limited to circular shapes. They could be square, elliptical, rectangular, or any other shape[3]. The circular loop is the most widely used due to its simplicity of creation.

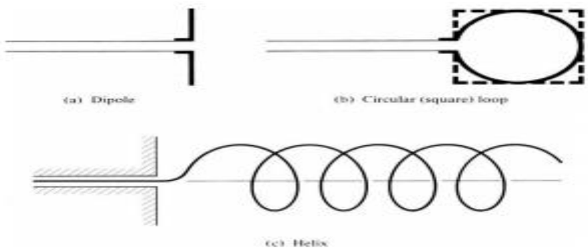


Fig 1.2: Wire antenna configurations [3]

2. Aperture Antenna

Aperture antennas may be more familiar to the general public nowadays than they were in the past due to the increasing demands for more complex antennas and the usage of higher frequencies. Fig 1.3 demonstrates a few different types of aperture antennas. Because it can be installed flush against the skin of the airplane or spaceship, this kind of antenna is highly beneficial for use in these environments. Moreover, they can be shielded from dangerous external circumstances by covering them with a dielectric substance.

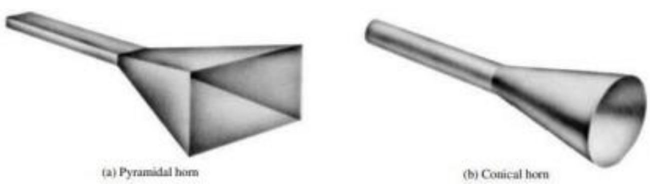


Fig 1.3: Aperture antennas configurations [3]

3. Reflector Antennas

The success of space travel has led to the progress of antenna theory. Sophisticated antennas were needed to send and receive signals that had to traverse millions of miles since long distance communication was necessary. A parabolic reflector is a common antenna form for such an application as shown in Fig 1.4. This type of antenna has been built with diameters as large as 305 m [3]. Such huge dimensions are essential to providing the tremendous gain required to send or receive signals over millions of kilometers of distance. The corner reflector is a form of reflector that is less frequent than the parabolic.

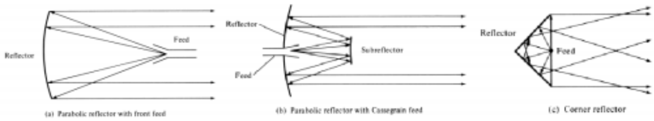


Fig 1.4: Reflector antennas configuration

4. Microstrip Antennas

Descamps proposed the concept of microstrip patch antennas in 1953. The first patent of a microstrip antenna design was awarded to Gatton and Bassinet in France in 1955 In the early 1970’s the first practical microstrip antennas were fabricated by Munson and Howell [4].The early 1980’s was a crucial period in publications, practical realism and manufacturing of the microstrip antennas. Present-day system requirements such as compact, lightweight, low profile conformal antennas that can be directly integrated into a variety of microwave circuits are an important factor in the development of printed antennas. Their low cost and ease of fabrication on printed circuit board (PCB) make them more attractive than the traditionally used lumped element antennas. Microstrip antennas may be made of any geometrical shape and dimension as shown in Fig 1.5.

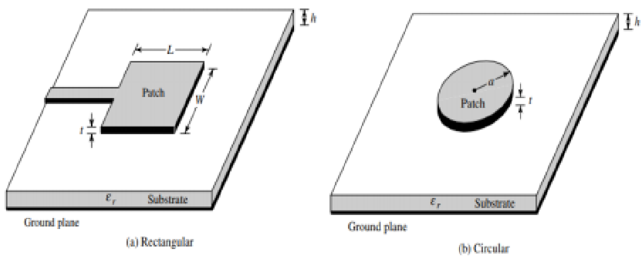


Fig 1.5: Microstrip (patch) antenna

II. Microstrip Antenna Working Principle

Microstrip line feeds come in a wide variety of designs, as Fig 1.6 illustrates. The feed line begins at the patch's edge in edge- and offset-edge-fed systems, but the microstrip line begins inside the patch in inset-fed systems. The purpose of the patch's inset cut is to match the feed line's impedance to the patch without the requirement for a separate matching element. The positive charge underneath the patch and the negative charge on the ground plane are creating attractive forces between the patch and the plane. A patch analysis typically sees the patch as a resonant cavity with metal (electric) walls within and ground plane, magnetic, or impedance walls at the edges.

Impedance matching happens when a patch resonates similarly to a resonant cavity. The antenna can function as efficiently as possible when the impedance matching is perfect. The field lines are consistent along the breadth and oscillate sinusoid dally along the length.

The patch's center and its two radiating boundaries represent the locations of the electric field and current maximums, respectively. A regular transmission line emits less power than a patch because adjacent counteracting fields match the fringing fields. Open circuits and discontinuities like corners and transitions emit power, although the quantity varies depending on how much of the radiation conductance load is applied to the line in relation to the patches. A patch's edges function as slots, and their excitations are dependent on the cavity's internal fields [6].

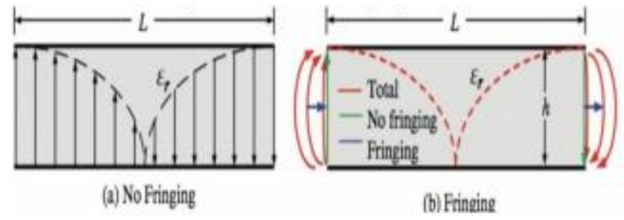


Fig 6.1: Electric field Lines

1. **Feeding Methods**

Microstrip patch antenna elements can be fed by a variety of methods. These methods can be classified into two categories: direct or indirect contact.

In the direct contact technique, the power is fed directly to the radiating patch using a connecting element such as a microstrip line or coaxial connector. In the indirect contact scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch [7].

1. **Microstrip Line**

A conducting metallic strip directly connects the path element to an RF power source in the microstrip line feed technology. The

benefit of this type of feed plan is that it allows for the planar structure to be created by etching both the feed and the patch element into the same substrate. The width of the feed line is less than that of the patch.

As shown in Fig 1.7, there are many different configurations of microstrip line feeds. In edge and offset edge-fed schemes, the feed line starts from the edge of the patch, while in inset Feed, the microstrip line starts from a location inside the patch.

The objective of the inset cut in the patch is to match the impedance of the feed line to the patch without need for any additional matching element [7]. he microstrip-line feed is easy to fabricate, simple to match by controlling the inset position and rather simple to model. However, as the substrate thickness increases, surface waves and spurious feed radiation increase, which for practical designs limit the bandwidth (typically 2–5%).

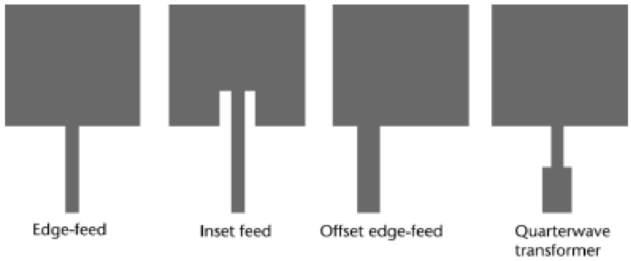


Fig 1.7: Different configurations of microstrip line feeds

2. **Coaxial Probe (coplanar feed)**

In coaxial feed technique, the inner conductor of the coaxial is pulled out to the patch through the substrate material and the outer conductor is connected to the ground as shown in Fig 1.8.

The main advantages of this technique are that it can be connected to the patch at any position to provide the impedance matching and it is compatible with coaxial cables. [6].

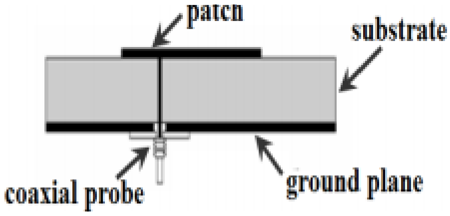


Fig 8.1: Coaxial feed structure

3. Aperture Coupling Feed

The radiating patch and microstrip feed line in the aperture-coupled feed technique are positioned on two distinct levels, divided by the ground plane as shown in Fig 1.9. The ground plane has a slot or aperture through which the patch and feed line are connected.

The coupling slot is usually centered under the patch, leading to lower cross-polarization due to the symmetry of the configuration. In the dual polarized antenna, there are two coupling slots, one for vertical polarization and other for horizontal polarization. The aperture's size, shape, and position all affect how much coupling occurs between the feed line and the patch. Spurious radiation is reduced because the ground plane separates the patch from the feed line.

To maximize radiation from the patch, a thick, low-dielectric material is utilized for the radiator at the top substrate, and a high-dielectric material is used for the feed line at the bottom. Narrow bandwidth is provided by this feeding plan.

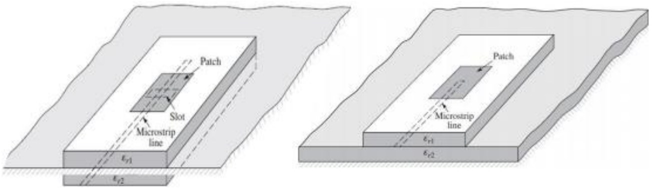


Fig 1.9: Aperture Coupling feed   Fig 1.10: Proximity-Coupling feed

4. Proximity- or Electromagnetically Coupling Feed

In proximity coupling feed method, the feed line is placed between two substrates while the patch is etched on the upper substrate and the ground on the lower substrate. This technique is preferred as it degrades the undesired feed radiation and achieves a very wide bandwidth. The utilization of two different substrates, one for the radiating patch and another one for the ground, helps optimize the individual performances. The main drawback of proximity coupling method is its fabrication complexity due to the difficulty of proper alignment of the dielectric layers [8].The structure of proximity coupled microstrip antenna is shown in Fig1.10.

2. Methods of Analysis

There are many methods of analysis for microstrip antennas. The most popular models are the transmission model, cavity model and full wave (which include primarily integrations/moment methods). The transmission line model is the easiest of all, it gives good physical insight, but is less accurate and it is more difficult to model coupling. Compared to transmission line model, the cavity model is more accurate at the same time more complex. However, it gives also physical insight and is rather difficult to model coupling, although it has been used successfully. In general, when applied properly, the full wave models are accurate, very versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements, and coupling. However, they are the most complex models and usually give less physical insight. In this section we will cover the transmission-line of rectangular patch only.

1. Transmission Line Model

The Transmission Line model is the simplest model used because it is easier to illustrate, representing the rectangular patch as a parallel plate transmission line connecting two radiating narrow slots (apertures), each of width W and height h, separated by a distance L. It gives a relatively good physical insight into the nature of the patch antenna and the field distribution for all modes. separated by a low-impedance Zc transmission line of length L. Results we get are not the best accurate compared with other methods but it is good enough to design the antenna. The first approximation we make is to assume that the thickness of the conductor t that forms the line has no effect on our calculations, because it is very thin comparing with the substrate h, $(h >> t)$; so, we use here empirical formulas that depend only on the line dimensions: The width W, the length L, the height h, and the dielectric constant ε_r of the substrate. [9].

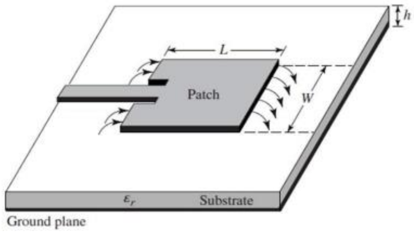


Fig 1.11: Transmission line model with inset-fed

- **Transmission line model consider the effects of various parameters described below.**

a. Fringing Field: The fringing field in rectangular microstrip antenna as shown in Fig. 1.12 arises from the radiating edges shown in the figure below. Fringing field are mainly depending on the dielectric

constant and length L to height h ratio. Since in most of the cases the L/h ratio is << 1 therefore the fringing fields are less.

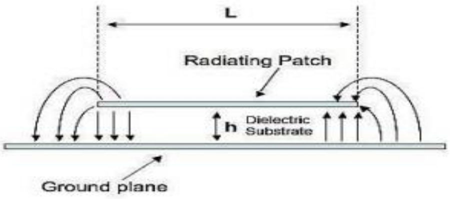


Fig 1.12: Fringing Field Effect

Higher dielectric constant substrate leads to bounded electric fields more enclosed in the substrate as used in the microstrip lines. While the lower dielectric constants substrates result in loosely bounded electric fields means they will go more further from the patch. Lesser the dielectric constant material used in substrate more bowed the fringing fields. We know that the fringing fields are responsible for the radiations from microstrip antenna. Therefore, lower dielectric constant more the fringing fields and more the radiations leads to better efficiency and better antenna performance. From figure it can be seen that fringing fields lines are not only enclosed in substrate but also go further out in the air. As the field lines travels in substrate and air also we have to calculate an Effective Dielectric constant by taking the air also in account as shown in Fig. 1.13 [9].

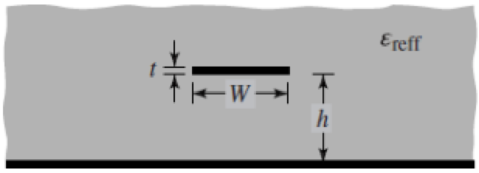


Fig 1.13: Effective Dielectric constant

The effective dielectric constant is a dielectric constant of the material for which the antenna characteristics are same as for the real one. The range of effective dielectric constant varies from $1 < \varepsilon_{reff} < \varepsilon_r$. In most cases the$\varepsilon_{reff}$ value is close to ε_r .

If the air is used as a substrate, then the effective dielectric constant is equal to dielectric constant $\varepsilon_{reff} = \varepsilon_r$..

The ε_{reff} for $W/h > 1$ can be given by equation 1.1.

$$\varepsilon reff = \frac{\varepsilon_r+1}{2} - \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{W}\right)^{-\frac{1}{2}} \qquad (1.1)$$

b. Effective Length, Resonant Frequency, and Effective Width:

Because of the fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions. Where the dimensions of the patch along its length have been extended on each end by a distance ΔL, which is a function of the effective dielectric constant $\varepsilon reff$ and the width-to-height ratio (W/h)A very popular and practical approximate relation for the normalized extension of the length is given by equation 1.2.

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \qquad (1.2)$$

Since the length of the patch has been extended by ΔL on each side, the effective length of the patch as shown in Fig. 1.41.

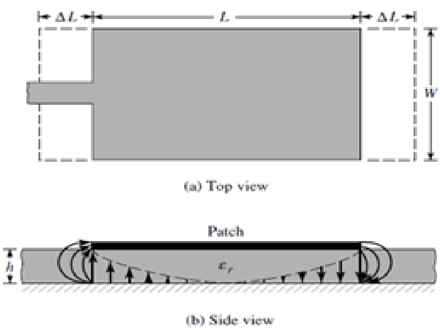


Fig1.41: Length Extension

This ΔL value mainly depends on the effective dielectric constant and the width to height ratio. Due to this length extension length of patch is about 0.48λ rather than 0.5λ. Therefore, to get the actual physical length of the patch equal to λ/2 we have consider the extension on both the ends and that is, the length of the patch is given by equation 2.16 [10].

$$L = Leff - 2\Delta L \qquad (1.3)$$

As we know for dominant mode the length of patch is equal to λ/2 therefore the $Leff$ is given by equation 1.4 and 1.5.

$$\text{Leff} = \frac{c}{fr} \tag{1.4}$$

$$L_{eff} = \frac{C_0}{2fr\sqrt{\varepsilon_{eff}}} \tag{1.5}$$

Where, C_0 is the velocity of light in free space and fr is the resonance frequency for which antenna is to be designed.

For the dominant mode TM_{010} there is no fringing fields along the width therefore there is no need to consider the effective dielectric constant. Width of the patch can be calculated by this formula is given by equation 1.6.

$$W = \frac{c_0}{2fr}\left(\frac{\varepsilon r+1}{2}\right)^{\frac{-1}{2}} \tag{1.6}$$

For the dominant mode TM010 the antenna resonates (without taking fringing into account) at the frequency given by equation 1.7.

$$fr = \frac{C_0}{2\,\text{L}\sqrt{\varepsilon_{eff}}} \tag{1.7}$$

And when considering the effective length and effective dielectric constant the antenna will radiate at the frequency. [10]

- **Array Antenna**

Microstrip arrays antenna are commonly employed to improve radiating system efficiency, directivity, and gain. This is because the radiation from a single antenna element is frequently very broad in pattern with huge beam angles. This is not suitable for point-to-point communications, which require more directed antennas.

Additionally, a single radiating element frequently produces radiation patterns with unsatisfactory bandwidth, efficiency, and gain parameters. All of these factors combine to make the use of a single element antenna undesirable. The use of antennas in an array design eliminates these disadvantages.

This the paper briefly describes the notion of arrays. Antenna arrays are essentially a collection of radiating devices that are geometrically arranged in a certain manner to produce the desired radiation pattern. Each antenna in the array is referred to as an element, and they can range from simple dipole antennas to monopole antennas, horn antennas, or, in this case, microstrip patches. The location of the antenna elements determines whether these arrays are linear, circular, planar, or three-dimensional.

There are two main types of antenna arrays: uniform and non-uniform. Uniform arrays are the most fundamental one-dimensional array antennas, featuring identical amplitude and differential phase distribution. This form of array has the narrowest main lobe and the most side lobes.

In contrast, a non-uniform array antenna with unequal amplitude distribution produces a more controlled side-lobe level. A phased array is a form of antenna array in which the spatial distributions of the radiated fields are electronically scanned to enhance the intended signal by injecting differential phase (and/or magnitude) into the input signal of the radiating components. Phased-array antennas were created primarily for radar uses, but are now increasingly being.

Employed for space-based communications applications due to its advantages in scanning, re-configurability, weight, and power .

Furthermore, advancements in the integration technology of compact microwave circuits have led to the deployment of these antennas in ground, ship, air, and space communications [12].

III. Antenna design

In this paper, explains demonstrates the design of the proposed antenna. The design procedure is divided into three major steps:

1. Designing the conventional rectangular microstrip patch antenna.
2. Designing 2x1 Array antenna using microstrip patch antenna.
3. Combine antenna with 2X1 Array antenna.

1. Analysis High Frequency Structure Simulator (HFSS)

analysis High-Frequency Structure Simulator (HFSS) is a general-purpose full-wave 3D electromagnetic (EM) simulation software for simulating and optimizing high-frequency electronic products like antennas, antenna arrays, high-speed interconnects, and printed circuit boards to name a few. Using analysis HFSS allows engineers to accurately evaluate the performance of complex designs before the prototype phase. Many antenna design application calculations cannot be done by hand, making this high-frequency software extremely valuable for the end-user [9].

2. Single Microstrip Patch Antenna.

A microstrip patch antenna is a type of radio antenna that consists of a metallic patch placed on a grounded dielectric substrate. The patch can take various shapes, such as rectangular, circular, triangular, or even more complex geometries. The main advantages of microstrip patch antennas are their low profile, lightweight, and ease of fabrication, making them suitable for a wide range of applications, including mobile devices, satellite communications, and radar systems.

3. Design and Simulation.

In this paper, the designing of Rectangular Microstrip patch antenna is done, The proposed microstrip antenna is coplanar with x-y plane and height of the antenna is in z plane.

The initial configuration of the proposed antenna is shown in Fig 1.5. With a simple patch and ground plane. (0.035mm) thick copper is used for patch and ground on both sides of the substrate which is "Duroid (tm)" material of (εr= 2.2, $tan\ \delta$ = 0.0009) with a standard thickness of 1.588mm, a rectangular patch of copper is built on the top of the substrate layer and a conducting ground is employed on the other side of the substrate.

The inset feed technique is used to achieve a good impedance matching between the feed line and the patch,. The procedure of design with given three main parameters to calculate the other dimensions of antenna includes the dielectric constant of the substrate (εr), the resonant frequency (fr), and the height of the substrate h. is as follows:

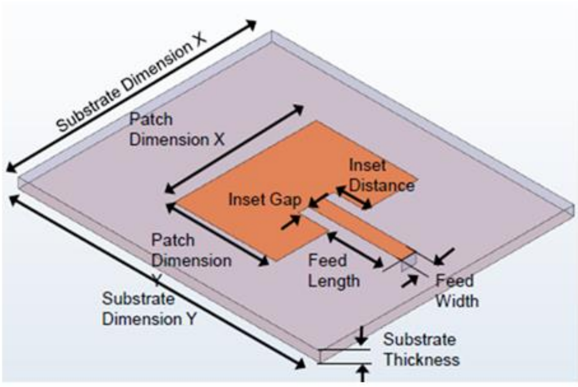


Fig1.15: Initial Geometry of the rectangular patch antenna.

1. $f_r = 2.4GHz$, this value of the resonant frequency was chosen because The Industrial, Scientific and Medical (ISM) Systems uses the frequency range from 2.4GHz - 2.5GHz.

2. $\varepsilon r = 2.2$, with loss tangent $tan\,\delta = 0.0009$, $h = 1.588$mm, this value is a one of standard thickness of Duroid (tm) material, because the thick substrates whose dielectric constant is in the lower end of the range because they provide better efficiency, larger bandwidth, loosely bound fields for radiation into space

3. Calculation of width of patch (W):

$$W = \frac{c_0}{2f_r}\left(\frac{\varepsilon_r+1}{2}\right)^{\frac{-1}{2}} \quad (1.8)$$

Substituting $c = 3x108\, m/s$, $\varepsilon_r = 2.2$ and $f_r = 2.4$GHz,
We get: $W = 49.410588\, mm$

4. Calculation of effective Dielectric constant (ε_{eff}).

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} - \frac{\varepsilon_r-1}{2}\,(1+12h/W)^{\frac{-1}{2}} \quad (1.9)$$

Substituting $\varepsilon_r = 2.2$, $W = 49.410588\, mm$ and $h = 1.588mm$ .We get : $\varepsilon_{eff} =$ 1.088946.

5. Calculation extension Length: It is used for calculating resonant frequency of Microstrip antenna.

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{eff}+0.3)\,(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)\,(\frac{W}{h}+0.8)} \quad (1.10)$$

Substituting $\varepsilon_{eff} = 1.088946$, $W = 49.410588\, mm$ and $h = 1.588 mm$ We get: $\Delta L = 1.07523\ mm$

6. Calculation of Length of patch: Effective Length (L_{eff}).

$$L_{eff} = \frac{C_0}{2fr\sqrt{\varepsilon_{eff}}} \qquad (1.11)$$

$$L = L_{eff} - 2\,\Delta L \qquad (1.12)$$

Substituting $Leff = 59.8931\ mm\ and\ \Delta L = 1.07523mm$
We get: $L = 57.74264\ mm.$

7. Calculation of inset feed point Y_0: Conductance (G).

$$G1 = \begin{cases} \frac{1}{90}\left(\frac{w}{\lambda_0}\right)^2, w \ll \lambda_0 \\ \frac{1}{120}\left(\frac{w}{\lambda_0}\right)^1\ w \gg \lambda_0 \end{cases} \qquad (1.13)$$

Calculation of resonant input resistance (Rin):

$$\text{Rin}\ (y = 0) = \frac{1}{2G1} \qquad (1.14)$$

$$R_{in}(y = y_0) = R_{in}(y = (0)cos^2\left(\frac{\pi}{L} y_0\right) \qquad (1.15)$$

$y_0 = 10.457\ mm$

8. Calculation of Width of the Feed Line Em-talk calculator was used to calculate the width Value =1.41 mm.

9. Calculate ground Plane dimensions

all patch antenna design must have a finite ground plane. The ground plane has similar dimension of the substrate but they are greater than the patch antenna dimensions by six times of the substrate thickness all-around of the periphery. As a result, the dimensions for the substrate and ground plane would be given in Equations (1.16) and (1.17) .

$$Lg = 6h + Lp = 6\,X\,1.588 + 57.74262 = 67.27062\ mm \qquad (1.16)$$

$$\text{Wg} = 6\text{h} + \text{Wp} = 6\,\text{X}\,1.588 + 49.410588 = 58.938588\text{mm} \qquad (1.17)$$

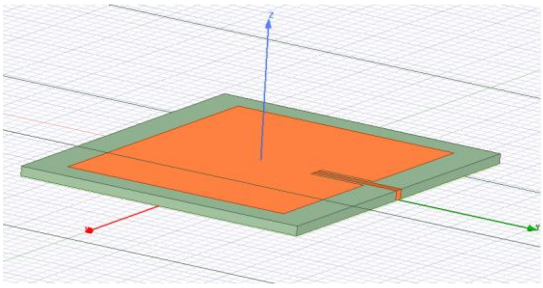


Fig1.16:Geometry of the patch Antenna

❖ Results and Discussion

1. Return Loss.

HFSS software is used to find the $|S_{11}|$ simulations result of this proposed antenna. as shown in Fig 1.17. The reflection coefficient of the designed antenna parameter is less than −10dB from 2.38GHz to 2.42GHz. BW = (2.42-2.38)GHz = 40 MHz. The impedance bandwidth is just the ordinary bandwidth of the antenna. Normally this is defined as the range of frequencies over which the return loss is acceptable. Percentage is referring to a quantity more commonly called fractional bandwidth (FBW). This is simply the absolute bandwidth (or impedance bandwidth) divided by the center frequency of the antenna. The fractional bandwidth is a better measure for bandwidth when comparing different antennas because it is independent of scale. Therefore, the FBW of the proposal antenna is 1.66% for the antenna with, these results satisfy the required specification.

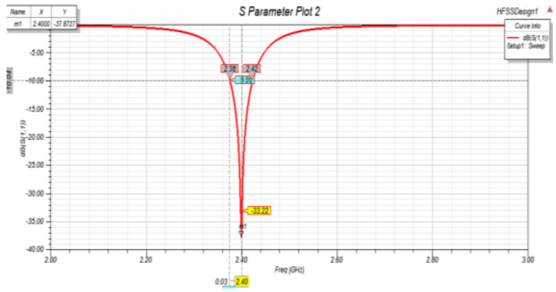


Fig 1.17: Bandwidth of antenna Return Loss at 2.40GHz

2. Radiation pattern

Far-field radiation pattern defines the variation of the power radiated by an antenna as a function of the direction away from the antenna. The far-field radiation pattern 3D plot is shown in **Fig 1.18**,As we can see the antenna demonstrates end-fire radiation patterns for the whole operating band, the maximum main lobe radiation was 22.15 dB at resonant frequency.

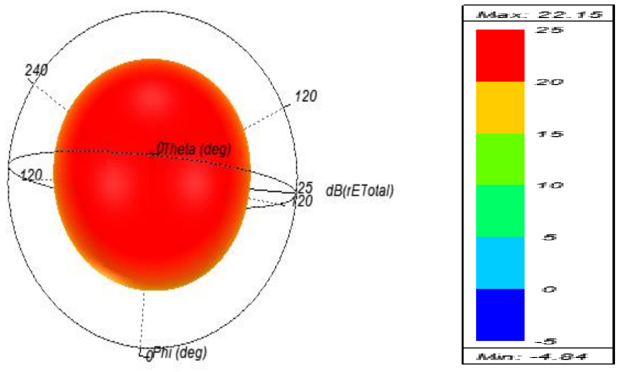


Fig 1.18: 3D radiation pattern at 2.40GHz

3. Gain

Fig 1.19 displays the maximum gain of the optimized design of the antenna, taking into account the bandwidth range obtained from the return loss; the maximum gain in this range was 4.37 dB at 2.4 GHz.

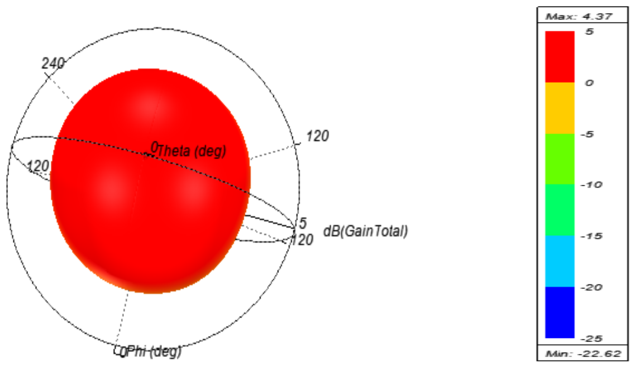


Fig 1.19: 3D radiation pattern of antenna gain at 2.40GHz

4. Directivity

Fig 1.20 displays Directivity of the optimized design of the antenna.

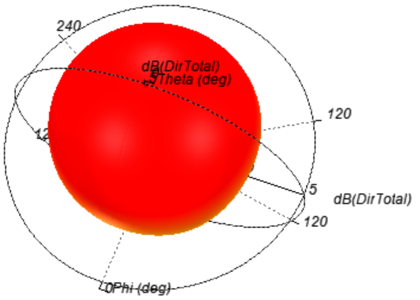


Fig 1.20: 3D plot of Directivity

5. Standing Wave Ratio (VSWR)

Fig 1.21 displays VSWR of the optimized design of the antenna.

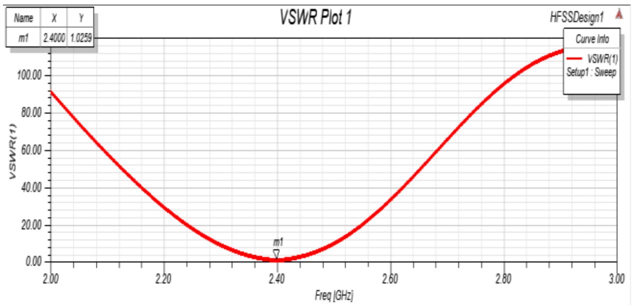


Fig 1.21: VSWR plot of Antenna at 2.4 GHz

6. Total simulation results of conventional antenna

Parameter	Definition	Value (mm)
Patch X	Width of the patch	50.4
Patch Y	Length of the patch	37.5
Sub H	Height of dielectric substrate	1.58
Sub X	Width of the dielectric substrate	210
Sub Y	Length of the dielectric substrate	118
Feed Width (W1)	Width of the Feedline	6.81
Feed Width (W2)	Width of the Feedline	1.40
Inset Distance	Distance inset patch	8.56
Inset Gap	Width of gap	0.7
Feed Length	Length of the feedline	37.7

The antenna simulation results are conferred in Table 1.1

Parameters	Value
Resonate frequency	2.4GHz
Bandwidth	40 MHz
Return loss (S_{11})	-37.87 dB
VSWR	1.03
Gain	4.37 dB
Directivity	4.51 dB
Antenna efficiency	97%

Antenna Array Design

1. Design and Network Analysis for 2x1 Antenna Array.

We used the same values of height of the dielectric substrate(h)and the same dielectric material at the design frequency so we used the same dimension of single patch antenna.

- The width of the patch W = 49.41069.
- Effective Dielectric Constant ε_{eff} of the patch = 2.11106.
- Extension of the patch length, ΔL of the patch = 0 .2885 mm.
- Actual length of the patch, L = 41.35621 mm.

- The value of the W_f= 1.41 mm.
- The value of the y_0= 10.457 mm.
- Input impedance of the patch Z_{in}= 204 Ω.

Knowing the physical dimensions L, W and Z_{in}, the feed line network parameters can be selected by setting 50 Ω feed line Z_1= 50 Ω, which splits into two 100 Ω ones, Z_2= 100 Ω as shown in the Fig 1.22.Then we found the width of the microstrip line at Z_1= 50 Ω and Z_2= 100 Ω are W_1=4.8125 mm and W_2= 1.4079 mm, respectively.

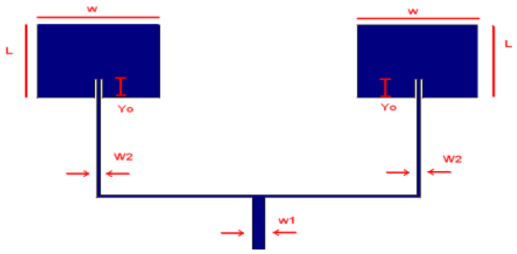


Fig1.22: 2x1 Array Network

1. Design and Simulation

In this paper, the designing of 2x1 Rectangular Microstrip patch antenna Array is done, The proposed microstrip antenna is coplanar with x-y plane and height of the antenna is in z plane. The initial configuration of the proposed antenna is shown in Fig 1.23, with 2 simple patch and ground plane. (0.035mm) thick copper is used for patches and ground on both sides of the substrate which is Duroid (tm) material of (εr= 2.2, $tan\ \delta$ = 0.0009) with a standard thickness of 1.588mm, 2 rectangular patches of copper are built on the top of the substrate layer with separate space (lamda/2) between patches and a conducting ground is employed on the other side of the substrate. The inset feed technique is used to achieve a good impedance matching between the feed line and patches.

By using previous calculation and HFSS optimization, the antenna final parameters are conferred in Table 4.2 and the geometry of antenna is shown in Fig 1.23.

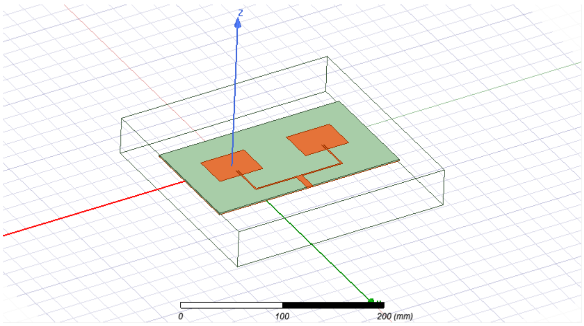


Fig 1.23: Geometry of the patch Antenna Array

Table 1.2: Final Dimensions of 2x1 Antenna Array

❖ **Results and Discussion**

1. Return Loss

It has been noted that reflection coefficient (S_{11}) in Fig 1.24 is equal to -18.02 dB at 2.4 GHz which is the minimum result. This indicates that the antenna is resonant and has given maximum radiation at 2.4GHz with an impedance bandwidth of 40 MHz from 2.38GHz to 2.4GHz.

The impedance bandwidth is just the ordinary bandwidth of the antenna. Normally this is defined as the range of frequencies over which the return loss is acceptable. Percentage is referring to a quantity more commonly called fractional bandwidth (FBW). This is simply the absolute bandwidth (or impedance bandwidth) divided by the center frequency of the antenna.

The fractional bandwidth is a better measure for bandwidth when comparing different antennas because it is independent of scale. Therefore, the FBW of the proposal antenna is 1.66% for the antenna with, these results satisfy the required specification.

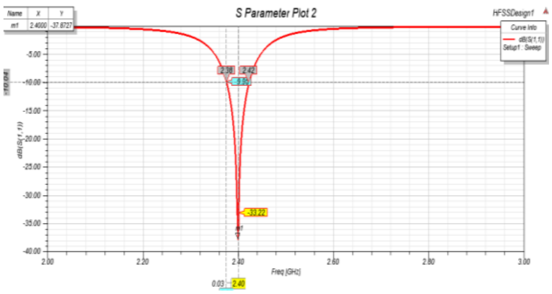


Fig 1.24: Bandwidth of antenna Return Loss at 2.40GHz

2. Radiation pattern

Far-field radiation pattern defines the variation of the power radiated by an antenna as a function of the direction away from the antenna. The far-field radiation pattern 3D plot is shown in Fig 1.25 ,As we can see the antenna demonstrates end-fire radiation patterns for the whole operating band, the maximum main lobe radiation was 22.15 dB at resonant frequency.

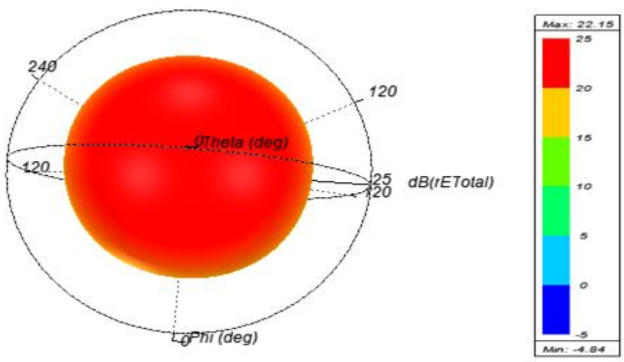
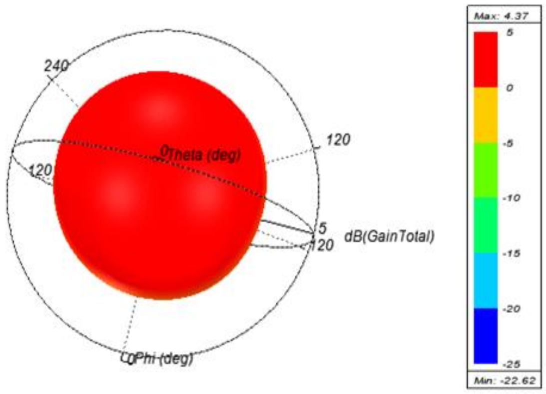


Fig 1.25: 3D radiation pattern of antenna gain at 2.40GHz

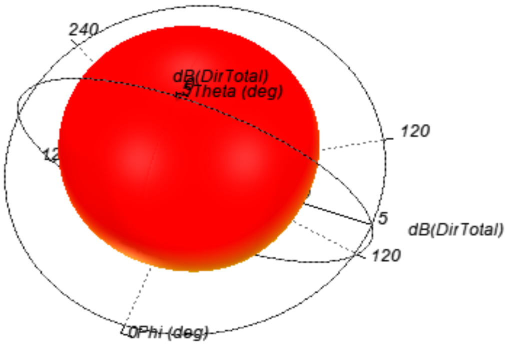
3. Gain

Fig 1.26 displays the maximum gain of the optimized design of the antenna, taking into account the bandwidth range obtained from the return loss; the maximum gain in this range was 4.37 dB at 2.4 GHz.



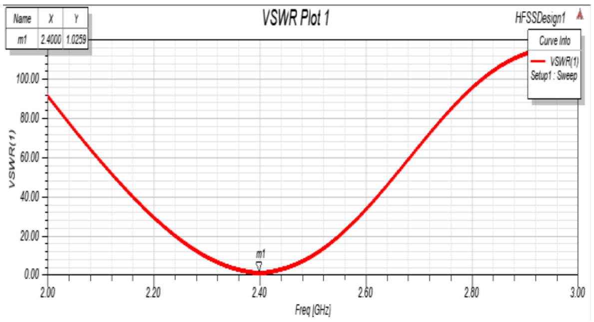
4. Directivity

Fig 1.27 displays Directivity of the optimized design of the antenna.



5. Standing Wave Ratio (VSWR)

Fig 1.28 displays VSWR of the optimized design of the antenna.



6. **Total simulation results of conventional antenna.**

The antenna simulation results are conferred in Table 4.2
Table 4. 2: Simulation Results of Single Element**.**

Parameters	**Value**
Resonate Frequency	2.4GHz
Bandwidth	40 MHz
Return loss (S_{11})	-37.87 dB
VSWR	1.03
Gain	4.37 dB
Directivity	4.51 dB
Antenna Efficiency	97%

4. **Antenna Array Design.**

1. Design and Network Analysis for 2x1 Antenna Array**.**

We used the same values of height of the dielectric substrate (h) and the same dielectric material at the design frequency so we used the same dimension of single patch antenna.

- The width of the patch W = 49.41069.
- Effective Dielectric Constant ε_{eff} of the patch = 2.11106.
- Extension of the patch length, $\Delta_L$of the patch = 0 .2885 mm.
- Actual length of the patch, L = 41.35621 mm.
- The value of the W_F= 1.41 mm.
- The value of the y_0= 10.457 mm.
- Input impedance of the patch Z_{in}= 204 Ω.

Knowing the physical dimensions L, W and Z_{in}, the feed line network parameters can be selected by setting 50 Ω feed line Z_1 = 50 Ω, which splits into two 100 Ω onesZ_2 = 100 Ω as shown in the Fig 1.29.

Then we found the width of the microstrip line at Z1 = 50 Ωand Z_2 = 100 Ω are W_1=4.8125 mm and W_2= 1.4079 mm, respectively.

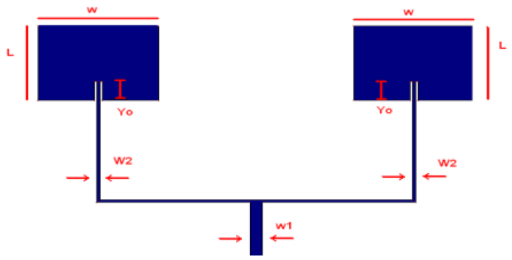


Fig 1.29: 2x1 Array Network

2. **Design and Simulation**

In this paper, the designing of 2x1 Rectangular Microstrip patch antenna Array is done, The proposed microstrip antenna is coplanar with $x - y$ plane and height of the antenna is in z plane. The initial configuration of the proposed antenna is shown in Fig 1.30, with 2 simple patch and ground plane. (0.035mm) thick copper is used for patches and ground on both sides of the substrate which is "Duroid (tm)" material of (ε_r= 2.2, $tan\ \delta$ = 0.0009) with a standard thickness of 1.588mm, 2 rectangular patches of copper are built on the top of the substrate layer with separate space lamda/2 between patches and a conducting ground is employed on the other side of the substrate. The inset feed technique is used to achieve a good impedance matching between the feed line and patches.

By using previous calculation and HFSS optimization, the antenna final parameters are conferred in Table 4.2 and the geometry of antenna is shown in Fig 1.30.

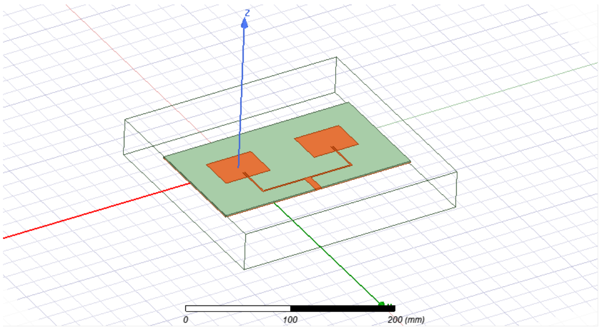


Fig 1.30: Geometry of the patch Antenna Array

3. **Results and Discussion**

1. Return Loss

It has been noted that reflection coefficient (S_{11}) in Fig 1.31 is equal to -18.02 dB at 2.4 GHz which is the minimum result. This indicates that the antenna is resonant and has given maximum radiation at 2.4GHz with an impedance bandwidth of 40 MHz from 2.38GHz to 2.4GHz.

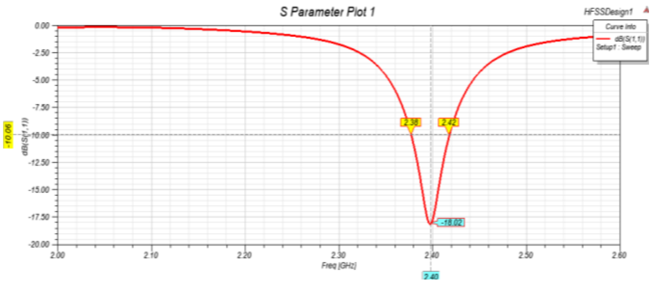


Fig 1.31: Return Loss at 2.40GHz

2. Input Impedance

Fig 1.32 represents the real and imaginary components of the antenna input impedance as can be seen, both the real and imaginary parts are fluctuating around 50 and zero ohm.

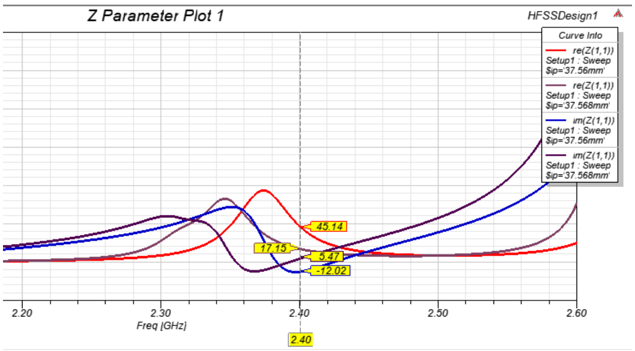


Fig1.32: Input impedance for the patch antenna Array

3. Radiation pattern

The far-field radiation pattern 3D plot as shown in Fig1.32 With maximum main lope of radiation pattern is 27.91 Db.

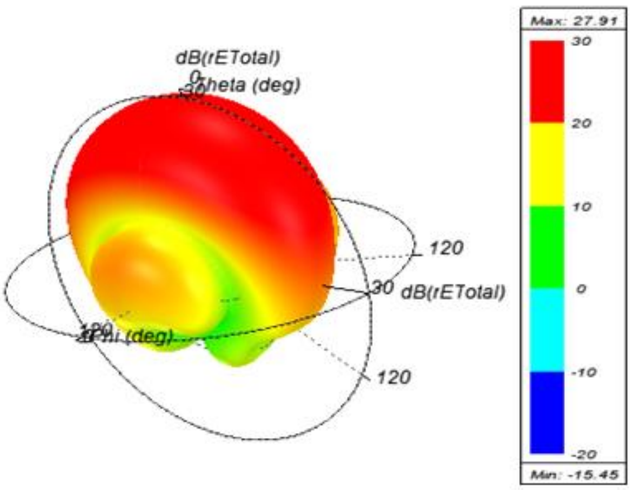


Fig 1.32: 3D radiation pattern at 2.40GHz

4. Gain

Fig 1.33 displays the maximum gain of the optimized design of the antenna, taking into account the bandwidth range obtained from the return loss; the maximum gain in this range was 10.20 dB at 2.4 GHz and the minimum was -33.16 dB.

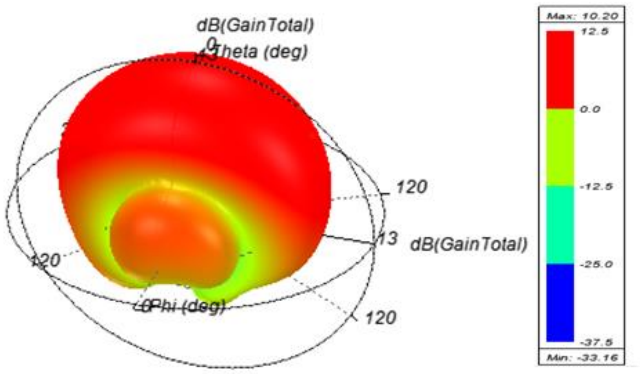


Fig 1.33: 3D plot of gain at 2.40GHz.

5. Directivity

Fig 1.34 displays Directivity of the optimized design of Array antenna.

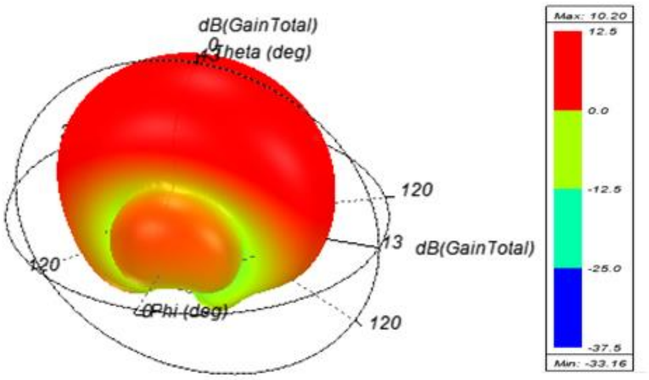


Fig 1.34: 3D plot of Directivity

6. Total simulation results of MPA array

Table 1. 4: Simulation Results of 2x1 Antenna Array

Parameters	Value
Resonate Frequency	2.4GHz
Bandwidth	40 MHz
Return loss (S_{11})	-18.02 dB
VSWR	1.3123
Gain	10.20dB
Directivity	10.32 dB

- **Resonant Frequency**: The 2x1 antenna array operates at 2.4 GHz, which is commonly used in wireless communications (e.g., Wi-Fi, Bluetooth).
- **Bandwidth**: The array has a bandwidth of 40 MHz, meaning it can operate effectively across a 40 MHz range without significant performance loss.
- **Return Loss (S_{11})**: A return loss of -18.02 dB indicates good impedance matching, meaning minimal signal is reflected back, ensuring efficient power transfer.
- **VSWR**: A Voltage Standing Wave Ratio (VSWR) of 1.3123 signifies a well-matched antenna system, with a near-optimal VSWR value (ideal value is 1).
- **Gain**: The 2x1 array provides a significant gain of 10.20 dB, enhancing signal strength and enabling better performance over long distances.
- **Directivity**: The directivity of 10.32 dB suggests a highly focused radiation pattern, improving signal targeting in a specific direction.

Discussion and Comparison Result

The simulation results of the 2x1 Microstrip Patch Antenna (MPA) array demonstrate several significant improvements in key performance parameters compared to a conventional single patch antenna.as shown in table 1.5. These improvements reflect the effectiveness of using an array configuration in antenna design, particularly for applications that demand higher gain and more focused radiation patterns.

Table 1. 5 : Compared Simulation Results between 2X1 antenna array & single Antenn

Parameter	Single ntenna	Antenna rray
Size (L×W) nm^2)	51 x 59	118×210
fl (GHz)	2.38	2.38
fh (GHz)	2.42	2.42
fr (GHz)	2.4	2.4
BW (MHz)	40	40
Gain at *fr* (dB)	4.37	10.20
S11 at *fr* (dB)	-37.87	-18.02
Directivity B)	4.51	10.32

IV. Conclusion

The two-element rectangular microstrip patch antenna array designed and simulated in this paper has demonstrated significant improvements over a single patch antenna in terms of gain, directivity, and radiation patterns. The use of HFSS software allowed for an efficient simulation process that optimized the antenna's performance at the 2.4 GHz operating frequency. The results show that converting a single antenna into an array enhances its overall performance, making it more suitable for applications in wireless communication systems. This paper successfully addressed the issues of low gain and narrow bandwidth associated with single-element antennas, proving that array designs offer a viable solution

- **Improvement in Gain**

The most notable outcome is the substantial increase in gain from 437 dB (single patch) to 10.20 dB (2x1 array), an improvement of approximately 57%. Gain is a critical factor in determining the strength and quality of the transmitted or received signal. Higher gain means that the antenna can transmit signals over a longer distance and with better clarity, which is vital in wireless communication systems. The significant gain improvement is achieved due to the array's ability to constructively combine the signals from the individual elements, thus concentrating the energy in a particular direction.

- **Enhanced Directivity**

The directivity of the antenna array also increases considerably from 4.51 dB (single patch) to 10.32 dB (array). Directivity is a measure of how well the antenna directs energy in a particular direction. The array's higher directivity results in a more focused radiation pattern, which reduces interference from unwanted directions and improves signal reception and transmission in the desired direction. This makes the antenna array ideal for applications where precise targeting of signals is required, such as radar or directional communications.

- **Trade-offs with Return Loss (S_{11})**

While the gain and directivity improve with the array, the return loss (S11) shows a decline from -37.87 dB for the single patch to -18.02 dB for the array. Return loss measures how well the antenna is matched to its feeding transmission line; a lower S11 value indicates better impedance matching and lower signal reflection. Although -18.02 dB is still an acceptable level, the decrease suggests that some efficiency is lost when transitioning to an array configuration. This could be due to increased complexity in matching multiple elements in the array. However, the value remains within acceptable limits for most practical purposes, ensuring that the array still performs efficiently.

- **Bandwidth Consistency**

Both the single antenna and the 2x1 array maintain the same bandwidth of 40 MHz. This consistency indicates that while the gain and directivity have improved with the array configuration, the bandwidth has not been compromised. Maintaining a stable bandwidth is crucial for ensuring that the antenna can handle the same range of frequencies without loss of performance, which is particularly important in communication systems where bandwidth is directly related to data transmission capacity.

- **Physical Size Consideration**

One of the trade-offs of using an array is the increase in physical size. The size of the 2x1 antenna array is 118×210 mm² compared to 51 x 59 mm² for the single patch antenna. This increase in size might not be a concern in applications where space is available, but in compact devices or systems with limited space, the larger size could be a limiting factor. Designers need to consider this trade-off between performance and size, especially in mobile or portable communication systems

.

- **Comparison of Resonant Frequency and Bandwidth**

Both configurations operate at a resonant frequency of 2.4 GHz, which is a common frequency band for wireless communication applications such as Wi-Fi, Bluetooth, and industrial, scientific, and medical (ISM) radio bands. The consistent bandwidth of 40 MHz ensures that both the single antenna and the array can handle the same frequency range without experiencing signal degradation or loss of data.

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