Design of Wideband Active Mixer by using an Active Inductor

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***Abstract*—A 1–10 GHz, radio frequency (RF) mixer with an active inductor (AI) designed in 0.18 μm Technology has been proposed in the paper. It uses a conventional single-balanced mixer and double-balanced mixer for demonstrating wideband performance without using an inductor. The AI-based single-balanced mixer achieves conversion gain (CG) of 6–3 dB, S11 of –12 dB, and the third-order input intercept point (IIP3) of 0.15–2 dBm. Moreover, the active transformer that is designed based on the proposed AI is used in the Gilbert cell mixer for improving the bandwidth (BW). The proposed AI-based Gilbert cell mixer achieves 4.5–3 dB of CG, and 2.7–3.8 dBm of IIP3. The 3-dB BWs of the proposed mixers are 1–10 GHz.**

***Keywords*—active inductor (AI), Single-balanced mixer, Gilbert cell mixer, wideband.**

I. Introduction

The recent release of 3GPP standard uses the sub-6 GHz band for the 5G application. That requires RF front-end to be wideband, linear, and low noise. The low-noise amplifier (LNA), and the mixer are critical component of the RF front-end. The wideband front-end needs LNA, and the mixer to perform the wideband operation. The mixer is critical components in the receiver which converts high frequencies to the base-band. Though, the mixer is second components in the receiver chain, it should provide flat gain over the desired frequency band.

Due to the advancement in complementary metal oxide semiconductor (CMOS) RF technologies, it is highly preferred for its integration to the back end design. However, the CMOS technologies introduce more parasitics, which limit the performance of the mixer for wideband operation. In order to improve the BW of the mixer, various CMOS mixers are proposed in the literature [1]–[3]. It uses inductor in order to provide band-width (BW) compensation. The on-chip inductor consume more space and provides lesser Q factor. There are various bulk injection technique [4]–[6] introduced for providing the wideband response. However, it suffers from high NF and flat BW. Therefore, this paper proposes the active inductor (AI) based bandwidth expansion technique for the conventional single-balanced mixer and the Gilbert cell mixer.

Moreover, the paper proposes novel AI and transformer for achieving wideband in the mixer. The next section discusses the issues related to the conventional mixer. Further, the proposed AI-based single-balanced mixer is discussed in section III. Section IV provides a detail analysis of the AI-based Gilbert cell mixer. Finally, section V gives the conclusions.

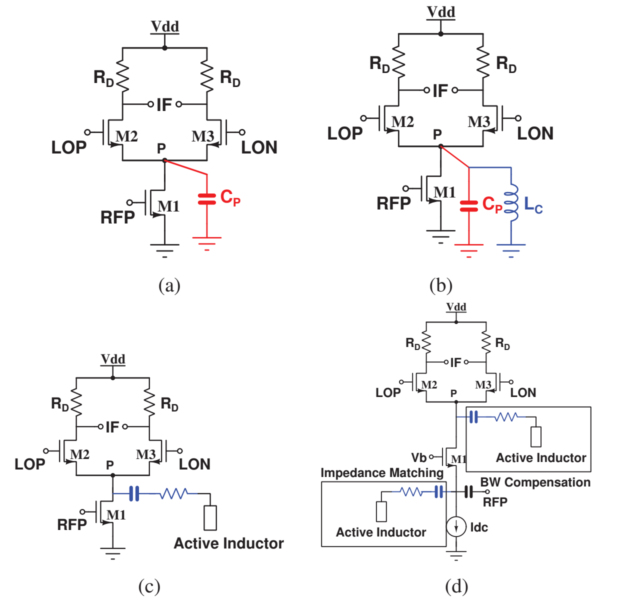

Fig. 1. (a) The single-balanced mixer. (b) The single-balanced mixer with BW compensation. (c) BW (bandwidth) compensation by using an AI. (d) The proposed single-balanced mixer by using AI.

II. Issues related to conventional mixer

There are basically two kinds of active mixer topologies that are widely studied and discussed in literature: the single-balanced [7] and the double balanced [2]. The CG of an active mixer is given by:

$$CG = \frac{2}{\pi}\frac{G_m}{G_{load}}. \tag{1}$$

However, (1) represents the DC conversion gain and it degrades over the wide frequency regime. Fig. 1a shows a conventional single-balanced mixer with capacitance C_P appearing at high frequencies at node P. This capacitance limits the mixer operation at higher frequencies and reduces the CG of the mixer. The CG of this mixer considering the C_P effect is given by:

$$CG = \frac{2}{\pi} g_{m1} R_D \frac{g_{m2}}{g_{m2} + j\omega C_P} \tag{2}$$

The tail node capacitance C_P limits the performance of the single-balanced mixer for wideband operations. The values of C_P is calculated by using Cadence simulator, which is given

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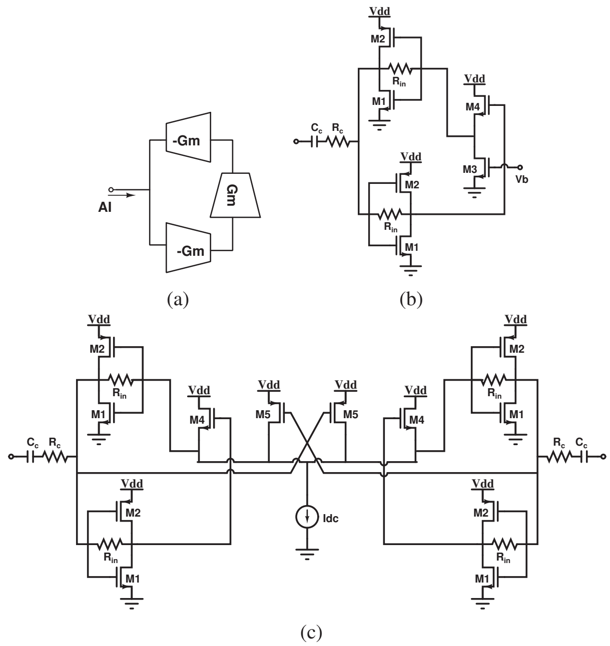

Fig. 2. (a) The model of Active Inductor (AI). (b) The proposed AI. (c) The proposed AI based transformer.

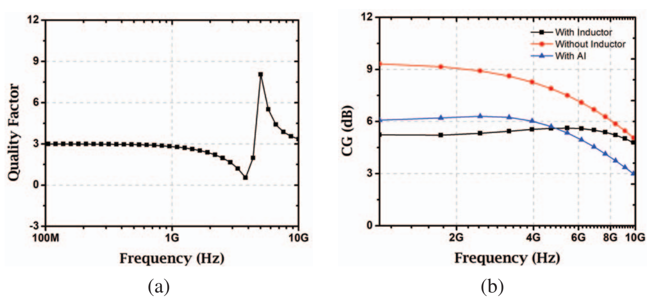

Fig. 3. (a) The quality factor of the proposed AI. (b) The CG comparison of the proposed single-balanced mixer.

by:

$$C_P = C_{GD1} + C_{DS1} + C_{GS2} + C_{GS3} \approx 660fF \quad (3)$$

If the effect of the C_P can be canceled out, the BW of the mixer will improve. Therefore, in order to compensate the effect of the C_P, the calculated inductance is approximately 6 nH by considering a cutoff frequency of 2.68 GHz. The calculated inductance is too high for CMOS Technology. It occupies around 300 um^2 size on-chip for realizing 6 nH of inductance. Moreover, the C_P increases as the frequency increases. The inductance should also vary with the frequency. Therefore, this paper proposes AI-based approach for improving BW while reducing the size on-chip.

III. The Proposed AI Based Mixers

A. The proposed single-balanced mixer

The proposed AI based single balanced mixer is shown in Fig. 1d. It has used AI at the input for providing the input matching for the wideband. Also, the AI is used at the tail node of the single-balanced mixer for improving BW. As explained in [8], the AI can be realized by connecting two transconductance amplifier as shown in Fig. 2a.

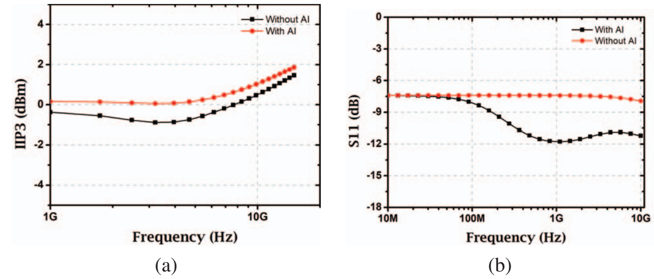

Fig. 4. (a) The IIP3 plot of the proposed single-balanced mixer. (b) The input matching (S11) of the proposed single-balanced mixer.

This paper proposes CMOS push-pull amplifier based AI that is shown in Fig. 2b. The negative transconductance is generated by using the CMOS push-pull amplifier. In order to get the AI, a buffer is introduced in between the two Gm cell. The proposed AI is realized for the single-balanced mixer as well as double balanced mixer. The differential AI is shown in Fig. 2c.

The proposed AI is simulated in 0.18μ UMC CMOS process. The simulated Q of the proposed AI versus frequency is shown in Fig. 3a. It achieves maximum Q of 8 at the desired frequency of 5 GHz. The inductance generated by the proposed active circuit is given by [8]:

$$L = \frac{C}{G_{m1}G_{m2}}. \quad (4)$$

In order to generate inductance of 6 nH, the derived values of C, and G_{m1} and G_{m2} are 500 fF, 9 mS, and 9 mS, respectively. The sizing and biasing of the transistors (M1–M4) are derived such that it provides the desired G_m.

B. The proposed AI based double-balanced mixer

As explained in section II, the tail node of the differential pair limits the BW of the Gilbert cell mixer. As shown in Fig. 5a, the C_P limits the BW of the mixer. In order to improve the BW, the C_P is canceled out by connecting the inductance in parallel to the capacitors. Therefore, the differential version of the proposed AI that is shown in Fig. 2c is developed. It uses a common current source pulled by the PMOS for providing differential behavior. The double balanced mixer by using the proposed differential AI is shown in Fig. 5b.

IV. Simulations And Results

The proposed AI-based single balanced mixer (Fig. 1d), and the double balanced mixer (Fig. 5b) are simulated by using

TABLE I. Comparison Of Results

	Single Balanced		Gilbert Cell	
	Without AI	With AI	Without AI	With AI
CG (dB)	3	6	6.62	3
BW (GHz)	1–4	1–10	1–6	1–10
NF (dB)	16.08	16.75	20.03	20.19
S11 (dB)	–7	–12	NA	NA
IIP3 (dBm)	-0.380	0.15	2.67	2.67

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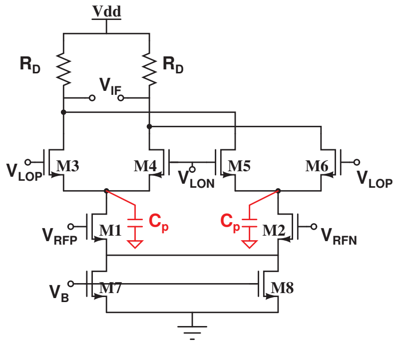
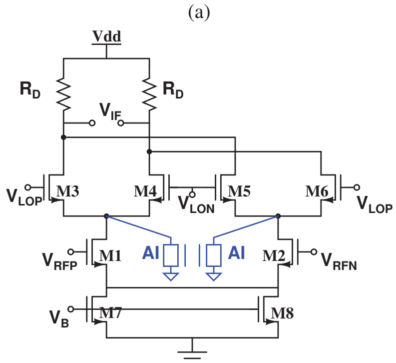
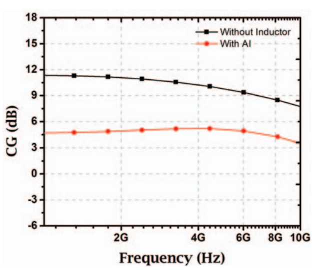


(a)

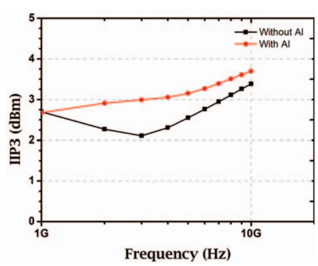


(b)

Fig. 5. (a) The double-balanced mixer. (b) The proposed AI-based Gilbert cell mixer.



(a)



(b)

Fig. 6. (a) The CG plot of the proposed Gilbert cell mixer. (b) The IIP3 plot of the proposed Gilbert cell mixer.

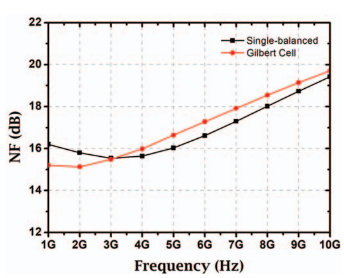


Fig. 7. The NF of the proposed mixer.

Cadence with 0.18μ UMC technology. The mixers are simulated with a supply voltage of 1.8 V, an input RF frequency ranging from 1 GHz to 10 GHz, and the IF frequency of 40 MHz. The amplitude of the RF signal is set at –30 dBm. The single-balanced mixer consumes power of around 12.15 mW at 1.8 V.

As shown in Fig. 6a, the simulated CG of the proposed single-balanced mixer is 6–3 dB for the frequencies 1–10 GHz. The third-order input intercept point (IIP3) is simulated by providing a 1 MHz separation between the two tones. The IIP3 of the proposed single-balanced mixer with and without inductor for the frequency range starting from 1 GHz to 10 GHz is plotted in Fig. 6a. The minimum IIP3 is 0 dBm at 1 GHz, and the maximum IIP3 is 2 dBm at 10 GHz. The input matching (S11) is plotted in Fig. 6a. The S11 of the proposed mixer is less than –10 dB for the 1–10 GHz of the frequency range.

The CG of the proposed AI-based Gilbert cell mixer is shown in Fig. 6a. It achieves CG of 4.5 dB for the frequency rang from 1 GHz to 10 GHz. The AI-based mixer achieves BW more than 10 GHz which is higher in comparison to the mixer without the inductor. The simulated IIP3 across the 10 GHz frequency span is shown in Fig. 6b. The IIP3 achieved is between 2.8 dBm to 3.9 dBm for frequency range starting from 1 GHz to 10 GHz, respectively. It is observed that the proposed AI-based mixer has higher IIP3 compared to the mixer without the inductor. The summary of the results are tabulated in Table I. It is observed that there is a substantial improvement in the BW while maintaining other mixer parameters.

V. Conclusion

The paper present the active inductor (AI) based mixer design for improving the BW. The proposed AI achieved quality factor of 8 at 5 GHz. The proposed AI improved the BW of the proposed mixer by 60 % compared to conventional mixers. The simulated results show that the proposed mixer achieves BW up to 10 GHz for the single balanced as well as Gilbert cell mixer. Therefore, the proposed AI-based mixers can be useful for wideband applications.

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