UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF A COMPACT AND VIALESS MICROSTRIP ULTRA-WIDEBAND BANDPASS FILTER

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

In the name of Allah, Most Gracious and Most Merciful

For the Sake of Islam

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Doctor of Philosophy

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In radio frequency and microwave systems, filters are the most essential component to select the required signals. They are built together with other components such as mixers, amplifiers, oscillators and switches. Filters work by blocking the unwanted signals and allowing the desired signals through them before feeding it into other components or devices. In the latest interest and future radio frequency and microwave high speed communication technology like Ultra-Wideband (UWB), a bandpass filter with large bandwidth (> 500 MHz) is required to fulfill the specifications. This is due to the UWB format signal which uses very short time pulse wave within 1.0 ns to 0.1 ns.

This thesis presents theories, methods, parameters, simulations and measurements of designed and development of bandpass filters to support UWB communication systems. There are four types of bandpass filters which are designed and developed to operate within 3.1 GHz to 10.6 GHz to support the UWB frequency range specification.

Initially, the designed model is derived from J-inverter which it is a transformation of low pass to bandpass Chebyshev filter. Type of response is chebyshev since it is able to perform an equal-ripple return loss response in the whole passband. The equal-ripple return loss response can keep the insertion loss almost flat in the whole pass band and sharp-out-of-band rejection response.

In the thesis, bandpass filters are designed and developed based on five poles quarter-wavelength short-circuited stubs model. The model is theoretically capable to expand the frequency bandwidth by tuning its h (interior admittance level of the stubs) factor. The related mathematical equations are applied into mathematical software to speed up the optimization of h factor and obtain the required admittance level for stubs and transmission lines.

The first bandpass filter has successfully shown the expansion in frequency bandwidth to support Ultra-wideband specifications. The filter uses five vias to short-circuit stubs to the ground. Stubs, transmission lines admittance and h are tuned slightly to expand the fractional bandwidth (FBW) more than 100 %. The measured scattering parameters are $|S_{21}|$ = 1.27 dB and S_{11} = -7.8 dB respectively. The second bandpass filter is improved by reducing the short-circuited via elements. First and second stubs are shared on the first via while fourth and fifth stubs share on the third via. Only third stub has its own via thus creating new transformation filter shape nicknamed as "Butterfly". This new shaped has 109 % of measured fractional bandwidth, lower scattering parameters $|S_{21}|$ which is below than 0.85 dB and S_{11} is better than -11.6 dB. Besides, it also reduces the number of via insertion in microstrip fabrication process.

The third bandpass filter has totally eliminates vias and thus simplifies the microstrip fabrication process. Vias are replaced by microstrip patched capacitors. At microwave frequencies, these capacitors are parasitic elements and their parameters contribute to the successful performance in S-parameters measurement. The measured scattering parameters $|S_{21}|$ and S_{11} are better than 1 dB and -16.9 dB respectively. The fourth filter is improved in terms of scale dimension and group delay compares to the third filter. The structure is via-less and the filter uses less microstrip patch capacitors to perform compact size with "Butterfly" shape. By reducing microstrip patched capacitors, the filter shows better S-parameters measurements in the UWB passband with the lowest scattering parameters $|S_{21}|$ 0.53 dB and S_{11} of -14.8 dB. The group delay varies minimum within 0.47 ns in the whole UWB pass band.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Kedoktoran

REKACIPTA DAN PEMBANGUNAN MIKROSTRIP PADAT DAN TANPA PIN ALIRAN ELEKTRIK PENAPIS ISYARAT JALUR LEBAR

Oleh

MOHAMMAD SHAHRAZEL BIN RAZALLI

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Di dalam sistem radio frekuensi dan mikrogelombang, penapis-penapis isyarat merupakan komponen yang paling utama untuk memilih isyarat-isyarat yang diperlukan. Mereka di bina bersama dengan komponen-komponen lain seperti pencampur isyarat, penguat isyarat, pengayun gelombang dan suis. Penapis bekerja dengan cara menahan isyarat-isyarat yang tak diperlukan dan melepaskan yang diperlukan melaluinya sebelum disalurkan ke komponen-komponen atau alat-alatan lain. Di dalam kepentingan terkini teknologi perhubungan radio frekuensi dan mikrogelombang seperti perhubungan Jalur Lebar, penapis jalur lebar dengan ciri keupayaan jaluran lebih besar daripada 500 MHz amat diperlukan untuk memenuhi perincian-perincian tersebut. Ini kerana sifat Jalur Lebar menggunakan masa isyarat yang amat pendek di dalam lingkungan 1.0 ns hingga 0.1 ns.

Tesis ini mempersembahkan beberapa teori, kaedah, piawaian, simulasi dan pengukuran dalam merekacipta dan membangunkan penapis perhubungan untuk menyokong sistem

Jalur Lebar. Terdapat empat jenis penapis Jalur Lebar yang direkacipta dan dibangunkan bekerja di dalam julat frekuensi 3.1 GHz hingga 10.6 GHz untuk menyokong perincian Jalur Lebar di dalam tesis ini. Pada permulaannya, mereka direkacipta dengan mengolah teori songsang-J yang diubahsuai dari penapis isyarat jalur rendah Chebyshev. Jenis keluaran isyarat adalah Chebyshev, kerana ia berkeupayaan untuk menghasilkan kehilangan pantulan yang sama-rata dikeseluruhan jaluran. Ke-samarataan kehilangan pantulan boleh mengawal kehilangan penyerapan yang rendah dikeseluruhan jaluran dan kejituan pemotongan di dalam penapisan isyarat.

Di dalam tesis ini, empat jenis penapis isyarat jalur lebar dicipta berlandaskan model lima kutub suku jarak gelombang jejari litar pintas. Model ini secara teorinya, berkeupayaan untuk mengembangkan jaluran dengan cara menala faktor h (nilai rintangan selari dalaman jejari litar pintas). Persamaan matematik yang berkaitan dengannya diolah dengan menggunakan siri perisian kiraan matematik untuk mempercepatkan penalaan faktor h untuk memperolehi nilai rintangan selari jejari dan penghubung garisannya.

Penapis isyarat jalur lebar yang pertama telah berjaya menunjukkan pengembangan jaluran frekuensi untuk menyokong perincian Jalur Lebar. Penapis isyarat ini menggunakan lima batang pin aliran elektrik bertujuan untuk menghubungkan jejari penapis isyarat ke kutub bumi. Kesemua rintangan selari jejari, penghubung garisannya dan nilai faktor h ditala sedikit demi sedikit untuk mengembangkan keluaran pecahan frekuensi jaluran melebihi 100%. Pengukuran had keselerakan parameter-parameter $|S_{21}|$ dan S_{11} adalah bersamaan dengan 1.27 dB dan -7.8 dB secara relatifnya.

Penapis isyarat yang kedua, ditingkatkan dengan cara mengurangkan bilangan penggunaan unsur-unsur litar pintas batang pin aliran elektrik. Jejari pertama dan kedua di dalam penapis isyarat tersebut dikongsi bersama oleh sebatang pin aliran elektrik yang pertama sementara jejari yang ke empat dan kelima dikongsi bersama oleh sebatang pin aliran elektrik yang ketiga. Hanya jejari penapis isyarat yang ke tiga sahaja menggunakan sebatang pin aliran elektriknya sendiri. Ini telah menyebabkan struktur penapis isyarat berubah kebentuk yang baru dengan nama panggilan sebagai ”Kupu-Kupu”. Pengukuran bentuk yang baru ini menghasilkan pecahan frekuensi jaluran sebanyak 109%, had keselerakan parameter-parameter $|S_{21}|$ adalah dibawah 0.85 dB dan S_{11} rendah daripada -11.6 dB. Tambahan lagi, ia juga mengurangkan proses memasukkan batang pin aliran elektrik di litar mikrostrip.

Penapis isyarat yang ketiga secara keseluruhannya telah melenyapkan terus penggunaan batang pin aliran elektrik dan secara tak langsung telah mengurangkan proses fabrikasi mikrostrip. Penggunaan batang pin aliran elektrik digantikan dengan kapasitor tempelan mikrostrip. Pada frekuensi mickrogelombang, elemen kapasitor-kapasitor ini bersifat parasit dan parameter-parameter mereka menyumbang kepada kejayaan prestasi pengukuran keselerakan parameter. Pengukuran keselerakan parameter-parameter $|S_{21}|$ dan S_{11} adalah lebih baik daripada 1 dB dan -16.9 dB secara relatifnya.

Penapis isyarat yang keempat ditingkatkan lagi dari segi skala dimensi dan ukuran kelewatan masa berkumpulan berbanding dengan penapis isyarat ke tiga. Strukturnya tiada mempunyai batang pin aliran elektrik dan menggunakan kurang kapasitor tempelan mirostrip untuk menghasilkan saiz yang lebih kecil dan bentuk ”Kupu-Kupu”. Dengan mengurangkan penggunaan kapasitor tempelan mikrostrip, penapis isyarat ini menunjukkan pertambahan baik di dalam pengukuran julat Jalur Lebar keselerakkan parameter dengan nilai-nilai had keselerakan parameter-parameter $|S_{21}|$ terendah sebanyak 0.53 dB dan S_{11} rendah pada -14.8 dB. Perubahan kelewatan masa berkumpulan adalah minimum pada 0.47 ns di dalam keseluruhan julat Jalur Lebar.

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I certify that an Examination Committee has met on to conduct the final examination of Mohammad Shahrazel bin Razalli on his Master of Science thesis entitled "Design and Development of a Wireless Radio Frequency Identification Reader Communication System at UHF Band" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is my original work except for the quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

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MOHAMMAD SHAHRAZEL BIN RAZALLI

Date:

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3D	-	Three Dimensional
5^{th} order	-	Five Poles
A/V	-	Audio Video
AWICS	-	Military Aircraft Transceiver
BAR	-	Baseband Radar
BPF	-	Band Pass Filter
BW	-	Bandwidth
C	-	Capacitor
CPW	-	Coplanar Wave Guide
CSRRs	-	Complementary Split Ring Resonators
DCC	-	Direct Chaotic Communication
DVD	-	Digital Video Disc
EBG	-	Electromagnetic Bandgap
EM	-	Electromagnetic
FBW	-	Fractional Bandwidth
FCC	-	Federal Communications Commission
FM	-	Frequency Modulation
FR4	-	Fiber-glass Resin type 4
FUC-EBG	-	Foliated Uni-Planar Compact-Electromagnetic Bandgap
Gbps	-	Gigabits per seconds
GPS	-	Global Positioning System

HD	-	High-Definition
HTS	-	High Temperature Superconductor
IMPULSE	-	Short-Duration Pulses, Short-Time Pulse, Ultra-Narrow Time
IT	-	Information Technology
JEMWA	-	Journal of Electromagnetic Waves and Applications
L	-	Inductor
LAN	-	Wireless Local Area Network
LCD	-	Liquid Crystal Display
LCP	-	Liquid-Crystal-Polymer
LPF	-	Low Pass Filter
LTCC	-	Low Temperature Co-Fired Ceramic
MEMS	-	Microelectromechanic System
MMIC	-	Monolithic Microwave Integrated Circuit
MMR	-	Multi-Mode Resonator
MOTL	-	Microwave and Optical Technology Letters
PBG	-	Photonic Bandgap
PCB	-	Printed Circuit Board
PIER	-	Progress in Electromagnetic Research
PULSAR	-	Pulse Synthetic Aperture
QW	-	Quarter-Wavelength
QWSCS	-	Quarter-wavelength Short-Circuited Stubs
R	-	Resistor
RF	-	Radio Frequency
RFID	-	Radio Frequency Identification

RLC	-	Resistor, Inductor, Capacitor
SAR	-	Synthetic Aperture Radar
SIR	-	Stepped-Impedance Resonators
SIW	-	Substrate-Integrated Waveguide
SMT	-	Surface Mount Technology
SRRs	-	Split-Ring Resonators
UC-EBG	-	Uni-Planar Compact-Electromagnetic Bandgap
UHF	-	Ultra High Frequency
UWB	-	Ultra-Wide Band
UWB-RT	-	UWB Radio Technology
VHF	-	High Frequency
VNA	-	Vector Network Analyzer
WIFI	-	Wireless Fidelity
WLAN	-	Wireless Local Area Network
WPAN	-	Wireless Personal Area Network

LIST OF NOTATIONS

a	-	Width in meter
C	-	Capacitance of two parallel plates
c	-	Velocity of Electromagnetic wave in free space (3.0 x 10^8 ms^{-1})
c_1 and c_2	-	Width of c_1 and c_2
C_a	-	Capacitance per unit length with air dielectric substrate
C_d	-	Capacitance per unit length with dielectric present
d	-	Coupled Spacing
d_1 and d_2	-	Length d_1 and d_2
f	-	Frequency Domain
h	-	Interior Filter Admittance level
$h(t)$	-	Impulse response
l	-	Length in meter
L_{Ar}	-	Insertion loss
L_R	-	Return loss
N degree	-	Pole
n	-	Number of Short-Circuited Stubs
p	-	Gap
PG	-	Processing Gain
Q	-	Quality factor
S_{11}	-	Input Reflection Loss
$\|S_{21}\|$	-	Magnitude of transmission Loss

S_{22}	-	Output Reflection Loss
SNR	-	Signal-to-Noise Ratio
T	-	Transmission Line Thickness
t	-	Time Domain
W_e	-	Effective Width of the Transmission Line
X_C	-	Impedance or Reactance in ohms
Yi	-	Admittance of Short-Circuited Stubs
$Y_{i,\ i+1}$	-	Admittance of Transmission line
Z_C	-	Characteristic Impedance
Zi	-	Impedance of Short-Circuited Stubs
$Z_{i,\ i+1}$	-	Impedance of Transmission line
ΔC	-	Capacitance
ΔL	-	Inductive Length
ε_0	-	Permittivity or Dielectric Constant of free-space
ε_r	-	Relative Permittivity or Dielectric Constant
ε_{re}	-	Relative Permittivity
η	-	Wave Impedance in Freespace
θ	-	Electrical Length
$\lambda/4$	-	Quarter-Wavelength

CHAPTER 1

INTRODUCTION

1.1 Background

The UWB stands for Ultra-Wide Band, founded by scientists and researchers who were working in time-domain electromagnetics. The first UWB concept was reported which fully described the transient behaviour of certain class of microwave networks through their characteristic impulse response [1-1]. The introduced time-invariant system concepts consist of swept frequency response, amplitude and phase measurements versus frequency.

This time-invariant system can be characterised by its response in a very small time scale. It is then categorized and called as impulse response, *h (t).* After the invention of sub-nanosecond baseband sampling oscilloscope by Hewlett-Packard in 1962, the microwave network impulse response could be identified, observed and measured. In 1968, Ross had applied the impulsive measurement method to design and develop radiating antenna elements [1-2]. From that time, scientists and researchers obviously realized that the short pulse radar could be developed from the same concept.

In 1972, Robbins [1-3] had invented a baseband radiation and reception systems. This has sped up the development of UWB communication systems. Since then, in the next following year, the first UWB communication system was patented by Sperry research center [1-4]. From that time on, this technology grew up rapidly and it was referred as baseband i.e. carrier-free. Since the technology is carrier-free, the method of