DESIGN AND ANALYSIS OF SUBSTRATE INTEGRATED WAVEGUIDE ANTENNA PERFORMANCE FOR MATERIAL CHARACTERIZATION (TEFLON)

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ABSTRAK

Permintaan sistem elektronik bersaiz kecil telah meningkat dari beberapa tahun. Antena tampalan ialah salah satu antena yang paling menarik untuk sistem bahagian hadapan RF bersepadu kerana keserasiannya dengan litar bersepadu gelombang mikro. Antena tampalan segi empat tepat mudah dibina dan dianalisis.Pandu gelombang bersepadu substrat telah dikaji sebagai kelas talian penghantaran bersepadu yang cekap serasi dengan teknologi planar, menawarkan perisai konsisten diri yang tiada tandingan dan prestasi faktor berkualiti tinggi. Dalam kertas ini, antena tampalan segi empat tepat jalur mikro yang dicadangkan disimulasikan pada prestasi analisis frekuensi resonans 2.4 GHz bagi antena pandu gelombang bersepadu substrat dengan pencirian bahan dengan menggunakan Teflon (polytetrafluorethylene) sebagai substratnya dan ketinggian substrat yang berbeza telah disiasat. Untuk simulasi, antena disiasat secara berangka menggunakan perisian High Frequency Structure Simulator (HFSS). Beginilah cara pengekstrakan maksimum boleh dilakukan daripada antena tampalan jalur mikro ringkas dengan menggunakan substrat Teflon. Selepas mengarang antenna tampalan segi empat tepat jalur mikro, keputusan rekaan telah diambil dan ditulis dalam kertas.

ABSTRACT

The demand of small size electronic systems has been increasing from several years. Patch antennas are one of the most attractive antennas for integrated RF front-end systems due to their compatibility with microwave integrated circuits. The rectangular patch antenna is easy to construct and analysis. Substrate Integrated Waveguide (SIW) was studied as a class of efficient integrated transmission lines compatible with planar technologies, offering incomparable self-consistent shielding and high-quality factor performances. In this paper, the proposed microstrip rectangular patch antenna is simulated at 2.4 GHz resonance frequency analysis performance of substrate integrated waveguide antenna with material characterization by using Teflon (polytetrafluorethylene) as its substrate and different height of the substrates were investigated. For the simulation, antennas are numerically investigated using High Frequency Structure Simulator (HFSS) software. This is how the maximum extraction can be done from a simple microstrip patch antenna by using a Teflon substrate. The simulation results were taken and are shown in the paper. The simple structured configuration and low profile of the proposed antenna makes the fabrication process easy

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LIST OF SYMBOLS

εr	Permittivity
H	Height
L	Length
W	Width

LIST OF ABBREVIATIONS

SIW	Substrate Integrated Waveguide
HFSS	High Frequency Simulation Software
FEM	Finite Element Method
FR4	Glass Fiber Epoxy Laminate
PTFE	Polytetrafluoroethylene
WIFI	Wireless Local Area Network
GPS	Global Positioning System
GSM	Global System for Mobile Communications
RFID	Radio Frequency Identification
PCB	Printed Circuit Board
WBAN	Wireless Body Area Network
MIMO	Multiple Input Multiple Output

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter provides a brief view of this project. The definition of the project title discussed in this chapter. Other than that, the background of this project, problem statement, objectives and scope of the project also explained in this chapter.

1.2 Project Background

An antenna, also known as an aerial, is a device used with a transmitter or receiver that serves as the interface between electric currents flowing through metal conductors and radio waves travelling across space. Electrical signals are transformed into electromagnetic waves via antennas, which act as both a sensor and a transducer. The majority of antennas are resonant structures that function effectively across a constrained frequency range. The system reception antenna is in charge of converting electromagnetic waves into their original electrical signal form in wire. The properties of the transmitting and receiving antennas are fully defined by Maxwell's equations[1].

For wireless LANs, there are three primary antenna classifications to choose such as omnidirectional, semi-directional, and highly directional. A signal can be transmitted in all directions using omnidirectional antennas. An antenna of this kind is an attempt to give universal coverage in all directions, even though it is impossible for an antenna to perfectly transmit a signal in all directions at equal strength under the fundamental rules of physics. Due to the need for high coverage in a general spherical area surrounding the antenna in client adapters and access points, this is the type that is most frequently seen in these devices. Semi-directional antennas have a focused, directed signal coverage over a wide area in their design. For point-to-point links, such as those between two buildings, highly directional antennas are employed. They are frequently used for dedicated links since they radiate a relatively narrow beam across a large area. So, a microstrip antenna is used here as an illustration of a directional antenna.

There are several advantages of this type of microstrip patch antenna, such as being planar, small in size, simple in structure, light weight, low in cost, compatibility with printed circuits and easy to be fabricated. Thus, it is attractive for practical applications like Bluetooth, Wi-Fi [2]. Although any continuous design is feasible, the most typical microstrip antenna shapes are square, rectangular, circular, and elliptical. Several patch antennas are built of a metal patch positioned mounted a ground plane utilising dielectric spacer rather than a dielectric substrate. The resulting structure has a wider bandwidth but is less robust. The rectangular microstrip patch antenna is about half a free-space wavelength long when air is utilised as the dielectric substrate. As the length of the antenna inversely proportional to dielectric constant of the substrate. In the wireless communication system, the antenna is one of the most critical components. A good design of antenna can improve overall system performance[3].

Substrate integrated waveguide (SIW) technology has recently emerged as a new method for creating tiny, low-loss, and economically viable parts, circuits, antennas, and entire systems at microwave and millimeter wave frequencies. SIW are planar devices created by linking the top and bottom metallic ground planes of a dielectric constant substrate with structure with two periodic rows of metallic or slots. A nonplanar metallic waveguide can be transformed using SIW technology which is planar in nature and is easily fabricable on and integrated into planar circuits. Additionally, SIW-based components can be integrated with other passive components and active printed circuit board components on the same board to the waveguide's planar shape. It is a simple geometry which make the rectangular patch is the most commonly used microstrip antenna, characterized by its length L, width W and thickness h, as shown in Fig 1.2.

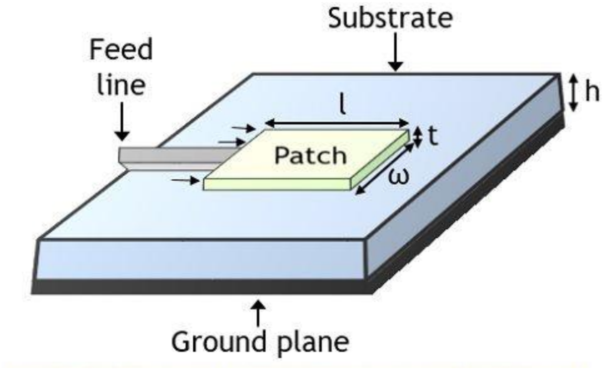

Figure 1.1 Microstrip Patch Antenna Structure

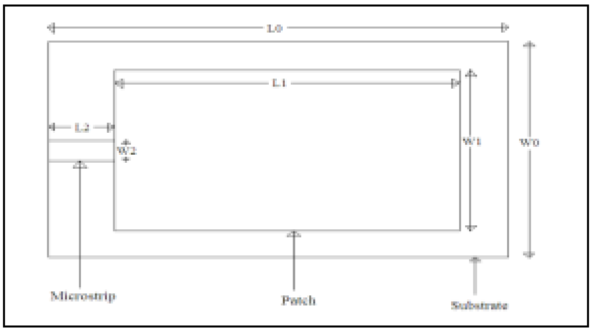

Figure 1.2 Antenna Geometry

1.3 Problem Statement

There are have some drawbacks in term of narrow bandwidth, low gain and feed radiation limited power handling capacity because the effect of properties of dielectric material used as a substrate for the antenna on the reflection loss performance. The dielectric constant is inversely proportional to the frequency. Therefore, due to the decrease the reduction of space charge polarization effect. In order to improve the reflection management, the low dielectric constant can shorten the effective electrical length of the leads.

The proposed antenna is rectangular in shape, which operates in the range of 2.4 GHz, require smaller antenna size in order to meet the miniaturization requirements of wireless communication. When we redesign the shape of a microstrip antenna and it covered with a dielectric layer, the resonant frequency and the gain can change which help upgrade or degrade the system performance. This is due to when use low dielectric constant, it leads to larger dimensions of antenna. Therefore, in order to design an antenna, need to have a compromise between the dielectric constant, antenna sizes, radiation efficiency and bandwidth or perform miniaturization technique.

The examination of Teflon substrate with adding SIW technique for high return loss and high antenna gain antenna with low profile for millimetre wave are needed due to the high cost of the rectangular waveguide (RWG).Therefore, in order to introduce appropriate correctness in the design of the antenna, it is important to determine the effect of dielectric layer and shapes on the antenna parameter[4] The development of applying SIW technique in communication devices help to increase by improvement of a new technologies used in passive circuits and SIW is suitable for fabrication by using printed circuit board in future development of antenna.

1.4 Research Objectives

The purpose of the study is:

- To study the performance of antenna efficiency by using dielectric constant substrate permittivity of TEFLON material on the patch antenna.

- To analyze the performance of antenna parameters by using SIW technology.

- To design antenna for achieve optimum range and good system performance for future wireless communication.

1.5 Scope of the Project

This research started on October, 2021 up to June ,2022. All the studies at Faculty of Electrical and Electronics Engineering Technology, Universiti Malaysia Pahang, Pekan Campus,26600 Pekan, Pahang, Malaysia. The research range could include a few different scopes including:

The research of this project focuses on three scopes. First and the foremost is antenna design project is to test the antenna performance using Substrate Integrated Waveguide technique with Teflon substrate on the patch antenna to observe the antenna efficiency performance.

Next, this research investigates on three different heights of the substrate of rectangular patch antenna in order to choose the best and suitable height for low dielectric constant Teflon substrate.

The different layers of the antenna are only the manipulated variable in this research study. Others parameters are kept constant variable depend on the performance. In term of layers is antenna with and without SIW addition technique and the frequency, coordination and the dimension of the design antenna area all in constant parameters.

1.6 Outline Thesis

In this thesis, the first chapter will explain the background of the antenna and wireless communication. Then the problem that effect the antenna materials and try to achieve the objectives of the project. There is scope of the project. first define. In next chapter discuss about the fundamental of the antenna and specifically related to the microstrip patch antenna. There have a summarize of the research gap analysis related the substrate material and SIW technique. In methodology, discuss about the SIW technique and design development. Apart from that, the method of solution of how to simulate the results. Next, discuss the parameters analysis and performance of the antenna in visual form. Final chapter is conclusion, limitations and future recommendation. In this chapter summarize overall chapters and discuss about the suggestion that can improvise the performance of the antenna to future researchers and wireless communication.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The aim of this chapter is to understand fundamental of the antenna parameters and its equations. Next, a review with researches that is related to the improving the parameter performance of the antenna. In addition, summarize the gap analysis that related to my propose antenna.

2.2 Types of Antenna

There are few types of antennas and its classification of antenna for the applications. The antennas can categorize based on the direction of the radiation emitted by them. For wireless communication systems, the antenna is one of the most critical components respectively in order to improve the overall system performance, need a good design of antenna. Some of antenna use in high gain applications when needs to monitor the radiation pattern. Here are some of the antenna and its applications.

.

Table 2.1 List of Types of Antenna

Types of antenna	Examples	Applications
Wire Antennas	Dipole antenna, Monopole antenna, Helix, Loop antenna	Personal applications, buildings, ships, automobiles, space crafts.
Aperture Antennas	Waveguide(opening), Horn antenna	Flush-mounted applications, air craft, space craft.
Reflector Antenna	Parabolic reflectors, corner reflectors	Microwave communication, satellite tracking, radio astronomy
Lens Antennas	Convex plane, Concave plane, Convex-convex, concave-concave lenses	Used for very high frequency applications
Microstrip Antenna	Circular shaped, rectangular shaped, metallic patch above the ground plate	Air-craft, space craft, satellites, missiles, cars, mobile phones.
Array Antenna	Yagi-Uda antenna, microstrip patch antenna, aperture array, slotted waveguide array	Used for very high gain applications, mostly when needs to control the radiation pattern.

2.3 Microstrip Rectangular Patch Antenna

2.3.1 Introduction

In the 1950s, the first micro strip antenna was developed. Unfortunately, printed circuit board (PCB) technology wasn't invented until the 1970s. Therefore, microstrip patch antenna become a very important antenna which is having wide range of applications due to their advantages like light weight, low profile, low cost and planar configuration. Microstrip antennas are widely used in a variety of application like radio frequency identification (RFID), broadcast radio, mobile system, global positioning system (GPS), satellite communication, television systems, multiple-input multiple-output (MIMO) systems as well as more. There seems to be little uncertainty that micro strip patch antenna will continue to find various applications in the future wireless communication due to its many unique and attractive characteristics.

The microstrip patch antenna properties include light weight, low profile, easy fabrication, compact and conformability to mounting structure. In this design, we are concentrating on rectangular microstrip patch antenna which consists of rectangular patch of length [L1] and width [W2] of the patch antenna. The proposed antenna works on the wireless local area network (WLAN) frequency of 2.4GHz (2400-2484MHz) which is based on IEEE 802.11b for WLAN applications. The substrate material used is TEFLON which has dielectric constant which lies in the 2.1.

The emergence of low-loss tangent substrate materials during this decade encouraged other researchers develop their research. Improved photolithographic methods, better theoretical modelling, and the substrate's attractive thermal and mechanical properties are further driving forces behind the development. Munson and Howell created the first useful antenna. Microstrip antennas and their arrays have since undergone substantial study and development, contributing to a variety of applications within the wide field of microwave antennas.

The purpose of microstrip patch antenna is to radiate and receive electromagnetic energy in microwave range and it plays an important role in wireless communication applications. The performance and operation of a microstrip antenna is dependent on the geometry of the printed patch [8] and the material characteristics of the substrate onto which the antenna is printed. Here, are the analysis and design equations. These all equations are to be used for calculating the resonant frequency, width, patch thickness and dielectric constant. The width of the rectangular microstrip antenna is given by:

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r + 1)}{2}}}$$

Equation 2.12

where C is the speed of light, f_o is the resonant frequency, and εr is relative dielectric constant of the substrate and by substituting the values of C = $3x10^8$ m/s

The effective dielectric constant is given by:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

Equation 2.13

where, h is the height of the substrate, W is the width of the patch W is width of the patch.

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}}$$

Equation 2.14

Hence, after the substitution the value C, the effective length will be mm unit. The different in length, the function of the effective dielectric constant and the ratio of width to height is given as below:

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

Equation 2.15

The actual length and width of the patch and substrate which are given as

$L = L_{eff} - 2\Delta L$ **Equation 2.16**

Length of ground L_g = 6h + L **Equation 2.17**

Width of ground W_g = 6h + L **Equation 2.18**

2.3.2 Advantages and Disadvantages

As a result, it has many applications across a wide frequency range, from around 100 MHz to 100 GHz. Although the size of a microstrip antenna has both advantages and disadvantages, there are several applications where the size is excessive. A microstrip antenna's frequency is inversely proportional with its size. Due to the sizes needed, microstrip patches are unsuitable at frequencies below microwave. The narrow bandwidth is one of the main drawbacks of these types of antennas[6]. A straight forward method of improving the bandwidth is increasing the substrate thickness. However, surface wave power increases and radiation power decreases with the increasing substrate thickness, which leads to poor radiation efficiency. Therefore, various other techniques are presented to provide wide-impedance bandwidths of microstrip antennas.

Table 2.2 Advantages and Disadvantages of MSA

Advantages of MSA	Disadvantages of MSA
They are light in weight.	They have narrow bandwidth.
They occupy low volume.	The efficiency is low.
They are of low-profile planer configuration.	They have low gain.
They can be made conformal to planar and non-planar surfaces.	They have low power handling capacity.
Their ease of mass production leads to a low fabrication cost.	They have low isolation between radiating elements and feed.

2.3.3 Applications of Microstrip Antenna

The implementation of microstrip antennas suits a variety of commercial applications. Microstrip patch antenna fulfils most requirements for mobile and satellite communication system and many kinds of microstrip antennas is designed for this purpose. There are other government and commercial applications in the area of mobile radio and wireless communications where the requirement of this antenna is suitable. It is also expected that due to the increasing usage of the patch antennas in the wide range this could take over the usage of the conventional antennas for the maximum applications[7].

i. Mobile Communication Systems and Satellite Communication

Microstrip patch antennas have been designed for use in mobile communication systems since they are compact, inexpensive, and low profile, which are all requirements for mobile communication.

ii. Doppler and other Radars.

Antenna in radar can be used for detecting moving targets such as people and vehicles. It demands a low profile, light weight antenna subsystem, the microstrip antennas are an ideal choice.

iii. Radio Frequency Identification (RFID)

The RFID can store a range of information from one serial number to several pages of data and it is use in different areas like mobile communication, logistics and manufacturing [2]. Generally, RFID system uses frequencies between 30 Hz and 5.8 GHz depending on its applications.

iv. Telemedicine Application

In telemedicine application antenna is operating at 2.45 GHz. Wearable microstrip antenna is suitable for Wireless Body Area Network (WBAN). In comparison to other conventional antennas, the proposed antenna had a higher gain and front-to-back ratio. It also had a semi-directional radiation pattern, which is preferred to an omnidirectional pattern to reduce unnecessary radiation to the user's body, and it met the requirements for both on-body and off-body applications.

v. Rectenna Application

Rectenna can be defined as rectifying antenna, a unique kind of antenna that converts microwave energy directly into DC electricity. As a result, the goal is to use the rectenna to transfer DC power over long wireless networks; however, this can only be performed to enhance the antenna's electrical dimensions.

vi. Global Positioning System Applications (GPS)

The proposed and examined microstrip patch antenna is thinner and less expensive than the thick ceramic patch antenna commonly used for automobile applications. With this configuration, a low noise amplifier can be simply integrated onto the substrate used for the feeding circuitry. Therefore, the use of quadrature feeding enables improved circular polarisation purity and a wider impedance bandwidth, reducing the dependence of ceramic antennas on the environment.

2.3.4 Feeding Technique

2.3.4.1 Microstrip Line Feed

This feeding technique in which the microstrip patch is directly connected with the conducting microstrip feed line [8]. In addition, the dimensions of the feed line are different than microstrip patch antenna and it is easy to fabricate and match. The microstrip line feed is shown in Figure 2.1.

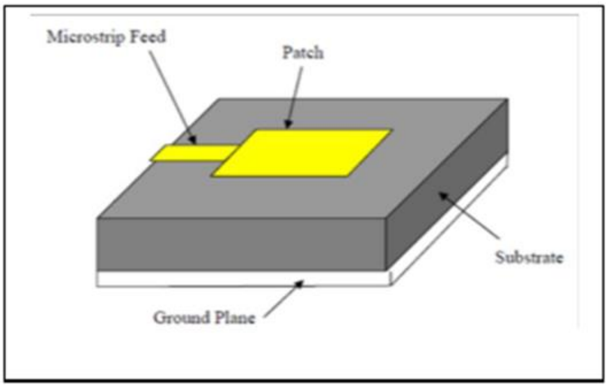

Figure 2.1 Microstrip Line Feed

2.3.4.2 Coaxial Probe Feed

The inner conductor of the coaxial cable is connected to the antenna's microstrip patch in this feeding technique, while the outer conductor is linked to the ground plane. In most techniques, the feed networks are isolated from the microstrip patch. The advantages of the coaxial feeding technique include efficient feeding, easy fabrication, and minimal spurious radiation. The coaxial probe feed is shown in Figure 2.2.

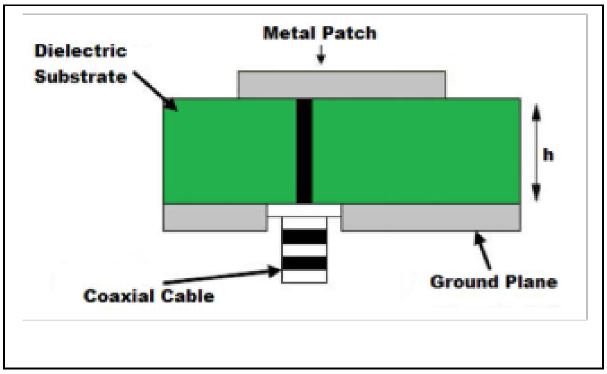

Figure 2.2 Coaxial Probe Feed

2.3.4.3 Aperture Coupled Feed

This feed is having two substrates, which are different from each other and are separated by a ground plane. Through a slot in the ground plane, the microstrip patch and feed line are coupled in this method. The advantages of the aperture coupled feeding method are pure polarisation and interference minimization. The aperture coupled feed is shown in Figure 2.3.

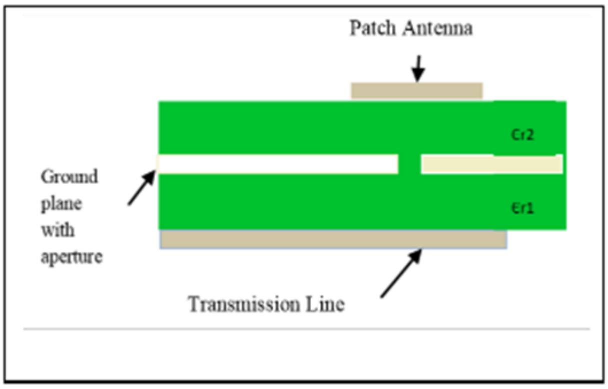

Figure 2.3 Aperture Coupled Feed

2.3.4.4 Proximity Coupled Feed

This feeding method design is quite complicated in comparison. This technology mainly consists of two dielectric substrates. The feed line is present between two substrates, and the microstrip patch is present on the upper surface of the upper dielectric substrate. It provides the widest bandwidth and prevents misdirected radiation. The proximity coupled feed is as shown in Figure 2.4.

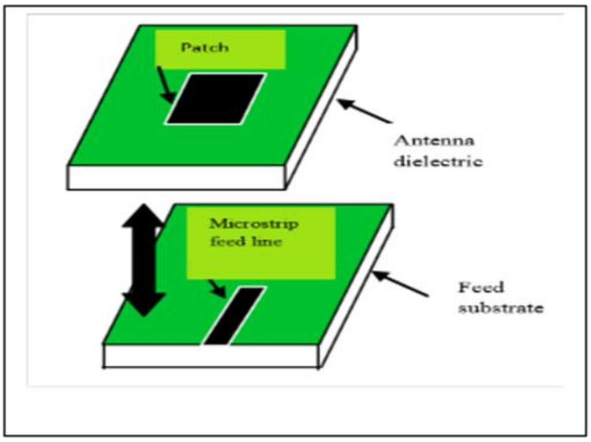

Figure 2.4 Proximity Coupled Feed

2.4 Fringing Field

A metallic patch is printed on a thin, grounded dielectric substrate in a conventional microstrip antenna. A dielectric material stands in between two conducting objects to form a conventional capacitor. This electric field is known as a fringing field because it extends beyond the immediate vicinity of the conductive objects. A microstrip antenna's performance is significantly impacted by the fringe field. The electric field in the patch's centre in microstrip antennas is zero. The radiation is due to the fringing field between the periphery of the patch and the ground plane. For rectangular patch shown in the Figure 2.5, there is no field variation along the width and thickness. The amount of fringing field is a function of the dimensions of the patch and the height of the substrate. Higher the substrate the more is the fringe fields[9].

Due to effect of fringing a microstrip patch antenna would look electrically wider compared to its physical dimensions. As shown in Figure 2.6, the waves travel both in substrate and air. Thus, an effective dielectric constant εreff is to be introduced. The effective dielectric constant εreff take in account both the fringing and the wave propagation in the line.

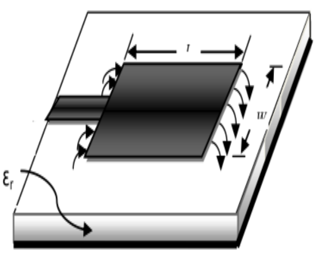

Figure 2.5 Fringing field of rectangular microstrip antenna

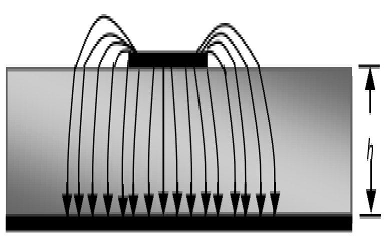

Figure 2.6 Electric field lines (Side View)

2.5 Research gap analysis

Table 2.3 Review of literature dielectric constant and SIW technique

Output for objectives: Summarize for analysis the dielectric constant for Teflon substrate and its performance

No	Articles	Author	HFSS/ CST	Substrate	Frequency (GHz)	Height of the substrate (mm)	Permittivity (εr)	Application	Type of antenna	Key Findings
1	Design and Fabrication Microstrip Patch Antenna at 2.4 GHz for WLAN Application using HFSS	Shera Prabjyot Singh (2016)	HSFF	FR-4 Epoxy material	2.4	1.5	4.4	WLAN	RMPA	It was found that the proposed antenna sufficient bandwidth was introduced through the microstrip feed line at the frequency 2.4 GHz was achieved.
2	Compact, Teflon Embedded, Dual-Polarized Ultra-Wideband (UWB) Antenna	Lars Reichardt (2012)	HFSS.	Duroid RT5880& TEFLON	3.5-13.5	0.79	2.1	Indoor Radar	Ultrawide-band antenna	Due to tapered slot lines were embedded into Teflon it was possible to obtain a compact size with a relatively high gain of up to 12 dBi.

3	Development of SIW Horn Antenna for Material Characterization	Nurul Afifi Alias (2020)	HSFF	RT/Duroid substrate	8.2-12.4	2.5	2.33	Material characterization application.	Horn& leaky-wave structures	The contribution of the findings was to develop a compact design of the SIW horn antenna with better performance compared to the conventional waveguide.
4	Microstrip Patch Antenna Parameters, Feeding technique and Shape of the Patch-A Survey	Udit Raithatha (2016)	HFSS	Rogers RT/Duroid 5880, FR4, Glass Epoxy, FR4 epoxy	3.42, 4.5 - 7.82, 1.476 & 1.12584, 1.3740-3.0760, 2,4	N/A	2.2, 4.4, 3.8-4.8	Wireless application, WiMAX, wideband applications, Bluetooth.	RMPA	The recent developments in the MSTPA is discussed, the effect of the shape and dimensions of the patch substrate also important to get the proper output parameters.
5	Rectangular Patch Microstrip Antenna-A Survey	Nikita Sharma (2014)	CST, HFSS, IE3D	N/A	N/A	N/A	N/A	Mobile, Satellite, Radar. RFID, GPS	MSA, MSA(Slot) & Printed dipole antennas	It was found that the configuration can overcome the low gain and power handling capacity. The feeding techniques able to improve their performances.
6	Comparative study of textile material characterization techniques for wearable antennas	Jeremiah O.Abolade (2021)	HFSS	Copper, Kente-Oke, Sanya, Alaari & Etu	2.5	0.08	1.68, 1.46, 1.32 & 1.51	Wearable devices	RMPA	The stub resonator technique to tune the permittivity to the actual value.

7	Study the Characteristics of Rectangular Microstrip Patch Antenna on Different Substrate Materials at 2.45GHz	Pavan K. Sharma (2012)	IE3D	PTFE, Taconic RF-30 (lossy), FR-4 (lossy)	2.4GHz	1.6	2.1,3.0,4.3	Integrated RF front-end systems	RMPA	It was found that when the dielectric constant of the substrate increased, the bandwidth and the gain decreased. The maximum directivity also decreased by increasing the permittivity of the substrate materials.
8	Performance Analysis of Microstrip Patch Antenna with Different Shapes and Materials in C Band	Mrs. Marry Joy Kinol (2019)	HFSS	FR-4 and RT-Duroid 5870	2.4 to 5	1.6,1.575	4.4,2.33	Wireless fidelity	E-shape MPA	Different shapes of antenna in this type, E-shape antenna produces the best radiation efficiency and return loss. The patch antenna with substrate material FR-4 gives better return loss than material RT-Duroid
9	Analysis and Design of Rectangular Microstrip Patch Antenna using HFSS	P.Kokila (2015)	HFSS	FR-4	2.42	0.794	4.4	Wireless local area networks (WLAN’s)	Microstrip antenna	In this paper, microstrip patch antennas can provide frequency agility, width, feedline flexibility, beam scanning and omnidirectional patterning.

10	Performance Analysis of Microstrip Patch Antenna employing Arcylic, Teflon and Polycarbonate as low dielectric constant substrate materials.	Aastha (2016)	CST	Acrylic, Teflon & Polycarbo nate	2.0-4.5	2	1.9, 2 & 2.1	IMT and WiMAX applications .	MSA	It was found that low dielectric constant materials on antenna performance in terms of resonant frequency, gain, directivity and half power beam width has been studied. It has been analysed that the resonant frequency shifts towards lower frequency as the dielectric constant of substrate increases.
11	Design & Fabrication of Rectangular Microstrip Patch Antenna for WLAN Symmetrical Slots	Mudit Gupta (2017)	HFSS	FR-4	2.44	1.6	4.4	W L A N	Microstrip Patch Antenna	The proposed antenna with symmetrical slot shows better performance that and without slot respectively.
12	Study on the effect of the substrate material type and thickness on the performance of the filtering antenna design	Mohamme d K. Alkhafaji (2019)	CST	RO3003 FR-4 RT/Duroid 5880	2.412	30.944 ,50,63	3.0,4,4,2.2	WLAN applications	Four-pole microstrip filtering antenna (monopole antenna)	The filtering antenna is suitable for WLAN applications and a relatively high bandwidth is fit the fast data transmission. So, RT/Duroid material is indicate suitable for this design.

13	Design of Substrate Integrated Waveguide to Improve Antenna Performances for 5G mobile communication application	E Sandi (2019)	CST	Rogers RT5880 SIW (alumina)	28	0.787	2.2 9.9	5G technology	Circular microstrip antenna	It has analysed that the by addition of SIW material to the design of the 5G MIMO antenna can significantly improve antenna gain and slightly reduce antenna bandwidth.
14	Different Substrates Use in Microstrip Patch Antenna-A Survey	Kiran Jain (2014)	CST	Foam, Duroid, Benzocyclobutane, Roger 4350, epoxy, FR4, Duroid 6010	2.5	N/A	2.2 to 12	Judicious selection	Microstrip Patch Antenna, Circular Patch	Minimum size is achieved by using foam substrate but it is costlier and losses are higher in it even the efficiency is much less than others and surface wave losses more severe for thicker substrate.
15	Design of Rectangular Microstrip Patch Antenna	Houda Wefelli (2016)	ADS	Glass Epoxy substrate (FR4)	4.1	1.6	4.4	Ultra-Wideband Rectangular Antenna	RMPA	The simulation of the design of UWB rectangular antenna in in the Advanced Design System and HFSS.

16	Design of Microstrip Patch Antenna For 5g Wireless Communication Applications	Tran Thi Bich Ngoc (2020)	CST	RO3003	28	0.5	3.0	5G network	RMPA	The simulated results have been taken with different thicknesses of the substrate, were given that the antenna resonated at 28 GHz bands a reflection coefficient around -25 dB.
17	Design and Analysis of Slot Antenna Parameters using HFSS	K. Phaninder Vinay	HFSS	RT/Duroid 5880, FR4, Bekelite, Benzocyclobutene	7.5	0.794	2.2, 4.4,5,2.65	Wireless applications	RMPA	It was found that by changing the substrate which has dielectric constant in optimum range can improve the radiation pattern of slot antenna. RTduroid5880 is capable of providing optimum results.
18	Design of H-plane Horn Antenna using Substrate Integrated Waveguide	Vandana Kumari (2021)	HFSS	N/A	9.75	(SIW) p=2 mm., d=1 mm. & Weff = 15.53	N/A	Microwave devices	H-plane Horn Antenna	The performance of the SIW is studied with respect to its equivalent waveguide. It resonated at 9.75 GHz with acceptable end fire radiation pattern has achieved.
19	Design & Simulation of Rectangular & Circular Patch Antenna with EBG Substrates.	Navneet Saroha (2015)	HFSS	RT Duroid	10.5	1.588	2.2	Aircraft, spacecraft, satellite	Rectangular & circular with EBG substrate	It was found that the circular patch with c slot antenna has low return loss with high gain and bandwidth.

20	Analysis of Substrate Integrated Waveguide Antennas	P. Pavithra (2017)	HFSS	Rogers 5880, FR4-epoxy	23.5 – 25.5,10.48	0.508,1.6	2.2 ,4.4	X, Ku & K Band Communication	Circular, dual slot with SIW	It has been analysed that the circular polarization can be achieving by increased the number of slots were inclined at 450.
21	The Performance of a Cylindrical Microstrip Printed Antenna for TM10Mode using Two Different Substrate at 5 GHz Range	Ali Elrashidi (2012)	HFSS	Teflon, RT/duroid -5880	60	N/A	2.02 to 2.5	Verifying the new model for a microstrip antenna for its flexibility on cylindrical bodies	Cylinder MPA	The temperature directly proportional to the effective dielectric constant. The VSWR and return loss are inversely proportional to the temperature.
22	Design and Simulation of Microstrip Patch array antenna for wireless communication at 2.4GHz	B. Sai Sandeep (2012)	HFSS	Rogers RT Duroid 5880(tm)	2.4	N/A	2.2	Wireless communications	RMSA	Thorough analysis, the thin substrate permits to reduce the size and radiation as the surface wave and low dielectric constant while for higher bandwidth, the better efficiency and low power loss..

23	Effect of Dielectric Constant on the Design of Rectangular Microstrip Antenna	Atser A. Roy (2013)	Sonnet lite	Alumina 99.5%, Quartz (Fused) & Roger RT5880	2	2	9.9,3.78 & 2.2	Wireless communication	RMSA	It has been studied that, thin substrates with higher dielectric constants, lead to greater losses. The smaller the VSWR the better the antenna performance in terms of bandwidth.
24	Comparative Study of Slotted Microstrip Antenna Fed Via a Microstrip Feed Line	DhivyaN (2014)		FR4	4.3	1.6	4.4	Wireless communication	MSA-Slot Antenna	The various combinations of square slot and U-shaped slots on the ground and patch provide improved impedance bandwidth values.
25	Assessment of Microstrip Patch Antenna Performance Based on the Dielectric Substrate	A.O. Mumin (2015)	HFSS	FR4 & Rogers	5.5	1.6 & 1.57	4.4, 2.33	Wireless communication	RMSA	It was found that the lower permittivity substrate better performance of the antenna than the higher permittivity of the substrate material.
26	Characteristics of SIW Based Horn Antenna for X-Band Application	Shibu Ghosh (2017)	HFSS	FR-4	5.6	h= 1.6 p= 4.7 d= 1	4.4	Large Radio	SIW Based Horn Antennas	The size of antenna was consistently reduced when we had used or incorporated a dielectric loading respectively.

27	Design and Optimization of Rectangular Patch Antenna Based on FR4, Teflon and Ceramic Substrates	M. Karthigai Pandian	HFSS	FR4, Teflon & Ceramic	9.5	N/A	4.4, 2.1& 8.4	spacecraft, aircraft, missile	RMPA	In was found that comparing the parameters for three different substrates, FR4 provides the accurate return loss and VSWR value.
28	Substrate Integrated Waveguide and Microstrip Antennas at 28GHz	Yaqdhan Mahmood Hussein (2020)	CST	Roger RT5880	28	0.508 & 0.127	2.2	5G network	MSA	When the thickness is decreased in SIW the gain is reduced. SIW antennas have better performance in term of gain and return loss than common patch antenna.
29	Microstrip Antenna for 5G Broadband Communication: Overview of Design Issues	David Alvarez Outerelo (2015)	CST	Acrylic	28 & 60	N/A	2.43	Wireless communicat ion	MSA	We observed a resonant frequency shift cause dielectric permittivity value, inaccuracy in the connector modelling, and problems with soldering the connector pin to the feeding line.
30	Design of Substrate Integrated Waveguide (SIW) Antenna	Hafssa Amer (2018)	HFSS	FR4	10	N/A	4.4	Planar devices	Patch antenna	The proposed antenna can be easily fabricated by ordinary single layer PCB process with very low cost.

2.6 Summary

Based on the previous research most studies reported on the FR4 and Roger5880/Duroid substrate material have better performance of the antenna in term of improve bandwidth, return loss and voltage standing wave ratio [11]. However, there is no studies has been reported on the antenna using Teflon substrate with the addition of substrate integrated waveguide on the performance parameters and no studies reported on the relationship between the thickness of the Teflon substrate with addition of the substrate integrated waveguide needed for patch antenna. This is due to the fact that the fluoropolymers that most useful in 5G include Teflon chemicals like polytetrafluoroethylene (PTFE) but it has some drawbacks why Teflon rarely find the market, actually this type of a chemical, called a polymer that tightly bound strings of repeating groups of atoms are too big to get into human cells. In fact, many countries consider polymers of little risk as finished chemicals. Alternatively, it can solve if the industry produces fluoropolymers in safer ways. This is an important fact that fluoropolymers allow the equipment to be safer and last longer and when it comes to 5G, this material particularly good wire and insulators which helps in high frequency data transmissions.

Recently, we know that the development of the cellular communication technology in the stage of entering the 5th generation (5G) which has the challenge of achieving high speed, power efficiency and system reliability [14]. Additionally, 5G's new microwave frequencies require a new generation of equipment which spealizes in production made with fluoropolymers and this wave can transmit more data. So, the network requires many small stations to receive and send data and each station needs wires, cables and antenna that last longer and good insulator such as Teflon material. In the studies, the American Chemistry Council said the 5G market for PTFE based material alone, in products like printed circuit boards, should grow from $350 million a year by 2030.As consumers around the world expect more and faster data, so the demand for fluoropolymers will grow.

According to some analysis papers, most of the researchers used High Frequency Simulation Software to design antenna because its automatic adaptive meshing techniques, which require you to specify only geometry, material properties and the desired output. Teflon which have low dielectric constant. FR4 epoxy glass substrates are the material of choice for most PCB applications. The material is very low cost and has excellent mechanical properties, making it ideal for a wide range of electronic component applications while Rogers RT/Duroid 5880 high frequency laminates are PTFE composites reinforced with glass microfibers. RT/Duroid 5880 laminates has a low dielectric constant (Dk) and low dielectric loss, making them well suited for high frequency/broadband applications. In addition, some papers researchers had an experiment by comparison these two main substrates with TEFLON and analysis the antenna parameters performance. Therefore, it shows TEFLON with the low dielectric constant 2.1 and the loss tangent 0.0002 was achieved more negative value for return loss and bandwidth which means good performance than others[2].Consequently, the comparison was not adding substrate integrated waveguide technique. Here it clearly knows that thickness of the substrate is very important to improve the efficiency of the antenna. According to the studies, for wireless communication the requirement resonant frequency is between 2.4GHz to 5GHz.

As such, this study aims to investigate and analysis the performance of the antenna of low dielectric constant substrate Teflon which is 2.1 by adding substrate integrated waveguide technique on the rectangular microstrip patch antenna. So, the objectives of this project were achieved in terms of performance return loss, VSWR and gain at the operating frequency 2.4 GHz when compared to the FR4 material. Although the Teflon material is quite expensive compare to other materials but it has several advantages that can improve the performance parameter of the antenna in future wireless communication respectively. In addition, the fabrication cost of various rf components using SIW structure is lower and due to use of metal, the conductor loss is lower. If a consumer needs better and a longer range for devices, use 2.4 GHz and if need higher speed and could sacrifice for range, the 5GHz band should be used [10].

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this third chapter explains in detail about the methodology that was used in this research to obtain the simulation results regarding understanding the effect of different adding SIW on the microstrip patch antenna using Teflon substrate the operating frequency 2.4GHz for wireless communication. This chapter includes series of processes during the planning of the project that were used for simulation to obtain the results based on the variables that were already being set to study, the design development and data analysis.

3.2 Research Flowchart

The set of methodology was used for this research is summarised into the flowchart shown. This is to give a metrological view of the entire process. It was started with identifying objectives, problem statements and project limitations that were discussed with the supervisor. Next, some journals were revised in order to create a suitable configuration for the experiment set up. Determine the most suitable methodology for the designing is the next step. After that, the simulations were done. Redesign and retest were done when necessary. Lastly, the discussion for the simulation results was done in this thesis writing.

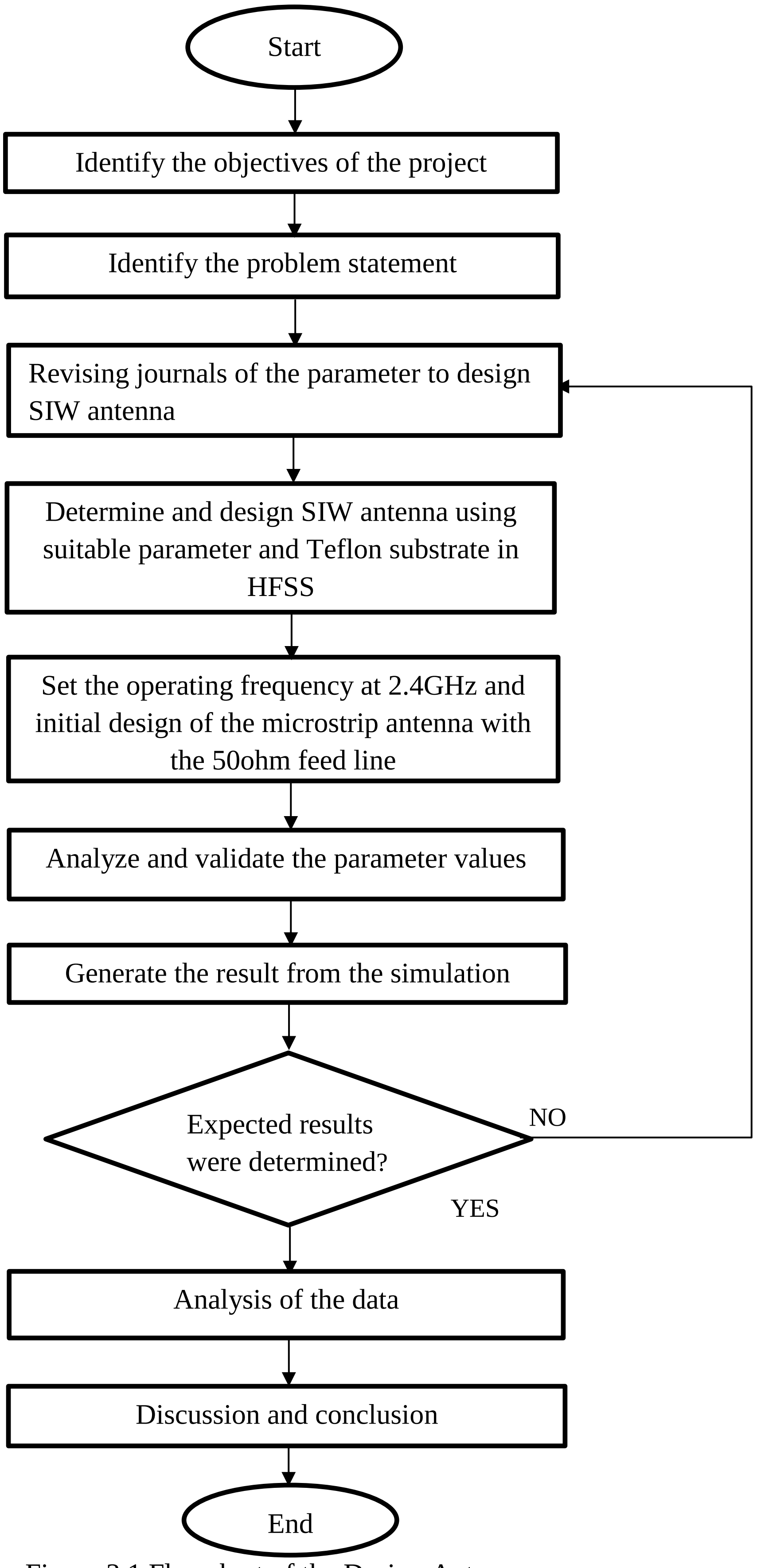

Figure 3.1 Flowchart of the Design Antenna

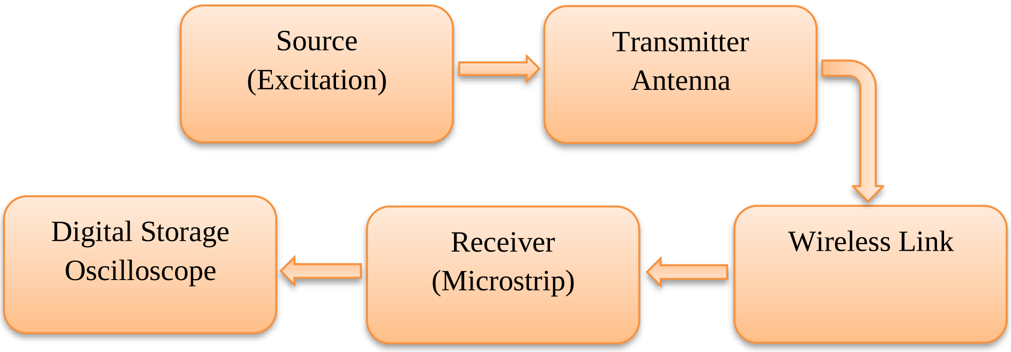

Figure 3.2 Functional Block Diagram of Antenna Process

3.3 Fundamental of the Antenna Parameter

The directional characteristics of the antenna are where the operational characteristics of a communication system have their basic roots. All the antennas are associated with a few fundamental parameters. These antenna parameters can be defined as properties of antenna or characteristics od antenna in other words.

3.3.1 Antenna Gain

Gain is a one the parameter that measure of the ability of the antenna to direct the input power into radiation in a particular direction and is measured at the peak radiation intensity. Consider the power density radiated by an isotropic antenna as shown in equation 2.1.

$$G = \frac{4\pi\eta A}{\lambda^2}$$

Equation 2.1

3.3.2 Power Density

Power density is a measure of power from the center of the antenna. It also can be defined as the product of the power density of an isotropic antenna and its gain respectively.

$$S = \frac{P * G}{4 * \pi * R^2}$$

Equation 2.2

3.3.3 Antenna Efficiency

Antenna efficiency can be defined as a ratio of power radiated by the antenna to the power supplied to antenna.

$$Antenna\ Efficiency = \frac{P_{RAD}}{P_T}\ \%$$

Equation 2.3

3.3.4 Effective Area

Antennas capture power from passing waves and deliver some of it to the terminals. Given the power density of the incident wave and the effective area of the antenna, the power delivered to the terminals is the product.

$$P_d = SA_{eff}$$ **Equation 2.4**

3.3.5 Directivity

The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions[5]. Gain and directivity just differ in their efficiency, yet directivity may be easily inferred from patterns.

D= 4 π(maximum radiation intensity)/total radiation power. **Equation 2.5**

3.3.6 Voltage Standing Wave Ratio

VSWR can be defined as the ratio between transmitted and reflected voltage standing waves in a radio frequency electrical transmission system and for an ideal system and voltage does not vary.

$$VSWR = (1 + |\Gamma|)/(1 - |\Gamma|)$$ **Equation 2.6**

3.3.7 Path Loss

To calculate delivered power and route loss, have to integrate the gain of the transmitting antenna with the effective area of the receiving antenna. By combining the two, we obtain the path loss as given below.

$$\frac{P_d}{P_t} = \frac{A_2 G_1(\theta, \phi)}{4\pi R^2}$$

Equation 2.7

Using the method, we easily calculate the path loss for various distance R units and frequency f in megahertz.

path loss(dB) = K_u + 20 log (fR) - G_1(dB) - G_2(dB) **Equation 2.8**

where KU depends on the length units as shown in table 3.1

Table 3.1 Units

Units	K_u
km	32.45
nm	37.80
Miles	36.58
m	-27.55
ft	-37.87

3.3.8 Input Impedance

The input impedance of an antenna at its terminals or the ratio of the voltage to the current the pair of terminals or the ratios of the appropriate elements of the electric to magnetic fields at a point. Hence the impedance of the antenna can be written as given below.

$$Z_{in} = R_{in} + jX_{in}$$ **Equation 2.9**

where Zin is the antenna terminal impedance, Rin is the antenna terminal resistance, and Xin is the antenna terminal reactance. The power stored in the near field of the antenna is represented by the fictional component, Xin, of the input impedance. The two parts that make up the input impedance's resistive part, Rin, are the loss resistance RL and the radiation resistance Rr.

3.3.9 Antenna Factor

Field strength E is measured by the engineering community using an antenna connected to a receiver like a spectrum analyzer, network analyzer, or RF voltmeter. The load resistor ZL in these devices typically matches the antenna impedance. The received voltage Vrec multiplied by the antenna factor AF results in incident field strength Ei. This is related to the effective antenna height:

$$\mathrm{AF} = \frac{E_i}{V_{\mathrm{rec}}} = \frac{2}{h}$$

Equation 2.10

Since it is frequently stated as dB(m1), AF has units of metres. Antenna factor is sometimes used to refer to the open-circuit voltage, which is equal to half the value provided by equation 2.11. Assuming that the antenna is parallel to the electric field, the observed electric field component is the antenna polarisation.

$$\mathrm{AF} = \sqrt{\frac{\eta}{Z_L A_{\mathrm{eff}}}} = \frac{1}{\lambda}\sqrt{\frac{4\pi}{Z_L G}}$$

Equation 2.11

A poor impedance match between the antenna and receiver and any cable loss that reduces the voltage and reduces the computed field strength can both affect this reading.

3.3.10 Return Loss

It is a one of the antenna parameters that shows how much power goes to the load and is lost since it is not reflected back. As a result, the RL acts as a parameter to show how effectively the transmitter and antenna have been matched. It is an antenna's S11, so put it simply.

3.3.11 Radiation Pattern

The far-field radiation characteristics of an antenna are plotted as a function of the spatial coordinates, which are defined by the elevation angle (θ) and azimuth angle (φ).

3.3.12 Beamwidth

Beamwidth is also an important factor and can be easily calculated from its 2D radiation pattern, is determined by the angle at which the half-power points of the pattern are radiated. The way in which beamwidth is determined is shown in figure 3.3.

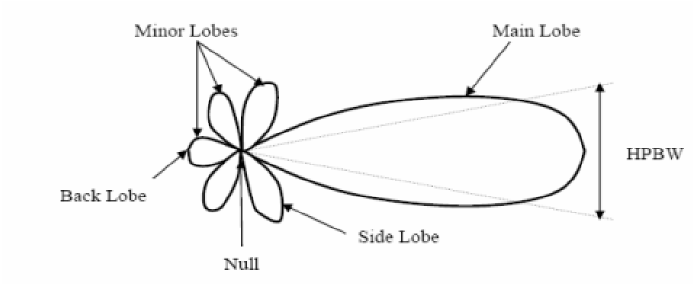

Figure 3.3 Determination of HPBW from radiation pattern

3.3.13 Bandwidth

The frequency range across which the antenna's characteristics are maintained at the appropriate level is known as the bandwidth of the antenna. The frequency range where the SWR is less than 2:1 is commonly measured to determine the SWR bandwidth. Since loss due to SWR equals -10log10(2:1) = -3dB.Return loss value is another frequently used parameter to estimate the bandwidth for resonant antennas.

3.3.14 Antenna Polarization

When an electromagnetic wave is radiated in a certain direction, it is said to be polarised. An electromagnetic wave's polarisation is the electric field vector's changing direction and relative strength over time.

Half-wave dipole antennas have a number of advantages, including input impedance that is not sensitive, length that matches size and directivity, and reasonable length. However, they also have some drawbacks, including the fact that they can only be used in combination and are not very effective while using a single element. The applications of half wave dipole antenna are use n television receivers and radio receivers[3].Antennas have to be classified to understand their physical structure and functionality more clearly[4].

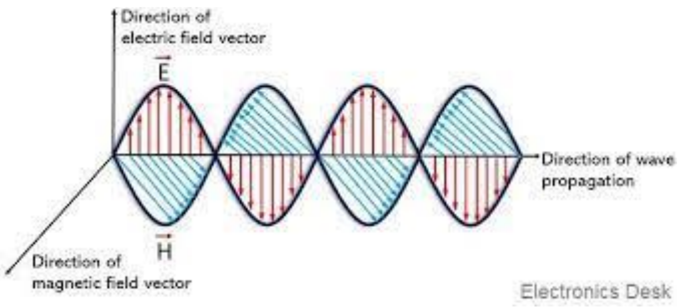

Figure 3.4 Direction of EM wave

3.4 Theory of Substrate Integrated Waveguide

Microstrip devices are ineffective in high frequency applications due to the tiny wavelengths at these frequencies, and their production calls for extremely tight tolerances. Waveguide devices are favoured at high frequencies, but their production is challenging. Consequently, substrate integrated waveguide evolved as a novel concept. Microstrip to dielectric-filled waveguide transition is called SIW (DFW). Vias for the waveguide's side walls assist transform a silicon on insulator waveguide into a substrate integrated waveguide (SIW). Substrate Integrated Waveguide (SIW) is also one type of transmission line that has been used in past few years [12].

The most important benefit of SIW technology is its ability to enable the total integration of all components including passive and active components and even antenna on the same substrate. SIW techniques are extremely well-liked in the community today because they may be utilised to address a variety of headache issues. There are two benefits of traditional metallic waveguide like high low loss and high-power handling with self-consistent electromagnetic shielding. Substrate integrated waveguide can then be viewed as a dielectric filled waveguide (DFW) where the vias replace the narrow walls of traditional rectangular waveguides to avoid leakage [13]. The presence (trapping) of surface waves, which often reduce antenna effectiveness, is a notable issue that arises at high frequencies. This phenomenon can be properly managed by the SIW. SIW components have the advantages of low leakage loss. The SIW technology has advanced quickly over the course of more than ten years. Additionally, multiformat and multifunction devices and systems can be made using the SIW approach in conjunction with other SICs platforms.

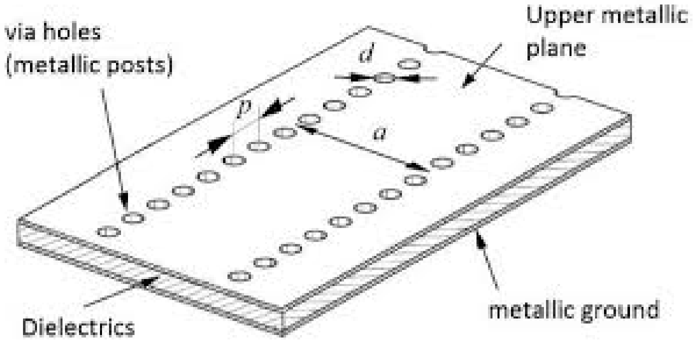

Figure 3.5 Substrate Integrated Waveguide

A rectangular waveguide structure in an integrated planar form, the SIW is also referred to as a post wall waveguide or a laminated waveguide. It can be created through the use of two rows of conducting cylinders, vias or slots embedded in a dielectric substrate that is electrically combined by two parallel metal plated, as shown in Figure 3.5 [14]. Substrate Integrated Waveguide The width of the SIW is the distance *a* between its two vias rows from center to center. Therefore, an effective width a_e can used to charcaterize more precisely the wave propagation. The distance between the two via holes is *p* and the via diameter is *d*.

3.5 Method of the Solution

3.5.1 Software Tools

Many engineers have utilised ANSYS High Frequency Structure Simulator (HFSS) to analyse electromagnetic components since its introduction in the late 1980s. HFSS was first applied to simulate waveguide transitions, but was soon employed to solve other engineering design problems. The HFSS is now used by designers in all electronics industry [11]. HFSS is frequently use during the design stage and is a crucial step in the design process for many types of electronic components, including airborne antenna systems, integrated circuits, high-speed interconnects, and others.

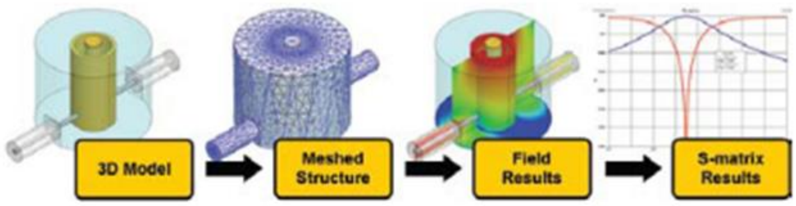

Figure 3.6 S-matrix simulation

There are six main steps to creating and solving a proper HFSS simulation

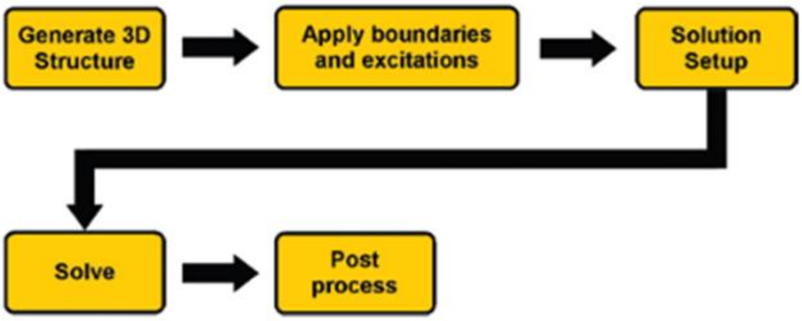

Figure 3.7 HFSS simulation procedures

Step One: The design of the physical model that a user intends to analyse is the first step in developing an HFSS model. The 3D modeller in HFSS can be used to create this model. A user can design a structure that is flexible in terms of geometric dimensions and material properties using the fully parametric 3D modeller. A user also has the option of importing 3D structures from mechanical drawing software like SolidWorks or AutoCAD. However, because imported structures have no "history" of how they were made, they cannot be specified. If parameterization of the structure is desired, a user will need to manually modify the imported geometry so that parameterization is possible [11].

Step Two: Generally, the assignment of boundaries occurs next. Boundaries are applied to particular surfaces of 3D objects or specially constructed 2D (sheet) structures.

Step Three: After the boundaries have been assigned, the excitations must be applied. The quality of the data HFSS will five for a particular model is directly impacted by the excitations, much like with boundaries. As a result, users are once more advised to read carefully this document's section on excitations. There are some useful rules that user can follow, even though creating and using excitations properly is important to reach the most accurate HFSS results.

Step Four: Once the boundaries and excitations have been created, the next step is to create a solution setup.. The user will choose a solution frequency, the desired convergence criteria, the maximum number of adaptive steps to be carried out, a frequency band over which solutions are required, and the specific solution and frequency sweep methodology to apply during this step.

Step Five: After the initial four steps have been completed by an HFSS user, the model is now ready for analysis. The model geometry, solution frequency, and available computer resources all have a significant impact on how long an analysis takes. A solution can be found in as little as a few seconds and could be long hours even overnight. It is frequently advantageous to transfer a certain simulation run to another computer that is nearby the users using HFSS's remote solve feature.

Step Six: Once the solution has finished, a user can post-process the results. Examining the model's S-parameters or plotting the fields inside and around the structure are two simple examples of post-processing findings. The distant fields generated by an antenna can also be examined by users. In essence, the post-processor enables for the plotting of any field quantity or S, Y, Z parameter. In addition, families of curves can be generated and the same process used to produce additional parameters if a parameterized model has been studied.

3.6 Material Selection

The permittivity of a material is related to the rate at which an electromagnetic wave travels through it and the amount of energy that an electric field store inside it. The permittivity of materials can be easily discussed using the dielectric constant. Besides that. the permittivity of a vacuum that is in outer space or there is no atoms or material in a volume and also known as free space is 8.854 x 10^{-12} [F/m]. Suppose the permittivity of a material such as FR4 is to be determined. FR4 is a common dielectric used in circuit boards as the insulator between the ground plane and the signal traces [15]. We measure the permittivity of this material to be 3.54 x 10^{-11} [F/m].

For this work Teflon (Polytetrafluoroethylene) is chosen as dielectric. Its permittivity of 2.1 with the loss tangent 0.0002. Furthermore, Teflon has low losses and good mechanical properties. PTFE composite material for use as printed circuit board substrates. In addition, PTFE composites are designed for exacting strip line and microstrip circuit applications. The unique filer results in a low destiny, light weight material for high performance weight sensitive applications.

Teflon is the registered trade name of the highly useful plastic material polytetrafluoroethylene (PTFE) and known as fluoropolymers. A polymer is a compound formed mixed with chemical reaction which combines particles. PTFE has many unique properties and it has a very high melting point and stable at very low temperatures. It can be dissolved specifically in hot fluorine gas or certain molten metals, so it is resistant to corrosion.

PTFE is used to impart stain-resistance to fabrics, carpets, and wall coverings, and as weatherproofing on outdoor signs. PTFE has low electrical conductivity, so it makes a good electrical insulator. It is used to insulate much data communication cable, and it is essential to the manufacture of semiconductors. Furthermore, Teflon has low losses and good mechanical properties [16].

PTFE polymerized from the chemical compound tetrafluoroethylene, or TFE as shown in Figure 3.8. The suitable selection of substrate material helps in improving the performance of an antenna. So, in order to get rid of these drawbacks, the low dielectric constant thick substrate or slotted patch can be employed [17]. So, using Teflon as a substrate material in microstrip antennas is highly recommended nowadays, especially in conformal microstrip antennas for its ability to bend over any surface.

Figure 3.8 Polytetrafluoroethylene (TEFLON)

3.7 Design Development

Here are the parameters equations that use for calculating to find the length and width of the patch antenna. The width of the rectangular MSA is given:

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r + 1)}{2}}}$$

Equation 3.1

where, C is the speed of light, is the resonant frequency, and is the Relative dielectric constant of the substrate. Now by substituting the values of C = 3x108 m/s.

Here, is the equation of the effective length will be mm:

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}}$$

Equation 3.2

Hence, by using these equations, the width of the patch is 50.2 mm and the length of the patch antenna is 42.2 mm respectively.

Therefore, the coordination of the microstrip antenna also important for rotating the axis. Apart from that, it can determine the location for designing patch antenna, feedline, fed and for creating the via holes on the top of patch antenna.

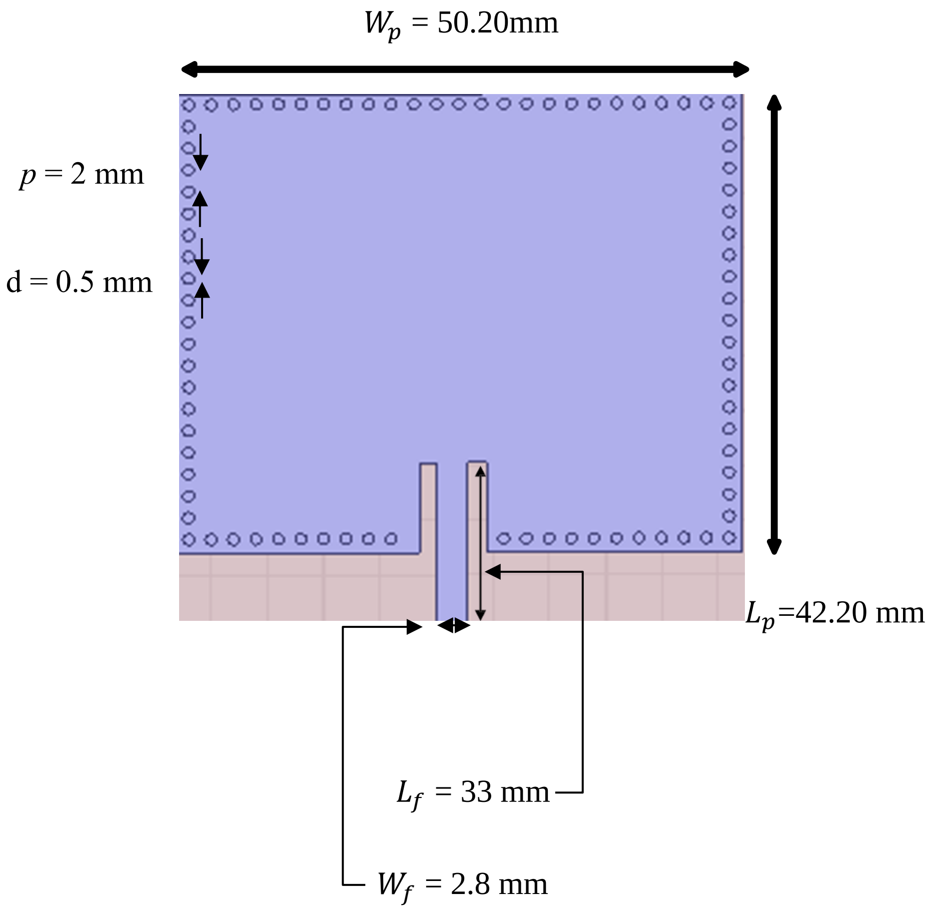

Figure 3.9 Dimension of the patch antenna

Table 3.2 Parameter of the dimension

Length of the patch, L_p
Width of the patch, W_p
Length of the feed, L_f
Width of the feed, W_f
Pitch between the via holes, p
Diameter between the via holes, d

3.8 Simulation Stage

3.8.1 The frequency setting

The frequency at HFSS precisely solve a particular simulation is known as the solution frequency. Additionally, the adaptive solution operates at this frequency, and it is the fields at this frequency that are used to determine whether or not a model has converged. The solution frequency should be set to the operating frequency of the device being simulation. For example, this picture set in 2.4GHz.

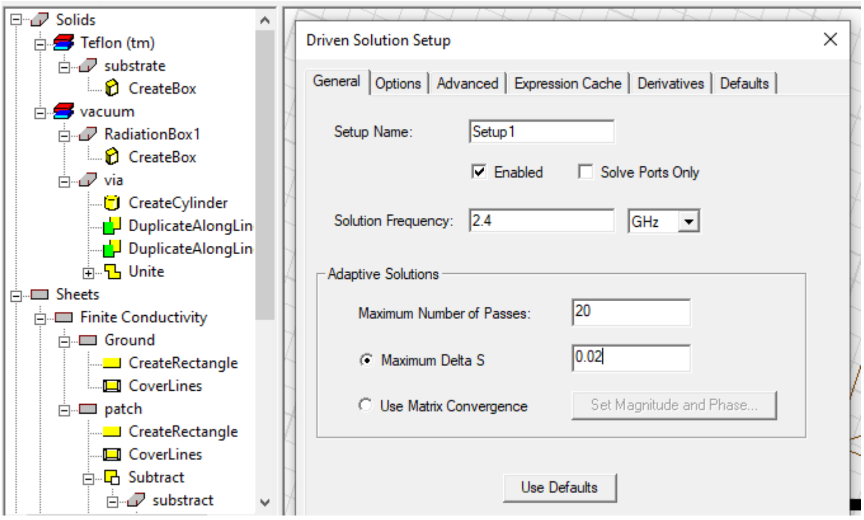

Figure 3.10 The Frequency setting

3.8.2 The delta S setting

As mentioned in the Figure 3.8, there have an adaptive process to ensure to ensure that HFSS yields the correct answer. There is a direct relationship between the electric fields in a simulation and the calculated S- matrix for that simulation in HFSS [10]. The difference in the magnitude of the S-parameters between two successive passes is the value of delta-S. Alternatively, the change in the distribution of the electric field between subsequent solutions in terms of the electric field. The analysis stops and is considered to have converged after the magnitude and phases of all S- parameters change by no more than the user-specified delta-S value. Therefore, to put it another way, once the electric fields in the given model stop changing, the field solution has converged and is valid.

3.8.3 The Different Frequency Sweeps

There are three main sweeps that are discrete sweep , the fast sweep and interpolating sweep are the three distinct sweep types in HFSS. The certain sweep type may be preferred depending on the needs of a user. Generally, the fast, interpolating, and discrete solution times for a frequency sweep type increase in that order. So, for my simulation I set fast sweep.

3.8.4 Assigning material

To change the material of an object to something other than the default material, select the object and select Edit and Properties. Alternatively, you can select the object and edit the material in the properties window that appears after the object has been selected. So, I set in Teflon material for this design.

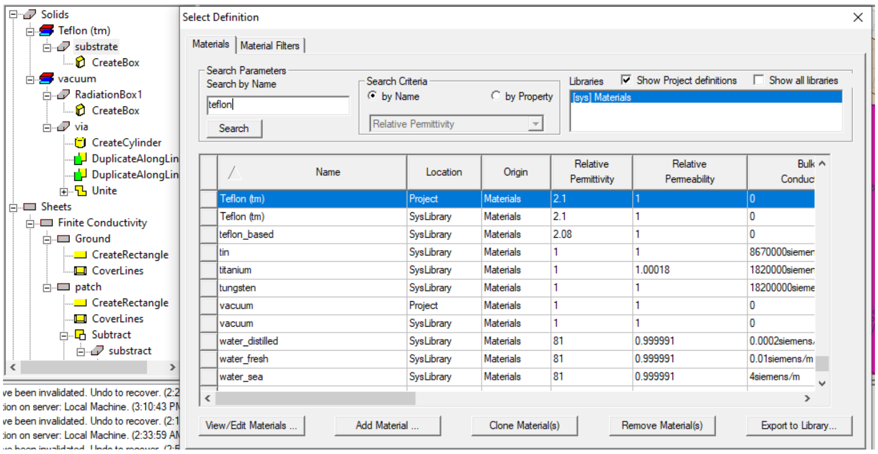

Figure 3.11 Material selection

3.8.5 Create a Radiation Box

Radiation box will allow waves to radiate far into space such as antenna designs. using radiation barrier. A model outside faces must be given radiation boundaries. These faces must be at least a quarter wavelength distant from any radiating surface when simulating an antenna. So, in this design I have created a radiation box. It is mandatory to analyse it in environment like a free space and I set the material for radiation box is vacuum.

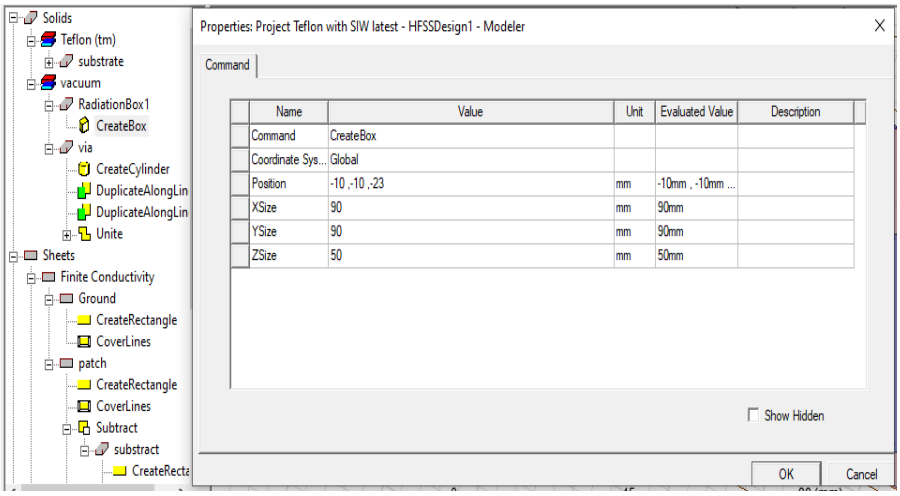

Figure 3.12 Radiation box

3.8.6 Lumped Port

The lumped port boundary is a modified impedance boundary. This boundary, in contrast to the impedance boundary, enables for the direct specification of a resistor, inductor or capacitor. After the user enters the values for R, L, or C, HFSS calculates the impedance per square of the lumped port boundary at each frequency, effectively converting the RLC boundary to an impedance boundary. So, in this design I have created the fed to assign lump and it is the way to gives the feedline it in direct contact and the height of the fed is 2 mm as a substrate.

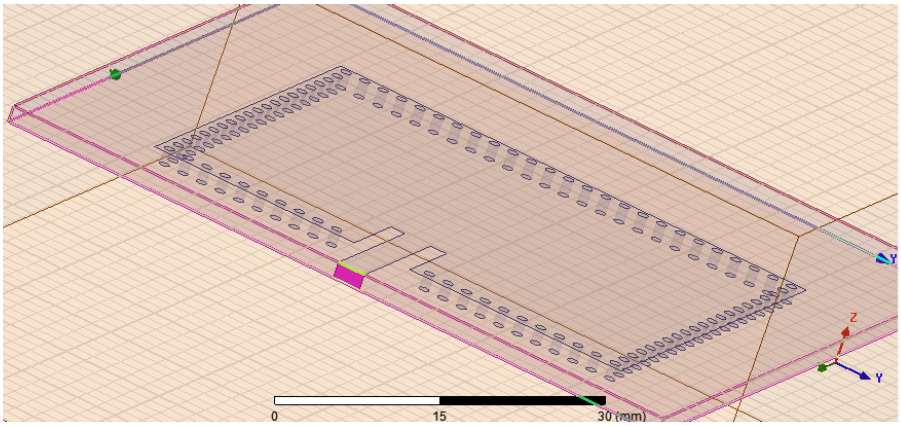

Figure 3.13 Lumped port

3.8.7 Substrate Integrated Waveguide

According to the above conditions, the parameters of the SIW are calculated as p=2 mm and d=0.5 mm. In addition, the p > d, states that the period should be larger than the cylinder diameter so that the circuit is physically realizable. A SIW is shown in Figure 4.1, where in it clearly evident that the side walls of the waveguide are replaced by periodic metallic vias. The vias can be simple holes or filled with air or filled with some other dielectric or can be metallic. The difference in the effective dielectric constants leads to confinement of the waves inside the walls.

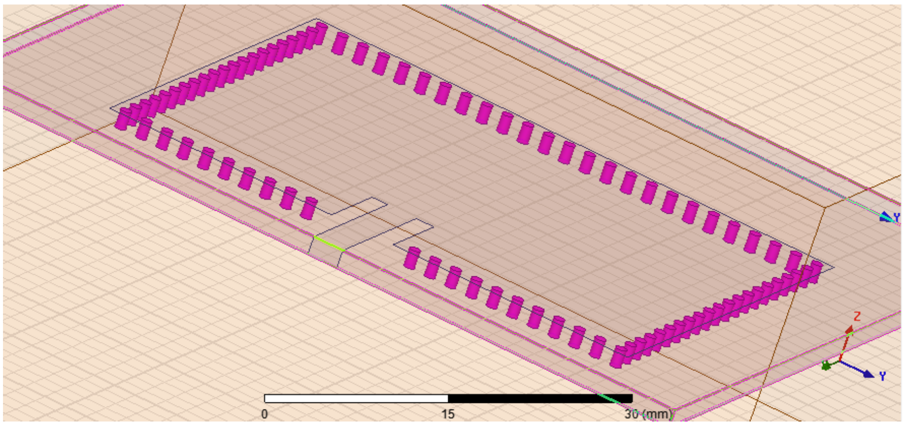

Figure 3.14 Structure of SIW

3.9 Summary

The summary of this chapter is the research flowchart of the project is very important to know the flow of the design progress until the simulated results. Apart from that, the basic fundamental of the parameters has to study to improve the antenna performance. The substrate integrated waveguide theory and material selection are very important for this project in order to achieve the objective of the project. The design development with a suitable dimension has been calculated with the given equations. Next, the explanation of the simulation software is stated to provide and important method of analysis which can easily verify and understand.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The chapter provides and discuss the data that were collected in this research. Analysis data for the performance of the substrate integrated waveguide technique for Teflon material is analysed. In addition, the performance of another substrate material also tested to analyse the comparison after adding other layer to the single patch antenna. This subchapter will explain about the results obtain from the sets of simulation that have been done. The operating frequency is 2.4 GHz.

4.1.1 Microstrip Rectangular Patch Antenna with TEFLON substrate

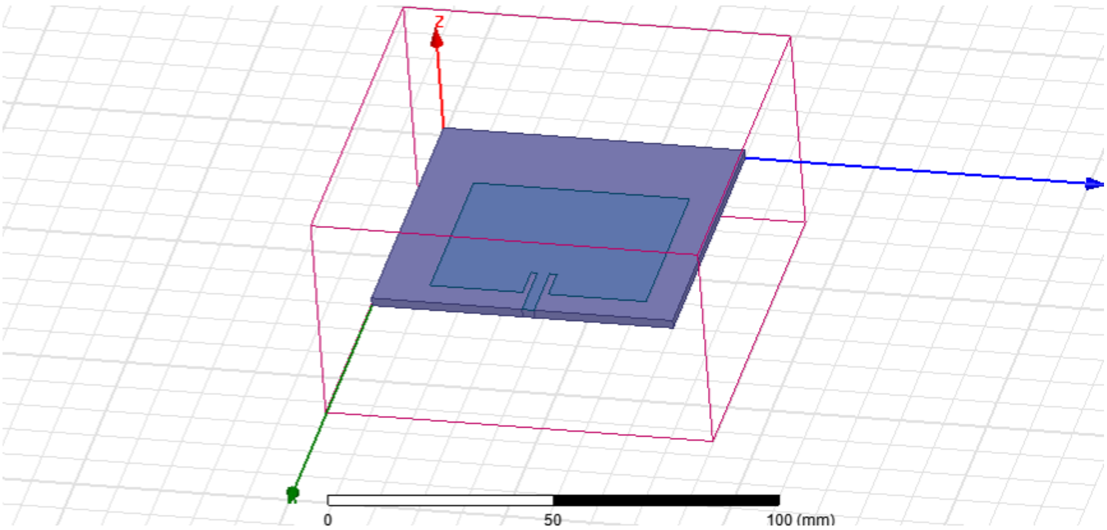

Figure 4.1 Design model of an antenna

4.1.2 Microstrip Rectangular Patch Antenna with TEFLON substrate with SIW addition

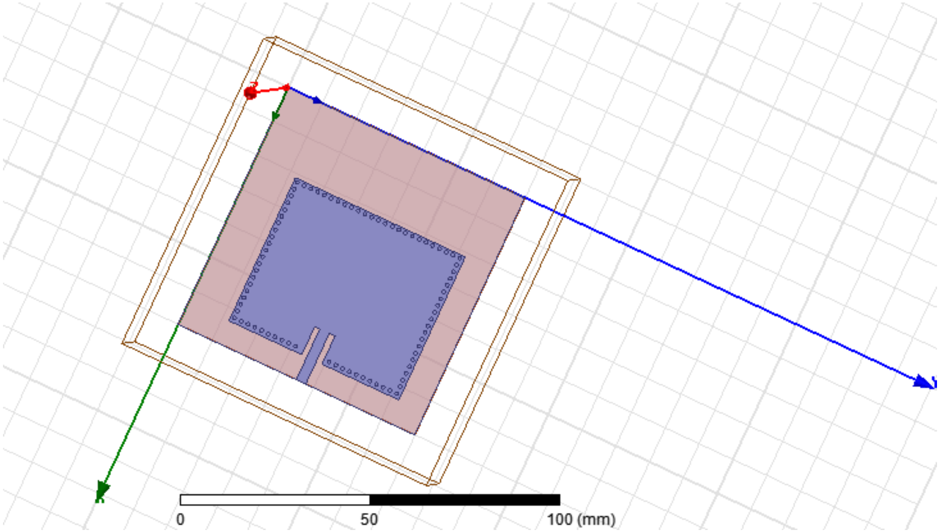

Figure 4.2 Design model of an antenna with SIW addition

Figure 4.1 is about the design of the rectangular microstrip rectangular patch antenna using TEFLON substrate consider as a design 1. Figure 4.2 is about the design of the microstrip rectangular patch antenna using TEFLON substrate with SIW addition technique consider as a design 2. The results of these two designs will be given different performance in term of return loss, VSWR, radiation pattern, gain and directivity based on the simulation.

4.1.3 Return Loss with Frequency for Design 1

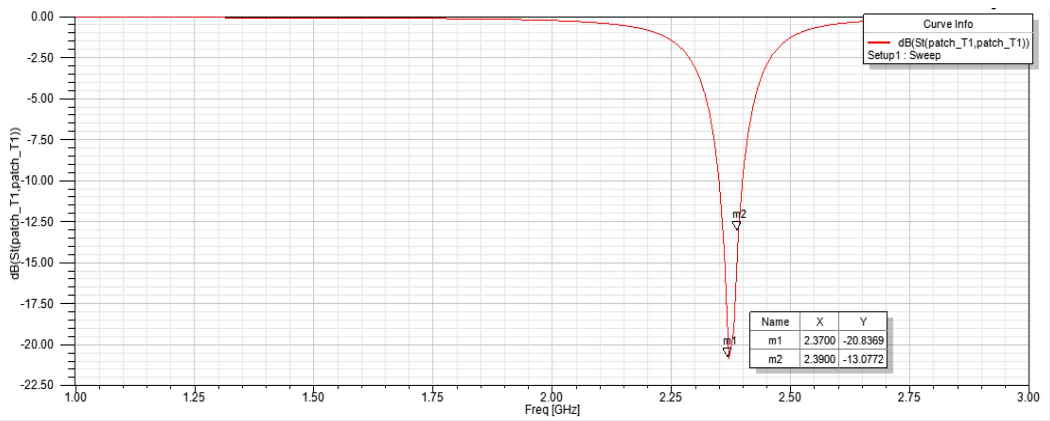

Figure 4.3 S-parameter graph of Teflon antenna

4.1.4 Return Loss with Frequency for Design 2

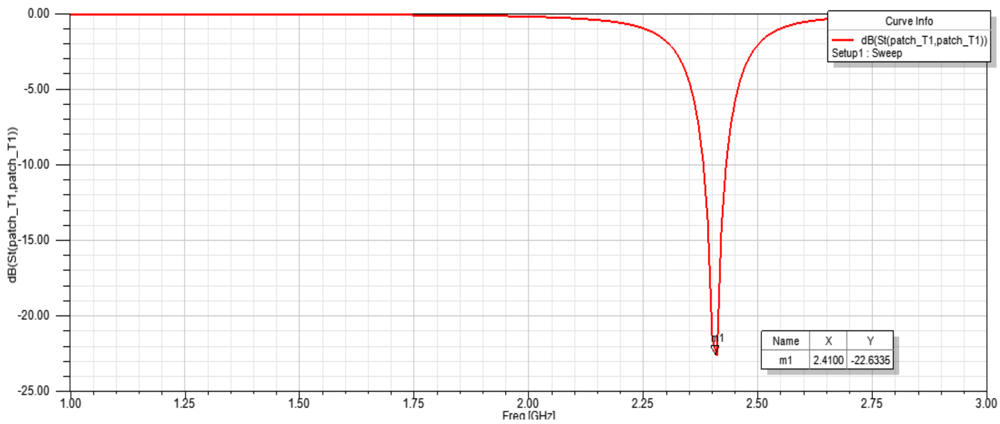

Figure 4.4 S-parameter graph of Teflon antenna with SIW addition

A high return loss is important as it will result in a lower insertion loss. From the figure 4.3, the return loss values obtained of the Teflon substrate with dielectric constant 2.1 and the loss tangent 0.0002 is -13.0772 dB at 2.39 GHz while in Figure 4.4 the return values obtained for Teflon substrate material with SIW addition technique is -22.6335dB at 2.41GHz. Since, the return loss is less than -10 dB, had not losses while transmitting the signal. From the Figure 4.3 it is clearly show that the designed antenna will not achieves 2.4 GHz. But, after adding the SIW layer on the rectangular patch antenna, the designed in Figure 4.4 resonates at the 2.41GHz frequency and also increasing in return loss values.

4.1.5 VSWR with Frequency for Design 1

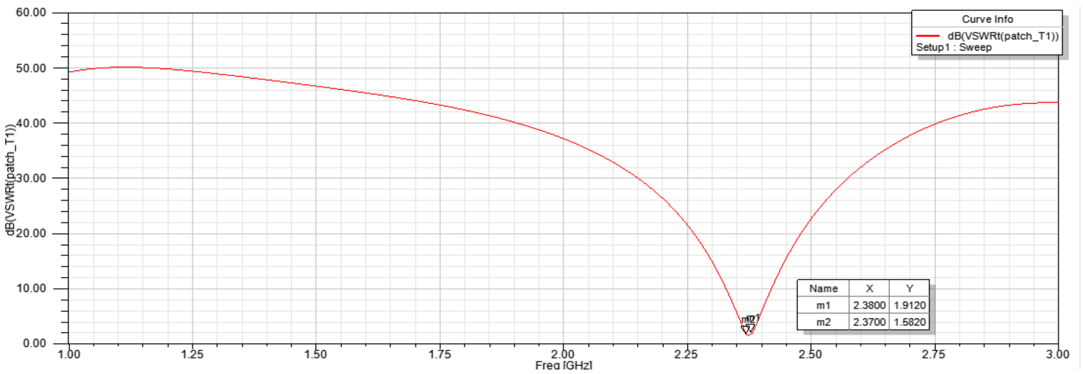

Figure 4.5 VSWR of Teflon antenna

4.1.6 VSWR with Frequency for Design 2

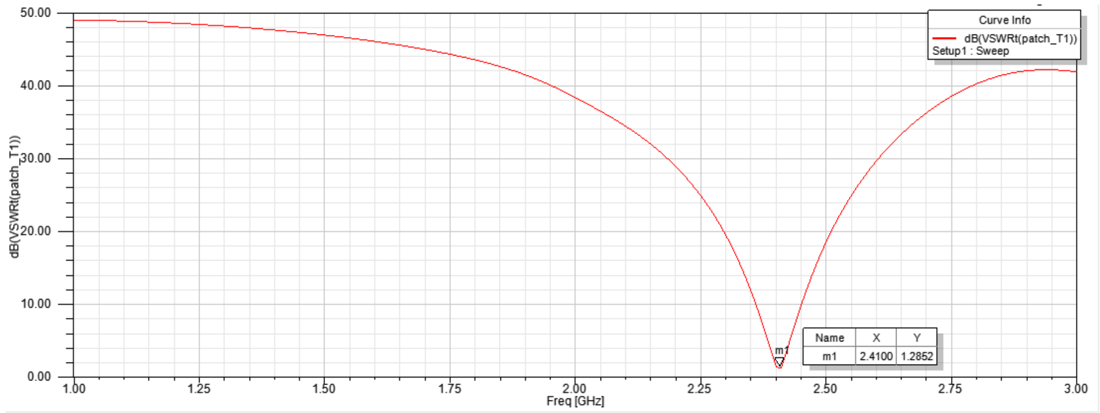

Figure 4.6 VSWR of Teflon antenna SIW addition

Figure 4.5 and Figure 4.6 shows the plot of VSWR frequency of the simulated antenna without SIW and with SIW respectively. In Figure 4.6 VSWR lied in the range 1-2 which has been achieved for 2.41 GHz frequency, near to operating frequency value. The VSWR at 2.41 GHz frequency is 1.2852 is shown in Figure 4.6 while VSWR for Figure 4.5 the antenna obtained 1.9120. So, the antenna with SIW addition present the better performance of VSWR in the band frequency. The lower the VSWR is, the better the antenna is impedance -matched transmission line and the higher the power delivered to the antenna and small VSWR can reduces the reflections from the antenna.

4.1.7 Radiation Pattern for Design 1

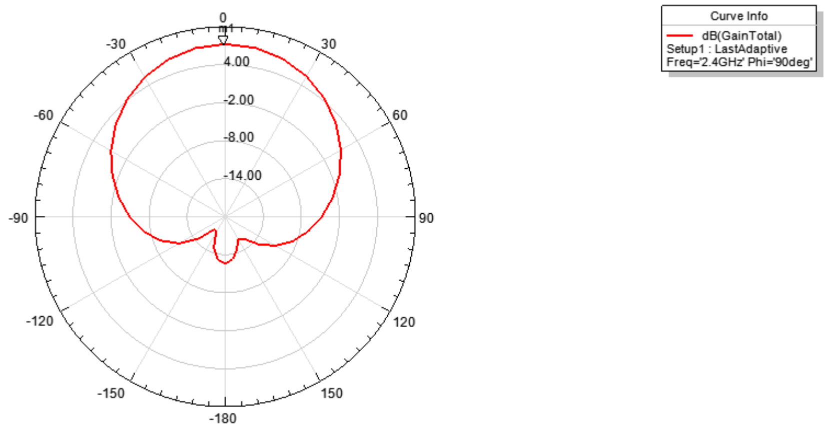

Figure 4.7 Elevation pattern gain Teflon in 2D

4.1.8 Radiation Pattern for Design 2

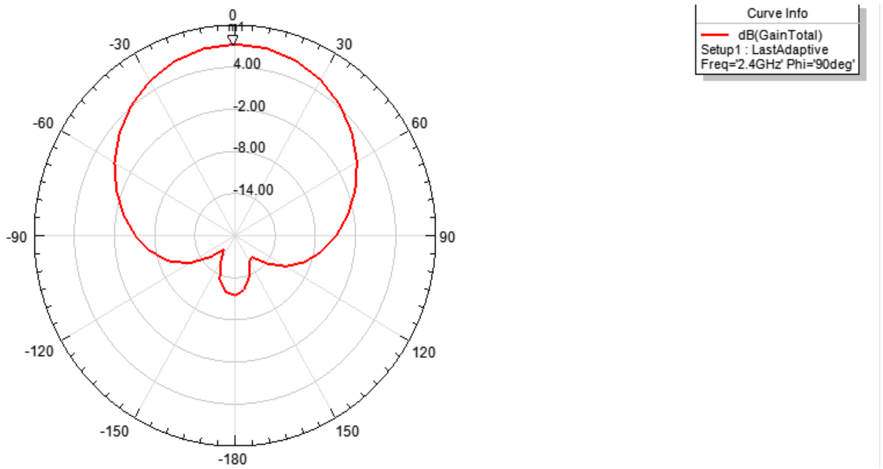

Figure 4.8 Elevation pattern gain Teflon with SIW addition in 2D

Radiation pattern is one of the antenna parameters since it is the way antenna distributes its energy in space. Since the microstrip antenna radiates normal on the patch surface, the elevation pattern for θ = 0 and θ = 90 degrees consider important. The radiation pattern showing the gain for the desired slotted antenna has been shown in Figure 4.9 and 4.10. In Figure 4.7 and 4.8, the elevation pattern for θ = 90 degree and its achieved gain was 7.2670 dB and 7.2852 dB respectively.

4.1.9 Antenna Gain for Design 1

Figure 4.9 3D polar plot gain of Teflon

4.1.10 Antenna Gain for Design 2

Figure 4.10 3D polar plot gain Teflon with SIW addition

From the Figure 4.9 and 4.10 above, the antenna gain achieved was 7.2670 dB for peak gain at 2.39 GHz and 7.2852 dB for peak gain at 2.41 GHz.This is also a radiation pattern but in 3D form.For the results,I set the solution frequency to 2.4 GHz with the assign the maximum number of adaptive 20 and maximum delta S of 0.02. for.So,for the antenna with SIW addition obtained higher gain which means particularly good at transmitting signals in a narrow beam.The radiation pattern for the proposed antenna is omdirectional and can be used at WLAN applications especially.However, there is no direct relationship between the permittivity and gain.The imaginary parts results in a loss of gain, so low loss tangent materials like Teflon are better.

4.1.11 Directivity for Design 1

Figure 4.11 Directivity of the Teflon

4.1.12 Directivity for Design 2

Figure 4.12 Directivity of the Teflon with SIW addition

One of the antenna parameters is directivity which means the measurement of the concentration of an antenna's radiation pattern in a particular direction. So, the directivity obtained in Figure 4.11 was 7.5220 dB while in Figure 4.12 was 7.5492 dB respectively. Hence, higher the directivity, further the beam travels. It clearly shown that, after adding SIW on the patch antenna, the value of the directivity increases, that improve more space division. It clearly shows that the maximum direction towards z-axis respectively.

4.2 Performance of FR4 material and Heights of the Substrate

Furthermore, to analyse the better performance of the proposed antenna, the different substrate material, FR4 and different heights of the substrate, 1.5 mm and 1.6 mm were tested. The below results show of the certain parameters were obtained based on the simulation. However, the reason chooses FR4 substrate as a test material due to its dielectric constant and loss tangent value. The chooses of the height values are based on the previous research papers. Most likely some researchers use the common height to generate and analysis the result of the parameters. The comparison of the heights help to meet the criteria to choose suitable value for the proposed antenna.

4.2.1 Return Loss with Frequency graph for FR4

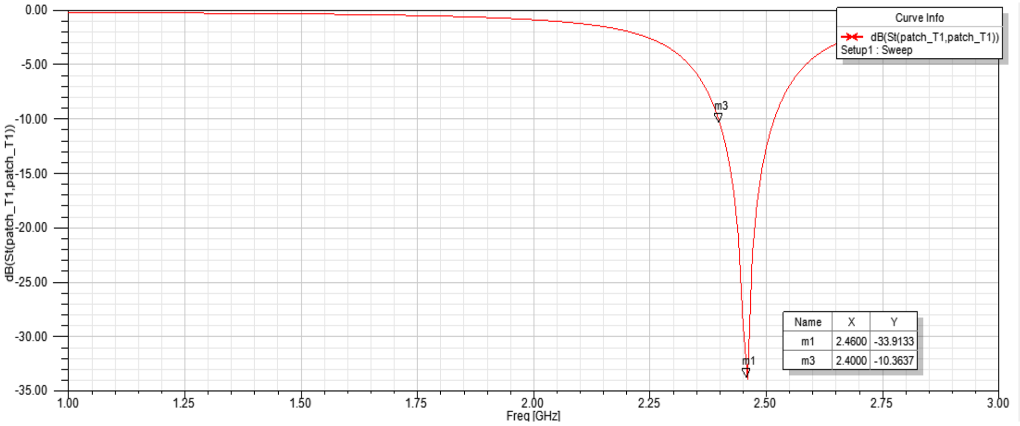

Figure 4.13 S11-parameter of FR4 with SIW addition

4.2.2 VSWR with Frequency graph for FR4

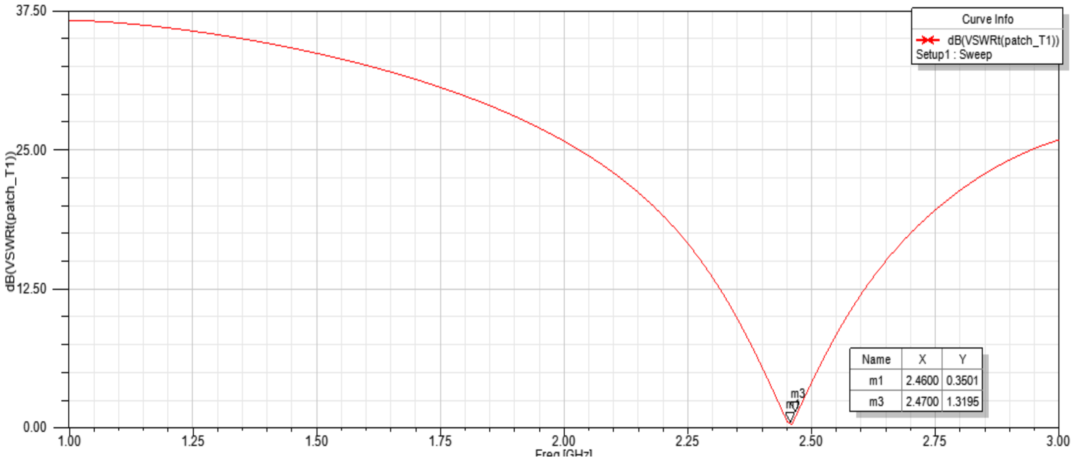

Figure 4.14 VSWR of FR4 with SIW addition

From the Figure 4.13 and 4.14 above, the substrate that tested for rectangular microstrip patch antenna was FR4 material with 0.02 loss tangent. I designed the antenna for this substrate to observe the differences the performance of the antenna parameter for return loss and VSWR compared to Teflon substrate. So, here it was found that the return loss achieved -10.3637 dB at the 2.46 GHz frequency and 1.3195 for VSWR at the 2.46 GHz frequency.

4.2.3 Return Loss with Frequency graph for 1.5 mm

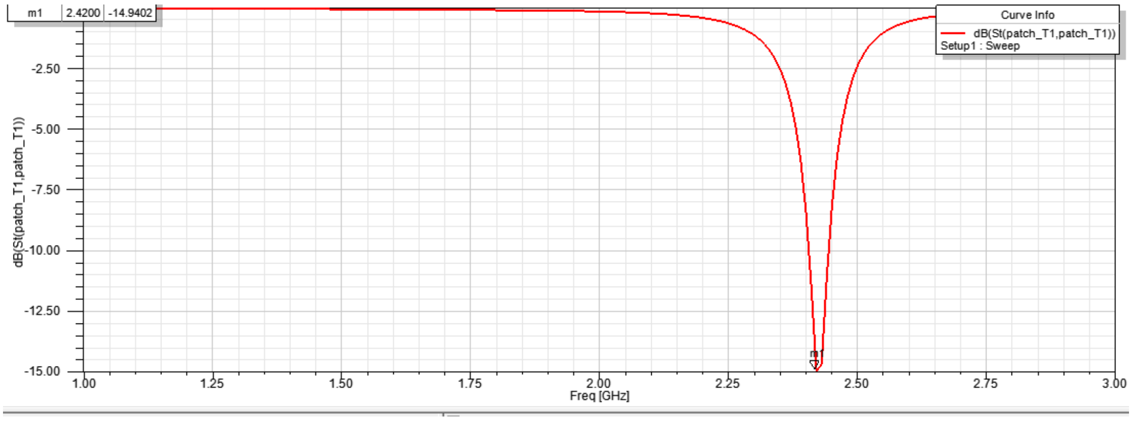

Figure 4.15 S-parameter of Teflon with SIW addition for 1.5 mm

4.2.4 Return Loss with Frequency graph for 1.6 mm

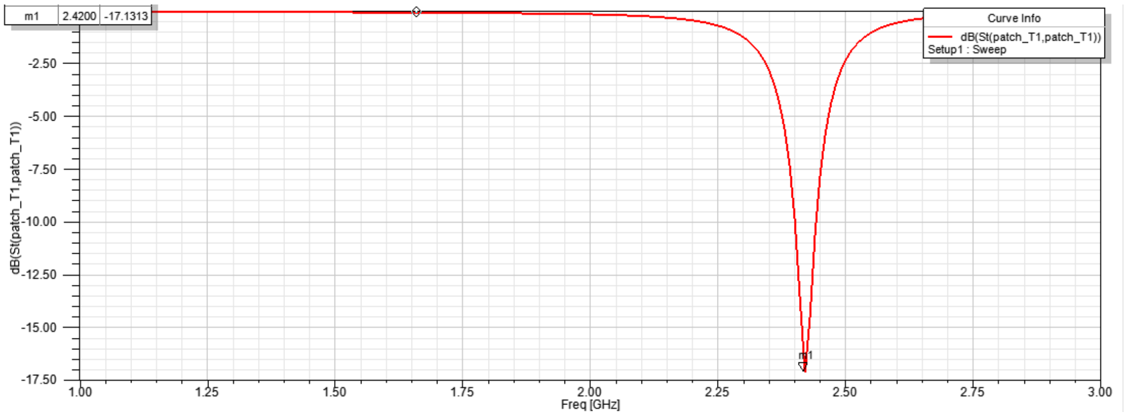

Figure 4.16 S-parameter of Teflon with SIW addition for 1.6 mm

Figure 4.15 and 4.16 shows that the performance of the different heights of the substrate were used in the design of the Teflon with SIW addition. It was observed that the return loss is -14.9402 dB at the resonant frequency of 2.42 GHz with height of the substrate is 1.5 mm and return loss is -17.1313dB at the resonant frequency of 2.42 GHz with height of the substrate is 1.6 mm respectively.

4.3 Parameter Analysis

Table 4.1 Geometrical parameter of the antenna

Dimension of the antenna/ Type of the Antenna	Height of the substrate, h (mm)	Length of the patch, L_p (mm)	Width of the patch, W_p (mm)	Length, L_s x Width of the substrate, W_s (mm)	Length of the feed, L_f (mm)
Teflon	1.5, 1.6, 2	42.2	50.20	70 x 70	33
Teflon with SIW adding		42.2	50.20	70 x 70	33

The geometrical parameter is very important when designing an antenna. The length of the patch is inversely proportional to the frequency and directly proportional to the wavelength. Hence, the dimensions of the length and width of the patch antenna were calculated by using the rectangular patch design equations as stated at equation 2.13& 2.15. From the Table 2.4, there are different height of the substrate 1.5mm,1.6mm and 2mm. Theoretically, low dielectric constant with thick will improve to increase the bandwidth. The height of the substrate inversely proportional to the bandwidth. Apart from that, in order for improving the return loss to get better value, there are changes in design parameters of the patch antenna like height of the substrate that suitable for the low dielectric constant Teflon with 2.1. Therefore, it has been chosen 2mm as a best height of the substrate compared to the other values based on the simulation results. It was observed that the return loss is -14.9402 dB at the resonant frequency of 2.42 GHz with height of the substrate is 1.5 mm and return loss is -17.1313dB at the resonant frequency of 2.42 GHz with height of the substrate is 1.6 mm as shown in Figure 4.15 and 4.16.

4.4 Analysis of Data

Table 4.2 Performance analysis of the antenna

Parameters /Antenna	Δt	εr	Return Loss (dB)	VSWR	Radiation Pattern (90 °)	Gain (dB)	Directivity (dB)
Teflon	0.0002	2.1	-13.0772	1.9120	7.2670	7.2670	7.5220
Teflon with SIW adding	0.0002	2.1	-22.6335	1.2852	7.2852	7.2852	7.5492
FR4-epoxy with SIW adding	0.02	4.4	-10.3637	1.3195	4.6577	4.6577	6.6354

As shown above, the graphs indicate the performance of the 2 different substrate materials, FR4 and Teflon which were used for the designing of microstrip patch antenna. Thorough analysis of the above resultant graphs indicates that Teflon with dielectric constant 2.1 and loss tangent 0.0002 shows the best performance. All the antennas were resonating at 2.4 GHz and are at a matched impedance of Z0 = 50Ω. We expect the antenna performance to best the others as the return loss achieves a greater negative value, voltage standing wave ratio achieves a value closer to the ideal value of 1 and the bandwidth achieved being maximum. The return loss achieved of the Teflon with SIW addition was of the minimum value of -22.6335 dB and SWR value as 1.2852 closest to the ideal value of 1. As mentioned previously that the reason for maximum bandwidth is due to the increase in size of the Teflon based antenna geometry as compared to the other substrate based on the geometry since bandwidth is directly proportional to antenna dimensions or antenna size [5]. In addition, the result show that with the addition of SIW material to the design of the rectangular microstrip patch antenna of Teflon substrate with SIW addition can significantly improve antenna gain from 7.2670 dB to 7.2852 dB and the directivity from 7.5220 dB to 7.5492 dB. Teflon has the lowest dielectric constant of 2.1 compared to the FR4 substrate which increases the return loss, VSWR, gain and directivity. Thus, summing up, Teflon is good dielectric substrate for microstrip patch antenna [14]. Thus, it is suggested that Teflon can be given preference over another considered substrate. Therefore, adding SIW technique have high capability to handle power, the radiation losses are lower and due to the metal, the conductor loss is lower. The most important is the cost of various rf components using SIW structure is lower during fabrication.

4.5 Summary

The summary of this chapter is to simulate and analyse the results, in a way that will yield maximum insight to help with decision making. There are two different result for different design antenna in term of return loss, VSWR, radiation pattern, antenna gain and directivity. Besides that, there are parameter analysis for dimension of the antenna to observe the performance of the antenna in term of different heights. In addition, the same design has been tested with different permittivity and dimension in order to observe and analysis the low dielectric substrate performance and SIW technique.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter will conclude the findings of this study based on the objective, literature and also results.

5.2 Conclusion

Antenna is very useful in the wireless communication system. It is well recognized that the antenna is one of the most important system components that limit or enhance system performance, depending on the design of such a component. The effect of the dielectric constant of Teflon material by adding substrate integrated waveguide technique were investigated and analysis in this project. Therefore, array geometries are always required that involve both radiating elements and feed network in most high-gain antenna applications. In fact, due to some drawbacks of Teflon material, the survey and the studies regarding this material has been minimized. The feeding techniques has been important part to improve their performances. There is simulation software HSFF are developed for microstrip antenna which make easy of designing in proper, accurately and in automatic way with eliminating all complexity. The development of the rectangular microstrip patch antenna have to be consider to analysis the better performance of the antenna. In designing of patch and feed, there need a coordination of the axis, length, width and height for patch, feed and substrate respectively. The simulation results indicated that the changes in height of the substrate and adding the latest technology SIW on the rectangular microstrip patch antenna has improved the performance of antenna in term of return loss, VSWR, radiation pattern, antenna gain and directivity. So, in order to improve the efficiency of the antenna performance there is need to consider the thickness of the dielectric constant substrate approximately. The technology used and research work increases the use of microstrip antenna and their performance day by day and also make better utilization in future for upcoming generation network.

5.3 Limitation

As a limitation, most compact microstrip antenna designs show decreased antenna gain due to the antenna size reduction. To overcome this disadvantage and obtain an enhanced antenna gain, substrate integrated waveguide technology needed to fabricate compact microstrip patch antenna. There are a limitation using substrate integrated waveguide structure. Due to use dielectric constant into the waveguide structure the dielectric losses will occur compared to air used in normal rectangular waveguide. Moreover, it depends on the frequency and hence milimeter wave applications of substrate integrated waveguide need to be consider. High permittivity substrate antenna gain that can be achieved is 10 dBi with a smaller radiating patch[11]. Surface wave losses become more severe for thicker substrate. Apart from that, in term of economy analysis, the Teflon is quite expensive compare to other materials due to its several drawbacks and the manufacturing of the chemical into Teflon material have to be consider.

5.4 Future Recommendation

Several improvisations can be applied for the future similar work to have a better research. It is recommended that the researcher could study the reduce the microstrip antenna patch antenna size even though after adding substrate integrated waveguide technique with Teflon substrate. This will help to study the performance of the antenna that have been using commercially at the wireless communication system.

Other than that, future researcher could develop an antenna design which can be suitable in term of geometrical parameter by using same substrate and structure for ultrawide band frequency. This will help to obtain wider bandwidth and higher gain for high quality wireless communication link.

Finally, future researchers could analysis other parameters of the antenna to observe accurate data that can be used in wireless communication. This will help a lot in improving the performance of the antenna for upcoming network generation.

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APPENDIX A
LIST OF THE DIELECTRIC MATERIAL

Dielectric Constants of Various Materials

Material	Min.	Max.
Air	1	1
Amber	2.6	2.7
Asbestos fiber	3.1	4.8
Bakelite	5	22
Barium Titanate	100	1250
Beeswax	2.4	2.8
Cambric	4	4
Carbon Tetrachloride	2.17	2.17
Celluloid	4	4
Cellulose Acetate	2.9	4.5
Durite	4.7	5.1
Ebonite	2.7	2.7
Epoxy Resin	3.4	3.7
Ethyl Alcohol	6.5	25
Fiber	5	5
Formica	3.6	6
Glass	3.8	14.5
Glass Pyrex	4.6	5
Gutta Percha	2.4	2.6
Isolantite	6.1	6.1
Kevlar	3.5	4.5
Lucite	2.5	2.5
Mica	4	9
Micarta	3.2	5.5
Mycalex	7.3	9.3
Neoprene	4	6.7

Material	Min.	Max.
Nylon	3.4	22.4
Paper	1.5	3
Paraffin	2	3
Plexiglass	2.6	3.5
Polycarbonate	2.9	3.2
Polyethylene	2.5	2.5
Polyimide	3.4	3.5
Polystyrene	2.4	3
Porcelain	5	6.5
Quartz	5	5
Rubber	2	4
Ruby Mica	5.4	5.4
Selenium	6	6
Shellac	2.9	3.9
Silicone	3.2	4.7
Slate	7	7
Soil dry	2.4	2.9
Steatite	5.2	6.3
Styrofoam	1.03	1.03
Teflon	2.1	2.1
Titanium Dioxide	100	100
Vaseline	2.16	2.16
Vinylite	2.7	7.5
Water distilled	34	78
Waxes, Mineral	2.2	2.3
Wood dry	1.4	2.9

High Frequency Simulation Software (HFSS)

APPENDIX B
GANNT CHART