DESIGN OF UP-CONVERSION MIXER FRONT END TRANSMITTER FOR CDMA APPLICATION AT 900MHz USING CMOS TECHNOLOGY

Oleh

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ABSTRACT

This report included design, and simulation results of up conversion mixer that operate at LO frequency 798 MHz. System and circuit design had been carried out with the aid of software program Cadence. Two steps up conversion mixer is a type of mixer that combines a single side band mixer and a double side balanced mixer to perform two steps up conversion process. First part of mixer will convert IF input signal at 40 MHz to 572 MHz by multiplication with LO signal at 532 MHz. The output of mixer part one consists 2 spectrum frequency at 572 MHz and 492 MHz. A Band pass filter is needed to filter the spectrum on 492MHz, the output signal after filtering process by band pass filter is at 572MHz. The output signal will become the input signal for mixer second part. Second part of mixer will convert the input signal at 572MHz to 838MHz by multiplication with another LO signal at 266MHz. The detail circuits design is discussed in chapter 5 and performance for each part of the mixer system are tested and measured in cadence. The results are listed in Chapter 6.

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CHAPTER 1

INTRODUCTION

This chapter consists of the objective and introduction of an up conversion mixer design. Some introduction of CDMA IS95 and transmitter Architecture are also discussed in this chapter. There are two type of transmitter Architecture which are direct Conversion Transmitter and double Conversion Transmitter. In this chapter both of the architecture will be discussed briefly.

1.1 Objective

This project objective is to present an up-conversion mixer at CDMA standard using CMOS Technology, The designed mixer is based on the typical Gilbert-cell with supply voltage 1V. This design was based on Double Conversion Transmitter. The input signal (intermediate frequency) is at 40 MHz. First stage of mixing process translates the input signal frequency to 572 MHz by using a local oscillator frequency at 532 MHz. Second stage of mixing process translates the output signal (572 MHz) from first mixing process to 838 MHz by using a local oscillator frequency at 266 MHz. The performance of the mixer was tested by the aid of software Cadence. The characteristics tested were Conversion gain, Noise figure, input 1 dB compression point and third order input intercepts point (IP3).

1.2 Introduction of CDMA IS95

IS-95 was the first CDMA mobile phone system to gain widespread use and it is found widely in North America. Its brand name is CDMA One and the initial specification for the system was IS95A, but its performance was later upgraded under IS-95B. It is this later specification that is synonymous with CDMA One. Apart from voice the mobile phone system is also able to carry data at rates up to 14.4 kbps for IS-95A and 115 kbps for IS-95B.The CDMA or code division multiple access system is very different. Although a complete summary of CDMA will not be included here, the basic principle of CDMA is that different codes are used to distinguish between the different users. CDMA uses a form of modulation known as direct sequence spread spectrum. Here a signal is generated that spreads out over a wide bandwidth. A code known as a spreading code is used to perform this action. By using a group of codes known as orthogonal codes, it is possible to pick out a signal with a given code in the presence of many other signals with different orthogonal codes. In fact many different base band "signals" with different spreading codes can be modulated onto the same carrier to enable many different users to be supported. By using different orthogonal codes interference between the signals is minimal. Conversely when signals are received from several mobile stations, the base station is able to isolate each one as they have different orthogonal spreading codes.

Table 1.1: Summary of Parameters in Is-95 System

System Parameter	Specification
Uplink frequency band	824-849 MHZ
Downlink frequency band	869-894 MHZ
Number of carriers/bands	20
bandwidth	1.25MHZ
Multiple access method	CDMA/FDMA
Chip rate	1.2288MCPs
Modulation	BPSK with QPSK spreading (D) 64-Ary orthogonal with QPSK spreading (U)
Speed bit rate	-9.6Kb/s
Region	USA , JAPAN KOREA

1.3 Introduction Transmitter Architecture

In contrast to RF receivers, RF transmitters accept base band information (either digital or analog) and perform RF/analog signal processing to transmit the information at the carrier frequency through the antenna. Fig. 1.1 is the functional block diagram of a transmitter. The transmitter performs modulation, up-conversion and power amplification. The base band signal is first conditioned by base band signal processing to eliminate the unwanted information in the signal spectrum. Depending on the modulation scheme for the wireless standard, the modulation and up-conversion can be combined. The up-converted signal is power-amplified for transmission through the antenna. Sensitivity and selectivity specifications in a transmitter are more relaxed than for receivers because the input signal is generally a band-limited base band signal; distortion and inter-modulation are the important specifications. In this section, a survey of typical transmitter architectures is presented, including the direct conversion and double conversion architectures. The discussions emphasize the relative merits of each architecture, their integrability and frequency synthesizer requirements.

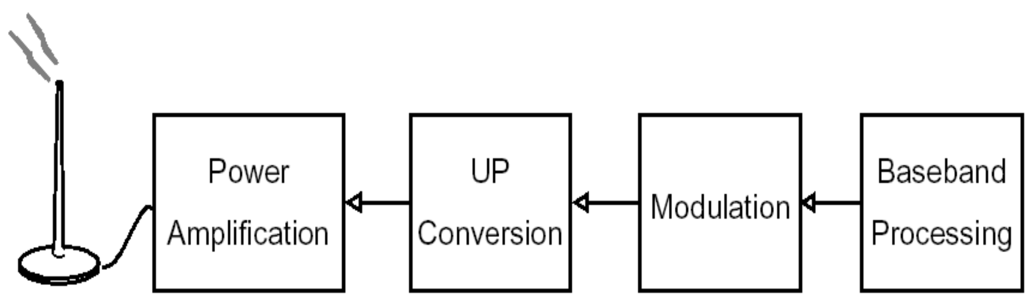

Figure 1.1: Functional Block Diagram for Wireless Transmitter (Rose, 2003)

1.3.1 Direct Conversion Transmitter

The most straightforward method to up-convert the modulated base band information to RF is through direct conversion. **Fig.1.2** shows a block diagram of a *Direct Conversion* transmitter where the channel-select LO frequency equals the carrier frequency. The digitally modulated signal is the input to the Digital-to-Analog Converter (DAC), and the analog representation of the input signal is filtered to eliminate aliasing due to the discrete time DAC. The filtered analog waveform is up-converted directly to the carrier frequency by mixers, and it is power-amplified by the Power Amplifier (PA). External RF filters generally are required before and after the PA to eliminate noise and spurious emission in unwanted frequency bands, which limit the integrability of this architecture. In a typical cellular telephone system, the output transmitted power can be as large as +33 dBm. Accounting for the insertion loss from the RF filter (worse with a duplexer), the power output from the PA may need to be 30% higher. Since the carrier frequency is identical to the LO frequency in a direct conversion transmitter, this modulated high-power PA output signal will radiate and affect the spectral purity of the nearby VCO output, which negatively impacts transmitter performance. This phenomenon is generally known as “VCO pulling” or “injection locking” Crystal. One solution to reduce VCO-pulling problem is to use a VCO frequency different from the carrier frequency. **Fig.1.3** is a block diagram of a direct conversion transmitter using the offset LO mixing technique. The sum of the LO frequencies equals the carrier frequency; however, each LO output is not affected by the PA output because their frequencies are sufficiently far away from the carrier in the frequency spectrum. The drawback of this architecture is the generation of unwanted sideband from the offset mixing process, which may require yet an additional filter.

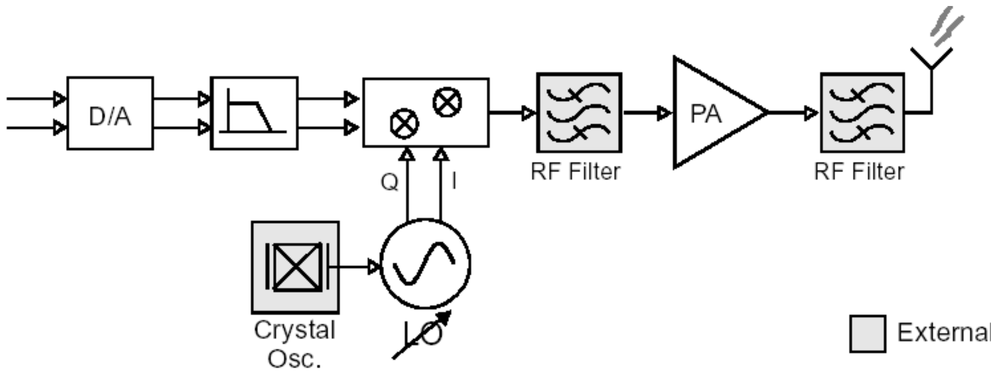

Figure 1.2: Direct Conversion Transmitter Block Diagram (Rose, 2003)

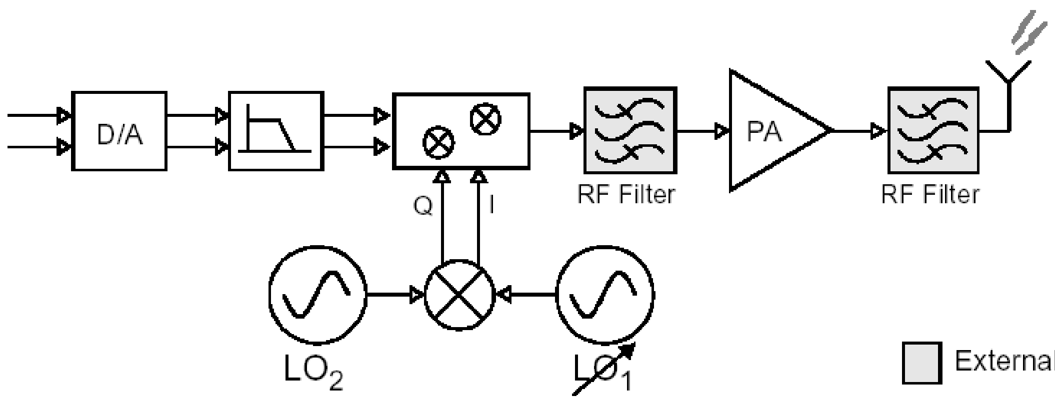

Figure 1.3: Direct Conversion Transmitter with Offset LO (Rose, 2003)

1.3.2 Double Conversion Transmitter

Another approach to reduce VCO-pulling is to up-convert the base band signal in two or more steps to RF, so that the VCO frequency is far from the PA output spectrum. **Fig. 1.4** is the block diagram for a Double Conversion transmitter. In this architecture, the base band I/Q channels undergo the quadrate modulation at a lower frequency (LO2), and the resulted IF (intermediate frequency) signal is up-converted to the transmit frequency with LO1. The sum of the LO frequencies is the exact carrier frequency. In addition to eliminating VCO-pulling, another advantage of double conversion over direct conversion is that the I/Q matching is better because the quadrate modulation is performed at a much lower frequency, LO2. However, spurious tones generated by LO2 will mix with the base band signal to the vicinity of IF, and generating an undesired image after double conversion. This is required to be attenuated to a sufficiently low level before PA with an external filter. In order to eliminate the external filter after LO1 mixing, multiple phases of LO2 can be used to generate an approximate sine wave representation of LO2, which can minimize the harmonic mixing for low-order harmonics. Furthermore, the RF filters before PA can be removed at the expense of an additional mixer stage to perform the active image rejection. Similar to frequency synthesizer considerations in the receive path, LO2 is chosen to be variable-frequency and LO1 to be fixed-frequency to improve the phase noise performance. This architecture enables the full integration of the transmit path including the PA and is currently under investigation **Fig. 1.5**

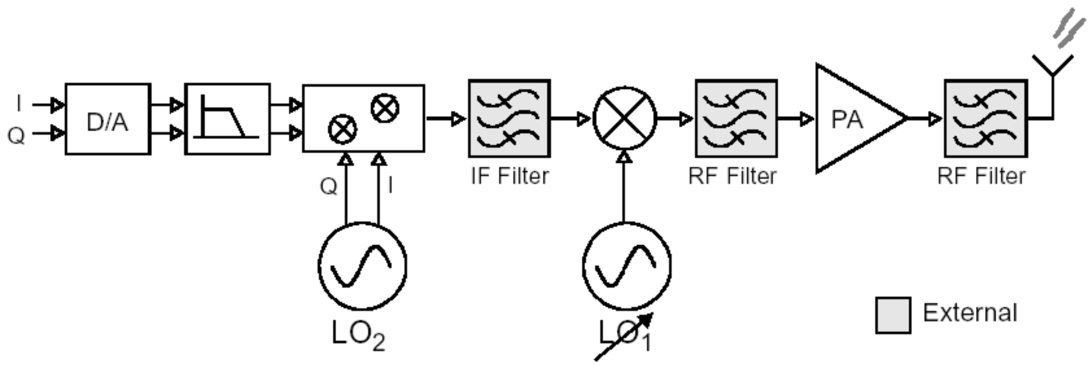

Figure 1.4: Double Conversion Transmitter (Rose, 2003)

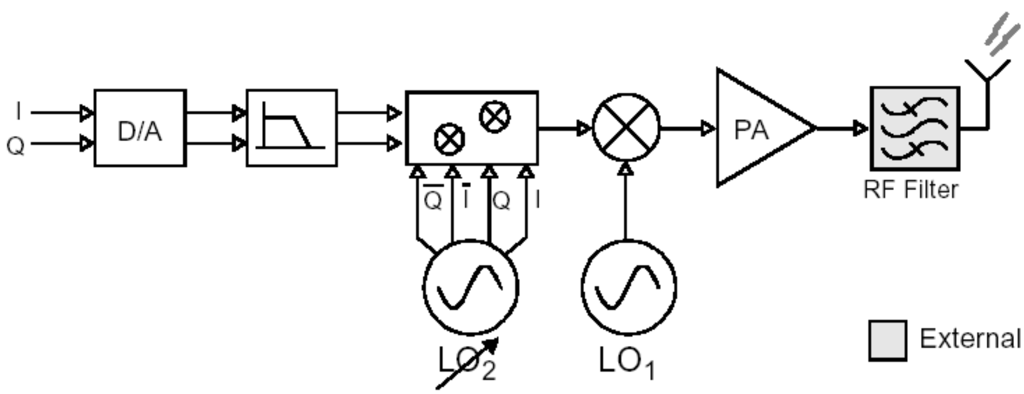

Figure 1.5: Integrated Double Quadrate Transmitter Architecture (Rose, 2003)

CHAPTER 2

THEORY OF OPERATION AND TYPE OF MIXER

The purpose of the mixer is to convert a signal from one frequency to another. In a transmitter, this conversion is from intermediate frequency to radio frequency. In this chapter, some simple conceptual of a mixer and basic operation of mixer will be discussed. Some introduction of single side balanced and double side balanced Gilbert cell mixers are discuss in this chapter too.

2.1 Simple Conceptual of a mixer

The input of mixer is simply a gain stage. The amplified current from the gain stage then passing into the switching stage. This stage steers the current to one side of the output or the other depending on the value of V2. If the control signal is a square wave, then this will have the effect of multiplying the current coming out of gain stage by +1 or -1. Multiplying a signal by another one signal will cause output signal have several of frequencies component. **Figure 2.1**

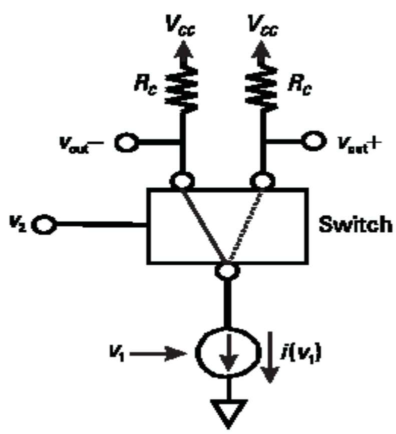

Figure 2.1 Rogers, 2003)

2.2 Basic Operation Mixer

Mixers are non-linear devices used in systems to translate (multiply) one frequency to another. All mixer types work on the principle that a large Local Oscillator (LO) RF drive will cause switching/modulating the incoming Radio Frequency (RF) to the Intermediate Frequency (IF). For a up-conversion mixer, it will work on the principle that a large Local Oscillator (LO) RF drive will cause switching/modulating the incoming Intermediate Frequency (IF) to the Radio Frequency (RF), **Figure 2.2**

The multiplication process begins by inputting two signals:

$$a = A\sin(\varpi_1 t + \theta_1) \qquad [2.1]$$

$$b = B\sin(\varpi_2 t + \theta_2) \qquad [2.2]$$

The resulting multiplied signal will be:

$$a.b = AB\sin(\varpi_1 t + \theta_1)\sin(\varpi_2 t + \theta_2) \qquad [2.3]$$

$$= -\frac{AB}{2}[\cos((\varpi_1 t + \theta_1) + (\varpi_2 t + \theta_2))$$

$$-\cos((\varpi_1 t + \theta_1) - (\varpi_2 t + \theta_2))] \qquad [2.4]$$

Where the part:

$\cos((\varpi_1 t + \theta_1) - (\varpi_2 t + \theta_2))$ is difference frequency

$\cos((\varpi_1 t + \theta_1) + (\varpi_2 t + \theta_2))$ is sum frequency

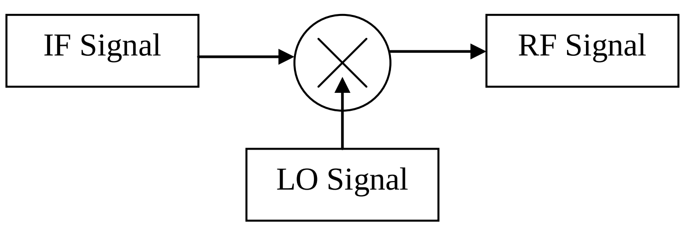

Figure 2.2: Basic Operation Mixer

2.3 Multiplier –based Mixers

Mixer based directly on multiplication generally show superior performance this is because they only generate the desired inter modulation product. Furthermore, because the input to a multiplier enter at separate ports, there can be a high degree of isolation between the three signal (LO, RF and IF). CMOS technology also provides excellent switch and one can implement outstanding multiplier with switches. One of the examples is single–balanced mixer and double balanced mixer.

2.3.1 Single Balanced Mixer

Single side balanced mixer were one of the common family of multiplier first converts the incoming RF voltage into a current and then performs a multiplication in the current domain. **Figure 2.3** were the simplest multiplier cell of single balanced mixer. In this mixer, V_{LO} is chosen large enough so that the transistors alternately (commutate) all of the tail current from one side to the other at the LO frequency. The tail current is therefore effectively multiplied by a square ware whose frequency is that of the local oscillator:

$$i_{out}(t) = \text{sgn}[\cos \varpi_{LO} t]\{I_{BIAS} + I_{RF} \cos \varpi_{RF} t\} \qquad [2.5]$$

A square wave consists of odd harmonics of the fundamental, multiplication of the tail current by the square wave results in an output spectrum that appears in **Figure 2.4**. The output consist of sum and difference component, each the result of an odd harmonic of the LO mixing with the RF signal. The odd harmonics of the LO appear directly in the output as a consequence of the DC bias current multiplying with LO signal. Because of the present of the LO in the output spectrum, this type of mixer is known as a single-balanced mixer.

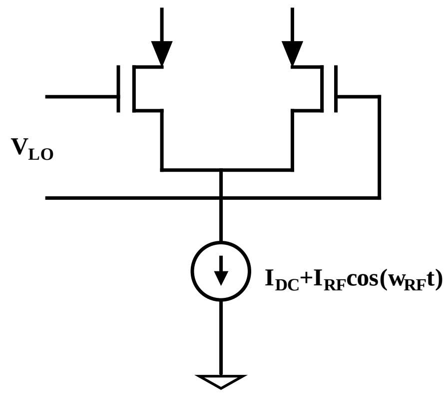

Figure2.3: Single –balanced mixer (Lee, 1998)

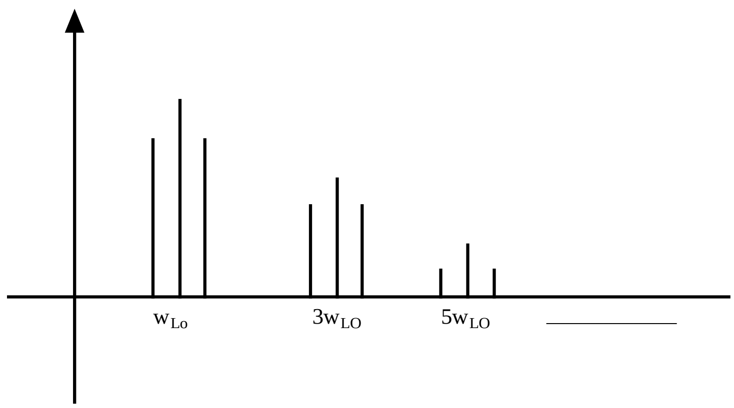

Figure 2.4: Representative output spectrum of single –balanced mixer (Lee, 1998)

2.3.2 Active Double-balanced Mixer

For the reason to prevent the LO product from to the first place, two single balanced circuits may be combined to produce a double-balanced mixer **Figure 2.5**. We assume that the LO drive is large enough to make the differential pair act like current switches. The two single balanced mixer are connected in anti parallel as far as the LO is connected but in parallel for RF signal. Therefore, the LO term sum to zero in the output, whereas the converted RF signal is doubled in the output. This mixer thus provides a high degree of LO-IF isolation, easing filtering requirements at the output. Below were some advantage and disadvantage of Double–balanced mixer.

Advantages:

(1) Both LO and RF are balanced, providing both LO and RF Rejection at the IF output.

(2) All ports of the mixer are inherently isolated from each other.

(3) Increased linearity compared to singly balanced.

(4) Improved suppression of spurious products (all even order products of the LO and /or the RF are suppressed).

(5)High intercept points.

(6) Less susceptable to supply voltage noise due to differential topography.

Disadvantages:

(1)Require a higher LO drive level.

(2)Require two baluns (although mixer will usually be connected to differential amplifiers).

(3) Ports highly sensitive to reactive terminations.

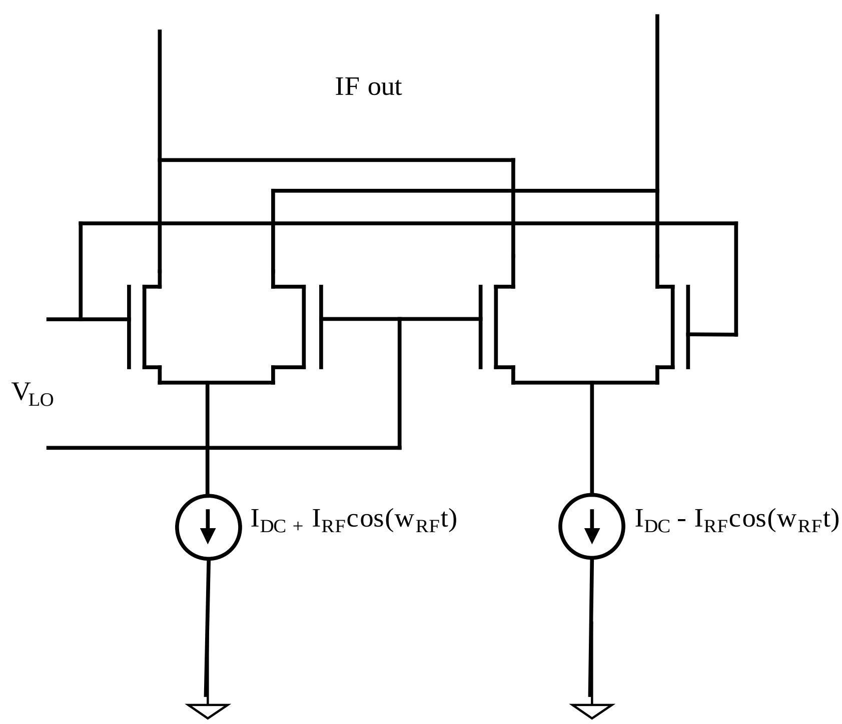

Figure 2.5: Active double –balanced mixer (Lee, 1998)

CHAPTER 3

MIXER CHARACTERISTIC DEFINITIONS

Mixers are non-linear devices used in systems to translate (multiply) one frequency to another. All mixer types work on the principle that a large Local Oscillator (LO), RF drive will cause switching/modulating the incoming Radio Frequency (RF) to the Intermediate Frequency (IF). The output thus consists of sum and difference components, each the result of an odd harmonic of the LO mixing with the RF signal. The characteristic of mixer are important to determined the performance of mixer

3.1 Conversion Gain

The conversion gain of a mixer is defined as the ratio of the desired IF or Base band output to the RF input. If the conversion gain is less than 1, it is referred to as conversion loss. This ratio can be expressed in terms of voltage or power and is usually given in dB:

$$PowerGain(dB) = 10.\log(\frac{p_{out}}{p_{in}}) \quad (3.1)$$

$$VoltageGain(dB) = 10.\log(\frac{V_{out}}{V_{in}}) \quad (3.2)$$

If the input is matched, a simple relation between the two gains is given by:

$$PowerGain(dB) = VoltageGain(dB) - 10.\log(\frac{R_s}{R_L}) \quad (3.3)$$

Where R_S is the source resistance and R_L is the load resistance.

The conversion gain of a mixer is an important specification because it affects the noise figure and linearity of the overall receiver. When calculating the overall input referred noise figure of the system, the noise from the stages following the mixer will be attenuated by the gain of the mixer or amplified by its loss. The conversion gain of a mixer will affect the overall linearity because the gain or loss will change the signal level presented to the stages following the mixer.

3.2 Noise Figure

The noise figure of a mixer is a measure of how much the signal-to-noise ratio is degraded by the mixer. An equation for noise figure is given as:

$$NF = \frac{SNR_{input}}{SNR_{output}} = \frac{N_s + N_a}{N_s} \tag{3.4}$$

where the SNR_{input} and SNR_{output} are the signal-to-noise ratio at the input and output respectively. N_s is the output noise power due to the source impedance and N_a is the output noise power added by the mixer. A good approximation for Equation 3.4 is given by Equation 3.5 where V_n^2 is an input referred voltage noise source.

$$NF \approx 1 + \frac{V_n^{\ 2}}{4kTR_s \Delta f} \tag{3.5}$$

Mixer noise figure can be specified as either single-sideband or double-sideband. SSB noise figure (SSB NF) is used for mixers that only contain input signal in one sideband of the input. The other sideband is removed by an image reject filter. DSB noise figure (DSB NF) applies to mixers where the input signal is contained in both input sidebands. DSB noise figure is applicable to direct conversion down converters and SSB applies to most other mixers. SSB NF assumes the noise coming from the source comes from only one of the input sidebands, while DSB NF assumes it comes from both input sidebands. If the conversion gain is equal for both the RF and image bands, the input referred single sideband noise power is twice as big as the input referred double side band noise power [2]. If we define an input referred voltage noise source from a case where

SSB NF was applicable as $V_{n}^{2}{}_{SSB}$, the same mixer would have a double side band equivalent, $V_{n}^{2}{}_{DSB}$, that is half as big .We can write:

$$NF_{SSB} \approx 1 + \frac{V_n^{\ 2}{}_{SSB}}{4kTR_s \Delta f} \tag{3.6}$$

$$NF_{DSB} \approx 1 + \frac{V_n{}^2{}_{DSB}}{4kTR_s\Delta f} \tag{3.7}$$

Equations 3.7 can be re-written as:

$$NF_{DSB} = 1 + \frac{V_n{}^2{}_{SSB}}{2 * 4kTR_s\Delta f} \tag{3.8}$$

Substituting Equation 3.6 into Equation 3.8 leads to the following relation between SSB and DSB NF:

$$NF_{DSB} = 1 + \frac{1}{2}(NF_{SSB} - 1) \tag{3.9}$$

Expressing this equation in dB results in:

$$NF_{DSB}(dB) = 10.\log[1 + \frac{1}{2}(10^{\frac{NF_{SSB}(dB)}{10}} - 1)] \tag{3.10}$$

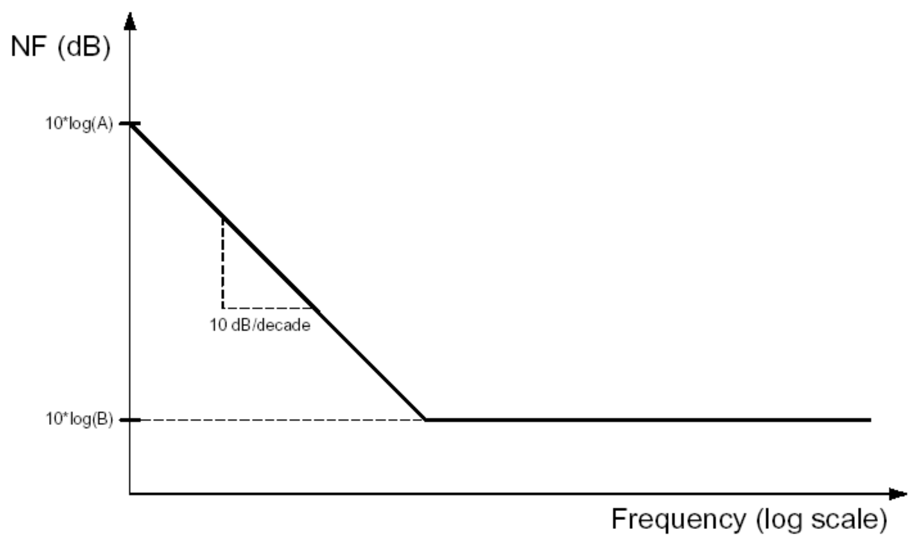

Figure 3.1: Noise figure vs. frequency for a conversion mixer (Rose, 2003)

3.3 Distortion

A mixer performs frequency translation so it is inherently a non-linear circuit. However, it is desirable for a mixer to act very linearly with respect to all nonlinearities except the one giving the desired frequency conversion. In general, a Volterra series for the mixer can be written as:

$$S_0 = a_1(\omega_1) \bullet S_i + a_2(\omega_1, \omega_2) \bullet S_i^{\,2} + a_3(\omega_1, \omega_2, \omega_3) \bullet S_i^{\,3} + \ldots\ldots. \qquad (3.11)$$

where S_I is the input signal, S_O is the output signal shifted in frequency by the desired conversion and the dot operator, $\bullet$, denotes a complex operator on the magnitude and phase, defined as:

$$X(\omega_1, \omega_2, \ldots) \bullet e^{j(\omega_1 + \omega_2 + \ldots)t} = \left| X(\omega_1, \omega_2, \ldots) \right| e^{j(\omega_1 + \omega_2 + \ldots)t + \angle X(\omega_1, \omega_2, \ldots)} \qquad (3.12)$$

The input-referred N th order intercept point (IIP_N) is used to characterize the distortion performance of a mixer. IIP_N is defined as the input power level where an N_{th} order distortion product's power is equal to the power of desired output. The desired output comes from the first order term in Equation 3.11 so a 1 dB increase in input power results in a 1 dB increase in the output power. The N_{th} order distortion comes from the N_{th} order term in Equation 3.11 so a 1 dB increase in input power results in an N dB increase in output distortion power. **Figure 3.2** shows the typical relation between the desired signal level and the N_{th} order distortion level at the output of a mixer. The solid lines are the actual signal power observed at the frequency of interest and the dashed lines represent the ideal behavior of the first and N $_{th}$ order terms of Equation 3.11. At low-power levels, the actual and ideal curves coincide, but as the input power is increased both curves show compression from their ideal values. This compression occurs because the higher order terms in Equation 3.11 produce frequency components at the same frequency as the first and N_{th} order terms. These components are negligible until the input power reaches a certain level. Once this level is reached, the higher order distortion components will affect the slope of the power curves as shown in **Figure 3.2**. From the geometry of **Figure 3.2** it is straightforward to show that:

$$IIP_N = P_{in} + \frac{P_{out1} - P_{outN}}{N-1} \qquad (3.13)$$

where P_{OUT1} and P_{OUTN} are the measured output power of the desired signal and N-$_{th}$ order distortion with an input of P_{in}.

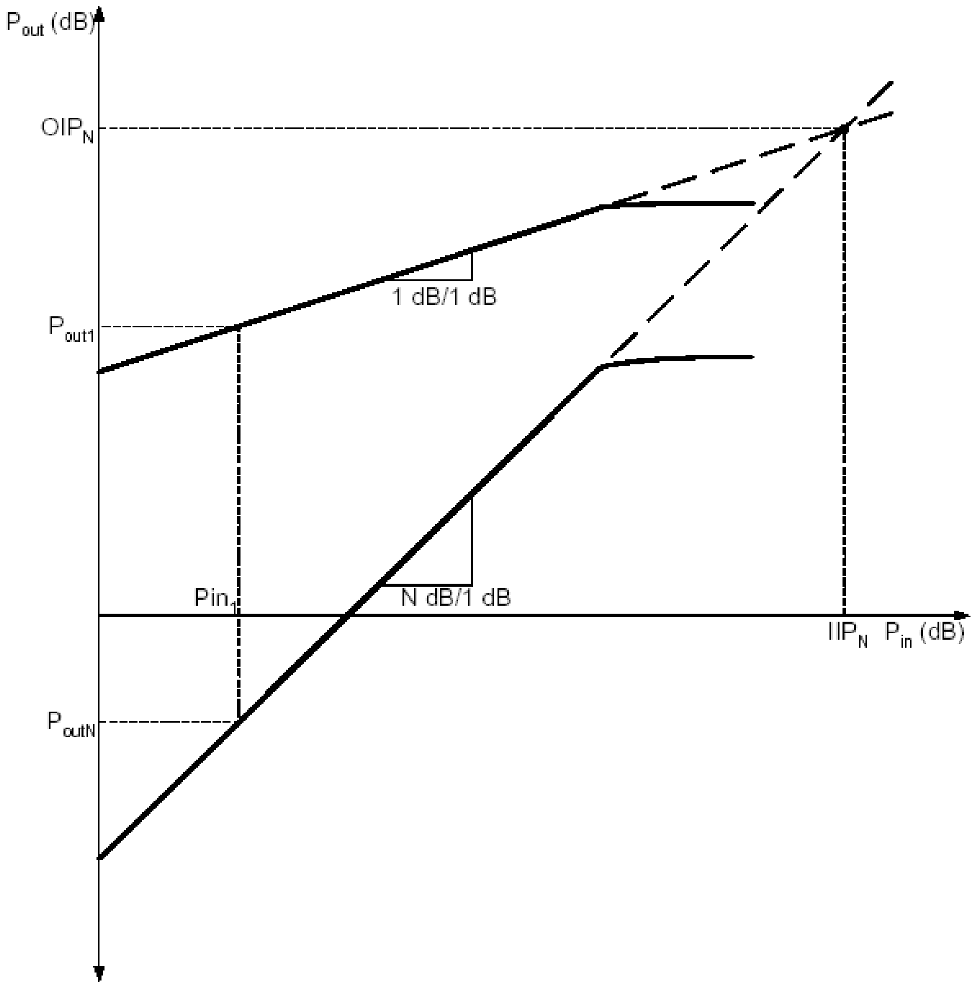

Figure 3.2: First order and N th order output power vs. input power (Rose, 2003)

3.3.1 Third order Intercept Point (IP3)

The third order intercept point is a theoretical point where the amplitudes of the inter-modulation tones at $2f_1 - f_2$ and $2f_2 - f_1$ are equal to the amplitudes of the fundamental tones at f1 and f2. This is also an important parameter used to characterize linearity of an amplifier. **Figure 3.3** shows the plots of third order intercept point where

$P_{in, mds}$ - minimum detectable signal (noise floor)

d_R - dynamic range

d_f - spurious free dynamic range

IP_{out} - third order intercept point

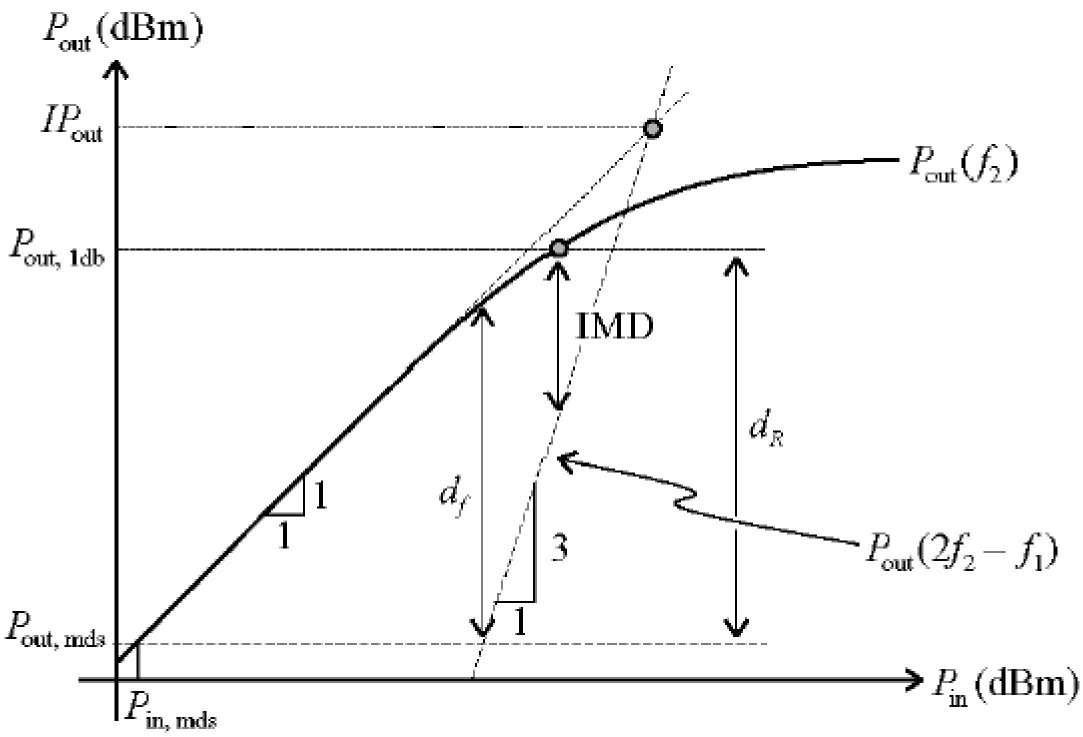

Figure 3.3: Third order intercepts point

3.3.2 1 dB Compression Point

Active RF devices are ultimately non-linear in operation. When driven with a large enough RF signal the device will generate undesirable spurious signal. At low input powers, this added component is insignificant, but as the input power increases, the conversion gain of the mixer will expand or compress depending on whether the non-linearity is in or out of phase with the fundamental component. In most practical mixers, the components are out of phase and the conversion gain undergoes compression. The metric generally used to gauge the gain compression is the 1 dB compression point (P_{-1dB}). This is defined as the input or output signal level where the gain is decreased by 1 dB from its ideal value. Like IIP_3, P_{-1dB} is used to estimate the largest input that a mixer can handle. However, IIP_3 is specified by extrapolating the first and third order curves from their values with small inputs, while P_{-1dB} is actually measured under large signal input conditions.

It is straightforward to show that if the compression is caused exclusively by third-order nonlinearity the input P_{-1dB} is

$$P_{-1dB} = IIP_3 - 9.6dB \tag{3.14}$$

However, it is often the case that nonlinearities higher than third-order contributes to the gain compression or the supply headroom limits the output signal. Both of these cause Equation 3.14 to be inaccurate.

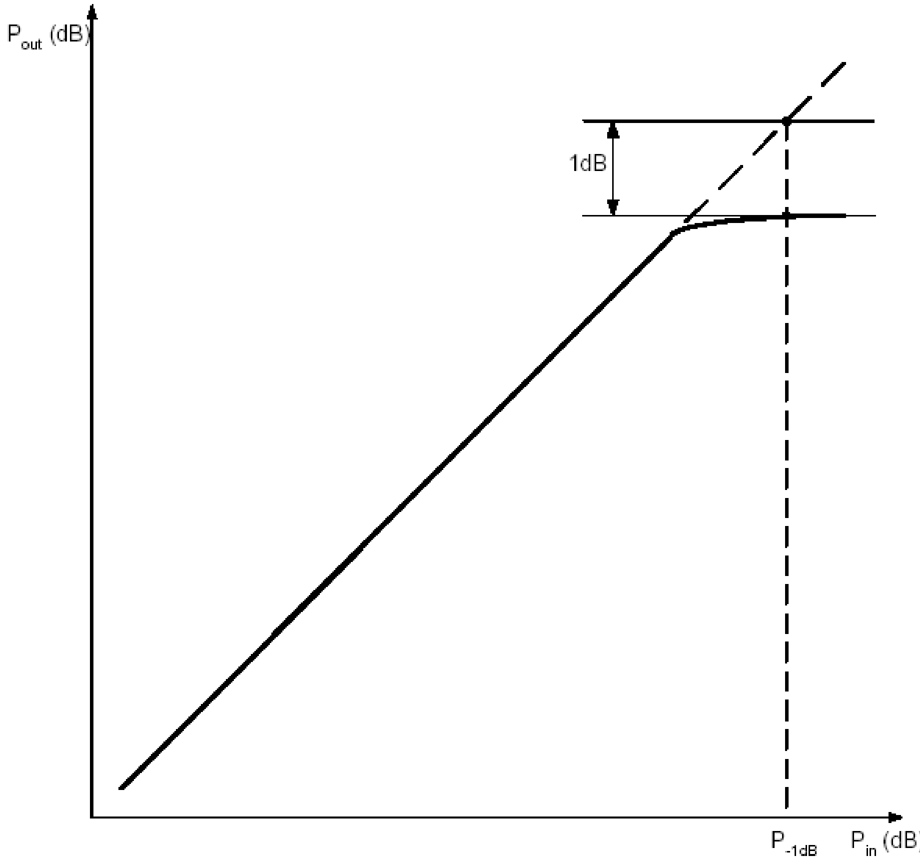

Figure 3.4: Graphical representation of the input P_{-1dB}. (Rose, 2003)

CHAPTER 4

PULLING INJECTION PHENOMENON AND LOW-VOLTAGE DESIGN TECHNIQUE

In this chapter, pulling injection phenomenon will be discussed. A low-voltage design technology by using LC tank method also was discussed in this chapter. The low voltage method was using in the mixer design and two step up conversion mixer helps to reduce the pulling injection effect.

4.1 Pulling Injection phenomenon

The architecture in **Figure 4.1** suffers from an important draw-back: disturbance of the transmitter local oscillator by the power amplifier. This issue arises because the PA output is a modulated waveform with high power and spectrum centered around the LO frequency .Despite various shielding techniques employed to isolate the VCO, the "noisy" output of the PA still corrupt the oscillator spectrum. This corruption occurs through a mechanism called "injection pulling"

The magnitude of the noise injected into the signal path is much less than the carrier, thereby arriving at a noise shaping function for oscillators. An interesting phenomenon is observed if the injected component is close to the carrier frequency and has a comparable magnitude. As the magnitude of the noise increases, the carrier frequency may shift toward the noise frequency and eventually "lock" to that frequency **Figure 4.2**.Called "injection pulling".

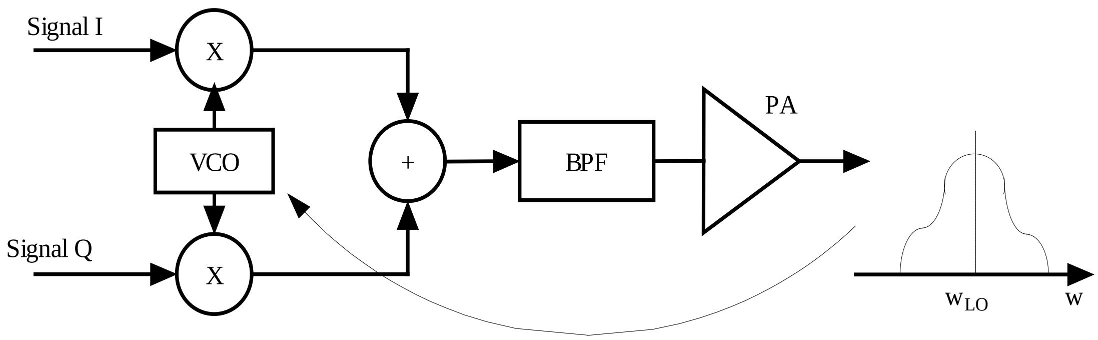

Figure 4.1: Leakage of PA output to oscillator (Razavi, 1998)

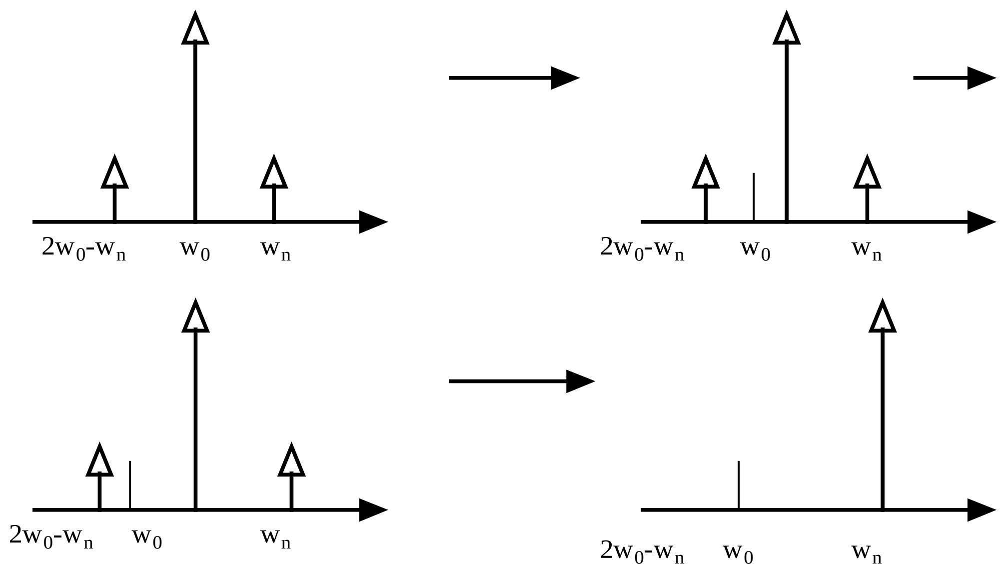

Figure 4.2: Injection pulling of an oscillator as noise amplitude increase (Razavi, 1998)

4.2 Low–Voltage Design Technique

We have illustrated two circuit elements connected in series between the Dc voltage rails. Each circuit elements represents at least one active component and several passive components. For biasing the circuit we need a minimum voltage of V_{on} to turn on all electrical components within each element .To turn on both circuit elements we need minimum power supply $2V_{on}$ .shown in **Figure 4.3**

We proposed scheme uses two on-chip LC tanks and one coupling capacitor. The function of the tanks is to provide low impedance across its terminals at dc and relatively high impedance at RF. The coupling capacitor is to couple the RF energy between the two elements. In RF frequency, the trapping elements essentially become open circuit and the coupling capacitor couple the RF signal between the two elements. Since the RF traps require no dc head room, the minimum voltage supply require is only V_{on}, not 2 V_{on} .shown in **Figure 4.4.**

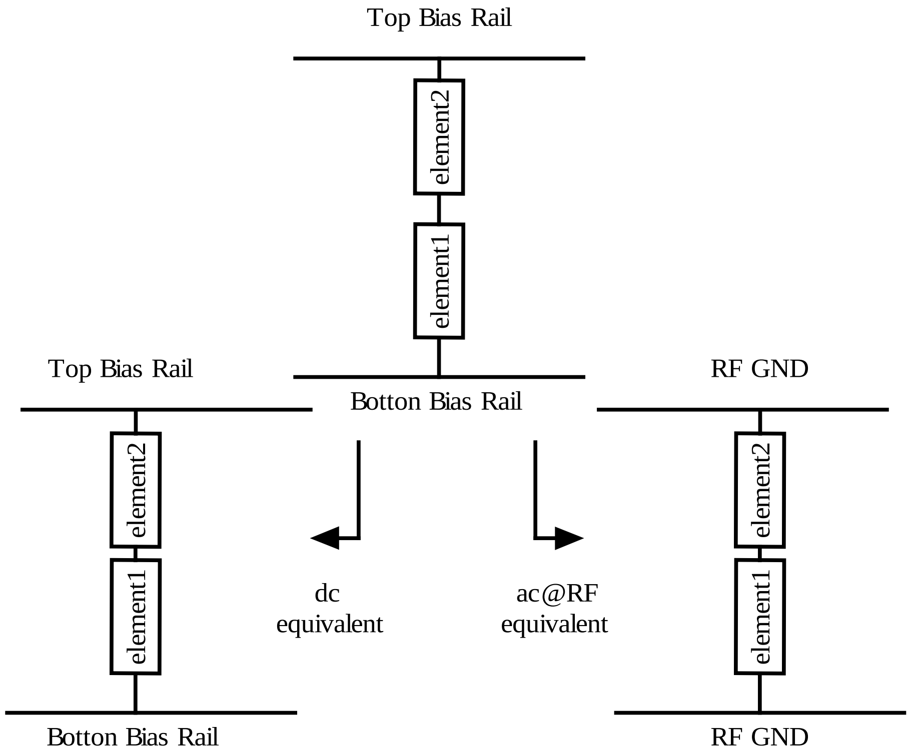

Figure 4.3: Typical topology used in RF integrated circuit circuits to realize biasing and Functionality (Manku, 1998)

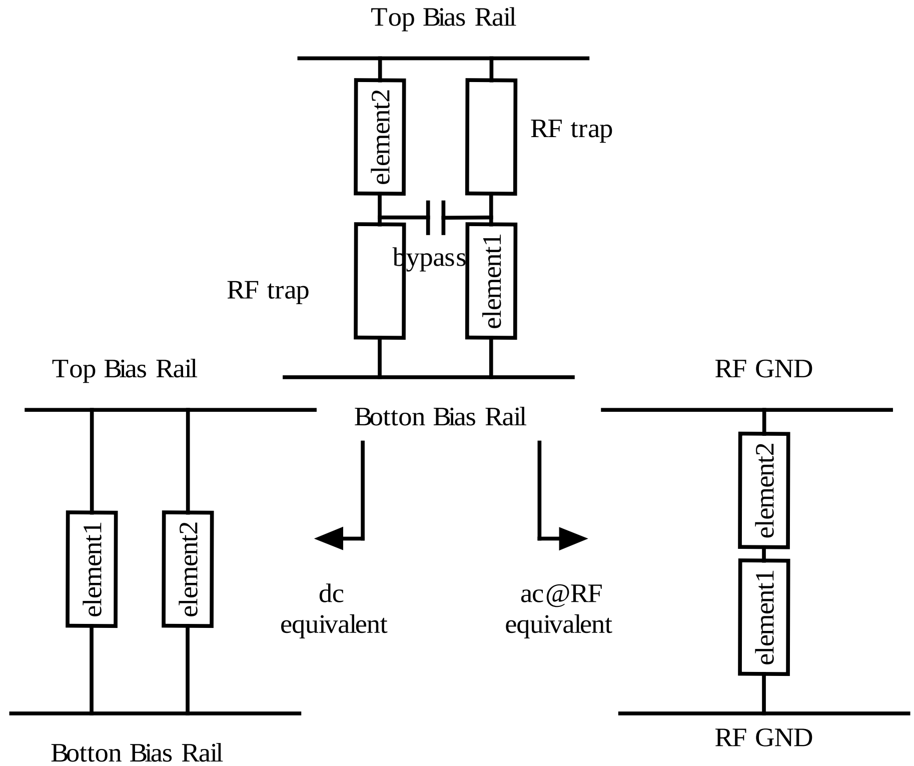

Figure 4.4: New topology using capacitive coupled RF trap to isolated dc biasing from RF (Manku, 1998)

CHAPTER 5
DETAILED DESIGN

In this chapter the detailed of two step conversion mixer will be discussed. Each parts of the two step conversion mixer are being discussed and low voltage technology are used in this mixer design. The parts discussed in this chapter are single side balanced, double side balanced, band pass filter and integrate mixer.

5.1 Two Step Conversion Mixer

An approach to circumventing the problem of LO pulling in transmitters is to up convert the base-band signal in two (or more) steps so that the power amplifier output spectrum is far from the frequency of the VCOs. Two step up-conversion mixers are shown in **Figure 5.1**. Here the intermediate input signal from DAC (digital to analog converter) is undergo modulation at frequency w_1, and the result is up-converted to $w_1 + w_2$ by mixing and filtering process. The first BPF (Band Pass Filter) suppress the harmonic of the first step mixing, while the second removes the unwanted sideband centered on at $w_1 - w_2$.

An advantage of two-step up-conversion over this the direct approach is that since modulation is performed at lower frequency. Also a channel filter may be used at the first modulation to limit to transmitted noise and spurs in adjust channel.