



**WIFI-UHF TRANSCEIVER DESIGN FOR 650-680  
MHZ TELEVISION WHITE SPACE (TVWS)  
SPECTRUM APPLICATION**

by

**KHAIRIL ANUAR KHAIRI  
(1630812147)**

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

**School of Computer and Communication Engineering  
UNIVERSITI MALAYSIA PERLIS**

2018

UNIVERSITI MALAYSIA PERLIS

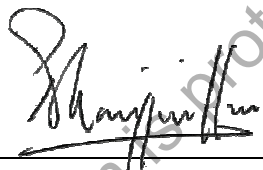
DECLARATION OF THESIS

Author's Full Name : KHAIRIL ANUAR KHAIRI  
Title : WIFI-UHF TRANSCEIVER DESIGN FOR 650-680 MHZ  
TELEVISION WHITE SPACE (TVWS) SPECTRUM  
APPLICATION  
Date of Birth : 14 APRIL 1974  
Academic Session : 2016/2017

I hereby declare that this 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 1997)\*
- RESTRICTED** (Contains restricted information as specified by the organization where research was done)\*
- OPEN ACCESS** I agree that my thesis to be published as online open access (Full Text)

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

  
\_\_\_\_\_  
**SIGNATURE**

Certified by:

\_\_\_\_\_  
**SIGNATURE OF SUPERVISOR**

740414-08-6021  
\_\_\_\_\_  
**(NEW IC NO. /PASSPORT NO.)**

ASSOC. PROFESSOR IR. DR.  
MOHD FAIZAL JAMLOS  
\_\_\_\_\_  
**NAME OF SUPERVISOR**

Date: \_\_\_\_\_

Date: \_\_\_\_\_

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

## ACKNOWLEDGMENT

In the name of Allah, First of all, I thank to Allah for being with me, giving me the strength, health and patience to complete this thesis.

More acknowledgements to my supervisor, Professor Ir. Dr Mohd Faizal Jamlos for his intellectual and academic inspirations and excellent support, caring, guidance throughout my research work. Without his mentoring, support and cooperation, I could not have completed this research project.

Special thanks also go to all my friends, colleagues and staff at Advanced Communication Engineering Centre (ACE), School of Computer and Communication Engineering, UniMAP, for their help and sharing knowledge and ideas during working in my project as well as to those whoever has helped me either directly or indirectly.

Lastly my earnest thanks to my parents Khairi bin Mohammad Ariffin, Rohana binti Lazim and my mother-law Halimah binti Abdullah for their support, love and prayer. Special thanks to my beloved wife Tun Qurratul Ain Bt Yaacob for your unconditional love, understanding, trust and for giving me the strength and support to reach for the stars and go for my dreams through all these years. I also dedicated this thesis to my much-loved children Megat Muhammad Mustaqim, Megat Muhammad Muaz, Megat Muhammad Mukhlis and Megat Muhammad Mufeed and I hope that this can be used as an inspiration to all of you. Remember, success doesn't just come and find you as you have to go out and get it.

Last but not least, I would also like to extend my appreciation and gratitude to all my siblings, brothers and sisters in-law for their support, love and prayer, without which I would not achieve my goal. The appreciation can hardly be expressed in words.

## TABLE OF CONTENTS

	<b>PAGE</b>
<b>DECLARATION OF THESIS</b>	<b>i</b>
<b>ACKNOWLEDGMENT</b>	<b>ii</b>
<b>TABLE OF CONTENTS</b>	<b>iii</b>
<b>LIST OF TABLES</b>	<b>vii</b>
<b>LIST OF FIGURES</b>	<b>ix</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xx</b>
<b>LIST OF SYMBOLS</b>	<b>xxii</b>
<b>ABSTRAK</b>	<b>xxiii</b>
<b>ABSTRACT</b>	<b>xxiv</b>
<b>CHAPTER 1 : INTRODUCTION</b>	<b>1</b>
1.1 Project Background & Motivation	1
1.2 Problem Statement	3
1.3 Thesis Objectives	7
1.4 Scope of Work	8
<b>CHAPTER 2 : LITERATURE REVIEW</b>	<b>11</b>
2.1 Overview	11
2.2 TV White Space	12
2.3 WiFi-UHF Transceiver (WUT)	14
2.4 Existing Projects	15
2.4.1 UHF CR prototype using Field Programmable Gate Array (FPGA)	15

2.4.2	TV White Space Converter prototype for WLAN routers	18
2.4.3	UHF Cognitive Radio prototype using scanner	23
2.5	Summary	29
<b>CHAPTER 3 : METHODOLOGY</b>		<b>30</b>
3.1	Introduction	30
3.2	Flow chart diagram	31
3.3	Requirement of studies	33
3.3.1	Agilent's ADS Software	33
3.3.2	Design Specification	34
3.3.3	Component parameters of the WUT system	36
3.4	Theoretical and calculation methods for subsystems design	41
3.4.1	Filters	41
3.4.1.1	Low Pass Filters (LPFs)	45
3.4.1.2	High Pass Filter (HPF)	50
3.4.1.3	Band Pass Filter (BPF)	53
3.4.1.4	Variable Band Pass Filter (VBPF)	57
3.4.2	Attenuator	67
3.4.3	Low Noise Amplifier (LNA)	74
3.4.4	Pre-Driver Amplifier	78
3.4.5	Driver Amplifier	80
3.4.6	Mixer	81
3.4.7	Voltage Control Oscillator (VCO) - Phase locked loop (PLL)	84
3.4.8	Circulator	86
3.5	WUT system design method	87
3.6	Experimental Design	90
3.6.1	Fabrication of WUT	91

3.6.2	Build of Material (BOM) Creation	92
3.6.3	Schematic Drawing & PCB Design of WUT	94
3.6.3.1	Schematic Diagram	94
3.6.3.2	PCB Layout	101
3.6.4	Fabrication of WUT main PCB	121
3.6.5	Assembly of WUT	128
3.6.6	Sub-system Characterization	130
3.6.6.1	Test Setup for Filters and Attenuators	133
3.6.6.2	Test Setup for VBPF	134
3.6.6.3	Test Setup for Circulator	135
3.6.6.4	Test Setup for Amplifiers	137
3.6.6.5	Test Setup Mixer	139
3.6.6.6	Test Setup for VCO-PLL	141
3.7	Physical Optimization of WUT's Sub-sections	142
3.8	WUT System Test	144
3.9	Summary	148
	<b>CHAPTER 4 : RESULTS &amp; DISCUSSIONS</b>	<b>150</b>
4.1	Introduction	150
4.2	Results and Discussions for subsystems	151
4.2.1	Low Pass Filter (LPF) 700MHz	151
4.2.2	Low Pass Filter (LPF) 1.8GHz	159
4.2.3	High Pass Filter (HPF) 2.4GHz	165
4.2.4	Band Pass Filter (BPF) 2.4GHz	170
4.2.5	Variable Band Pass Filter (VBPF)	175
4.2.6	T-Pad 3dB Attenuator	181

4.2.7	Pi-Pad 6dB Attenuator	183
4.2.8	Low Noise Amplifier (LNA)	185
4.2.9	Pre-Driver Amplifier	190
4.2.10	Driver Amplifier	193
4.2.11	Mixer	195
4.2.12	Circulator	202
4.2.13	Voltage Controlled Oscillator and Phase Locked Loop (VCO-PLL)	207
4.3	WiFi-UHF Transceiver (WUT) System	211
4.3.1	Transmitter	211
4.3.2	Receiver	216
<b>CHAPTER 5 : CONCLUSION</b>		<b>222</b>
5.1	Summary	222
5.2	Future Work	224
<b>REFERENCES</b>		<b>226</b>
<b>APPENDIX A</b>		<b>231</b>

## LIST OF TABLES

	<b>PAGE</b>	
Table 3.1	Design Specifications	35
Table 3.2	Design Specifications of 700MHz LPF	49
Table 3.3	Design Specifications of 1.8GHz LPF	50
Table 3.4	Design Specifications of 2.3GHz HPF	52
Table 3.5	Design Specifications of 2.4GHz BPF	56
Table 3.6	Design Specifications of 700MHz VBPF	67
Table 3.7	Freq and Power Test Condition for Transmitter System Test	146
Table 3.8	Freq and Power Test Condition for Receiver System Test	147
Table 4.1	Components value of LPF before and after optimization	156
Table 4.2	Components value of LPF with 6dB attenuator before and after optimization	159
Table 4.3	Components value of Tx LPF before and after optimization	163
Table 4.4	Components value of Rx LPF before and after optimization	165
Table 4.5	Components value of Rx HPF before and after optimization	170
Table 4.6	Components value of BPF before and after change	174
Table 4.7	Components value of VBPF before and after optimization	180
Table 4.8	Components value of 3dB Pi-Pad attenuator	183
Table 4.9	Frequency mixing orders for the mixer	196
Table 4.10	ADL5350 characterization result per datasheet	200



Table 4.11	ADL5350 characterization result with WUT frequencies	202
Table 4.12	WUT Transmitter System Test Conditions and Result	216
Table 4.13	WUT Receiver System Test Conditions and Result	221

©This item is protected by original copyright

## LIST OF FIGURES

	<b>PAGE</b>	
Figure 1.1	Frequency spectrum is running out (receiving low signal) due to increasing number of users	4
Figure 1.2	Building wireline cable in rural area would cost much	5
Figure 1.3	Huge campus needs multiple access points to do the wireless network	5
Figure 1.4	Using multiple access points in rural area can create blind spots	6
Figure 2.1	Frequency allocation for Analog TV & Digital Terrestrial TV Broadcasting	13
Figure 2.2	Malaysia's analogue terrestrial television broadcasting using VHF and UHF	13
Figure 2.3	Top-level block diagram of CR prototype	17
Figure 2.4	Block diagram of a UHF cognitive radio node	17
Figure 2.5	The complete block diagram of the UHF converter	20
Figure 2.6	The main components of the system that enables Wi-Fi devices to operate in the TV bands	25
Figure 2.7	System interconnection diagram	27
Figure 2.8	Block diagram of S-Band to UHF frequency	28
Figure 3.1	Overall flowchart diagram of the entire project	32
Figure 3.2	Overview look of the ADS software	34

Figure 3.3	Proposed WiFi-UHF Transceiver architecture integrated with WLAN module	35
Figure 3.4	Block diagram of the proposed WUT system	38
Figure 3.5	Schematic Circuit diagram design of the LPF at 700MHz	47
Figure 3.6	Schematic Circuit diagram design of the LPF at 700MHz in Momentum	48
Figure 3.7	Schematic Circuit diagram design of the LPF at 1.8GHz	48
Figure 3.8	Schematic Circuit diagram design of the LPF at 1.8GHz in Momentum	48
Figure 3.9	The entire design process of 700MHz and 1.8GHz LPF	49
Figure 3.10	Schematic Circuit diagram design of the HPF at 2.3GHz	51
Figure 3.11	Schematic Circuit diagram design of the HPF at 2.3GHz in Momentum	51
Figure 3.12	The entire design process of 2.3GHz HPF	52
Figure 3.13	Schematic Circuit diagram design of the BPF at 2.4GHz	54
Figure 3.14	Schematic Circuit diagram design of the BPF at 2.4GHz in Momentum	55
Figure 3.15	The entire design process of 2.4GHz BPF	56
Figure 3.16	The resonance circuit connected to a source of resistance $R_s$	58
Figure 3.17	Frequency response of the resonant circuit	58
Figure 3.18	Schematic design of a (a) capacitive coupling (b) inductive coupling circuit	60
Figure 3.19	Resonator response comparison of two critically coupled resonators	61

Figure 3.20	Configuration of a variable/ switchable filter using two identical resonators coupled inductively.	62
Figure 3.21	Tuning range parameters	63
Figure 3.22	(a) Varactor tuning circuit implementation (b) Capacitance versus varactor tuning voltage	64
Figure 3.23	Schematic Circuit diagram design of the VBPF	65
Figure 3.24	Schematic Circuit diagram design of the VBPF in Momentum	66
Figure 3.25	The entire design process of 700MHz VBPF	66
Figure 3.26	Attenuator connection in the circuit	68
Figure 3.27	Basic T-Pad attenuator circuit	69
Figure 3.28	Schematic circuit diagram design of the T-Pad attenuator	70
Figure 3.29	Schematic circuit diagram design of the T-Pad attenuator	70
Figure 3.30	Basic Pi-Pad attenuator connection	71
Figure 3.31	Schematic circuit diagram design of the Pi-Pad attenuator	72
Figure 3.32	Schematic circuit diagram design of the Pi-Pad attenuator in Momentum	73
Figure 3.33	The entire design process of Attenuator	73
Figure 3.34	BJT biasing of BFR 540 transistor	77
Figure 3.35	DC biasing circuit design for BFS540 transistor in ADS software	78
Figure 3.36	(a) Functional block diagram of ADA-4643 (b) Biasing configuration for ADA-4643	79
Figure 3.37	Functional block diagram for ADL 5324	81

Figure 3.38	Functional block diagram for ADL 5350	82
Figure 3.39	Functional block diagram for ADL 5350	84
Figure 3.40	Phase Lock Loop (PLL) feedback system	85
Figure 3.41	Functional block diagram of ADF4360-3	86
Figure 3.42	Schematic circuit diagram of the transmitter path	88
Figure 3.43	Schematic circuit diagram of the receiver path	89
Figure 3.44	Schematic circuit diagram of the WUT system using circulator	89
Figure 3.45	Schematic circuit diagram of the WUT system using SPDT switch	90
Figure 3.46	Arrangement of WUT's sub-sections on main PCB	92
Figure 3.47	BOM list of 700MHz LP-F	93
Figure 3.48	Schematic Circuit diagram of Tx Post LPF at 700MHz	95
Figure 3.49	Schematic Circuit diagram of Tx Pre LPF at 700MHz	95
Figure 3.50	Schematic Circuit diagram of Tx LO LPF at 1.8GHz	96
Figure 3.51	Schematic Circuit diagram of Rx VBPF at 470-770MHz	96
Figure 3.52	Schematic Circuit diagram of Rx LO LPF at 1.8GHz	97
Figure 3.53	Schematic Circuit diagram of Rx HPF at 2.3GHz	97
Figure 3.54	Schematic Circuit diagram of BPF at 2.4GHz	98
Figure 3.55	Schematic Circuit diagram of 6dB Pie-Pad Attenuator	98
Figure 3.56	Schematic Circuit diagram of 3dB Pie-Pad Attenuator	99
Figure 3.57	Schematic Circuit diagram of Power Distribution to Power Amplifiers	100

Figure 3.58	Schematic Circuit diagram of Power Distribution to VBPF and Mixers	100
Figure 3.59	Structure of WUT main PCB Layers	101
Figure 3.60	TOP layer of WUT	103
Figure 3.61	GND layer of WUT	104
Figure 3.62	PWR layer of WUT	105
Figure 3.63	BOTTOM layer of WUT	106
Figure 3.64	PCB layout of Tx Post LPF at 700MHz	107
Figure 3.65	PCB layout of Tx Pre LPF at 700MHz and 6dB Pie-Pad Attenuator	108
Figure 3.66	PCB layout of Tx LO LPF at 1.8GHz	108
Figure 3.67	PCB layout of Rx VBPF at 470-700MHz	109
Figure 3.68	PCB layout of Rx LO LPF at 1.8 GHz	110
Figure 3.69	PCB layout of Rx HPF at 2.35GHz	110
Figure 3.70	PCB layout of BPF at 2.4GHz	111
Figure 3.71	PCB layout of 3dB Pie-Pad Attenuator	111
Figure 3.72	PCB layout of Power Distribution circuit	112
Figure 3.73	Board size scaling	113
Figure 3.74	Define mounting hole of daughter board	114
Figure 3.75	Placement of components	115
Figure 3.76	Routing of traces	116
Figure 3.77	Ground plane placement	117

Figure 3.78	Grounding void	118
Figure 3.79	Routing for PWR layer	119
Figure 3.80	Fiducial and mounting hole placement	120
Figure 3.81	Ground shielding and dimensioning	121
Figure 3.82	Image expose	122
Figure 3.83	CNC drilling	123
Figure 3.84	Etching	124
Figure 3.85	Plated through hole copper plating	125
Figure 3.86	Flying probe test	126
Figure 3.87	Silkscreen and soldermask	127
Figure 3.88	WUT Assembly without RF cables	129
Figure 3.89	WUT Assembly with RF cables	130
Figure 3.90	Evaluation Plan for each WUT's Sub-Section	132
Figure 3.91	Test Setup (a) for RF Filters except for VBPF (b) Pie-Pad Attenuator	133
Figure 3.92	Test Setup for Rx 700MHz VBPF	135
Figure 3.93	Test Setup for Circulators	137
Figure 3.94	Test Setup for ADL5650 Pre-Driver Amplifier	138
Figure 3.95	Test Setup for ADL5324 Driver Amplifier	139
Figure 3.96	Test Setup for ADL5521 LNA	139
Figure 3.97	Test Setup for ADL5350 Mixers	141
Figure 3.98	Test Setup for ADF4360 VCO-PLL	142

Figure 3.99	Test Setup for WUT Transmitter	145
Figure 3.100	Test Setup for WUT Receiver	147
Figure 4.1	Simulated frequency response for LPF 700 MHz	152
Figure 4.2	Simulated frequency response for LPF 700 MHz with momentum	153
Figure 4.3	Measured Vs Simulated frequency response for LPF	154
Figure 4.4	Measured Vs Simulated (momentum) frequency response for LPF	154
Figure 4.5	Optimized Vs Simulated frequency response for LPF	155
Figure 4.6	Multiple frequency responses for LPF with 6dB attenuator during optimization	157
Figure 4.7	Optimized Vs Simulated frequency response for LPF + 6dB attenuator	158
Figure 4.8	Frequency response for LPF	160
Figure 4.9	Measured Vs Simulated frequency response for Tx LPF	161
Figure 4.10	Optimized Vs Simulated frequency response for Tx LPF	162
Figure 4.11	Measured Vs Simulated frequency response for Rx LPF	164
Figure 4.12	Optimized Vs Simulated frequency response for Rx LPF	164
Figure 4.13	Frequency response for HPF	166
Figure 4.14	Measured Vs Simulated Frequency response for HPF	167
Figure 4.15	Measured Vs Simulated (momentum) Frequency response for HPF	167
Figure 4.16	Multiple frequency responses for HPF during optimization	168



Figure 4.17	Optimized Vs Simulated Frequency response for HPF	169
Figure 4.18	Frequency response for BPF	171
Figure 4.19	Measured Vs Simulated Frequency response for BPF	172
Figure 4.20	Measured Vs Simulated (momentum) Frequency response for BPF	172
Figure 4.21	Multiple frequency responses for BPF during optimization	173
Figure 4.22	Freq responses of SAW filter Vs simulated BPF	174
Figure 4.23	Frequency response for VBPF at V=6.0V	176
Figure 4.24	Frequency response for VBPF at V= 4.5V	176
Figure 4.25	Measured Vs Simulated Frequency response for VBPF at V=6.0V	177
Figure 4.26	Measured Vs Simulated (momentum) Frequency response for VBPF at V=6.0V	177
Figure 4.27	Multiple frequency responses for VBPF during optimization	178
Figure 4.28	Optimized Vs Simulated Frequency response for VBPF at V=6.0V	179
Figure 4.29	$S_{11}$ response for 3dB T-Pad attenuator	181
Figure 4.30	$S_{21}$ response for 3dB T-Pad attenuator	182
Figure 4.31	Measured Vs Simulated $S_{21}$ response for 3dB Pi-Pad attenuator	182
Figure 4.32	Measured Vs Simulated (momentum) $S_{21}$ response for 3dB Pi-Pad attenuator	183
Figure 4.33	$S_{11}$ response for 6dB Pi-Pad attenuator	184
Figure 4.34	$S_{21}$ response for 6dB Pi-Pad attenuator	184

Figure 4.35	$S_{12}$ and $S_{21}$ response for LNA s-parameter simulation by using *.s2p file	185
Figure 4.36	$S_{12}$ and $S_{21}$ response for LNA s-parameter simulation by using spice model	186
Figure 4.37	Gain and NF curves for *.s2p file simulations	187
Figure 4.38	Summary of results for Gain and NF simulation	187
Figure 4.39	Stability factor curve for *.s2p file simulations before resistive loading	188
Figure 4.40	Stability factor curve for *.s2p file simulations after resistive loading	189
Figure 4.41	Pout Vs Pin characterization of LNA ADL5521	190
Figure 4.42	S-parameter test circuit diagram for ADA4643	190
Figure 4.43	$S_{21}$ response for Pre-driver Amplifier	191
Figure 4.44	Pout Vs Pin characterization of Pre-Driver Amplifier ADL5606	192
Figure 4.45	$S_{21}$ response for Driver Amplifier	194
Figure 4.46	Pout Vs Pin characterization of Driver Amplifier ADL5324	194
Figure 4.47	Harmonic Balance test circuit diagram for mixer component	196
Figure 4.48	Harmonic balance signals from the mixing process	197
Figure 4.49	Harmonic balance signals of Up and Down-Conversion in WUT	198
Figure 4.50	Specification of ADL5350 in Datasheet	198
Figure 4.51	S-parameter test circuit diagram for Circulator component	203
Figure 4.52	S-parameter results for Circulator component test	203

Figure 4.53	Insertion loss and isolation of RF-LAMBDA RFLC-101-1 in datasheet	204
Figure 4.54	Frequency response of RF-LAMBDA RFLC-101-1 for Port1 and 2	205
Figure 4.55	Frequency response of RF-LAMBDA RFLC-101-1 for Port2 and 3	205
Figure 4.56	Insertion loss and isolation of RF-LAMBDA RFLC301G in datasheet	205
Figure 4.57	Frequency response of RF-LAMBDA RFLC301G for Port1 and 2	206
Figure 4.58	Frequency response of RF-LAMBDA RFLC301G for Port1 and 3	207
Figure 4.59	Data Sheet of ADF4360-3	209
Figure 4.60	RF output power of ADF4360 for Rx LO	210
Figure 4.61	RF output power of ADF4360 for Tx LO	210
Figure 4.62	Power level of the 2.4 GHz WiFi signal after 3dB attenuation	212
Figure 4.63	Power level of sum and difference frequency signal from the mixer	213
Figure 4.64	Power level of the output UHF signal	214
Figure 4.65	WUT Transmitter Test System Setup	215
Figure 4.66	Power level of the input UHF signal	217
Figure 4.67	Power level of the amplified UHF signal by LNA	218
Figure 4.68	Up converted Wi-Fi signal after suppression of difference signal	219

Figure 4.69	Power level of output signal at the front end of 2.4GHz transmitter	219
Figure 4.70	WUT Receiver Test System Setup	220

©This item is protected by original copyright

## LIST OF ABBREVIATIONS

ADS	Advanced Design System
BPF	Band Pass Filter
BW	Bandwidth
CAD	Computer-aided Design
CR	Cognitive Radio
dB	Decibel
dBm	Decibel of Measured power referenced to 1 milliwatt (mW)
DUT	Device Under Test
EF	Error Function
FCC	Federal Communications Commission
HPF	High Pass Filter
IEEE	Institute of Electrical and Electronics Engineering
IF	Intermediate Frequency
ISM	Industrial, Scientific and Medical
LNA	Low Noise Amplifier
LO	Local Oscillators
LOS	Line of Sight
LPF	Low Pass Filter
NF	Noise Figure
PA	Power Amplifier
PCB	Printed Circuit Board
PLL	Phase-locked Loop
PN	Part Number
RF	Radio Frequency
RX	Receiver
SAW	Surface Acoustic Wave
SNR	Signal-to-noise Ratio
TX	Transmitter
TVWS	TV White Space Spectrum
UHF	Ultra High Frequency
VBPF	Variable Band Pass Filter
VCO	Voltage Control Oscillator
VNA	Vector Network Analyzer
Vctrl	Voltage Control
WB	Wide-Band
WLAN	Wireless Local Area Network

Wi-Fi      Wireless Fidelity  
WUT      WIFI UHF Transceiver

©This item is protected by original copyright

## LIST OF SYMBOLS

$\Omega$	Ohm
$\epsilon_r$	Relative Permittivity
$\eta$	Efficiency
$\epsilon$	Permittivity
$\sigma$	Conductivity
$c$	Speed of light ( $3 \times 10^8 \text{ ms}^{-1}$ )
$\lambda$	Free space wavelength
$C$	Capacitance
$R$	Resistance
$L$	Inductance
$\epsilon_{eff}$	Effective permittivity
$\lambda_g$	Guided Wavelength
$Y$	Admittance
$f_c$	Resonance frequency

©This item is protected by original copyright

## **Rekabentuk WiFi UHF Transceiver Untuk Aplikasi Spektrum Ruang Putih Televisyen 650-680 MHz**

### **ABSTRAK**

Penyelidikan telah mencetuskan minat untuk mengkaji secara lebih mendalam sekiranya wujud kemungkinan untuk memanfaatkan frekuensi daripada ruang putih televisyen yang jarang digunakan dalam lingkungan band 470-770 MHz supaya dapat menggantikan Wi-fi frekuensi 2.4 GHz yang spectrum frekuensinya hampir habis digunakan. Reka bentuk, simulasi, fabrikasi, pembuktian secara eksperimen dan pengoptimuman terhadap litar didalam Wi-fi-UHF transceiver untuk mencapai kebolehan bagi membuat penukaran frekuensi secara menaikkan dan menurunkan frekuensi diantara 2.4 GHz dan band UHF adalah dipersembahkan didalam tesis ini. WUT yang mempunyai beberapa bahagian seperti penapis, pengadun, penguat dan pelemah direka secara menyeluruh melalui satu seni bina yang hanya menggunakan satu VCO-PLL untuk merealisasikan penaik dan penurunan signal RF diantara 2.4 GHz dan 650-680 MHz. Penurunan frekuensi diantara 2.4 GHz dan 650-680 MHz dilakukan semasa pemancaran signal RF manakala penurunan frekuensi berlaku sebaliknya. Dengan memprogramkan VCO-PLL kepada frekuensi tertentu sebagai pengayun setempat (LO) signal RF pada 2.4 GHz dapat diturunkan kepada mana mana frekuensi didalam lingkungan 650-680 MHz yang mana frekuensi tersebut akan dipancarkan menerusi antena ke udara. Pada laluan atau bahagian penerimaan frekuensi pula, penyelarasan keatas VBPF melalui potensiometer dapat membolehkan WUT menerima apa sahaja frekuensi didalam lingkungan 650-680 MHz yang akan bercampur dengan frekuensi LO tertentu daripada VCO-PLL yang sama untuk menghasilkan signal 2.4 GHz. Reka bentuk yang mempunyai mekanisma yang sebegini unik dapat membuka jalan agar WUT dapat berfungsi sebagai transceiver yang tidak memerlukan langsung pengubahsuaian keatas Wi-Fi modem yang sedia ada. ADS digunakan sebagai alat untuk membuat rekaan dan simulisasi terhadap bahagian-bahagian litar secara individu menurut speifikasi masing-masing sebelum kesemua bahagian-bahagian ini diintegrasikan menjadi satu sistem yang lengkap. Hasil simulasi membuktikan WUT berjaya menurunkan frekuensi daripada 2.4 GHz kepada 650-680 MHz dengan kenaikan 9.5dB manakala penaikan frekuensi daripada 650-680 MHz kepada 2.4 GHz juga berjaya dicapai. Begitu juga WUT yang sebenar dapat melakukan fungsi yang sama tetapi dengan penurunan 42.7dB untuk penaikan frekuensi dan 22.6dB untuk penaikan frekuensi.



# WiFi UHF Transceiver Design For Television White Space (TVWS) Spectrum Application

## ABSTRACT

Studies have sparked an interest to look further into the possibility of research to make beneficial of underutilized Television White Space (TVWS) frequency band of 470 MHz-770 MHz to substitute the 2.4 GHz Wi-Fi which has been running out of frequency spectrum. The design, simulation, fabrication, experimental validation and optimization of a Wi-Fi-UHF Transceiver (WUT) circuit to achieve a capability of up and down-conversion between frequency of 2.4 GHz and UHF band are presented in this thesis. The WUT which is consisted of subsections like filters, mixers, amplifiers and attenuators are comprehensively designed with an architecture of utilizing a single VCO-PLL to perform up-conversion and down-conversion of RF signals between 2.4 GHz and 650-680 MHz correspondingly. The down-conversion from 2.4 GHz to 650-680 MHz is performed during the RF transmission while up-conversion is the other way around. By programming VCO-PLL to certain frequency as local oscillator (LO), the 2.4 GHz RF signal can be down-converted to any frequency within 650-680 MHz which will be transmitted out from the antenna into the air. On the receiver path, pre-adjustment of the VBPF through potentiometer enabled WUT to receive any frequency within 650-680 MHz which will be mixed-up with certain LO frequency from the same VCO-PLL to generate the 2.4 GHz. Such unique design mechanism has paved the way for WUT to work as a transceiver without any change or modification required to the existing Wi-Fi modem. ADS is used as a tool to design and simulate the subsection circuits separately towards specific design goals prior to integration as complete WUT system. The simulation results shows that WUT is able to down-convert 2.4 GHz to 650-680 MHz with gain of 9.8 dB meanwhile the up-convert of 650-680 MHz to 2.4 GHz managed to have gain of 5.6 dB. Also the physical WUT is able to perform similarly, but with up-conversion gain of -42.7dB and down-conversion gain of -22.6dB.