DESIGN AND ANALYSIS OF WIDEBAND SIW BANDPASS FILTER USING DEFECTED GROUND STRUCTURE FOR 5G COMMUNICATION SYSTEM

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

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2020

DECLARATION

I declare that this report entitled "Design and Analysis of Wideband SIW Bandpass Filter using Defected Ground Structure for 5G Communication System" is the result of my own work except for quotes as cited in the references.

Signature : ....

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Date : 21th August 2020

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

Signature	:	…………… ……………
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Date	:	21th August 2020

DEDICATION

To my family,

for always loving and supporting me forever.

ABSTRACT

5G is the fifth technology generation for telecommunications and mobile networks known to have been in operation since 2019. Fast speeds of the network, superior reliability and minimal latency are the key aim for 5G implementation. Yet 5G technology continues to be developed for everyday use. One of the best examples of microwave communication improvement is the bandpass filter. A large number of applications, including using Defected Ground Structure (DGS) in the band-pass filter, have been discovered. A bandpass filter is therefore suggested. The 5G communication network, running in the 26–28 GHz band, is equipped for this filter. The parameters for defected ground structure (DGS) will be used to evaluate the SIW band pass filter performance. Return loss should be greater than -10 dB and insertion loss less than -3 dB which are the suggested criteria for this filter. Therefore, in terms of all two parameters referred to previously, the performance for SIW bandpass filters is analysed. The proposed design will be evaluated at the end of this project and will see which design is appropriate for 26GHz.

ABSTRAK

5G adalah generasi teknologi kelima untuk telekomunikasi dan rangkaian mudah alih yang diketahui telah beroperasi sejak 2019. Kelajuan pantas rangkaian, kebolehpercayaan yang unggul dan kependaman minimum adalah tujuan utama pelaksanaan 5G. Namun, teknologi 5G terus dikembangkan untuk penggunaan seharian. Salah satu contoh terbaik peningkatan komunikasi gelombang mikro ialah penapis lulus jalur. Sebilangan besar aplikasi, termasuk menggunakan Defected Ground Structure (DGS) dalam penapis lulus jalur, telah ditemui. Oleh itu, penapis lulus jalur dicadangkan. Rangkaian komunikasi 5G akan berjalan di jalur 26-28 GHz, dilengkapi untuk penapis ini. Parameter untuk Defected Ground Structure (DGS) akan digunakan untuk menilai prestasi penapis lulus jalur SIW. Kehilangan kembali harus lebih besar daripada -10 dB dan kehilangan sisipan kurang dari -3 dB yang merupakan kriteria yang disarankan untuk penapis ini. Oleh itu, dari semua kedua parameter yang disebut sebelumnya, prestasi penapis lulus jalur SIW dianalisis. Reka bentuk yang dicadangkan akan dinilai pada akhir projek ini dan akan melihat reka bentuk mana yang sesuai untuk 26GHz.

ACKNOWLEDGEMENTS

Praise be to Allah for his blessings and give me the strength to carry on with my final year project.

I am very grateful to my supervisor, Dr. Noor Azwan bin Shairi for his guidance and continuing supervision, as well as for supplying the details needed to complete the project, and for his encouragement. His encouragement and guidance are truly appreciated. Otherwise, it was not possible to do this project. I learned a lot, whether practically or theoretically, under his guidance.

With some of the most awesome people, my life is so blessed. I also wish to thank especially my friends, Nurul Hidayah and Muhammad Zaim, who always have been together at UTeM since our first day. In my tough moments, they still motivate me, as well as support me. Finally, thank you for the beautiful way in which you affect my life for, Saiful Hatin. May all the memories remain forever in our hearts.

Deepest thanks and appreciation to my parents, Md Khider Bin Ab Rahman and Normah Binti Ahmad for their love, encouragement and guidance and assistance in my life, and also the prayers during the study, from beginning to end. Your love is beyond any words.

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LIST OF SYMBOLS AND ABBREVIATIONS

5G	:	Fifth Generation
WiMAX	:	Worldwide Interoperability for Microwave Access
SIW	:	Substrate Integrated Waveguide
RWG	:	Rectangular Waveguide
DGS	:	Defected Ground Structure
SRR	:	Split-ring Resonator
TE	:	Transverse Electric
TM	:	Transverse Magnetic
TEM	:	Transverse ElectroMagnetic
ADS	:	*Advanced Design System*
QoS	:	Quality of Service
RF	:	Radio Frequency
LTE	:	Long Term Evolution
3D	:	Three Dimension
GHz	:	Giga Hertz
dB	:	Decibel

CHAPTER 1:

INTRODUCTION

Nowadays, new telecommunications technology has increased more frequently and the greatest demand on the market is growing. The Government's effort to support new wireless communication application invention and innovation. Examples of wireless communication include Microwave, Satellite and WiMAX applications. The new technology offers the positive advantage and enhancement of telecommunications infrastructure and provides the three essential things for the customer which are coverage, reliability and quality of service (QoS). In terms of coverage the customer receives the necessary signal rate from electromagnetic waves. The speed of uploading and downloading to the computer is more rational and fair for the capacity. Subsequently, the good quality of service (QoS) also does not provide data transmission errors so there was no problem with the service [1].

1.1 Background

During the past few years, Defected Ground Structure (DGS) has played a significant role in radio frequency / microwave circuits. In 1999, a first defected ground structure was suggested, based on the concept and implementation of photonic band-gap (PBG) structure, which can be found with the configuration of planar circuits and low pass filters [2]. Nevertheless, because of the modeling difficulties, it is difficult to use the PBG system for the design of microwave parts. Another challenge in using the PBG circuit is the radiation from the regular etched effects [3]. A DGS is where ground plane metal is purposely modified with certain geometry to improve performance. A variety of slot geometry is realized by etching a faulty pattern in the ground plane that perturbs the distribution of shield current in the ground plane. It can also be used in various circuits [2] with antenna, filters, delay lines, phase shifters and so on.

There is already much interest in designing integrated circuits for microwaves and millimeter waves in a recent Substrate Integrated Waveguide (SIW) approach. The SIW is synthesized by inserting two metal rows into a substratum via holes. Contrary to traditional rectangular waveguide distributions, is the field distribution of a SIW. This makes it easy to integrate into microwave circuits and millimeter wave circuits [4], taking advantage of a low cost, high Q-factor etc.

In 2001, this paper [5] proposed a new technology to integrate high density microwaves and millimeter waves. This technique uses dielectric or metal rows in order to synthesize non-radiated dielectric waveguides, plates or rectangular waveguides inside a dielectric substratum. The idea of incorporation into a dielectric substratum of two rows of metal posts was suggested in first in [6].

1.2 Problem Statements

In the new era of modern technology, everybody in the world has desired to communicate with others throughout the system, especially to link them in far-reaching communication. This is a situation different than a hundred years ago. Therefore, the increasing type of communication demanded the more advanced telecommunications system. Conventional technologies, like a rectangular metal waveguide or a microstrip, are either too costly or unable to achieve the necessary output in the design of high quality passive components. This aims to produce the element that can boost the telecommunications system's better performance in order to provide the good communication service. Since this problem occurs, the communications system must provide the service with less disturbance among users in order to achieve the high quality of service (QoS).

Dozens of front-end wireless communication applications were influenced by high-quality bandpass filters (BPFs). In order for many self-connected cars to be called, one or more bandpass filters are required in both mobile and satellite transceivers for IoT/IoE. Such technological requirements led to significant electronic and microwave innovations, including the multi-band and multi-standard specialist field of mm-wave communications. Since 5G wireless networks are using mm-wave frequencies (24.5-29.5 GHz) for broadband width and thus speeds of data, high-performance mm-wave bandpass filters are anticipated to be used by large-scale distributed users [7]. Specifically, for small cell front-end modules in which isolation from nearby frequency band interference is essential.

1.3 Objectives

The project 's objectives are:

1. To design the wideband SIW bandpass filter using Defected Ground Structure (DGS) for 5G communication system.
2. To analyze and select the best performance of the SIW bandpass filter for 5G communication system at 26 GHz.

1.4 Scope of Project

The project scope includes designing the layout and performing layout analysis in Advance Design System (ADS) software.

The SIW bandpass filter is designed with the use of ADS software. The layout will be designed according to all the specifications and requirements in ADS software to allow the layout to operate at 26 - 28 GHz band to achieve a return loss of more than -10 dB and less than -3 dB as it is the most important requirement for a 5 G communication system.

The study of the SIW bandpass filter in ADS software will be performed after the layout has been built in ADS software. There are three parameters of DGS split-ring resonator will be tested in ADS which are the distance between two DGS split-ring resonator, the length of split opening and the width of DGS split-ring resonator. The output for that configuration will be evaluated and the most effective and appropriate configuration of the 26 GHz bandpass filter for 5 G communication system will be calculated.

1.5 Structure of Project

This thesis is composed of five chapters to report the research work at 26 GHz for the performance analysis of the SIW bandpass filter for 5 G communication system.

The overall project comprises Chapter 1. The declaration of problem will be stated in this chapter. After that, the project's goals and scope will be defined by referring to the statement on problem. The ranges must be clearly set out. Only significant project will be listed in this chapter.

Chapter 2 dealt with study of the literature. In this chapter, the source of these researches must be appropriate in the format of the program such as books, papers, articles and website relating to bandpass filter and defected ground structure. Gaining the specified information for this project will be elaborated in more detail.

Chapter 3 consists of the research methodology used for the development of this project. Methodology is the process flow and the use of technique from the first step until the end of the project. The chapter clarifies the approaches from start to finish used in this project. This method is very important to ensure that the project is carried out and that the goals and objectives of the project are achieved.

Chapter 4 is a summary of the results, the performance of the project, and the study findings resulting from the experiments described in tables, figures, and graphs. Each segment will contain the results of the software simulation. The estimated output value is being compared to the observed value.

Chapter 5 sums up the project's outcomes. It concluded on the project whether or not it is achieving the desired goal and objective. Both the chapter outlines some suggestions on the architecture and the program itself for further development and improvement. Also inside the chapter are recommendations for future inventors.

CHAPTER 2:

LITERATURE REVIEW

This chapter explains the literature review that was conducted from various developed projects referred to for project purpose development. It will discuss information details excerpted from a few specific elements and topics.

2.1 Introduction

The literature review for this item briefly outlines and explores the success of other projects across the globe within the same area of research. Gaining information and making the conversation about the relevant subject of the project is very important. All the information and data from the various types of sources such as journal, article, and filter related technical report were analyzed. It implements the method used to increase the output of the bandpass filter. The Defected Ground Structure (DGS) will be discussed further. Similar to the other structure type, this structure represents the simplest and most compact design structure. There are several forms of DGS design including rectangular triangle, open loop dumbbell shape and DGS hairpin. Fixing a bandpass filter within the 26 – 28 GHz band is the best type.

2.2 Introduction to 5G

Currently it is impossible to imagine life without modern wireless connection as it started from 1990. It moves forward with our modern life, allowing societies to operate efficiently nowadays, and it plays a very good role in terms of politics, economy, education, health, entertainment, logistics travel and all the industries available in these days. To have a productive life, we need to obtain and share information from different sources, particularly in this modernizing era, where internet is the most reliable and used source. This is because it is much easier to access all the information on the internet from wherever we are, as long as we are connected to the Internet [8].

For example, different applications may set different performance requirements, and below are listed the highest demands that are needed in some configurations. Therefore, it is important first to define and prepare for fulfilling specifications for a 5G network to understand more effectively the technological challenges facing 5G. To fulfill the 5G wireless communication, which is data rate, latency and energy and cost, there are three engineering requirements. The data rate and the need to support an explosion in mobile data traffic is the driver behind 5G, which is clearly indicated by [9] on the 5G engineering requirement. Data levels can be calculated in different ways and each of these metrics has a 5G objective. Above all, the aggregated amount of data network that could be serving refers to the total data rate or area capacity. First is the edge rate or the average of 5 per cent. This alludes to the most terrible data rate a client can sensibly hope to get when it's within the system's scope. The maximum rate is the best-case data rate a customer may choose for any network configuration. On the subject of latency, the paper stated that 5G could help a latency of round trip of around 1ms, an order faster than current 4G with round trip latencies of approximately 15ms. The last engineering requirement for 5G is energy and cost. Supposedly, energy and cost utilization will diminish, however it ought not to be increment on a for every connection premise. Figure 2.1 shows the Millimeter-wave-enabled network with phantom cells.

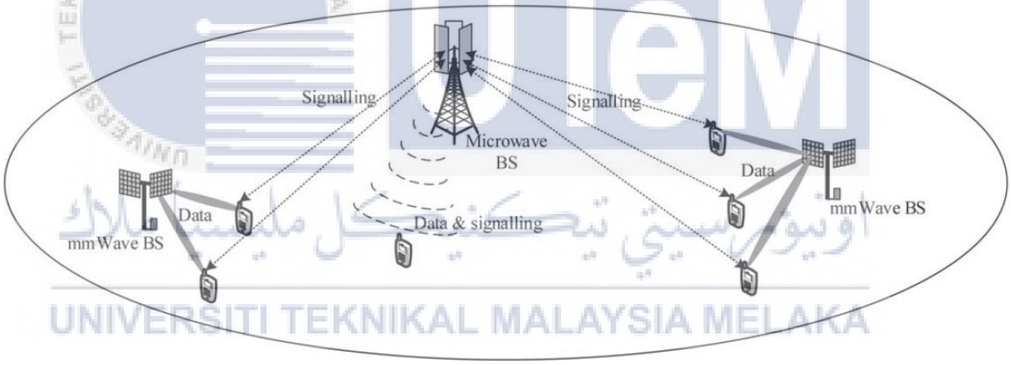

Figure 2.1: Millimeter-wave-enabled network with phantom cells [9]

2.3 Bandpass Filter

Essentially, an electrical filter is a circuit that can alter, reshape or reject all unwanted electrical signal frequencies and only accept and transmit certain signals that the circuit designer is obligated to provide. In other words, undesirable signals are "filtered out" and depending on their frequency an optimal filter distinguishes and transfers sinusoidal inputs.

The bandpass filter passes and rejects (attenuates) frequencies within specific ranges outside the scope. There are applications where a specific band, or distribution, or frequencies must be separated from a broader spectrum of mixed signals. For this reason, filter circuits can be built to combine low-pass and high-pass properties in one filter. For wireless transmitters and receptors, the band pass filters are used in the main. The principal function of a filter in a transmitter is limit the bandwidth of the output signal to the minimum needed to transmit the information at the desired speed and format. A bandpass filter in a receiver allows the detection or processing of signals within a specified frequency range while preventing the transmission of signals at undesirable frequencies.

A low-pass filter is an electronic filter that processes low-frequency signals but attenuates (reducing) signals with higher frequencies than the cut-off frequencies. Although a high-pass filter is vice-versa a low-pass filter. Please see the different characteristics of all 4 filters in Figure 2.2 below.

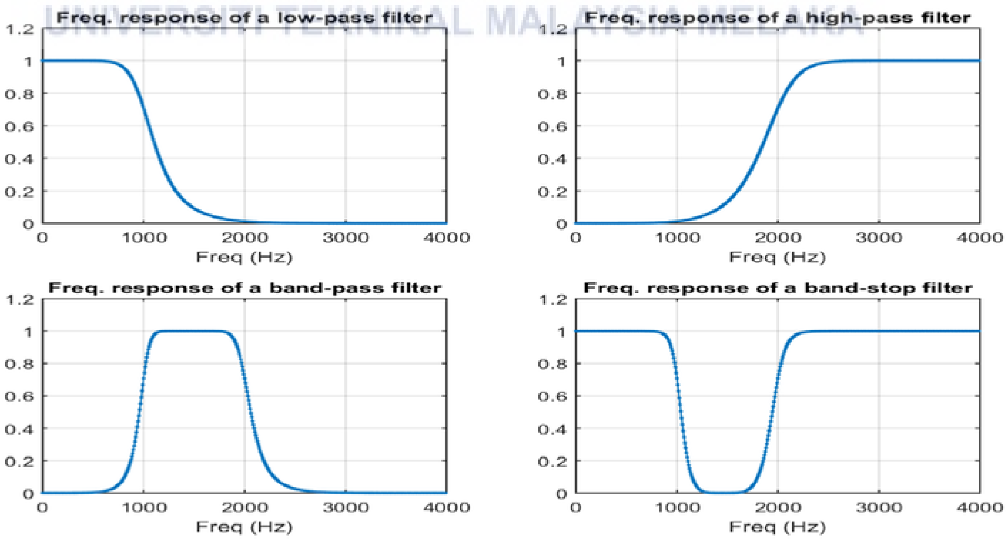

Figure 2.2: Frequency Response of Lowpass, Highpass, Bandpass and Bandstop Filter.

2.4 Fundamentals of the Substrate Integrated Waveguide

2.4.1 Introduction of Substrate Integrated Waveguide (SIW)

The principal function of a wave guide is to guide or direct the propagation of an electromagnetic wave by coop in wave energy. A rectangular waveguide is usually made of hollow metal pipes with a uniform cross section.

Variations exist between the wave guide transmission lines and the TEM. At least two conductors are connected to a transmission line and TE 's propagation mode has a cut-off rate of zero. For the signal propagation, a TEM line cross section has no other minimum size than that defined by loss of dissipation [10].

2.4.2 SIW vs Conventional Rectangular Waveguide

In millimeterwave applications, the traditional rectangular ondulatory guide is commonly used because its propagation loss is smaller than other modern technologies. It has a large, 3-dimensional setup, however, limiting compatibility with other circuits. SIW technology is an appealing option because the architecture has a low propagation loss profile and mass production is feasible using batch processing techniques. Although low-cost, high-Q passive components including resonators, filters, connectors, power dividers and antennas have been built with the SIW structure, some problems still need to be solved before moving on to commercial production to complete integration of the SIW system [11].

2.4.3 TE Mode

All electromagnetic waves consist of propagation, but perpendicular to one another, of electrical and magnetic fields in the same direction. Both the electrical and magnetic fields are perpendicular (transverse) to the wave travel direction along a normal transmission line. Transverse modes exist in radio waves and microwaves which are limited to a waveguide. Transverse modes exist due to the boundary conditions on the wave by the waveguide. For example, a radio wave in a hollow metal wave guide must have null tangential electrofield amplitude on walls of the wave guide, so the transversal pattern of the electrical wave field is restricted to the walls. It quantizes the modes served by a wave-guide for this reason. Transverse modes come in different types:

i. No electrical field in the propagation direction for TE (Transverse Electrical) modes.

ii. No magnetic field in the direction of propagation is used in TM modes (Transverse Magnetic).

iii. TEM modes (Transverse Electro Magnetic) are not propagative electric or magnetic fields.

iv. Hybrid modes in the direction of propagation of electrical and magnetic fields non null.

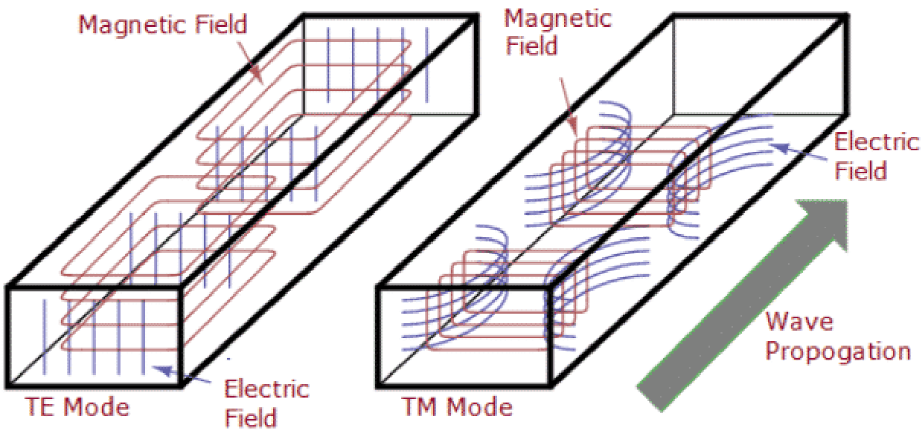

Figure 2.3: Magnetic and electric fields in rectangular waveguide in TE and TM mode [6].

Hinter [6] describes TE mode analysis; also shows the derivation *m* and *n* terminals in TE modes, known as TE_{mn} modes, and in TE_{10} as shown in Figure 2.3, lowest TE cut-off mode.

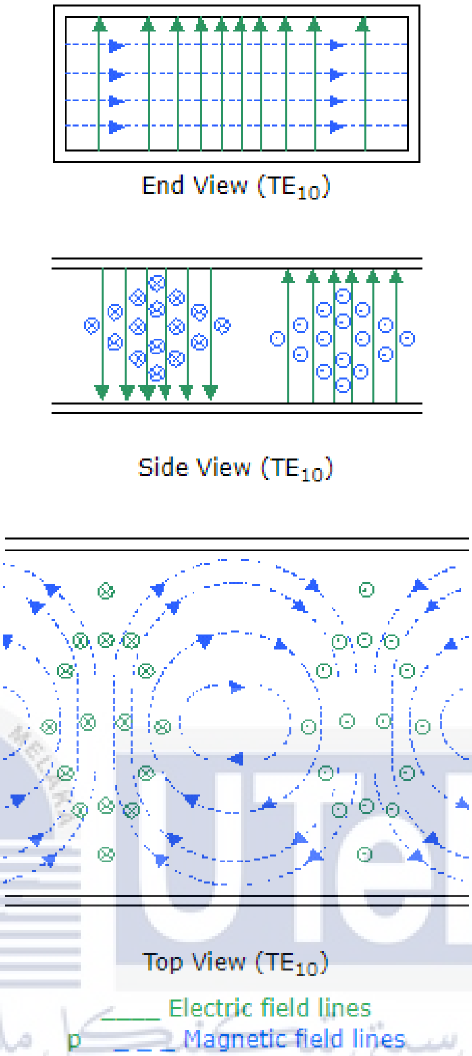

Figure 2.4: Electric and Magnetic Fields for the TE_{10} Mode in Waveguide [6].

2.4.4 Theory of Substrate Integrated Waveguide (SIW)

Substrate integrated waveguide is a new type of line, which some researchers have been studying intensively and developing extensively for decades. Microstrip devices are not successful in high frequency applications, and because high frequency wavelengths are short, very tight tolerances are needed for the manufacture of microstrips. High frequency waveguide devices were favored; but their production process was difficult. Therefore, a new idea emerged: an integrated waveguide to the substratum. SIW is a transition from the dielectric-filled (DFW) microstrip. The dielectric wave guide is converted into an integrated waveguide (SIW) by means of vias for the side walls of the waveguide.

The definition of the Substrate Integrated Waveguide is a rectangular waveguide formed by two solid conductive planes separated by a dielectric substratum, with conductive side walls emulated by rows of metallic cross-plated vias as shown in Figure 2.5. The SIW is a synthesis of the waveguide in a substrate, and the propagating wave is bounded by holes [10].

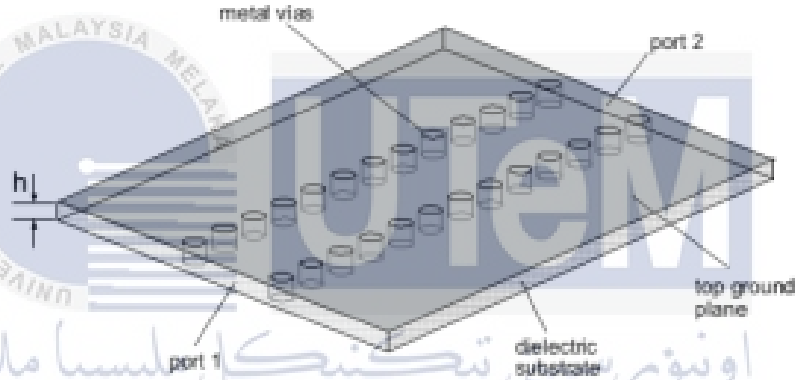

Figure 2.5: Modelled SIW Structure

The substratum 's built-in waveguide is made of a periodic structure through holes. A SIW retains the advantages of standard rectangular waveguide, like its Q factor and high-power conductivity characteristics [10]. Figure 2.6 shows *h* being the height of the substratum and *w* the distance between two parallel hole sets. TE_{10} is a continuous propagation.

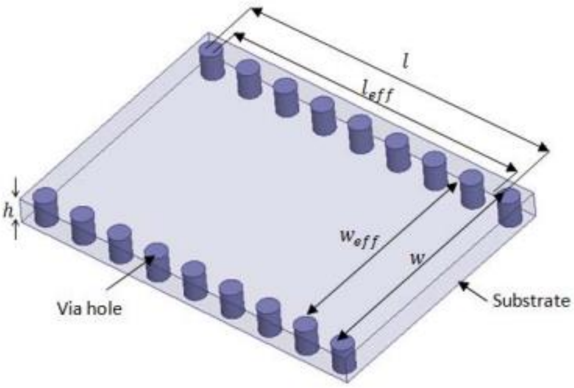

Figure 2.6: The Basic of the SIW Structure [12]

The length of the SIW cavity is calculated as the initial dimensions of the simulation software by the corresponding resonance frequency of [6]:

$$f_{101} = \frac{C}{2\pi\sqrt{\varepsilon_r \mu_r}} \sqrt{(\frac{\pi}{w_{eff}})^2 + (\frac{\pi}{l_{eff}})^2}$$

They are expressed in the dominant TE_{101} mode, in which the corresponding width and length of the SIW cavity is w_{eff} and l_{eff}:

$$l_{eff} = l - \frac{d^2}{0.95 \cdot p}$$

$$w_{eff} = w - \frac{d^2}{0.95 \cdot p}$$

Where the *w* and *l* of the SIW cavity are the true width and length. C is the speed of light constant in free space, π_r and μ_r are the relative permittivity and relative permeability of the substratum [12]. While *d* is the diameter of the through holes, while *p* is the distance between two through a hole, as shown in Figure 2.7.

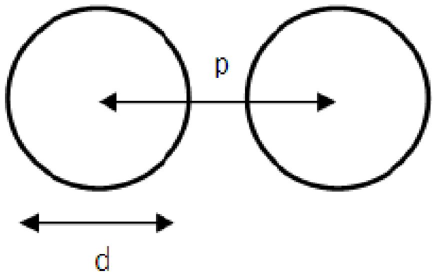

Figure 2.7: The diameter and pitch for via hole [12]

2.4.5 Via Holes

Figure 2.8: Wave Propagation in the Substrate Guided

The bilateral edge walls of a large part of the SIW are to be realized via holes. Miniaturization and integration of large-scale systems put a fascinating demand on multi-layer interconnect geometries, one of the most important discontinuities in multi-layered circuits is through holes. There are also other studies regarding the behavior of through holes. The design parameter of via hole is [12]:

$$d < \frac{\lambda_g}{5}$$

$$p \leq 2d$$

Through experimental and theoretical analysis, Laso et al [15] showed that they work in high frequency as broadband reflectors or short circuits through holes. Periodically arranged along the microstrip line, they analyzed with a half wavelength separation, single through holes. As the number of vias increases, reflectivity greatly increases.

2.5 Basic Properties of Filter

Basic properties of filter are necessary to describe the performance. There are some basic properties to design the filter.

2.5.1 Insertion Loss

Insertion loss in RF switch defines the amount of signal attenuation that occurs for a given switch path. In other words, it is a ratio of signal power at input and output ports of a closed switch [14]. Insertion loss is expressed in decibels and it reflects negative quantity. The better the insertion loss, the higher the insertion loss value. In other words, it will be a smaller negative number.

2.5.2 Return Loss

The general definition of return loss is a ratio of reflected signal to the incident signal at an input circuit or network. Most RF switch designs require a very good return loss at used port. Return loss is expressed in decibels and it reflects negative quantity. The better the return loss, the lower the return loss value. In other words, it will be a larger negative number.

2.6 Fundamentals of the Defected Ground Structure

Several new concepts for distributed microwave-circuits have been implemented in the last few years. One such approach is a defected ground structure or DGS, where the ground plane metal is intentionally changed for an improves performance by a microstrip (or striplines, or coplanar waveguides). The term "defect" simply means that the floor plane usually sees itself as an approximation to the endless, perfectly conductive power sink. For example, at microwave frequencies the idealized action of perfect ground is excluded from the ground plane. Although additional DGS disturbances change the ground plane's uniformity, they do not make it deficient [15].

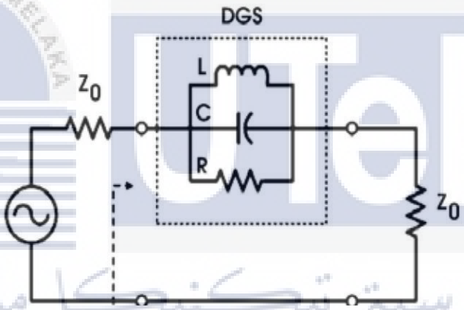

Figure 2.9: Equivalent Circuit of a DGS Element [16]

The basic element of DGS, positioned immediately under a transmission line and coupled with a line for efficient coupling, is a resonant gap or hole in ground metal. In any resonant buildings may be included in Figure 2.9. The LC ratio, the coupling coefficient, the higher-order response, as well as other electric parameters are different in the occupied area. The best framework for the particular application should be selected by a user. For a DGS, the corresponding circuit is a series parallel tuned circuit with the connecting transmission line [17].

The line segment is the input and output impedances, while the corresponding L, C, and R values are determined by the dimensions and position of the DGS structure relative to the transmission line. The center frequency selection and practical factors such as a size or a shape not overlapping other parts of the system or a design which is easy to cut to the ideal center frequency [15].

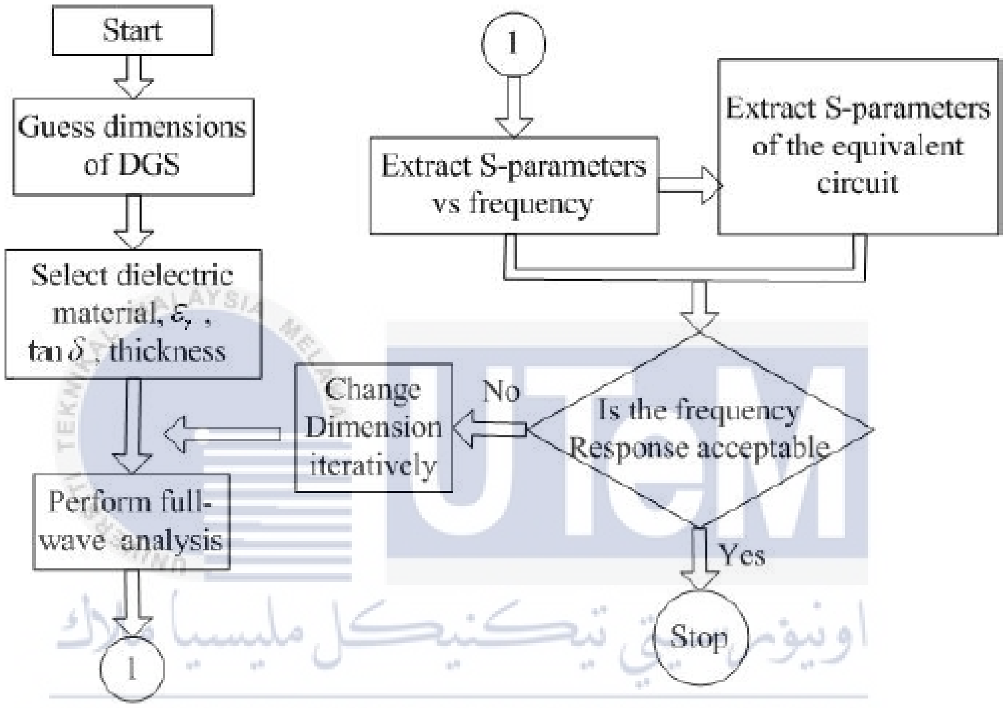

Figure 2.10: Conventional Design and Analysis Method of DGS [2]

This interference can modify the characteristics of a transmission line such as line capacitance and inductance. It distrusted the shield current flow in the ground level due to a terrestrial defect. Any error in the microstrip's ground plane will in a term result in increased efficient capacity and inductance.

The remaining frequency behavior does not improve dramatically as the DGS microstrip with the use of the bent microstrip. The technique of bending leads to 2D configuration, in which many bends follow a structure similar to the meander line within the microstrip line. This concept has a small stopband, which can be in a fair circuit for a large number of times [2].

The new DGS device proposed has many advantages compared to dumbbell DGS:

a. More compact circuit and higher slow wave factor. The filter circuit with "H" slots is much less than that with dumbbell DGS about 26.3% [18].
b. Low stopping range and deeper dismissal.
c. An external Q slightly bigger. The DGS and U-slot DGS are for the same frequency of the resonance in order to compare the U-slot DGS with conventional DGS transfer characteristics. Q spiral DGS has a factor of 7.478 (3 dB in the 0.39 GHz bandwidth), while the u-slot DGS has a 36.05 high Q-factor (3 dB in the 0.081 GHz bandwidth) [19].

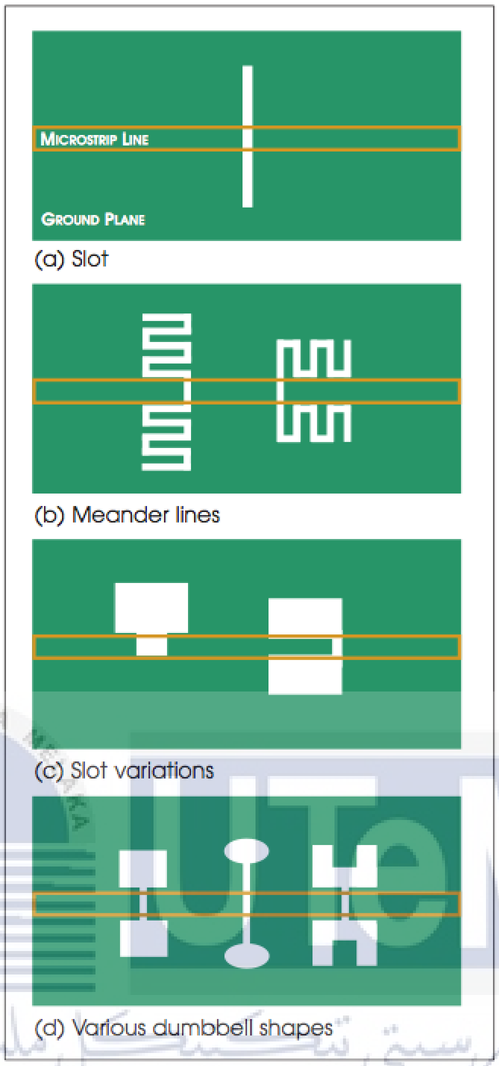

Figure 2.11: Common Configurations for DGS Resonant Structures [16]

In a word, increasingly new DGSs are being proposed that bring great convenience to the design of the microwave circuit in order to realize different compact structures of passive and active devices and to suppress the harmonies.

2.6.1 DGS Characteristics

In the microwave circuit, DGS has two main slow wave spreading characteristics in pass band and band stop characteristics.

Due to the defect of slow-wave propagation in the pass band, the corresponding inductive component increases and produces equivalently the highly efficient dielectric constant, which is a slow-wave property because of this, for the same physical duration, the DGS line has the longer electric duration than the normal microstrip line [3]. It can get the desired resonance frequency by changing the various dimensions of the defect [3].

Meanwhile, bandstop functions indicated that the DGS unit's equivalent circuit can explain the effect of the band gap. Because of the DGS segment the inductance of the sequence increases the microstrip reaction as the frequency rises. Therefore, the other frequency range will start to be rejected. The parallel capacitance with the inductance series allows the attenuation pole to be located, which represents the resonance frequency of parallel resonators. As the operation frequency increases, as the band gap between the propagating frequency bands may occur, the capacitance reaction decreases. The corresponding circuit should also demonstrate low-pass and bandstop filter efficiency simultaneously to highlight the cut-off and attenuation pole characteristics of the proposed DGS section at the same time.

To summarize, the ratio waves velocity factor of a 'natural' line to a slow-wave structure is a slow-wave factor. In comparison to the "normal" wavelength of the dielectric medium, the higher the Slow-Wave-Factor the lower the transmission line's wavelength [1].

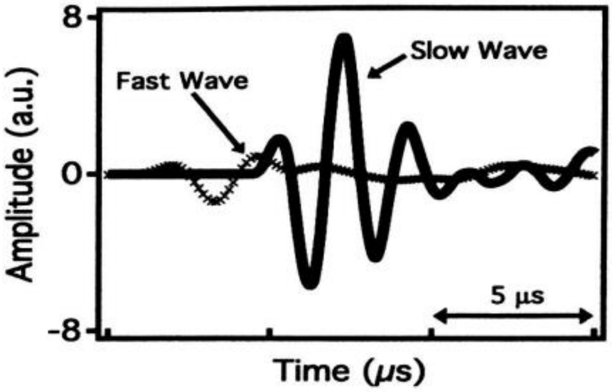

Figure 2.12: The fast-wave and slow-wave that comprise the model waveform [20]

CHAPTER 3:

METHODOLOGY

This chapter explains the details of the techniques and method used to accomplish this project. A step by step taken from choosing a title until finishing is explained in this chapter. Methodology includes the planning, development, design and management of the project. The idea gained into the project build-up were based on the consideration on many aspects taken into account from the previous chapter.

3.1 Introduction

This project is about designing and producing a high performance bandpass filter and also to develop a bandpass filter based on a SIW with DGS. Some of the methods are followed to make the goal of this project successful. Analysis or literature review is done from books, internet, websites, articles, and course notes prior to starting this project. This is done to get the project's overall idea. All the required information is collected and evaluated from this research to make the project development flow smoothly.

The next step is to draw the outline or a flowchart to explain how the procedure will be done. It is important to understand the definition with the elements that play a major role in this design, such as Defected Ground Structure (DGS) and Substrate Integrated Waveguide (SIW). Advances Design System (ADS) software or Computer Simulation Technology (CST) for data collection, testing and performance analysis is used to calculate the filter's output. It is suggested that this software analyze the results that may arise for this project.

When all the necessary equipment and components are obtained and all literature review survey data has been reviewed, the circuit and project design will be completed. This method will obey the timeline of the Gant Chart perfectly in order to prevent any delays in completing this task.

3.2 Project Implementation

The most important aspect in the implementation phase is planning of projects. Proper preparation should be stressed to ensure that the project is completed successfully, and also to prevent issues during the process. To complete the simulation program on time, it is very important to have that systematic planning and implementation. Figure 3.1 below demonstrates project execution.

3.2.1 Flowchart of the Project

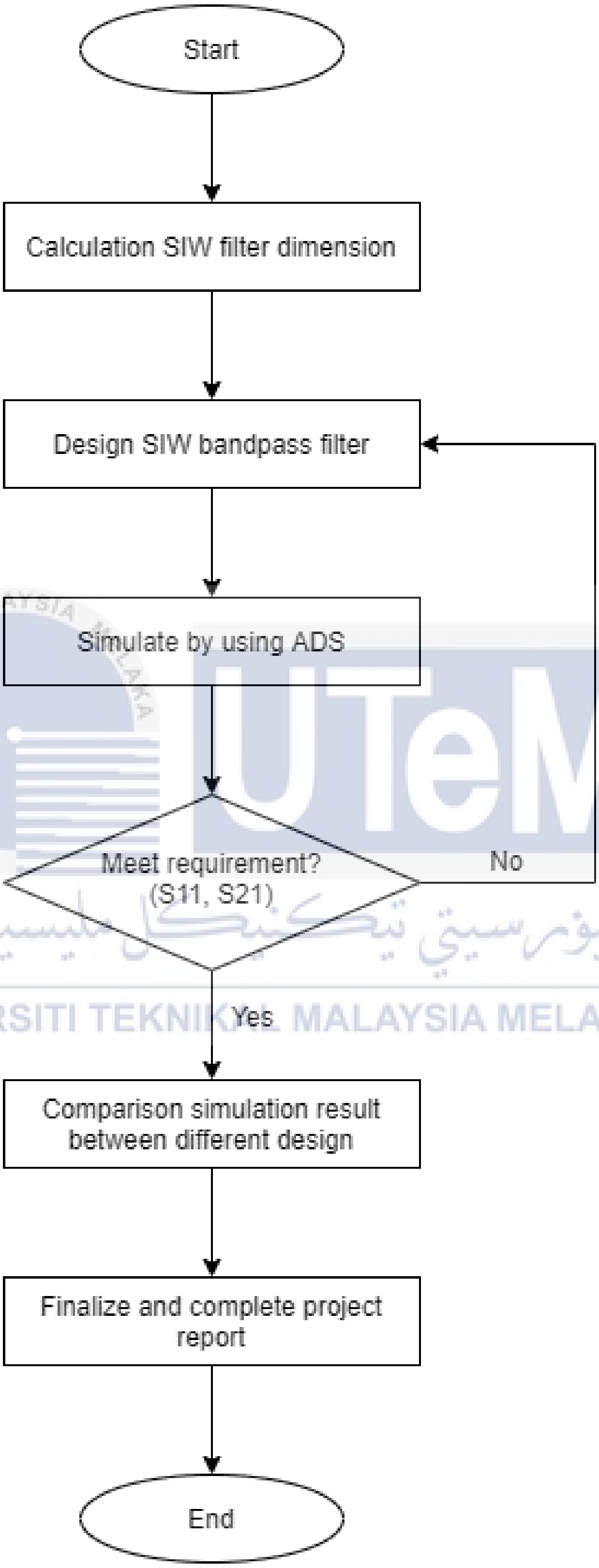

Figure 3.1: Flowchart of the project

The commencement of the project is to identify the project title. The title must be related to the project's statement of problem, objectives and scope. A preferred title is in the field of research supervisor so he can assist with the problems we will experience. The plan is submitted to the supervisor for approval after an appropriate title has been selected. Then the project proposal was submitted to the project coordinator after it has been approved by the supervisor. If accepted, then the proposal should proceed to the next step. If not, then the proposal should be done again

A work related to the subject must be studied and thoroughly understand in order to understand more about the project. The details could be obtained from journal, internet, book of references, instructions from the supervisor and so on. It must contain a point obtained during the search process in the literature review, and must be evaluated before being included in the content. Methodology is all about the decision taken on the basis of research and the studies that have been done to implement this project. The relevant circuit for this project must also be mentioned here.

Finding software for the design and simulation is started after defining the goals, concepts and fundamental resource. The simulation component represents a very important step in deciding whether the end product is exactly as we planned. If there is an error in the simulation the filter must be troubleshooting again. Advances Application System (ADS) software is used to stimulate the filter process. If the simulation result is different from planned, then recalculation of all processes is needed. The result will be finally compared with the other design until it meets the design requirements.

3.3 Design of the Bandpass Filter

3.3.1 Filter Design

All SIW band pass filter parameters are shown in Figure 3.2 and Figure 3.3, while the filter parameter values are shown in Table 3.1.

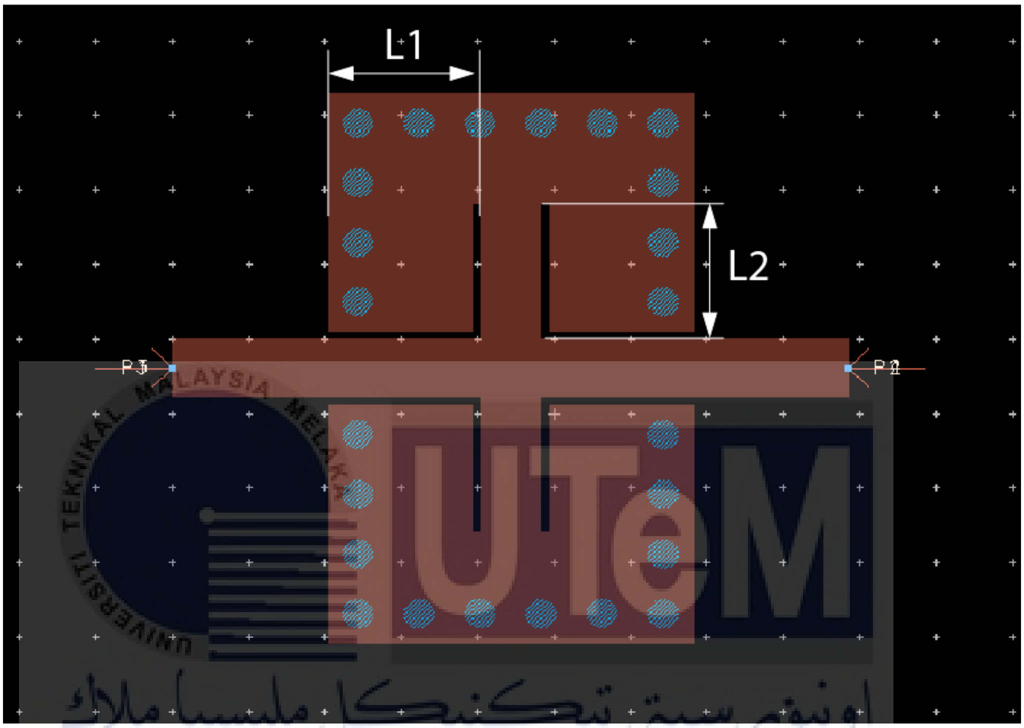

Figure 3.2: Top layout of 26 GHz bandpass filter with DGS

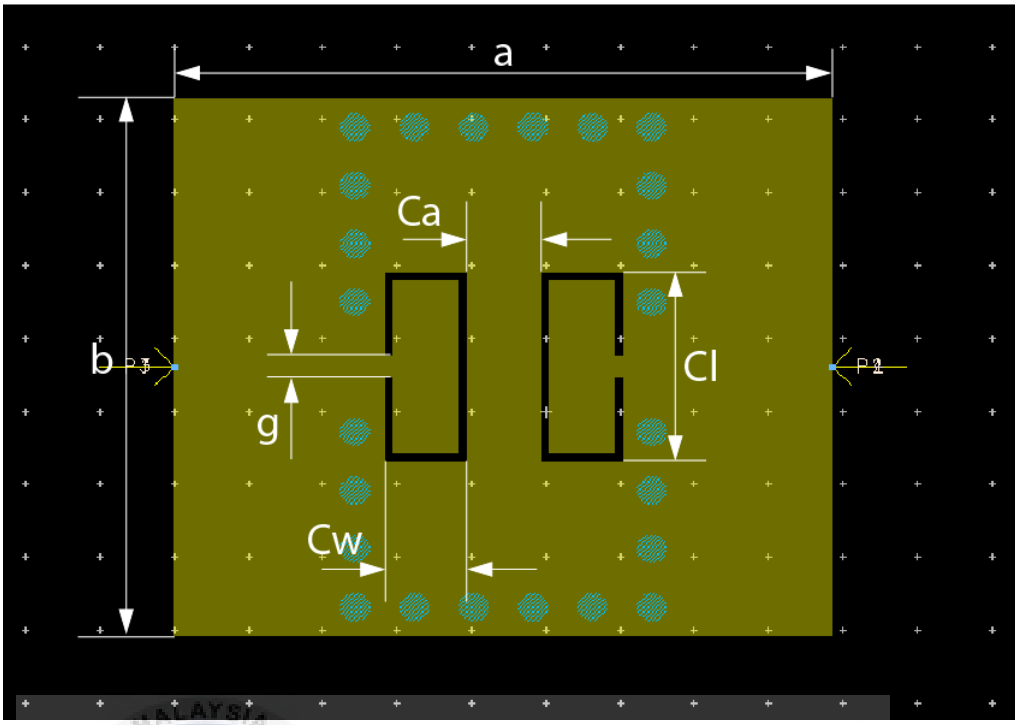

Figure 3.3: Bottom layout of 26 GHz bandpass filter with DGS

Table 3.1: Parameter values of the filter

Symbol	Value (mm)
a	8.86
b	7.38
Cl	2.59
Cw	1.1
g	0.3
L1	2
L2	1.8
Ca	1

3.3.2 Substrate Material and Thickness

Substrate material must be chosen first to start designing a bandpass filter. Roger Duriod5880 substrate was chosen for this project based on low cost, and easier to acquire the content. The parameter specification for Roger Duriod5880 substrate is described in the table below.

Table 3.2: Parameter Specification for Roger Duriod5880 substrate

Parameter	Symbol	Value
Substrate thickness	h	0.254 mm
Relative permittivity	ε_r	2.2
Loss tangent	$\tan\delta$	0.0009

3.3.3 Design Specification

The specifics of the proposed bandpass filter are listed and summarized in this section. The bandpass filter specification is targeted for high-power applications where the expected loss of insertion and return is less than -3 dB and greater than -10 dB, respectively. The frequency used in this project is 26 GHz which is required for a 5 G communication system. Following several requirements, the bandpass filter was developed. Table 3.2 shows bandpass filter design specification.

Table 3.3: Design Specification of Bandpass Filter

Parameter	Value
Center frequency, f_c	25.88 GHz
Lower cut-off frequency, f_1	24.25 GHz
Upper cut-off frequency, f_2	27.5 GHz
Bandwidth	2.75 GHz
Insertion loss (S_{21})	< -3 dB
Return loss (S_{11})	> -10 dB

3.4 Software Used

3.4.1 Advanced Design System software

Simulation of the DGS circuit is done by using Advance Design System software. Advance Design System is leading automation software in electronic design applications for RF, microwave, and signal integrity. ADS pioneers leading companies in the wireless communication & networking and aerospace & defense industries such as S-parameters and 3D EM simulators, the most innovative and commercially common technologies used. In an integrated platform for WiMAX, LTE, multi-gigabit per second data connections, radar, and satellite applications, ADS offers complete, standard architecture and testing with Wireless Libraries and circuit-system-EM co-simulation.

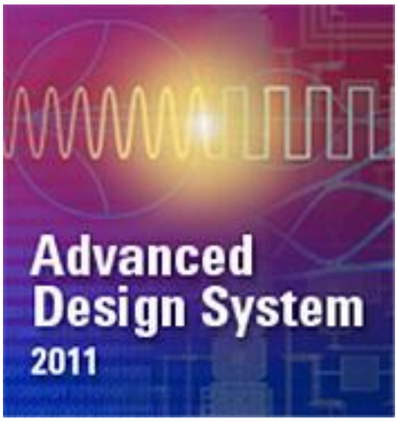

Figure 3.4: Advanced Design System 2011

The advantages of using ADS are the full, integrated collection of simple, precise and easy-to-use program, circuit and EM simulators that allow first-pass design success in a complete desktop flow. With a user-friendly interface, the application-specific Design Guides represent years of experience. ADS's are primarily funded by leading industry partners and foundry partners, or months earlier than others.

They are just a few important elements that were used during simulation of the DGS circuitry. For example, the schematic diagram consisting of the wideband SIW bandpass filter circuit, the display of data for each output result (S-parameter), the DGS simulation layout and the simulation of system momentum.

CHAPTER 4:

RESULTS AND DISCUSSION

4.1 Introduction

The results and analysis of the project are discussed in this chapter. The outcome will be more concerned about return loss, S_{11} and insertion loss, S_{21}.

4.2 Parametric Study

4.2.1 Effect of DGS split-ring resonator

In order to study the effect of DGS split-ring resonator at the bottom copper part of the substrate, two designs were used. The first one, is SIW bandpass filter without DGS split-ring resonator known as finite ground, and the second design is SIW bandpass filter with two DGS split-ring resonator faced to the back of each other.

4.2.1.1 Performance of Design 1 (Without DGS split-ring resonator)

Figure 4.1 shows the layout of bottom layer without DGS split-ring resonator while based on Figure 4.2 presents the simulation results at the range of 26 -28 GHz. The simulation results are insertion loss and return loss.

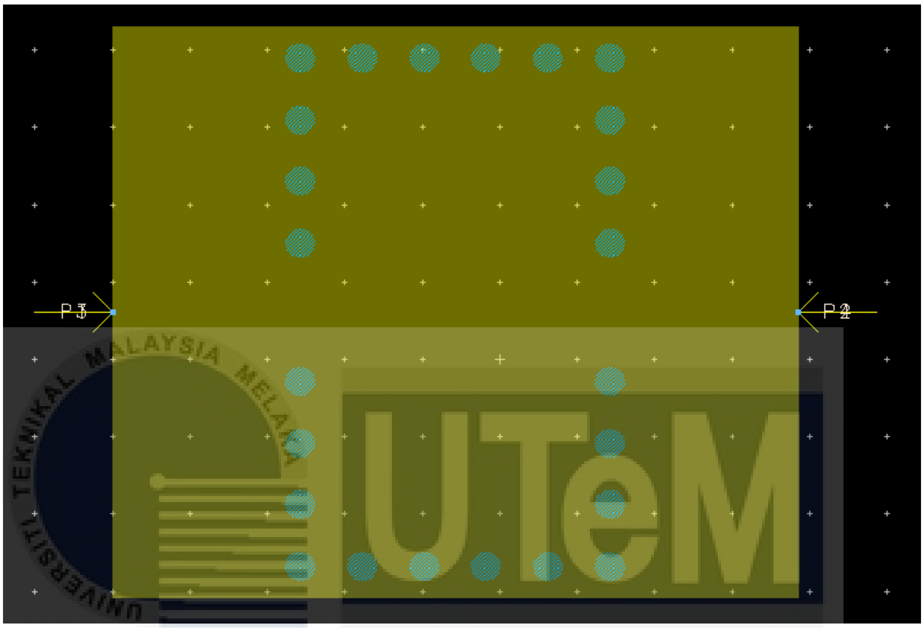

Figure 4.1: Without DGS split-ring resonator

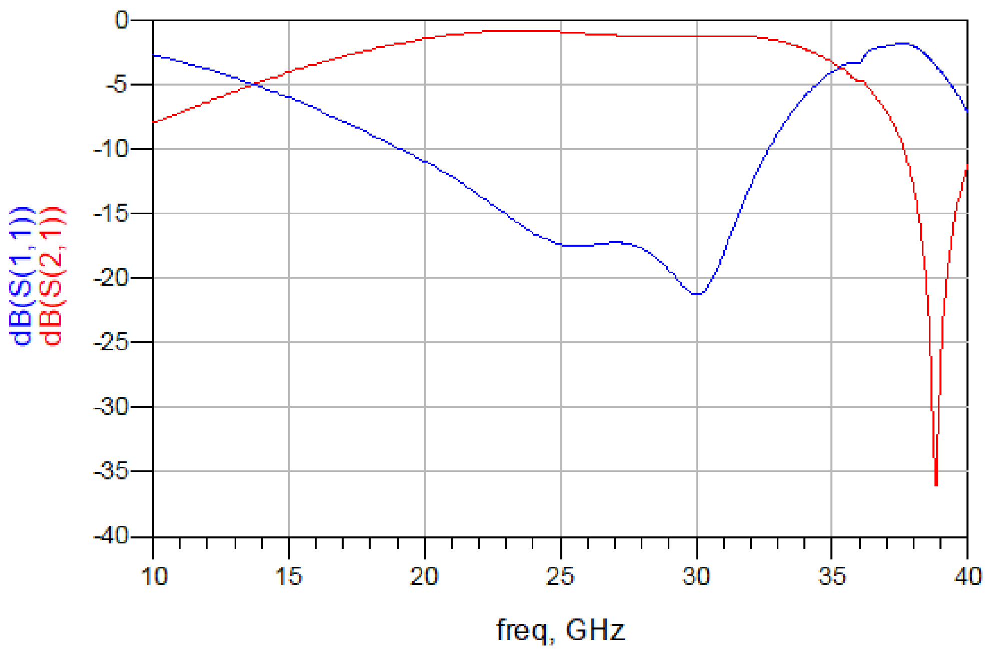

Figure 4.2: Return loss and insertion loss of design 1

From the Figure 4.2, the first design without DGS split-ring resonator, the bandwidth is 21.65GHz with two resonance frequency and the return loss is bigger than -10 dB. The resonance frequency is at 25.31 GHz and 30 GHz with return loss of -17.44 dB dB and -21.24 dB.

The comparison of obtained data and expected data at 26 GHz were shown and summarized in Table 4.1.

Table 4.1: Expected and simulated result of design 1 at 26 GHz

Parameters	**Expected result**	**Simulation result**
Return loss	More than -10 dB	-17.41 dB
Insertion loss	Less than -3 dB	-1.03 dB

4.2.1.2 Performance of Design 2 (With two DGS split-ring resonator)

The bottom layer layout with the DGS split-ring resonator shows in Figure 4.3 while the simulation results are presented at the 26-28 GHz range, based on Figure 4.4. Insertion loss and return loss are the results of the simulation.

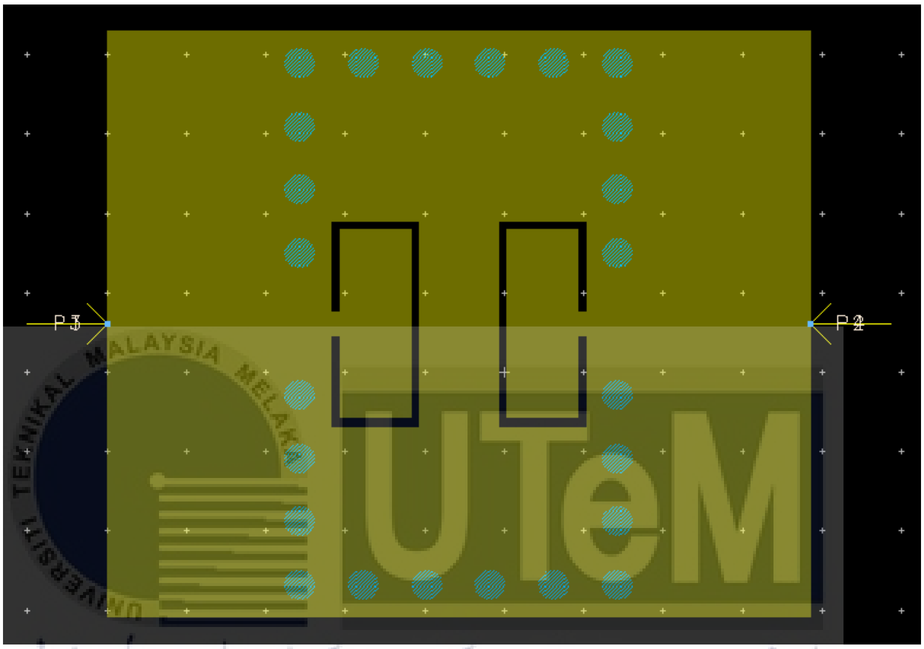

Figure 4.3: With two DGS split-ring resonator faces to the back of each other

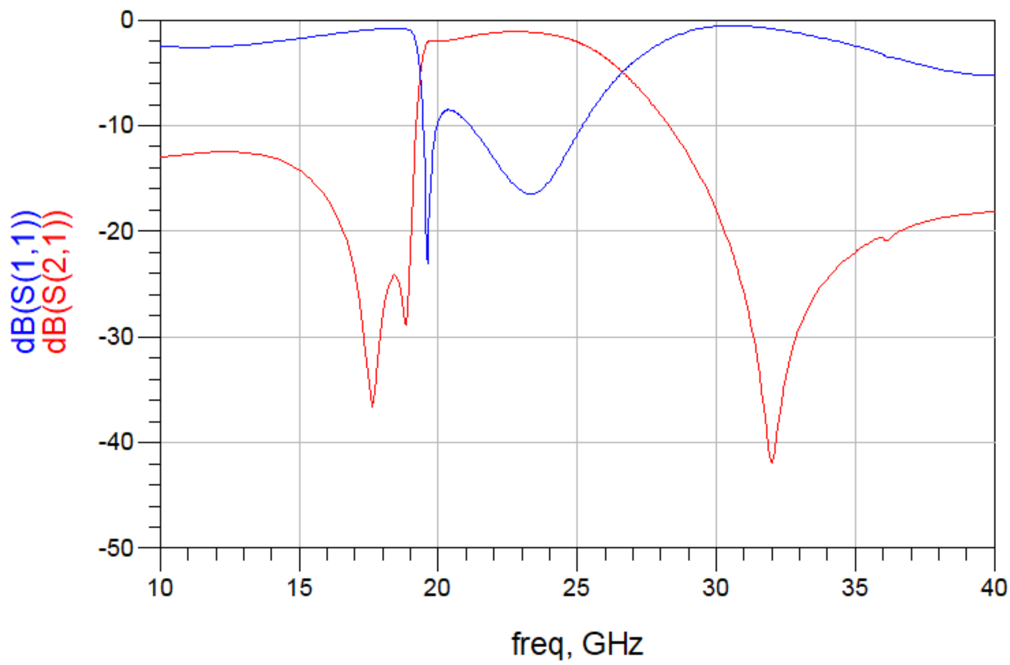

Figure 4.4: Return loss and insertion loss for design 2

Figure 4.4 indicates a bandwidth of 7.28 GHz with two resonance frequencies for the second configuration of two split-ring DGS Resonators. Return loss is greater than -10 dB. For a return loss of -23.05 dB and -16.51 dB, the resonance frequency is 19.62 GHz and 23.34 GHz.

Table 4.2 revealed and summarized the comparison of data collected and the predicted 26 GHz.

Table 4.2: Expected and simulated result of design 2 at 26 GHz

Parameters	**Expected result**	**Simulation result**
Return loss	More than -10 dB	-6.81 dB
Insertion loss	Less than -3 dB	-3.57 dB

Thus, based on the previous design, it shows as the number of DGS split-ring resonator increase, it produces more mode of resonance. In other words, the method of using DGS split-ring resonator will produce a multiple-mode resonator (MRR).

4.3 Tuning Parameter

The parameters of the simulated DGS were tuned in order to find the relationship with the result obtained.

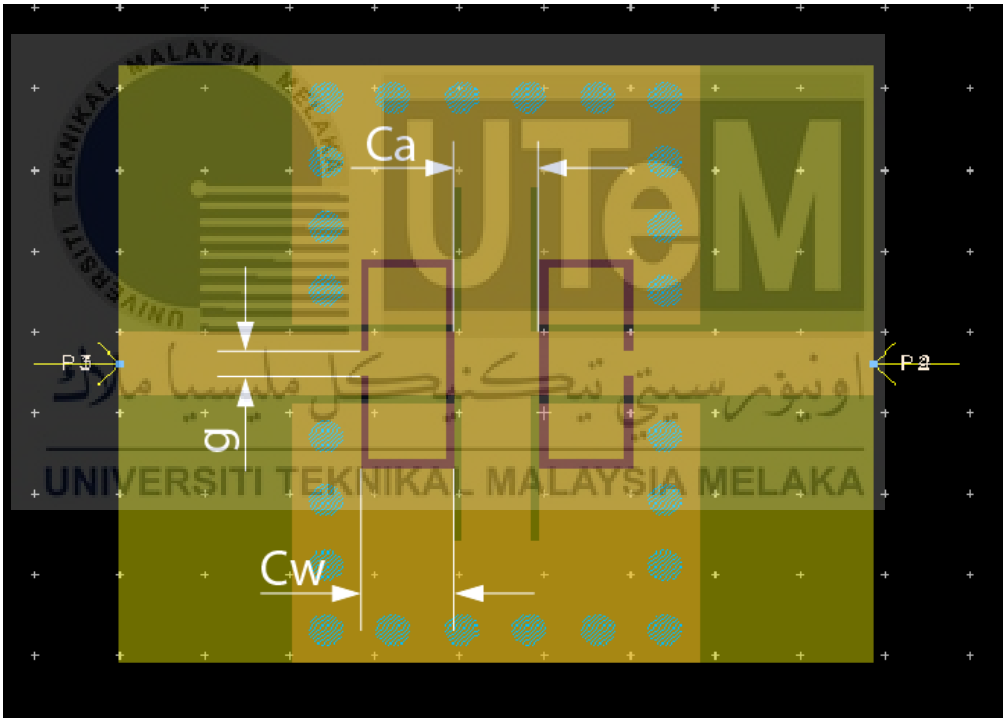

Figure 4.5: Two DGS split-ring resonator

Figure 4.7 shows the parameters that were used to tune in order to understand the relationship with the return loss and insertion loss result. The value of *Ca*, *g* and *Cw* were tuned to see the changes obtained in the simulated result. Below is the original value for each parameter before it is tuned.

Ca = 1.0 mm

g = 0.3 mm

Cw = 1.1 mm

4.3.1 Effect of Parameter *Ca*

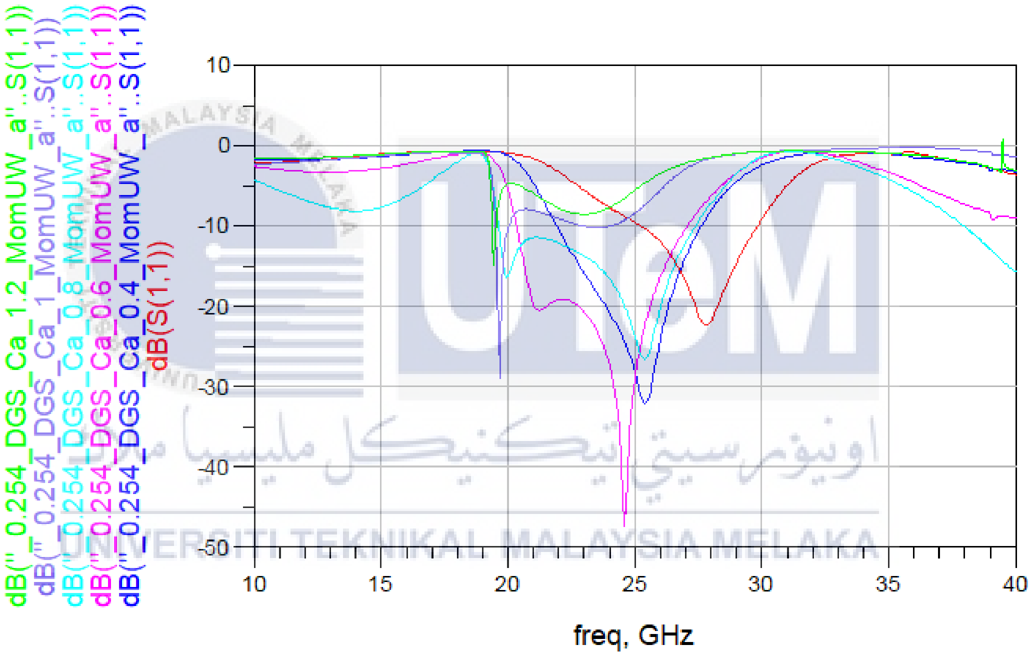

Figure 4.6: Changes in return loss due to changes in value of *Ca*

Figure 4.5 shows the effects on the simulated graph when parameters *Ca* was changed from 0.2 mm to 1.2 mm. By increasing *Ca*, the centre frequency down shifts to lower frequency. The center frequency is being modified step by step from 25.68 GHz to 21.18 GHz, with a small frequency of 4.5 GHz for *Ca* = 0.2 mm to 1.2 mm.

The figure above concludes that by changing parameter *Ca*, the centre frequency will be affected.

Table 4.4 displayed changes of return loss and insertion loss at 26GHz when the distance value was checked at 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm, 1.0 mm and 1.2 mm between two split-ring DGS.

Table 4.3: The changes for all two parameter at 26 GHz

***Ca*, mm**	**Insertion loss, dB**	**Return loss, dB**
0.2	-0.21	-11.92
0.4	-0.10	-24.23
0.6	-2.50	-16.41
0.8	-4.98	-20.26
1.0	-1.31	-5.57
1.2	-3.30	-3.47

4.3.2 Effect of Parameter g

The value for the length of split opening, g are 0.3 mm, 0.6 mm and 0.9 mm were tested, to study the frequency response.

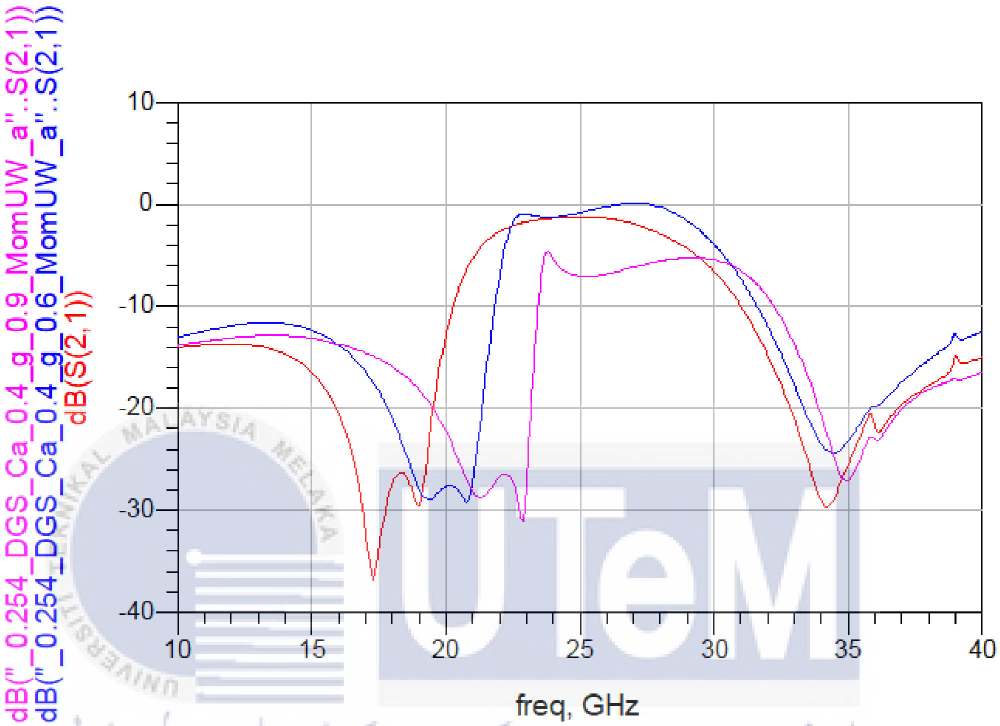

Figure 4.7: Changes in insertion loss due to changes in value of *g*

Figure 4.7 illustrate the changes of the location of the transmission zeros. By increasing *g* from 0.3 mm to 0.9 mm, the location of lower and upper transmission zeros shifts upwards. It is up shifted from 17.3 GHz to 21.3 GHz and 34.2 GHz to 34.9 GHz. This proves that by changing the value of *g*, the location of transmission zeros will be affected too.

The changes of the return loss and insertion loss were shown at 26 GHz and summarized in Table 4.4.

Table 4.4: The changes for all two parameter at 26 GHz

g, mm	Insertion loss, dB	Return loss, dB
0.3	-1.37	-20.21
0.6	-0.20	-6.93
0.9	-6.76	-6.05

4.3.3 Effect of Parameter *Cw*

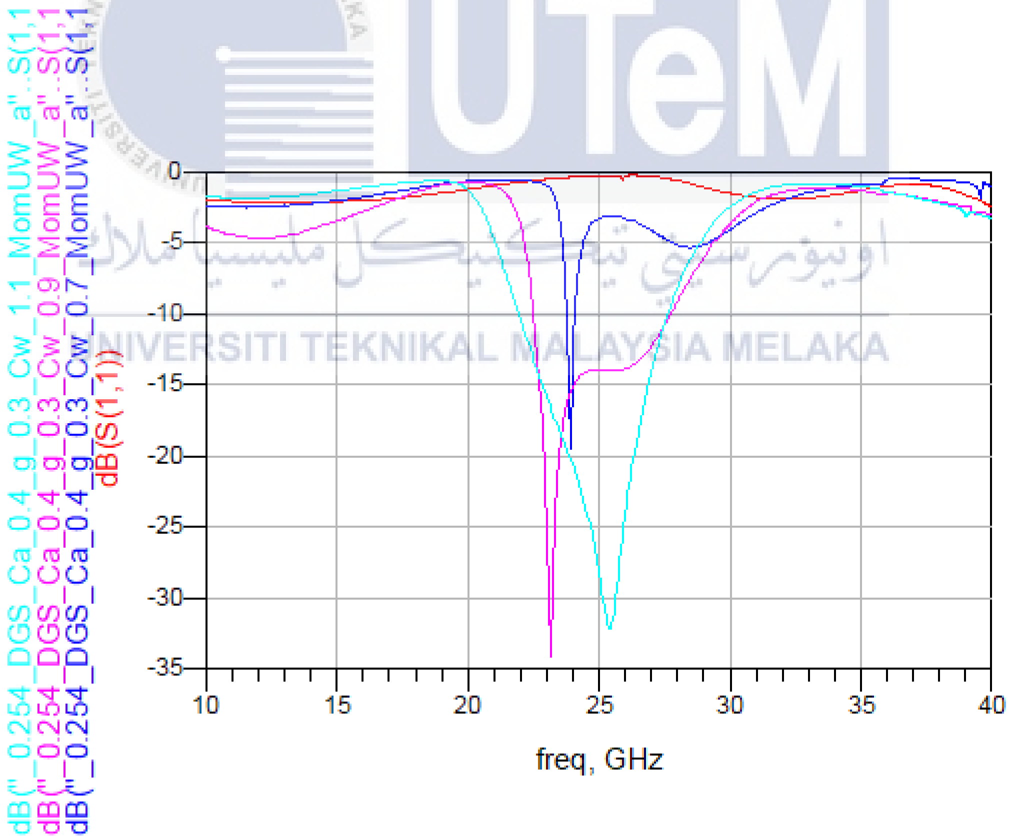

Figure 4.8: Changes in return loss due to changes in value of *Cw*

The values measured for *Cw* are 0.5 mm, 0.7 mm, 0.9 mm and 1.1 mm to examined the relationship between the width DGS split-ring resonator, *Cw* and frequency response. The effect of parameter *Cw* is shown in Figure 4.8. When the value of *Cw* is decreased beyond a certain limit, the band pass filtering characteristics loses. If the parameter *Cw* is decreased beyond 1.1 mm, the filter loses the attenuation pole. From the figure above, it can be concluded that, the band pass filtering characteristics is affected when the parameter *Cw* is changed.

In Table 4.5, the changes for all two parameters have been pointed out at the 26 GHz.

Table 4.5: The changes for all two parameter at 26 GHz

***Cw*, mm**	**Insertion loss, dB**	**Return loss, dB**
0.5	-28.23	-0.31
0.7	-2.99	-3.27
0.9	-0.41	-13.88
1.1	0.22	-18.26

4.4 The Best Design of Bandpass Filter

From the result that was obtained through parameter changes, it can be concluded as per table below.

Table 4.6: Summary of changes in tuning parameters

Parameter Changes	Results
Effect on *Ca*	Change in centre frequency
Effect on *g*	Change in location of transmission zeros
Effect on *Cw*	Change in bandwidth and bandpass characteristics

Based on the Table 4.6, it is understood that any changes in these three parameters will affect the results obtained in return loss and insertion loss. A change in *Ca* affects the centre frequency. Therefore, in order to tune for the range of 26 GHz, the length of *Ca* need to be changed further more. The other parameters were kept constant as it does not influence much in the objective of this project.

After analyzing all the parameters with a split-ring resonator, the final filter design comes with the bandpass, which can perform very well and achieve the requirement of 26 GHz. The parameters *Ca* = 0.4 mm, *g* = 0.3 mm and *Cw* = 1.1 mm were chosen to be the best outcome compared to others. The simulation result was shown in Figure 4.9 for bandpass filter with two DGS split-ring resonator.

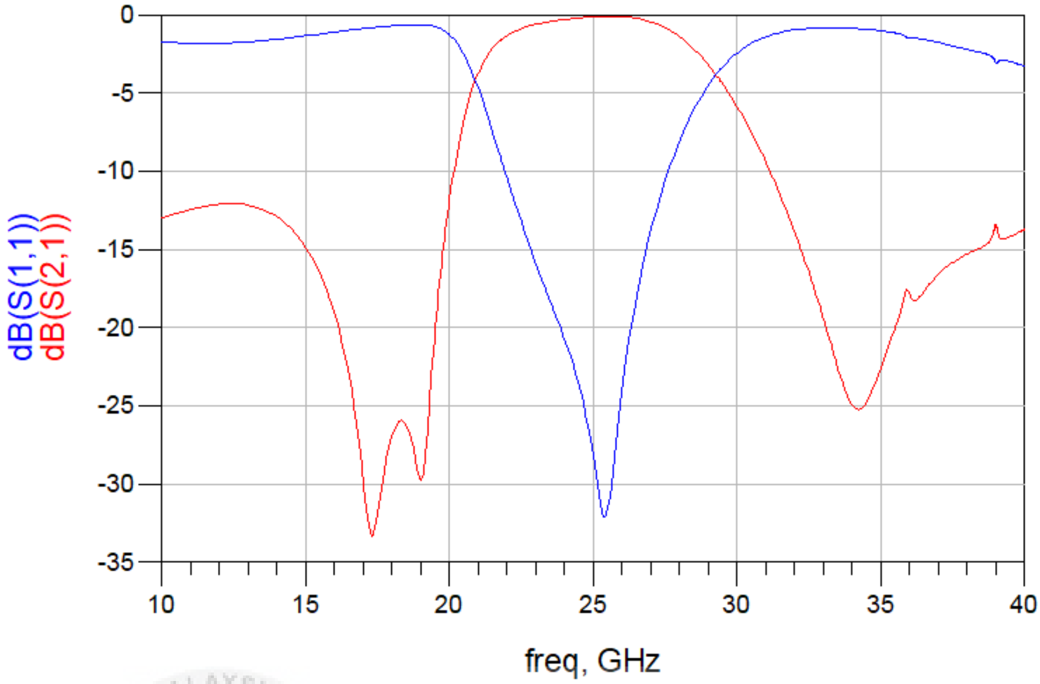

Figure 4.9: Parameter *Ca* = 0.4 mm, *g* = 0.3 mm and *Cw* = 1.1 mm

CHAPTER 5:

CONCLUSION AND FUTURE WORKS

5.1 Introduction

It summarizes in this chapter the work carried out in the previous chapter and suggests that this project should be improved.

5.2 Conclusion

Defected ground structure is the type of structure that is normally placed into the microstrip line ground plane. The Advanced Design System (ADS) software was developed and simulated for DGS structure layout and for EM simulation.

The effect can be used as the one chosen if it is suited for the filter at a certain frequency. Moreover, the specific DGS structure is selected in the center frequency according to the appropriate bandwidth (Q). The DGS will mitigate the specific frequency range, which enhances the Q factor and improves line transmission efficiency.

This project investigates DGS's parametric effect on the 26 GHz bandpass filters. DGS parameters are analyzed in three different terms, namely the distance between two DGS split-ring resonators, *Ca*, the length of the split-ring opening, *g* and the width of the DGS split-ring resonator, *Cw*. In this project, when changing the DGS parameter, the filter 's performance can be analyzed. The results were insertion loss and return loss. In addition, this filter can give a wide range of tuning by changing the parameters.

5.3 Future Works

In future, there will be some work to develop this project. To further expand and improve this work, the following could be considered in the future:

- Use a different type of structure to be placed in the ground plane, like the electromagnetic band gap or Substrate Integrate Waveguide.
- Use various substratum types. The DGS performance is shown differently with different dielectric values, thickness and tangent loss.

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