COMPUTER AIDED DESIGN AND FACRICATION OF MICROWAVE BALANCED MIXER

MOHAMMAD AKASHAH BIN NOORDIN

This report is submitted in partial fulfillment of requirements for award of Bachelor of Electronic Engineering (Telecommunication Electronics) With Honours.

Faculty of Electronics and Computer Engineering
Universiti Teknikal Malaysia Melaka

MAY 2007

UNIVERSTI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : COMPUTER AIDED DESIGN AND FABRICATION OF MICROWAVE BALANCED MIXER

Sesi Pengajian : 2006/2007

Saya MOHAMMAD AKASHAH BIN NOORDIN
(HURUF BESAR)

mengaku membenarkan Laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (√) :

☐ **SULIT*** (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ **TERHAD*** (Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☑ **TIDAK TERHAD**

Disahkan oleh:

(TANDATANGAN PENULIS)

(COP DAN TANDATANGAN PENYELIA)

Alamat Tetap: NO. 38, KAMPUNG SUNGAI GELUGUR, 08000 SUNGAI PETANI, KEDAH

MAISARAH BT ABU
Ketua Jabatan (Kej Telekomunikasi)
Fakulti Kej Elektronik dan Kej Komputer (FKEKK),
Universiti Teknikal Malaysia Melaka (UTeM),
Karung Berkunci 1200,
Ayer Keroh, 75450 Melaka

Tarikh: 09/05/2007

Tarikh: 9/5/07

"I hereby declare that this report is the result of my own work except for quotes as cited in the references."

Signature : ....

Name : MOHAMMAD AKASHAH BIN NOORDIN

Date : 09 MAY 2007

"I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering (Telecommunication Electronics) With Honours."

Signature : ....
Name : MRS. MAISARAH BINTI ABU
Date : 09 MAY 2007

I dedicate this book to my family, my supervisor Mrs. Maisarah binti Abu, UTeM's lectures and all my dearest friends.

ACKNOWLEDGEMENTS

Special thanks to my supervisor, Mrs. Maisarah binti Abu for her guidance and support in favor of me to accomplish my project. Her patience and tolerance has made me more encouraged to make this project possible. Without her support and assistance the completion that I had now is unfeasible.

Not forgotten to Mr. Mohamad Zoinol Abidin bin Abdul Aziz for his direction in using Microwave Office 2004. His compassion is really helping me during the difficulties of finishing my work.

Last but not least to my friends Po'be and Kechik, for their invaluable assistances towards this thesis project and my family especially my parents. Without their support and understanding this project would not have been possible.

ABSTRACT

The purpose of this project is to design, fabricate and test the microwave balanced mixer circuit. The mixer was designed using Microwave Office 2004 software. Then the designed mixer was fabricated on FR4 board with the specification of dielectric constant, $\varepsilon_r = 4.7$ at frequency, f = 2.4GHz. Generally, mixer circuit needs the nonlinear element to generate the harmonic of spectrum signal. In this project the Schottky 1PS76SB17 from Philips Semiconductor was used to generate the output of spectrum consists of the original with the sum and different signal. Besides that, the hybrid or baluns circuit are needed to make the passive element operate efficiently. In this case, the directional coupler is used as the hybrid coupler. To ensure that the entire signal can be produced productively, the Wilkinson power divider is used. The performance of this mixer was simulated by simulating its isolation, return loss and insertion loss. The experimental validation to verify the performance of the designed mixer was done using the Network Analyzer and Spectrum Analyzer.

ABSTRAK

Tujuan utama pembinaan projek ini adalah untuk mereka bentuk, membina dan menguji pencampur gelombang mikro terimbang. Pencampur terimbang ini direka bentuk menggunakan perisian Microwave Office 2004 dengan spesifikasi pemalar dielektrik, $\varepsilon_r = 4.7$ pada frekuensi, f = 2.4GHz. Kebiasaannya, litar pencampur memerlukan elemen pasif untuk menghasilkan kepelbagaian isyarat spektrum. Dalam projek ini diod Schottky 1PS76SB17 dari Philips Semiconductor telah digunakan untuk menghasilkan isyarat yang mengandungi isyarat asli serta hasil tambah dan tolaknya. Selain itu, litar pencampur atau *baluns* diperlukan untuk memastikan elemen pasif itu berfungsi dengan sempurna. Dalam kes ini, pengganding terarah telah digunakan sebagai pengganding pencampur. Untuk memastikan keseluruhan isyarat dapat dihasilkan dengan produktif, pembahagi dua kuasa Wilkinson telah digunakan. Prestasi litar penambah ini diukur melalui pengasingan, kehilangan kembali dan kehilangan penyisipan. Eksperimen yang dijalankan untuk menilai prestasi litar ini dijalankan melalui Rangkaian Penganalisis dan Spektrum Penganalisis.

CONTENT

CHAPTER	TITLE		PAGE
	TITLE		i
	REPORT STATUS VERIFICATION FORM		ii
	SUPERVISOR APPROVAL		iii
	DECLARATION		iv
	DEDICATION		v
	ACKNOWLADGMENT		vi
	ABSTRACT		vii
	ABSTRAK		viii
	CONTENT		ix
	LIST OF ABBREVIATIONS		xiii
	LIST OF APPENDICES		xiv
	LIST OF FIGURES		xv
	LIST OF TABLES		xvii
	LIST OF SYMBOLS		xviii
I	**INTRODUCTION**		1
	1.1	PROJECT INTRODUCTION	1
	1.2	OBJECTIVES	2
	1.3	SCOPE OF WORK	2
	1.5	PROJECT METHODOLOGY	3
	1.6	EXPECTED RESULTS	5

II	**LITERATURE REVIEW**			6
	2.1	CHAPTER OVERVIEW		6
	2.2	MIXER THEORY		6
		2.1.1	Mixer Types and technologies	9
		2.1.2	Mixer Parameter	11
			2.1.2.1 Dynamic Range	11
			2.1.2.2 1dB Compression point	11
			2.1.2.3 LO Drive Level	12
			2.1.2.4 Conversion Loss	12
			2.1.2.5 Isolation	12
			2.1.2.6 DC Polarity	13
	2.3	DIRECTIONAL COUPLER		13
		2.3.1	Coupling Factor	16
		2.3.2	Loss	16
		2.3.3	Isolation	17
		2.3.4	Directivity	19
	2.4	WILKINSON POWER DIVIDER		19
		2.4.1	Lossless Divider	20
		2.4.2	Parameter Definition	25
			2.3.2.1 Insertion Loss	25
			2.3.2.2 Isolation	26
			2.3.2.3 VSWR	26
			2.3.2.4 Internal Power Dissipation	27
	2.5	SCHOTTKY DIODE		28
		2.5.1	Current and Voltage Relation	29
		2.5.2	Schottky Chip Equivalent Circuit	30

		2.5.3	Total Capacitance	31
			2.4.3.1 Junction Capacitance	32
			2.4.3.2 Overlay Capacitance	32
		2.4.4	Series Resistance	33
		2.4.5	Figure of Merit	34
		2.4.6	Mixer Diodes	35
			2.4.6.1 Equivalent Circuit	36
		2.4.7	Mixer Diode RF Parameter	37
			2.4.7.1 Conversion Loss Theory	37
			2.4.7.2 Noise Temperature Ratio	38
			2.4.7.3 Noise Figure	39
			2.4.7.4 RF Impedance	40
			2.4.7.5 IF Impedance	41
			2.4.7.6 Receiver Sensitivity	41
	2.5	MICROWAVE OFFICE 2004		42
III	**DESIGN PROCEDURE**			45
	3.1	CHAPTER OVERVIEW		45
	3.2	CALCULATION		45
		3.2.1	Calculation for Directional Coupler	46
		3.2.2	Calculation for Power Divider	52
	3.3	SIMULATION		55
		3.3.1	Mixer Simulation	56
		3.3.2	Result from Simulation	58
	3.4	FABRICATION		62

IV	**MEASUREMENT AND RESULTS**	65
	CHAPTER OVERVIEW	65
	4.1 FABRICATION METHOD	65
	4.2.1 Result from Measurement	66
V	**CONCLUSION AND SUGGESTION**	71
	5.1 CHAPTER OVERVIEW	71
	5.2 DISCUSSION	71
	5.3 CONCLUSION	73
	5.4 SUGGESTION	74
	REFERENCE	75

LIST OF ABBREVIATIONS

FTD	Frequency Time Domain
FET	Field Effect Transistor
VSWR	Voltage Standing Wave Ratio
SMT	Surface Mount Thickness
RF	Radio Frequency
IF	Intermediate Frequency
LO	Local Oscillator
EM	Electromagnetic
IEEE	Institute of Electrical and Electronic Engineers
PCB	Printed Circuit Board
UV	Ultra Violet
SNR	Signal to Noise Ratio
SMA	Sub Miniature version A
BALUNS	Balance and Unbalances

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Branch-Line coupler	77
B	Power Dividers	83
C	Data Sheet of Schottky diode 1PSxSB17	88

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.0	Project Methodology	4
2.0	The circuit of a diode single mixer	7
2.1	The circuit of a diode single mixer with balance control	8
2.2	Balanced mixer family circuit	10
2.3	Branch line coupler	14
2.4	Input and output port for branch line coupler	15
2.5	Coupling insertion loss	17
2.6	Two-tone receiver test	18
2.7	(a) Power division (b) Power combining	20
2.8	(a) Wilkinson power divider (b) Equivalent transmission line	21
2.9	Port simulation for Wilkinson power divider	22
2.10	Wilkinson power divider fabricating in the microstrip board	22
2.11	Schottky diode chip equivalent circuit	31
2.12	Mixing function	36
2.13	Equivalent circuit of a mixer diode	37
2.14	Design platform	42
2.15	Design flow	44
3.0	Length and width for transmission line	46
3.1	Directional coupler circuit	47

3.2	Calculation using TXline	49
3.3	Calculation using TXline for section B	52
3.4	Wilkinson power divider circuit	53
3.5	Calculation using TXline	54
3.6	Calculation using TXline for section B	54
3.7	Circuit schematic	55
3.8	Directional coupler circuit designed circuit	56
3.9	Wilkinson power divider designed circuit	57
3.10	Mixer designed circuit	57
3.11	Mixer EM structure	58
3.12	Return loss	58
3.13	Isolation	59
3.14	Insertion loss	59
3.15	VSWR	60
3.16	Input from port 1	60
3.17	Input from port 2	61
3.18	Ultra-violet ray unit	62
3.19	The etching tank	63
3.20	Complete balanced mixer circuit	63
3.21	Testing the functionality of the circuit using Network Analyzer	64
3.22	Using the Spectrum Analyzer	64
4.0	Return loss (Port 1,1)	66
4.1	Return loss (Port 2.2)	66
4.2	Return loss (Port 3,3)	67
4.3	Isolation (Port 1,2)	67
4.4	Insertion loss (Port 1,3)	68
4.5	Insertion loss (Port 2,3)	68
4.6	Output signal at 1.5GHz	69
4.7	Output signal at 1GHz	69

LIST OF TABLES

TABLE NO.	TITLE	PAGE
1.0	Expected result for single balanced mixer	5
2.0	Mixer comparison	11
3.0	Material parameter and electrical characteristic	46
3.1	Simulation result	61
4.0	Comparison between simulation and measurement result	70

LIST OF SYMBOLS

α_{mn}	Phase difference between the input signals at port m and port n
λ	Wavelength
λ_g	Guided wavelength
b	Coupling coefficient
Z_o	Characteristic impedance
C	Coupling
D	Directivity
I	Isolation
L	Transmission line length
Θ	Phase shift
w	Transmission line width
h	Substrate height
ε_r	Dielectric constant
ε_{eff}	Effective dielectric constant
c	Velocity of light in free space
f	Operating frequency
$tan\ \delta$	Dissipation factor
ε_o	Permittivity of free space
μ_o	Permeability of free space
M	Mitre variable
Γ	Reflection coefficient

CHAPTER I

INTRODUCTION

1.1 Project introduction

Mixer is a fundamental building block in many RF systems and is a standard component wireless communication systems. In most cases, the mixer plays a big role in defining the overall performance of these systems. This project deals with designing and developing microwave balanced mixer at 2.4GHz using Microwave Office 2004. IF bandwidth in microwave balanced mixers are generally limited of the frequencies below approximately 3 GHz, due to the physical realization of the single balanced out at the IF-port. RF input matching and RF-LO isolation can be improved through the use of this balanced mixer, which consist of directional coupler combined with the Wilkinson power divider. Certain parameters that have to be concerned in this project were conversion loss, isolation, bandwidth, signal spectrum and the VSWR of the mixer circuit.

1.2 Objectives

The objectives that are required to be achieved from this project are:

- To comprehend with the concept and the operation of balanced mixer.
- To design and simulate balanced mixer circuit using AWR/ADS software.
- To analyze the parameters of balanced mixer circuit
- To fabricate the circuit using the microstrip board.

1.3 Scope of work

- Search the information of the balanced mixer operation. Define the circuits and its components.
- Calculate the theoretical value for each parameter in the circuits. The dynamic range, LO drive level, conversion loss and DC polarity.
- Design and simulate balanced mixer circuit using AWR/ADS software. Make adjustment of the parameters if necessary.
- Construct the acceptably circuit from the simulating process using the microstrip board. Fabricate the coordination of each element.
- Testing and analyzing the mixer circuit using network analyzer and spectrum analyzer.

1.4 Project Methodology

Instruments

Design : Design by using Microwave Office 2004 software.

Fabrication : Fabricate by using FR-4 board.

Measurement : Vector network analyzer and spectrum analyzer.

The methodologies that are used to complete this project are, firstly defined the title from lecturer, suitable website, books and other appropriate references. The understanding of the concept of balanced mixer system, coupling signal, directional coupler and power divider is necessary to complete this project. Subsequently, the suitable diode is choosing. In this case the Schottky-diode from Philips manufacturing was chosen. Next, the designing of the balanced mixer is planned using the Microwave Office 2004 software. After that, the designed circuit was fabricated on the FR4 board. Lastly, the complete circuit was measured using network analyzer and spectrum analyzer. The complete methodology is shown in Figure 1.0.

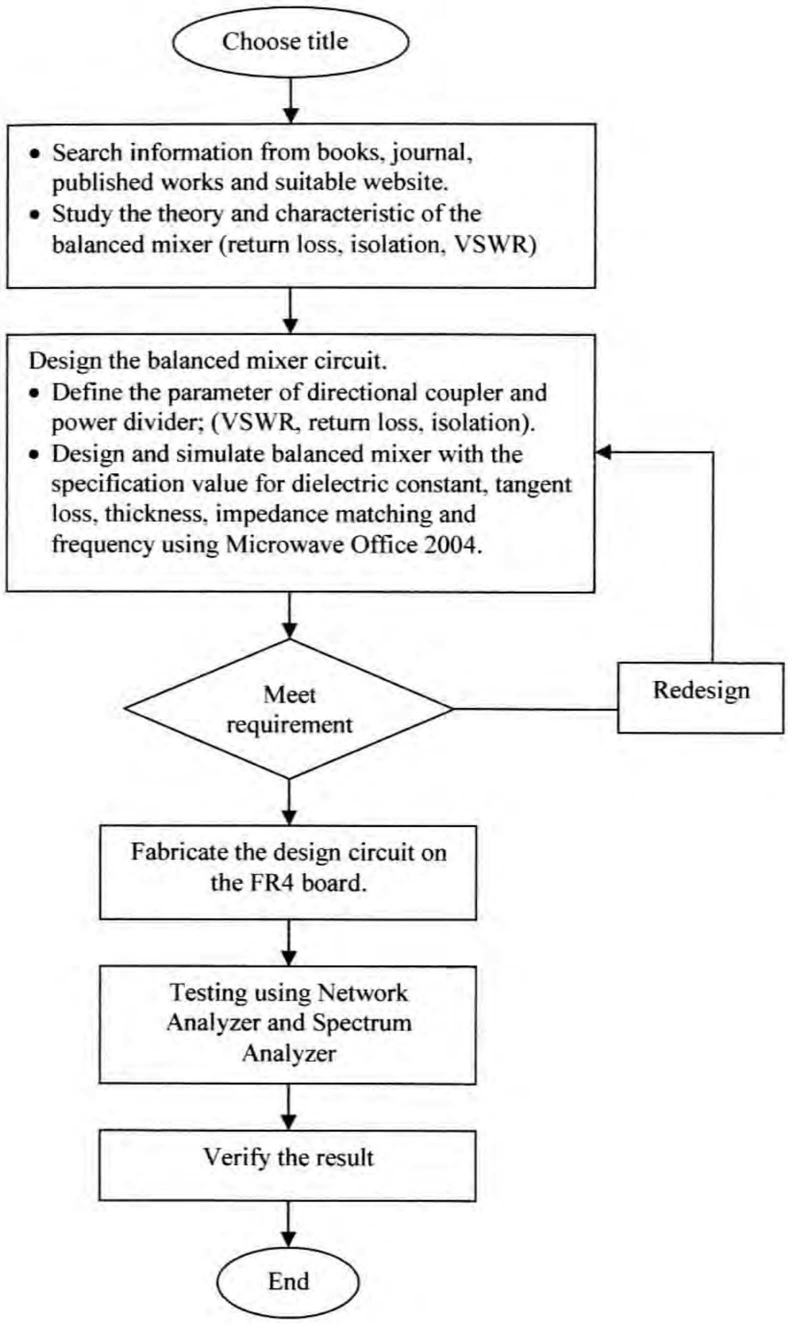

Figure 1.0: Project methodology

1.5 Expected Result

The input signals is the RF and LO, while the output signal is the IF in the case of a down-converter. Obtain minimum conversion losses and maximum isolation between the input and output ports. The expected result of this balanced mixer is shown in Table 1.0.

Conversion loss	3-7 dB
Noise figure	1-5 dB
Return Loss	20-40 dB
Isolation	10-30 dB
VSWR	1-3

Table 1.0: Expected result for Microwave balanced mixer.

CHAPTER II

LITERATURE REVIEW

2.0 CHAPTER OVERVIEW

This chapter mainly discuss about the theories for mixer, directional coupler, Wilkinson power divider and microwave office software that are used to complete this project. Certain method of calculation does not apply in this project because of the value for some parameters are depending on component's manufacturer.

2.2 MIXER THEORY

Mixers can be broadly categorized as a passive circuit. Passive mixers primarily use Schottky-barrier diodes, although a relatively new type of passive mixer, the FET resistive mixer, recently has become popular. FET resistive mixers use the resistive channel of a MESFET to provide low-distortion mixing, with approximately the same conversion loss as a diode mixer. Active mixers use either FET or bipolar devices. FETs (either MESFETs or HEMTs) are used for most microwave and RF applications where active mixers are employed; bipolar junction transistors (BJTs) and occasionally