SUBSTRATE INTEGRATED WAVEGUIDE WITH DEFECTED GROUND STRUCTURE FOR MICROWAVE FILTER DESIGN

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Specially dedicated to
My beloved parents, brother, sister, friend who have encouraged, guided and inspired me throughout my journey of education in this lovely University of Technical Malaysia Melaka.

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ABSTRACT

This paper presents novel designs of Substrate Integrated Waveguide (SIW) with Defected Ground Structure (DGS) for Microwave Filter Design. The first design of SIW is half mode substrate integrated waveguide (HMSIW) that possesses highpass characteristic of SIW but the size is nearly half reduced. Then the second design is an asymmetric defected ground structure (ADGS), composed of two square headed slots connected with a rectangular slot transversely under a microstrip line. Then both design combined and become half mode substrate integrated waveguide with asymmetric defected ground structure for microwave filter design. Substrate integrated waveguide is a waveguide that synthesize inside a substrate and the propagating wave is delimit by arrays of via holes [1]. While the defected ground structure behaves like a resonator by etching the ground plane of the SIW cavity [2]. This technique provides an excellent avenue to design millimeter wave circuits such as filters, resonators and antenna [3]. It can be easily connected to other planar microwave transmission lines and devices. Its features a high-pass characteristic of conventional waveguide with a high Q factor characteristic and has an advantage of compactness, good suppression characteristic and low cost. All simulation has been done by using Advance Design System (ADS) Momentum. Fabricating the design and test it with the simulated result will validate the simulation result with the theory. Standard PCB used because the cost of fabrication is cheap and reproducible.

ABSTRAK

Kertas kerja ini membentangkan reka bentuk novel *Substrate Integrated Waveguide (SIW)* dengan *Defected Ground Structure (DGS),* rekabentuk penapis gelombang mikro. Reka bentuk pertama SIW adalah setengah saiz SIW asal iaitu *Half Mode SIW (HMSIW)* yang mempunyai ciri-ciri asal SIW tetapi saiz hampir separuh dikurangkan. Kemudian reka bentuk yang kedua ialah *Assymetric DGS (ADGS),* terdiri daripada dua slot segi empat yang bergabung dengan slot segiempat tepat melintang di bawah garis mikrostrip. Kemudian reka bentuk kedua-duanya digabungkan dan menjadi penapis gelombang mikro. HMSIW mengawal pergerakan gelombang di dalam substrat dan gelombang pembiakan membatasi oleh tatasusunan melalui lubang [1]. Teknik ini menyediakan satu laluan yang baik untuk mereka bentuk litar gelombang milimeter seperti penapis, resonator dan antena [3]. Ia boleh mudah disambungkan ke alatan penghantaran gelombang mikro dan peranti. Mempunyai ciri untuk pandu gelombang konvensional dengan ciri-ciri faktor Q tinggi dan mempunyai kelebihan kompak, penindasan ciri-ciri yang baik dan kos yang rendah. Kesemua simulasi telah dilakukan dengan menggunakan *Momentum* di dalam perisian *Advance Design System (ADS).* Mereka bentuk dan menguji keputusan simulasi akan mengesahkan hasil simulasi dengan teori.

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SIW	-	Substrate Integrated Waveguide
HMSIW	-	Half Mode Substrate Integrated Waveguide
DGS	-	Defected Ground Structure
AGDS	-	Asymmetric Defected Ground Structure
ADS	-	Advance Design System
HFSS	-	High Frequency Simulation System

CHAPTER 1

INTRODUCTION

RF, microwave, and millimeter-wave filters have been subject to intensive studies and extensive developments for decades. However, conventional technologies for designing high-quality passive components, including a metal rectangular waveguide or microstrip line, are either too expensive or not able to provide required performances. As wireless and mobile communication services start expanding, the compact and high-quality RF filters design has been challenged. Waveguide is a good choice to get a high power capability and low loss, but the only things that make people reconsider it because it comes with a price. Furthermore, it is bulky and difficult to integrate with other microwave device. While in the other hands, microstrip (TEM) - based devices can easily integrate with other microwave transmission lines and devices.

In 2001, Wu [4] proposed a new technique for high density integration microwave and milimeter-wave system. In this technique, non-radiative dielectric waveguide, slab waveguides or rectangular waveguide are synthesized inside a dielectric substrate, using rows of dielectric or metal holes. The idea to integrate a rectangular waveguide inside a dielectric substrate with two rows of metal post was first proposed in [5].

1.1 Objective of the Project

The objective of this project is:

i. To produce high performance bandpass filter at the end of the project.

ii. To design and develop a bandpass filter base on a SIW with DGS with a bandwidth 4 GHz – 12 GHz by using FR-4 substrate.

1.2 Problems Statement

A low cost manufacturing and design in microwave subsystem is the most highlighted issues today. The demand for high performance (high Q factor), low loss, small volume, and excellent reproducibility microwave filter is always high. The conventional technologies for designing high-quality passive components, including a metal rectangular waveguide or microstrip line, are either too expensive or not able to provide required performances.

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1.3 Scope of the Project

The scope of this project is to analyze, design, and fabricate a Substrate Integrated Waveguide (SIW) with Defected Ground Structure (DGS) bandpass filter. This filter design can be achieves by understanding the basic concepts of bandpass filter designs. To apply SIW technology in bandpass filter, the concept of SIW must be understood. The SIW replace the waveguide walls with a series of metallic via holes through the substrate to achieve the same effect of metallic walls. This filter will be fabricated only by using those techniques only, without any active component.

The fabrication process needs to be done carefully in order to minimize the difference between simulation and measurement results to produce high performance bandpass filter. A part from it, types of board have been chosen is the one of factor that affected the results in terms of performance and reproducibility. Measuring the performance of the substrate integrated waveguide and defected ground structure by using software Advance design system (ADS) in collection of data collection, testing, and performance analysis. Fabricate and compare result with simulation.

The substrate used must be low cost, small in size and has a good reproducibility. The proposed design of the ADGS and HMSIW only will be used in the making of this project.

CHAPTER 2

BACKGROUND

2.1 Bandpass Filter

Basically, an electrical filter is a circuit that can be designed to modify, reshape or reject all unwanted frequencies of an electrical signal and accept or pass only those signals wanted by the circuit's designer. In other words they "filter-out" unwanted signals and an ideal filter will separate and pass sinusoidal input signals based upon their frequency.

Bandpass Filter passes frequencies within certain range and rejects (attenuates) frequencies outside that range. There are applications where a particular band, or spread, or frequencies need to be filtered from a wider range of mixed signals. Filter circuits can be designed to accomplish this task by combining the properties of low-pass and high-pass into a single filter. Bandpass filters are used primarily in wireless transmitters and receivers. The main function of such a filter in a transmitter is to limit the bandwidth of the output signal to the minimum necessary to convey data at the desired speed and in the desired form. In a receiver, a bandpass filter allows signals within a selected range of frequencies to be heard or decoded, while preventing signals at unwanted frequencies from getting through.

A lowpass filter is an electronic filter that passes low-frequency signals but attenuates (reduces the amplitude of) signals with frequencies higher than the cutoff frequency. While a highpass filter is a vice-versa from lowpass filter. We can see the different of the characteristic of all 4 filters in the figure 2.1 below.

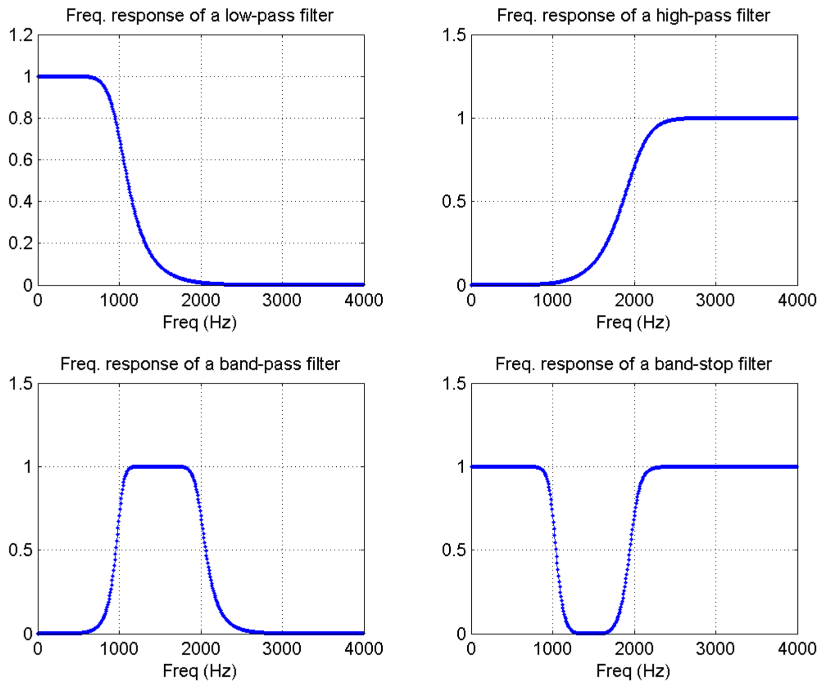


Figure 2.1: Frequency Response of Lowpass, Highpass, Bandpass, and Bandstop Filter.

All of this filter type use active component like capacitor, inductor and resistor. It make the filter became large. The microwave filter that were stated in this project was a passive type filter which is consist only a transmission line and a ground structure, no active component used.

2.2 Fundamentals of the Substrate Integrated Waveguide

2.2.1 Introduction

A main function of a waveguide is for guide or directs the propagation of an electromagnetic wave by coop in the wave energy. A regular waveguide normally consist of hollow metallic pipes with uniform cross section.

There are differences between waveguide and TEM transmission lines. A transmission line has a minimum of two conductors and supports TE mode of propagation, which has a zero cut-off frequency. There is no minimum size for the cross section of a TEM line in order for signal propagation to occur other than that determinate by dissipation losses [1].

2.2.2 SIW vs. conventional rectangular waveguide

In millimetre-wave applications, the conventional rectangular waveguide is widely used as its propagation loss is lower than other recent technologies. However, it has a bulky, three-dimensional configuration that limits integration with other circuits. SIW technology is an attractive alternative as the structure has a low profile with a low propagation loss, and mass production is possible using batch fabrication techniques. Whilst SIW structures have been used to design low-cost high-Q passive components such as resonators, filters, couplers, power dividers and antennas, there are still a few issues to be solved to achieve complete SIW system integration before moving to commercial production [27].

2.2.3 TE Mode

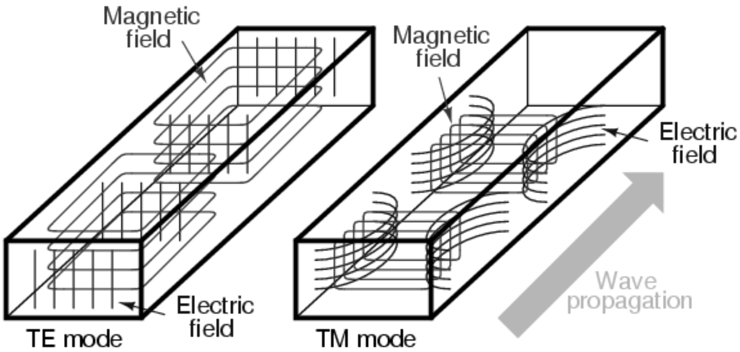
All electromagnetic waves consist of electric and magnetic fields propagating in the same direction of travel, but perpendicular to each other. Along the length of a normal transmission line, both electric and magnetic fields are perpendicular (transverse) to the direction of wave travel. Transverse modes occur in radio waves and microwaves confined to a waveguide. Transverse modes occur because of boundary conditions imposed on the wave by the waveguide. For example, a radio wave in a hollow metal waveguide must have zero tangential electric field amplitude at the walls of the waveguide, so the transverse pattern of the electric field of waves is restricted to those that fit between the walls. For this reason, the modes supported by a waveguide are quantized. Transverse modes are classified into different types:

I. TE modes (Transverse Electric) no electric field in the direction of propagation.

II. TM modes (Transverse Magnetic) no magnetic field in the direction of propagation.

III. TEM modes (Transverse Electro Magnetic) neither electric nor magnetic field in the direction of propagation.

IV. Hybrid modes nonzero electric and magnetic fields in the direction of propagation.



Magnetic flux lines appear as continuous loops
Electric flux lines appear with beginning and end points

Figure 2.2: Electric and Magnetic Fields for the TE and TM Mode In A Rectangular Waveguide [5].

Hunter [5] explains the analysis of TE modes; it also shows the derivation of the *m* and *n* terms in TE modes, called TE_{mn} modes, as well as the lowest cutoff mode for TE, TE_{10}, as shown in figure 2.3.

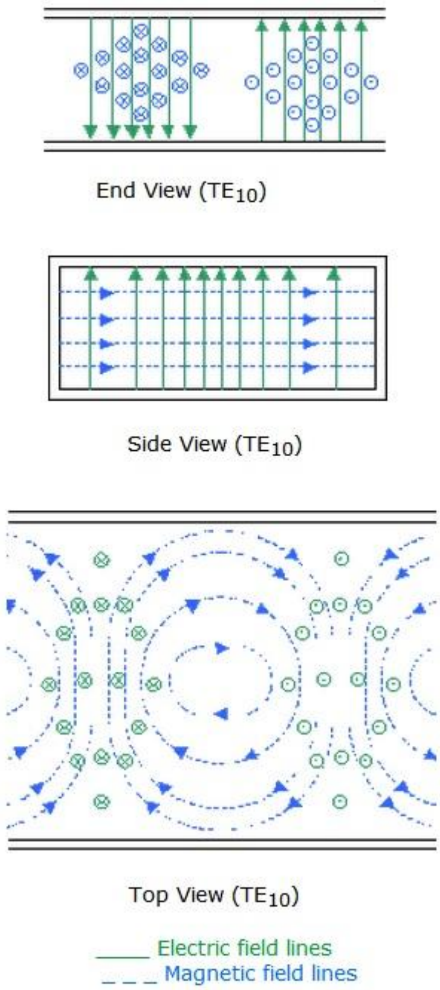


Figure 2.3: Electric and Magnetic Fields For The TE_{10} Mode In Waveguide [5].

2.2.4 Substrate Integrated Waveguide (SIW)

Substrate integrated waveguide is a new form of transmission line that have been subject to intensive studies and extensive developments for decades by some researchers. In high frequency applications, microstrip devices are not efficient, and because wavelength at high frequencies are small, microstrip device manufacturing requires very tight tolerances. At high frequencies waveguide devices are preferred; however their manufacturing process was difficult. Therefore a new concept emerged: substrate integrated waveguide. SIW is a transition between microstrip and dielectric-filled waveguide (DFW). Dielectric filled waveguide is converted to substrate integrated waveguide (SIW) by the help of vias for the side walls of the waveguide.

The definition of the substrate integrated waveguides are a rectangular waveguides formed by two solid conductor planes, separated by a dielectric substrate, with conductor sidewalls emulated by rows of metalized through-plated vias as shown in the figure 2.3 below. The SIW is a waveguide synthesize inside a substrate and the propagating wave is delimited by arrays of via holes [1].

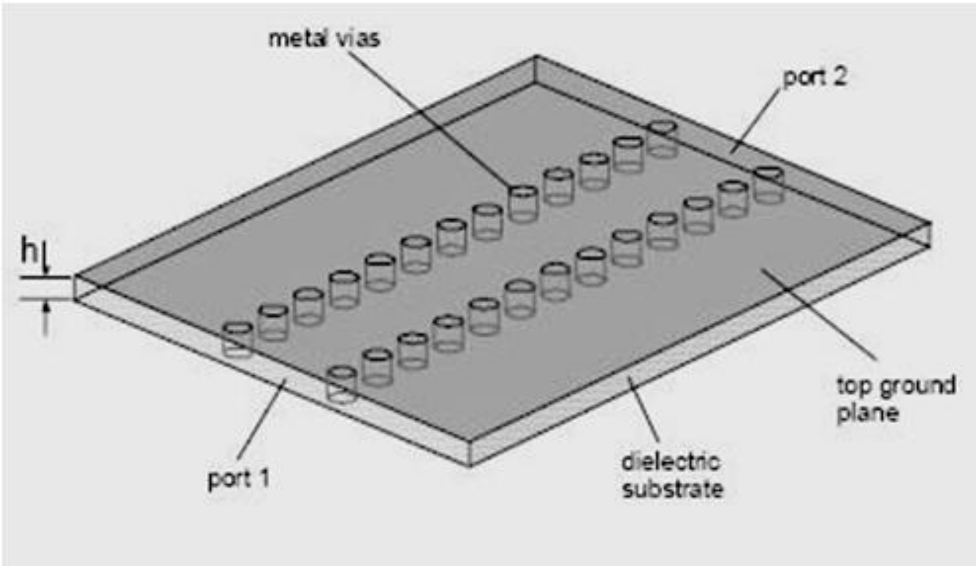


Figure 2.4: Modelled SIW Structure.

The substrate integrated waveguide is made of a periodic via holes structure. A SIW preserves the advantages of the conventional rectangular waveguide, like its Q factor and high power conducting capability characteristic [1]. In figure 2.4, *h* is the substrate height and *w* is the distance between two parallel arrays of via holes. It is the propagation constant of the TE_{10}. *d* is the diameter of the via holes, while *p* is the space between two via hole, from centre to centre.