

A +15dBm IIP3 Mixer with Even-Order Input Harmonic Termination

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Abstract—A broadband bipolar mixer with $>+14\text{dBm}$ IIP3 between 1-11GHz is presented. Within this frequency band, the mixer achieves a conversion gain and noise figure better than 2.0dB and 11dB, respectively. In normal operation, the mixer is driven by 200mV-pk LO and draws 2mA from a 1.5V supply.

Index Terms—Harmonic Termination, Intermodulation Distortion, and RF mixer.

I. INTRODUCTION

As wireless devices for wireless local area networking (IEEE802.11 or WLAN) and wireless personal area networking (IEEE802.15 or WPAN) are embraced by more users, the transmitted and received signals from a wireless device appear as interferences to other nearby devices, and degrade the quality of reception. This is especially true in tightly networked urban environments, where different standards have to coexist with each other. Removal of distortions (e.g., third-order intermodulation distortion, or IMD3) via filtering is not possible as it falls within the pass-band of the receiver. A common way of combating this interference is by increasing power consumption. This is undesirable for a handheld radio transceivers which operates from a battery.

Fig. 1 shows a block diagram of a superheterodyne radio-frequency (RF) receiver with two preamplifiers, each individually tuned to a different band. The outputs from these preamplifiers are fed into a mixer for downconversion to an intermediate frequency (IF) or low-IF/baseband to facilitate analog-to-digital conversion filtering and detection. Often, the overall linearity of the such receivers is determined by the mixer.

The effects of an even-order input harmonics termination on a mixer are investigated in this paper. Two mixers (with and without termination) were designed, simulated, and compared. Simulations show that the selection of an appropriate termination resistance can result in up to 15dB improvement in

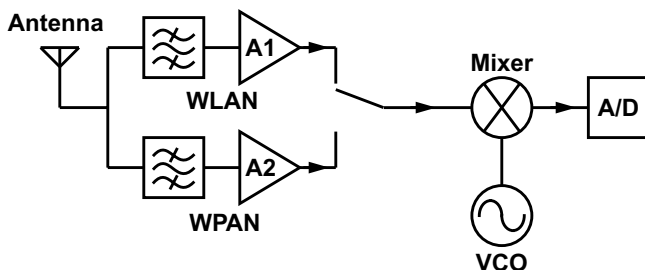


Figure 1: Dual-standard RF receiver.

IIP3 over the range from 1-11GHz. Simulation results also show that the input termination does not have adverse effects on conversion gain and noise figure. Within the 1-11GHz range, the simulated conversion gain, IIP3, and noise figure are 2dB, $\sim 14\text{dBm}$, and $<11\text{dB}$, respectively.

II. CIRCUIT DESCRIPTION

Fig. 2 shows the schematic of the most widely used integrated mixer, the Gilbert modulator [1]. It consists of an emitter-coupled pair cascaded by a 4-transistor current commuting circuit. The RF input (V_{RF}) is converted to in-phase and anti-phase currents by the emitter-coupled pair, and are then fed to the cascaded transistors (Q_{3-6}), which are driven by the local oscillator signal (V_{LO}).

IM distortions generated at the output of the Gilbert modulator is caused by the nonlinearity across the base-emitter junctions of the emitter-coupled input pair and the nonlinear operation of the current commuting circuit.

Distortion generated by the emitter-coupled pair can be reduced by utilizing linearization techniques such as local series feedback (e.g., emitter degeneration). This is accomplished by trading gain for lower distortion via increasing the bias current (I_B) and/or increasing the degeneration impedance (Z_{EE}). However, practical limitations with regard to power dissipation and signal-to-noise ratio limits the distortion reduction that can be realized by local feedback. Other circuit topologies such as optimal input biasing, out-of-

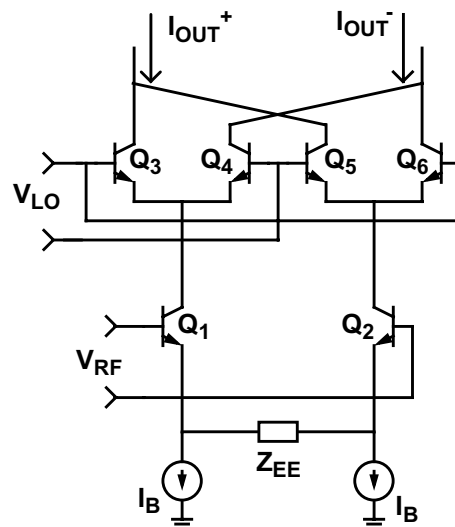


Figure 2: Double-balanced Gilbert modulator.

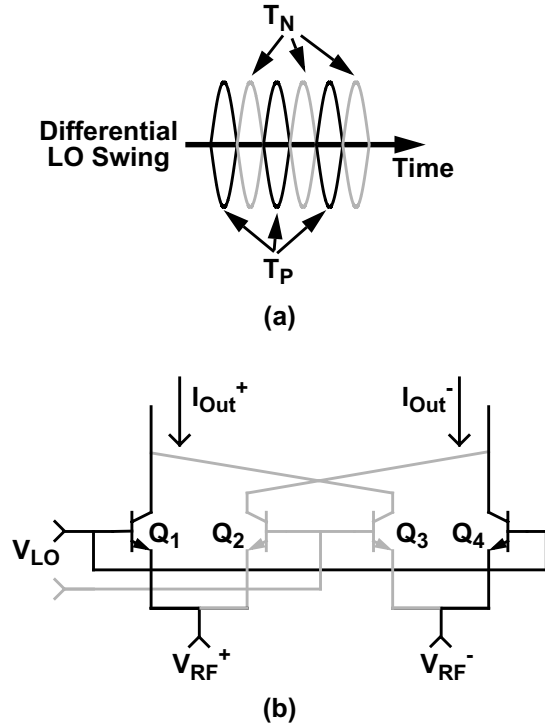


Figure 3: differential LO Swing and Switching quad.

band termination [2], and even-order termination [3] had also been proposed and demonstrated as an alternative to mitigate the distortion generated by an emitter-coupled pair.

This distortion can be eliminated by substituting a transformer balun for the emitter-coupled pair [5]. With the transformer, IM3 of the mixer is now generated by the switching quad Q_{3-6} in Fig. 2. Distortion produced by the quad is a function of bias current, transistor size, and LO amplitude [4]. Often, the choice of LO drive amplitude and the quad bias current are traded-off against noise as well as distortion.

The LO drive voltage applied to the switching quad is normally many times larger than thermal voltage (e.g., 200-500mV-pk differential). At sufficiently large LO drive voltages, only a pair of the transistors are turned on during most of the LO cycle. For example, transistors pair Q_1 and Q_4 (Fig. 3b) are turned on during the first half-cycle, T_P (Fig. 3a). During the next half cycle, T_N , Q_2 and Q_3 are on, while Q_1 and Q_4 are off. This effectively results in a pair of differentially-driven common-base stages between the RF(input) and IF(output) for the majority of the LO cycle.

Linearization using an even-order harmonic input termination had been demonstrated for linear amplification (e.g., a balanced common-emitter stage [3]). The fact that the switching quad operates as a pair of differentially driven common-base stages (for sufficiently large LO swing) suggests that an even-order harmonic termination should also be an effective method of distortion nulling for the quad.

Fig. 4 shows the schematic of a double-balanced mixer with an input transformer stage T_1 . This is similar to the mixer

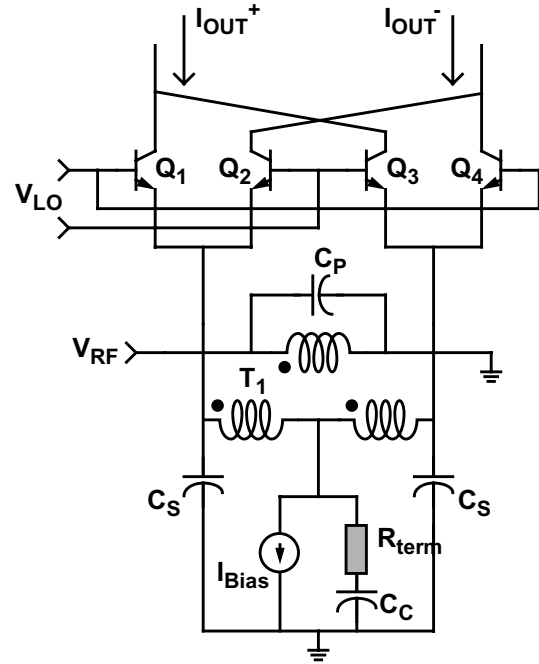


Figure 4: Double-balanced mixer with even input termination.

reported in [5] with an additional even-order termination resistor. This resistor is added to the input loop for distortion cancellation.

III. SIMULATION RESULTS AND DISCUSSION

Simulations of the mixer of Fig. 4 with and without even-order input termination were carried out using Agilent's ADSTM harmonic balance simulator in a 0.13 μ m SiGe BiCMOS process. The mixers were biased from a 1.5V supply, and an ideal transformer used at the RF, LO, and IF ports for single-ended to differential conversion. Transistors Q_{1-4} were chosen to have (length/width) of (5 μ m/0.12 μ m).

The effects of having the termination resistance (R_{term} in Fig. 4), LO voltage swing (V_{LO}), and quad bias current (I_{Bias}) were analyzed via simulation. The normalized IIP₃ (with $R=0\Omega$ as a reference) for the mixer downconverting an RF signal from 5GHz to 130MHz for various LO swing (106, 141, 177, 212, and 247mV-pk at each base) are plotted in Fig. 5 ($I_{bias}=2$ mA) and Fig. 6 ($I_{bias}=3$ mA).

Simulation results indicate that distortion generated at the output of the switching quad can be optimized by appropriate selection of the even-order termination resistor. Furthermore, three behavioural effects can also be summarized. First, the existence of an optimal resistance for a particular combination of LO swing and bias current (e.g., for 212mV-pk and 2mA combination, the IIP₃ improved by 14.6dB with the selection of 13 Ω for the termination resistor). Second, the optimal termination resistance increases with increasing LO swing for a fixed bias current. For example, for the 2mA case, optimal

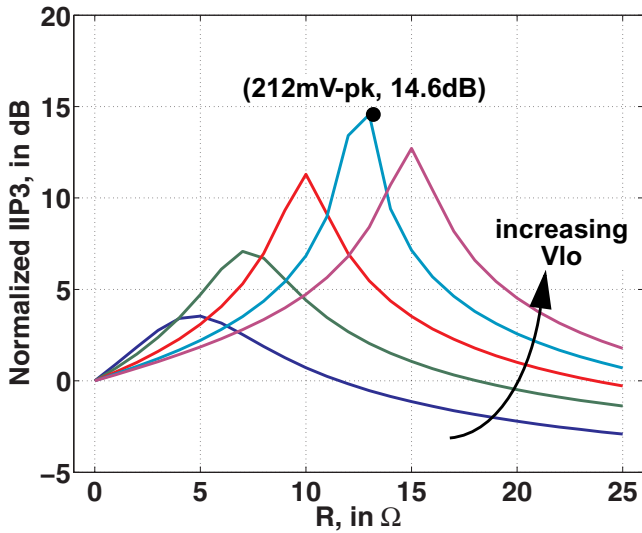


Figure 5: Normalized IIP3 for 2mA bias current.

resistance increased by 5Ω when the LO swing was raised from 177mV-pk to 247mV-pk. Third, the optimal resistance decreases with increasing bias current for a fixed LO swing. For 212mV-pk swing, the optimum value of resistance decreased to 8Ω when the bias current was increased to 3mA. Simulations also showed that there is minimal on the overall noise figure since the termination resistor only appear in the even-order loop.

Appraisal of the even-order termination as a form of distortion linearization for a broadband mixer was also investigated. The mixer is biased at 2mA, driven by an LO swing of 200mV-pk, also has a 500Ω differential IF load. Correspondingly, an 11Ω termination resistor was chosen for the highest IIP₃. The simulated fundamental and IM3 output power levels for two mixers (with and without the harmonic termination) operating as 5GHz downconverting mixers are shown in Fig. 7. The mixers have a conversion gain of 2.1dB (with optimal termination) and 0.5dB (without termination).

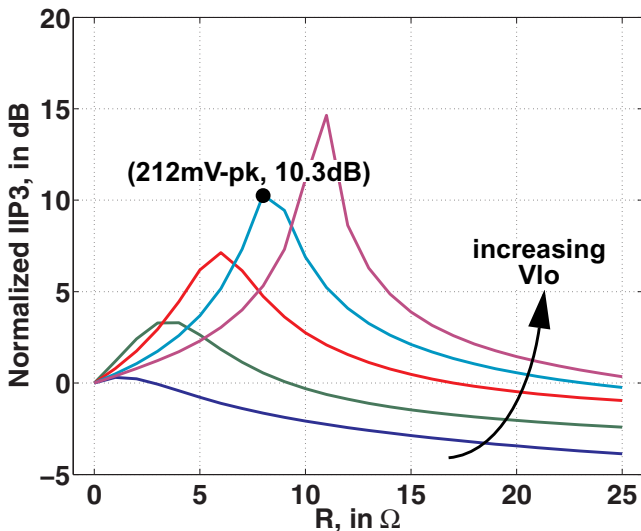


Figure 6: Normalized IIP3 for 3mA bias current.

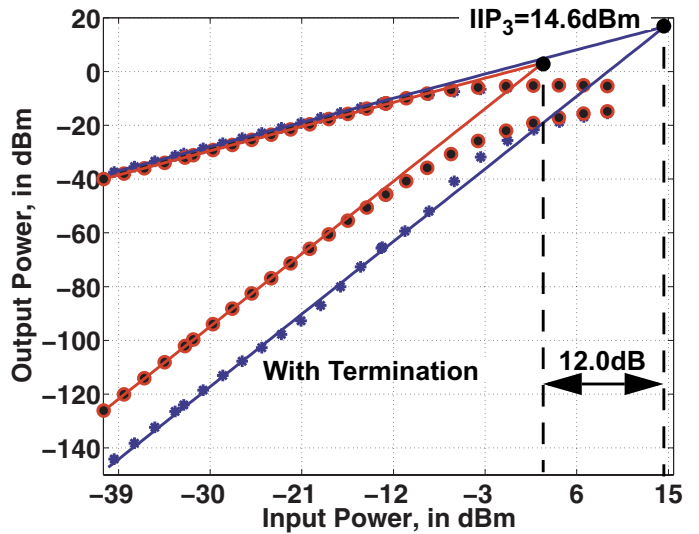


Figure 7: Distortion performance of mixers at 5GHz.

Both mixers have an input P_{-1dB} point of approximately -13dBm. Fig. 7 also shows that with the appropriate even-order termination, linearity could be improved by 12dB, yielding a maximum IIP₃ of 14.6dBm at 5GHz. The termination only affects weakly nonlinear distortion. This is evident from the fact that 1-dB compression for both mixers are approximately the same. The 1-dB compression points are primarily determined by waveform clipping at the IF outputs (as indicated in simulation).

Effects of process variations were also simulated. Values for the termination resistor and LO swing were allowed to vary $\pm 10\%$ from their respective nominal values. The performance for the two mixers (with and without termination resistor) and the worst case performance due to process variation are summarized in Table 1.

Table 1: Effects of process variation at 5GHz.

R_{Term} , in Ω	V_{lo} , in mV-pk	IIP ₃ , in dBm	G_p , in dB
11 (Ropt)	177 ($V_{lo,opt}$)	14.6	2.1
10 (0.9Ropt)	190, (1.1 $V_{lo,opt}$)	9.8	2.6
12 (1.1Ropt)	156 (0.9 $V_{lo,opt}$)	8.8	1.7
0	177 ($V_{lo,opt}$)	2.2	0.5

Simulation results predict that the process variation has minimal effect on the conversion gain. However, linearity could be degraded by up to 6dB. In the worse case scenario, linearization via even-order termination still offers more than 6.6dB improvement compared to the mixer without any termination resistor.

Simulated conversion gain, linearity, and noise figure between the 1-11GHz for the linearized mixer ($R_{Term}=11\Omega$) are shown in Fig. 8. The conversion gain remains constant at approximately 2dB across the RF band. The constant conversion gain resulted in an almost constant single-sideband 50Ω noise figure of 10dB. The simulated IIP₃ varies between 13.8 and 16.1dBm within the same band.

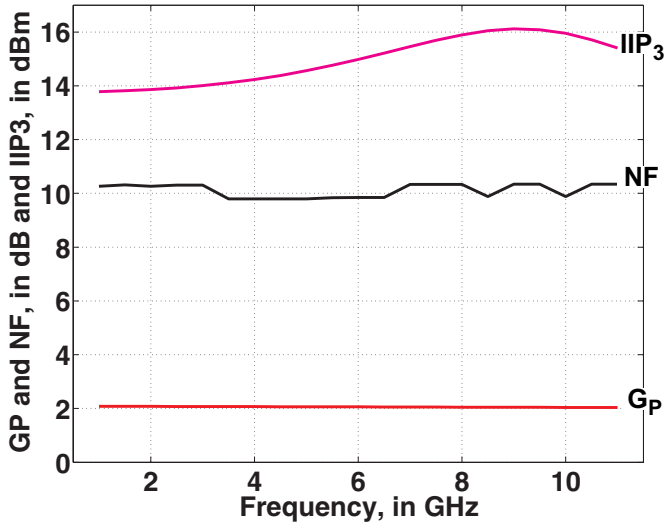


Figure 8: Conversion gain, IIP₃, and NF between 1-11GHz

Table 2 summarizes the simulation results for the mixers at 2GHz. Two other highly linear mixers reported from the literature [6] and [7] were also included for comparison (values quoted are measured results).

Table 2: Summary of Performance.

Performance Parameters	This Work		[6]	[7]
	w/ R _{Opt}	w/o R _{Opt}		
Conversion Gain, in dB	2.1	0.5	8.7	1.5
IIP ₃ , in dBm	14.6	2.7	10.0	27.5
SSB Noise Figure, in dB	11.0	12.4	9.8	15.6
Total Bias Current, in mA	2		8	160
V _{CC} , in V	1.5		2.2	5
Power Dissipation, in mW	3		17.6	800

Comparison of the mixers show that the an even-order harmonic termination resistor could be used to realize a low-voltage, low-power, highly linear mixer. The simulated IIP₃ is about 4dB better than that reported in [6] at an a much lower level of power consumption. Although the linearity reported in [7] is much higher (>13dB higher) than the mixer with harmonic termination, this was realized at a over 200x higher power consumption.

IV. CONCLUSION

A low-voltage and low-power highly linear mixer was demonstrated. Operating in the 1-11GHz band, high linearity (+13-16dBm IIP₃) can be achieved by an appropriate selection of an even harmonic termination resistor. The termination resistor has minimal effect on the noise figure and conversion gain.

ACKNOWLEDGEMENT

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