DESIGN OF UP-CONVERSION MIXER USING SILTERRA 0.18 µm CMOS PROCESS TECHNOLOGY

Oleh

Mohd Zakaria Bin Husin

Disertasi ini dikemukakan kepada

UNIVERSITI SAINS MALAYSIA

Sebagai memenuhi sebahagian daripada syarat keperluan

untuk ijazah dengan kepujian

SARJANA MUDA KEJURUTERAAN (KEJURUTERAAN ELEKTRONIK)

Pusat Pengajian Kejuruteraan

Elektrik dan Elektronik

Universiti Sains Malaysia

Mei 2006

ABSTRACT

This dissertation presents a design of up conversion mixer for Ultra Wideband (UWB) application using Silterra 0.18 μm CMOS process technology. The design includes study of the current UWB technology, RF transceiver system and in depth of the mixer. After gain some knowledge of the design matters, the design of the real circuit is taken placed. The mixer that is going to be design is based on active double balanced Gilbert type topology. This type topology is chosen among the others topology (i.e. single balanced) because it have better performance in terms of gain, intermodulation, port-to-port isolation and the suppression of local oscillator (LO) signal. A large LO signal at the RF output port typically leads to very poor mixer intermodulation performance and can also cause compression in the first RF amplifier. A double balanced mixer structure provides not only fully differential, but also a virtual ground for the LO signal at the output RF port, and no special active or passive circuitry is required to provide this LO short. In this design, new technique to improve linearity and performance of the mixer was introduced. Current bleeding technique using PMOS was utilized in the design in order to improve the linearity, conversion gain and noise figure. The performance of this mixer is expected to have conversion gain larger than 5 dB, 1dB compression larger than 5 dBm, input IP3 (IIP3) larger than 10 dBm and consume power of 36 mW from 1.8 V supply voltage. Mixer will multiply input signal IF which is frequency at 264 MHz with local oscillator (LO) signal which is frequency at 3.96 GHz and hence produced the output RF signal which is at frequency of 3.696 GHz. All simulation of the mixer is done by using Spectre from Cadence design kit.

ABSTRAK

Disertasi ini mempersembahkan rekabentuk pencampur naik (up mixer) untuk kegunaan UWB dengan menggunakan teknologi proses piawai CMOS Silterra 0.18 μm. Rekabentuk pencampur ini melibatkan pemahaman tentang UWB, system RF dan secara mendalam berkenaan pencampur. Selepas memperolehi serba sedikit pengetahuan tentang perkara-perkara yang berkaitan, pembinaan litar dimulakan. Pencampur yang akan direkabentuk kelak adalah berdasarkan kepada topologi jenis dwi terimbang aktif Gilbert. Topologi ini dipilih dalam rekabentuk kerana mempunyai prestasi yang baik dari segi gandaan, pengasingan diantara liang (port) dan penindasan isyarat LO. Dalam rekabentuk ini, teknik baru telah diperkenalkan untuk meningkatkan lelurusan dan gandaan penukaran. Teknik pendarahan arus menggunakan transistor PMOS telah diperkenalkan dalam rekabentuk ini dengan tujuan untuk memperbaiki lelurusan dan gandaan penukaran. Rekabentuk ini adalah untuk digunakan dalam system UWB tetapi, untuk memudahkan, hanya satu saluran sahaja daripada 3 saluran dalam mod 1 UWB yang akan digunakan dalam rekabentuk. Prestasi pencampur ini dijangkakan menghasilkan gandaan lebih besar daripada 5 dB, pemampatan 1dB lebih besar daripada 5 dBm, masukan IP3 (IIP3) lebih besar daripada 10 dBm dengan melesapkan kuasa sebanyak 36 mW daripada sumber voltan sebanyak 1.8 V. keluaran RF dengan frequensi 3.696 GHz dimana masukan IF mempunyai frekuensi 264 MHz dan LO pula mempunyai frekuensi 3.96 GHz. Kesemua penyelakuan litar dilakukan menggunakan kit rekabentuk Cadence. Penyelakuan yang dilakukan adalah berdasarkan penyelaku Spectre. Pencampur ini dijangkakan mempunyai perlakuan/prestasi yang baik dengan lelurusan yang tinggi dan baik gandaan penukaran.

ACKNOWLEDGEMENT

Alhamdulillah, thanks to Allah for blessing me and give me strength and ability to complete my project and done this report at this hard of moment. Without Him, I would not be able to complete my work.

I want to thanks to School of Electric and Electronic, Science University of Malaysia for providing me the final year project. Without this project, I would not be able to graduate from this university. First and foremost, my sincerest gratitude goes to Dr. Tun Zainal Azni Zulkifli, who not only as my supervisor for this final year project but also as my beloved lecturer. Without his invaluable knowledge and guidance throughout this thesis, impossible for me to understand everything of what I'm doing.

I also want to thanks Dr.Tun Zainal because providing me the Cadence design tools to assist my project. I must admit that, without those tools, very difficult for me to do any simulation.

Next I would like to thanks my thesis teammates, Yap Hock Liam, Moh Kim Hock and Ruhaifi Abdullah Zawawi for their assistance, support and encouragement through this thesis. My sincere thanks must also go to all my friends who have supported me in many ways through these years.

Last but not least, I would like to take this opportunity to thanks my family especially my mother who had always support and encourage me in many fields.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

AC	Alternating Current
C	Capacitor
DC	Direct Current
dB	Decibels
dBm	Decibels with respect to 1mW
DRC	Design Rule Check
DSB NF	Double-Sideband Noise Figure
F	Noise Factor
G_m	Transconductance of the Gilbert mixer
g_m	Gate Transconductance of a MOSFET
IC	Integrated Circuit
ID	MOSFET Drain Current
IF	Intermediate Frequency
IM3	Third-Order Intermodulation Products
IP3	Third-Order Intercept Point
IIP3	Input-IP3
L	Inductor
LNA	Low Noise Amplifier
LO	Local Oscillator
LPF	Low Pass Filter
LVS	Layout versus Schematic

MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
NMOS	N-channel MOSFET
NF	Noise Figure
OFDM	Orthogonal Frequency Division Multiplexing
P1dB	1dB Compression Point
PLL	Phase Locked Loop
RF	Radio Frequency
R	Resistance
RFIC	Radio Frequency Integrated Circuit
PSS	Periodic Steady State
SNR	Signal-to-Noise Ratio
SSB NF	Single-Sideband Noise Figure
SPDR	Spurious-free Dynamic Range
SPSS	Swept Periodic Steady State
UWB	Ultra Wideband
VCO	Voltage Controlled Oscillator
VRF	Voltage Amplitude of RF signal
VLO	Voltage Amplitude of LO signal
VDS	Voltage of Drain Relative to Source
VGS	Voltage of Gate Relative to Source
VTH	Voltage of Transistor Threshold

CHAPTER 1

INTRODUCTION

1.1 Introduction To UWB System

Ultra wideband (UWB) is one of the newest technologies for radio frequency (RF) wireless communication system. This unique system uses a short duration pulse (about few nano-seconds) signal to transmit a data, unlike the traditional narrowband system which uses a sinusoidal signal to transmit a data [Carson, 1990]. This comparison can be shown in **Figure 1.1**.

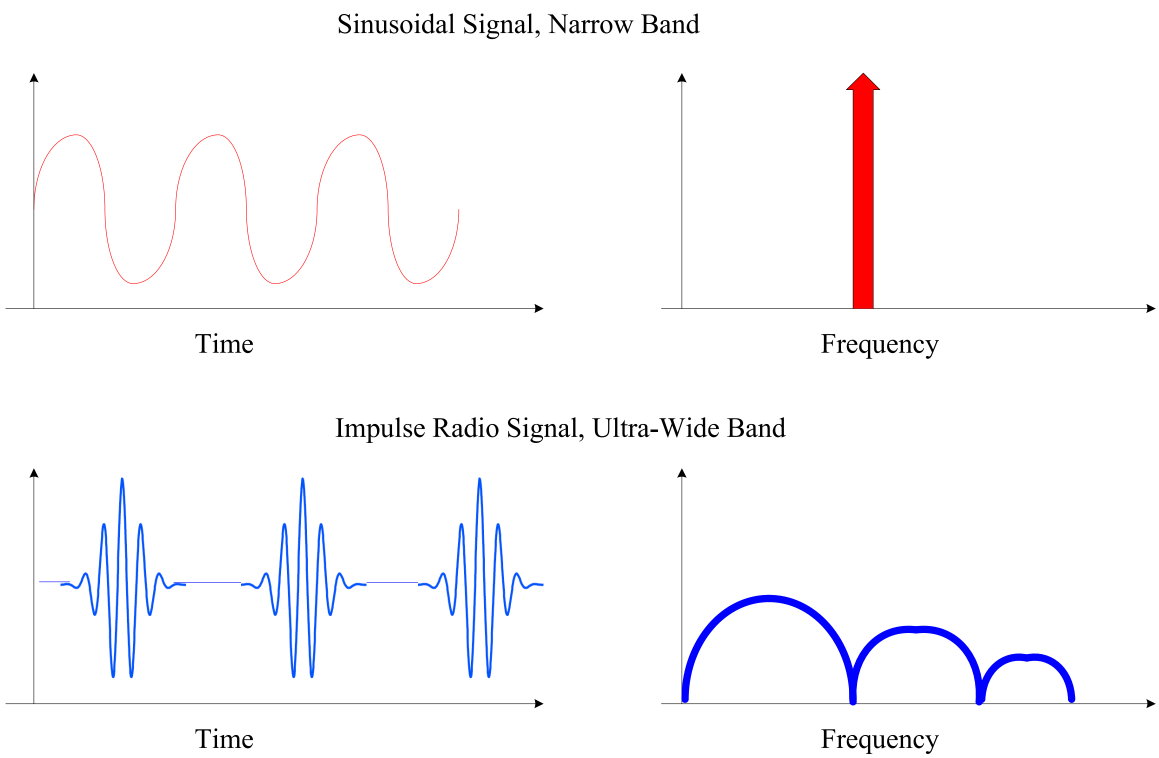

Figure 1.1: Comparison between UWB and narrowband

This short duration pulse transmission result in wide bandwidth at frequency spectrum. UWB formerly intended for military communication, radar and remote sensing uses only. Since March 2002, the Federal Communications Commission (FCC) in the United States has issued to extend the used of UWB for data communications as well as for radar and safety applications. After recognizing the potential advantages of UWB, the Federal Communications Commission (FCC) developed a report to allow uses of UWB as a communications and imaging technology. Since there, many countries have developed a regulation for use UWB as a data communication.

Ultra wideband signals are different with narrowband signal in many ways. All narrowband signals have large periods resulting in a narrow spectral bandwidth, which deviates around a carrier frequency [Colomines, et al, 1998]. Ultra wideband signals have exactly the opposite characteristics. They transmit small impulses, typically having pulses duration about few nano-seconds. The result of having such small impulse is that ultra wideband signals have spectral density spread out over a wide range of frequency in the range of giga-hertz.

With its large bandwidth, ultra wideband systems are able to support high data rates up to 400 Mbps for short range application. With such high data rates, it even surpasses the current favorite IEEE 802.11. Another advantage of having such broad range of frequency is that ultra wideband signals would be able to penetrate through walls, making a transfer of high resolution video through wall become a reality. Besides having a large bandwidth, the power density of the signal is also being spread over the large range, causing the signal to almost disappear among noises. Since the transmitted signals are at noise level, a well-designed ultra wideband system should not be interfering with the transmission of the other narrowband signals and thus can co-exist with the current narrowband technologies. Overlapping between UWB system and other wireless system is shown in **Figure 1.2**. In addition, working in noise level enables transmission of the signals to be carried out in a highly secured condition. Ultra wideband systems have low power level requirements, meaning that it can save longer battery life and very useful for wireless devices.

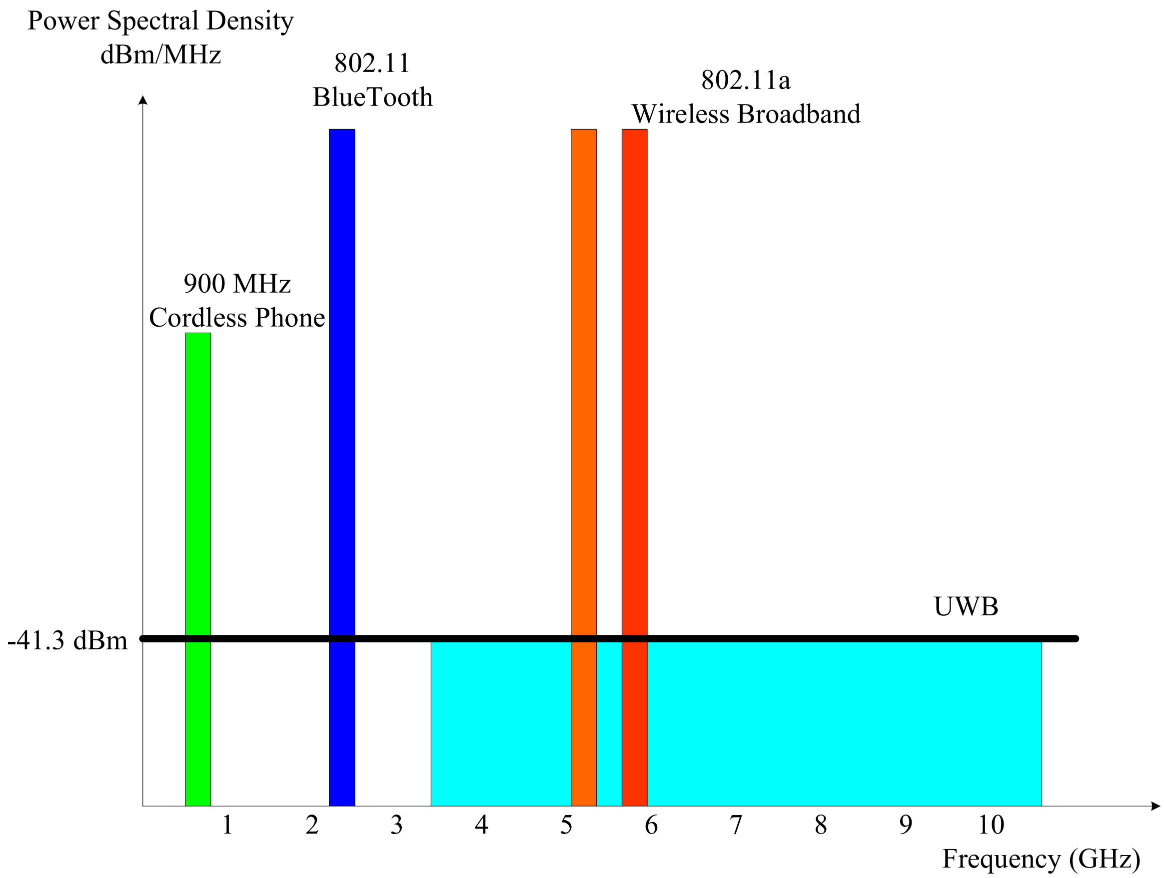

Figure 1.2: Overlapping between UWB and other wireless system

As the spectral density of ultra wideband signals are very wide, there has always been a concern of it interfering with the existing narrowband system. That is why FCC came up with a set of regulations restricts the operations of devices utilizing ultra wideband technologies. However, one of the important conditions is that the power levels of the UWB signal in this spectrum must be low enough to avoid interference with the already existing RF systems.

The FCC has specifies the certain power emission levels and put a restriction to that. Part 15 from the FCC restriction implies that the highest emission power level must not exceed -41.3 dBm per MHz. This is a very low power and suitable for co-existing with other technologies in the UWB allocated band.

FCC defines ultra wideband signals as signals having fractional bandwidth greater than 0.20 or has an absolute bandwidth greater than or equal to 500MHz, regardless of what the fractional bandwidth is. Here are some of the other terms FCC uses to define ultra wideband signals.

- Fractional Bandwidth (measured from -10 dB below peak emission)

$$FractionalBandwidth, \eta = \frac{2(f_H - f_L)}{f_H + f_L} \qquad (1.1)$$

Where, f_H and f_L denotes the upper and the lower frequency respectively.

- Bandwidth = frequency bounded by the two points 10 dB below the maximum emitted emission
- Center frequency, f_C

$$f_C = \frac{f_H + f_L}{2} \tag{1.2}$$

1.2 Introduction To Transceiver

Transceiver is the most important part in RF front-end wireless communication system. It contain of transmitter path and receiver path. The basic and simple transceiver system is shown in **Figure 1.3**.

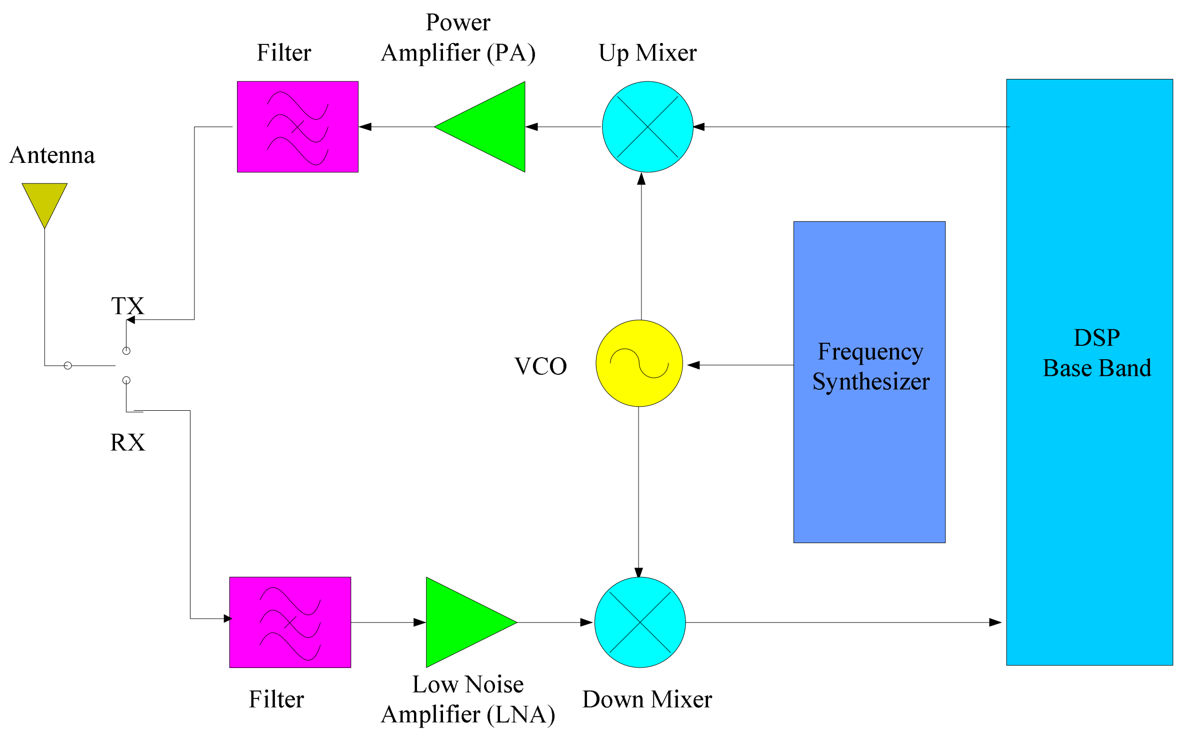

Figure 1.3: Basic Transceiver system

At the receiver path, the RF signal which is at the higher frequency is received through antenna and going into filter. In this filter, the signal is filtered out and only desired frequency is passed to the next stage. The signal is then amplified through low noise amplifier (LNA). From LNA, that signal is down converted to intermediate frequency (IF) or base band frequency (BB) which is at the lower frequency by multiply it with local oscillator (LO) before the signal can be extracted to get any information at the base band stage. This multiplication process is done by down mixer.

At the transmitter path, the information signal is received from the digital base band. This signal then is up converted to the higher frequency. Conversion of lower frequency base band signal to a higher frequency RF signal is done by up mixer. Conversion of signal by up mixer is simply multiplication process between base band signal and the local oscillator (LO). The up converted signal is then amplified by the power amplifier (PA) to amplify the signal before it can be transmitted.

1.3 Objective Project

This project objective is to design an up-conversion mixer for UWB application using Silterra 0.18 μm CMOS technology. The design is based on Gilbert type mixer with utilizing current bleeding technique. This current bleeding technique which is formed from the PMOS transistor is expected to have high linearity and better conversion gain. From the proposed OFDM UWB band, this design using channel 2 from mode 1 which is range of frequency from 3.696 GHz to 4.224 GHz with the centre frequency at 3.96 GHz.

The input IF signal is at 264 MHz and the LO signal is at 3.96 GHz which from the mixing will produce 3.696 GHz and 4.224 GHz. 4.224 GHz can be filtered out because that is not the interest of frequency.

Beside of the learning how to design a good up conversion mixer, through this project also can give new knowledge about the latest technology of wireless communication system which is UWB system. UWB system is a unique wireless system because it operates with very low power and can give a high data rates transfer compared to others wireless system. Design for such condition is very difficult and very challenging. Through this project also can give a valuable experience from usage of the Cadence design tools. This design tools is one of the state of the art design tools which is used by many company and design foundry for their design purpose.

1.4 Report Organization

There are three primary topics of interest discussed in this dissertation, including discussion of UWB system, design of front-end up conversion mixer, and a simulation to evaluate the performance of the overall mixer.

Chapter 1 provides some basic background information on UWB system including the basic definition, specification and the application. Introduction to transceiver system also has been discussed in this chapter. The whole transceiver block systems have been explained briefly including the transmission of the RF signal.

Chapter 2 and 3 are discussed more in the mixer including the introduction, basic definition of mixer, important characteristic of mixer such as conversion gain, noise figure and linearity. Topology of mixer also has been discussed in this chapter where at the end, the best topology was chosen for detail design.

The detail design of up mixer is described in chapter 4. Better technique to improve the performance of the mixer was introduced and implemented in the design. Final design of the core mixer has been discussed in this chapter.

Chapter 5 discussed more in simulation of the mixer which is including the design tool, design specification, type of analysis using for run the simulation and overall performance summary also has been discussed.

CHAPTER 2

MIXER THEORY

2.1 Introduction

Mixers are essential part of RF front-end transceiver which they are used to translate (multiply) from one frequency to another frequency. Both side of the front-end transceiver, either at the receiver path or the transmitter path, have the mixer to perform a frequency translation. At the transmitter path, this translation can be done by multiplying the incoming signal (either IF signal or BB signal) with the local oscillator (LO) signal, hence produced desired signal (RF signal). This operation are called an up-conversion because it translate smaller incoming frequency (IF or BB) to a higher frequency (RF), while at the receiver, the operation are called as down conversion because it translate from high frequency (RF) to lower frequency (IF).

2.2 Basic Conceptual Of A Mixer

All mixer types work on the principle that a large local oscillator (LO) drive will cause switching (or modulating) the smaller incoming intermediate (IF) or baseband (BB) frequency to a higher outgoing radio frequency (RF). This operation can be realized from **Figure 2.1** as shown as follow.

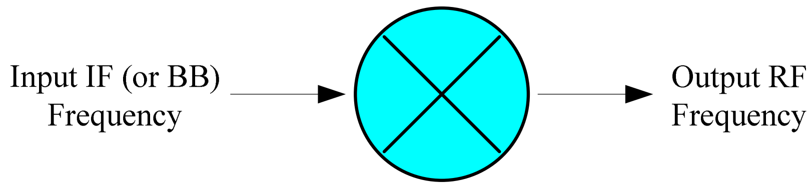

Figure 2.1: An Up-Conversion Mixer Model

The basic operation of a mixer can be done by multiplication of two signals in the time domain as shown in equation below [Gray, et al, 2000].

$$V_{IF} = A\sin(\omega_1 t + \theta_1) \quad (2.3)$$

$$V_{LO} = B\sin(\omega_2 t + \theta_2) \quad (2.4)$$

Hence, the result of multiplication signal will be,

$$V_{IF} * V_{LO} = V_{RF} = AB\sin(\omega_1 t + \theta_1)\sin(\omega_2 t + \theta_2) \quad (2.5)$$

Using identity of trigonometry,

$$V_{RF} = -\frac{AB}{2}\left[\cos((\omega_1 t + \theta_1) + (\omega_2 t + \theta_2)) - \cos((\omega_1 t + \theta_1) - (\omega_2 t + \theta_2))\right] \quad (2.6)$$

$$V_{RF} = -\frac{AB}{2}\left[\cos((\omega_1 + \omega_2)t + (\theta_1 + \theta_2)) - \cos((\omega_1 - \omega_2)t - (\theta_1 + \theta_2))\right] \quad (2.7)$$

where,

A and B are constant

From the multiplication result in equation (2.5), there are two type of frequency for RF The sum of frequency which is desired frequency (RF frequency),

$$\cos((\omega_1 + \omega_2)t + (\theta_1 + \theta_2))$$

and the difference frequency which it's not desired frequency and can be filtered out,

$$\cos((\omega_1 - \omega_2)t - (\theta_1 - \theta_2))$$

From the schematic perspective, a mixer generally have a gain stage as an input, a switching stage as a current steering/switching and a differential RF output stage such as the one as shown in **Figure 2.2** [Lee, et al, 2000].

The input current from the IF frequency is amplified by the gain stage at the bottom of the circuit. The amplified current from the gain stage is then steered to one side of the output or the other depending on the value of the LO drive voltage. The result from this switching is a mixing of the LO and IF frequencies with the output are differentially.

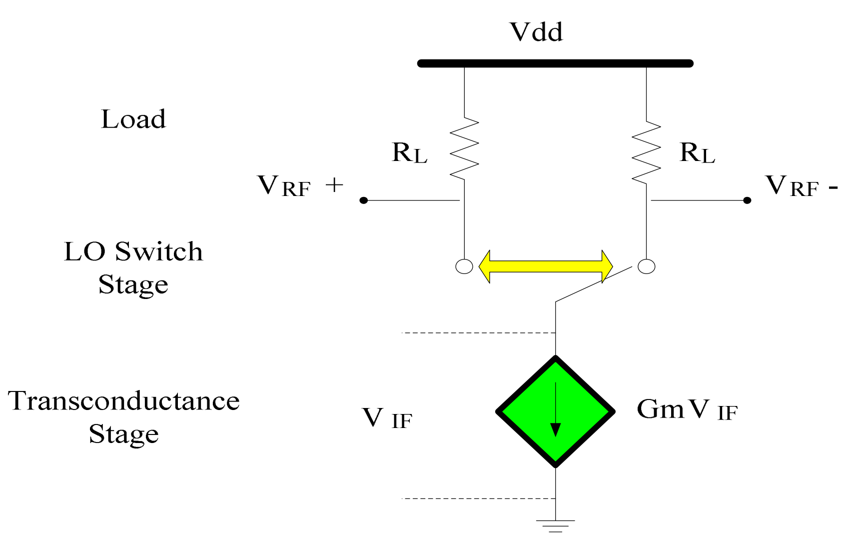

Figure 2.2: Simple conceptual schematic of a mixer

2.3 Characteristic Of A Mixer

The design of mixers forces many compromises between conversion gain, local oscillator (LO) power, linearity, noise figure, port-to-port isolation, voltage supply and current consumption. Because mixer is not a linear device and it is very difficult to achieve all characteristic performance simultaneously, so the specifications of mixer performance must be prioritized, based on the application. For transmitter, the noise figure is not so important rather than linearity and conversion gain. All this specification will be discussed further in this chapter.

2.4 Conversion Gain

The conversion gain of a mixer can be defined as the ratio (in dB) between the output RF signals to the input IF signal. This ratio can be defined in two terms, which are the voltage conversion gain and the power conversion gain. The voltage conversion gain is the ratio of the rms (root means square) voltage of the RF signal (from the sinusoidal signal) to the rms voltage of the IF signal.

$$VoltageGain(dB) = 20\log\left(\frac{V_{RF}(rms)}{V_{IF}(rms)}\right) \qquad (2.8)$$

where,

$$V(rms) = \frac{V_{peak}}{\sqrt{2}} \qquad (2.9)$$

The power conversion gain of a mixer is defined as the RF power delivered to the load divided by the available IF power from the source.

$$PowerGain(dB) = 10\log\left(\frac{P_{RF}}{P_{IF}}\right) \quad (2.10)$$

From both equation of conversion gains (2.8) and (2.10), the mixer is said to have a gain if the result is positive value, while if the result is negative value, the mixer is said to have a loss in gain. The conversion gain of a mixer is an important characteristic because it determines the overall system performance. The system will have high linearity from the high conversion gain.

2.5 Noise Figure

In any electrical circuit, signals are subjected to degradation and corruption due to the effects of physical interaction between traveling electrons. This noise corruption can be measured as signal-to-noise (SNR) ratio. Signal-to-noise (SNR) ratio also can be defined as the ratio of the signal power to the total noise power. Noise factor (F) is defined as the ratio between SNR at the input relative to SNR at the output. Noise figure is noise factor measured in decibels [Razavi, 2001].

$$NoiseFactor, F = \frac{SNR_{IN}}{SNR_{OUT}} \quad (2.11)$$

$$NoiseFigure(NF) = 10\log F = 10\log \frac{SNR_{IN}}{SNR_{OUT}} \tag{2.12}$$

From the equation (2.12), it shows that from the noise figure (NF) equation, we can measures how much the signal-to-noise ratio (SNR) of a signal degrades because of the added noise as it passes through the mixer.

Basically, there are two types of noise figure in mixer,

i. Single-sideband noise figure
ii. Double-sideband noise figure

2.5.1 Single-sideband (SSB) Noise Figure

Single-sideband (SSB) noise figure is used for mixer if the only one side band of the noise from the signal ω_1 and not the image frequency ω_1-1 as an input to a mixer. This is the case where there are a band-pass filter added in front of the mixer. Example of the single-sideband noise figure can be illustrated from **Figure 2.3**.

Let say, the input frequency, IF= 264 MHz, LO= 1900 MHz, hence will give the output frequency RF= 2164 MHz with the image frequency of 1636 MHz as shown in **Figure 2.3**.

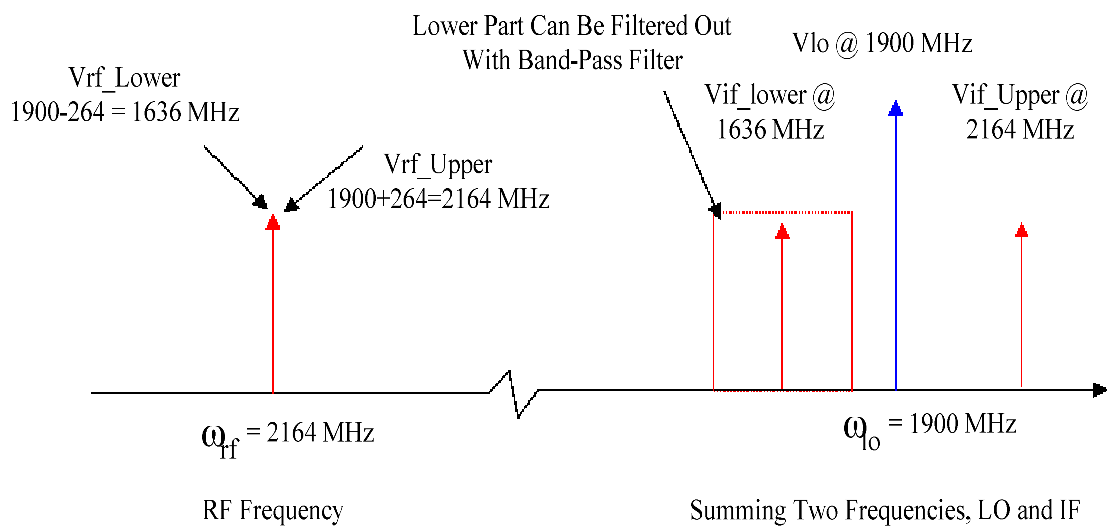

Figure 2.3: Single-sideband conversion of noise figure

2.5.2 Double-Sideband (DSB) Noise Figure

Double-sideband (DBS) noise figure is used in mixer when the input signal is contain both upper and lower sideband. In DSB NF, both sidebands are available thus it has twice as much power available at the RF port compared to the SSB signal. As a result, its conversion loss is 3dB less than that of an SSB NF signal. In other words, since the SSB-NF has signal power in only one sideband and both measures between SSB-NF and DSB-NF contribute the same amount of RF noise, the SSB NF will amount to 50% or 3dB higher than that of the DSB NF.

2.6 Linearity

It is clearly that, all active RF devices such as the mixer are non-linear when operating especially when the device deals with large frequency of signal. Linearity describes the region of operation where the output signal varies proportionally to the input signal. Linearity is very important characteristic in mixer design. Losing linearity in mixer will cause the output signal to be distorted. There are several ways to measure the linearity of a mixer. 1-dB compression and the third order intercept points are typically used to measure linearity [Razavi, 1998].

2.6.1 1-dB Compression

For the ideal linear device, the desired output power is linearly proportional to a given input power. However, as we know that, mixer is not a linear device and due to the effects of noise and intermodulation distortion, mixer behavior will deviate from desired linearity thus entering a region of saturation or compression. The 1dB compression point is simply described as the point where the output power of the mixer is 1dB less than of the ideal gain for a given input power. 1dB compression point is shown in **Figure 2.4**.

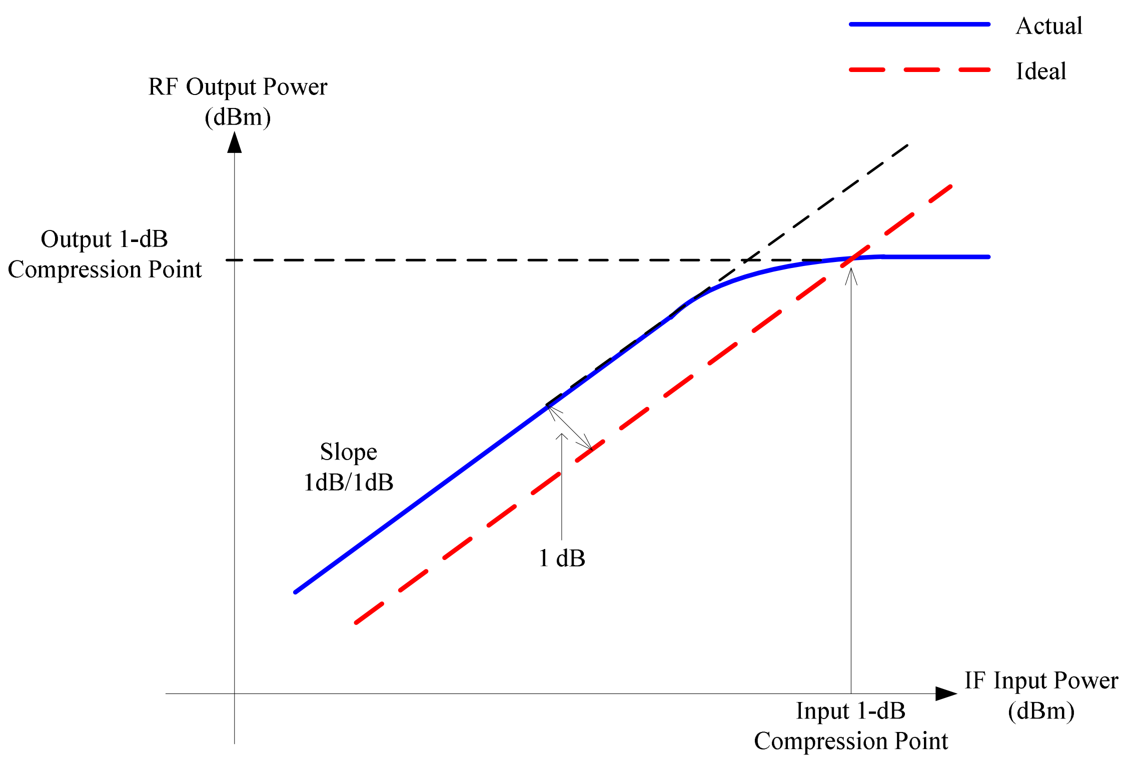

Figure 2.4: Definition of the 1-dB Compression Point

2.6.2 Third Order Intercept Point (IP3)

Third order intercept point (IP3) is a theoretical point at which the fundamental and third order response intercepts. This point is found when two input signals spaced relatively close together on the frequency spectrum fed into the mixer, one being the desired signal from the channel of interest and the other being the undesired signal (an interfering signal of the adjacent channel). The effects of these signals are known as intermodulation and appear at the output of the mixer. The most critical and important one is the third-order intermodulation (IM3) product since it falls directly in the frequency band of interest. This situation can be shown in **Figure 2.5 (a)**. The IM3 components will be at $2\omega_1 - \omega_2$ and $2\omega_2 - \omega_1$ which is in the desired frequency causing intermodulation distortion.

The undesired intermodulated signals are amplified by a non-linear cubic relationship to the input signal strength. Ideally we can say that as the IF input power signal increases, the output power of the undesired IM3 signals will intersect with the output power of the RF signal. This intersection is referred to as the IP3 point [Razavi, 1998].

In the reality, this intercept point will never really occur because of the fact that signal will saturate at some certain point. The extrapolation of their linear line will serve as a good estimation for the IP3 point. This IP3 can be illustrated as **Figure 2.5 (b)**. If the IP3 is referenced to the input or output power of the mixer, it is known as the input third-order intercept point (IIP3) or output third-order intercept point (OIP3) respectively.

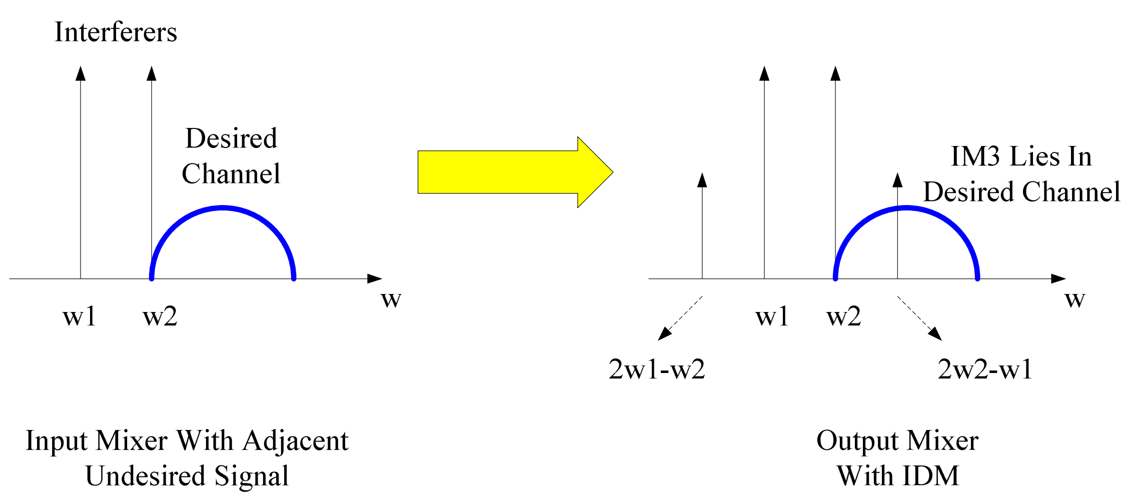

Figure 2.5 (a): Intermodulation signal due to nearby interferers

The overall usable range, known as the spurious-free dynamic range (SFDR) can be from the **Figure 2.5 (b)**, the SFDR of a system can be defined as a ratio where the input power level is same as the intersection between IM3 and the minimum detectable signal (noise floor)

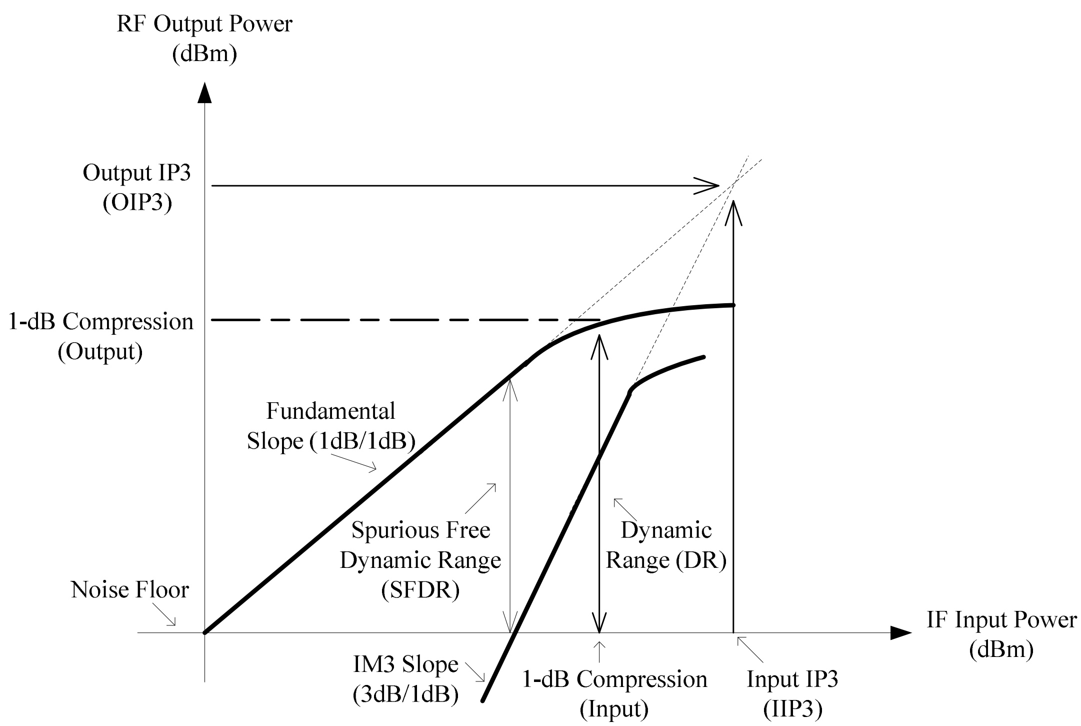

Figure 2.5 (b): Third Order Intercept Point

CHAPTER 3

MIXER TOPOLOGIES

3.1 Types Of Mixer

Mixer is an essential part of wireless communication systems. Modern wireless communication system demand stringent dynamic range requirements. To meet the standard requirement of wireless communication system, mixer must be design accordingly with the respect of power consumption, application and so on. There are many types of mixer in wireless communication.

3.2 Passive And Active Mixers

Mixers can be first divided into active or passive mixer. Passive mixers which it operation is based on driving the transistor in triode region, have a higher linearity and better frequency response. Passive mixer doesn’t have a gain but instead of having a conversion loss hence are not widely used in RF systems. Active mixers on the other hand generally have gain thus reducing noise contributed by the succeeding stages [Yang, et al, 2004].

3.3 Single Balanced Mixers

Mixers with single-ended IF signal at the input transconductance stage is called a single-balanced mixer. An example of single-balanced mixers is shown on **Figure 3.1**. Single-balanced mixers are rarely used because it is more susceptible to noise in the LO signal. Single balanced mixers are much less complex (less use of balun) compared to the double balanced mixers but it have poor performance in term of IF to RF and LO to RF rejection. The main drawback of single-balanced mixers is the LO-RF feed through. This effect even worst if the frequency of RF is much closer to the LO frequency which this happen in direct conversion architecture where the RF frequency is equal to LO frequency. The LO signal is not suppressed perfectly at the output of the mixer.

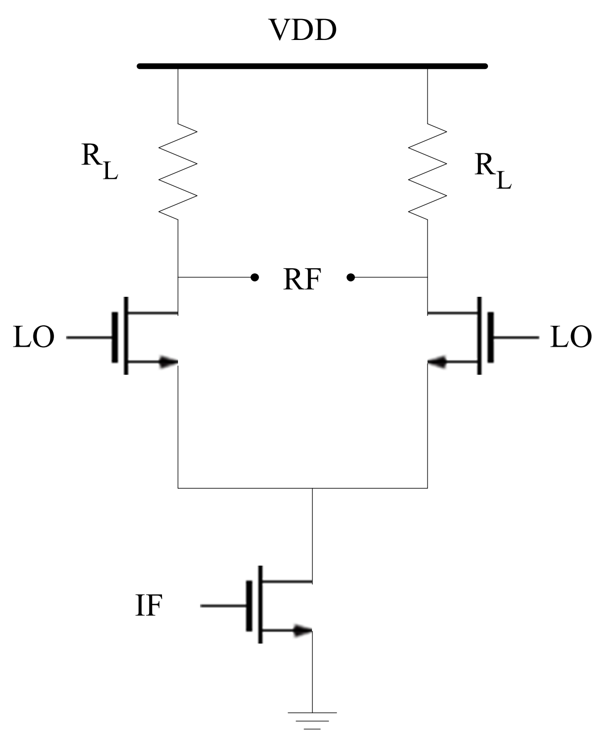

Figure 3.1: Single-Balanced Mixers

3.4 Double Balanced Mixers

Double balanced mixers are used to prevent the LO products from reaching the output. Double balanced mixers can be form with two single-balanced circuits with the input IF transistors connected in parallel and the LO switching pair in anti-parallel. Therefore, the LO terms sum to zero and the IF signal doubled in the output. The ideal of double balanced mixer can be illustrated in **Figure 3.2**. The voltage of the input IF signal is amplified and converted into current by a driver stage.

The LO signal is used to steer all of the current from one transistor to the other at the LO switching stage. Finally, the RF output voltage is created due to the current through the load resistors. This configuration provides a high degree of LO-RF isolation make it easier to filter out at the output with simple filter configuration. Double balanced mixers are less susceptible to noise than the single-balanced mixers because of the differential IF signal. There are several advantages and disadvantages in double balanced mixer topology design as described below.

Advantages:

1) Both LO and IF are balanced, hence providing both LO and IF rejection at the RF output.
2) All ports of the mixer are isolated from each other.
3) Linearity is increased compared to single balanced.
4) Suppression of the spurious products improved.
5) Intercept points is higher.

Disadvantages

1) Higher LO switch drive level.
2) Required more baluns compared to the single balanced.

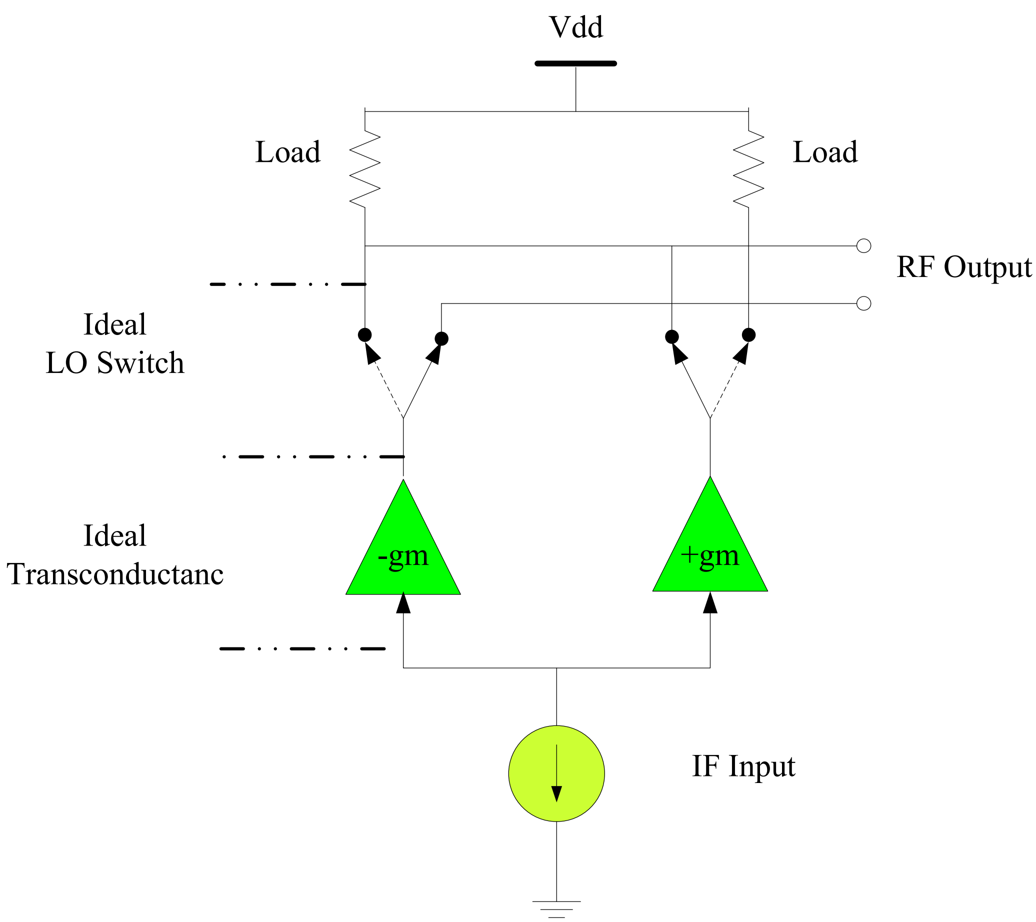

Figure 3.2: Ideal double balanced mixer

3.5 Gilbert Cell Mixers

Gilbert Cell is the most popular used for active, double balanced mixer topology in RF system design. The basic circuit of Gilbert Cell mixer is shown in **Figure 3.3**. This type of mixer is very symmetrical and hence it can remove the unwanted IF and LO output signals from the RF by cancellation.

An important mixer requirement is linearity. There are several ways to increase linearity such as increasing the voltage supply or increasing the current. However, the most common and effective method to improve linearity is to use some type of source degeneration. Resistors are used when the size of the circuit needs to be minimized. Inductor degeneration is usually preferred because it has no thermal noise to degrade the noise figure, and it saves headroom because there is no voltage drop across it. In the design, resistor degeneration was used because the circuit must operate over a broad bandwidth.

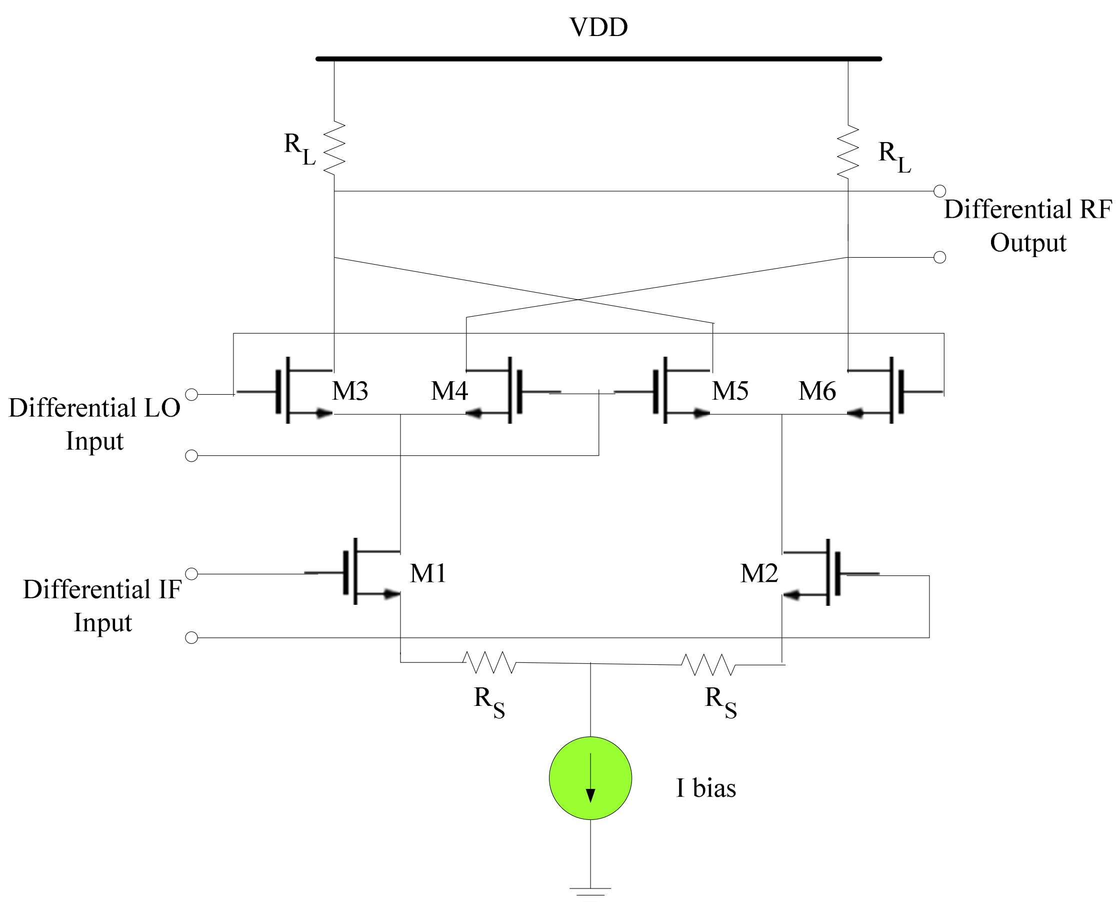

Figure 3.3: Basic circuits of Gilbert Cell mixer with source degeneration