



**Faculty of Electronic and Computer Engineering**

**DESIGN OF SWITCHABLE DUAL-BAND BANDPASS FILTER FOR  
WIRELESS COMMUNICATION**

**Yully Erwanti binti Masrukin**

**Master of Science in Electronic Engineering**

**2018**

**DESIGN OF SWITCHABLE DUAL-BAND BANDPASS FILTER FOR WIRELESS  
COMMUNICATION**

**YULLY ERWANTI BINTI MASRUKIN**

**A thesis submitted  
in fulfillment of requirements for the degree of Master of Science  
in Electronic Engineering**

**Faculty of Electronic and Computer Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2018**

## DECLARATION

I declare that this thesis entitled “Design of Switchable Dual-Band Bandpass Filter for Wireless Communication” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : YULLY ERWANTI BINTI MASRUKIN

Date : .....

## 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 Master of Science in Electronic Engineering.

Signature : .....

Supervisor Name : PROFESSOR DR ZAHRILADHA BIN  
ZAKARIA

Date : .....

## **DEDICATION**

Dedicated to ALLAH Almighty, my loving parents and my sister for your infinite and unfading love, sacrifice, patience, encouragement and best wishes

## ABSTRACT

Due to the progression growth of multiservice wireless communication systems in a single device, multiband bandpass filter has attract a great attention to the end user. Therefore, multiband bandpass filter is a crucial component in the multiband transceivers systems which can support multiple services in one device. Multiband bandpass filter with wideband passband has been drawing a lot of interests of researcher to carry out innovative synthesis and techniques designing the multi-band bandpass filters with less complexity, minimal cost and high performance. Therefore, this thesis presents new technique in designing the switchable dual-band bandpass filter at 2.4 GHz and 3.5 GHz for WLAN and WiMAX applications. Firstly, the wideband bandpass filter was designed centred at frequency of 3 GHz. This filter was constructed by employing the topology of stepped impedance resonator (SIR). This method offer various benefits for instance minimizing the number of elements and transmission zeroes are achieved. As a way to eliminate the interference from existing system that operates in the frequency band, a defected microstrip structure (DMS) was applied and implemented to produce a wide notch band. As the DMS was integrated to the bandpass filter, the dual passband was produced centred at 2.55 GHz and 3.48 GHz with 3 dB bandwidth of 19.6 % and 18.7 %, respectively. In order to generate the switchable characteristic, the PIN diode was introduced at the dual-band bandpass filter. It exhibits that the measured results for switchable attributes when the diode is at OFF state, the wide passband is produced with the fractional bandwidth of 62.1 % centred at 2.9 GHz. Meanwhile, for the diode in ON state, the dual-passband has produced which centred at 2.5 GHz and 3.45 GHz. The first passband possess the fractional bandwidth of 24 % while the second passband is 20.3 %. This structure is very useful for wireless communication systems and applications as it can be easily integrated with other planar devices. Advanced Design System (ADS) software was used to simulate the design from circuit element to physical momentum realization. The experimental results showed good agreement with the simulated results. The benefits of the integrated band-pass filter and defected structure are the reduction of the overall size and ease to fabricate.

## ABSTRAK

*Disebabkan oleh perkembangan pelbagai servis sistem komunikasi tanpa wayar dalam satu peranti tunggal, pelbagai laluan jalur penapis telah mampu mendapat perhatian dari pengguna akhir. Oleh itu, pelbagai laluan jalur penapis merupakan komponen penting dalam sistem penghantar terima pelbagai jalur yang boleh menyokong pelbagai servis dalam satu peranti. Pelbagai jalur laluan jalur penapis dengan berjalur lebar tinggi laluan lurus telah menarik minat penyelidik untuk menjalankan sintesis yang inovatif dan teknik-teknik baru dalam menghasilkan pelbagai jalur penapis yang kurang kompleks, kos minima dan mempunyai prestasi yang tinggi. Oleh itu, kajian projek ini membincangkan teknik-teknik baru dalam mereka-bentuk suis dwi-jalur laluan jalur penapis pada 2.4 GHz dan 3.5 GHz untuk aplikasi WLAN dan WiMAX. Pertama, penapis laluan jalur berjalur tinggi direka berpusat di frekuensi 3 GHz. Penapis ini dibina dengan menggunakan topologi langkah galangan penyalun. Kaedah ini menawarkan pelbagai manfaat seperti mengurangkan bilangan unsur dan mencapai sifar penghantaran. Salah satu cara untuk menghapuskan gangguan dari sistem sedia ada yang beroperasi dalam jalur frekuensi, struktur mikrostrip yang telah dirosakkan telah digunakan dan dilaksanakan untuk menghasilkan jalur takuk yang luas. Apabila struktur yang dirosakkan disatukan bersama laluan jalur penapis, dua penapis laluan lurus terhasil pada 2.55 GHz dan 3.48 GHz dengan 3 dB jalur lebar untuk 19.6 % dan 18.7 %. Untuk menghasilkan ciri-ciri yang boleh suis, PIN diod diperkenalkan di dwi-jalur penapis laluan jalur. Ia mempamerkan bahawa keputusan ukuran bagi ciri-ciri boleh suis apabila diod adalah pada keadaan 'OFF', laluan lurus luas dihasilkan dengan lebar jalur pecahan 62.1% berpusat pada 2.9 GHz. Sementara itu, bagi keadan 'ON', dwi-jalur laluan telah dihasilkan dan berpusat di 2.5 GHz dan 3.45 GHz. Jalur laluan yang pertama mempunyai lebar jalur pecahan 24 % manakala jalur laluan kedua adalah 20.3 %. Struktur ini sangat berguna untuk sistem tanpa wayar kerana dengan mudah dapat dintegrasikan bersama peranti satah lain. Perisian Advanced Design System (ADS) telah digunakan untuk simulasi reka bentuk daripada elemen litar bagi merealisasikan momentum fizikal. Keputusan eksperimen menunjukkan kesepadan yang baik dengan keputusan simulasi. Manfaat penapis jalur bebas bersepadu dan struktur yang telah dirosakkan adalah berjaya mengurangkan saiz keseluruhan dan memudahkan untuk di fabrikasi.*

## ACKNOWLEDGMENTS

Alhamdulillah, first of all, I would like to express my gratitude to Almighty for blessing me with strength and courage to complete this thesis. From the beginning till the end of this thesis, I have so many people who stand by me; given me guidance for every obstacle that stand in my way. Therefore, I would like to express my deepest appreciation to those involved in this report.

Words cannot express my gratitude towards my supervisor, Professor Dr. Zahriladha Bin Zakaria for the patience and humble supervision in the course of his project. May the sky be your limits in all your future endeavours and may jannatul-firdaus be your abode in the hereafter.

Last but not least, I would like to express my appreciation to my beloved parents Madam Rabiah Binti Hussein and my late father Mr Masrukin Bin Ideris as well as my sister and grandmother for the unconditional love and support that let me through the toughest days in my life. To all my friends who shared ideas to make my thesis better especially Nur Shaheera Alia, I hope we can have a good grade for our effort. For those whom not stated here, I would like to thank for their help, friendship and countless support to me. May Allah S.W.T. bless all of them for their support and kindness.

Thank you.



## TABLE OF CONTENTS

	PAGE
<b>DECLARATION</b>	
<b>APPROVAL</b>	
<b>DEDICATION</b>	
<b>ABSTRACT</b>	<b>i</b>
<b>ABSTRAK</b>	<b>ii</b>
<b>ACKNOWLEDGEMENTS</b>	<b>iii</b>
<b>TABLE OF CONTENTS</b>	<b>iv</b>
<b>LIST OF TABLES</b>	<b>vii</b>
<b>LIST OF FIGURES</b>	<b>viii</b>
<b>LIST OF APPENDICES</b>	<b>xvi</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xvii</b>
<b>LIST OF SYMBOLS</b>	<b>xix</b>
<b>LIST OF PUBLICATIONS</b>	<b>xxi</b>
<b>CHAPTER</b>	
<b>1. INTRODUCTION</b>	<b>1</b>
1.1 Research Background	1
1.2 Problem Statement	4
1.3 Objectives	6
1.4 Scope of Research	6
1.5 Contribution of the Thesis	7
1.6 Organization of Thesis	9
<b>2. LITERATURE REVIEW</b>	<b>11</b>
2.1 Introduction	11
2.2 Basic Concept of Filter	12
2.2.1 Types of Filters	12
2.2.2 Degree of the Network, $N$	15
2.3 Important Definitions	16
2.3.1 Return Loss	17
2.3.2 Insertion Loss	17
2.3.3 Group Delay	17
2.4 Microstrip Structure	18
2.4.1 Waves in Microstrip Line	19
2.4.2 Effective Dielectric Constant	19
2.4.3 Characteristic Impedance	20
2.5 Design of Conventional Stub Filter	22
2.5.1 Short Circuited Design	24
2.6 Design of Stepped-Impedance Resonator	25
2.7 Wideband Filters	27
2.7.1 Comparison of Wideband, Moderate Band and Narrowband	27
2.7.2 Review of Wideband Microwave Bandpass Filter	29
2.8 Defected Structure	39
2.8.1 Defected Ground Structure (DGS)	39
2.8.2 Defected Microstrip Structure (DMS)	43
2.9 Dual-Band Bandpass Filter	51

2.10	Switchable	59
2.10.1	Switchable Filter	60
2.11	Summary	65
<b>3.</b>	<b>RESEARCH METHODOLOGY</b>	<b>67</b>
3.1	Introduction	68
3.2	Flow Chart of the Project	65
3.3	Design of Wideband Bandpass Filter Based on Conventional Stub Filter	71
3.3.1	Short Circuit Design	77
3.3.2	Physical Layout/Simulation	78
3.4	Design of Wideband Bandpass Filter Based on Stepped Impedance Resonator (SIR)	86
3.5	Defected Structure	88
3.5.1	Modeling Structure of Defected Microstrip Structure (DMS)	88
3.6	Design of Dual-Band Bandpass Filter	90
3.6.1	Integration of Wideband Conventional Stub with DMS	90
3.6.2	Integration of Wideband SIR with DMS	92
3.6.2.1	Position 1 of U-Shaped DMS Notch Filter	92
3.6.2.2	Position 2 of U-Shaped DMS Notch Filter	93
3.7	Switchable Dual-Band Bandpass Filter	93
3.7.1	Implementation of Pin Diode in DMS structure	93
3.8	Fabrication and Measurement Process	94
3.9	Summary	95
<b>4.</b>	<b>RESULTS AND DISCUSSIONS</b>	
4.1	Introduction	96
4.2	Design of Wideband Bandpass Filter Based on Conventional Stub Filter	97
4.2.1	Short Circuited Design	97
4.2.1.1	Results of Bandpass Filter Based on Conventional Stub	100
4.2.2	Physical Layout/Simulation	102
4.2.2.1	Results of Bandpass Filter Based on Physical Layout	103
4.2.3	Fabrication and Measurement Results	108
4.3	Design of Wideband Bandpass Filter Based on Stepped-Impedance Resonator (SIR)	110
4.3.1	Physical Layout/Simulation	112
4.3.1.1	Physical Layout Based on Calculation	112
4.3.1.1.1	Results of Bandpass Filter Based on Calculation	113
4.3.1.2	Physical Layout Based on Optimization	114
4.3.1.2.1	Results of Bandpass Filter Based on Optimization	115
4.3.2	Fabrication and Measurement Results	118
4.4	Results of Defected Microstrip Structure (DMS)	121
4.4.1	Defected Microstrip Structure Conventional T-inverse Shaped	121
4.4.2	Defected Microstrip Structure Conventional C- Shaped	123
4.4.3	Defected Microstrip Structure Conventional U-shaped	125

4.5	Results of Dual-Band Bandpass Filter	130
4.5.1	Integrated U-shaped DMS with Conventional Stub Filter	130
4.5.2	Integrated U-shaped DMS with Stepped Impedance Resonator (SIR) Bandpass Filter	138
4.6	Comparison of Dual-Band Bandpass Filter with Other Researcher	139
4.7	Results of Switchable Dual-Band Bandpass Filter	141
4.8	Summary	146
<b>5.</b>	<b>CONCLUSION AND FUTURE WORK</b>	<b>148</b>
5.1	Conclusion	148
2.2	Future Work	150
	<b>REFERENCES</b>	<b>151</b>
	<b>APPENDICES</b>	<b>166</b>

## LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Comparison of past studies on wideband bandpass filter	36
2.2	Comparison of the structure of Defected Microstrip Structure (DMS)	50
2.3	Comparison of selected literature on dual-band bandpass filter	56
3.1	Specifications for dual-band bandpass filter based on SIR filter	92
4.1	Bandpass filter specification for quarter wavelength short circuit stub	97
4.2	Design parameter for 5 <sup>th</sup> order stub bandpass filter with quarter-wavelength short-circuited stubs	98
4.3	Microstrip design parameters for 5 <sup>th</sup> order stub bandpass filter with quarter-wavelength short-circuited stubs	102
4.4	Bandpass filter specification for triple-mode (SIR)	111
4.5	The computed value of $\Omega_k$	111
4.6	The value of normalized transmission poles, $f_p(k)$	111
4.7	Specifications for dual-band bandpass filter based on conventional stub filter	131
4.8	Specifications for dual-band bandpass filter based on SIR filter	138
4.9	Comparison the performance of dual-band bandpass response for selected studies	139

## LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Basic architecture of SDR at the transceiver system	2
1.2	SDR receiver	3
2.1	Frequency response of (a) lowpass filter, (b) highpass filter, (c) bandpass filter and (d) bandstop filter	13
2.2	Maximally flat and equal-ripple low pass filter responses	14
2.3	Lowpass generalized Chebyshev response	15
2.4	Illustration of bandpass response at certain bandwidth	16
2.5	Comparison of group delay for different types of response	18
2.6	A basic of microstrip structure	18
2.7	Transmission line bandpass filter with quarter-wavelength short- circuited stubs	23
2.8	Modeling circuit of the proposed wideband bandpass filter	25
2.9	Element values for Chebyshev lowpass prototype filters	25
2.10	Normalized resonant frequencies and their separation versus impedance ratio of a multimode SIR	26
2.11	Geometry structure of the SIR	27
2.12	Comparison of the narrow band, moderate band and wideband	28

	response	
2.13	Asymmetric coupled microstrip ring resonator and resonance curve of the structure a) Topology of the proposed SRCL filter (b) Simulated results of proposed filter	29
2.14	Configuration of dual-mode capacitance loaded-meander ring resonator	30
2.15	(a) Experimental Circuit (b) Simulated and Measured Response	31
2.16	(a) Design of the fabricated filters the SEWBPF (b) The full-wave simulated and measured results of the fabricated SEWBPF	32
2.17	(a) Topology of the proposed SRCL filter; (b) Simulated results of proposed filter	32
2.18	(a) Configuration of proposed SIR filter with source-load (b) Simulated and measured results of designed filter	33
2.19	(a) The structure of SIR filter (b) The simulation of the SIR filter	34
2.20	(a) Fabricated composite right/left-handed (CRLH) SIR filter (b) Measured and simulated response of the CRLH SIR BPF	35
2.21	The first DGS unit (a) Dumbbell DGS unit and (b) Simulated S-Parameter	40
2.22	Common arrangements for DGS resonant structures (a) slot, (b) meandered lines, (c) slot variations and (d) dumbbell shapes	41
2.23	Various types of DGS; (a) spiral head, (b) arrowhead-slot, (c) H-shape slots, (d) inverse T-shape, (e) open-loop dumbbell and (f) interdigital DGS	42
2.24	Unit cell (a) DMS and (b) DGS	44

2.25	Frequency response of two DMS (solid line) and DGS (dotted line)	44
2.26	Microstrip structure layout of (a) SILPF with embedded OCSR and rectangular patch combined feedline (b) H-shaped introduced in SILPF layout	46
2.27	Simulated S-parameters result of SILPF with and without H-shaped DMS at OSCR	46
2.28	Traditional DMS and new T-shaped DMS (a) Traditional T-shaped (b) Inner T-shaped DMS (c) Equivalent circuit of transmission line (d) equivalent circuit of DMS	47
2.29	Configuration of the proposed (a) tri-band (b) quad-band	48
2.30	(a) The proposed dual-band filter using U-DMS (b) Simulated and measured results of proposed dual-band filter	49
2.31	(a) Circuit configuration of the filter design (b) The simulated and measured response	51
2.32	(a) Fabricated filter; (b) Simulation and measurement responses	52
2.33	Basic layout of SIR	53
2.34	(a) Structure of fabricated filter (b) Simulated and measured responses of proposed dual-passband filter	53
2.35	(a) Configuration of meandering scheme SIRs (b) Simulation and measurement response with the resonant frequency at 2.4 GHz and 5.2 GHz	54
2.36	(a) Novel improved dual-band bandpass filter (b) Simulated and measured frequency responses of the improved dual-band filter	55
2.37	Equivalent circuit and configuration of pin diode bias circuit, (a)	60

	Forward bias, (b) Reverse bias and (c) bias circuit	
2.38	Switchable notch structures (a) Scheme A; (b) Scheme B	61
2.39	EM-simulated results for the switchable notch structures; (a) Notch switched on; (b) notch switched off.	62
2.40	(a) Configuration of proposed filter; (b) circuit of pin diode; (c) Measured S-parameter at off state of upper passband; (d) Measured S-parameter at off state of lower passband	63
2.41	Schematic of proposed filter	64
2.42	(a) Simulated and measured results with pin diodes ON (b) Simulated and measured results with pin diodes OFF	64
2.43	Structure of proposed switchable dual-band BPF with wide stopband	65
3.1	Flow chart of the project	69
3.2	Modelling circuit of the proposed wideband bandpass filter	77
3.3	Element values for Chebyshev lowpass prototype filters	77
3.4	Illustration of the designed 5 <sup>th</sup> order stub bandpass filter	86
3.5	3-D view of microstrip for 5 <sup>th</sup> order stub bandpass filter with quarter-wavelength short-circuited stubs	86
3.6	Normalized resonant frequencies and their separation versus impedance ratio of a multimode SIR	87
3.7	Geometry structure of the SIR	88
3.8	Structure of conventional DMS	88
3.9	Defected Microstrip Structure (a) Proposed U-shaped DMS structure (b) The equivalent circuit of U-shaped DMS	89
3.10	The integration layout of wideband bandpass filter with one U-shaped	91



	of DMS	
3.11	The integration layout of wideband bandpass filter with two U-shaped of DMSs	91
3.12	The U-shaped DMS fitted in the structure of wideband bandpass filter	92
3.13	The U-shaped DMS fitted in the structure of wideband bandpass filter	93
3.14	Basic structure of biasing circuit for pin diode	94
3.15	Measurement instrument of Vector Network Analyzer (VNA)	95
4.1	Filter design that derived from a circuit model for 5 <sup>th</sup> order stub bandpass filter with quarter-wavelength short-circuited stubs	99
4.2	Simulated result of the distributed element quarter wavelength short circuit stubs band pass filter	100
4.3	Optimized of the fifth-order quarter-wavelength short-circuited stubs bandpass filter	101
4.4	Layout of the designed microstrip for 5 <sup>th</sup> order stub bandpass filter with quarter-wavelength short-circuited stubs	102
4.5	Effect diameter of via hole variation	104
4.6	Effect of thickness substrate variation	104
4.7	The layout of the substrate Roger Duroid 4350	105
4.8	Transmission line for optimized short-circuited stubs bandpass filter	106
4.9	Physical layout for optimized short-circuited stubs bandpass filter	106
4.10	3-D view of physical layout of microstrip short circuit stubs bandpass filter	107
4.11	Simulated results of physical layout short-circuited stubs bandpass filter	107
4.12	Current flow visualization of short circuit stub bandpass filter (a) at 3	108

	GHz (b) at 1.5 GHz and (c) at 4.5 GHz	
4.13	Dimension of fabricated short-circuited stubs bandpass filter	109
4.14	Performance of simulated and measured response	109
4.15	Group delay between the simulated and measured results	110
4.16	Preliminary structural parameters	113
4.17	Coupling between two structure of symmetric SIR with a gap, $g = 0.4\text{mm}$	113
4.18	Simulated result for the calculated physical layout of SIR	114
4.19	Optimized physical structure of symmetric SIR with a gap, $g_1 = 0.3\text{mm}$ and $g_2 = 0.4\text{ mm}$	114
4.20	3-D view of symmetric SIR wideband bandpass filter	115
4.21	Optimized physical layout of SIR	115
4.22	Effect of gap coupling, $g_1$ is varied and $g_2$ is fixed	116
4.23	Effect of gap coupling, $g_2$ is varied and $g_1$ is fixed	116
4.24	3-D view physical layout of SIR bandpass filter Shaped	117
4.25	Simulated result for the optimized physical layout of SIR	117
4.26	Fabricated of SIR bandpass filter	118
4.27	Current flow visualization of SIR bandpass filter (a) at 3 GHz (b) at 1.5 GHz and (c) at 4.5 GHz	119
4.28	Simulated and measured results of SIR bandpass filter	120
4.29	Group delay of the SIR bandpass filter	120
4.30	Defected Microstrip Structure (DMS) of Conventional T-inverse Shaped	122
4.31	Effect of notch response when $w_1$ is varied	122

4.32	Effect of notch response when $l_2$ is varied	123
4.33	Defected Microstrip Structure (DMS) of Conventional C-inverse Shaped	124
4.34	Effect of notch response when $l_1$ is varied	124
4.35	Effect of notch response when $w_2$ is varied	124
4.36	Defected Microstrip Structure (DMS) of Conventional U-inverse Shaped	126
4.37	Simulated Notch Response of U-shaped DMS	126
4.38	Effect of notch response when $w_1$ is varied	127
4.39	Effect of notch response when $l_2$ is varied	127
4.40	Equivalent circuit of microstrip structure	128
4.41	Effect of notch response, $L_p$ is varied and $C_p$ is fixed	129
4.42	Effect of notch response, $C_p$ is varied and $L_p$ is fixed	129
4.43	Comparison of simulated notch response for conventional DMS of T-inverse shaped, C-shaped and U-shaped	130
4.44	Proposed integrated of bandpass filter with one U-shaped DMS	132
4.45	Simulated result for integrated of bandpass filter with one U-shaped DMS	132
4.46	Effect of dual-band response as $d$ is varied bandpass filter	132
4.47	Proposed integrated of bandpass filter with two U-shaped DMSs	133
4.48	3-D view of microstrip short circuit stubs with U-shaped DMS	134
4.49	Comparison simulated response of a dual-band bandpass filter for the integration of one DMS and two DMSs	134
4.50	Effect of dual-band response as $d_1$ is varied	135

4.51	Current flow visualization of integrated bandpass filter with DMS (a) at 1.5 GHz, (b) at 3 GHz and (c) at 4.5 GHz	136
4.52	Fabricated of integrated bandpass filter with U-shaped DMS	136
4.53	Comparison between simulated and measured response of dual-band bandpass filter	137
4.54	Comparison of group delay between simulated and measured response of dual-band bandpass filter	138
4.55	Schematic of the proposed switchable dual-band bandpass filter	142
4.56	Simulated result for switchable dual-band bandpass filter	143
4.57	Fabricated of switchable dual-band BPF	143
4.58	Comparison between simulated and measured response of switchable dual-band bandpass filter when (a) pin diode is OFF state (b) pin diode is ON state	145
4.59	Comparison of group delay between simulated and measured response of switchable dual-band bandpass filter when (a) pin diode at OFF state (b) pin diode at ON state	146

## **LIST OF APPENDICES**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	Roger Duroid RO4350B	166

## LIST OF ABBREVIATIONS

<i>ADS</i>	-	Agilent Technology Advanced Design System
<i>BB</i>	-	Baseband
<i>BPF</i>	-	Bandpass Filter
<i>CDMA</i>	-	Code Division Multiple Access
<i>CRLH</i>	-	Composite Right/Left-Handed
<i>DGS</i>	-	Defected Ground Structure
<i>DMS</i>	-	Defected Microstrip Structure
<i>EM</i>	-	Electromagnetic
<i>EBG</i>	-	Electromagnetic Band Gap
<i>FM</i>	-	Frequency Modulation
<i>GSM</i>	-	Global System for Mobile communication
<i>LNA</i>	-	Low Noise Amplifier
<i>MEM</i>		Microelectromechanical
<i>NB-SRR</i>	-	Non-Bianisotropic Split-Ring Resonator
<i>OCSR</i>		Open Circuit Stub Resonator
<i>PBG</i>	-	Photonic Band Gap
<i>RF</i>	-	Radio Frequency
<i>RX</i>	-	Recieve

<i>SDR</i>	-	Software Defined Radio
<i>SEWBPF</i>	-	Single-Ended Wideband Bandpass Filter
<i>SICL</i>	-	Substrate Integrated Coaxial Line
<i>SILPF</i>	-	Stepped-Impedance Low Pass Filter
<i>SIR</i>	-	Stepped Impedance Resonator
<i>SR</i>	-	Software Radio
<i>TEM</i>	-	Transverse Electromagnetic
<i>TX</i>	-	Transmit
<i>UE</i>	-	Unit Element
<i>UHF</i>		Ultra High Frequency
<i>UIR</i>		Uniform Impedance Resonator
<i>UWB</i>	-	Ultra-Wideband
<i>VHF</i>		Very High Frequency
<i>VNA</i>	-	Vector Network Analyzer
<i>WCDMA</i>		Wideband Code Division Multiple Access
<i>WiMAX</i>	-	Worldwide Interoperability for Microwave Access
<i>WLAN</i>	-	Wireless Local Area Network

## LIST OF SYMBOLS

$C$	-	Capacitance
$L$	-	Inductance
$R$	-	Resistance
$\omega$	-	Angular frequency
$\omega_c$	-	Angular cut-off frequency
$\omega_o$	-	Angular centre frequency
$\alpha$	-	Bandwidth scaling factor
$c$	-	Speed of light
$\lambda$	-	Wavelength
$\lambda_o$	-	Centre frequency wavelength
$\lambda_g$	-	Centre guide wavelength
$N$	-	Number of order(s)
$f_o$	-	Centre frequency
$f_c$	-	Cut-off frequency
$f_r$	-	Resonant frequency
BW	-	Bandwidth
FBW	-	Fractional Bandwidth
$\epsilon_o$	-	Permittivity of free space