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Design of Active CMOS Gilbert Mixer with High IIP3 and Low Noise Figure for UHF Applications

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Abstract: *This paper presents improved circuits of CMOS Down conversion mixers. Double Balanced Gilbert cell topology is adopted in the design for achieving good isolation among the ports. Inductive source degeneration and current bleeding techniques are employed to improve IIP3 and noise figure of the mixer. High conversion gain is achieved through the use of active loads. Conversion gain of PMOS load based mixer is changed from 8.3dB to 5.7dB and the IIP3 from 11.944dBm to 22.259dBmby using current bleeding technique in inductively degenerated Gilbert mixer. Current Mirror load based mixer has simulated conversion gain of 18.27dB with 9.975dBm IIP3 and 8.4dB SSB NF. Mixers are designed to operate at 2.5 GHz RF frequency with an IF frequency of 250MHz. The proposed mixers are fabricated in 180nm CMOS technology using 1.8V supply.*

Keywords: *Current Bleeding, source degeneration, IIP3, Flicker noise, High linearity, Conversion gain, Noise Figure, Double balanced, transconductance.*

1. INTRODUCTION

The invention of wireless telegraphy for sending morse code has made its way to the present technologies such as Bluetooth, WiFi, Zigbee, WLAN, GPS, IEEE 802.11 a/b/g etc. For the procurement of all these services by an electronic device, area requirement and power consumption of the transceiver circuit must be minimized.

Mixer, a frequency translation device is generally employed at the second stage in an RF receiver front-end. The performance of the overall receiver system is immensely dependent on the linearity, Noise Figure and the distortion level of this subsystem.For obtaining progressively high performance of the mixer at low operating voltage, minimum leakage, high speed and small power consumption with reduced number of transistors, various circuits have been developed by various researchers. The most popular and widely used active mixer is a Gilbert cell mixer which functions like a four quadrant multiplier. It essentially consists of two single balanced mixers with their outputs cross-coupled together in current domain [1].The RF and LO inputs are fed as well their corresponding IF output is taken in a differential manner. Although it consumes twice as much of power as a single balanced mixer, its excellent port to port isolation, compact structure, high conversion gain and spurious noise cancellation make it suitable to be used as microwave mixers [2].

The linearity of the mixer is mainly influenced by the switches, tail current source and the trans-conductance stage. The effect of imperfect switching on the linearity is obtained as the summation of the inter-modulation distortion caused due to the switches and the transconductors. The small value of switch ON voltage and the large LO drive is required for reducing such nonlinearities. However, too large value of LO power could increase nonlinearities due to capacitive loading at the common source nodes [3] of the switching pairs. For proper switching moderate power level of the LO signal must be ensured. Trans-conductors also affect the IIP3 (third order input intercept point) of mixer circuit, for which linearity enhancement techniques like LNA can be employed. The techniques that are popularly used in Gilbert mixer are source degeneration and current bleeding (current injection).

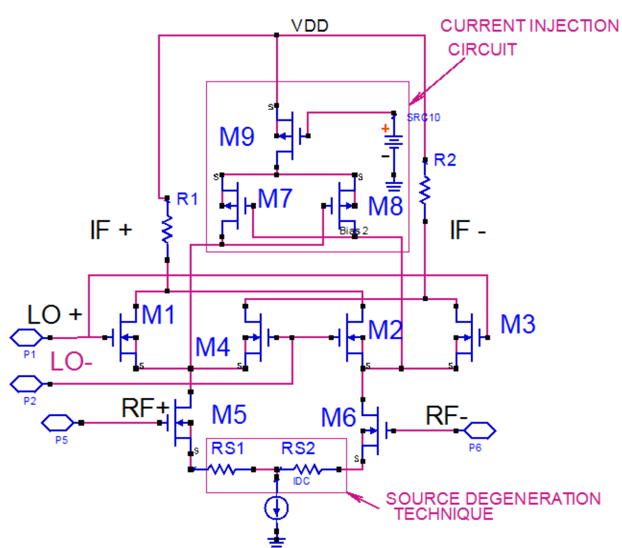


Fig. 1.Gilbert cell Mixer with source degeneration and Current Injection techniques

2. LINEARITY OF THE SIGNAL PATH

2.1 SOURCE DEGENERATION TECHNIQUE

For enhancing linearity of the mixer, source degeneration resistors or source degeneration inductors are added to the transconductance transistors. If a passive degeneration resistor is used, mixer becomes almost linear because of the increase in the range of input voltage but the gain is reduced. Degeneration inductor could stabilize the circuit by adding a real and positive component to input impedance and therefore helps in impedance matching also. However, capacitive degeneration could not be employed because it introduces a negative resistance g_mZs into the input impedance which leads to oscillatory behavior [4]. Degeneration inductor best suits to linearity requirement with increasing frequency but gain of the mixer starts decaying and an inductor requires more area on chip as well. The Q factor of the on chip inductor is mainly limited by the metal losses and conduction through substrate occurring in bulk silicon technology. Ordinary digital IC therefore incorporates spiral inductors with low Q factor only.

2.2 CURRENT INJECTION TE CHNIQUE

In the Gilbert mixer circuit, RF transistors operate in saturation and therefore their conversion gain and IIP3 are given by $CG = \frac{2}{\pi} R_L \sqrt{K_N I_D}$ and $IIP3 = 4\sqrt{\frac{2}{3}\frac{I_D}{K_N}}$, where $K_N = 2\mu_n C_{ox}\frac{W}{L}$. Both CG and IIP3 are directly proportional to the square root of the bias current. It seems that both can be simultaneously increased by enhancing this current. However practically with increase in bias current, voltage drop across the load resistor increases and disturbs the operation of LO switches. To eliminate this drawback, drain current of RF transistors is increased without increasing the current through the switching transistors by using current injection or current bleeding technique as shown in Figure 1.Transistors M7 and M8 are used for injecting a dynamic current which is equal to the bias current in the switching pairs when switching takes place and thereby enhances the linearity of the path [5-9].

3. PMOS LOAD AND CURRENT MIRROR LOAD

If an active load is used instead of a passive load in a Gilbert mixer, significant reduction in area as well as higher could be attained. Higher small signal resistance at the output produces high conversion gain. In an active load, minimum supply voltage required which depends upon the drain-source voltage drop in the transistor which is much less compared to that of apassive resistor. AMOS transistor operating in the saturation region can act as an active load whose output resistance is modulated by the drain current controlled by the gate voltage [5].However MOS transistor adds more flicker noise to the circuit.

Current mirror load can also provide higher conversion gain but itconverts differential input into single ended output but at the expense of bandwidth [5, 10].

In this paper two Gilbert cell mixers are designed one with PMOS load whose linearity is enhanced by using current bleeding technique and the other with current mirror load for which linearity is enhanced by adding capacitors in parallel. Parallel RC circuit formed by the output impedance of transistor and the added capacitor in the load circuit acts as a high pass filter which suppresses the harmonic components of higher order and improves the third order intercept point.

4. SIMULATION RESULTS

4.1 PMOS LOAD AND INDUCTIVE SOURCE DEGENERATION

The circuit is simulated with PMOS load operating in saturation region Bias voltage of 0.84V at the gates of the devices and degeneration inductors of 1nH at the source of the transconductance transistors.W/L ratio for the PMOS transistors is 38µm/0.18µm.

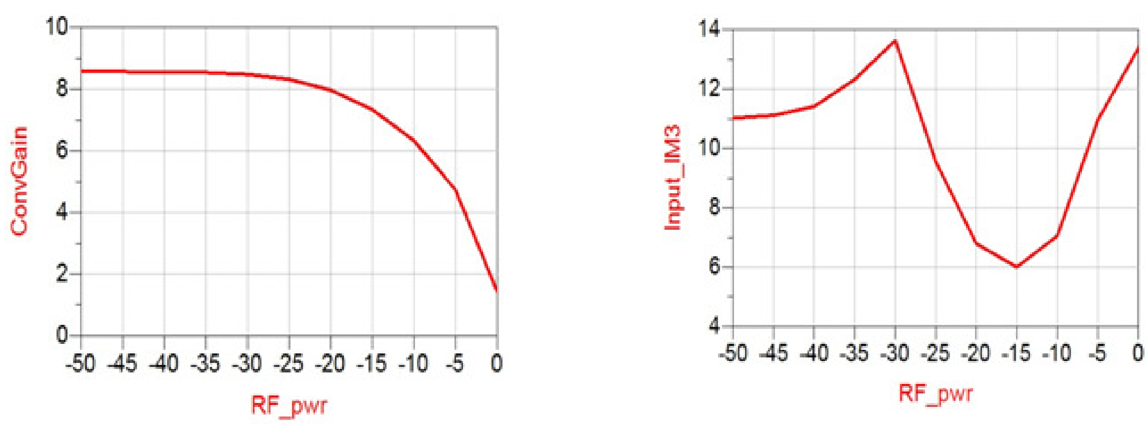


Fig. 2. Conversion gain (dB) versus RF Power (dBm) and Input IM3 (dBm) versus RF Power (dBm)

The variation of the conversion gain and input IM3 (third order intermodulation point)with input RF power for PMOS load based Gilbert mixer is shown in the Figure 2. The mixer has achieved the maximum gain 8.576 dB which maintained its approximately constant value up to -25 dBm, beyond this point the gain is decreasing with increase in RF power. Maximum IIM3 is 13.644dBm obtained -30 dBm RF power.

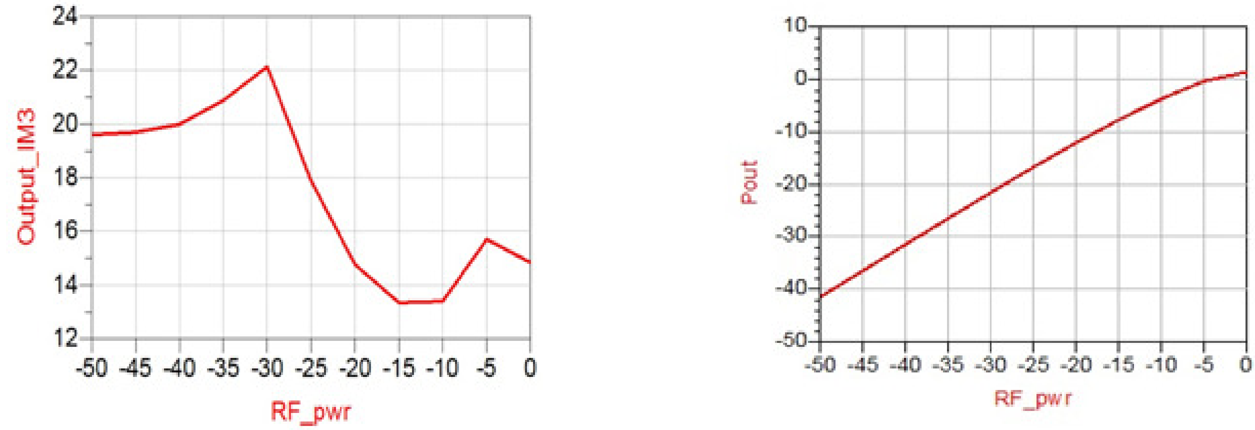


Fig. 3. Output IM3 (dBm) versus RF Power (dBm) and Pout (dBm) versus RF Power (dBm)

Figure 3 shows the simulated plots for output IM3 (third order intermodulation point) versus RF power andoutput IF power versus RF power with PMOS load based circuit. The OIM3 plot has maximum amplitude 22.129 dBm at -30 dBm RF power. The output power versus RF power plot shows that IF power at the output increases almost linearly with increase in input power. The output power at -30 dBm RF power is -21.515 dBm.

Figure 4 shows the variation of conversion gain with RF frequency with PMOS load. The positive conversion gain is obtained from 250 MHz to 6.9 GHz with maximum value 8.614 dB at 2.0 GHz frequency.

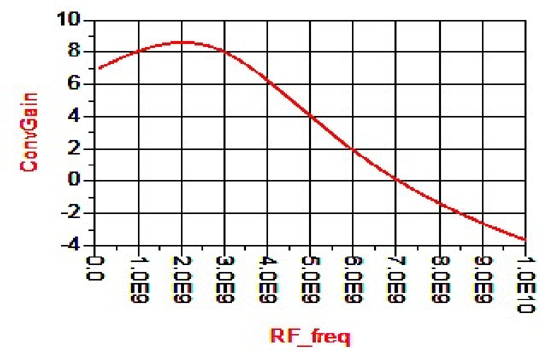


Fig. 4. Conversion gain (dB) versus RF frequency (GHz)

4.2 PMOS LOAD WITH CURRENT INJECTION AND INDUCTIVE SOURCE DEGENERATION

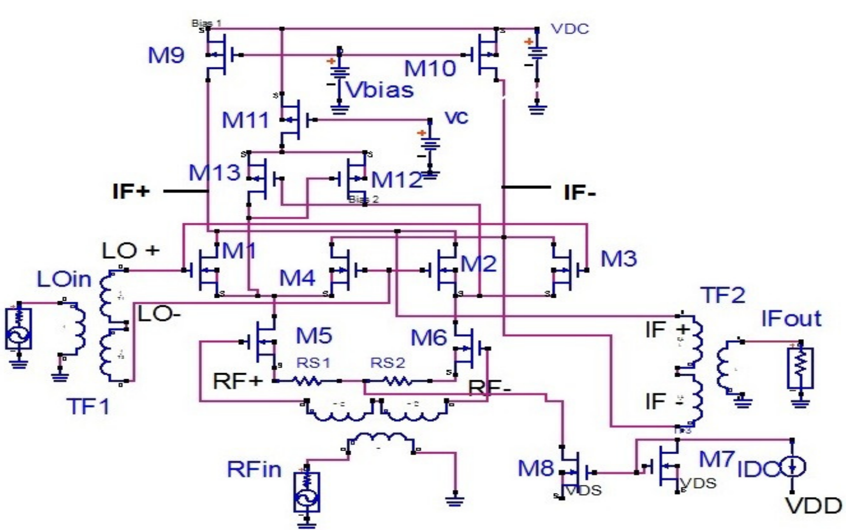


Fig. 5. PMOS load based Gilbert mixer with current injection method

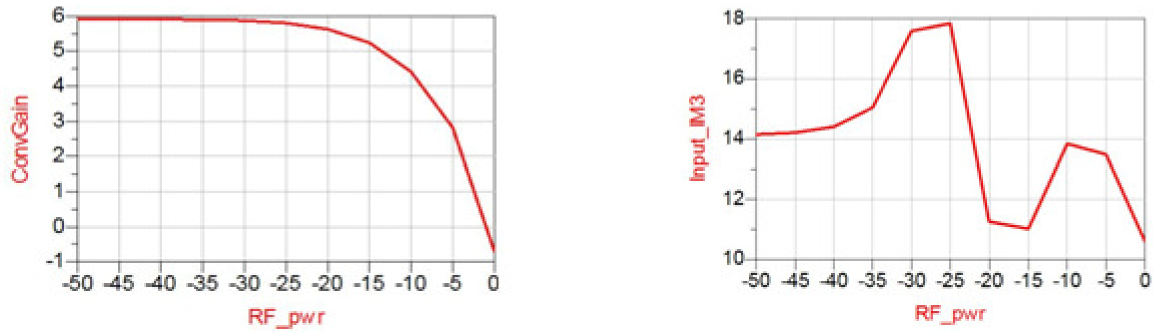


Fig. 6. Conversion Gain (dB) versus RF Power (dBm) and Input IM3 (dBm) versus RF Power (dBm)

The variation of the conversion gain and Input IM3 with input RF power for mixer employing current injection is shown in Figure 6. The mixer has achieved the maximum gain 6dB which maintained its approximately constant value up to -25dBm, beyond this point the gain is decreasing with increase in RF power.

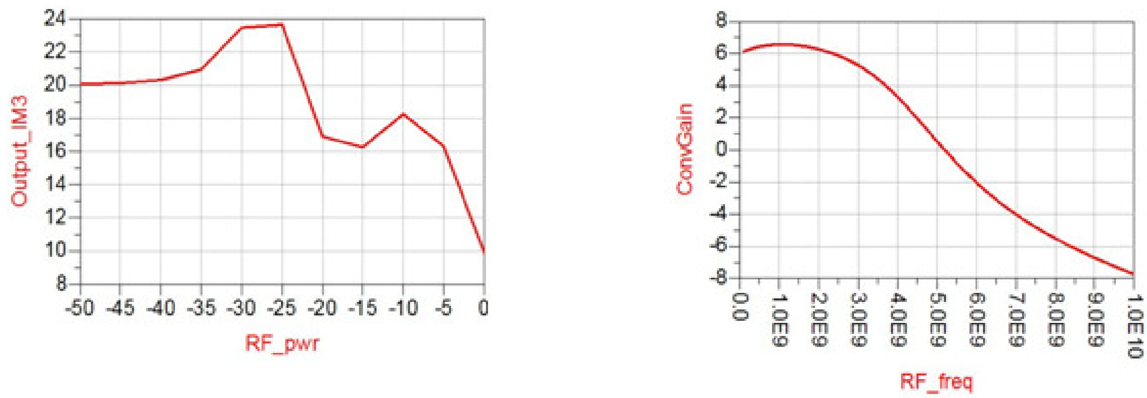


Fig. 7. Output IM3 (dBm) versus RF Power (dBm) and Conversion Gain (dB) versus RF frequency (GHz)

The Output IM3 is shown in Figure 7. Theplot has maximum amplitude ~23dBm around -30dBm RF power. The variation of conversion gain (in dB) with RF frequency (in GHz) shows that positive conversion gain is obtained from 250 MHz to 5 GHz.

4.3 CURRENT MIRROR LOAD AND INDUCTIVE SOURCE DEGENERATION

The mixer is simulated with current mirror circuit as load and degeneration inductors of 1nH. The W/L ratio for the PMOS transistors at the load is 22(µm)/0.18(µm).

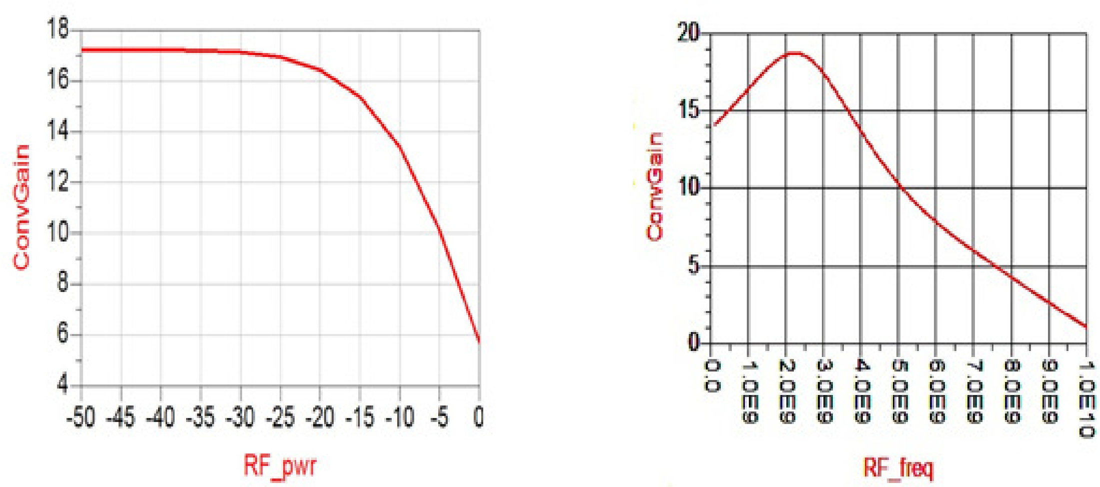


Fig. 8.Conversion Gain (dB) versus RF Power (dBm) and Conversion gain (dB) versus RF frequency (GHz)

The variation of the conversion gain and Input IM3 with input RF power is shown in the Figure 8.The mixer has achieved the maximum gain 16.94dB which maintained its nearly constant value up to -25 dBm, beyond this point the gain is decreasing with increase in RF power. The variation of conversion gain (in dB) with RF frequency (in GHz) shows positive conversion gain from 250 MHz to 10 GHz with maximum value 18.763 dB at 2.2GHz frequency.

Figure 9 shows the current mirror load with parallel load used in the Gilbert mixer for lineartiyenhancement.Figure 10 shows conversion gain and Input IM3 for various values for parallel capacitors.Conversion gain variation with RF frequency in Figure 11 shows that bandwidth is significantly improved by the use of capacitors.

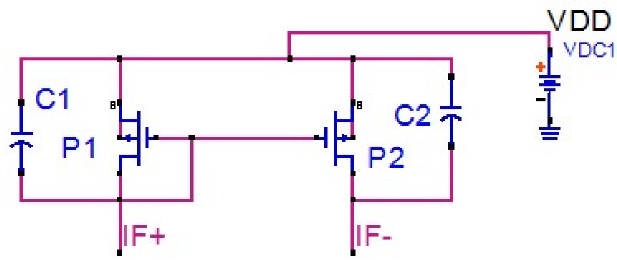
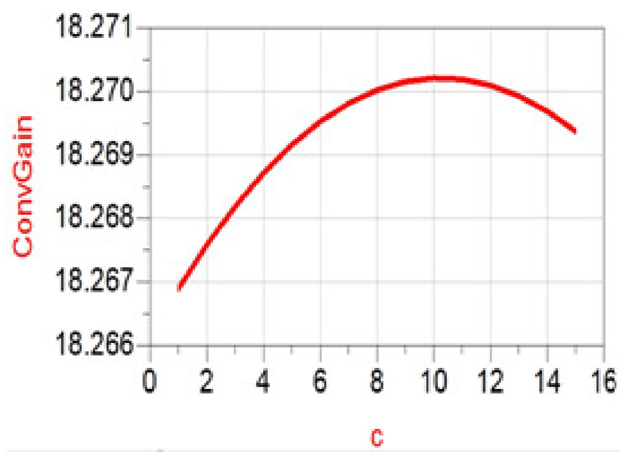


Fig. 9.Current mirror load with parallel capacitors



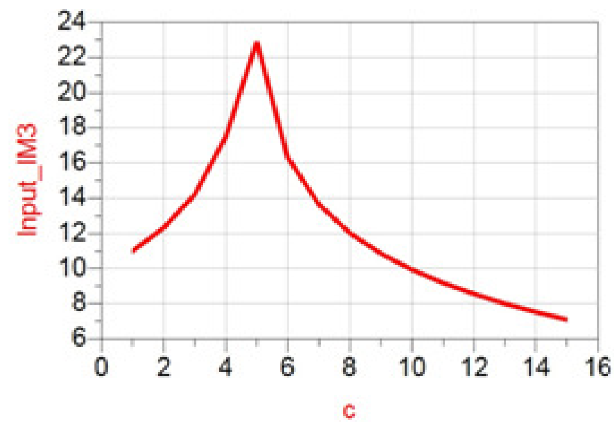


Fig. 10.Variation of conversion Gain (dB) and Input IM3 (dBm) with parallel capacitor c (f F)

TABLE 1: Performance Comparison of Mixers

Parameters → Loads ↓	CMOS Technology (µm)	Conversion Gain (dB)	Input IP3 (dBm)	NF_{SSB} (dB)	Topology
This work	0.18	18.266	9.975	8.4	Current Mirror load(without capacitor)
		18.269	22.889	8.4	Current Mirror load(with capacitor c=5fF)
		8.328	11.944	10.3	PMOS load (without DCI)
		5.7	22.259	10.9	PMOS load and DCI
[6]	0.18	15	-6.3	10.6	DCI
[7]	0.13	11.4	4.4	20	Resistive load + DCI
[8]	0.18	14	13.0	8.4	Resistive load + DCI
[9]	0.13	0.5	10.5	11	Resistive load + DCI
[10]	0.18	11.676	-15	7.989(DSB)	Current Mirror Load

**DCI-Dynamic current injection*

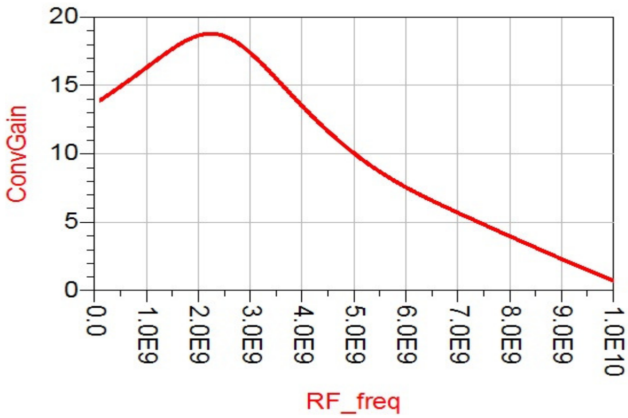


Fig. 11.Conversion gain (dB) versus RF frequency (GHz)

5. CONCLUSIONS

Highly linear Gilbert mixers with reasonable conversion gain and low noise figure have been implemented.IIP3 obtained in PMOS load based mixer is approximately doubled without significant degradation of conversion gain and noise performance. Current mirror load based mixer can provide very high conversion gain and has very low noise figure as well .The performance further improves with the use of capacitors in parallel to the PMOS transistors of current mirror. Table 1 shows the comparison of the previously reported papers with the proposed mixers.

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