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Mixers of Ultra-High Gain from 5.0 to 18.0 GHz

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ABSTRACT

Mixers in the communication system provide the possibility of encoding and decoding radio-frequency EM waves with signals through the help of local oscillators. A mixer with capability of high conversion gain, good isolation, and good linearity is comparably appreciated. Extensively wide ranges of frequencies, from 5.0 to 18.0 GHz, are to be examined addressing the promising functions of mixers in this study. A TSMC 0.18 μm CMOS model implanted in Agilent ADS is used for the circuit designs. Generated from Gilbert Cell Mixer, the modified circuits take advantage of extra active and passive devices to optimize the conversion gains. Characteristics of high conversion gain over 20 dB or even higher (as high as 29.842 dB at −40 mW RF power at working frequency 6 GHz) and low noise figures (NF) are shown.

Keywords: Gilbert Cell Mixer; P1dB; Linearity; Noise Figure (NF); Conversion Gain; Isolation

1. Introduction

Mixers are indispensable components in transceiver system (transmitter and receiver) in the communication system, providing the possibility of encoding and decoding radio-frequency EM waves with signals through the help of local oscillators. As quoted as "Mixer", a mixer mixes two input signals with different frequencies and yields an output signal with a specific frequency. A mixer with capability of high conversion gain, good isolation, and good linearity is comparably appreciated.

Traditional Gilbert Cell [1] in **Figure 1** composing of six NMOS devices mainly generates two differential currents, namely, i_{D1} and i_{D2}, flowing through M1 and M2 with the common trans-conductance (g_m). In one aspect, the two currents associate the two inputs, one from the local oscillator imposing on the two sets, (M3, M4) and (M5, M6), and the other from RF signals impacting on M1 and M2, as expressed as follows:

$$\begin{cases} i_{D1} \cong \dfrac{C_{ox}^{(1)} \mu_N W}{L} \left(v_G - v_{th} \right) v_{DS1} \\ i_{D2} \cong \dfrac{C_{ox}^{(1)} \mu_N W}{L} \left(v_G - v_{th} \right) v_{DS2} \end{cases} \quad (1)$$

with $g_{m1} = \dfrac{\partial i_D}{\partial v_G} = g_{m2}$. In Equation (1), $C_{ox}^{(1)}$ is oxide capacitance (F/m²), μ_N is the mobility (m²/sV), and L is the channel length. Because of the multiplication of $v_G = v_{Go} \cos(\omega_{LO} t)$ and $v_{DS} = v_{DSo} \cos(\omega_{RF} t)$ in Equation (1), the output IF_P signals are resulted, as derived in Equation (2), achieving raising and lowering of frequencies, *i.e.*, $(\omega_{RF} \pm \omega_{LO})$.

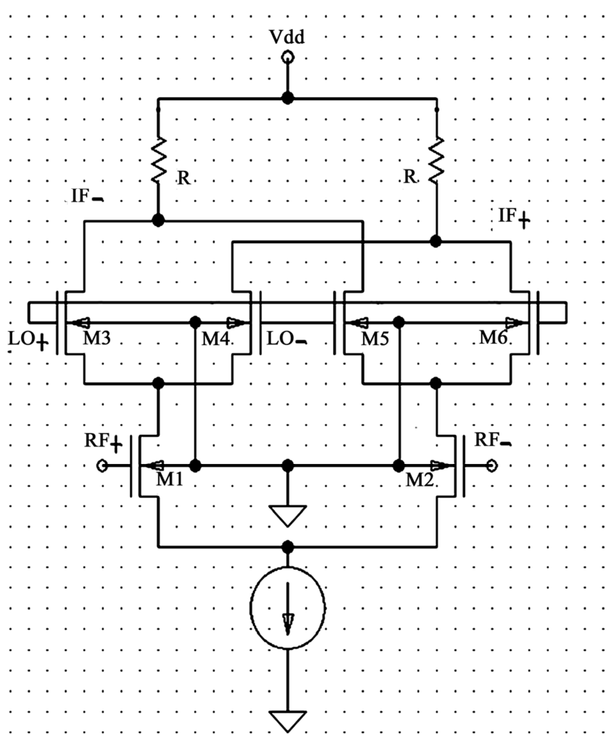


Figure 1. The conventional Gilbert Cell Mixer.

$$v_G v_D = v_{Go} v_{DSo} \cos(\omega_{LO} t)\cos(\omega_{RF} t) = \frac{v_{Go} v_{DSo}}{2} \cos\left[(\omega_{RF} + \omega_{LO}) t\right] + \cos\left[(\omega_{RF} - \omega_{LO}) t\right] \quad (2)$$

In this paper, a powerful mixer using an extensively generated circuit based on Gilbert Cell with sufficient current sources in the downstream is proposed as shown in **Figure 2**. Somehow, to enhance the stability and the amplification, the symmetrical topology is used by duplicating the unit in **Figure 3** on both sides of **Figure 2**. Advanced Design System (ADS) by Agilent implemented with a TSMC 0.18 micron model is to be used to evaluate the circuit design.

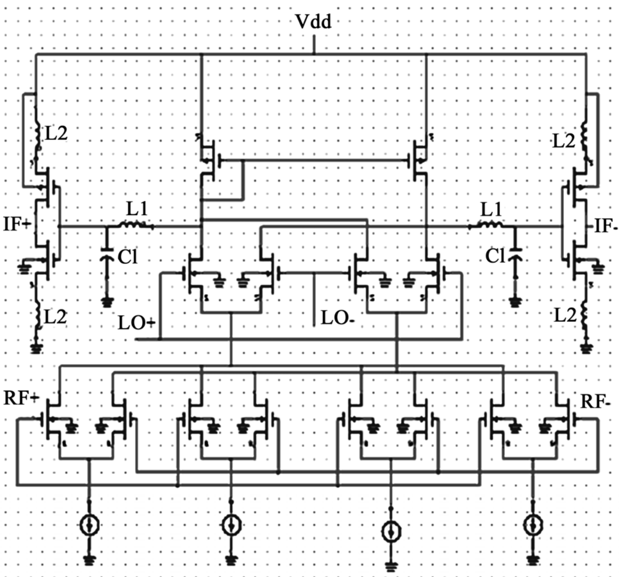


Figure 2. Four-current-source Gilber Cell Mixer with two inverters enhancing the amplifying effects.

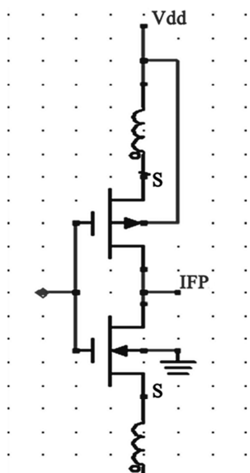


Figure 3. The inverter-like CMOS units.

2. Mixer Circuit Design

For the sake of larger current flow, the circuit in **Figure 2** generated from the conventional Gilbert Cell Mixer is to be optimized using four I_{bias}'s instead of only one I_{bias}. To avoid the unnecessary power consuming, passive resistors are never considered. With the introduction of inductors and capacitors (L1, and C1), the noise figures are expected to be lowered. And the isolations at higher frequencies ranged from 6 GHz to 18 GHz are supposed to be better because of the two sets of inverter-like units as shown in **Figure 3**. Each set is inserted with two inductors (L2), one in the upstream and the other in the downstream, to keep the radio frequency signals from leaking. The whole set in **Figure 3** is thus operated to raise the conversion gains as well. The symmetrical topology is to be used and the current sources are adjusted step by step. The number of mirror units is to be imposed and the number of symmetrical NMOS devices where LO and RF are applied is carefully examined and determined.

3. Results and Analysis

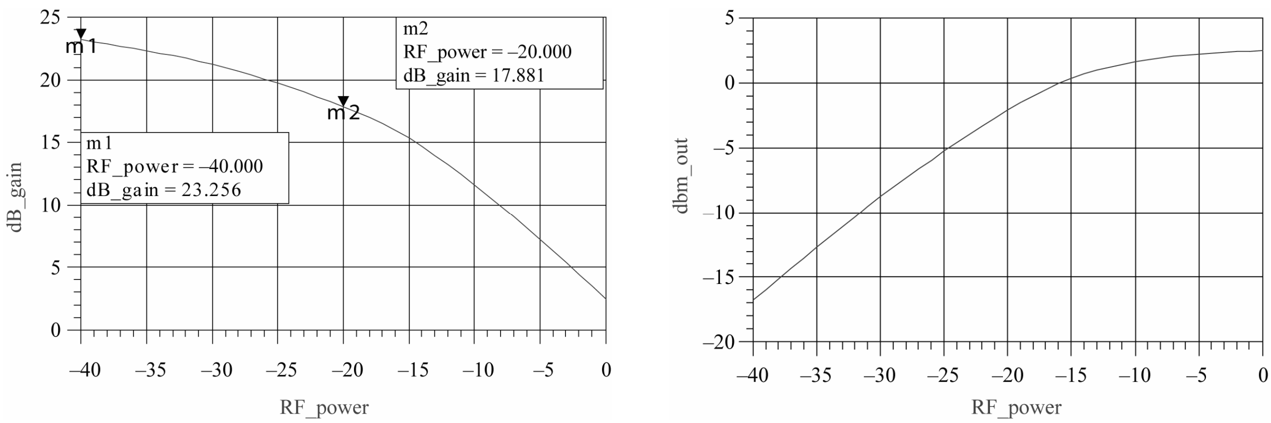
In general, the conversion gains are normally high above 20 dB from 6 GHz to 18 GHz as listed in **Table 1**, in which the maximum conversion gain can be even as high as almost 30 dB. As shown in **Figure 4(a)**, the exciting results are strongly appreciated at 15 GHz, such as the conversion gains = 23.256 dB at RF_power = –40 mW, 17.881 dB at RF_power = –20 mW, and even over 2.5 dB at RF power = 0 mW. This circuit executes not only the function of a mixer but also enhance the conversion gain, which is quite encouraging and convincing. Two reasons are speculated: 1) the four current sources require higher current to flow through the whole component; and 2) the two inserted inductors in series with the inverter-like CMOS devices keep the high frequency signals from dumping to the ground [2-7]. **Figure 4(b)** also demonstrates the surprisingly good linearity at such a high frequency from power –40 mW to power –20 mW, extending to about power –15 mW at P1dB point. In addition, the isolations among LO (Terminal 1), RF (Terminal 2), and IF (Terminal 3) are to be found in **Figure 5**, in which S12 = –15.173 dB, S23 = –28.902 dB, and S13 = –24.783 dB and all are satisfying. Unfortunately, the noise figure NF = 8.400 dB in **Figure 6** is not sufficiently low as expected. Nevertheless, it is still controllable and is expected to be lowered in the near future.

4. Discussions

The last two columns of **Table 1** show the encouraging conversion gains up to 18 GHz at RF_power = –40 mW and at RF_power = –20 mW. As compared to the previous work in [8], the conversion gains can be even

Table 1. Comparisons of the previous work and this work.

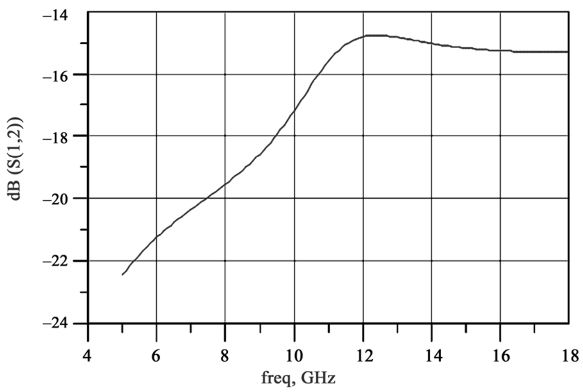
	Freq. (GHz)	Previous Work [3]		This Work	
		Gain (dB) At RF_Power = –40 mW	Gain (dB) At RF_Power = –20 mW	Gain (dB) At RF_Power = –40 mW	Gain (dB) At RF_Power = –20 mW
TSMC 0.18 m Process	6.0	21.153	18.884	29.841	20.623
	7.0	22.583	19.167	28.640	20.524
	8.0	22.142	18.852	27.757	19.856
	9.0	21.599	18.349	27.220	19.726
	10.0	20.954	17.745	26.616	19.482
	11.0	NA	NA	26.042	19.231
	12.0	NA	NA	25.471	18.950
	13.0	NA	NA	24.854	18.577
	14.0	NA	NA	24.052	17.954
	15.0	NA	NA	23.256	17.881
	16.0	NA	NA	21.925	18.146
	17.0	NA	NA	20.987	17.711
	18.0	NA	NA	20.100	17.280



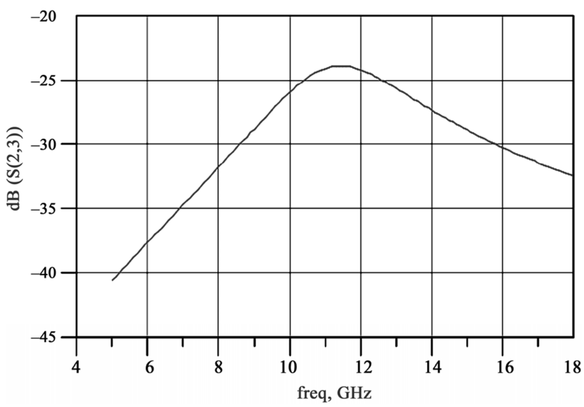
(a) (b)

Figure 4. (a) The conversion gain; and (b) the linearity.

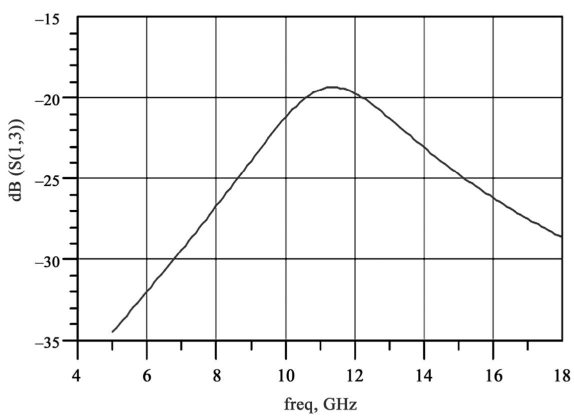
noticeably better from 6 GHz to 10 GHz. It is due to careful tuning on the passive devices and the stable symmetrical topology, which can be seen in the mirror feature. In addition, the inverter-like CMOS devices with inductors in series play the roles of keeping the high frequency signals away from dumping to the ground, and thus contribute significantly to the conversion gains. The current sources were kept the same at 2 mA for its satisfactory status in this structure compared to the previous design [8]. Somehow, the currents of the four current sources and the voltage of the voltage source are expected to be lower in the continuous work. In the mean time, noise figures are to be lowered in the near future, too, even at such high working frequencies.



(a)



(b)



(c)

Figure 5. The isolation among LO (Terminal 1), RF, (Terminal 2) and IF (Terminal 3) at 15 GHz (a) LO-RF (b) RF-IF (c) LO-IF.

5. Conclusion

A Gilbert-Cell Mixer based mixer is introduced with two inverter-like CMOS units in series with two inductors. The conversion gains are found to be significantly improved. The good isolation, acceptable noise figure, and linearity are to be checked. The encouraging data shows the promising applicable circuit designs. One would continue to develop the total solution for the whole component and even the whole system.

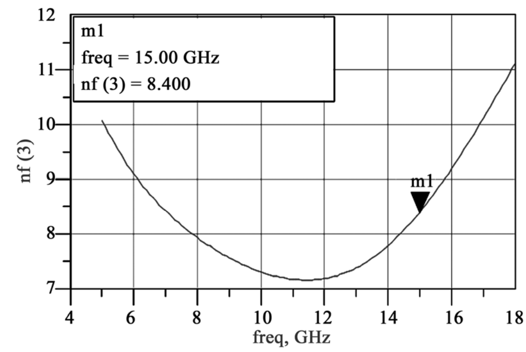


Figure 6. Noise figure at IF at 15 GHz.

6. Acknowledgements

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