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# Low power up-conversion mixer with gain control function

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ABSTRACT

This work develops a low-power up-conversion mixer. The developed mixer integrates the LC parallel resonant technique, the inverter amplifier technique, the resistive-feedback technique, and the resistive source degeneration technique. Therefore, it has higher conversion gain, low power consumption, a large IF bandwidth, and gain control functionality, which provides favorable linearity. The output radio frequency of the proposed mixer is between 1950 MHz and 2000 MHz, and the input frequencies are 50 MHz to 100 MHz. The measured conversion gains of the mixer in high-gain mode and low-gain mode are 9.5 dB and 1 dB, respectively; the measured input third-order intercept points (IIP3) in high-gain and low-gain modes are 0 dBm and 7 dBm, respectively. The DC operation point of the proposed mixer does not differ between the modes. The mixer dissipates 2 mW of power at a supply voltage of 1.2 V, and is used in a Taiwan Semiconductor Manufacturing Company 90 nm RF CMOS process. The area of the chip is 0.7 mm$^2$.



## 1. Introduction

In recent years, rapid advances have been made in communication systems [1–6], especially with respect to 4G Long-Term Evolution (4G LTE) applications [7,8]. The up-conversion mixer [9–14] is an important component of a 4G LTE transceiver, which is used to convert intermediate-frequency (IF) signals to radio-frequency (RF) signals, then transmitted through the air by a power amplifier [15,16]. Therefore, the amplitude of the radio-frequency signals must be within a certain range to meet the requirements of the power amplifier. Accordingly, the mixer must have a gain control function to cover the range of amplitudes of these signals.

Conventional Gilbert-cell double-balanced mixers have been used in mixers of various designs. Their cascade structure provides effective port-to-port isolation, which reduces the feedback interference from RF to IF. Additionally, the Gilbert-cell double-balanced mixers also provide good common mode noise rejection owing to their fully differential structure [10,17]. However, conventional Gilbert-cell double-balanced mixers exhibit poor gain control. The linearity, IF bandwidth and power consumption are also important parameters of the mixer. When the input signals are strong enough to saturate the mixer, harmonic noise is produced, and transmitted to the air by the power amplifier. A mixer with high linearity prevents the generation of this harmonic noise.

To satisfy the demand for powerful data transmission and portable applications, mixers with large IF bandwidths and low power consumption are required. However, the circuit design of mixers frequently depends on tradeoffs among conversion gain, power consumption [11,12], bandwidth, and linearity [10,11]. Developing a mixer architecture that provides high conversion gain, low power consumption, large IF bandwidth, and high linearity is difficult. This work proposes a new mixer circuit, which exploits the LC parallel resonant technique, the inverter amplifier technique, the resistive-feedback technique, and the resistive source degeneration technique to provide high gain, low power consumption, a large IF bandwidth, and gain control. The following sections analyze and discuss this mixer circuit.

## 2. Proposed circuit

Determining the DC operating points of an analog circuit is a critical step in its design, as these points affect its performance. Similarly, the DC operating points of a mixer circuit affects its performance. The DC operating points of a mixer circuit should be fixed. However, the conversion gain of a traditional mixer varies with its DC operating points. Variation of the DC operating points potentially causes the mixer circuit to operate in an unstable state.

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The proposed mixer circuit has a gain control function, but in this experiment, is implemented without any variation of its DC operating points, so it exhibits stable performance and is easily designed. Fig. 1 shows the proposed up-conversion mixer circuit. Table 1 presents the parameters of the proposed up-conversion mixer.

A mixer typically comprises three stages, which are the IF trans-conductance stage, a local oscillator switch, and an output load impedance, which are analyzed and discussed below.

Unlike the IF trans-conductance stage of the conventional mixer, that of the proposed mixer uses the resistive-feedback technique in Fig. 2 to provide wideband input matching. Therefore, the IF bandwidth of the proposed mixer can be increased by adjusting the feedback resistances $R_1$ and $R_2$. The resistive-feedback technique also exploits self-bias, making the circuit more streamlined.

Unlike standard mixers, the proposed mixer is based on the inverter amplifier [18], which increases the trans-conductance (gm) of the mixer without increasing its power dissipation. Therefore, the proposed mixer consumes less power. Fig. 2 shows the IF trans-conductance stage circuit of the proposed mixer.

The IF trans-conductance of the proposed half circuit in Fig. 2 is, (when the switch transistor $M_9$ is turned off) given by

$$gm_{IF} = -\frac{R_1}{R_s + R_1}\left(\frac{gm_{M1}}{1 + gm_{M1}R_3} + gm_{M3}\right) \tag{1}$$

where $R_s$, $R_1$, and $R_3$ represent the source impedance, the feedback resistance, and the source degeneration resistance, respectively, and $gm_{M1}$ and $gm_{M3}$, are the transistor trans-conductances of $M_1$ and $M_3$, respectively. According to Eq. (1), the resistor $R_3$ reduces the trans-conductance of $M_1$. Accordingly, the proposed mixer has a small IF trans-conductance and is operated in low-gain mode.

When the proposed mixer is operated in high-gain mode, the switch transistor $M_9$ is turned on, and the impact of the source degeneration resistors ($R_3$ and $R_4$) is negligible. Therefore, the IF trans-conductance of the proposed half circuit in this stage is given by

$$gm_{IF} = -\frac{R_1}{R_s + R_1}(gm_{M1} + gm_{M3}) \tag{2}$$

Eq. (2) yields a higher IF trans-conductance ($gm_{IF}$) than Eq. (1). Therefore, the IF trans-conductance of the proposed mixer can be changed by turning on/off transistor $M_9$. However, regardless of whether transistor $M_9$ is turned on or off, no DC current flows through transistor $M_9$, so the DC operating point does not vary with the turning on/off of transistor $M_9$. Resistances $R_3$ and $R_4$ also limit the current that flows through the IF trans-conductance stage. Therefore, the proposed mixer has stable DC operation points.

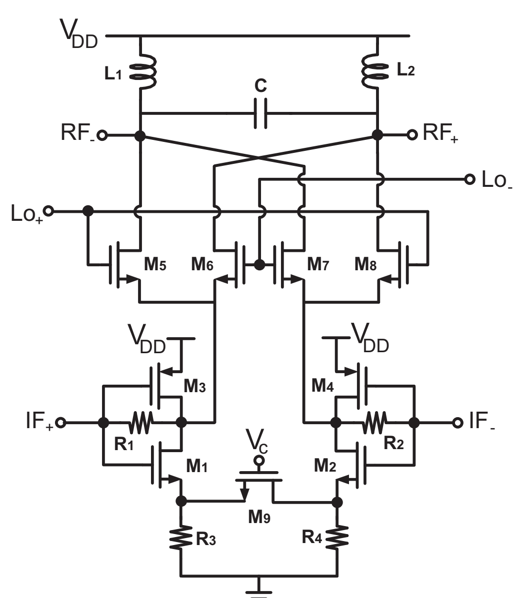


**Fig. 1.** Proposed up-conversion mixer circuit.

**Table 1**
Parameters of proposed up-conversion mixer (in Fig. 1).

| Transistors | $L$ (nm) | $W$ (nm) | Fingers |
|---|---|---|---|
| $M_1$–$M_2$ | 100 | 4000 | 16 |
| $M_3$–$M_4$ | 100 | 2000 | 16 |
| $M_5$–$M_8$ | 100 | 2000 | 4 |
| $M_9$ | 100 | 5000 | 10 |
| $R_1$–$R_2$ | 5000 (ohm) | | |
| $R_3$–$R_4$ | 140 (ohm) | | |
| Source impedance ($R_s$) | 50 (ohm) | | |
| $L_1$–$L_2$ | 3 (nH) | | |
| $C$ | 0.5 (pF) | | |

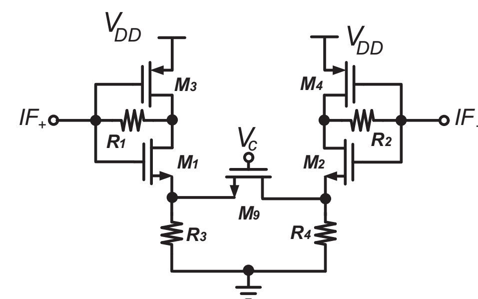


**Fig. 2.** Proposed IF trans-conductance stage.

The local oscillator switch stage comprises transistors $M_5$–$M_8$, which are utilized to switch the IF signal currents on and off. Therefore, the IF signals can be up-converted to a radio frequency, and the conversion gain of the proposed mixer is derived as

$$\text{Conversion Gain} = \frac{2}{\pi} gm_{IF} R_L \tag{3}$$

The output load impedance stage is the parallel LC tank circuit ($L_1$, $L_2$ and $C_1$). The impedance ($R_L$) of the parallel LC tank circuit can be obtained using the following simplified equation.

$$R_L^2 = \frac{R_{ind}^2 + \omega^2 L_1^2}{\left(1 - L_1 \frac{C}{2}\omega^2\right)^2 + R_{ind}^2 \frac{C^2}{2}\omega^2} = \left(\frac{R_{ind}^2 + \frac{2L_1}{C}}{R_{ind}^2 \frac{C^2}{2}\omega^2}\right) \tag{4}$$

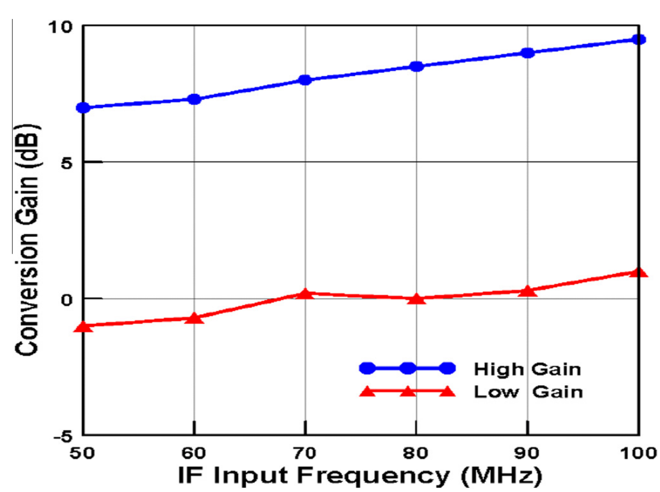


**Fig. 3.** Measured conversion gain of mixer at various IF frequencies. (LO frequency is fixed at 1900 MHz.)