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Faculty of Engineering

# DEVELOPMENT OF SAMPLING MIXER FOR ULTRA-WIDEBAND APPLICATIONS

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Bachelor of Engineering with Honours
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# DEVELOPMENT OF SAMPLING MIXER FOR ULTRA-WIDEBAND APPLICATIONS

**EZWAN BIN MUHAMAD**

This project is submitted in partial fulfilment of
The requirements for the degree of Bachelor of Engineering with Honours
(Electronics and Computer Engineering)

Faculty of Engineering
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*To my beloved family, friends and the one who need it*

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# ABSTRAK

Tesis ini ditulis bertujuan untuk membuat kajian tentang CMOS sampel signal digabungkan bersama LNA yang kurang gangguan untuk diaplikasikan pada rangkaian jalur lebar. Litar yang dicadangkan ini direka untuk berfungsi pada jalur lebar berfrekuensi 4GHz dengan menggunakan transistor berteknologi CMOS 0.18 μm. Teknik suis dua peringkat digunakan untuk mencapai penambahan kuasa yang tinggi, suis yang pantas dan bergangguan rendah. Daripada keputusan yang diperolehi menunjukan nilai ganguan adalah bersamaan dengan 3dB dan persampelan frekuensi mampu mencapai sehingga 250MHz dengan menggunakan voltan 1.8 V. Perisian PSpice digunakan untuk membuat simulasi litar dan memperolehi keputusan simulasi.

# ABSTRACT

This thesis aims to study the design of a low-noise CMOS sampling mixer with integrated switching LNA for ultra-wideband. The proposed circuit is designed to work at a wideband frequency of 4 GHz using CMOS 0.18 μm transistor technologies. A two stage switching technique is implemented to achieve low noise figure, high gain and fast sampling. The obtained results show a noise figure equal to 3 dB and sampling frequency up to 250 MHz with 1.8.V dc supply voltage. The simulation and result were obtained by using PSpice software.

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| | | |
|---|---|---|
| ADC | – | Analog to Digital Converter |
| ASIC | – | Application Specific Integrated Circuit |
| Clk | - | Clock |
| CMOS | – | Complementary Metal Oxide Semiconductor |
| dB | – | Decibel |
| dc | – | Direct Current |
| DSP | – | Digital Signal Processing |
| FCC | – | Federal Communication Commission |
| FET | – | Field Effect Transistor |
| FPGA | – | Field Programmable Gate Array |
| GHz | – | Giga Hertz |
| I-UWB | – | Impulse Ultra Wideband |
| IC | – | Integrated Circuit |
| IF | – | Intermediate Frequency |
| $IIP_3$ | – | Third Order Input Intercept Point |
| IMD | – | Intermodulation Distortion |
| JFET | – | Junction Field Effect Transistor |
| L | - | Length |
| LNA | – | Low Noise Amplifier |
| LO | – | Local Oscillator |
| LPI | – | Low Probability of Intercept |
| MAC | – | Medium Access Control |
| MDS | – | Minimum Discernable Signal |

| | | |
|---|---|---|
| MOS | – | Metal Oxide Semiconductor |
| MOSFET | – | Metal Oxide Semiconductor Field Effect Transistor |
| MHz | – | Mega Hertz |
| MC-UWB | – | Multicarrier Ultra Wideband |
| NF | – | Noise Figure |
| RF | – | Radio Frequency |
| RFIC | – | Radio Frequency Integrated Circuit |
| RFID | – | Radio Frequency Identification |
| Rms | – | Root Mean Square |
| SNR | – | Signal to Noise Ratio |
| Spurs | – | Spurious Signal |
| $S_1O_2$ | - | Silicon Dioxide |
| S/H | – | Sample and Hold |
| UWB | – | Ultra Wideband |
| W | – | Width |
| WPAN | – | Wireless Personal Area Network |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

RF mixer is an essential part of wireless communication systems such as cellular phones, global-positioning systems, and wireless broadband Internet. These are things that need to be considered in designing RF mixer such as conversion gain, linearity, input impedance, port to port isolation and noise figure. RF mixer is placed between low-noise amplifier (LNA) and analog to digital converter (ADC) of the receiver and also known as down conversion mixer. The function of the mixer is to perform frequency translation by multiplying two signals together, and produce an output containing both original signals, and new signals that have the sum, and difference of the frequency of the signals. Mixers have been implemented in a wide variety of ways. The most popular are diode mixers, Gilbert mixers, FET mixers and sampling mixers.

The diode mixer is a very popular design and available in a wide variety of frequency bandwidth and distortion specs. The main disadvantages of diode mixer are large LO power is required. With this much LO power and even with good isolation, there may be significant LO in the IF output. At large RF signal power, the RF voltage modulates the diode conduction, thus lots of distortion will result in this situation. Diode mixer also limited by baluns. FET mixer is not as well known but it has a good performance. The conversion loss will be similar to the diode mixer and large LO drive voltage is needed. Gilbert mixer is very widely used active mixer because it has better isolation than the diode and FET mixers, and it also require less LO power than the passive mixers. Its main liability is large signal handling capability because $IIP_3$ is much lower than passive mixers. The sampling mixer is preferred because it generates fewer spurs. It also done in low frequency and has low power consumption.

In telecommunication systems, noise figure is a measure of degradation of the signal to noise ratio (SNR). The noise figure is the ratio of the output noise power of a device to the thermal noise in the input at standard noise temperature (290K). Basically, the noise figure is the difference in decibels (dB) between the noise output of the actual receiver to the noise output of an ideal receiver with the same overall gain and bandwidth. This make the noise figure a useful figure of merit for terrestrial systems where the antenna effective temperature is usually near the standard 290K. In this case, one receiver with a noise figure 2dB better than another will have an output signal to noise ratio that is about 2dB better than the other.

Due to demanding performance requirements for wireless systems, several technologies have been considered for replacing the current wireless systems which is ultra-wideband (UWB). Ultra-wideband is a radio technology that can be used at very low energy levels for short range high bandwidth communications by using a large portion of the radio spectrum. This method is using pulse coded information with sharp carrier pulses at a bunch of center frequencies in logical connections. UWB communications transmit in a way that does not interfere largely with other more traditional narrow band and continuous carrier wave uses in the same frequency band. In particular, UWB wireless system has potentially low power, high data rate and resilience to multipath fading effect.

In general, this thesis will focus on designing the circuit in reducing the noise figure of a sampling mixer for ultra-wideband at transceiver part. This analysis is done due to the characteristic of a sampling mixer itself and future demand of wireless systems.

## 1.2 Project Objectives

1. To investigate the technique and method used for sampling mixer in order to decrease noise figure (NF).
2. To design a circuit topology and measure all components of sampling mixer in order to meet the specifications for ultra wideband (UWB) applications.
3. To gain knowledge of PSpice software and the various type of analysis.

## 1.3 Thesis Outline

Chapter 1 describes the problems statement and the issues for the mixers and the demanding performance of ultra-wideband. Furthermore it is also listed the main objectives of the thesis.

Chapter 2, the literature review section describes the theory and fundamental concept of ultra-wideband, noise, mixer and low noise amplifier. It will explain in more detail about the design concept approach.

Chapter 3 discusses specification for the design analysis and the selection of the appropriate circuit technology. It also discusses the sampling mixer and LNA design. The source determination and simulation results were stated with explanations. Thus, the design process was explained.

Chapter 4 discussed about the design simulation result and the analysis of the circuit. The results are discussed and testified related to the objective of the project.

Chapter 5 summarizes all the analysis for this project. The conclusions are made in this chapter based on the result and analysis. The recommendation for future development and improvement are also included in this chapter.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Ultra Wideband

Ultra wideband (UWB) communication systems can be broadly classified as any communication system whose instantaneous bandwidth is many times greater than the minimum required to deliver particular information. This excess bandwidth is the defining characteristic of bandwidth. The very first wireless transmission, via the Marconi Spark Gap Emitter was essentially a UWB signal created by the random conductance of a spark. The instantaneous bandwidth of spark gap transmission vastly exceeded their information rate. Users of these systems quickly discovered some of the most important wireless system design requirements which are providing a method to allow a specific user to recover a particular data stream and allowing all the users to efficiently share the common spectral resource.

In February 2002, Federal Communications Commission (FCC) legalizes Ultra Wideband (UWB) for commercial use with 7.5 GHz of unlicensed spectrum, allocated at 3.1 to 106 GHz frequency band. This opens a lot of commercial exploitation in short range high data rate wireless communication, Radio Frequency Identification (RFID), automotive sensor and through wall imaging. UWB allows up to a few centimeters ranging accuracy ranging and involve short discrete transmission pulses instead of continuously modulating a code into a carrier signal. This technology offers high data rates for radio communications, extremely high accuracy for location systems and good resolution for radars which using an inherently low cost architecture and only milli-watts of power. UWB has been the focus of much research and development recently. UWB offers solutions to applications such as see-through-the-wall, security applications, family communications and supervision of children, search and rescue, medical imagine, which makes UWB an ideal candidate for wireless home network [3].

UWB has several features that differentiate it from conventional narrowband systems;

i) Large instantaneous bandwidth enables fine time resolution for network time distribution, precision location capability or use as radar.

ii) Short duration pulses are able to provide robust performance in dense multipath environments by exploiting more resolvable paths.

iii) Low power spectral density allows coexistence with existing user and has a Low Probability of Intercept (LPI).

iv) Data rate may be traded for power spectral density and multipath performance.

UWB systems are unique because of their large instantaneous bandwidth and the potential for very simple implementations. Additionally, the wide bandwidth and potential for low-cost digital design enable a single system to operate in different modes as a communication device, radar or locator. Taken together, these properties give UWB systems a clear technical advantage over other more conventional approaches in high multipath environments at low to medium data rates.

Table 2.1: Summary of FCC restriction on UWB operation [3].

| **Application** | **Frequency Band for Operation** | **User Restriction** |
|---|---|---|
| Communications and measurement systems (sensors) | 3.1 – 10.6 GHz (different emission limits for indoor and outdoor systems) | None |
| Vehicular radar for collision avoidance, airbag activation and suspension system control | 24 – 29 GHz | None |

| | | |
|---|---|---|
| Ground penetrating radar to see or detect buried objects | 3.1 – 10.6 GHz and below 960MHz | Law enforcement, fire and rescue, research institution, construction |
| Wall imaging systems to detect objects contained in walls | 3.1 – 10.6 GHz and below 960 MHz | Law enforcement, fire and rescue, construction |
| Through wall imaging systems to detect location or movement of objects located on the other side of a wall | 1.99 – 10.6 GHz and below 960 MHz | Law enforcement, fire and rescue |
| Medical system for imaging inside people and animals | 3.1 – 10.6 GHz | Medical personnel |
| Surveillance systems for intrusion detection | 1.99 – 10.6 GHz | Law enforcement, fire and rescue, public utilities and industry |