Highly Linear 20 GHz-Micromixer in SiGe Bipolar Technology

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***Abstract* — An active mixer operating at 20 GHz based on the Gilbert Micromixer topology was designed and fabricated in SiGe technology. High performances are measured and especially an excellent linearity for moderate current consumption is demonstrated. The circuit shows an Output IP3 of +12 dBm and a conversion gain Gc of +7.7 dB for an optimum LO power of only -2 dBm. The bias current in the entire circuit is only 25 mA for a chip size of 1.8 x 2 mm².**

I. Introduction

The continuously increase of operating frequencies in wireless communication systems and the need of low cost production lead to many investigations on different technologies available on the market for mixer design. SiGe bipolar technology meets perfectly these requirements because of its manufacturing capabilities of standard silicon technologies, integration and cost advantages [1].

Mixers play an important role in RF communication systems. One of the most important parameter in mixer is the linearity. The best mixer should exhibit a 3rd order intercept point (IP3) as high as possible to be considered as highly linear. Various linearization methods like emitter-degeneration, feedback, multi-tanh technique, diode linearizer [2] or class-AB RF stage [3] can be utilized to improve the linearity.

The Gilbert Micromixer [3,4,5], compared to the commonly used Gilbert cell, offers a higher IP3 mainly due to its RF stage working as a class-AB amplifier. This stage allows a single-ended input RF signal to be converted linearly into a differential current to drive the mixer core. The simplified circuit diagram of the structure is shown in Fig. 1.

In this paper, a monolithic Gilbert Micromixer converting a 20 GHz input signal to 1 GHz and integrated in SiGe technology is reported. So far, none mixer using this structure and such technology which operates in the K-band has been published. The mixer demonstrates a 3rd order intercept (OIP3) and a 1 dB compression ($P_{out,1dB}$) points referred to the output of +12 dBm and +2.1 dBm respectively, when the input LO power (P_{LO}) is set to only -2 dBm. The differential gain (Gc) is equal to +7.7 dB and the bias current in the integral circuit is only 25 mA for a chip size of 1.8 x 2 mm².

In the next section, a detailed description including circuit design, simulations and layout considerations of the Micromixer topology is proposed. Section 3 shows measurement setup and results. Discussion on circuit performances is presented in section 4. Finally, conclusions on this work are given in the last section.

II. Circuit Design and Simulations

The Gilbert Micromixer, compared to the Gilbert cell commonly used, offers a higher linearity mainly due to its RF stage working as a class-AB amplifier. In this section the Gilbert Micromixer structure is first described in detail. The second part deals with the optimization on transistors and additional circuitry to improve mixer performances. Finally, the layout is described and simulated results are summarized.

A. Gilbert Micromixer Structure

From Fig. 1, it is obvious that the RF stage of the traditional Gilbert cell has been replaced by a class-AB amplifier as the mixer core stays strictly the same. The RF stage is made of a current mirror and a common base transistor formed by T1, T2, T3 and C1.

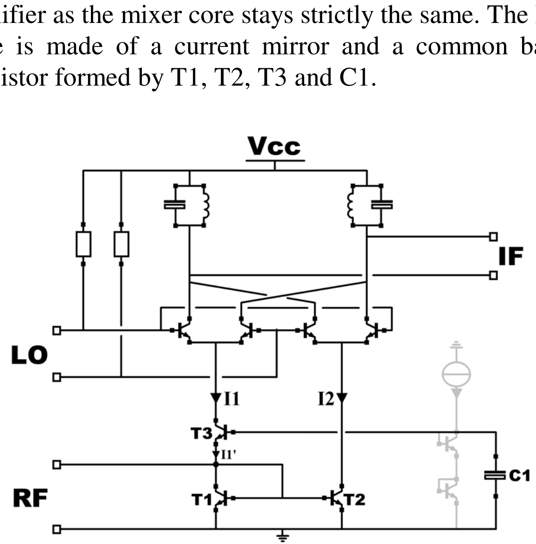

Fig. 1. Simplified circuit diagram of the Gilbert Micromixer.

The RF signal drives the input stage through the current mirror and the emitter of the common base transistor. On positive voltages of RF, the current mirror operates while the common base transistor is not conducting, therefore the current I_2 is generated. In the opposite way, I_1 is generated only on negative voltages of RF when the common base is conducting and the current mirror is not operating. The two currents I_1 and I_2 are clearly non sinusoidal and out of phase as shown in Fig.2. However, the mixer core is driven by the differential current $I_{Diff} = I_1 - I_2$, thus the quantity to consider is not I_1 or I_2 but I_{Diff}. As a consequence, the current I_{Diff} of the RF stage is perfectly sinusoidal as illustrated in Fig. 2. and this improves the linearity of the resulting circuit. This stage is biased by a translinear loop and a second current mirror.

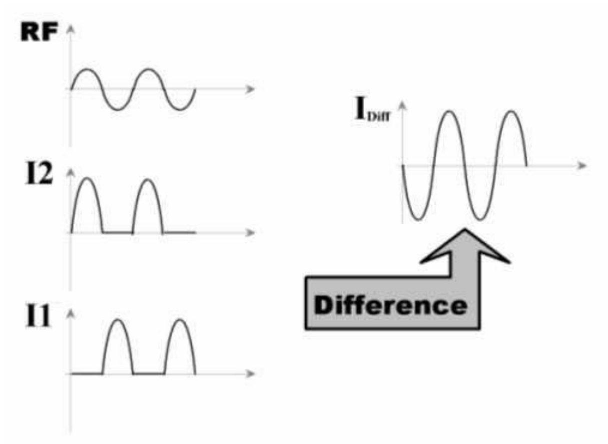

Fig. 2 : Currents in the RF stage

The mixer core of the Micromixer is the same as in the Gilbert cell. The biasing is realized through simple resistors connected to the supply.

Because of the large biasing current and high operating frequency, matching technique described in [3,4,5] cannot be used in this design. Thus, additional LC networks are placed at each input port of the mixer to provide a good match to the reference impedance.

A 1 GHz band-pass filter is used to improve the linearity and to match the output path to 50Ω. This filter delivers different impedance values at different frequencies of interest changing by consequence the gain.

An investigation on transistors available in this technology has been done to find out the best geometry and biasing current giving a good trade off between Ft, Fmax, noise figure and linearity. A transistor biasing current of 10 mA showed reasonable results.

B. SiGe Integration

The symmetry of the structure has been carefully respected to avoid unbalances of the two differential LO and IF signals. Fig. 3 shows the chip micro photograph. The die size is 1.8 x 2 mm². Lines have been modeled using built-in transmission line models available in ADS. The simulation results observed are a OIP3 of +9 dBm when P_{LO} is set to -6 dBm, the Gc and noise figure (NF) obtained are +9 dB and +29 dB, respectively.

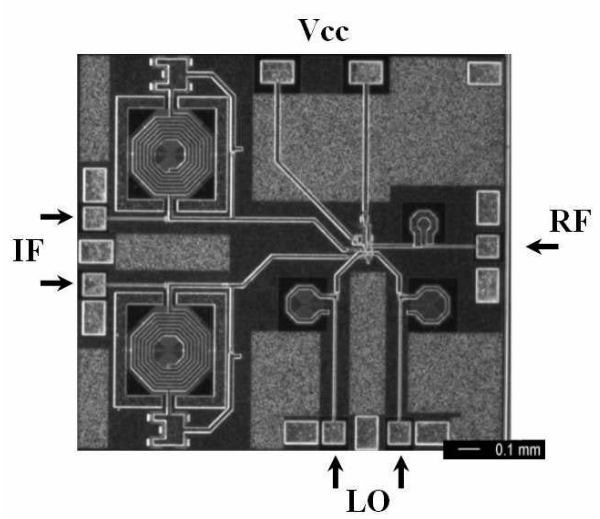

Fig. 3 : Chip micro photograph

III. Measurement Results

Measurements have been carried out using a GGB probe at the RF port. LO and IF path are differential signals, thus specific GSGSG probes from CASCADE MICROTECH have been used for these ports. Differential LO signal is generated with an ANRITSU source and a commercial KRYTAR 3dB 180° coupler. Most of the external connections are made thanks to K connectors. The entire circuit is biased at +4.8 V from a single supply and the current drawn by the mixer is 25 mA.

The measured conversion gain as a function of the two inputs power LO and RF are plotted in Fig. 4 and Fig. 5. It can be clearly seen that the optimum P_{LO} is -2 dBm giving a Gc of +7.7 dB.

The input 1dB-compression-gain power $P_{in,1dB}$ can be determined from Fig. 5 and is found to be equal to -4.8 dBm which corresponds to a Gc of +6.9 dB and a $P_{out,1dB}$ of +2.1 dBm.

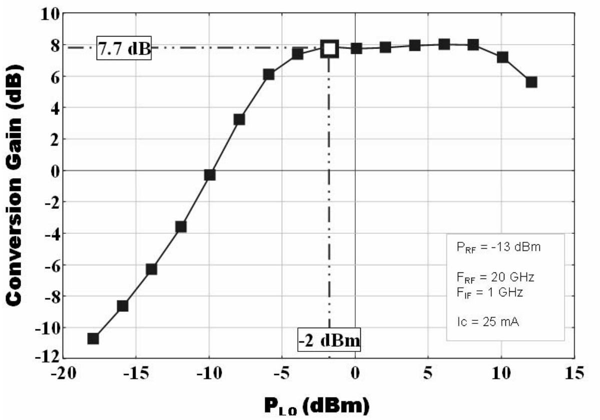

Fig. 4 : Conversion gain vs LO input power

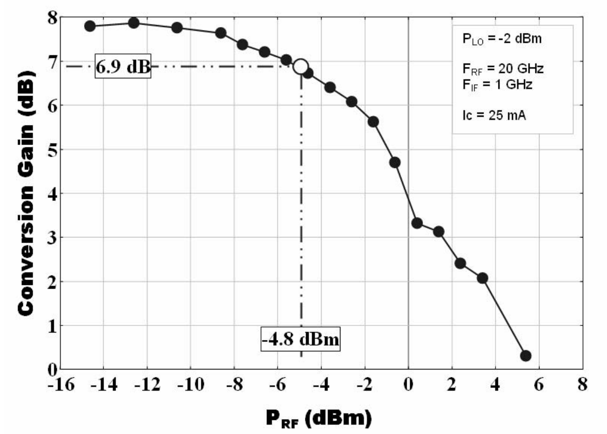

Fig. 5 : Conversion gain vs RF input power

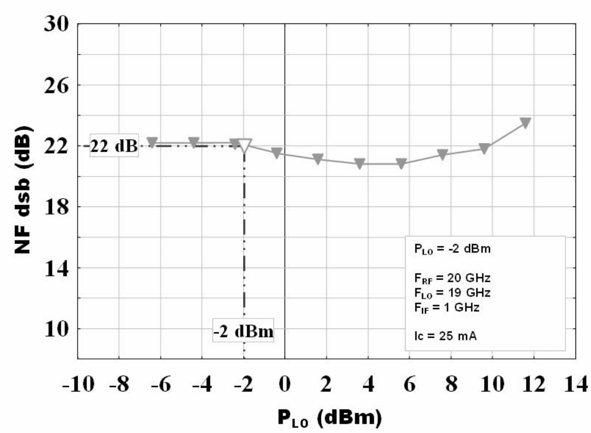

Fig. 7 : NF_{dsb} vs LO input power

	Measured	Simulated
Supply voltage	+4.8 V	+4.8 V
Supply current	25 mA	20 mA
P_{LO} (Optimum)	-2 dBm	-6 dBm
P_{RF}	-13 dBm	-20 dBm
F_{RF}	20 GHz	20 GHz
F_{IF}	1 GHz	1 GHz
Gain	+7.7 dB	+9 dB
3rd order intercept point referred to output	+12 dBm	+9 dBm
1dB compression point referred to output	+2.1 dBm	-
NF_{dsb}	+22 dB	+29 dB
Chip size	1.8 x 2 mm²	
Technology	0.25 µm SiGe BiCMOS process	

Table 1 : Performance summary

The 3rd order intercept point is determined by two-tone measurements. A power combiner is used to provide the RF tones and P_{LO} is set to its optimal power (-2 dBm). An investigation has been done to work out the best offset between the two input frequencies. These two frequencies F_{RF1} and F_{RF2} are respectively 20 GHz and 19.9 GHz. The measured OIP3 is then +12 dBm.

Fig. 6 describes the OIP3 and IIP3 versus P_{LO}. It can be seen that the input and output IP3 have their maximum around P_{LO} = -2 dBm. The corresponding 3rd order intercept point referred to the input (IIP3) is then +4.5 dBm.

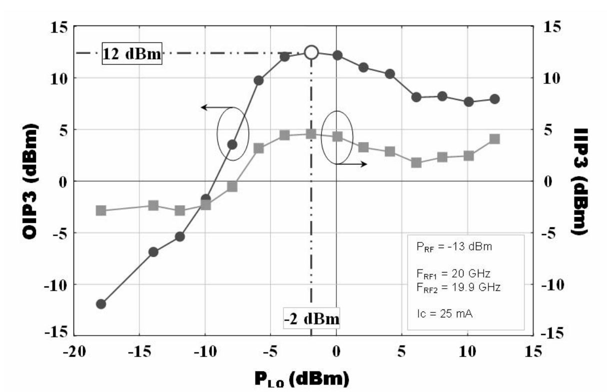

Fig. 6 : OIP3 and IIP3 vs LO input power

The measurements of the noise figure have been carried out on-wafer using the noise meter 8970B from AGILENT. Fig. 7 plots the double side band noise figure (NF_{dsb}) as a function of the P_{LO}. It can be seen that the noise stays relatively constant when the LO input power is sweept from -5 to 10 dBm. At the optimum P_{LO} the noise is equal to +22 dB.

Measured and simulated mixer performances are summarized in Table 1.

IV. Results Discussion

When comparison between mixers linearity is required, the supply current (Ic) has to be taken into account as this parameter is strongly related to the linearity [2]. To compare published mixers, the OIP3 is then to be considered versus the consumed current. Fig. 8 resumes the state of the art of microwave mixer linearity performances.

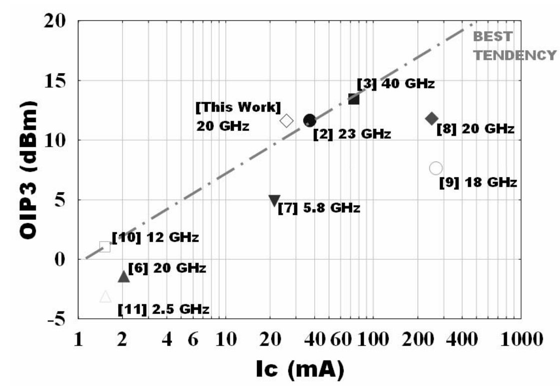

Fig. 8 : State of the art for monolithic mixer OIP3 vs Ic

As expected, mixers exhibiting large OIP3 drain a large supply current. The best mixer should appear in the left corner of the figure, where high linearity and low supply current are achieved. The dashed line in Fig.8 then illustrates the trend of the best mixer linearities. Our work demonstrates the best trade off (high linearity and moderate supply current) compared to the other mixers.

The Gilbert Micromixer is popular for its good linearity, nevertheless it can be seen from the simulation and measurements that the noise figure is high. This issue can be overcome by reducing the current drawn through the transistors in the RF stage but this leads to a lower conversion gain and linearity.

V. CONCLUSION

Excellent OIP3 for moderate bias current can be reached using Micromixer topology, a variant structure to common Gilbert Cell. Well known as a highly linear structure, the mixer presented in this paper has an OIP3 of +12 dBm. For the first time, this topology has been integrated in SiGe technology operating at 20 GHz and demonstrates high potentialities in microwave application. Besides excellent linearity, good conversion gain and low LO power are observed, Gc = +7.7dB and P_{LO} = -2 dBm when the current supply is 25 mA.

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REFERENCES

[1] Hackl S., Bock J., Wurzer M., Scholtz A.L., "40 GHz monolithic integrated mixer in SiGe bipolar technology", *Microwave Symposium Digest, 2002 IEEE MTT-S International*, Volume: 2, 2-7 June 2002 pp. 1241 – 1244

[2] Mingquan Bao, Yinggang Li, Cathelin A., "A 23 GHz active mixer with integrated diode linearizer in SiGe BiCMOS technology", *Microwave Conference, 2003. 33rd European*, Volume: 1, 7-9 Oct. 2003 pp. 391 - 393 Vol.1

[3] Gilbert B., "The MICROMIXER: a highly linear variant of the Gilbert mixer using a bisymmetric Class-AB input stage", *Solid-State Circuits, IEEE Journal of*, Volume: 32, Issue: 9, Sept. 1997 pp. 1412 – 1423

[4] Meng C.C., Lu S.S., Chiang M.H., Chen H.C., "DC to 8 GHz 11 dB gain Gilbert micromixer using GaInP/GaAs HBT technology", *Electronics Letters*, Volume: 39, Issue: 8, 17 April 2003 pp. 637 – 638

[5] Hernandez E., Berenguer R., Melendez J., Rodriguez, Aguilera J., "An integrated downconverter circuit in 0.8 um SiGe technology for DCS-1800 applications", *RFDesign*, Issue: September 2003 pp. 56 – 64

[6] Hackl S., Wurzer M., Bock J., Meister T.F., Knapp H., Aufinger K., Boguth S., Treitinger L., Scholtz A.L., "Benefits of SiGe over silicon bipolar technology for broadband mixers with bandwidth above 10 GHz", *Microwave Symposium Digest, 2001 IEEE MTT-S International*, Volume: 3, 20-25 May 2001 pp. 1693 - 1696 vol.3

[7] Sang-Heung Lee, Ja-Yol Lee, Seung-Yun Lee, Chan Woo Park, Sang Hoon Kim, Hyun-Chul Bae, Jin-Yeong Kang, Kyoung-Ik Cho, "A 5.8 GHz mixer using SiGe HBT process", *Microwave Conference, 2003. 33rd European*, Volume: 1, 7-9 Oct. 2003 pp. 403 - 406 Vol.1

[8] Kobayashi K.W., Gutierrez-Aitken A., Cowles J., Tang B., Desrosiers R., Medvedev V., Tran L.T., Block T.R., Oki A.K., Streit D.C., "15 dB gain, DC-20 GHz InP HBT balanced analog mixer and variable gain amplifier with 27 dB of dynamic range", *Radio Frequency Integrated Circuits (RFIC) Symposium, 1999 IEEE* , 13-15 June 1999 pp. 105 - 108

[9] Bannister D.C., Zelley C.A., Barnes A.R., "A 2-18 GHz wideband high dynamic range receiver MMIC", *Radio Frequency Integrated Circuits (RFIC) Symposium, 2002 IEEE*, 2-4 June 2002 pp. 147 - 149

[10] Kienmayer C,Tiebout M,; Simburger W., Scholtz A.L., "A low-power low-voltage NMOS bulk-mixer with 20 GHz bandwidth in 90 nm CMOS", *Circuits and Systems, 2004. ISCAS '04. Proceedings of the 2004 International Symposium on*, Volume: 4 , 23-26 May 2004 pp. IV - 385-8 Vol.4

[11] Kuo-Hua Cheng, Eing-Tsang La, Jou C.F, "Design of a new RF micromixer with low power and high performance in 0.25/spl mu/m CMOS technology", *Advanced System Integrated Circuits 2004. Proceedings of 2004 IEEE Asia-Pacific Conference on*, 4-5 Aug. 2004 pp. 141 - 144.