DESIGN AND DEVELOPMENT OF SUBSTRATE INTEGRATED WAVEGUIDE (SIW) BANDPASS FILTER

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“This is hereby declared that all materials in this thesis are my own work and all the materials that have been taken from some references have been clearly acknowledged in this thesis.”

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ABSTRACT

A substrate integrated waveguide (SIW) bandpass filter is designed in order to obtain the required parameter responses from 8.0 GHz to 10.5 GHz by using 3D tool software based on the method integrate rectangular waveguide (RWG) due of simplicity and easier to analyze.

FR-4 board is used with the specified information include the dielectric constant of substrate ($\epsilon_r = 4.7$), the resonant frequency, f_r = 9.0GHz and substrate height (h=1.6mm).

The main parameters concerned are reflection loss (S_{11}) and insertion loss (S_{21}). A prototype of the SIW bandpass filter has been built and tested by Vector Network Analyzer (VNA). Then the measurement result obtained would be compared to the simulation result. The difference between both of the results would be discussed in the result section.

ABSTRAK

Sebuah substrat waveguide bersepadu (SIW) bandpass penapis dirancang dalam rangka untuk mendapatkan respon parameter yang diperlukan dari 8.0 GHz sampai 10.5 GHz dengan menggunakan software 3D tool berdasarkan cara mengintegrasikan waveguide persegi panjang (rwg) kerana kesederhanaan dan lebih mudah untuk menganalisa.

FR-4. Papan ini diketahui memiliki nilai pemalar dielektrik ($\epsilon_r = 4.7$), frekuensi resonan adalah (f_r = 9.0GHz) dan ketinggian papan FR-4 ialah (h=1.6mm).

Parameter yang akan diuji dalam kajian kali ini adalah nilai return loss, (S_{11}) dan insertion loss (S_{21}). Sebuah prototaip dari bandpass penapis SIW telah dibina dan diuji oleh Vector Network Analyzer (VNA). Seterusnya nilai-nilai dari proses pengukuran dibandingkan dengan nilai dari proses simulasi. Sekiranya terdapat sebarang perubahan nilai antara kedua-dua proses, langkah-langah mengurangkan berbezaan tersebut akan diambil dan akan di bincangkan di bahagian keputusan ujikaji.

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ABBREVIATION

VSWR	-	Voltage Standing Wave Ratio
SIW	-	Substrate Integrated Waveguide
RWG	-	Rectangular Waveguide
CST	-	*Computer Simulation Technology*
HFSS	-	High Frequency Structure Simulator
VNA	-	Vector Network Analyzer
SMA	-	Sub-Miniature Version A
TE	-	Transverse Electric
TM	-	Transverse Magnetic
TEM	-	Transverse ElectroMagnetic
MIC	-	Microwave Integrated Circuits
Mbps	-	Mega bit per second
GHz	-	Giga Hertz
dB	-	Decibel
IEEE	-	Institute of Electrical and Electronic Engineering
PCB	-	printed circuit board

CHAPTER 1

INTRODUCTION

1.1 Introduction

Recently, the development of wireless communication systems brings the fourth generation system with over 100 Mbps data rate from the third generation mainly alert on the voice and image service. In the fourth generation systems, the high-speed data transfer for various multimedia services needs the wideband available in millimeter-wave. In order to achieve the implementation of transceiver operating at millimeter-wave, it costs many efforts and time for the development of millimeter-wave devices. In addition, the system working at millimeter wave requires low-profile, compact, low loss devices, and highly advanced packaging technology.

Over recent years, the interest in microwave techniques for communication systems has grown tremendously and also the development and the performance of microwave active and passive circuits for wireless technologies has become extremely advanced. Microwave amplifiers have become one of the most critical active circuits that employed in the system applications. Broadband amplifiers with good performance have been successfully realized in the past 3 decade in hybrid and monolithic technologies. Therefore the wide bandwidths amplifiers have been firmly establish in the fields of microwave, optical communication, instrumentation and Electronic Wars (EW) [1].

A new concept Substrate Integrated Waveguide (SIW) has already attracted much interest in the design of microwave and millimeter-wave integrated circuits. The SIW is synthesized by placing two rows of metallic via-holes in a substrate. The field distribution in an SIW is similar to that in a conventional rectangular waveguide. Hence, it takes the advantages of low cost, high Q-factor etc., and can easily be integrated into microwave and millimeter wave integrated circuits [2].

1.2 Problem Statement

RWG provide very high Q factor and also high in performance filter but it is high cost and difficult to connect between planar and non-planar structure. SIW provide an alternative to Rectangular Waveguide system. The main advantages are minimum loses, less expensive and easy to make connection to other planar devices. Thereby, focus of this characteristics project is as follows:

i. The each length of x, y, z axes are reduced in proportion to root square of employed substrate dielectric constant.
ii. Side walls are realized by placing two series array of via.
iii. Bandwidth : 1GHz
iv. Frequency Range : 8GHz – 10.5GHz
v. Pass Band : 8.5GHz – 9.5GHz
vi. Stop band insertion loss -25dBm at 10.5GHz & -40dBm at 8GHz
vii. Return loss : 20dB

1.3 Objectives

The objectives of this project are:

- To integrate a Rectangular Waveguide (RWG) into substrate.

- To design SIW base on the filter application.
- To design a SIW bandpass filter that operates for X-band frequency with 1GHz bandwidth and insertion loss below 0.5dB.

1.4 Scope of Work

The scope of this work is to design and develop a SIW bandpass filter. The following lists of objectives must be completed with this in mind:

a) The scopes of this project are making literature review which will survey on the journal, magazine, conference paper or textbook.
b) During literature review all the information such as the theory and design of microwave filter will explore.
c) Calculation based on Chebyshev response will be made.
d) The preliminary work will use 3D simulation tools and the result will compared with the theoretical result.
e) Finally, fabricate and make measurement for analysis result on fabricate device.

1.5 Methodology

This project will start with background study of SIW basic concept, via holes design and transition for input and output port of SIW concept. All was done by guidance by reference the journal, articles and books that related to this project either in website or any materials. After understand the concepts which is related, the study about 3D tool software been done. In this project, designing and simulation any circuit are done by using HFSS and CST software as 3D simulation tools software. Then the calculation of circular post hole with using the appropriate formulas needs to be done. Next, simulate single stage amplifier design by using CAD tool. After all the designing process is done, the circuit then fabricated with using PCB etching process. Lastly, testing and measure meet of the prototype is done by using the network analyzer.

CHAPTER 2

LITERATURE REVIEW

2.1 Substrate Integrated Waveguide Bandpass Filter

The Substrate Integrated Waveguide (SIW) features high-pass characteristics it was established in that a TE_{10} like mode in the SIW has spreading characteristics that are almost identical with the mode of a dielectric filled rectangular waveguide with an equivalent width. SIWs can be realized with a linear array of metalized via holes or metal posts entrenched in the similar substrate used for the planar circuit [3]. Several transition structures have been proposed to excite the dielectric guide. In these structures, the rectangular wave guide and the planar circuits (such as microstrip line or coplanar waveguide) are built onto the same substrate and the transition is formed with a simple EM matching geometry between both structures [4].

Figure 2.1 shows the structure of an SIW, which is composed of the top and bottom metal planes of a substrate and two parallel arrays of via holes and also known as via fence in the substrate. The via holes must be shorted to both metal planes to provide vertical current paths, as shown in Figure 2.2, otherwise the propagation characteristics of SIW will be significantly degraded. Since the vertical metal walls are replaced by via fences for the SIW structures, propagating modes of SIW are very close to, but not exactly the same as, those of the rectangular waveguides. This can be verified by checking the modal surface current patterns.

Only patterns with solely vertical current distributed on the side wall survive in SIWs. For example, Figure 2.2 shows the TE_{10} mode surface current distribution of a rectangular waveguide. The current path will not be cut by the via fences, therefore TE_{10} mode can be supported in an SIW.

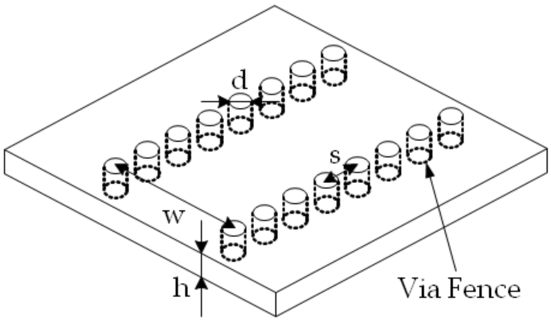

Figure 2.1: Structure of SIW [4]

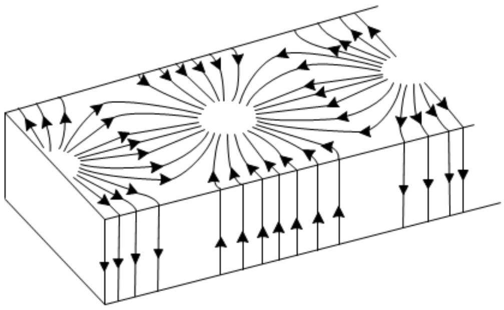

Figure 2.2: Surface Current for TE10 Mode [4]

In this project, a lossy commercial dielectric substrate was preferred in which SIW microwave components are developed. In order to demonstrate the potentials of the FR-4 dielectric substrate using a low-cost printed circuit board fabrication technique, a substrate integrated waveguide filter pass band at 8.5 GHz to 9.5 GHz was designed, simulated, fabricated and characterized experimentally.

Substrate integrated waveguides (SIW), which succeed to the advantages from traditional rectangular waveguides without their bulky configuration, aroused recently in low loss and high power planar applications. However, systems with rectangular waveguides are often large and heavy. Transitions between rectangular waveguides and planar circuits cannot be held without extra supporting structures. Recently, SIWs were planned as a replacement for miniaturized and light weighted applications. SIW, as its name, can be easily integrated into the substrates of planar circuits, such as printed circuit boards (PCB) with their standard fabrication processes. Compared with conventional rectangular waveguides, SIW has the advantage of low-cost, compact, and easy-integration with planar circuits. Although their quality factors cannot compete with those of traditional rectangular waveguides, they are more suitable in system integration.

2.2 Bandpass Filter

A microwave filter is a device that removes from a signal some unnecessary component or feature. Filtering is a class of signal processing, the defining feature of filters being the complete or partial suppression of some aspect of the signal. Most often, this means removing some frequencies and not others in order to suppress interfering signals and reduce background noise.

A band-pass filter is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range. These filters can also be created by combining a low-pass filter with a high-pass filter. An ideal bandpass filter would have a completely flat passband for example with no gain or attenuation throughout and would completely attenuate all frequencies outside the passband. Additionally, the transition out of the passband would be instantaneous in frequency. The bandwidth of the filter is simply the difference between the upper and lower cutoff frequencies.

2.3 Lumped Element Filter

Lumped elements have been in use in microwave circuits for more than 30 years. This topic deal exclusively with these circuits where lumped elements, in addition to size reduction, it also provide distinct benefits in terms of bandwidth and electrical performance on that filter. Such circuits are classified into two categories passive circuits and control circuits.

The basic theory of filters is based on a combination of lumped elements such as inductors and capacitors as shown in Figure 2.3. This configuration is for the lowpass filter, and can develop a prototype design with added the input–output impedance and a cutoff frequency. From here, it is simply a matter of scaling the g values for various elements to obtain the desired frequency response and insertion loss. Table 2.1 shows the value of g for Chebyshev response. In addition, other filter types such as highpass, bandpass, and band-stop merely require a transformation in addition to the scaling to obtain the desired characteristics. [12]

Table 2.1: Element Value for Equal-Ripple Low-Pass Filter Prototypes (g0 = 1, ω_c = 1, N =1 to 10, 0.5dB) [13]

0.5dB Ripple							
N	g1	g2	g3	g4	g5	g6	g7
1	0.6986	1.0000					
2	1.4029	0.7071	1.9841				
3	1.5963	1.0967	1.5963	1.0000			
4	1.6703	1.1926	2.3661	0.8419	1.9841		
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000	
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841
7	1.7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372
8	1.7451	1.2647	2.6564	1.3590	2.6964	1.3389	2.5093
9	1.7504	1.2690	2.6678	1.3673	2.7239	1.3673	2.6678
10	1.7543	1.2721	2.6754	1.3725	2.7392	1.3806	2.7231

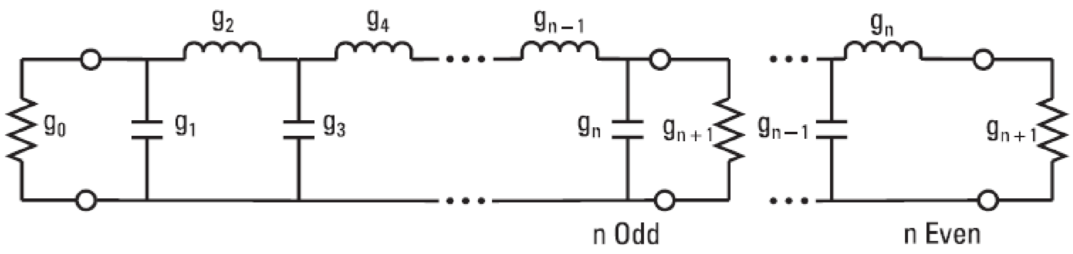

Figure 2.3: Low Pass Prototype [12]

When discuss about lumped elements, there are two broad main categories of inductors and capacitors. The first is surface mount parts, which are suitable for use on a microwave printed circuit board and another category is thin-film lumped elements, which are used on microwave integrated circuits (MICs) on alumina or other hard substrates, as well as in MMIC implementations. Surface mount capacitors can be useful up to Ku-band frequency, while the inductors generally have self-resonances below X-band frequency. Thin-film capacitors are used routinely up to 100 GHz in MMICs. Lumped inductors on thin-films and MMICs take the shape of spiral inductors, and are limited to frequencies Ku-band and lower.

Used in band-pass filters, lumped elements can really help designs. Not only are the resulting filters compact, but they have no natural reentrant modes that will encounter with other filter technologies such as planar resonator structures.

In each resonator of a lumped-element band-pass filter will find both elements, which are an inductor and a capacitor. The series elements, the L-C are combined in series. In the shunt elements, the LC is combined in parallel. Screw this up and will create a band-stop filter instead of a band-pass filter.

2.4 Chebyshev Response

The Chebyshev (or Chevyshev, Tschebychev, Tschebyscheff or Tchevysheff, translate from Russian term) filter has a smaller transition region than the same order Butterworth filter, at the expense of ripples in its pass band. This filter gets its name because the Chebyshev filter minimizes the height of the maximum ripple, which is the Chebyshev criterion. Chebyshev filters have 0 dB relative attenuation at dc. Odd order filters have an attenuation band that extends from 0 dB to the ripple value. Even order filters have a gain equal to the pass band ripple. The number of cycles of ripple in the pass band is equal to the order of the filter [8].

Chebyshev filters are analog or digital filters having a steeper roll-off and more passband ripple (type I) or stopband ripple (type II) than Butterworth filters. Chebyshev filters have the property that they minimize the error between the idealized and the actual filter characteristic over the range of the filter, but with ripples in the passband. This type of filter is named in honor of Pafnuty Chebyshev because their mathematical characteristics are derived from Chebyshev polynomials. Because of the passband ripple inherent in Chebyshev filters, filters which have a smoother response in the passband but a more irregular response in the stopband are preferred for some applications. Comparing Figures 2.4 below, it is easy to see the trade-offs in the response types. Moving from Bessel through Butterworth to Chebyshev, notice that the amplitude discrimination improves as the transient behavior gets progressively poorer [8].

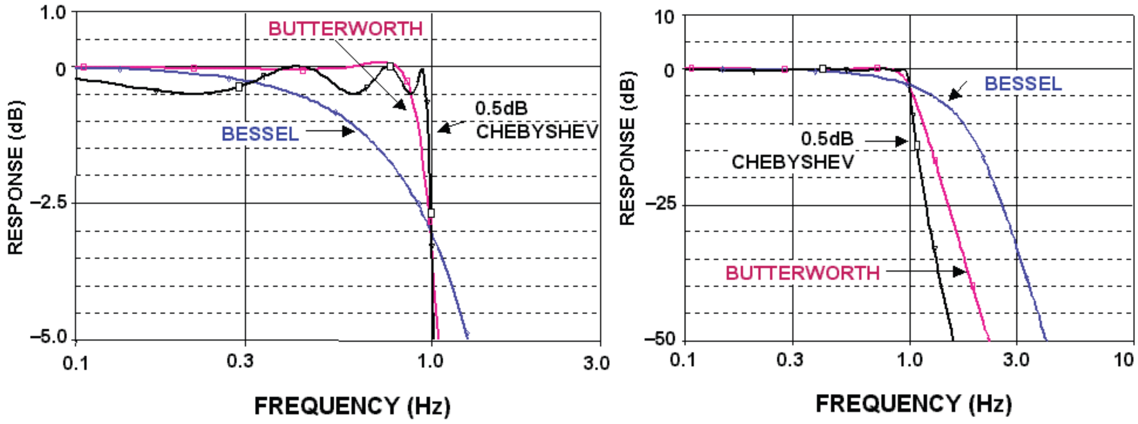

Figure 2.4: Comparison of Amplitude Response of Bessel, Butterworth, and Chebyshev Filters [8]