Mohamed Khider University of Biskra

Faculty of Science and Technology

Department of Electrical Engineering

Master's Thesis

Science and Technology
Field: Telecomunication
Option: Network and Telecommunication

Réf. : …………………

Presented By :
Bendjeddou Aymen

COMPACT DESIGN AND SIMULATION OF PRINTED ANTENNA WITH GROUND SLOT

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Compact Design and simulation of printed antenna with ground slot

Presented by: *Favorable opinion of the supervisor:*

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Stamp and signature

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Summarize (English and Arabic)

This project presents a compact design of a micro-strip printed antenna which is an inseparable part of the wireless networks. our work is focused on the Ground slot technique applied to obtain a broadband antenna that can radiate in X-bands. This technique is used to enhance the bandwidth and other parameters. We also studied the positive impact of properly shorting the size of the antenna at the S11, gain, and bandwidth. furthermore, we compare the effect of using two different materials to design the isolated layer one with a low dielectric constant and then the second.

يقدم هذا المشروع تصميمًا مضغوطًا لهوائي الرقعة المطبوع المغذى باستخدام طريقة ال Inset-feed والذي يعد جزءًا لا يتجزأ من الشبكات اللاسلكية ،يركز عملنا على تقنية الفتحة الأرضية المطبقة للحصول على هوائي واسع النطاق يمكن أن يشع في نطاق X-band تستخدم هذه التقنية لتحسين عرض النطاق الترددي والمعلمات الأخرى. درسنا أيضًا التأثير الإيجابي للهوائي الذي تم تصغير حجمه بشكل صحيح على S11 والكسب وعرض النطاق الترددي. علاوة على ذلك ، قارنا تأثير استخدام مادتين مختلفتين لصناعة الطبقة العازلة للهوائي واحدة ذات ثابت عازل منخفض عن الثانية.

Dedication

My Work is dedicated to my family and many friends.

I owe a special tribute to my devoted parents, who supported me throughout my studies.

I dedicate this work to my teachers and express my gratitude to them.

Acknowledgments

I'd want to thank my supervisor, Mr. Ameid Sofiane, for continuously guiding and encouraging me to be professional and do the right thing even when the going became rough.

I would like to thank my friends who contributed by observing and helping me to reach questions that gave me some right ideas, my friend Ayoub Hmaden and Rezgui Nedjme Eddine, and I also thank my friend Hablatou Messaoud who always contributed to correcting the thesis methodology.

Thanks to the research gate community which has provided many in-depth answers to important elements of my work.

I'd want to convey my heartfelt gratitude to Mohamed Khider University and all of the electrical engineering professors for their thoughtful guidance.

I'd like to express my gratitude to all of my friends and coworkers with whom I've shared good times, memories, and acknowledgment.

Finally, I'd like to express my gratitude for my family's support and love, especially my parents, brothers, and sisters. They kept me going, and without their help, this task would not have been possible

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AIGaIP: Aluminium gallium indium phosphide

ASPs: Ultra wideband stacked Patches.

FDTD: finite difference time domain

GaAs: Gallium arsenide

MMICs: Microwave Monolithic Integrated Circuits

MSA: Microstrip Antenna

OEIC: Opto-Electronic Integrated Circuits

PCBs: Printed Circuit Board.

RF: Radio Frequency

RL: Return Loss

UBP: Ultra Boradband Printed

Contents

INTRODUCTION

General Introduction

In recent years, mobile communication systems (GSM900, GSM1800, UMTS, and PCS), wireless computer links, remote controllers, satellite mobile phones, and wireless internet have all seen significant expansion. The size of electronics required for mobile applications has shrunk dramatically in recent years, but their functionality has improved. The antennas required for the various applications should be tiny, lightweight, low profile, have a broad bandwidth, be inexpensive, and be able to integrate with MIC/MMIC circuits.

There are many other types of antennas, but the microstrip patch antenna is the most used currently due to its many advantages, including ease of manufacture and inexpensive cost. The antennas' intrinsically low bandwidth limits the types of applications that MSAs may do. As a result, boosting the MSA's BW has been a major focus of research in the sector. The enormous number of papers on the subject published in journals and conference proceedings reflects this. In fact, throughout the previous few decades, various broadband MSA configurations have been recorded. As a result, in our project, we wish to design a Broadband microstrip patch antenna.

Thesis's objective:

The objective of this project is to design a broadband E-shaped Microstrip antenna with a small geometry (Width and Length) that can radiate in X-band frequency(satellite, radar applications) and study the effect of Slots in the ground plane.The High Frequency Structure Simulator (HFSS)Version 13 is used to design and simulate the antenna.

Thesis outline:

This thesis is divided into three chapters organized as follows:

Chapter 1: an introduction to the wirless technologies The important element that made the field of communications develop rapidly is the invention of the printed antenna This chapter focuses largely on a particular type of it, which is the microstrip patch antenna, which explains its applications, advantages and disadvantages, as well as some basics about how it works and the most important parameters such as:gain, directivity, VSWR, efficiency, polarization, Radiation pattern, smith chart and S11.

Chapter 2: The second chapter talks about the effect of changing the shapes of the patch antenna, as well as the effect of adding Slots on antenna parameters. One of the most important parts in this chapter is the methods of optimizing MSA to get better results in terms of Bandwidth, gain, S11 ...etc. It also shows some materials used in the manufacture of antenna and different between them.

Chapter 3: In this chapter we designed an E-shaped Broadband Microstrip Antenna for X-Band applicatopns with and without Ground Slot techniques and observed how the results were improved as well as comparing the same design using two different materials, Ro4350 and FR4-Epoxy.

1. Chapter 1: Antenna Fundamentals Proprieties

1.1. Introduction

The world had a great development in communication technologies from the eighties of the last century to the present day, The wireless communication is the most used type in our life it can be found in phones, cars, hospitals, military fields, and more. The reason for this development is due to the invention called the antenna, So what is the antenna? Its Types, and especially characteristic of Printed Microstrip Antenna(Patch Antenna).

1.2. What is Antenna?

A wireless communication system has two main components the Transmitter and the Receiver each of which contains an antenna, Antenna is a metallic device used for radiating and/or receiving electromagnetic waves. information like sound, video, and documents could be transmitted in form of microwaves (1).

As we mentioned in the introduction, antennas are used in several fields, but do we use the same type of antenna in all fields? If this is not possible, what are the types of antennas and the characteristics of each type?

1.3. Antennas Types

Table 1.1: Antenna Types and Characteristics

Antenna Type	Characteristics	Example
Electrically small Antenna	• $L<<\lambda$ • (L: Antenna length) • Low cost • Low efficiency • Low gain • impedance with Low real R and high imaginary X	• Goubau antenna • Foltz antenna • Rogers cone
Resonant	• $L=\frac{\lambda}{2}$ • Medium gain • Narrow bandwidth • Real impedance value	• Dipole Antenna
Broad-Band	• Wide band-width	• Spiral Antenna

	• Medium gain • Medium impedance	
Aperture	• High gain • High real impedance • Used with microwave frequency	• Horn Antenna • Reflector Antenna
Microstrip (Patch antenna)	• Low fabrication cost • Small size • High performance	Used in : • satellite • Missiles • Aircraft • Spacecraft

(2)

1.4. Microstrip Antennas

The Microstrip Patch Antenna is a single-layer design with four pieces in general (patch, ground plane, substrate, and the feeding part). Patch antennas are resonant antennas with only one element. Everything (such as the radiation pattern input impedance, for example) is fixed once the frequency is specified.

The patch is an extremely thin ($t \ll \lambda 0$, where $\lambda 0$ is the free space wavelength) radiating metal strip (or array of strips) positioned on one side of a thin no conducting substrate, with the ground plane being the same metal on the opposite side.

Typically, the metallic patch is comprised of thin copper foil that has been plated with corrosion-resistant metal such as gold, tin, or nickel. Patches come in a variety of shapes, some of which are depicted in figure (1.1), with the rectangular and circular patches being the most popular.

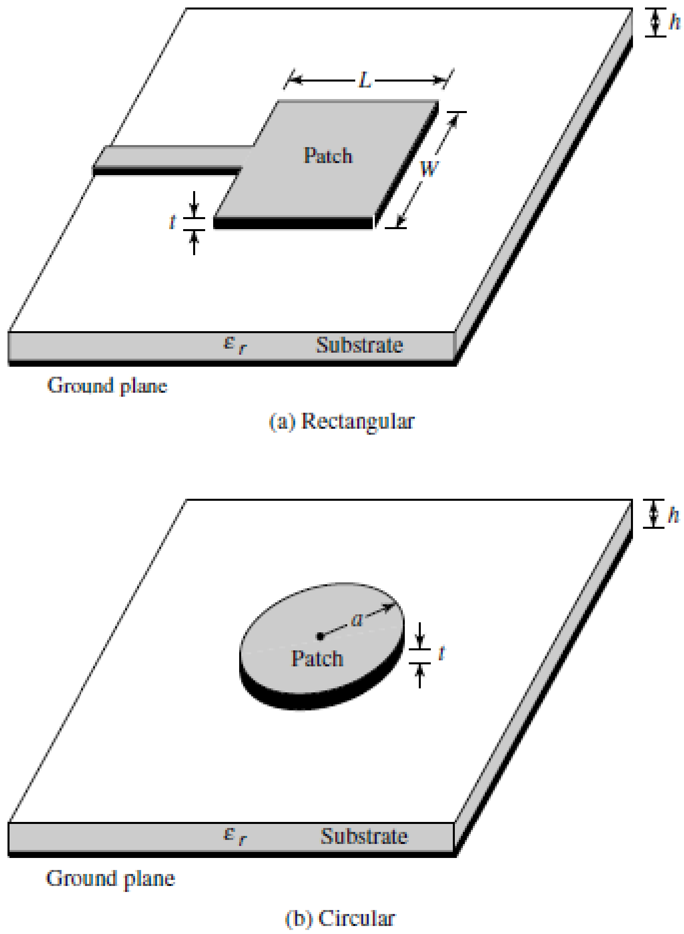


Figure 1.1: Patch antenna most used types

The thickness of the substrate layer is 0.01–0.05 of the free-space wavelength (λ0). It's mostly utilized to ensure that the patch and its ground plane are properly spaced and supported mechanically. It's also commonly used to load and shrink patches using high dielectric constant materials. The substrate material should have a loss tangent of less than 0.005 and have a minimum insertion loss. According to the dielectric constant r, substrate materials can be divided into three types. (1).

1. Having a relative dielectric constant Ɛr in the range of 1.0–2.0. This type of material can be air, polystyrene foam, or dielectric honeycomb.
2. Having Ɛr in the range of 2.0–4.0 with material consisting mostly of fiberglass reinforced Teflon.

3. With an Ɛr between 4 and 10. The material can consist of ceramic, quartz, or alumina

A microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other. The Dielectric Substrate is made of five different materials: Duroid, Benzocyclobutane, Roger 4350, FR4-epoxy, and Bakelite.

Wich material should we use ? substrate material depends on, which band you want to operate

- FR4(high loss, low gain antenna, cheap, easy availability);
- low loss and low permittivity (RT Duroid 6002, PTFE, high gain antennas).
- Low loss material for a substrate is having a high cost. The ground material is generally copper.
- ceramic (Rogers RO 3200, low cost, GPS patch antenna). (3)

Methode of Analysis MSA:

There is several methods to analyze MSA's such as: Cavity Model, transmission line, analytical model, numerical model.

1.5. Advantages of Microstrip Antenna

Microstrip antennas have the advantages of being compact, low profile, lightweight, and conformable to planar and non-planar surfaces. When mounted, it just takes up a small amount of space in the building. Using modern printed circuit technology, they are simple and inexpensive to produce. Patch antennas, on the other hand, have drawbacks. Microstrip antennas have several drawbacks, including low efficiency, narrow bandwidth of less than 5%, and low RF power due to the close proximity of the radiation patch to the ground plane (not suitable for high-power applications). (4)

1.6. Application of Microstrip Antenna

In wireless communication, the microstrip patch antenna has a variety of uses. Satellite communication, for example, necessitates circularly polarized radiation patterns, which can be achieved with a square or circular patch microstrip antenna. Circularly polarised microstrip antennae are employed in global positioning satellite (GPS) systems. They are small in size and, because of their location, highly pricey.

RFID (radio frequency identification), mobile communication, and healthcare all use microstrip antennae. An RFID system is made up of two parts: a tag and a reader. It typically operates at frequencies ranging from 30 Hz to 5.8 GHz.

Microstrip antennae operate at 2.45 GHz in telemedicine applications. Microstrip antennae that may be worn are appropriate for wireless body area networks. Telemedicine applications can benefit from an antenna with a gain of 6.7 dB and a front-to-back ratio of 11.7 dB that resonates at 2.45 GHz.

WiMax refers to the IEEE 802.16 standard (worldwide interoperability for microwave access). With a data throughput of 70 Mbps, it can cover a radius of up to 48 kilometers (30 miles). Microstrip antennae are capable of resonating at several frequencies. As a result, these can be employed in WiMax communication devices.

1.6.1. Mobile Communication

Small, low-cost, low-profile antennae are required for mobile communication. As antennae, semiconductor-based diodes or detectors are utilized in some mobile handsets. They work at microwave frequencies and are similar to p-n diode photo-detectors. Omnidirectional antennas are frequently used in mobile phones. Antenna types include planar inverted-F antennas, folded inverted conformal antennas, and monopole antennas. In addition, handsets often include a retractable whip antenna.

1.6.2. Medical applications

Microwave energy is claimed to be the most effective means of producing hyperthermia in the treatment of malignant tumors. The radiator chosen for this function should be light, easy to handle, and durable. Only a patch radiator can meet these criteria.

Microstrip radiators for inducing hyperthermia were first constructed using printed dipoles and annular rings that were designed using S-band technology (2-

4 GHz). Later, the design was based on an L-band circular microstrip disk (1-2 GHz). The temperature inside the human body is measured using two connected microstrip lines with a flexible separation.

1.6.3. Monitoring Human Body Data

Currently, antennae are used to continuously monitor biometric data of the human body in several applications. To do so, they must remain so close to the human body at all times that they can continuously monitor biometric data and transmit it to the outside world. If the antenna is firm, it will not be able to remain permanently attached to the human body. An antenna constructed of textile material is safe to wear and can be worn for long periods. Wearable antennas will be useful in fields such as healthcare, recreation, and firefighting.

Due to the current miniaturization of wireless devices, textile materials are increasingly being utilized in the development of flexible wearable systems. Textile materials make attractive substrates for flexible antennae because fabric antennae may be easily integrated into clothing.

The radiating patch and ground plane of this unique patch antenna are composed of conductive textile material. The substrate is a textile with a specified dielectric constant as well. It's called a textile antenna since everything is composed of textile material (5).

1.7. Types of antennas patches

Microstrip patch antennas come in a variety of shapes, each tailored to a certain set of properties. The most frequent types of millimeter-wave frequencies are rectangle, square, and circular patches, which are represented in figure (1.2).

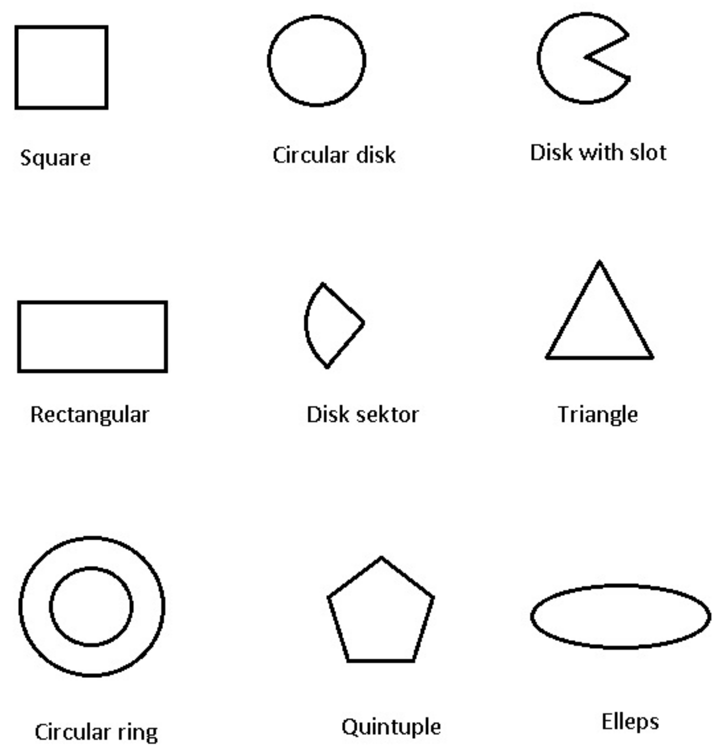


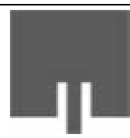
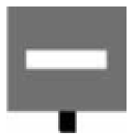
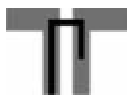
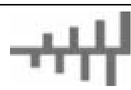
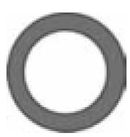
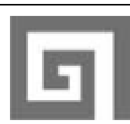
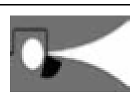
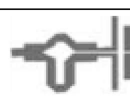
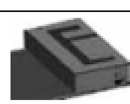
Figure 1.2: Antenna patch types

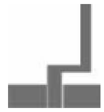
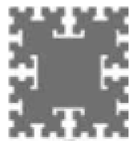
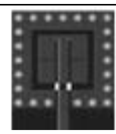
The substrate we choose is also crucial; we must consider temperature, humanity, and other operational environmental ranges. The thickness of the substrate h has a significant impact on the antenna's resonance frequency r and bandwidth BW. The microstrip antenna's bandwidth will rise as the substrate thickness h increases, but only to a point; otherwise, the antenna would stop resonating (4).

1.8. Types of Printed Antennas

Different types and technologies of printed antennas might be chosen depending on the application. Planar microwave technology such as microstrip, slot lines, coplanar waveguide (CPW), and customized printing gave rise to printed antennas. The geometry of the radiating element feeds, or ports that allow for excitation and radiation are used to classify the many types of printed antennas. Different categories exist based on their features. Table 1.1 compares several types of planar antennas.

Table 1.2 Planar Antenna comparison

Type	*Sketch*	*Radiation Pattern*	*Directivity*	*Bandwidth*
Microstrip Patch		Broadside	Medium	Narrow
Slot		Broadside/ bidirectional	Low/medium	Medium
Dipole		Broadside	Low	Medium
LPDA		End-fire	Medium	Wide
Bow tie		Broadside	Medium	Wide
Circular loop		Broadside	Medium	Narrow
Spiral		Broadside	Medium	Wide
TSA		End Fire	Medium/high	Wide
Quasi-Yagi		End Fire	High	Wide
PIFA		Broadside	Medium	Medium

Monopole		Broadside	Low	Medium
Fractal		Broadside	High	Wide
Leaky wave		Scannable	High	Medium

1.9. Microstrip Antenna Working Principal

As seen in Figure 1.3, a microstrip patch radiates from fringing fields around its edges. A charge dispersion is established between the ground plane and the beneath of the patch when the metallic patch is excited by feed. Because the patch has a positive charge and the ground plane has a negative charge, attraction forces are created between the patch and the ground plane. The patch is viewed as a resonant cavity with metal (electric) walls between the patch and the ground plane and magnetic or impedance walls around the borders in a general analysis. When a patch resonates as a resonant cavity, it is said to be impedance matched. With perfect impedance matching, the antenna may attain maximum efficiency. The field lines are constant in width but fluctuate in length in a sinusoidal pattern. The current is greatest in the patch's center, while the electric field is greatest at the patch's two radiating borders. A regular transmission line, unlike the patch, radiates less power because the bordering fields are balanced by surrounding counteracting fields.

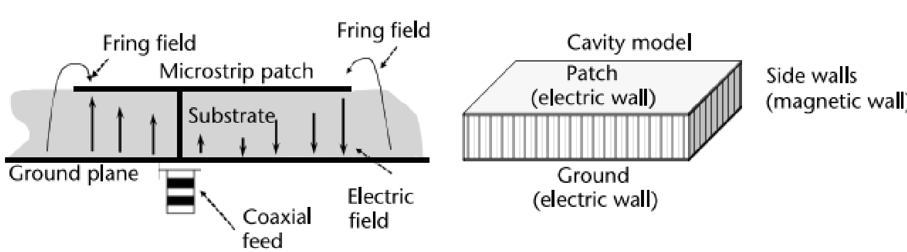


Figure 1.3: Microstrip patch radiation mechanism and cavity model representation

Open circuits and discontinuities such as transitions and corners radiate power, although the amount depends on the line's radiation conductance load relative to the patches. The edges of a patch operate as slots, and their excitations are determined by the cavity's internal fields. A thick dielectric substrate with a low dielectric constant is preferable for antenna construction because it gives higher efficiency, larger bandwidth, and better radiation, although it increases antenna size. Higher dielectric constants, which are less efficient and result in a narrower bandwidth, are required to construct a small microstrip patch antenna. As a result, a balance between antenna size and antenna performance must be struck. (6)

1.10.Cavity Model of Rectangular Microstrip Patch

The microstrip patch is represented in the cavity model by assuming that the substrate material is truncated and does not extend beyond the patch's edges, as shown in Figure 1.3. The substrate's four side walls serve as magnetic walls, and they represent four thin holes (slots) through which radiation passes. Electric barriers (conductors) on the top and bottom limit the internal area of the dielectric substrate to a cavity. Using the equivalence principle, the radiated field is determined. The field inside the cavity is considered to be zero, and the equivalent surface currents on the cavity's surface represent its influence on the field in the infinite region outside (5). Therefore, the tangential H components at the slots are equal to zero:

$$\mathbf{J_s} = \hat{\boldsymbol{n}} \times \mathbf{H} = \mathbf{0} \qquad \mathbf{1.1}$$

The equivalent magnetic current density is the only factor that has a significant impact on the radiated field.

1.11.Antenna Parameters

1.11.1. Radiation Pattern

The radiation pattern is defined as "a mathematical function or a graphical representation of the radiation properties as a function of space coordinates."

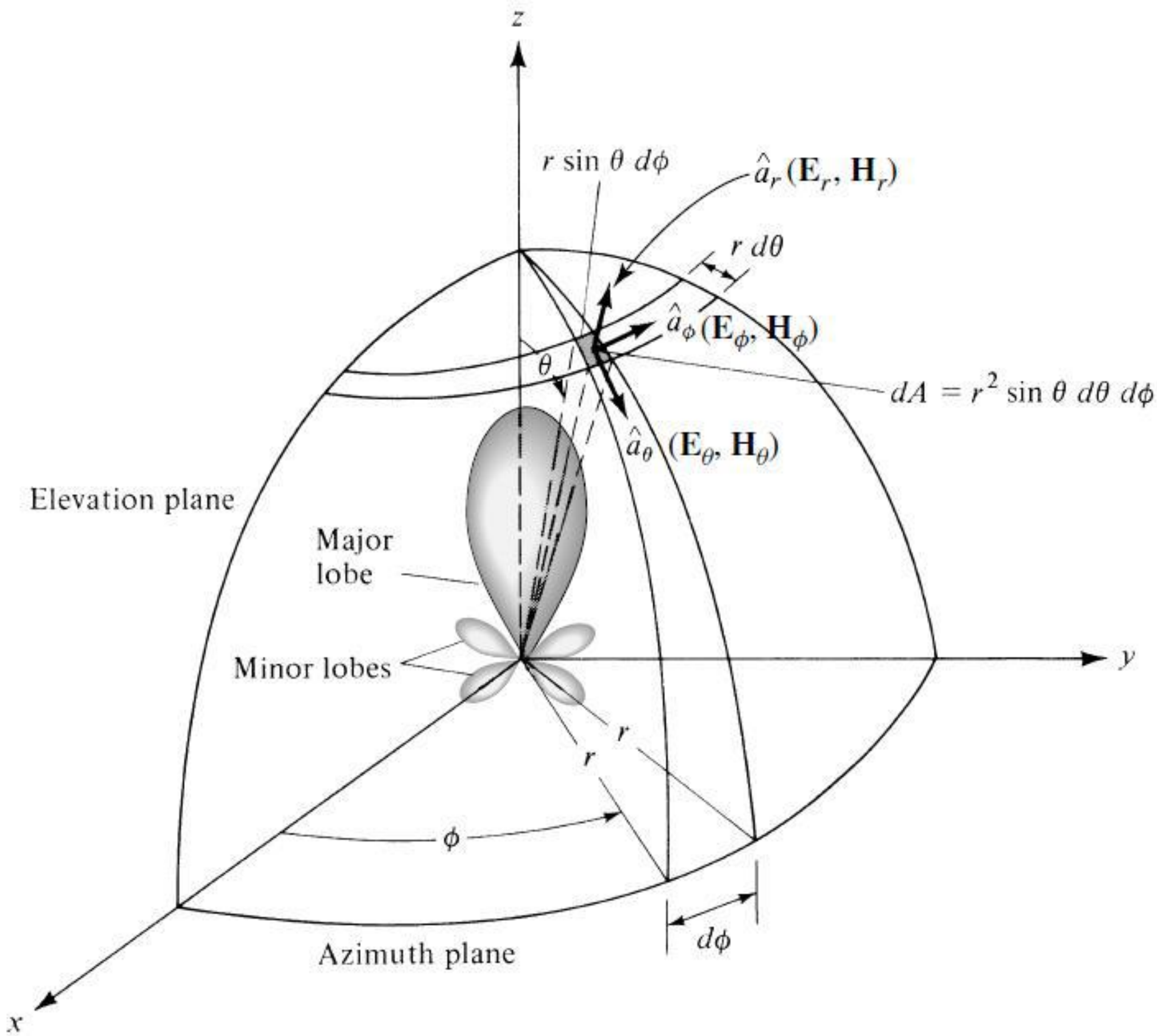


Figure 1.4 : Radiation pattern graphical representation (1)

$$\mathcal{P}rad = \frac{1}{2}\mathbf{Re} \iint \mathbf{s}\ \mathbf{E1} \times \mathbf{H2}\,.\,\mathbf{ds} \qquad 1.2$$

$$\mathcal{P}rad = \frac{1}{2\eta} \iint (|E\theta|^2 \times |E\theta^*|^2) r^2 sin\theta \, d\theta d\Phi \qquad \textbf{1.3}$$

We'd like to point out that the electric field E within the patch is normal to the patch and the ground plane, and the magnetic field H is parallel to the strip edge for a microstrip antenna. The dominant mode polarization of a rectangular patch antenna is linear and directed along the patch dimensions.

1.11.2. Efficiency and Quality Factor

The power radiated from the microstrip element divided by the power received by the input to the element is the efficiency of a microstrip patch antenna. The dielectric loss, conductor loss, reflected power (Voltage Standing Wave Ratio VSWR), cross-polarized loss, and power dissipated in any loads in the element are all factors that affect the antenna's efficiency and determine whether it is high or low.

Most antenna literature includes references to this research and includes a general expression of the radiation efficiency.

$$\mathrm{e} = \frac{\mathcal{P}rad}{\mathcal{P}rec} \qquad \textbf{1.4}$$

Where:

Prad= Power radiated by the antenna.

Prec=Power Accepted by the antenna.

Efficiency can also be expressed in terms of the quality factor Q as follows:

$$e = \frac{1/Q_{\mathrm{rad}}}{1/Q_t} = \frac{Q_t}{Q_{\mathrm{rad}}} \tag{1.5}$$

Qt = total quality factor

Qrad = quality factor due to radiation (space wave) losses.

$$\frac{1}{Q_t} = \frac{1}{Q_{rad}} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_{sw}} \tag{1.6}$$

Qc = quality factor due to conduction losses (ohmic).

Qd= quality factor due to dielectric losses.

Qsw= quality factor due to surface waves.

The majority of microstrip antennas have an efficiency of 80 to 90%. For a slender antenna.

$$h \ll \lambda_{\mathrm{o}}, t <\ll \lambda_{\mathrm{o}} \tag{1.7}$$

There are approximate formulas to calculate the quality factor:

$$Q_c = h\sqrt{\pi f \sigma \mu} \tag{1.8}$$

$$Q_d = \frac{1}{\tan \delta} \tag{1.9}$$

$$Q_{rad} = \frac{2\omega\varepsilon r}{hGt/l} K \tag{1.10}$$

Where:

Tan δ = The loss tangent of substrat.

σ= conductivity of conductor.

Gt/l = the total conductance per unit length.

1.11.3. Directivity and Gain

An antenna's directivity refers to its capacity to focus energy in a certain direction. "Directivity (of an antenna) (in a given direction) is the ratio of the radiation intensity in a particular direction from the antenna to the radiation intensity averaged over all directions," according to IEEE Standard 145-1983. The total power radiated by the antenna divided by four equals the radiation intensity. The directivity of a system is always greater than one (7).

$$D = \frac{\frac{1}{2} Re\left(E_\theta H'_\varphi - E_\varphi H'_\theta\right)(\theta = 0)}{P_{\text{rad}}/4\pi} \quad \textbf{1.11}$$

$$\eta_o = 120\pi$$

for the directivity D of a rectangular patch antenna. In this approximation, note that (ɵ=0).

$$D \approx \frac{4(koW)^2}{\pi\eta G_{rad}} \quad \textbf{1.12}$$

Where Grad= radiation conductance of the patch

According to IEEE Std 145-1983, the directed gain is "the ratio of the radiation intensity in a particular direction to the radiation intensity that would be obtained if the antenna's power was emitted isotropically." The antenna's directivity can be used to achieve more gain:

$$G = eD \quad \textbf{1.13}$$

The antenna's effectiveness is denoted by the letter e. Because efficiency is between 0 and 1, the gain is always less than directivity. With increasing substrate thickness h and patch width W, the directivity increases. In contrast, when h and W decrease, the beamwidth is projected to decrease.

1.11.4. Impedance Matching

The maximum power transfer hypothesis asserts that for maximum power to be transferred from a source with fixed internal impedance to a load, the load's impedance must be the same as the source's “Jacobi’s low”.

$$Zs = Z_L^* \qquad \textbf{1.14}$$

Zs = impedance of the source.

Zl= impedance of the load.

Because most microwave applications have a 50Ω input impedance, we want to match the antenna to 50 ohms. As demonstrated in picture 1, we can start by modeling the patch as a parallel equivalent admittance Y(1.5).

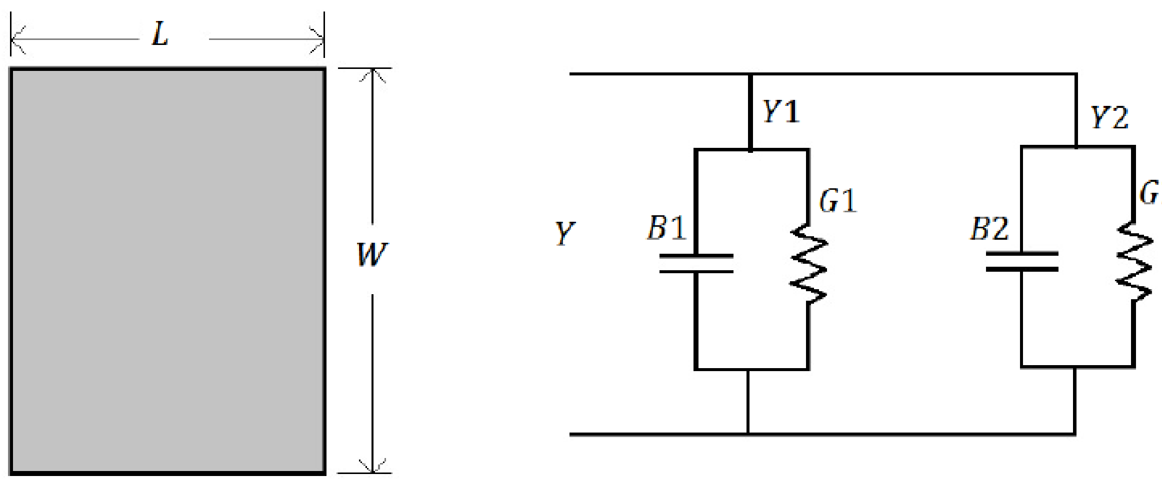


Figure 1.5: Rectangular patch and its transmission model equivalent

Where:

$$Y = \frac{1}{z_L} = G + jB \qquad \textbf{1.15}$$

Here we have (1)

$$Y1 = Y2 \qquad 1.16$$

That's mean:

$$G1 = G2, B1 = B2 \qquad 1.17$$

A general expression for the conductance G1 is given by [1, 4, 5, and 8]

$$G1 = \frac{2P_{\mathrm{rad}}}{|V_o|^2} \qquad 1.18$$

Where:

Vo is the voltage across the slot.

$$P_{rad} = \frac{|V_o|^2}{2\pi\eta_o}\int_0^{\pi}\left[\frac{\sin\left(\frac{k_oW}{2}\cos\theta\right)}{\cos\theta}\right]^2 \sin^3\theta d\theta \qquad 1.19$$

Therefore G1 can be expressed as:

$$G1 = \frac{1}{120\pi}\int_0^{\pi}\left[\frac{\sin\left(\frac{k_0W}{2}\cos\theta\right)}{\cos\theta}\right]^2 \sin^3\theta d\theta \qquad 1.20$$

Going back to equation (1.14):

$$Z_S = R_S + jX_S = Z_L^{*\prime} = R_L - jX_L \qquad 1.21$$

$$Z_S = \frac{1}{Y_S} = R_s = \frac{1}{2G_1} \qquad 1.22$$

According to C. Balanis [1] taking into account the mutual effects of the parallel equivalent admittance Y1 and Y2 shown in figure (1.5);

$$R_{in} = \frac{1}{2(G1 \mp G2)} \qquad \textbf{1.23}$$

Where "the plus (+) sign is used for modes with odd (antisymmetric) resonant voltage distribution beneath the patch and between the slots, while the minus (-) sign is used for modes with even (symmetric) resonant voltage distribution beneath the patch and between the slots," and "the minus (-) sign is used for modes with even (symmetric) resonant voltage distribution beneath the patch and between the slots." (1).

$$G12 = \frac{1}{|V_o|^2} \iint_s E1 \times H2^* \cdot ds \qquad \textbf{1.24}$$

Where:

E1 is the electrical field radiated by Y1

H2* is the magnetic field radiated by Y2

$$G12 = \frac{1}{120\pi} \int_0^{\pi} \left[\frac{\sin\left(\frac{k_o W}{2} \cos\theta\right)}{\cos\theta} \right]^2 J_o(k_o L \sin\theta) \sin^3\theta d\theta \qquad \textbf{1.25}$$

Jo is the Bessel function of the first kind of order zero.

Finally, the position of the feed point of the patch (where the impedance of the patch at that point is 50Ω) can be found in the following equation:

$$\text{Rin} = \frac{1}{2(G1 \mp G12)} \cos^2\left(\frac{\pi}{L} y_0\right) \qquad \textbf{1.26}$$

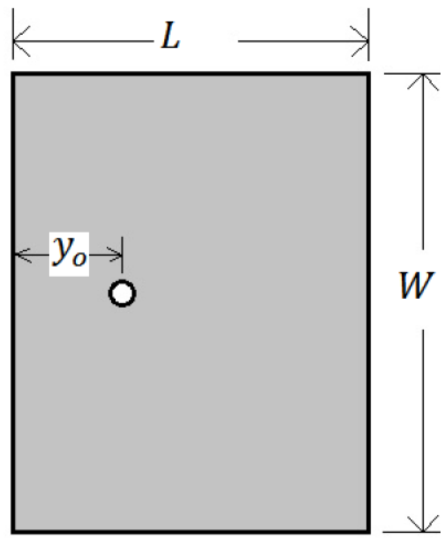


Figure 1.6:Dimesions of patch

The impedance of the microstrip patch antenna is independent of the substrate dielectric constant r or the height of the substrate h, as shown by equations (1.18) to (1.26). The resonance input resistance is highly influenced by the patch width W; raising W reduces the patch's input resistance Rin figure(1.6).

1.11.5. Return Loss

When evaluating an antenna, return loss is a vital factor to consider. It has something to do with impedance matching and the maximum power transfer theory. It's also a metric for how well an antenna transmits power from the source to the antenna. The return loss (RL) is calculated as the ratio of the antenna Pin's incident power to the power reflected from the source Pref's antenna; the mathematical expression is:

$$RL = 10\log_{10}\frac{P_{\text{in}}}{P_{\text{ref}}} \qquad \textbf{1.27}$$

For good power transfer, the ratio $\frac{P_{\text{in}}}{P_{ref}}$ is high. Another definition of return loss The difference in dB between the power delivered to the antenna and the power reflected from it can be calculated using equation (1.27). When the antenna is passive, it is always positive, and when it is active, it is always negative. The equation (1.27) can be stated as follows in terms of voltage, voltage-standing-wave-ratio (VSWR), and impedance (8):

$$RL = 10\log_{10}\left|\frac{1}{\rho}\right| \qquad \textbf{1.28}$$

$$= -20\log_{10}|\rho|\ (dB) \qquad \textbf{1.29}$$

$$RL = 20\log_{10}\left|\frac{VSWR+1}{VSWR-1}\right| \qquad \textbf{1.30}$$

$$= (40\log_{10} e)\,\text{artanh}\left|\frac{1}{VSWR}\right| \qquad \textbf{1.31}$$

$$RL = 20\log_{10}\left|\frac{Z_1+Z_2}{z_1-Z_2}\right| \qquad \textbf{1.32}$$

Where ρ is the complex reflection coefficient at the input of the antenna.

VSWR is the voltage standing wave ratio.

Z1 and Z2 are the impedance of the source and the antenna.

1.11.6. Polarization

An antenna's polarization is the polarization of the wave emitted by the antenna. Otherwise, a receiving antenna will not resonate unless it has the same polarization as the sending antenna. Polarization is an electromagnetic wave feature that specifies the amplitude and direction of the electric field vector as a function of time, or "the orientation of the electric field for a given point in space." When a basic straight wire is mounted vertically, it has one polarization, and when it is mounted horizontally, it has a different polarization (1.7).

There are three types of polarization: linear, circular, and elliptical. The antenna is vertically linear polarized when the electric field is perpendicular to the earth's surface, and horizontally linear polarized when the electric field is parallel to the earth's surface, in linear polarization the antenna radiates power in the plane of transmission, only one plane.

In the propagation direction, a circular polarization antenna radiates power in all planes (vertical, horizontal, and between them). In one period of the wave, the plane of propagation rotates in a circle, completing one complete cycle.

From Maxwell's Equations:

$$\nabla \times E = -j\omega\mu H \qquad \textbf{1.33}$$

$$\nabla \times H = (\sigma + j\omega\varepsilon)E \qquad \textbf{1.34}$$

$$\nabla \cdot E = \frac{\rho}{\varepsilon} \qquad \textbf{1.35}$$

$$\nabla \cdot H = 0 \qquad \textbf{1.36}$$

We get the value of H from equation 1.34 and replace it to equation 1.33 we get

$$\nabla \times E = -j\omega\mu H \times (\sigma + j\omega\varepsilon)E/\nabla \qquad \textbf{1.37}$$

By multiplying the equation 1.37 by ∇ we get

$$\nabla \times \nabla \times E = -\gamma^2 E \qquad \textbf{1.38}$$

Where: $\gamma^2 = j\omega\mu H \times (\sigma + j\omega\varepsilon)$

Using the proprieties follow (9) and by replacing the equation 1.35 in 1.39 we get 1.40:

$$\nabla \times \nabla \times E = \nabla(\nabla . E) - \nabla^2 E \qquad \textbf{1.39}$$

from equation (1.33) is as follows [1, 3, 4, 6, 7, and 10]:

$$\nabla^2 E - \gamma^2 E = \nabla(\rho/\varepsilon) \qquad \textbf{1.40}$$

In free space (ρ=0)

$$\nabla^2 E - \gamma^2 E = 0 \qquad \textbf{1.41}$$

Equation (1.38) has many possible solutions to it (10); one possible solution is:

$$E = E_o e^{j\omega t + \gamma z} \hat{X} \qquad \textbf{1.42}$$

$$E = E_o e^{j\omega t + \gamma z} \hat{Y} \qquad \textbf{1.43}$$

$$E = E_o e^{j\omega t \pm \gamma x} \hat{Z} \qquad \textbf{1.44}$$

Now consider the figure (1.7); the electromagnetic wave radiated by an antenna has an electric field E with two components Ex and Ey where:

$$E_x = |E_x| \cos(\omega t - \beta z) \qquad \textbf{1.45}$$

$$E_y = |E_y| \cos(\omega t - \beta z + \varphi) \qquad \textbf{1.46}$$

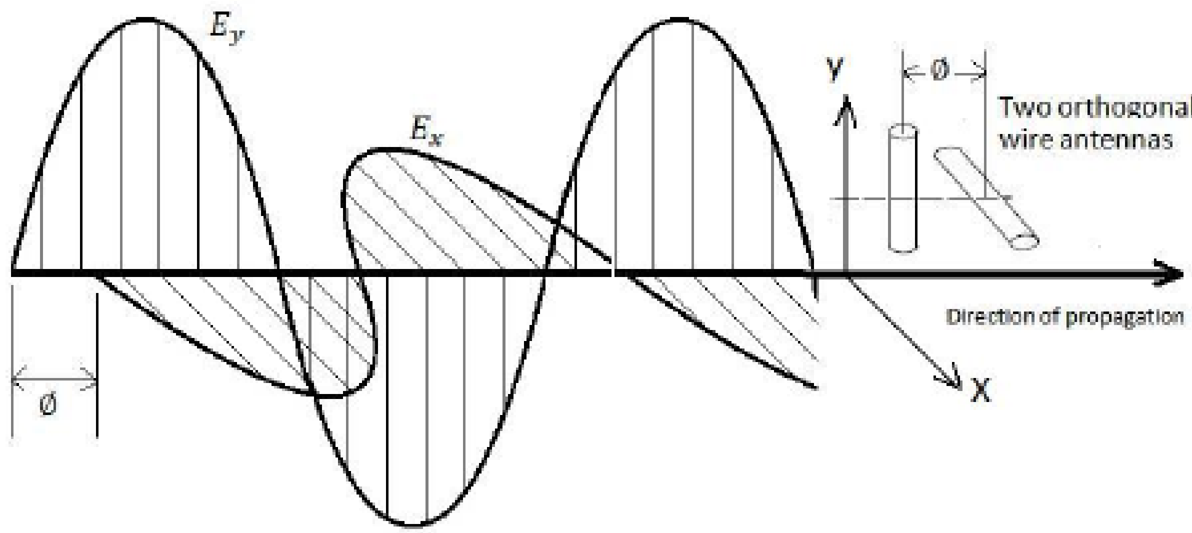


Figure 1.7:Polarization of electromagnetic wave

The amplitudes of the field components in the x and y directions are |Ex| and |Ey|, respectively. Another solution to the wave equation is Equations (1.42) and (1.43). (1.38). The components |Ex| and |Ey| of equations (1.42) and (1.43) describe the type of polarization of the electromagnetic wave and the antenna; when |Exy| or |Ey| is zero, the wave and antenna are said to be linearly polarized; when |Ex|= |Ey|≠0, the antenna and wave are circularly polarized; and when |Ex|≠|Ey|≠0 the antenna and wave are elliptically polarized. Linear polarization is utilized in applications such as television transmission. Because of what is known as Faraday Rotation to the electromagnetic wave, circular polarization is widely used in satellite communication because linear polarization is poor and difficult to match in satellite transmission, which means "linear polarized electromagnetic wave may be rotated by an unknown amount (depending on the thickness and temperature of the ionosphere, as well as the frequency; the rotation is high at lower frequencies and small at higher frequencies)".

1.12.Conclusion

Because of the great importance of the basics of antennas in the study and improvement of manufacturing, in this chapter we covered the most important basics of antennas. In addition, we categorized printed antennas and showed how important the patch antenna is in terms of cost and ease of manufacture, as well as its effectiveness in the field of communications.

On the other hand, we mentioned the most important areas in which MSA's are used and the way they work with most of the methods used in analyzing their results.

2. Chapter2: Microstrip Antenna Feeding and improvement techniques

2.1. Introduction

With the invention of a new type of antenna called MSA's, antenna design became required with certain specifications such as small size, good gain, high or low frequency range depending on its field of use and excellent efficiency. Considering the possibility of integrating the antenna with different surfaces.

In this chapter we will talk about the effect of conductor shape on antenna parameters and most of the feeding techniques used in MSA with the importance of choosing the right type as it has an effect on antenna performance, in addition to that we will detail most of the methods used to improve antenna performance and materials used in manufacturing patch antenna with pros and cons of each.

2.2. The Effect of Conductor Shape

Many conductor forms have been proposed and researched for a microstrip patch antenna over the years. A quick description of the benefits and drawbacks is provided below. We're presuming that the patch is only used in the lowest order mode, which is how it's usually used because it's the smallest.

2.2.1. Rectangular Patches

Rectangular shapes were the first and most widely used patch conductor geometry. To generate a mode in this direction, the rectangular patch antenna is excited at some point along the resonant dimension, L. Figure 2.1 depicts the currents excited on a rectangular patch, as well as their direction of propagation. (11).

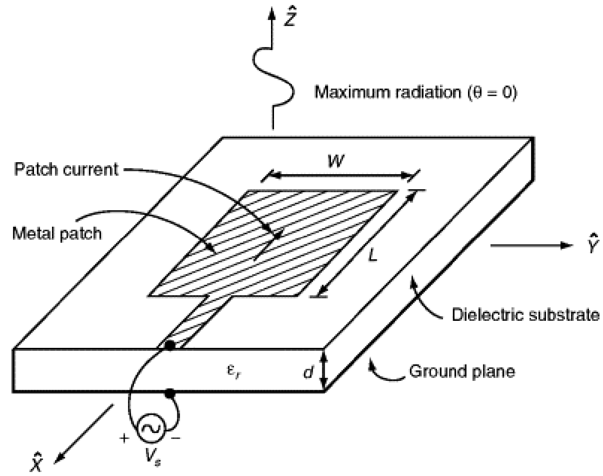


Figure 2.1:Geometry of a Rectangular Microstrip Antenna.

It consists of a rectangular metal patch on a dielectric substrate and is excited by a voltage source across the metal patch and the bottom ground plane of the substrate. The microstrip antenna produces maximum radiation in the broadside direction (θ = 0), with ideally no radiation along the substrate edges (θ = 90°), The width of the patch affects the impedance level at resonance as well as the bandwidth (a second-order effect), while the length of the patch determines the resonant frequency: The antenna's input impedance decreases as the patch width increases.

Keep in mind that this statement is only true in specific circumstances (relatively thin substrate material). These connections are not mutually exclusive when the material thickness increases to greater than 0.03λ0, and the feeding process and location can substantially modify all performance measurements.

Rectangular patches, in general, have the highest impedance bandwidth of all the conductor forms, simply because they are larger than the others. Dual or circular polarization can be generated using square patches (11).

2.2.2. Circular and Elliptical Patches

These are the second most common geometric shapes. Because circular and elliptical patches are slightly smaller than rectangular patches, they have lower gain and bandwidth. A circular patch conductor's dominant modal distribution differs from that of a rectangular/square patch conductor.

The overall impact is similar to the rectangular patch case: the current magnitude (represented by the size of the arrows) is greatest in one direction. The radius of a circular patch, like that of a square patch, is the only degree of freedom in its conductor shape. As a result, changing the radius affects the circular patch's resonance frequency. The feed location, under conservative conditions, will control the antenna's input impedance at the desired resonance frequency.

The inherent symmetry of circular geometry was one of the key reasons it was extensively researched in the past. This enabled the development of full-wave analysis tools that used a spectral domain technique and were more computationally efficient than their rectangular counterparts.

This was critical in the early stages of patch design and development since it allowed for the efficient exploration and optimization of performance trends in more complex structures (such as stacked patches). Importantly, because the differences in performance of different conductor-shaped patches are minor, these trends might be applied to other geometries. Systems utilizing circular patch antennas are becoming increasingly rare (9), as a result of the introduction of various rigorous, computationally fast full-wave design tools, such as Ensemble and IE3D (11).

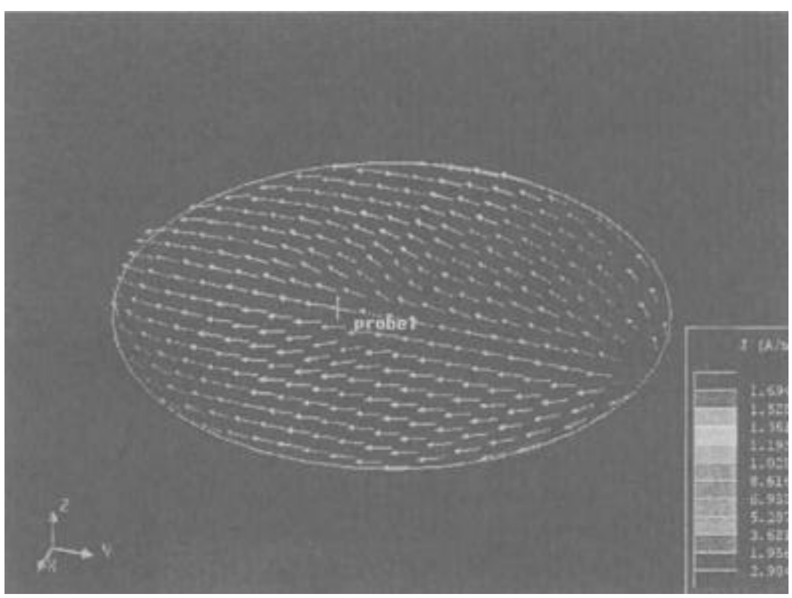


Figure 2.2:Typical Fields Excited on a Circular Patch Antenna

2.2.3. Triangular and Disc Sector Patches

The patch geometries of triangular and disc sector patches are smaller than their rectangular and circular equivalents, albeit at the cost of increased bandwidth and gain.

Due to their lack of symmetry in the design, triangular patches also produce higher degrees of cross-polarization. The current distribution on a triangular patch conductor is shown in Figure 2.3. Currents oriented in the orthogonal direction to the primary polarization field contribute to cross-polarization fields.

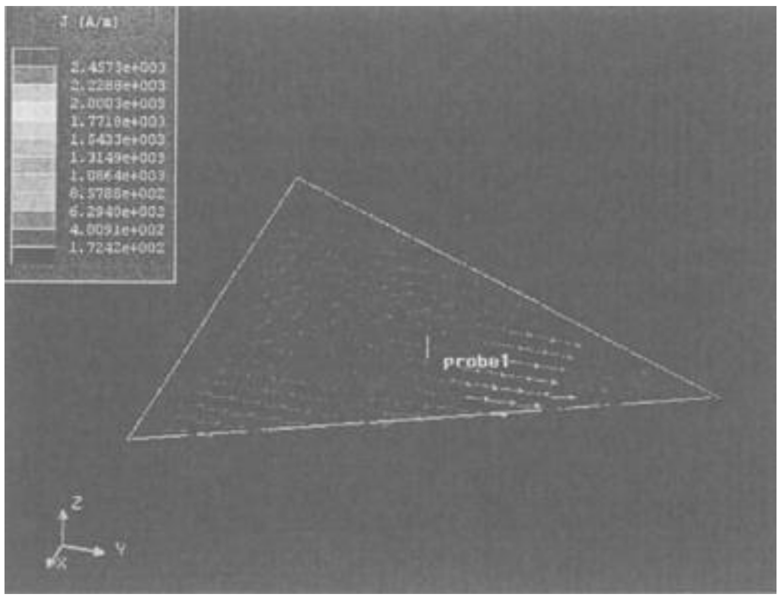


Figure 2.3:Typical Fields Excitedon a Triangular PatchAntenn

The rectangular patch has a comparable number of design freedoms as the triangular and disc sector patches. If the TM01 mode is excited in a disc sector antenna, the radius of the disc controls the resonant frequency, while the sector angle regulates the bandwidth and impedance. Dual-frequency and dual-polarization patches can be created using either of these conductor configurations depending on the aspect of the triangle and the disc sector, however, the bandwidth is often very limited. The polarization for each frequency band is also orthogonal in the dual-frequency patch (11).

2.2.4. Annular Rings

The smallest conductor shape is an annular ring geometry, which comes at the sacrifice of bandwidth and gain. One issue with an annular ring is that exciting the lowest order mode and obtaining an input impedance close to 50 at resonance is a difficult operation. impedance values of 150 to 250 Ω are relatively common. To feed this element, non-contact types of stimulation are usually necessary at the sacrifice of antenna efficiency. The symmetry difficulties that plagued the circular patch examples apply here as well. Figure 2.4 depicts the current distribution of a probe-fed annular ring. (11).

Because the annular ring has one additional design variable than the circular patch, it should be easier to manage its reaction. The printed antenna's resonance frequency may be controlled using both the inner and outer ring dimensions, which is particularly useful. The impedance bandwidth becomes narrower as the inner radius approaches the outside radius dimension. (11).

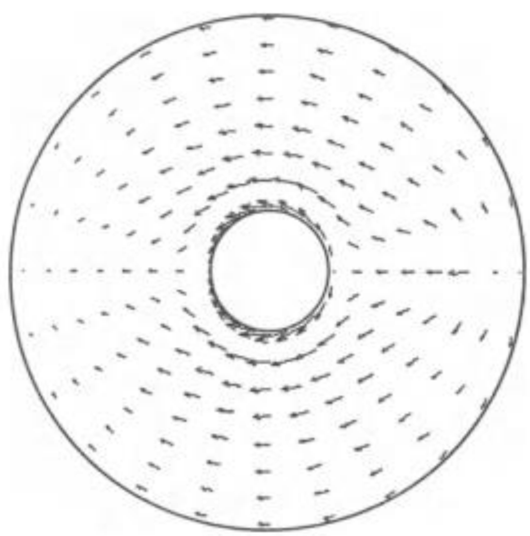


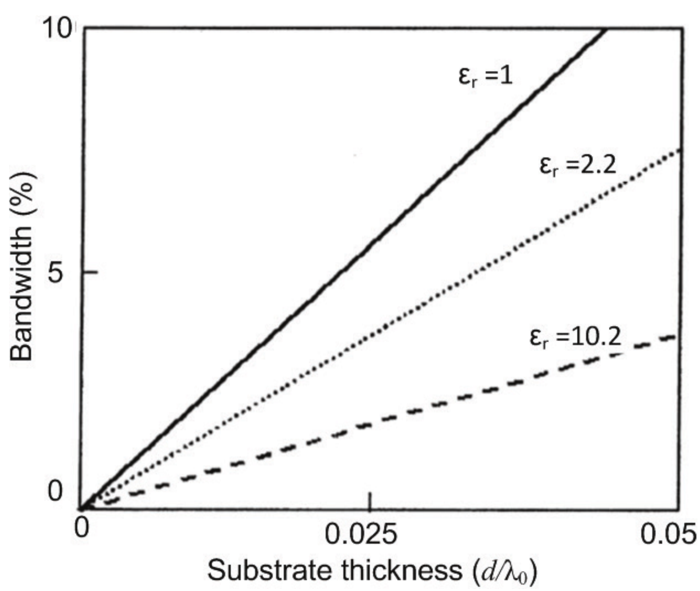
Figure 2.4:Typical CurrentslFields Excited on an Annular RingPatch

2.3. Impedance and Radiation Performance of single layer Patches

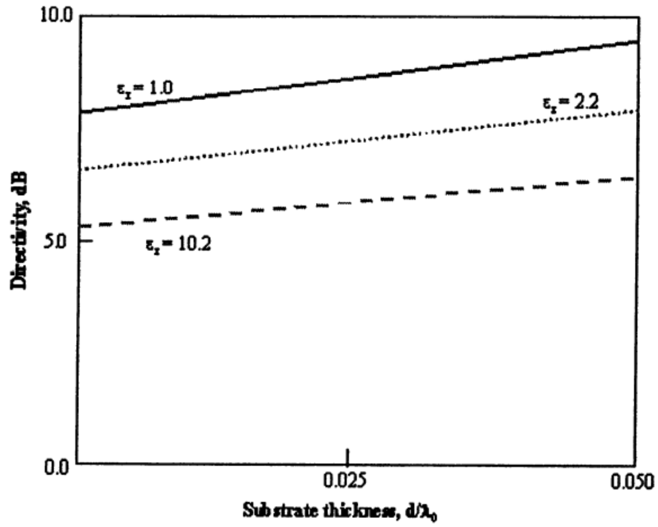
Figure 2.5 depicts some basic, yet critical performance trends for a single layer microstrip patch antenna as a function of the laminate parameters employed to build the substrate. The features of microstrip patch antennas in their pure form with a simple, perfect excitation mechanism are represented by these performance trends. Although rectangular patches are the most popular, various conductor shapes offer similar reactions.

Figure 2.5.a shows the impedance bandwidth (defined as a 10 dB return loss bandwidth) for various dielectric constant values as a function of the laminate's electrical thickness. The greater the bandwidth of the microstrip patch antenna, as seen in this graph, the thicker the substrate material. A key takeaway from Figure 2.5.a is that the lower the dielectric constant, the greater the antenna's bandwidth. Please note that due to challenges with making microstrip patches radiate efficiently at these thicknesses, the trends will not be sustained for very thick material.

Figure 2.5.b shows the directivity of a patch antenna as a function of electrical thickness for various dielectric constants. Simply put, because the microstrip patch antenna installed on the low dielectric constant laminate is physically larger than the antenna mounted on the high dielectric constant laminate, it has a larger collecting area and thus stronger directivity. Because the volume of the antenna grows larger, the directivity increases slightly as the thickness increases (11).



(a)



(b)

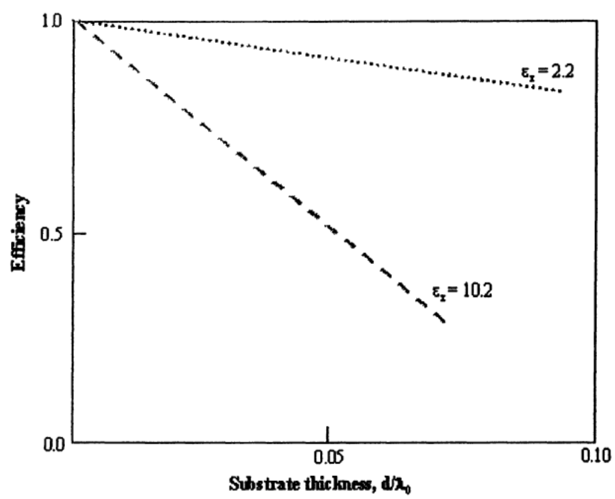


Figure 2.5:Performance trends of single-layered patch antennas: (a) impedance bandwidth; (b) directivity; (c) surface wave efficiency

A microstrip patch antenna suffers from three types of loss: conductor loss, dielectric loss, and surface wave loss. The first two of these loss mechanisms are dependent on the substrate material's quality. The latter is owing to the material's properties, specifically the dielectric constant and the thickness. Surface waves are propagation modes that are supported by the grounded substrate that is utilized to make the patch antenna. Figure 2.5.c shows the surface wave efficiency of a microstrip patch antenna as a function of substrate thickness for multiple dielectric constants. As seen in this diagram, the higher the dielectric constant, the more power is lost to the surface wave and, hence the antenna's efficiency decreases. Please note that when Ɛ= 1.0, there are no surface waves excited. For a typical microstrip patch substrate (Ɛr= 2.55), Figure 2.5 depicts the parameters in which each surface mode is launched. The only surface wave mode that has to be considered in most practical circumstances is the TM01 mode, which is always present (unless Ɛr= 1.0).

One of the oft-touted advantages of microstrip patch technology is the integration of microstrip patch antennas with MMIC (Microwave Monolithic Integrated Circuits) and OEIC (Opto-Electronic Integrated Circuits) technology, which appears to be a key challenge in Figure 2.5. MMICs and OEICs are often made of thin materials with a high dielectric constant (note: the dielectric constant for GaAs and AIGasInP, common materials for MMICs and aBICs is approximately 13). In this setting, attempting to create a microstrip patch antenna would result in an antenna with low bandwidth and radiation performance. Even attempting to directly integrate microstrip patch technology with passive microwave circuits like filters and couplers poses a challenge, as high dielectric constant and thin laminates are often used to make these circuits compact, such as Alumina materials (Ɛr =10.2).

Figure 2.6 depicts a typical E and H-plane co-polar radiation pattern. The radiation pattern is relatively broad in both orthogonal directions, as can be seen in this plot. Due to the existence of the surface wave mode and other higher-order modes being launched towards entire (ɵ= 90°), E-plane patterns are often wider than H-plane patterns.

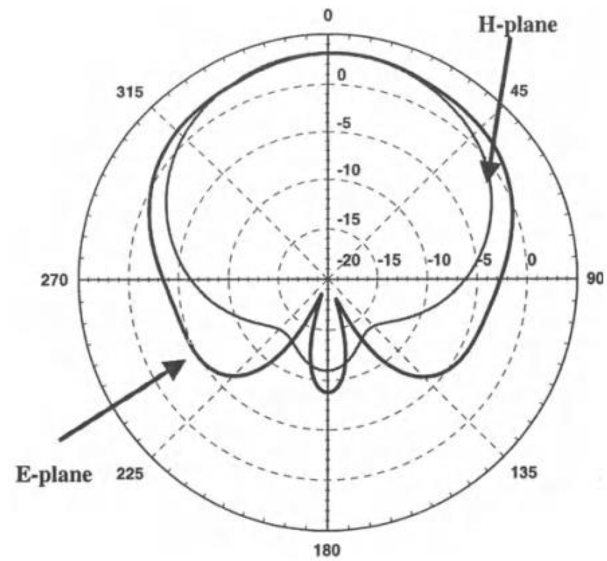


Figure 2.6:RadiationPattern of a Microstrip Patch Antenna (11)

The first design approach for any microstrip patch solution can be determined in Figure 2.5. If only a low impedance bandwidth solution is required, say less than 5% of the operating frequency, the material for the patch can be chosen by referring to Figure 2.5.a. After this has been determined, the next step is to choose the conductor shape.

This will be determined by the antenna's available area as well as the required polarization. Because the gain of a single microstrip patch element is generally constant and may be easily raised using arraying techniques, the antenna gain is usually determined considerably later in the process. After you've decided on the above, the next step is to research feeding techniques, or how to get electricity to and from the patch antenna.

2.4. Enhancing the Bandwidth and Gain of Microstrip Patch Antennas

There are intuitive methods for increasing antenna bandwidth but first, we must recognize that we require more resonant radiators, which must be properly linked.

2.4.1. Intrinsic Techniques

To increase the bandwidth of a microstrip patch antenna, two inherent approaches can be used: utilize a thick laminate as the antenna's substrate, and make sure the laminate's dielectric constant is low, close to one. A direct contact microstrip patch antenna's bandwidth can be increased by as much as 10% by doing so.

2.4.2. Microstrip Antenna Feed Techniques For single Element

A variety of approaches can be used to feed microstrip patch antenna elements. Direct and indirect contact are the two types of methods that can be used. The power is delivered directly to the radiating patch using a connecting device such as a microstrip line or coaxial connector in the direct contact technique. Electromagnetic field coupling is used in the indirect contact system to transfer power between the microstrip line and the radiating patch. Microstrip line, coaxial probe, proximity coupling, and aperture coupling are the four most common feed techniques (6).

1.1.1.1 Microstrip Line Feed

A conducting metallic strip directly connects the path element with an RF power source in the microstrip line feed technology. This type of feed design has the benefit of allowing the feed to be etched on the same substrate as the patch element, resulting in a planar structure. In comparison to the patch, the feed line is narrower. Microstrip line feeds can be configured in a variety of ways, as shown in Figure 2.7 (6).

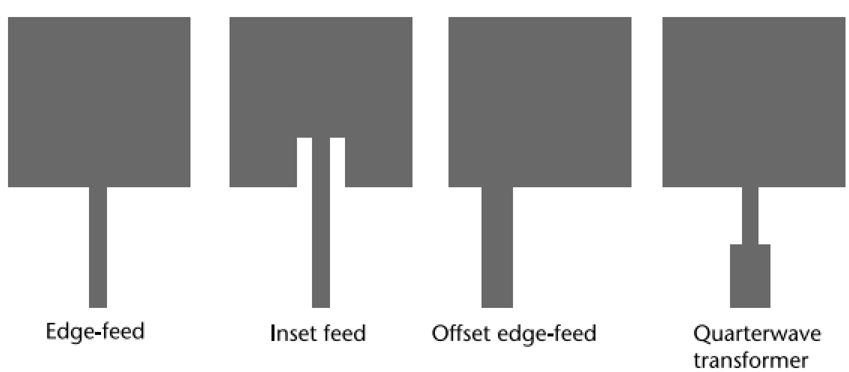


Figure 2.7 Different feeding mechanisms in a microstrip patch antenna

The feed line in edge and offset edge-fed schemes originate from the patch's edge, whereas the microstrip line in inset Feed starts from a place inside the patch. The inset cut in the patch's goal is to match the feed line's impedance to the patch without the use of any extra matching elements. This is accomplished by carefully adjusting the line's inset position and impedance. Inset-fed is a simple feeding method that offers ease of manufacture, modeling simplicity, and impedance matching. Unwanted cross-polarized radiation is one problem of the microstrip line feed(6) .

2.4.2.1. Coaxial Feed

A common way for feeding microstrip patch antennas is coaxial or probe feed. The coaxial feed's inner conductor passes through the dielectric and is attached to the radiating patch, while the outer conductor connects to the ground plane. To match the patch's input impedance, the coaxial feed can be inserted anywhere inside the patch.

The amount of spurious radiation produced by this feed method is low. However, it has a narrow bandwidth and is difficult to simulate because a hole must be bored in the substrate and the connection protrudes outside the ground plane, which prevents it from being flat for thick substrates (h > 0.02λ0), making it difficult to utilize in array applications. Another disadvantage of thicker substrates with broad bandwidth is that the increased probe length causes the input impedance to become more inductive, causing matching issues. 50 SMA connectors are coaxially fed in practice. The point (Xf, Yf) in the x-y coordinates can be used to determine the feeding probe point, as shown in Figure 2.5. The coordinates are provided by (2.1) (6):

$$X_f = \frac{L}{2} \text{ and } R(Y_f) = R(y=0)\cos^2\left(\frac{\pi y_0}{L}\right) \qquad \textbf{2.1}$$

where R(y = 0) is the edge impedance of the patch.

2.4.2.2. Aperture-Coupled Feed

The radiating patch and the microstrip feed line are arranged on two different levels and separated by the ground plane in the aperture-coupled feed approach, as shown in Figure 2.8. The patch and the feed line are connected via an aperture or a slot in the ground plane. Due to the symmetry of the design, the coupling slot is frequently centered under the patch, resulting in lesser cross-polarization. There are two coupling slots in the dual-polarized antenna, one for vertical polarization and the other for horizontal polarization.

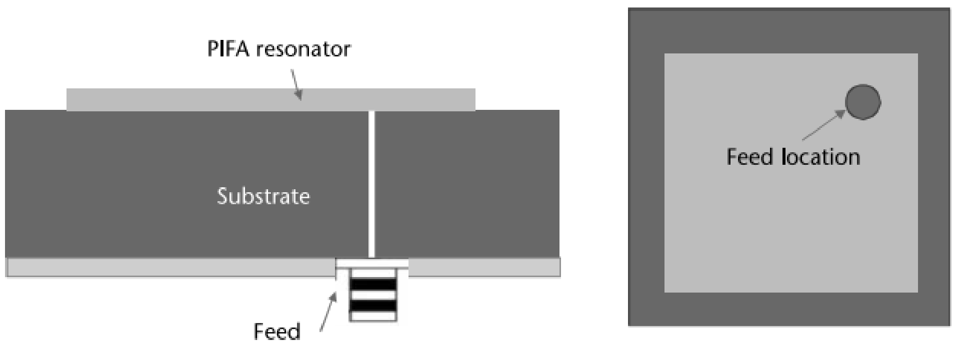


Figure 2.8 Coaxial-fed microstrip patch antenna (side and top view)

The size, shape, and position of the aperture dictate the amount of coupling from the feed line to the patch. The ground plane separates the patch and the feed line, reducing spurious radiation. To optimize radiation from the patch, a thick, low dielectric constant material is utilized for the feed line at the bottom and a thick, high dielectric constant material is used for the radiator at the top substrate. This method of feeding has limited bandwidth (6).

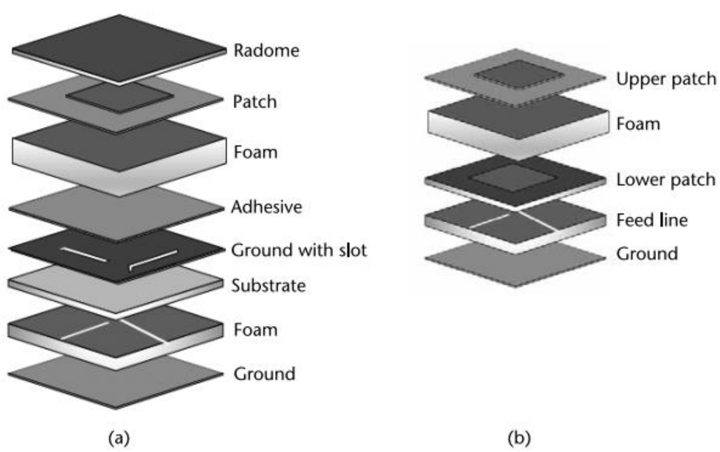


Figure 2.9:Microstrip antenna feed mechanisms : (a) aperture-coupled antenna, and (b) proximity coupled antenna.

2.4.2.3. Proximity- or Electromagnetically Coupled Feed

An electromagnetically couple feed is another name for proximity-coupled feeding. The fundamental benefit of this feed technique, as illustrated in Figure 2.9, is that it reduces spurious feed radiation while still providing extremely high bandwidth (up to 14 percent) due to an overall increase in the thickness of the microstrip patch antenna. This approach also allows for the selection of two dielectric materials, one for the patch and the other for the feed line, to improve individual performance. Controlling the length of the feed line and the width to-line ratio of the patch allows for matching. The main disadvantage of this feed structure is that it is difficult to manufacture due to the need for accurate alignment of the two dielectric layers (5). Table 2.1 shows a comparison of all primary microstrip antenna feeding designs.

Table 2.1:Feeding Techniques Comparison

Characteristics	*Microstrip Line Feed*	*Coaxial Feed*	*Aperture-Coupled Feed*	*Proximity-Coupled Feed*
Spurious feed radiation	More	Less	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Ease of fabrication	Easy	Soldering and drilling needed	Alignment required	Alignment required
Bandwidth	2%–5%	2%–5%	2%–5%	14%
Polarization purity	Good	Poor	Excellent	Poor

2.4.3. Matching System

The use of a matching system between the antenna and the transmitter (or receiver) can improve substantially the bandwidth, for example:

- Stubs (narrowband)
- Quarter-wavelength transformer (multiple sections)
- Filters with passive lumped components

- Filters with active devices

The use of a matching system increases the complexity and cost. (12)

2.4.4. Multiple Resonances

An antenna with numerous resonances has a multi-band characteristic, and a wide bandwidth can be obtained if the resonances are coupled together (near enough). There are a few different approaches to add numerous resonances, and we'll go through each one in-depth.

2.4.4.1. Slotted patches

Extra resonances can be introduced by cutting slots in the patch. Several slots are frequently utilized, each with different dimensions, orientations, and positions. There are a variety of slot shapes that could be utilized in patch design to increase bandwidth including: Figure 2.2 depicts the L-shape and H-shapes. Patch with an H-shape slot.

Effect of Slots on Bandwidth

In terms of voltage standing wave ratio, input impedance frequency variation, or radiation pattern. The frequency range across which a microstrip patch antenna is matched with that of a feed line within prescribed limits is defined as the VSWR or impedance bandwidth. The frequency range over which a microstrip patch antenna is matched with the feed line within specified constraints is defined as its bandwidth.

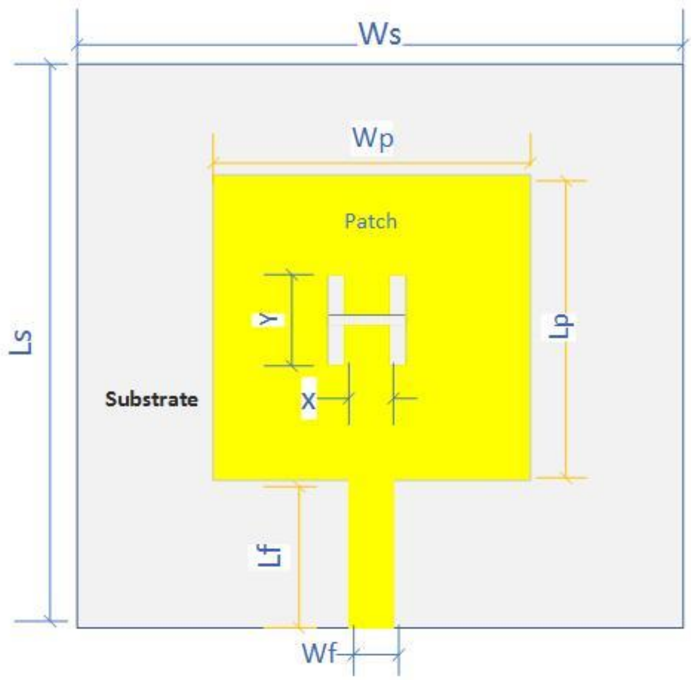


Figure 2.10:Microstrip patch antenna with H-shape slot

The bandwidth is commonly defined as the range of frequencies where the VSWR is less than two. The VSWR criterion is sometimes required for severe applications. With the help of slots, the antenna's bandwidth is increased. These structures are periodic in nature, preventing all electromagnetic surface waves from propagating inside a specific frequency band termed the bandgap, allowing for extra control of electromagnetic wave behavior beyond traditional guiding/filtering structures.

A) Effect of Slots on the Gain

Gain compares the intensity of an antenna in one direction to the intensity produced by a hypothetical ideal antenna that radiates evenly in all directions, isotropically, and has no losses. We can improve the antenna gain by employing a high permittivity substrate and a modified slot shape.

B) Effect of Slots on antenna size, Axial Ratio and Return Loss

The slot size of a microstrip patch antenna can be lowered. This effect can be achieved by altering the current path. Current is modified when slots are carved into the patch. In comparison to a microstrip patch antenna with no slots, current goes via an extra patch.

Axial Ration It is the ratio of the polarization ellipse's minor and major axes. A narrower axial ratio bandwidth is produced via shorter slot length.

By increasing the length and width of the slot antenna, the return loss can be decreased when using a double or dual slot stacked patch approach.

2.4.4.2. Horizontally Coupled Parasitic Patches

Horizontally linking parasitic patches to the stimulated patch was proposed and researched in the early 1980s. The approach is based on the idea that if the connecting element or elements' resonance frequency differs somewhat from that of the driving patch, the antenna's total bandwidth can be increased. Figure 2.11 depicts a driven probe-fed rectangular patch with two parasitic patches in the y-axis direction on either side of the exciting patch. The lengths and widths of each patch for controlling resonance frequency and bandwidth, as well as the space between the parts, are key parameters. The gaps tend to influence the patch coupling and hence the tightness of the resonant loop (or loops) in the antenna's impedance locus.

This enhancement strategy has resulted in bandwidths of the order of 20%, albeit there are a few drawbacks to employing parasitically coupled patches. To begin with, wide parasitic elements are required to attain these appropriate bandwidths, making the overall size of the printed antenna configuration electrically huge and thus challenging to construct an array without grating lobe difficulties. Due to the lack of symmetry of the produced currents concerning the printed antenna center, the radiation patterns of parasitically connected patches tend to be warped over the useful impedance bandwidth.

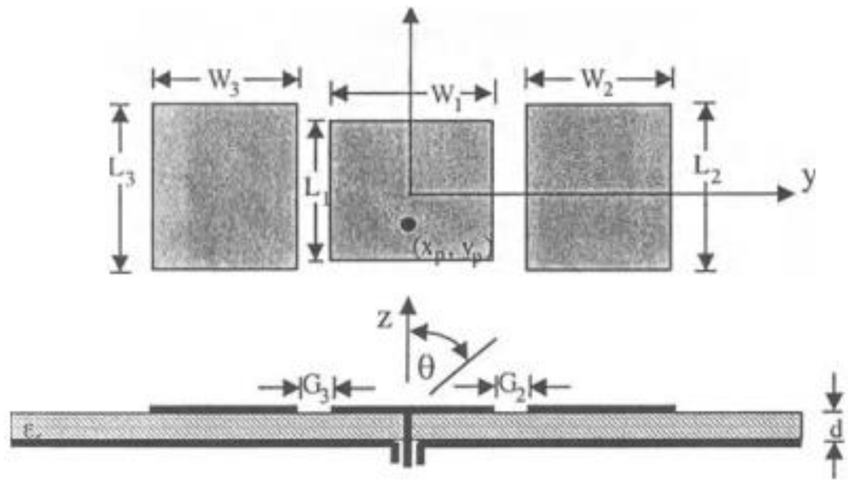


Figure 2.11:Horizontal Parasitically Coupled Patches

To create several resonances, slightly different patches with varying lengths must be used, and the patches must be very near together to give the necessary coupling. The obvious downside of this strategy is the larger area.

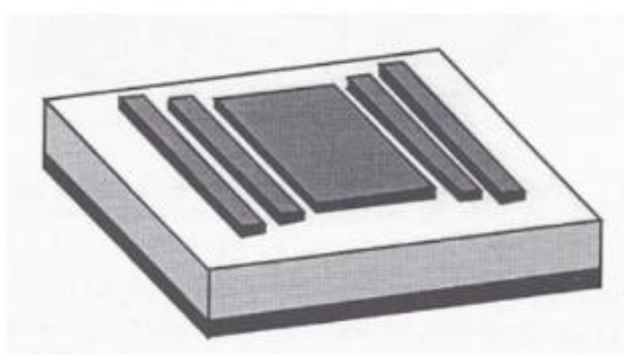


Figure 2.12: Parasitic microstrip antenna patch

2.4.4.3. Stacked Patches

A microstrip antenna typically has a narrow band and a modest gain of 6-7dBi. The wide-band or high gain characteristic is created by stacking a parasitic patch as shown in figure 2.13. The properties are determined by the hp distance between the elements.

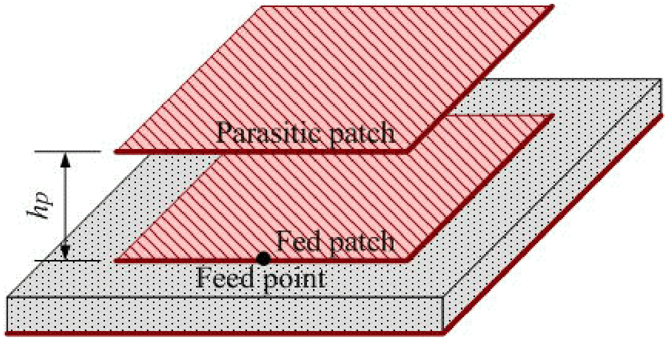


Figure 2.13:Stacked Microstrip Antenna

For the first time, the behavior mechanism of a stacked antenna is synthetically clarified by studying the findings calculated using the FDTD approach. The stacked microstrip antenna has unique properties such as high gain and wide bandwidth. The bandwidth is increased when the size of the parasitic patch is roughly equal to the size of the fed patch and the distance between the fed patch and the parasitic patch is about 0.1 wavelength. The gain improvement is realized when the distance is around a half wavelength. So yet, only a restricted range of these traits has been recorded.

It has been successfully proposed a three-element stacked microstrip antenna with wide bandwidth and good gain. A fed patch and two parasitic patches make up the three-element stacked microstrip antenna. The impedance bandwidth is increased by the parasitic patch close to the fed patch, while the gain is improved by the parasitic patch half a wavelength away from the fed patch (13).

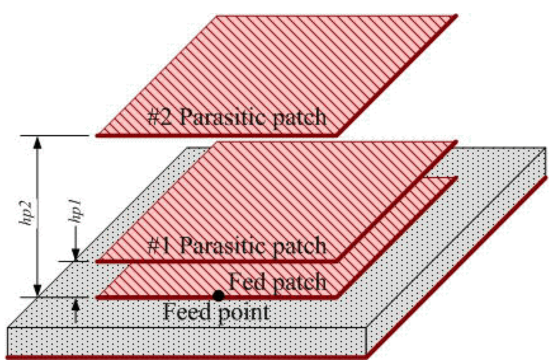


Figure 2.14:3-Element Stacked Microstrip Antenna with Wide-Band and High-Gain Performances

2.4.5. Large Slot Excited Patches

Boosting the slot size is a straightforward and frequent approach to increasing the bandwidth of an aperture-coupled patch without increasing the antenna's complexity through stacking. The slot and the patch are now the two tightly connected radiating structures. In reality, using a relatively large slot to achieve large bandwidth from an aperture-coupled patch is a natural development. The Thick dielectric material is required to extend the bandwidth of a microstrip patch antenna.

To ensure that power is coupled to the patch positioned on a thick dielectric layer in an aperture-coupled patch environment, the slot size must be raised. With this rather simple approach, bandwidths of more than 40% have been attained. Large slot excited patches have all of the advantages of aperture coupled patches, but because they use a non-contact excitation method, they do not suffer from the current discontinuity issues that plague probe and edge fed patches. (11)

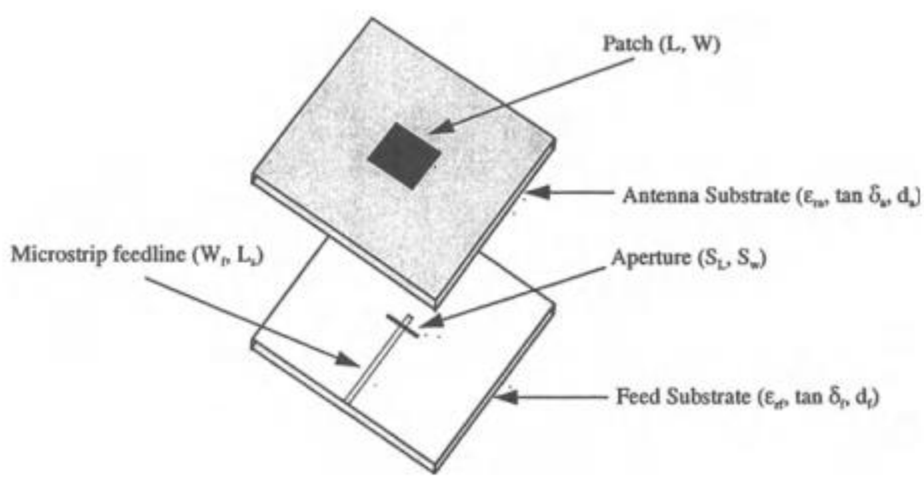


Figure 2.15:Large Slot Aperture Coupled Patch Antenna

2.4.5.1. Methods to reduce backward directed radiation

Placing a shielding plane behind a big slot stimulated patch antenna is a common way to improve the antenna's radiation properties. This method removes any unnecessary radiation at the back. The addition of a shielding plane, on the other hand, allows parallel plate wave-guide modes to propagate. The antenna's efficiency can be severely harmed by power transmitted into these modes.

Another typical method is to enclose the aperture in a cavity, which is known as a cavity-backed solution. The use of a cavity eliminates directly radiated backward fields (not diffracted ones) but at the cost of increased manufacturing complexity and cost.

As shown in Figure 2.15, another option to enhance the front-to-back ratio is to use a microstrip antenna element as a reflector behind the aperture. This element's activity is similar to that of a Yagi-Uda dipole array. Incorporating a reflector into an aperture-linked patch antenna, on the other hand, is significantly easier. Because of the thick foam substrate utilized, proximity coupling between the feedline and the reflecting element is negligible, allowing the reciprocity technique of analysis to be applied. The ground plane also protects the directed patch elements from the reflector. As a result, only the interactions between the reflector and the aperture must be considered, yielding a straightforward analysis. The addition of a reflecting element does not influence the antenna's input impedance for aperture coupled patch designs with a front-to-back ratio of 10dB or greater. As a result, including a reflector element in current designs is simple. (11)

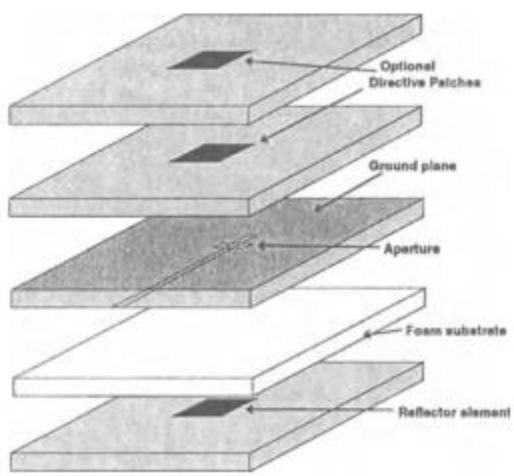


Figure 2.16:Geometry of Aperture Coupled Microstrip Antenna with Reflector Element

2.4.6. Ultra-wideband Stacked Patches (ASPs)

In this part, we'll see how to efficiently increase the bandwidth of the ASP antenna while minimizing the influence on its gain characteristics. To increase the ASP's bandwidth, the needed band is divided into many sub-bands, with antennas constructed specifically for each of these sub-bands. A log-periodic antenna is essentially a succession of these antennas, each covering a distinct band and cascading one after the other.

Implementing a parallel version of the subdivision, in which the signal is first to split into sub-bands using a multiplexer, and then each of the split signals is supplied to a specifically built antenna, is a more resilient means of producing exceptionally broad bandwidth. The setup employed in this study consists of a diplexer and a pair of ASP antennas that are designed to cover adjacent bands. If the entire device is treated as a single antenna, the bandwidth of one of the ASPs is doubled. The diplexer's design is critical in ensuring that the correct band of frequencies is sent to the appropriate patch. (11)

One of the UBP's key goals is to maintain a relatively consistent gain across the whole band. Two ASP antennas were positioned close to each other to lower the overall size of the UBP antenna. A photograph of the UBP antenna is shown in Figure 2.17. The challenge is whether the two ASP antennas will interact, resulting in a distorted pattern. Another question is whether insertion loss and mutual coupling at the diplexer's cross-over frequency will be a problem when measuring the ultra-wideband antenna's input impedance and gain. Return loss and radiation pattern data will be used to evaluate these issues.

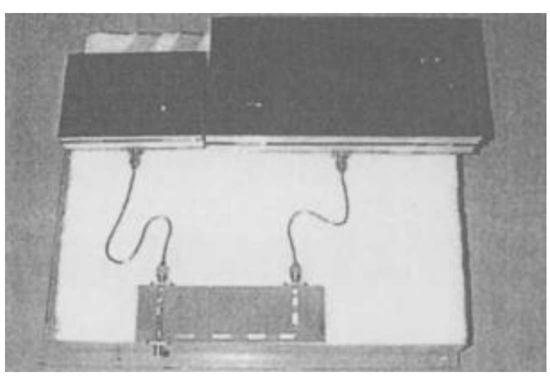


Figure 2.17:Photograph of Ultra-wideband Printed Antenna

2.4.7. Devices Used in Real lab Measurement

If our lab realized using real devices we must use an anechoic chamber for radiation pattern measurement and a vector network analyzer for S-parameters and input impedance.

The RF anechoic chamber it's a room shielded with no reflected or unwanted electromagnetic waves generally, it's used to test Radars, and antennas, in an environment with no noise or interference, the anechoic chamber is made of foam absorbent materials consisting of a fireproofed urethane foam loaded with carbon black, and cut into long pyramids.

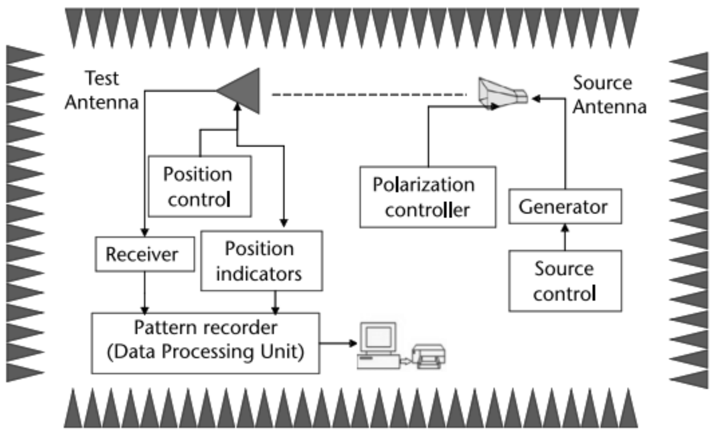


Figure 2.18:Antenna radiation pattern measurement setup in an anechoic chamber.

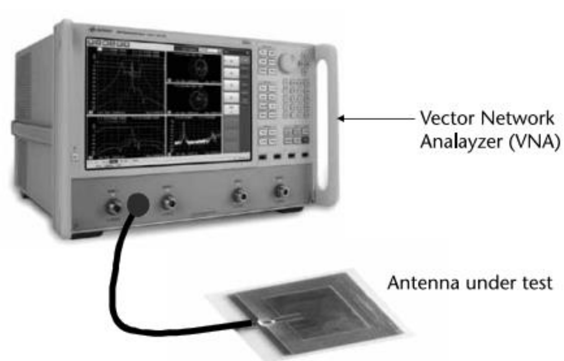


Figure 2.19:Antenna S-parameter and input impedance measurement setup using a vector network analyzer

2.5. Information About Antenna Material

This is important information about the most famous insulating materials used in creating the patch antenna. It is important to know their properties. Some materials are used in specific fields, for example, Textile Materials that are used to collect data on the human body and that do not pose a danger, each of which has certain characteristics such as temperature, cost ...etc.

2.5.1. Roger4350

Rogers Ro4350b high-frequency materials are non-PTFE hydrocarbon/ceramic laminates with glass fiber reinforcement developed for high volume, high-performance commercial applications.

Ro4350b is designed to deliver high RF performance while remaining cost-effective to manufacture. The outcome is a low-loss material that can be manufactured at a cheap cost using normal epoxy/glass (FR4) techniques. As operational frequencies rise to 500 MHz or higher, the number of laminates available to designers shrinks dramatically. The RO4350b PCB offers the features that RF microwave engineers need, allowing for repeatable filter, coupling network, and impedance-controlled transmission line design.

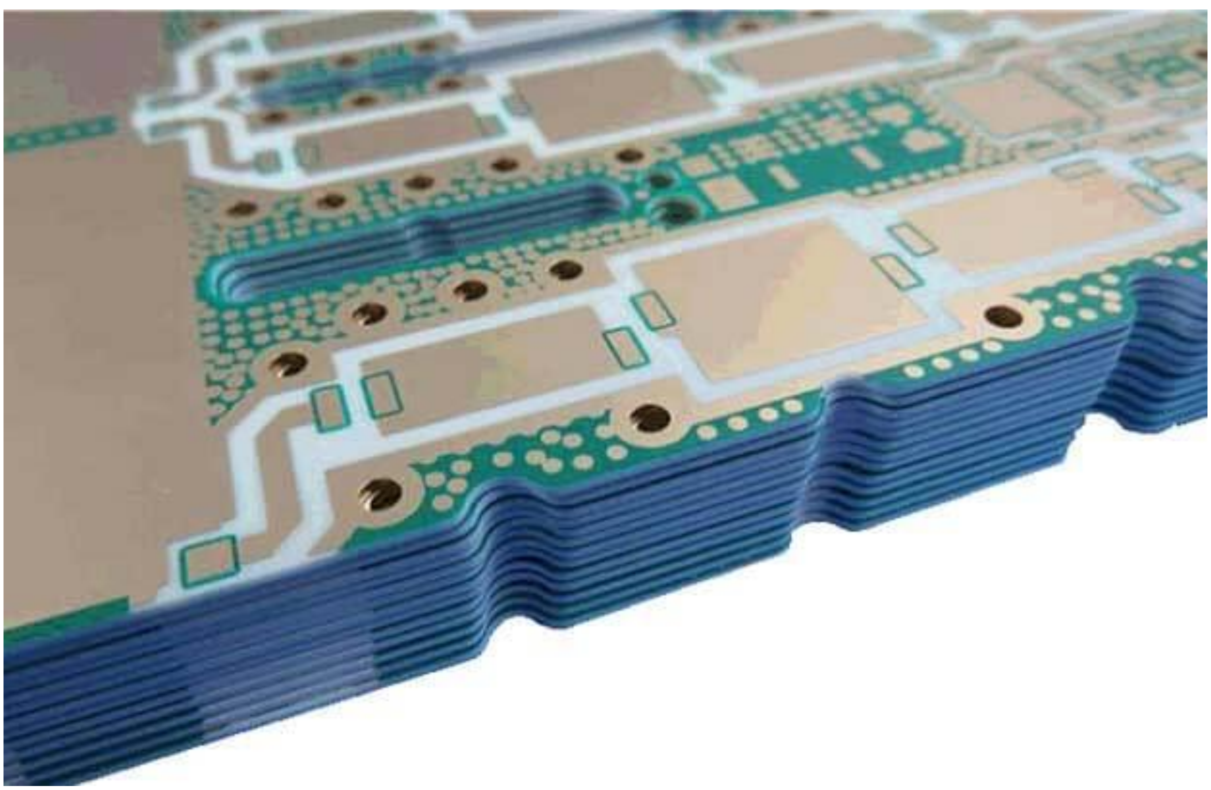


Figure 2.20:Rogers 4350b

The RO4350b series material's low dielectric loss allows it to be used in many applications where conventional printed circuit board laminates are limited by higher operating frequencies. The dielectric constant has one of the lowest temperature coefficients of all printed circuits, and it remains stable across a large frequency range. As a result, it's an excellent choice for broadband applications (14).

2.5.2. FR4-Epoxy

The popular and adaptable high-pressure thermoset plastic laminate FR-4 glass epoxy has a good strength-to-weight ratio.

FR-4 is most typically utilized as an electrical insulator because of its low water absorption and high mechanical strength. Flame retardant is abbreviated as "FR," and Type "4" refers to woven glass-reinforced epoxy resin. In both dry and humid circumstances, the material is known to keep its outstanding mechanical and electrical insulating properties.

These qualities, combined with strong manufacturing capabilities, provide a wide range of possibilities for electrical and mechanical applications (15).

2.5.3. Difference Between Roger4350B & Fr4-epoxy

You should choose the best material for producing the highest quality Antenna. So, let’s explain the main difference between the famous Substrat materials according to price, Frequency, Impedance stability, Temperature, and space application.

2.5.3.1. Cost

In comparison to Rogers material, FR-4 is less expensive. FR-4 is inexpensive. As a result, manufacturers favor it since it has the lowest processing costs. Basically, you can choose between these two materials based on your wants and requirements.

FR-4 will be your first choice if you wish to make your PCBs on a low budget. Also, Rogers materials are an excellent choice if you require high-quality, high-performance PCBs.

2.5.3.2. High-Frequency

Rogers has even produced high-frequency special laminates, which are quite popular. Furthermore, when compared to PCBs manufactured with FR-4 materials, designers discover that Rogers materials have a dielectric constant reduction of nearly 20%. Rogers materials are the finest choice if your project requires high-frequency laminations for maximum electrical and mechanical needs.

2.5.3.3. Impedance Stability

Impedance is the measurement of the resistance of an electric current to the passage of energy when a certain level of voltage is applied. A line of resistance in the reaction of an electric current is an excellent illustration of impedance. Furthermore, stable impedance is now required in many designs. As a result, it is an area where both of these materials differ. FR-4 and Rogers are two examples. The fact is that FR-4 is a low-cost material. However, they are extremely vulnerable to large fluctuations in dielectric constant over the substrate's length and width. Even when the temperature changes, it happens.

Rogers materials are the best if you need PCBs that perform reliably in a wide range of temperatures with minor variances. Rogers materials are also the finest in high-temperature settings, where your PCBs must perform.

2.5.3.4. Temperature Management

Rogers materials are preferable if PCBs must operate over a wide temperature range with little change. In short, when it comes to temperature control, Rogers material outperforms FR-4 since it has less variance.

In comparison to FR-4 materials, high-frequency thermoset-based laminates like Rogers' products are extremely durable. They're also well-known for their ability to withstand high temperatures. As a result, they will be your best option.

2.5.3.5. Space Application

Almost every major country is sending more and more people into space for exploration. As a result, you cannot use all of the resources; instead, you must select the best one. Because high functionality is required for space exploration. Many materials can fail in such a high-functioning environment. There is, in fact, outgassing in the space. When all trapped gases are released during the curing process of powder coating, this is known as outgassing. Rogers materials, on the other hand, are ideal for space applications. They are low outgassing for all space applications and exploration (16).

Table 2.2:Comparing Roger4350B and Fr4-Epoxy proprieties

Materials	Operating Temperatures(C^0)	glass transition temperature Tg (C^0)	Ɛr Design dielectric constant	Cost
Roger4350B	-50 to 150	>280	3.66	high
Fr4-epoxy	-50 to +100	135	3.4 to 8.4	low

2.6. MSA's Geometry

To Design an MSA we need to specify the material used for the substrat because it's the basic to calculate the dimensions of the MSA, such as length, width, of substrat, patch and ground plane. The operation frequency should be chosen depending on the Band desired and can be calculated following the formula:

$$f_r = \frac{c}{2(L + 2\Delta L)\varepsilon_{eff}} \quad \mathbf{2.2}$$

Where:

ΔL: is the equivalent length extension that financial records for the fringing fields at the two open ends.

ε_{eff} : is the effective relative permittivity

The dimensions of the patch are calculated following analytical formula (1) (17):

a)Patch Width:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_\mathrm{r} + 1}} \qquad \mathbf{2.3}$$

Where :

c : free space velocity of light

ε_r: Dielectric constant of substrate

b) Effective dielectric constant is calculated from:

$$\boldsymbol{\varepsilon}_{\mathbf{eff}} = \frac{\boldsymbol{\varepsilon}_\mathbf{r} + \mathbf{1}}{\mathbf{2}} + \frac{\boldsymbol{\varepsilon}_\mathbf{r} - \mathbf{1}}{\mathbf{2}}\left(\frac{\mathbf{1}}{\sqrt{\mathbf{1} + \frac{\mathbf{12h}}{\mathbf{w}}}}\right) \qquad \mathbf{2.4}$$

c) Length of metallic patch (L):

$$\mathbf{L} = \mathbf{L}_{\mathbf{eff}} - \mathbf{2\Delta L} \qquad \mathbf{2.5}$$

Where: $\mathbf{L}_{\mathbf{eff}} = \frac{\mathbf{c}}{\mathbf{2f_r}\sqrt{\boldsymbol{\varepsilon}_{\mathbf{eff}}}}$

d) Calculation of Length Extension:

$$\frac{\boldsymbol{\Delta}\mathbf{L}}{\boldsymbol{h}} = \mathbf{0.412}\,\frac{(\boldsymbol{\varepsilon_{eff}} + \mathbf{0.3})\left(\frac{\boldsymbol{W}}{\boldsymbol{h}} + \mathbf{0.264}\right)}{(\boldsymbol{\varepsilon_{eff}} - \mathbf{0.258})\left(\frac{\boldsymbol{W}}{\boldsymbol{h}} + \mathbf{0.8}\right)} \qquad \mathbf{2.6}$$

e) Length and width of Ground plane (Wg,) :

$$\boldsymbol{W_g} = \boldsymbol{6h} + \boldsymbol{W} \qquad \mathbf{2.7}$$
$$\boldsymbol{L_g} = \boldsymbol{6h} + \boldsymbol{L}$$

f) Feed line length (Lf):

$$\mathbf{L_f} = \frac{\boldsymbol{\lambda}_\mathbf{g}}{\mathbf{4}} \qquad \mathbf{2.8}$$

Where: $\boldsymbol{\lambda}_\mathbf{g} = \frac{\lambda}{\sqrt{\varepsilon_{\mathbf{eff}}}}$

:guided wave length.

2.7. Conclusion

In this chapter, we covered important points that will help in understanding and obtaining good results in the process of designing the Microstrip Antenna, including the improvement of antenna parameters, where we showed the effect of changing the shape of the patch and also the most important methods that can be used to improve the Gain, bandwidth...etc, the chapter also cover the important of materials used for substrat and it's impact on antenna efficiency and other parameters, At the end of the chapter we talked about some important devices used in testing and measuring anetenna parameters.

Here are some important points we got from this chapter:

- In rectangular MSA The width of the patch affect the imput impedance and the bandwidth while the resonant frequency determined by the length of the patch.
- The thicker substrat layer the greater bandwidth.
- Selecting materials with lower dielectric constant results a greater gain and bandwidth.
- Antenna installed on low dielectric constant substrat laminate larger and has strong directivity.
- MSA's suffers from 3 types losses: conductor loss, dielectric loss, and surface wave loss.
- The MSA's technologie has the ability to integrate with MMIC circuits.
- Well selecting of antenna feed technique could enhance It's parameters.
- Using Matching system like stubs between antenna and transmitter can improve the impedance matching and the bandwidth.

- With the help of slots we could get a larger bandwidth, also it's prevents all electromagnetic surface waves from propagating inside specific frequency band termed bandgap.
- Materials such as Roger4350B has better results and should be used in Domains that require accurate results, and This is why it is more expensive than Fr4-epoxy

3. Chapter3: Design and Simulation of Microstrip Antenna

3.1. Introduction

The most vital step is to finalize design specifications. Design specifications are driven based on the application. Normally antenna specifications are given by the system engineer after doing the system-level analysis and simulation of a complete system such as a 5G network and radar system. A wireless mobile communication antenna has a completely different specification than that of a satellite or radar antenna system. Important antenna design specifications were covered in Chapter 1.

Antenna specifications such as operating frequency, bandwidth, gain, radiation pattern, and polarization are driven by system requirements. The first step in designing a printed antenna is to choose an appropriate substrate. After collecting the design requirement, the next step is to select the radiating element, the size of the antenna, the feeding mechanism, and the electromagnetic simulation technique needed to get antenna performance. Proper feed selection for single-radiation elements and feed network design for array antennas are other crucial design steps. Microstrip antenna design steps are shown in Figure 3.1.

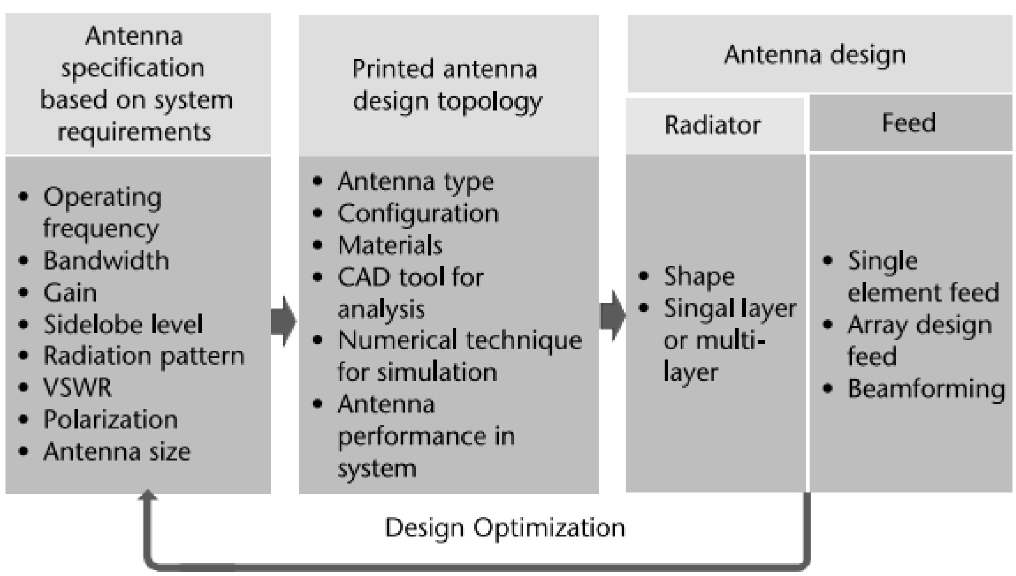


Figure 3.1 Microstrip patch antenna design flow

3.2. Design and Simulation Process

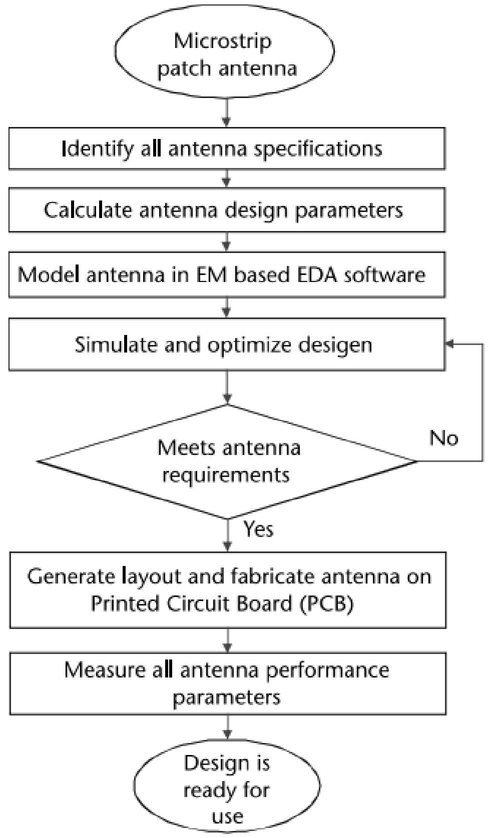


Figure 3.2 Microstrip antenna design and fabrication process

3.2.1. Antenna Simulators

There is much software that could be used to simulate antenna design and measurement the most used are: ANSOFT HFSS and CST simulator.

3.2.2. CST Simulator

CST is a very powerful tool for circuit simulation and design, with unique features that make it an invaluable part of the designer's working day. CST includes a wide variety of electronic circuit elements, packaged stripline, waveguide transmission lines, antennas – anything that you might need to simulate a radio frequency (RF) circuit layout. The software comes complete with many applications ready to run illustrating the design of complex systems and has even more applications available on our website.

3.2.3. HFSS Simulator

The HFSS (High-Frequency Structure Simulator) is a multi-domain circuit simulator used to design high-frequency electronic devices such as filters, transmission lines, and components. Use HFSS to gain insight into the design of your circuit and optimize it before you layout. It is possible to accurately predict the size, materials, geometries, and performance of your circuit well in advance before committing to fabrication. HFSS provides accurate RF and microwave simulation technology that allows you to see the big picture before you begin to build.

3.2.4. Difference between HFSS and CST

There are many similarities between the CST and HFSS software, but they do differ in some key ways. The most significant difference is how each program handles Radiation Analysis (DA). In HFSS you have to design your Radiation Box and make sure it fits into your design. With CST it's all done for you automatically in the software.

3.2.5. Microstrip Simulation and Measurement

To design a rectangular patch antenna used for X-band communication frequency such as Radar, The length *L*, width *W,* and thickness of a substrate *h* information is needed, this patch is a single layer antenna as we mentioned before in chapter 2 there are many methods to feed antenna, in this case, we use Microstrip line feed and exactly the Inset Feed method the main reason of it is to match impedance between the feed line and the patch.

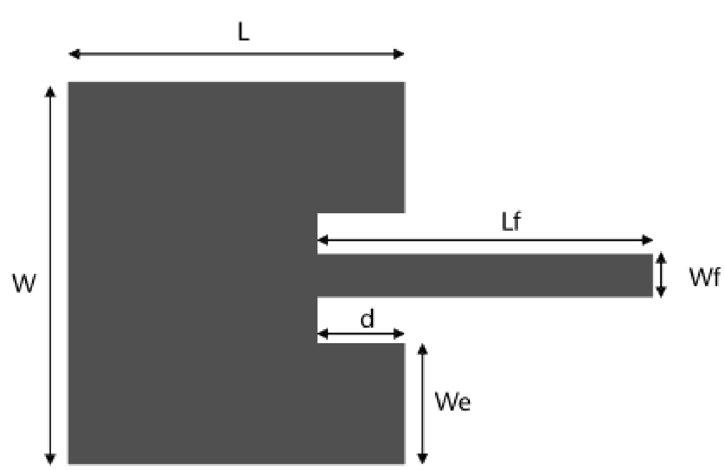


Figure 3.3:Inset fed rectangular microstrip antenna design

dimensions of the patch could be calculated using approximation formulas developed by some researchers, The typical values of rectangular patch antenna dimensions are:

$0.3\lambda_0 < L < 0.5\lambda_0$, λ_0 is the free-space wavelength.

$0.003\lambda_0 < h < 0.05\lambda_0$, h is the dielectric substrate high.

$2.2 < \varepsilon_r < 12$, is the dielectric constant of the substrate.

The first dimension that has to be calculated is the width of the patch an approximation formula developed by Bahl and Bhartia shown in equation 3.1.

$$W = \frac{\lambda_0}{2\sqrt{0.5(\varepsilon_r + 1)}} \qquad \textbf{3.1}$$

The effective permittivity in the substrate is evaluated using the formula by Schneider (6).

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12h/w}}\right) \qquad \textbf{3.2}$$

We need the effective permittivity to calculate the length of the patch as shown in equation 3.3.

$$L = \frac{c_0}{2f_r\sqrt{\varepsilon_{eff}}} \qquad \textbf{3.3}$$

Where $C_0 = 2.998\times10^8$ meter/second represents the velocity of the electromagnetic wave in free space, the effective length of the patch antenna is not equal to the physical length because of the fringing field at the edge of the patch so a fring factor ΔL (correction factor) must be subtracted to obtain the effective length, equation 3.4 represent the fring factor.

$$\Delta L = 0.412h\frac{(\varepsilon_{\mathrm{eff}} + 0.300)}{\varepsilon_{\mathrm{eff}} - 0.258}\frac{\left(\frac{W}{h} + 0.264\right)}{\left(\frac{W}{h} + 0.813\right)} \qquad \textbf{3.4}$$

the effective length, L_{eff}, of a rectangular antenna element is:

$$L_{eff} = L - 2\Delta L \qquad \textbf{3.5}$$

Finally, The substrate height is mentioned in the respective material data sheet provided by the manufacturer so we don't need to determine the high., All antenna specifications are detailed in table 3.1.

Table 3.1:MSA E-shaped Design Characteristics

Frequency Operation	The Material used for substrat	The Material used for Microstrip	Dielectric Height
10 GHZ	Roger4350 Ɛr=3.66	copper	H=0.7874mm

Table 3.2:shows the calculated Antenna Patch dimensions and the input impedance.

Patch Length (mm)	Patch Width (mm)	Input impedance (Ω)	Substrat Width(mm)	Substrat Length(mm)
7.5	10	209.7	40	40

As shown in Figure 3.4 the metallic patch has been fed using the inset method and connected to the ground plane the space between the metallic patch and the ground represents the Substrate dielectric layer All of these aforementioned items are enclosed in an airbox before the antenna parameters are measured, the simulation done in 22 temperature. The Rogero4350 material could be used in high temperatures Tg > 280^0c. there are many methods to analyze microstrip antenna a simple way to do that is the transmission line method.

Now we have to Calculate the position of the inset feed point using equation 3.6:

$$Y_0 = \frac{L}{\pi}\cos^{-1}\left(\sqrt{\frac{Z_{in}}{R_{in}}}\right) \quad \textbf{3.6}$$

Where Zin and Rin are the input impedance and the input resistance of the patch respectively. the input impedance and resistance have been detailed in chapter 1, the new design dimensions are shown in figure 3.5.

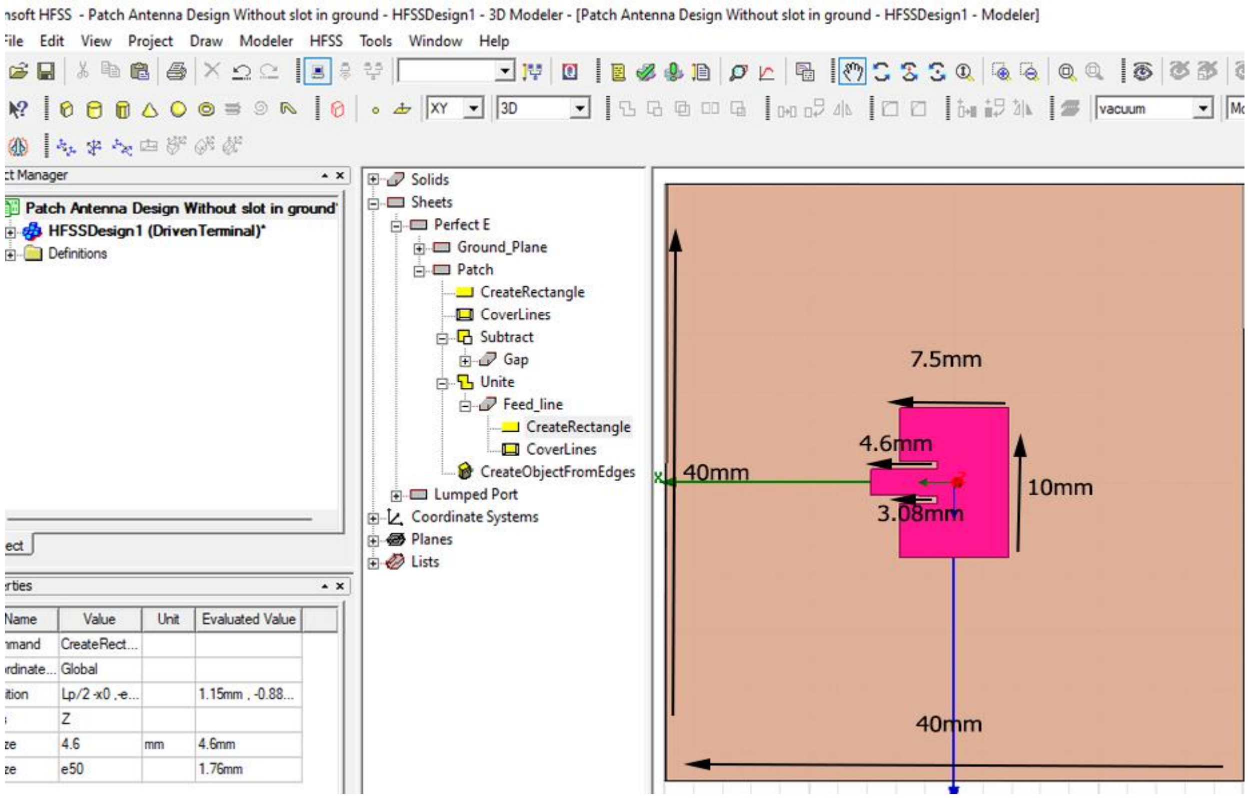


Figure 3.4:Patch antenna and substrate dimensions on Hfss

The Hfss Simulator Software replaces many devices needed to calculate Antenna parameters such as Radiation pattern, S parameters, input impedance, gain …etc.

3.2.6. Result and discussion

When we complete the design and simulation of the microstrip antenna we got results of the Radiation pattern, VSWR, Gain, and S11 parameter.

A) S11:

S11 is illustrated in Fig 3.6. We obtain a very low return loss, -19.59 dB, at a frequency of 10 GHz.The figure implies that the antenna radiates best at this point. Further, at 8.5 GHz the antenna will radiate virtually nothing, as S11 is close to 0 dB (so all the power is reflected).

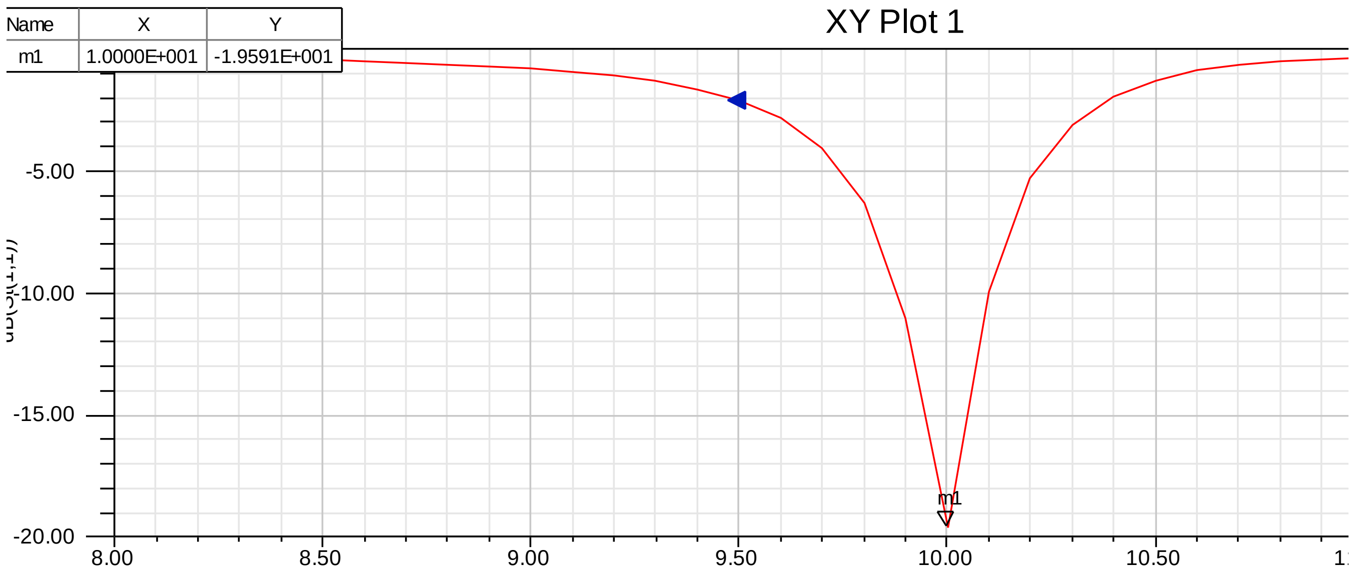


Figure 3.5:S-Parameter S11 in the function of frequency

B) Bandwidth:

We can determine the bandwidth from the figure 3.6 The acceptable frequency range starts when S11 <= -10db so where the power conversion is at its best, the energy conversion takes the greatest value when the resonance frequency is valued 10GHZ so BW=F2-F1= 10.100-9.877 =223MHZ.

C)VSWR

In figure 3.7 we can remark that the minimum VSWR value at resonant frequency 10GHZ is equal to 1:1.2337, this means that we have a good matching between the transmission line and the patch, and there is a relation between the Reflection Coefficient, Return Loss, and VSWR so we can calculate the percentage of power reflected to know how much power the antenna is radiated.

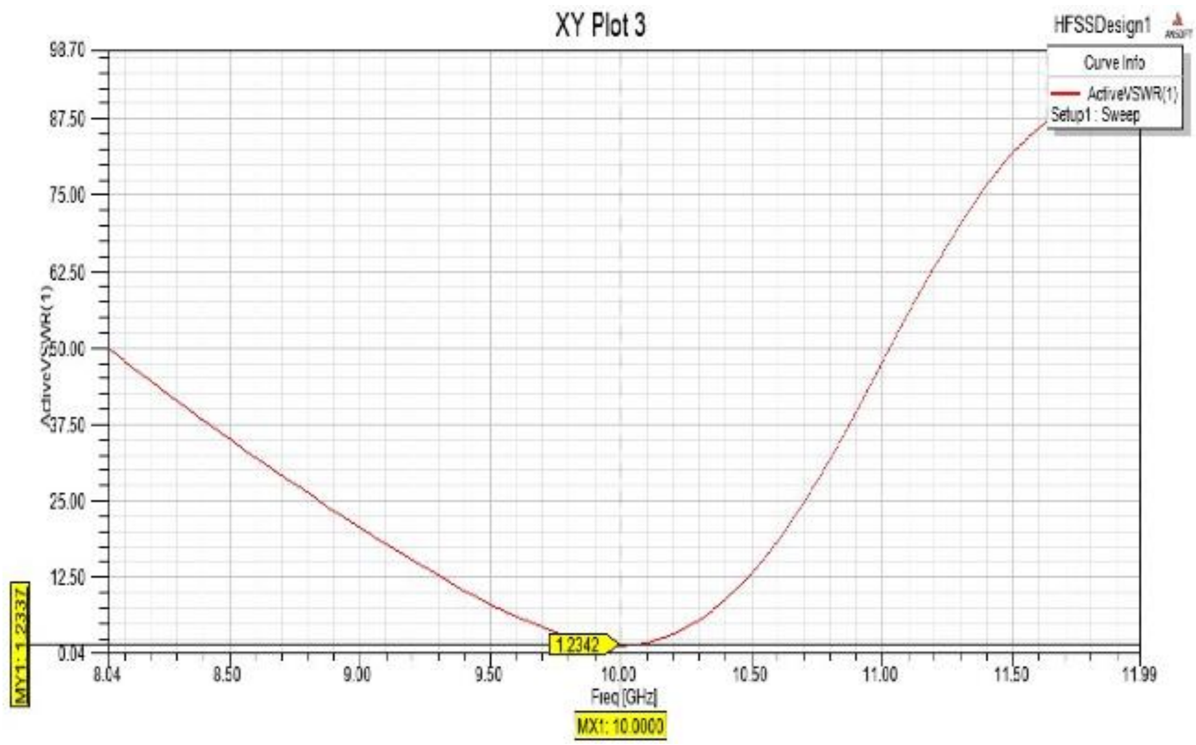


Figure 3.6:VSWR Plot

$$\text{Reflected power } (p) = 100 * \Gamma^2 \quad \textbf{3.7}$$

Where the Γ is the reflection coefficient given by equation 3.8:

$$|\Gamma| = (\text{ VSWR } - 1)/(\text{ VSWR } + 1) \quad \textbf{3.8}$$

After calculation, we found that the reflection coefficient=0.105 so the percentage of reflected power=1.09% Based on this result, it can be said that the percentage of energy transferred from the antenna is 98.9% and, This is because of good matching between the transmission line and the antenna patch.

D) Radiation Pattern:

The radiation pattern shows max power radiation in the direction of 0 degrees this means that our antenna is a directional in the Z-axis.

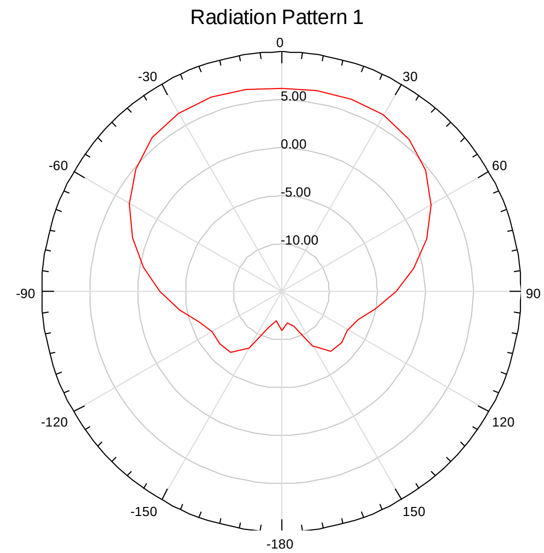


Figure 3.7: Radiation Pattern LastAdaptive Frequency 10GHz with Phi=0deg

E) Gain:

a clear power distribution shown in figure 3.9 in the 3D Gain plot.

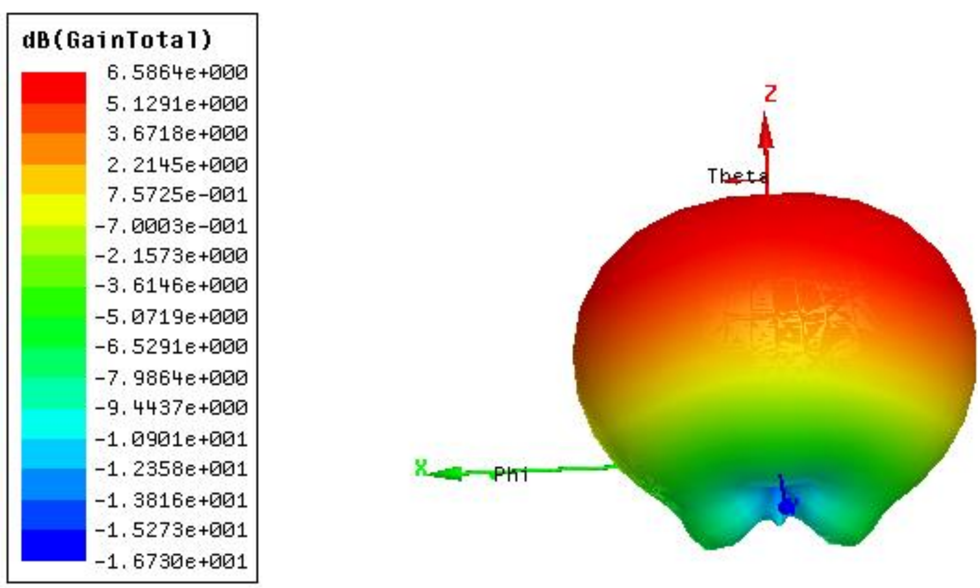


Figure 3.8:3D Gain Polar Plot

Figure 3.10 represents the variation of gain in terms of the frequency, we can note that after the resonant frequency the gain has a decrement decrease, in the other direction the gain increases incrementally till it achieves 6.66db at 9Ghz frequency.

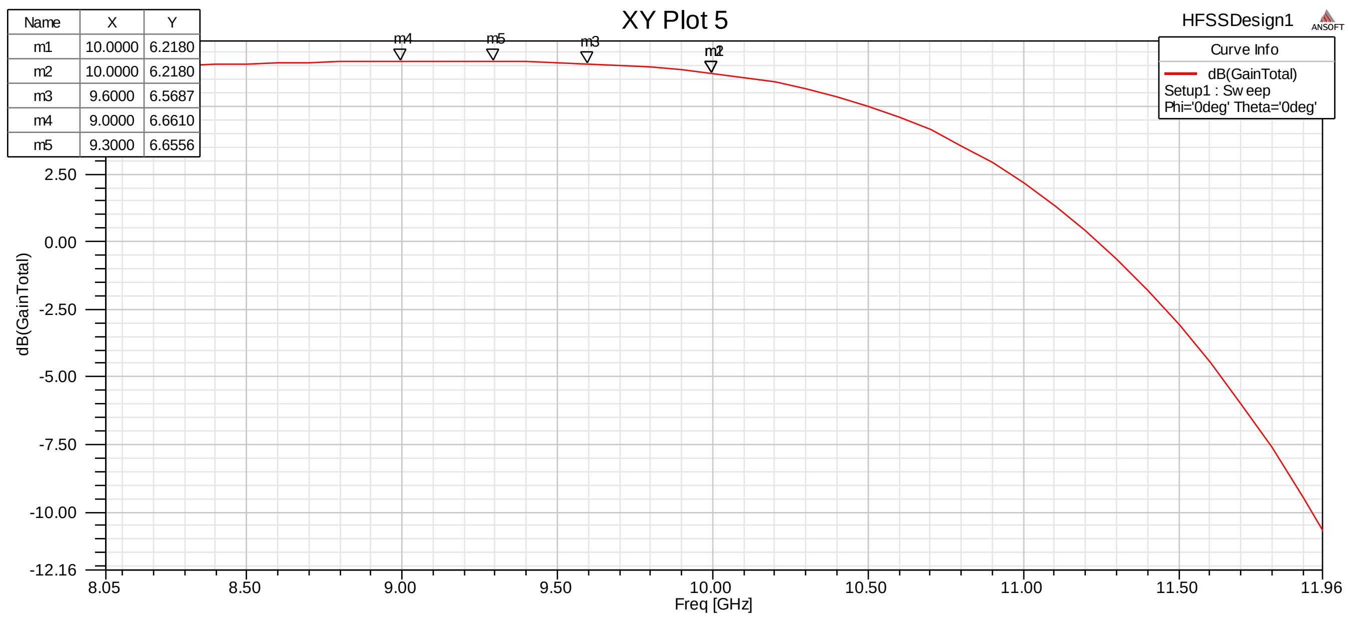


Figure 3.9: the Gain variation in terms of the Frequency

F) Smith Chart:

Figure 3.11 shows the impedance characteristics of the designed antenna where the m1 point represents the reactance value Rx at 10Ghz frequency.

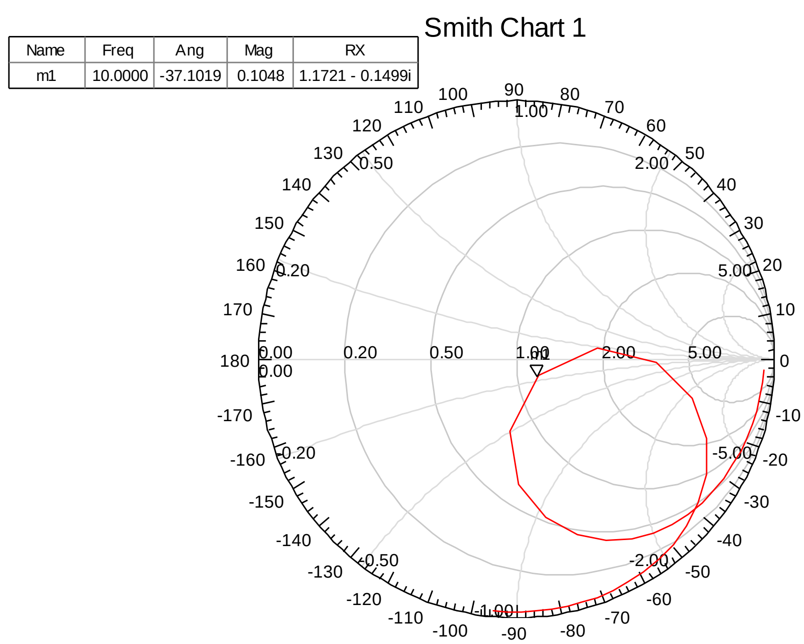


Figure 3.10:S11 in smith chart

The smith chart shows that our antenna needs more enhancement because the real part of the impedance value is close to 1 and the imaginary part close to 0 to get max power transfer without losses we have to make the impedance close to the pure resistive case as much as we can and this is what we will do in next title.

3.2.7. Enhancing Microstrip Antenna Using Ground Slot technique

Microstrip antennas have many advantages such as low fabrication cost, and high efficiency but the big problem is the narrow bandwidth in this part, we try to enhance the results of the previous rectangular antenna by adding 3 slots to the ground plane with proper length and width, Noting its effect on the rest of antenna parameters. figure 3.12 shows that all the slots have the same distance between them and the feed point we try to keep the feed point in the middle of the two side slots whenever we increase the length of the slot to get better results. we also change the length of the feed line to get better impedance matching and to reduce the reactance value after many attempts, we found a suitable feed line length Fl=3.999mm so that reduce the reactance value to 0.00Xi this value also could be enhanced by increasing the 3 slots length.

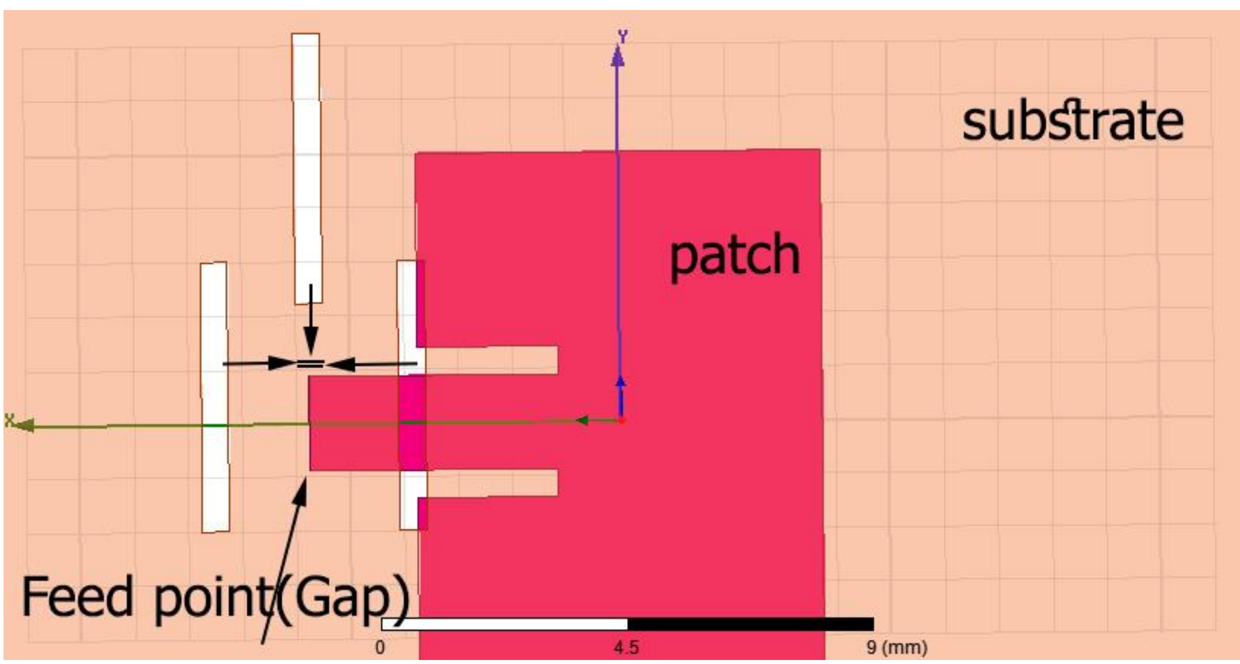


Figure 3.11: microstrip antenna with 3 slots in the ground plane

We start with a 5mm slots length and a fixed width of 0.5mm, By changing the length of the slots in incremental we have recorded a change in the antenna parameters shown in table 3.2.

Results:

Table 3.3:Comparing Antenna Parameter before and after adding slots with different lengths

Ant	Slot length(mm)	Fr(GHz)	Bandwidth(MHZ)	S11(dB)	Gain(dB)	% η
Rect0	non	10	223	-19.59	6.5724	94.01
Rect1	5	10	243	-20.93	6.5950	94.03
Rect2	6	10	242	-21.25	6.5968	94.11
Rect3	7	10	243	-21.23	6.5529	94.08
Rect4	8	10	241	-20.77	6.4621	93.34
Rect5	9	10	242	-21.01	6.5038	93.66
Rect6	10	10	243	-21.28	6.5763	93.65
Rect7	11	10	242	-21.08	6.6485	95.26
Rect8	12	10	242	-20.91	6.5757	94.41
Rect9	13	10	244	-21.36	6.5513	94.26
Rect10	15	10	245	-21.55	6.6475	95.64

Table 3.2 represents the change in antennas parameters in terms of Slot lengths, Through the measured values, we can note that no matter how we change the length of the aperture, the resonant frequency remains constant, and this is a good thing, while the Bandwidth values have increased with the change in the length of the Slots, as the highest value measured is 245MHz at Rect10 with the best efficiency rate of 94.16% and Gain increased to 6.6475dB, The S11 measured at Rect10 shows us that the impedance matching between the feed line and the

patch is excellent, as the energy conversion ratio, in this case, is the greatest value we have reached during the previous ten experiments.

From Equations 3.7 and 3.8 we found that the reflected power is less than 1% which is 0.69% of all the power so, the radiated power achieves 99.31%.

3.2.8. Antenna Size Reduction and further enhancement

We can make some improvements to the antenna by adjusting the size of the ground plane by following the following laws (18):

$$Lg = 6h + Lp \qquad 3.9$$

$$Wg = 6h + Wp \qquad 3.10$$

Depending on some researchers a general rule for the Substrat dimensions could be used To avoid the effect of substrate edges on antenna performance, we should pick a substrate with length and width equal to three times the length and width of the patch antenna (19).

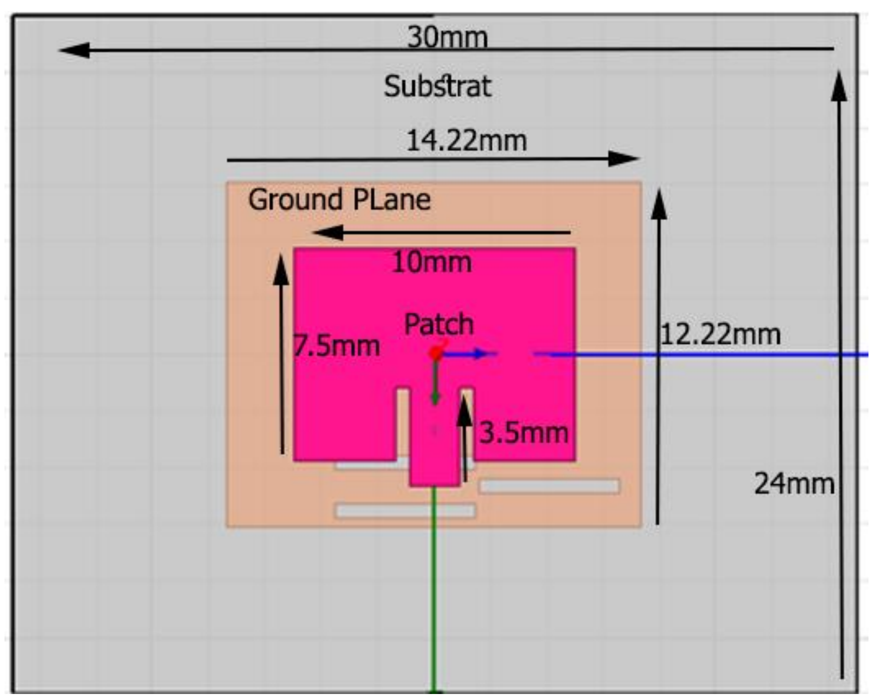


Figure 3.12: Final Form of the rectangular microstrip antenna

Table 3.4: represents the changes made to the size of some antenna elements to improve it's performance.

Substrate Width(mm)	Substrate Length(mm)	Ground Plane Length(mm)	Ground Plane Width(mm)	Feed Line length(mm)
30	24	12.22	14.22	3.5

As we saw in the results of Table 3.2, after reducing the length of the feeding line, we got a better impedance matching. As for Table 3.3, we changed the size of the feeding line as well as the size of each insulating layer And the ground layer to improve the antenna parameters the Ground plane size effect was explained in the second chapter.

In table 3.5 we compare antenna parameters of 3 cases, in Rect0 there is no slot in the ground plane while in Rect1 the antenna has 3 slots with a length of 5mm in the ground furthermore, the Rect1(2) is the same as Rect1 but the substrate size, ground plane, and the feed line have been changed Following the values in table 3.4.

Table 3.5:Comparing Antenna Parameters before and after changing the size of substrat and ground plane

Antennas	Slot length(mm)	Fr(GHz)	Bandwidth(MHZ)	S11(dB)	Gain(dB)	% η
Rect0	non	10	223	-19.59	6.5724	94.01
Rect1	5	10	243	-20.93	6.5950	94.03
Rect1(2)	5	10	250	-25.47	7.2548	91.05

A) Bandwidth and S11:

Through the results of the previous table, we can see the clear difference between the Bandwidth and the S11 after making successive changes, From Rect0 to Rect1(2) we get 250 Mhz of the frequency range. Also, the gain has been improved to 7.2548dB which is in the acceptable range (from 6dB to 9dB).

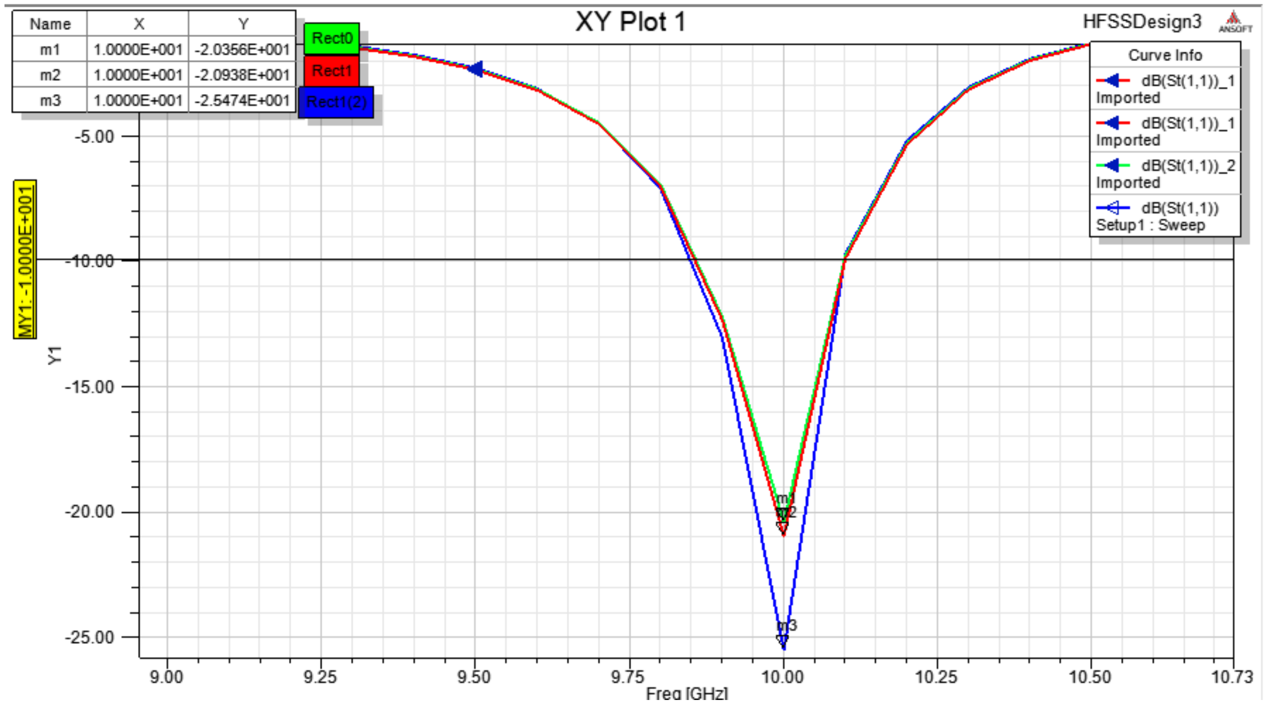


Figure 3.13: S11 plot

According to the S11(Rect1(2)), the reflection coefficient is equal to 0.056 so the reflected power will be 0.32% of 99.68% radiated power and it's 0.78% higher than Rect0.

B) Radiation Pattern:

As we explain before that our antenna is directional according to the 3D plot gain so the directivity is on the Z-axis, the figure 3.14 show that the angle from -30 to 30 degrees represents the HPBW(Half Power Beam Width) where the most power is radiated, and the main lobe in the direction of 0 degrees and the back lobe in the back direction represents the energy wasted.

If we compare the Rect0 and Rect1 with Rect1(2) the most likely to use is the Rect1(2) results, Simply we can say that the power radiated from the antenna is the function of angular position and radial distribution from the antenna, another difference between Rect1(2) and the two previous experiments is that the energy wasted in the back lobe is greater in the last case.

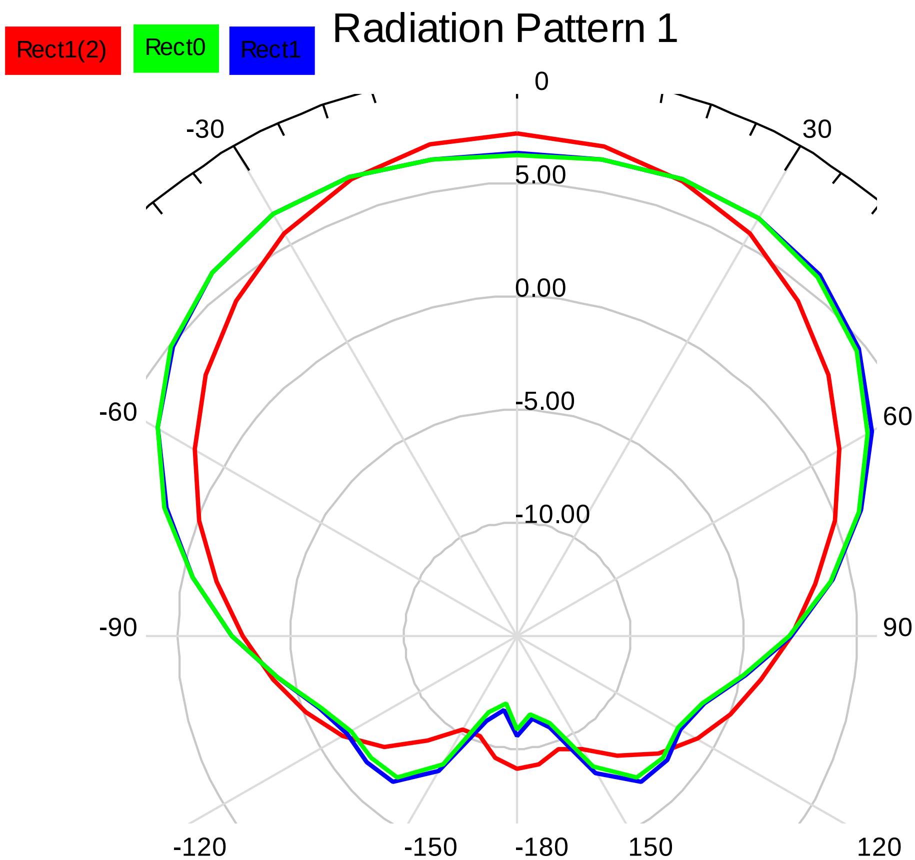


Figure 3.14: Radiation pattern comparison of Rect 0,1, and 1(2)

3.3. Comparing Roger4530 and Fr4-Epoxy material results

In this part, we try to explain the difference between the use of Roger4350 material and FR4-Epoxy, from what was previously mentioned in the second chapter. The cost of using Fr4-epoxy material is lower than its counterpart. We will explain through this experience why this difference in price and field of use.

Since we want to change the material of the insulating layer, the dielectric constant will change and therefore the dimensions of the patch, the ground plane, and the insulating layer will also change.

Table 3.6: Represents the dimensions of the new patch antenna after changing the insulating layer material

Ɛr	Lp(mm)	Wp(mm)	Lg(mm)	Wg(mm)	Ls(mm)	Ws(mm)	H(mm)
4.4	6.88	9.12	11.61	13.85	20.66	27.38	0.7874

After the simulation, we used the same principle of Rect1(2), where the length of the slots at the level of the ground layer is 5 mm with changing the size of the feeding line so that we get the best possible result. The Rect3 results obtained and compared to Rect1(2) are as follows:

Table 3.7:Comparation result of Ro4350 and FR4-Epoxy Materials

Antennas	Slot length(mm)	Fr(GHz)	Bandwidth(MHZ)	S11(dB)	Gain(dB)	% η
Rect3	5	10	168	-12.01	4.9933	60.32
Rect1(2)	5	10	250	-25.47	7.2548	91.05

Where Rect3 is the result of MSA designed using Fr4-Epoxy material.

Through the results of the previous table, the clear difference between Rect1(2) and Rect3 can be seen. After changing the substrat, we noticed a significant decrease in gain from 7.2548 dB to 4.9933 dB, efficiency from 91.05% to 60.32%, and bandwidth from 250 Mhz to 168 Mhz.

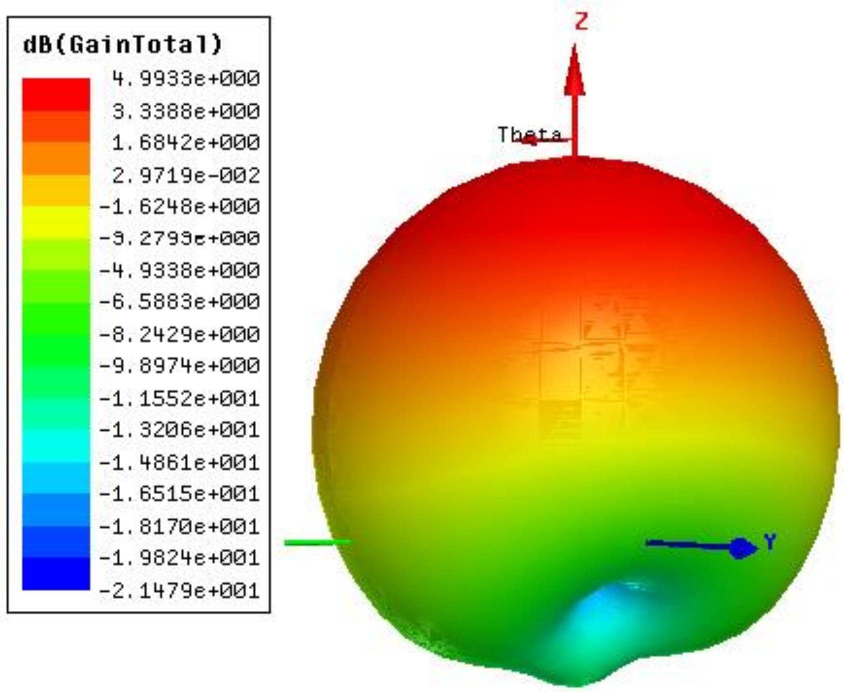


Figure 3.15:3d Polar Gain Plot

In addition, we noticed an increase in the value of S11, which is not good and is a sign of bad impedance matching, According to Equation 3.7, we can conclude that the percentage of lost energy is 6.32%, so we consider it as a lossy antenna.

By comparing the previous results, we can say that FR4-Epoxy cannot be used in areas that require accurate results, such as radar and missile systems, as the loss rate is large, and this explains the low cost of this material.

3.4. Conclusion

The Ground Slot technique helps to achieve a broadband MSA for X-band applications and solves the main problems of the MSA's such as the narrow bandwidth, low gain, and low efficiency, so the antenna could be used for radar applications Without the fear of excessive waste of energy. This technique is not limited to a specific shape only, but the shape of the slots can be changed to obtain better results if it's possible.

CONCLUSION, PERSPECTIVES, AND FUTURE SCOPE

3.5. General Conclusion, Perspectives, and future scope

The rapid progress of communication technology in recent years has played a major role in the level of information transmission and collection, as well as in the case of antennas that work in the the X-band frequency. It is no longer limited to the extent of antenna radiation only, but also the accuracy and gain, as well as the value of the energy lost concerning the transmitted energy. On the other hand, small electronic circuits have greatly affected the size of devices so that antennas are much smaller than their predecessors. Among these types of printed antennas, their advantages are the ability to be included in MMIC circuits and on different surfaces.

MSA is among the most important types of printed antennas, as its advantages are its small size, low manufacturing cost, and lightweight. In contrast, this type of antenna suffers from many problems including low bandwidth, low gain, and efficiency. In this project, we conducted a study on The method of improving these antennas using the Ground Slot technique combined with other important elements such as the type of feed and the material used in the manufacturing. We designed a Broadband E-Shaped microstrip antenna with dimensions of 30 * 24 mm^2 with a resonant frequency of 10GHz.

The first design was an E-shaped microstrip antenna with an inset feed method without applying the ground slot technology so that we could compare the results before and after applying the technique, as well as the matter where we got better results in terms of gain and bandwidth, on the other hand, we noticed the effect of changing the size of the substrat And the ground plane on antenna parameters and how reducing its size led to an improvement in gain, bandwidth, and S11, except for the effectiveness, which decreased by 3%.Finally, we studied the effect of changing the insulating layer material on antenna performance and size, Roger4350 material was more effective and better than FR4-epoxy, and this clearly proved the reason for its lower cost than the first, and the areas that require accurate results mostly depend on Roger4350 due to its features shown in Chapter Two .

Perspectives and Future Scope

Perspective:

- The ground slot technique has a great effect on bandwidth, gain, and S11.
- Using the inset feed method helps to get better impedance matching as well as a lower input reflected power.
- Properly reducing the size of the ground plane and the substrat could decrease the losses and increase the radiated power.
- The Roger4350 material has a great effect to enhance gain and other antenna parameters.

Future Scope:

- Use a diode to make the antenna frequency reconfigurable.
- Changing the patch shape to circular could enhance bandwidth by 8%.

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