



**IMPROVEMENT OF TECHNIQUE TO CONVERT
CHEBYSHEV, BUTTERWORTH AND COMPOSITE
LOW PASS FILTER INTO MICROSTRIP CIRCUIT**

by

**LIEW HUI FANG
(1330110940)**

A thesis submitted in fulfillment of the requirements for the degree of
Master of Science (Microelectronic Engineering)

**School of Microelectronic Engineering
UNIVERSITI MALAYSIA PERLIS**

(2014)

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

Author's full name : LIEW HUI FANG
Date of birth : 3 FEBRUARY 1988
Title : IMPROVEMENT OF TECHNIQUE TO CONVERT CHEBYSHEV,
BUTTERWORTH AND COMPOSITE LOW PASS FILTER INTO
MICROSTRIP CIRCUIT
Academic Session : 2013/2014

I hereby declare that the thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as :

- CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)*
- RESTRICTED** (Contains restricted information as specified by the organization where research was done)*
- OPEN ACCESS** I agree that my thesis is to be made immediately available as hard copy or on-line open access (full text)

I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of _____ years, if so requested above).

Certified by:

SIGNATURE

880203-35-5302

(NEW IC NO. / PASSPORT NO.)

Date : ____ 30/12/2014 ____

SIGNATURE OF SUPERVISOR

PROF. DR. SYED IDRIS SYED HASSAN

NAME OF SUPERVISOR

Date : ____ 30/12/2014 ____

NOTES : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

ACKNOWLEDGEMENT

First of all, I thank God that He has given me the strength and wisdom to complete this Msc thesis. It is by His blessing and providence that I am able to solve the obstacles along the way and finish the research and thesis.

I would like to express my deepest gratitude to my supervisor Professor Dr. Syed Idris Syed Hassan for his supervision over this work. His encouragement and guidance have always helps me to grow in knowledge and passion for my study. Not forgetting my co-supervisor, Associate Professor Dr. Mohd Fareq Abd. Malek and Associate Professor Dr. Yufridin Wahab for their inputs and assistance in helping me to complete this thesis.

I would like to take this opportunity to express my appreciation to the Dean of School of Microelectronic Engineering, Dr. Rizalafande Bin Che Ismail for his support in this study. I also want to thank Mr. Mazlee Mazalan, Mr. Mohd Ghauth Sazali and Mr. Nasir for their kindness and assistance throughout the laboratory work of this research. I would also like to express my gratitude to the rest of the academic staffs and technical staff in School of Microelectronic Engineering who in one way or another had contributed and assisted in this project.

My sincere thanks go to my friends and colleagues who are Wee Fwen Hoon, Liyana Zahid and Lee Yeng Seng for their accompanies, support and constructive discussions that aided me throughout the research. I would like to highly appreciate the Malaysian Ministry of Higher Education for providing the Fundamental Research Grant Scheme (FRGS) for their financial support. Many thanks must go to Universiti Malaysia Perlis (UniMAP) for the academic support.

Last but not least, I would like to thank my family members for their unfailing love and moral supports. They have never ceased to encourage me and motivate me all the time.

TABLE OF CONTENTS

	PAGE
DECLARATION OF THESIS	i
ACKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	vii
LIST OF FIGURES	ix
LIST OF ABBREVIATIONS	xvii
LIST OF SYMBOLS	xix
ABSTRAK	xxii
ABSTRACT	xxiii
CHAPTER 1 INTRODUCTION	
1.1 Introduction	1
1.2 Problem Statement	4
1.3 Objective of Study	5
1.4 Scope of Study	5
1.5 Outline of the Thesis Structure	6
CHAPTER 2 LITERATURE REVIEW	
2.1 Introduction	8
2.2 Various Design Techniques of Microstrip Lowpass Filter	10

2.2.1	Conversion of Microstrip Line by Using ABCD Network Parameters Method	11
2.2.2	Conversion of Microstrip Line Circuit by Using Shunt short/ Open Circuited Series Stubs	14
2.2.3	Conversion of Microstrip Composite Filter by Using Image Parameter Technique	30
2.2.4	Conversion of Microstrip Line by Using Implicit Space Mapping (SM) Optimization Technique	35
2.2.5	Conversion of Microstrip Circuit by Using Richard's Transformation and Kuroda's Identity Technique	38
2.2.6	Conversion of Microstrip Line By Using Insertion loss Method, Richard's Transformation and Kuroda's Identity Technique	40
2.3	Summary of Classification Trasforming Technique	48
2.4	Basic Theory Design of Lumped Elements Butterworth Low Pass Filter	49
2.5	Basic Theory Design of Lumped Elements Chebyshev Low Pass Filter	51
2.6	Basic Theory Design of Lumped Elements Composite Low Pass Filter	53
2.6.1	Constant-k, T-section	54
2.6.2	For m-derived T Section Sharp Cutoff	56
2.6.3	Matching Section	57
2.7	Summary of Literature Review	58

CHAPTER 3 METHODOLOGY

3.1	Introduction	61
3.2	Project Methodology	61
3.3	Design of Lumped Elements Butterworth, Chebyshev and Composite Low Pass Filter Design	63
3.4	Conversion of Lumped Circuit to Microstrip Line Design Technique	65
3.4.1	Chebyshev/ Butterworth Microstrip Line Form	66
3.4.2	Design of Composite Filter into Microstrip Line Form	72

3.5	ADS Simulation Software	75
3.5.1	Filter Specification and Design	76
3.5.2	S-Parameter	76
3.5.3	Simulating Filters Circuit	77
3.6	Microstrip Transmission Line Design	82
3.7	Measurement Setup	83
3.8	Procedures of Calibration Process (S_{11} or S_{22} Reflection Measurement)	88
3.9	Procedure of Measurement	89
3.10	Summary	90

CHAPTER 4 RESULTS AND DISCUSSIONS

4.1	Introduction	91
4.2	Results of Lumped Elements and Microstrip Line Butterworth, Chebyshev and Composite Low Pass Filter	91
4.2.1	Butterworth Low Pass Filter Frequency Response	92
4.2.2	Verification of Microstrip Line Butterworth Low Pass Filter Frequency Response with its Lumped Element circuit	100
4.2.3	Chebyshev Low Pass Filter With 0.01 Ripple Frequency Response	103
4.2.4	Verification of Microstrip Line Chebyshev Low Pass Filter Frequency Response with its Lumped Element circuit	111
4.2.5	Composite Low Pass Filter Frequency Response	114
4.2.6	Composite Low Pass Filter Frequency Response: Lumped Element vs Microstrip Line	116
4.3	The Comparison Frequency Response Results of Proposed Technique and Previous Research	117
4.4	Summary of Simulation and Measurement Results	121

CHAPTER 5 CONCLUSIONS AND FUTURE WORK	
5.1 Conclusions	123
5.2 Recommendations for Future Work	124
REFERENCES	126
APPENDICES	
APPENDIX A: PROTOTYPE CHEBYSHEV LOW PASS FILTER CIRCUIT (n=3, 4, 5, 6, 7, 8 and 9)	133
APPENDIX B: PROTOTYPE BUTTERWORTH LOW PASS FILTER CIRCUIT (n=3, 4, 5, 6, 7, 8 and 9)	134
APPENDIX C: PROTOTYPE COMPOSITE LOW PASS FILTER CIRCUIT	135
APPENDIX D: PCB FABRICATION PROCEDURES	136
LIST OF PUBLICATIONS	141
LIST OF AWARDS	144

LIST OF TABLES

NO.		PAGE
2.1	Classification of Various Conversion Techniques of Microstrip Low Pass Filter.	44
2.2	Element values for Butterworth low pass prototype filters ($g_0 = 1.0, \Omega_c = 1, L_{Ar} = 3.01$ dB at Ω_c)	51
2.3	Chebyshev 0.01dB equal ripple (RLF-26.4 dB)	52
3.1	Butterworth low pass filters prototype values.	63
3.2	Chebyshev low pass filters prototype values.	64
3.3	Composite low pass filters prototype values.	64
3.4	Representative component symbol of width and impedance	70
3.5	The transmitter and received S-parameter specification value	76
4.1	Simulation and measurement results for Butterworth filters.	100
4.2	Comparison between the proposed technique (with fringing compensation) and direct conversion (without compensation) for Butterworth filters.	102
4.3	Simulation and measurement results for Chebyshev filters.	111
4.4	Comparison between the proposed technique (with fringing compensation) and direct conversion (without compensation) for Chebyshev filters.	113
4.5	Simulation and measurement results for Composite filter.	116
4.6	Comparison measurement results for microstrip filters with	119

proposed technique and previous research.

© This item is protected by original copyright

LIST OF FIGURES

NO.		PAGE
2.1	Two-port network representation.	12
2.2	Cascaded network representation with ABCD parameters.	12
2.3	Low pass prototype for 5 th order, 0.2 dB ripple, Chebyshev filter.	13
2.4	Layout of the filter.	13
2.5	Configurations of asymmetric half wavelength resonators filter with shunt open stubs.	15
2.6	Equivalent circuit of the asymmetric half-wavelength resonators coupling structure with shunt open stubs.	16
2.7	Photograph and size of filter, (a) filter without shunt open stubs, (b) filter with four shunt open stubs and (c) filter with eight shunt open stubs.	16
2.8	Dimensions of soft substrate microshield line.	18
2.9	Measured performance and circuit pattern of filter, (a) with no centre stub and (b) with centre stub only.	18
2.10	Transmission line models of the proposed filter prototype based on series stubs, (a) low pass filter prototype with short-circuited series stubs and (b) high pass filter prototype with open-circuited series stubs.	21
2.11	Schematics layouts of two prototype filters (n=3), (a) low pass	22

	filter dimensions, (b) High pass filter dimensions.	
2.12	Low pass filter (n-3) using hybrid slotline and coplanar-waveguide structures.	23
2.13	Highpass filter (n-3) using hybrid slotline and coplanar-waveguide structures.	23
2.14	Layout of the 3 rd low pass filters, (a) semi-lumped filter and, (b) open stub filter.	24
2.15	The method illustrated in third-order filter, (a) topology used for 3 rd filter and, (b) equivalent of lumped prototype.	27
2.16	Layout of the new open stubs filters, (a) third –order and, (b) seven-order.	28
2.17	Layout of proposed low pass filter (units in mm).	30
2.18	Composite low pass filter, (a) the layout of combinations four sections to become a complete Composite low pass filter and (b) the classical lumped elements design are converted into microstrip line form and with equivalent of short length of transmission line into inductance or capacitance.	33
2.19	Design 1: the inductor representative microstrip line is placed with a ground in the other end.	34
2.20	Design 2: inductor representative microstrip line when the ground are represented with a longer microstrip line.	34
2.21	Microstrip low pass elliptic filter structure.	37
2.22	Coarse model simulated by ADS.	38

2.23	Geometric view of low-pass filter (LPF) of ISM band.	40
2.24	Simulated circuit of Rectenna heaving Antenna+ Filter+ Rectifier.	40
2.25	Schematic diagram of LPF (lumped elements) in network.	42
2.26	Schematic diagram of LPF (microstrip line) design by ADS.	42
2.27	Layout of LPF using microstrip line.	43
2.28	Block diagram of circuit components in the Composite filter.	53
2.29	Low-pass, constant-k filter section in T-network.	55
2.30	m-derived T-section.	57
2.31	Bisected π - matching section.	58
3.1	Methodology flow chart.	62
3.2	Schematic diagram of Chebyshev/ Butterworth filters for n-5.	66
3.3	Model for series inductor with fringing capacitors.	66
3.4	Model for shunt capacitor with fringing inductors.	67
3.5	Chebyshev Low pass filters n-5 with fringing.	71
3.6	Chebyshev/Butterworth low pass filters n-5 from Fig. 3.2.	72
3.7	Schematic diagram of Composite filters.	74
3.8	Composite, low-pass filters after correction due to fringing.	74
3.9	A two port network.	77
3.10	ADS schematic design of Butterworth filters.	78
3.11	ADS schematic design of Chebyshev filter.	78
3.12	ADS schematic design of Composite filter.	79
3.13	Microstrip line circuit for Composite low pass filter type.	80

3.14	Butterworth/ Chebyshev 5 th order low pass circuit layout.	81
3.15	Composite low pass circuit layout.	81
3.16	Microstrip geometry and field configuration.	82
3.17	Line-Calc from ADS software.	83
3.18	The actual measurement low pass filter circuit on network analyzer setup	86
3.19	The port for open, short circuit and matched 50 Ohms load when connected to network analyzer.	82
3.20	Top view of port open, short circuit and matched 50 Ohms load.	87
3.21	Procedures of calibration (Port 1 & Port 2) on network analyzer.	87
4.1	Butterworth 3 rd order result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of microstrip line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation.	93
4.2	Butterworth 4 th order result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of microstrip line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line	94

	filters with fringing compensation.	
4.3	Butterworth 5 th order result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of microstrip line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation.	95
4.4	Butterworth 6 th order result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of microstrip line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation.	96
4.5	Butterworth 7 th order result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of microstrip line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation.	97
4.6	Butterworth 8 th order result, (a) simulation result of lumped	98

element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of microstrip line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation.

- 4.7 Butterworth 9th order result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of microstrip line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation. 99
- 4.8 Chebyshev 3rd order result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation. 104
- 4.9 Chebyshev 4th order result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of line

- filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation.
- 4.10 Chebyshev 5th order result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation. 106
- 4.11 Chebyshev 6th order result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation. 107
- 4.12 Chebyshev 7th order result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation. 108

- measurement result of microstrip line filters with fringing compensation.
- 4.13 Chebyshev 8th order result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation. 109
- 4.14 Chebyshev 9th order result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation. 110
- 4.15 Composite low pass filters result, (a) simulation result of lumped element filter, (b) simulation result of microstrip line filters without fringing compensation, (c) simulation result of line filters with fringing compensation, (d) measurement result of microstrip line filters without fringing compensation and (e) measurement result of microstrip line filters with fringing compensation. 115

© This item is protected by original copyright

LIST OF ABBREVIATIONS

ADS	Advanced Design System
BiT	Bismuth Titanate
BST	Barium Strontium Titanate
CBCPW	Conductor Backed Coplanar Waveguide
CPW	Coplanar Waveguide
CST-MW	Computer Simulation Technology Microwave
DC	Direct Current
Dk	Dielectric Constant
DGS	Defected Ground Structure
EM	Electromagnetic
HFSS	High Frequency Structural Simulator
HPF	High-Pass Filter
I/O	Input/Output
LPF	Low Pass Filter
MEMS	Micro-electro Mechanical System
MMIC	Monolithic Microwave Integrated Circuits
MoM	Method of Moment
PCB	Printed Circuit Board
PNA-X	Microwave Network Analyzer
PTH	Plated-Through-Holes
RF	Radio Frequency

RLF	Return Loss Filters
RX	Receiver
SM	Space Mapping
SMA	Sub-Miniature version A
SST	Silk Screen Top
TCDk	Thermal Coefficient of Dielectric Constant
TE	Electric component in transverse mode
TX	Transmitter
UHF	Ultra High Frequency
UV	Ultra Violet
VSWR	Voltage Standing Wave Ratio
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Networking

LIST OF SYMBOLS

c	Speed of light
C	Capacitor
C_i	The final capacitor value
C_{fL}	Fringing capacitance
3D	Three dimension
d	microstrip substrate thickness
d_c	Length of microstrip capacitance
d_L	Length of microstrip inductance
f_c	Center frequency
ϵ_r	Relative dielectric constants
ϵ_e	Effective dielectric constant
g_n	Normalized value
h	Height of dielectric substrate
L	Inductor
L_i	The final inductor value
L_{As}	Minimum stopband attenuation
L_{AR}	Equal ripple Chebyshev response
L_{fc}	Fringing inductance
m	Matching
n	Number of order
Q	Quality

Q_e	External quality factor
S	Space
δ	Loss tangent
S_{in}	Input port
S_{out}	Output port
S_{11}	Return loss (VSWR)
S_{12}	Insertion loss
S_{21}	Gain
S_{22}	Output VSWR
t	Conductive strip thickness
Ω_s	Matching Ohm
Ω	Ohm
Ω_c	Normalized Frequency
λ	Guided wavelength
λ_d	Wavelength of operating frequency in dielectric
λ_0	Free space wavelength of the resonant frequency
ω_c	Cutoff frequency ($2\pi f$)
ω_0	Radian frequency at free space
W	Conductor Width
ω_α	Infinite attenuation frequency
ω_{op}	Sharp cutoff frequency point
Z	Impedance
Z_{iT}	Internal image impedance

Z_o	Characteristic impedance
Z_{oC}	Lowest line impedance
Z_{oL}	Highest line impedance
Z_{max}	Maximum impedance
Z_{min}	Minimum Impedance
θ_c	Electrical length

© This item is protected by original copyright

MENAMBAHBAIK TEKNIK PENUKARAN PENAPIS LULUS RENDAH CHEBYSHEV, BUTTERWORTH DAN KOMPOSIT KE LITAR MIKROSTRIP

ABSTRAK

Tujuan tesis ini ialah untuk membentangkan teknik penambahbaikan penukaran litar penapis lulus rendah elemen tergumpal Chebyshev, Butterworth dan Komposit kepada litar mikrostrip yang beroperasi pada jalur Frekuensi Ultra-tinggi UHF (2.5 GHz) untuk sistem komunikasi tanpa wayar. Satu teknik penambahbaikan mengubah litar elemen tergumpal ke dalam bentuk talian mikrostrip untuk semua tertib tinggi penapis lulus rendah Chebyshev, Butterworth dan Komposit telah diperkenalkan. Penapis laluan rendah Butterworth dan Chebyshev tertib tinggi telah direka pada riak lulus jalur 0.01 dB dan tertib $n= 3, 4, 5, 6, 7, 8$ dan 9 serta dilaksanakan pada papan cetak FR4. Litar telah disimulasikan dan dibangunkan dengan menggunakan Advanced Design System (ADS) tanpa menggunakan teknik pengoptimuman supaya dapat mengekalkan ciri sambutan sebenar. Penapis kemudiannya ditukarkan ke dalam talian mikrostrip menggunakan teknik pampasan pinggiran. Faktor pampasan pinggiran telah diambil kira disebabkan wujudnya pengaruh mikrojalur dan pemuat mikrojalur di pinggiran. Keputusan analisis daripada litar elemen tergumpal dibandingkan dengan teknik yang dicadangkan untuk mengubah litar elemen tergumpal ke dalam talian mikrostrip. Dari keputusan simulasi ADS menunjukkan bahawa sambutan litar mikrostrip talian bagi semua jenis penapis lulus rendah dengan faktor pampasan pinggiran mempunyai persamaan atau persetujuan yang baik dengan litar tergumpalnya. Secara keseluruhannya, keputusan simulasi telah mencapai persetujuan yang sangat baik dengan keputusan ukuran bagi semua ketiga-tiga jenis penapis lulus rendah mikrostrip. Ini menunjukkan bahawa teknik yang dicadangkan mencapai persetujuan yang agak baik dengan yang direka bentuk. Dengan kata lain, teknik ini mampu untuk menyelesaikan reka bentuk tertib tinggi penapis lulus rendah Butterworth, Chebyshev dan Komposit ke dalam litar talian mikrostrip. Kehilangan balikan (S_{11}) yang mewakili ketidak padanan telah mencapai nilai melebihi 20 dB. Keputusan juga telah menunjukkan bahawa kehilangan sisipan adalah kurang daripada 1 dB, ini bermakna kira-kira 80% daripada isyarat yang dihantar diterima oleh beban. Prestasi sambutan frekuensi di jalur henti (S_{21} pada $2fc$) telah mencapai melebihi daripada 40 dB. Prestasi keluaran semakin bertambah baik apabila bilangan tertib dinaikkan, dan lebih banyak frekuensi yang tidak diingini boleh dihapuskan.