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Resonant amplifier-based sub-harmonic mixer for zero-IF transceiver applications

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ABSTRACT

This paper describes a novel low voltage low power resonant amplifier-based sub-harmonic mixer using current-reuse-bleeding technique for zero-IF transceiver systems applications. The novel resonant amplifier-based sub-harmonic balun is designed and used in the mixer, which can double the frequency of the local oscillation (LO) signal. Moreover, the sub-harmonic balun can provide a pair of double frequency LO signals, unlike the conversional mixers, the novel sub-harmonic requires only one low power LO input. The proposed mixer delivers a remarkable conversion gain of 14.5 dB with local oscillator (LO) power of −2 dBm, and its power consumption is 0.65 mW with 0.8 V supply voltage. The input-referred third-order intercept point (IIP3) of the mixer is 1 dBm, and the chip area is only 0.52 mm^2.

1. Introduction

In recent years, due to the rapid growth of radio frequency (RF) communication systems, low cost and low power wireless transceivers are demanded. Because of the simplicity and low power consumption, the zero-IF transceiver systems become more and more popular. However, the zero-IF transceiver systems suffer from the self-mixing problem, which seriously deteriorates the performances of the zero-IF transceiver systems. Fig. 1 is a classic diagram of RF zero-IF transceiver system, the mixer transforms the RF signal into intermediate frequency (IF) signal in the receiver, and transforms the IF signal into RF signal in the transmitter. Just like the voltage controlled oscillators (VCOs) [1,2], the mixers are very important blocks in zero-IF RF transceiver systems, and its performances have significant influence on the whole transceiver.

DC offset is a serious problem of the zero-IF transceiver systems, which increases noise and intermodulation distortion of the transceivers. The LO leakages and their self-mixing in the mixers are the main cause of DC offset problem, and the four LO leakage paths are depicted in Fig. 1. The antennas of the transceiver recapture the LO leakages, and the recaptured leaked LO signal mixes with the LO signal of the voltage controlled oscillator (VCO) down to zero IF (known as LO self-mixing), and a DC level is generated, which appears as serious interference to the IF signals of the transceiver.

To solve the DC offset problem in zero-IF transceiver systems, the sub-harmonic mixers [3–11] are proposed. The second-order harmonic of the LO signal is used in the sub-harmonic mixers for the up or down mixing process. In other words, the frequency of the VCO is f_{Lo}, the LO signal used for mixing is $2f_{Lo}$. This means if the LO leakages is recaptured and self-mixed, there is no DC offset interference generated. Moreover, the required frequency of the VCO is half of the LO signal, which simplifies the design of oscillators and synthesizers. Hence, the sub-harmonic mixers are more suitable to build integrated RF transceiver for higher frequency applications. However, most of the reported sub-harmonic mixers require four quadrature LO signals (0°, 90°, 180°, 270°) or two LO signals (0°, 180°) [3–11], moreover, the number of stacked transistors of the reported mixers is three [3–6,8–11], and their supply voltage is greater than 1.2 V.

In this paper, a low voltage low power resonant amplifier-based sub-harmonic mixer using current-reuse-bleeding (CRB) technique is presented. Because the novel resonant amplifier-based sub-harmonic balun is adopted in the mixer, only one LO signal is required in this mixer. Moreover, the frequency of the LO signal could be doubled by this resonant amplifier-based balun, which make this kind of mixers suitable for higher frequency application. The measured results show that the proposed resonant amplifier-based sub-harmonic mixer only consumes 0.65 mW from 0.8V supply voltage, and it achieves 10.4 dB conversion gain with −2 dBm LO power.

The contents of this paper are organized as follows. In Section 2, the operational principle and circuit realizations are presented. The measured results of the sub-harmonic mixer are presented in Section 3. Finally, the conclusions of this work are given in Section 4.

2. Circuit description

2.1. The resonant amplifier-based Sub-harmonic balun

Fig. 2 is the proposed resonant amplifier-based sub-harmonic

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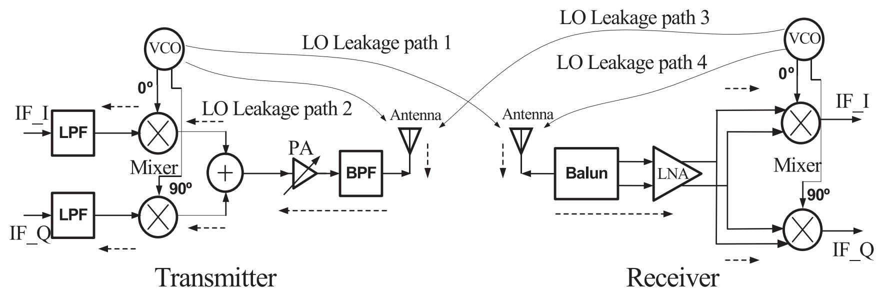

Fig. 1. Block diagram ofzero-IF transceiver system.

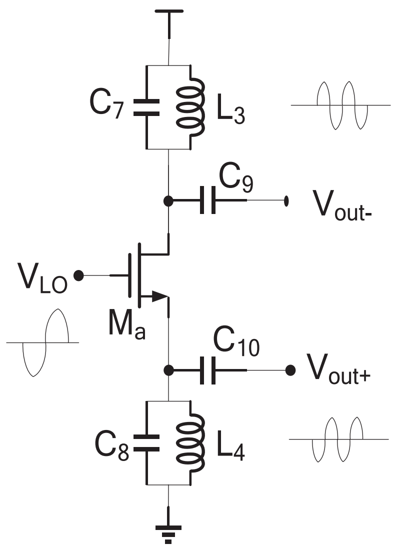

Fig. 2. The resonant amplifier-based sub-harmonic balun.

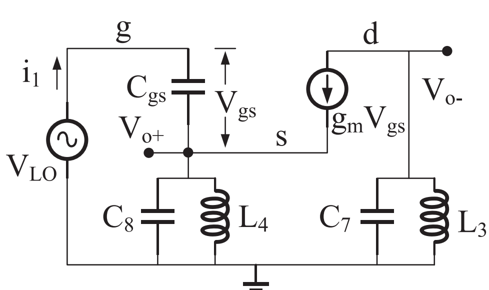

Fig. 3. The small signal equivalent circuit of the sub-harmonic balun.

balun, and its small signal equivalent circuit is presented in Fig. 3. The frequency of the LO signal could be doubled by this resonant amplifier-based balun.

By routine circuit analysis, the output voltages could be expressed as:

$$V_{O+} = (g_m V_{gs} + i_1)\frac{1}{sC_8 + \frac{1}{sL_4}} \tag{1}$$

$$V_{O-} = -g_m V_{gs}\frac{1}{sC_7 + \frac{1}{sL_3}} \tag{2}$$

where g_m is the transconductance and V_{gs} is the gate-source voltage of the transistor M_a, respectively.

The current i_1 in Eq. (1) is the gate current of the transistor M_a. According to the CMOS technology, the gate current is zero in low frequency, and it is also very small in relatively high frequency. Moreover, the drain current g_mV_{gs} is relatively larger than the gate current i_1, and the two currents satisfy:

$$g_m V_{gs} >> i_1 \tag{3}$$

This means the gate current i_1 could be neglected, choosing $L_3 = L_4$ and $C_7 = C_8$, the two output voltages satisfy:

$$V_{O+} = -V_{O-} \tag{4}$$

From Eq. (4), it is clear that the proposed sub-harmonic balun could provide two inverted and equal magnitude output voltages.

Actually, two inverted LO signals are necessary in conventional double-balanced mixers. However, only one LO signal is required in the proposed sub-harmonic mixer using the novel sub-harmonic balun.

The amplifier in Fig. 2 is a resonant amplifier, the input voltage, drain current of the transistor M_a and the output voltage are presented in Fig. 4.

Because the amplifier is a resonant amplifier, and the drain current of the transistor M_a is steeple cosine pulse, which could be expressed as:

$$\begin{cases} i_d = i_{d\max}\cos(\omega t) & (-\frac{\pi}{2} + 2n\pi) < \omega t < (\frac{\pi}{2} + 2n\pi) \\ i_d = 0 & others \end{cases} \tag{5}$$

Decomposing the steeple cosine pulse into Fourier series, we can get:

$$i_d = I_{do} + I_{dm1}\cos(\omega t) + I_{dm2}\cos(2\omega t) + \dots + I_{dmn}\cos(n\omega t) + \dots \tag{6}$$

$$\begin{cases} I_{do} = \frac{1}{2\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} i_d d_{\omega t} = \frac{i_{d\max}}{\pi} \\ I_{dm1} = \frac{1}{\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} i_d\cos(\omega t) d_{\omega t} = \frac{i_{d\max}}{2} \\ I_{dm2} = \frac{1}{\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} i_d\cos(2\omega t) d_{\omega t} = \frac{2i_{d\max}}{3\pi} \\ \dots\dots \\ I_{dmn} = \frac{1}{\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} i_d\cos(n\omega t) d_{\omega t} \end{cases} \tag{7}$$

From Eqs. (6) and (7), it is clear that the second harmonic of the input voltage is generated in the drain current of the transistor M_a.

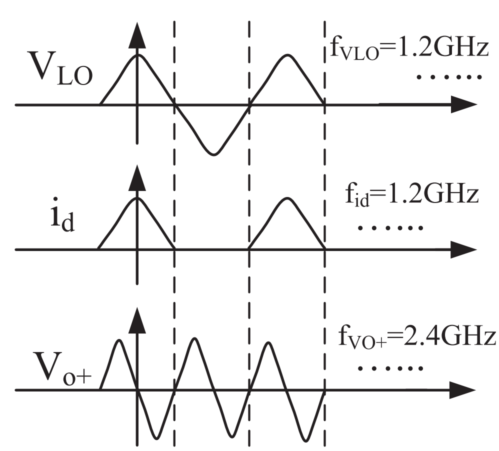

Fig. 4. The input voltage, drain current and output voltage of the balun.