Faculty of Electronic and Computer Engineering

DESIGN AND ANALYSIS OF SINGLE BALANCED DIODE MIXER FOR UWB APPLICATIONS

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Master of Science in Electronic Engineering

2018

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**A thesis submitted
in fulfillment of the 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 and Analysis of Single Balanced Diode Mixer for UWB Applications" 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 : Mohammed Yahya Qaid Al-gumaei

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 : Dr. Noor Azwan Bin Shairi

Date : ....

DEDICATION

To my beloved mother and father

ABSTRACT

In wireless communication systems, the development of ultra-wideband (UWB) Radio Frequency (RF) front-end sub-components (e.g. amplifiers, filters, switches, antennas and mixers) are highly desired, and they were developed to support several RF front-end systems. The main function of the RF mixer is frequency conversion, where the low conversion loss is one of the key parameters in RF mixer design. Mixer also act as critical components in modern RF and Microwave systems. The unique of the mixer is it can convert RF power from one frequency into another frequency. There are various forms of RF mixer designs which can be used to obtain a good conversion loss and good isolation where these mixer designs have trade off in performance and complexity. Hence, this research proposes an UWB Single Balanced Schottky diode mixer design using Coupled Line and Branch Line baluns for applications of ultra-wideband in 3 to 10 GHz frequency range. Basically, an UWB Single Balanced Schottky diode mixer was designed using two different baluns (Coupled Line and Branch Line). The usage of these two baluns aims to improve the bandwidth and producing a good performance in simple and inexpensive way. The used baluns are determined using a simple mathematical model where it can be combined from different multi sections of Coupled Line and Branch Line to achieve the desired bandwidth. The key advantage of the proposed UWB Single Balanced diode mixer with Coupled Line and Branch Line baluns is a wider bandwidth with low conversion loss and high isolation. Besides, low cost and small size as these mixers was designed in microstrip transmission line. As a result, the simulated and measured results showed conversion loss less than 19 dB and isolation of 50 dB over the frequencies between 3 to 10 GHz. Despite low conversion loss and high isolation performance, the proposed Single Balanced diode mixer (with Coupled Line and Branch Line baluns) used only two Schottky diodes compared to Double Balanced diode mixer to achieve good performance over UWB applications.

ABSTRAK

Dalam sistem komunikasi wayarles, pembangunan jalur lebar ultra (UWB) sub-komponen bahagian depan Frekuensi Radio (RF) (contohnya penguat, penapis, suis, antena dan pencampur) adalah sangat dikehendaki, dan ianya telah dibangunkan untuk menyokong beberapa sistem hadapan RF. Fungsi utama pencampur RF adalah penukaran frekuensi, di mana kehilangan penukaran yang rendah adalah salah satu parameter utama dalam reka bentuk pencampur RF. Pencampur juga bertindak sebagai komponen yang penting dalam sistem RF moden. Pencampur yang unik dapat menukar kuasa RF dari satu frekuensi ke frekuensi yang lain. Pelbagai jenis reka bentuk pencampur RF yang baik boleh digunakan untuk memperolehi kehilangan penukaran dan pengasingan yang baik di mana reka bentuk pencampur mempunyai keseimbangan tersendiri antara prestasi dan kerumitan. Oleh itu, kajian ini mencadangkan reka bentuk Pencampur diod Schottky Seimbang Tunggal UWB menggunakan balun garis berpasangan dan balun garis cabang untuk aplikasi UWB dalam lingkungan frekuensi 3 hingga 10 GHz. Pencampur diod Schottky Seimbang Tunggal UWB direka menggunakan dua balun yang berbeza (garis berpasangan dan garis cabang). Penggunaan kedua-dua balun ini bertujuan untuk menambahbaik lebar jalur dengan menghasilkan prestasi yang baik dengan cara yang mudah dan murah. Reka bentuk balun ditentukan dengan menggunakan model matematik yang mudah di mana ia boleh digabungkan dari pelbagai bahagian garis berpasangan dan cabang garis untuk mencapai jalur lebar yang dikehendaki. Kelebihan utama pencampur RF Seimbang Tunggal UWB yang dicadangkan dengan garis berpasangan dan garis cabang adalah lebar jalur yang lebih luas dengan kehilangan penukaran yang rendah dan pengasingan yang tinggi. Selain itu, kos yang rendah dan saiz yang kecil dapat dihasilkan pencampur ini direka bentuk dalam garis penghantaran mikrostrip. Hasilnya, keputusan simulasi dan pengukuran menunjukkan kehilangan penukaran adalah kurang daripada 19 dB dan pengasingan adalah 50 dB dalam lingkungan frekuensi 3 hingga 10 GHz. Walaupun kehilangan penukaran yang rendah dan prestasi pengasingan yang tinggi, Pencampur Seimbang Tunggal yang dicadangkan (dengan garis berpasangan dan garis cabang) hanya menggunakan dua diod Schottky berbanding dengan Pencampur Seimbang Berganda untuk mencapai prestasi yang baik dalam aplikasi UWB.

ACKNOWLEDGEMENTS

First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Dr. Noor Azwan Bin Shairi from the Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for his essential supervision, support and encouragement towards the completion of this thesis.

I would also like to thank my co-supervisor Prof. Dr. Zahriladha Bin Zakaria for his advices, recommendations and suggestions throughout this project. The door to my supervisors was always open whenever I had a question about my research or writing. He steered me in the right direction whenever he thought I needed it.

Special thanks to all my colleagues, my beloved mother, father and siblings for their moral support in completing this degree. Finally, thanks to everyone who motivated me to finish up my project.

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LIST OF ABBREVIATIONS

ADS	-	Advanced Design System
CMOS	-	Complementary Metal Oxide Semiconductor
DC	-	Direct Current
FCC	-	Federal Communications Commission
FET	-	Field-Effect Transistors
FR4	-	Flame Retardant 4
GaAs	-	Gallium Arsenide
LNA	-	low noise amplifier
LTE	-	Long Term Evolution
MEMs	-	Micro Electro Mechanicals
MMIC	-	Monolithic Microwave Integrated Circuit
MIMO	-	Multi-Input Multi-output
PCB	-	Printed Circuit Board
pHEMT	-	Pseudomorphic High Electron Mobility Transistor
RO4350B	-	Rogers series
RF	-	Radio Frequency
SiGe	-	Silicon Germanium
SIR	-	Step Impedance Resonator
SPST	-	Single Pole Single Throw
WiFi	-	Wireless Fidelity
WiMAX	-	Worldwide Interoperability for Microwave Access

LIST OF APPENDICES

LIST OF PUBLICATIONS

Journals:

1. M. Y. Algumaei, N. A. Shairi, Z. Zakaria and I. M. Ibrahim, 2018. "Design of Ultra-Wide-Band Single Balanced Schottky Diode Mixer," Journal of Telecommunication, Electronic and Computer Engineering (JTEC), 10(1-7), pp.63-66.

2. M. Y. Algumaei, N. A. Shairi, Z. Zakaria and I. M. Ibrahim, 2017. "Review of Mixer and Balun Designs for UWB Applications," *International Journal of Applied Engineering Research (IJAER),* 17, pp. 6514-6522.

Conference:

1. M. Y. Algumaei, N. A. Shairi, Z. Zakaria and B. H. Ahmad, 2018 "A Single Balanced Mixer using Compact Branch Line Balun for Ultra-wideband Applications," in; *IEEE International Workshop on Electromagnetics: Applications and Student Innovation Competition*.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Nowadays, the development of UWB RF front end sub-components such as mixer, filter (Zakaria *et al.*, 2013), switch (Zobilah *et al.*, 2016), amplifier (Saifullah *et al.*, 2016) and antenna (Abu *et al.*, 2016) are highly desired and are developed to support several RF front end systems. Traditionally, RF mixer has been the most misunderstood component available in designing and analyzing the modern microwave transceiver systems (Marki and Marki, 2010) and (Pavio *et al.*, 1988). The most common application of RF mixers is in the transceiver systems where two frequencies beat together in a nonlinear element to generate two different frequencies (Oxley, 2002).

In general, a mixer is a three port electronic device that uses a nonlinear or time-varying element to achieve frequency conversion (Pozar, 2012), where two of these ports are “input” ports and the other port is an “output” port. The nomenclature for the three mixer’s ports are the Radio Frequency (RF) port, the Local Oscillator (LO) port, and the Intermediate Frequency (IF) port. This concept is illustrated in Figure 1.1.

As a basic knowledge, there are several classes of mixer designs with different classifications, either diode or FET mixers, such as Single Ended mixers, Single Balanced mixers, and Double Balanced mixers, where these mixers have different circuit configurations depending on their specifications and applications that may be suitable from one to another (K. Chang, I. Bahl, 2002).

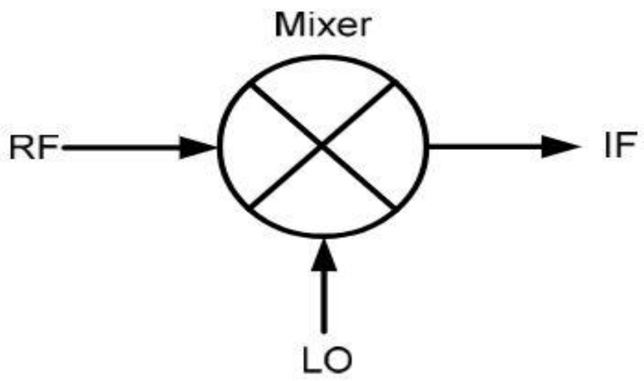

Figure 1.1: Diagram of the mixer.

The growing demand for ultra-wideband operational bandwidth with high quality and operational efficiency, lower manufacturing cost, and lower power consumption has become more widespread in microwave communication systems (Pozar, 2012). A Single Balanced diode mixer finds enormous applications in the modern microwave systems. There are several applications such as in microwave imaging, radars, communication, instrumentation, etc. Many of these applications concentrate on the frequency range between 3 to 11 GHz (Su *et al.*, 2014).

Therefore, in this study, an ultra-wideband discrete Single Balanced diode mixer for UWB applications is proposed. The Single Balanced diode mixer design was based on two Schottky diodes with two different types of baluns (Coupled Line and Branch Line). The balun circuit plays a major role in generating differential output signals that characterize balanced amplitude and phase, to convert the Single-Ended signal into a differential signal suitable for the input terminal of the mixer (Jorgesen and Marki, 2010). Besides that, a Low Pass Filter (LPF) was used in the mixer design to attenuate the unwanted signals and also to match the mixer's diode with the IF port.

1.2 Problem Statement

RF mixing is one of the key processes within RF technology and RF design. It enables signals to be converted to different frequencies and thereby allowing the signals to be processed more effectively. A good conversion loss (the difference in power between the input RF power level and the desired output IF frequency power level) is one of the key parameters in RF mixers design.

According to Kassiri; and Deen (2013), one of the most common problems in UWB transceiver systems designs is that the low noise amplifier (LNA) (as the first component after antenna) is usually Single-Ended and output of this component should be connected to the mixer which has a differential input structure. One solution to this is to build a balun (unbalanced to balanced converter) where a balun circuits play an important role in generating differential output signals which characterize balanced amplitude and phase, to convert the single ended signal to a differential signal suitable for input terminal of the mixer.

From literature study, there are various forms of RF mixer designs which can be used to obtain a good conversion loss and good isolation. However, for the solution of discrete circuit design using balanced mixer with passive element of diode, there are trade-offs in these good conversion loss, high isolation and bandwidth. Compared with Single Balanced diode mixer, more complex mixer circuit is created using two baluns and four diodes for Double Balanced diode mixer (Cao, Tang and Wang, 2016).

However, in microwave communication systems, the development of low cost and high performance wide band sub-components such as switches, filters, antenna and mixers are highly desired and developed to support several RF front-end systems. Hence, in this study, a Single Balanced topology with passive element of Schottky diodes has been used in RF mixer design with Coupled Line and Branch Line baluns in order to get a low conversion loss and high isolation with only two diodes and one balun circuit for Single Balanced diode mixer to support UWB applications.

1.3 Objectives

The objectives of this research work are as follows:

1. To design, fabricate and test ultra-wideband discrete Single Balanced diode mixer using Coupled Line and Branch Line baluns for UWB applications at frequency range from 3 to 10 GHz.
2. To analyze the performance of ultra-wideband Single Balanced diode mixer and validate the outcomes of the investigations through experimental works in a laboratory.

1.4 Scope of Research

The scopes of this research work are as follows:

1. To design ultra-wideband discrete Single Balanced diode mixer using Multi-Section Coupled Line balun using Advance Design System (ADS) software. The output spectrums of mixer are analyzed in the ADS software in terms of conversion loss and LO-RF isolation. The circuit of the mixer is designed as a layout in ADS in order to be prepared for fabrication.
2. To design ultra-wideband discrete Single Balanced diode mixer using Branch Line balun using Advance Design System (ADS) software. The output spectrums of the mixer are analyzed in the ADS software in terms of conversion loss and LO-RF isolation. The circuit of the mixer is designed as layout in ADS in order to be prepared for fabrication.
3. To fabricate the all circuits of ultra-wideband discrete Single Balanced diode mixer in order to validate the performance of the ultra-wideband discrete Single Balanced