An Improved CMOS GHz-Range Gilbert Mixer

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ABSTRACT:
In this paper, a new topology of Gilbert mixer with improved power consumption using the CMOS 0.18μm TSMC RF design kit is proposed. The proposed mixer is a down conversion one working in 2.4GHz radio frequency (RF), with a 2.5GHz local oscillator (LO) and a 100MHz intermediate frequency (IF). The circuit of this mixer is based on a low power differential transconductor in RF stage, wherein the ac and dc current paths through the source degeneration resistors and dc bias are isolated from each other. The supply is 1.8Vdc and the obtained power consumption is as low as 1mW.

KEYWORDS: CMOS, Gilbert mixer, Low power, Differential transconductor, RF transceiver, ISM frequency bands.

1. INTRODUCTION

As a major building block in monolithic RF transceivers in Industrial, Scientific and Medical bands (ISM), and specially in the cheap and popular CMOS processes, Gilbert mixers have been the subject of numerous research works [1-8]. This is while; this block itself is based on three differential transconductor cells, whose topologies affect the important parameters of the mixer. These parameters are work frequency, Noise Figure (NF), Conversion gain (CG), linearity and power consumption. Hence, different differential transconductor topologies have been the topic of numerous research works [9-11]. And, it is interesting that in addition to the above application and excellent features such as high input/output impedances, ability to replace OpAmps in mathematic operations and modeling of the negative resistor (NR) in analog circuits, due to the simplicity of the circuit, differential transconductors can work in GHz-range frequencies as well.

On the other hand, when the design of a high performance Gilbert mixer is of concern, among different transconductor topologies proposed so far, the differential transconductors with special characteristics exist, which should not be overlooked [9], [10]. This sort of transconductors, in addition to simplicity and the high speed as such, are low power as well. And, their design is simple, since their ac and dc currents paths through degeneration resistors and bias means, respectively, are isolated from each other. And, this latter feature makes the power consumption independent from linearization and transconductance (Gm) in these special trancsonductors. Hence, in the Gilbert mixer topology proposed in this text, the performance is investigated, while the transconductor proposed in [9] is used for RF stage.

In section 2, the proposed Gilbert mixer is analyzed and compared with its chosen counterpart benchmark.

In section 3, the parameters NF, CG, linearity, and power consumption are discussed.

In section 4, the simulations using CMOS 0.18μm TSMC RF design kit are utilized to evaluate the performances of the proposed mixer and its counterpart benchmark.

In section 5, the simulation results of the proposed Gilbert mixer topology are compared with the measurement reports of other similar works.

And, conclusions come in section 6.

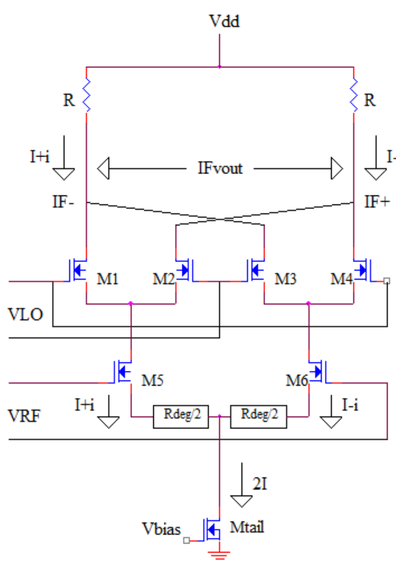
2. THE PROPOSED IDEA

Fig. 1(a) and Fig. 1(b) indicate the chosen benchmark and the proposed Gilbert mixers, respectively. In these Fig.s, the quad switch transistors M1, M2, M3 and M4 are supposed to switch on/off the differential output IF current, M5 and M6 secure the differential couple or transconductor for the input RF stage and Mtail is the tail current source. The name double balance for the Gilbert mixer calls for the fact that both the LO and RF signals are applied in differential sense. Clearly, all the above transistors are also the sources of thermal noise and affect the NF, work frequency, power consumption and other parameters. However, despite Fig. 1(a), in Fig. 1(b) the ac and dc currents that pass the Rdeg and dc bias transistors, respectively, are isolated from each other. That is, in Fig. 1(b), the ac and dc currents coming from the M1 and M2 transistors pass through the Rdeg and M7 and M8 transistors, respectively. Obviously, compared to the benchmark circuit in Fig.

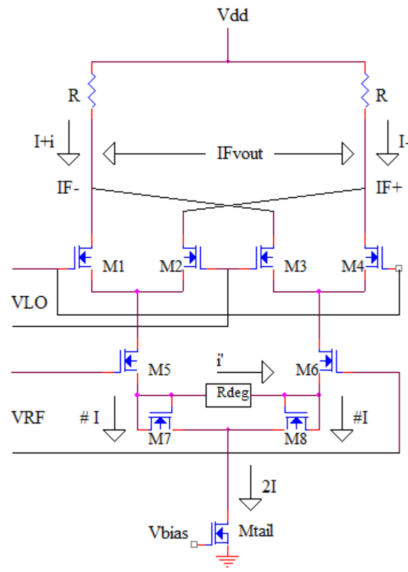
1(a), this means an important degree of freedom for the designer. This is because, in Fig. 1(b), the linearization and the Gm tuning obtained from it at the output of the RF stage are independent from the power consumption. Hence, this degree of freedom in Gm tuning and the linearization without affecting the power consumption can be invaluable. That is, during the design of a Gilbert mixer at the frequency of interest, this degree of freedom simplifies the tradeoff between the power consumption and the amount of the intercept point (IP3) and 1dB compression point (P1dB), which affect the linearity more and less, respectively. Also, it is notable that the Gm in RF stage for both Fig 1(a) and Fig. 1(b) may be obtained using [9]:

$$\frac{1}{Gm} = -\frac{1+k.Rdeg(KI)^{1/2}}{(KI)^{1/2}} = -\frac{1+k.gm.Rdeg}{gm} \qquad (1)$$

Wherein, $(KI)^{1/2} = gm5/2 = gm6/2 = gm$, $K = \mu C_0 W/2L$ and the gm is the series equivalent of gm5 and gm6 or the trans conductances of M5 and M6, respectively, and I is the dc current. The coefficient k is 1 for Fig. 1(a) and less than or equal to 1 for Fig. 1(b), while it reflects the effect of the trans conductor topology utilized in RF stage on the effective amount of Rdeg [9]. From Fig. 1(b) and equation (1) it is clear that the Gm in RF stage can be tuned either by changing the dc current by changing the sizes of M5, M6, M7, M8 and Vtail or by changing the Rdeg. And this is while, the changing of Rdeg does not change the current I. On the other hand, the same analysis for the benchmark in Fig. 1(a) does not show such a degree of freedom or independency of the current I from the linearization using the degeneration resistors Rdeg/2. Clearly, this degree of freedom is invaluable during the design procedures.



(a)



(b)

Fig. 1. Schematic of the utilized Gilbert mixers: (a) Benchmark. (b) Proposed.

3. NF, CG, POWER AND LINEARITY ISSUES

Since the differential trans conductor securing the RF stage in the proposed mixer in Fig. 1(b) is low power compared to the benchmark in Fig. 1(a) [9], it can cause the proposed Gilbert mixer to dissipate much less power.

From the NF, linearity and CG point of views, simulations will show the results. However, recalling the fact that the linearization is conventionally determined in RF stage, compared to the benchmark, in the proposed mixer this can be done, while the linearization is independent of power consumption. That is, if Rdeg/2 in the benchmark is changed, the bias current I and power consumption change. However, in the proposed mixer, the changing of Rdeg does not affect the dc current I or power consumption. Also, it is worth recalling that the linearity of a differential transconductor is calculated as follows [10]:

$$HD3 = \frac{KI}{32I^2(1+k\,R_{deg}\sqrt{KI}\,)^3}V_m^{\,2} \qquad (2)$$

4. SIMULATIONS

Simulation of Fig. 1(a) and Fig. 1(b) were done using the CMOS 0.18 μm TSMC RF design kit. While all the substrates were grounded, the results were obtained under 1.8Vdc supply, f_{RF}=2.4GHz, and f_{LO}=2.5GHz. Rdeg=7Ohm, W/L=18/0.18um for M1, M2, M3, M4, M5, M6, W/L=320/0.18um for M7, M8, W/L=40/0.18um for Mtail and Vtail=0.7Vdc were chosen. And, obtained the power consumptions were 5.9mW for the benchmark and 1mW for the proposed

Gilbert mixer. Fig. 2 shows the CG for both circuits. And, Fig. 3, Fig. 4 and Fig. 5, respectively, illustrate the NF, input referred P1dB and input referred 3rd order intercept point (IIP3) for the benchmark and proposed Gilbert mixers.

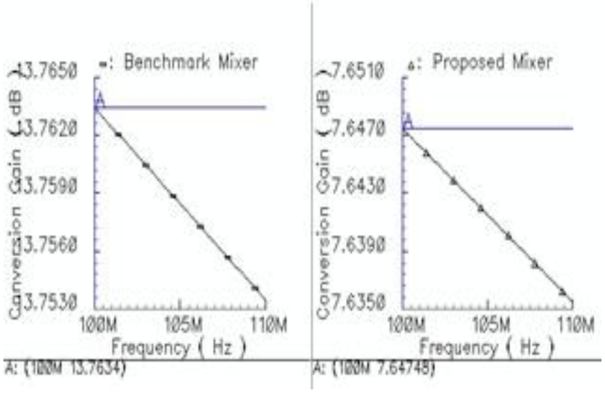


Fig. 2. Comparison of CG for the benchmark and proposed Gilbert mixers.

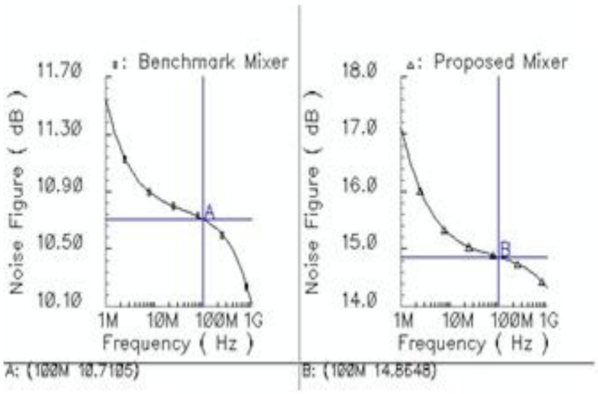


Fig. 3. Comparison of NF for the benchmark and proposed Gilbert mixers.

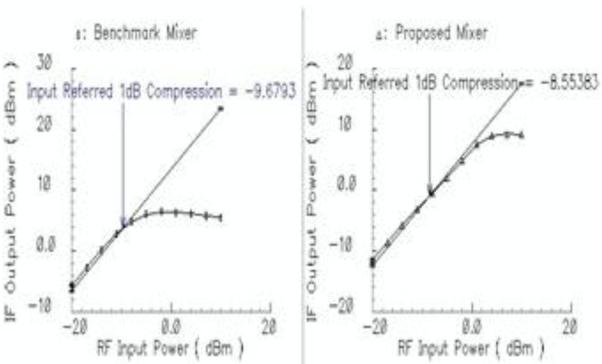


Fig. 4. Comparison of P1dB for the benchmark and proposed Gilbert mixers.

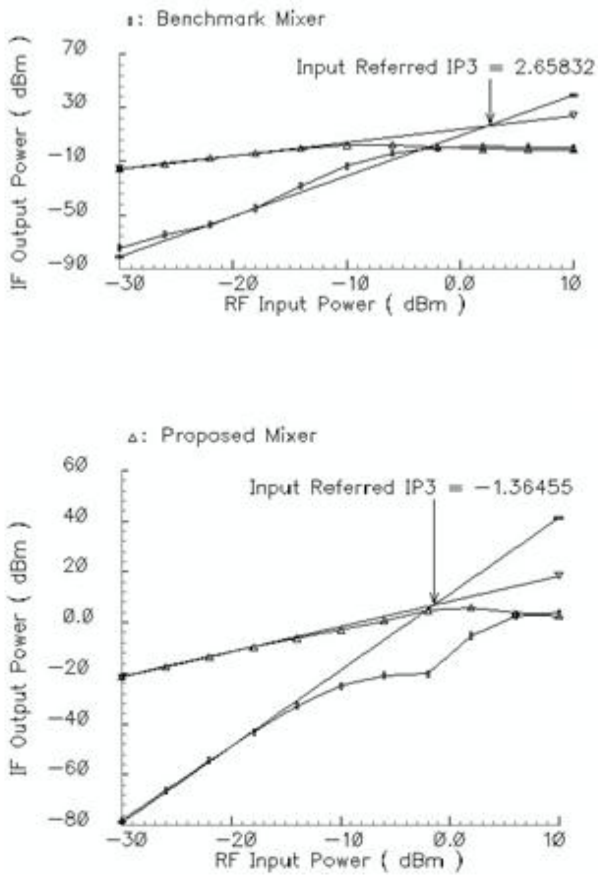


Fig. 5. Comparison of input referred IP3 for the benchmark and proposed Gilbert mixers.

5. COMPARISONS

For comparisons the following equation can be used as a Figure of Merit (FOM) [7, 8]:

$$FOM = 20\log f_{RF} + G - NF + IIP3 - 10\log P \qquad (3)$$

Wherein, f_{RF} is the RF frequency in Hz, G is the CG in dB, NF is the noise figure in dB, IIP3 is the input referred intercept point in dBm and P is the power consumption in Watt.

Table 1, indicates the simulation results of the benchmark and proposed Gibert mixers. Based on this table, compared to the benchmark, the proposed mixer has noticeably improved the power consumption (1mW versus 5.9mW), and has improved P1dB as well (-8.55dBm versus -9.67dBm).

Table 1. Comparison of the simulation results of the benchmark and proposed Gilbert mixers.

Gilbert mixer	Benchmark	Proposed
Technology (μm)	0.18	0.18
VDD (V)	1.8	1.8
RF (GHz)	2.4	2.4
P (mW)	5.9	1
Gain (dB)	13.76	7.64
SSB NF (dB)	10.71	14.86
P_{1dB} (dBm)	-9.67	-8.55
IIP3 (dBm)	2.65	-1.36

Comparison with other report is made in table 2. Based on this table, the proposed mixer gives comparable FOM with other similar but measurement reports.

Table 2. Comparison of the simulation results of the proposed mixer with similar but measurement reports.

	Proposed	[7]	[7]	[8]
Technology (μm)	0.18	0.18	0.18	0.18
VDD (V)	1.8	1	1	0.8
RF (GHz)	2.4	5.8	5.8	1.9
P (mW)	1	1	1	0.4
Gain (dB)	7.64	3.4/-0.8	14.7/13.6	1
SSB NF (dB)	14.86	28/37	20/26	11
P_{1dB} (dBm)	-8.55	0.9/6.5	-13.9/-14	…
IIP3 (dBm)	-1.36	11/15.3	-4.3/-5.2	-9
FOM	209	212/203	216/208	201

6. CONCLUSION

The idea of using a low power differential transconductor in RF stage of a down conversion Gilbert mixer resulted in CG=7.54dB, NF=14.86dB, P1dB=-8.55dBm, IIP3=-1.36dBm and a power consumption as low as 1mW in f_{RF}=2.4GHz and f_{LO}=2.5GHz.

The use of the proposed mixer topology in faster but more expensive technologies such as GaAs can cause further researches for faster low power Gilbert mixers.

From the viewpoint of the applications other than Gilbert mixer, the trans conductor used as the RF stage can be considered as a low power circuit. Hence it can be used in the low power analog filters such as GM-C.

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