

A 23 GHz Active Mixer with Integrated Diode Linearizer in SiGe BiCMOS Technology

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Abstract — Active mixers operating at 23 GHz are designed and fabricated in SiGe technology. An integrated diode linearizer is used to improve the linearity of the mixer. Measurement and simulation show excellent agreement. Typically, 10 dB double-sideband noise figure, 10 dBm IIP3 and 2 dB conversion gain are measured, featuring low noise and high linearity in a same design.

I. INTRODUCTION

Several high frequency mixers (>20 GHz) have been developed in SiGe technology recently [1]-[5]. They are active mixers based on Gilbert-cell topology that usually offers high conversion gain, moderate noise figure and relatively poor linearity as compared with passive mixers. Therefore, it is a challenge to design an active mixer with both low noise and high linearity at high frequencies.

Using large bias current may improve linearity, but this will normally result in high noise figure. On the other hand, using small bias current may reduce noise figure, but this will normally degrade linearity. Hackl et al. designed a mixer [3] that consumes 9 mW dc power only and has double sideband (DSB) noise figure of 6 dB at 20 GHz. Its input-referred 3rd-order intercept point (IIP3), however, is -11.3 dBm that is regarded to be insufficient for most wireless applications, e.g., point-to-point microwave radios. In contrast, using a much larger dc bias, ~300 mW, Hackl and Böck [4] managed to improve the IIP3 of their mixer to +11.3 dBm at 31 GHz. The DSB noise figure obtained, 15 dB, is much higher then.

This paper reports two monolithic active mixers operating at frequency of 23 GHz. In one of the mixers, an integrated diode linearizer is utilized to improve the linearity. Such a linearizer, the so-called pre-distortion, has been applied to power amplifier design [6]. By comparing the linearity performance of the two mixers, i.e., with and without the linearizer, the present work demonstrates that the same technique is also applicable to mixer design for linearity improvement.

II. MIXER AND LINEARIZER CIRCUITS

A. Active Mixers

A double balanced Gilbert topology (Fig. 1) is used for the mixers that convert a RF signal to a 1 GHz IF. Among others, high port-to-port isolation is one of the advantages the balanced topology may offer. In this design, a single-ended RF input drives the transconductance stage. Both inductive and resistive emitter-

degeneration are utilized to improve the linearity and the input impedance match. The resistors and inductor, dc bias, as well as the size of the transistors in the transconductance stage (i.e., BJT1 and BJT2) are chosen by performance optimization towards low noise and high linearity.

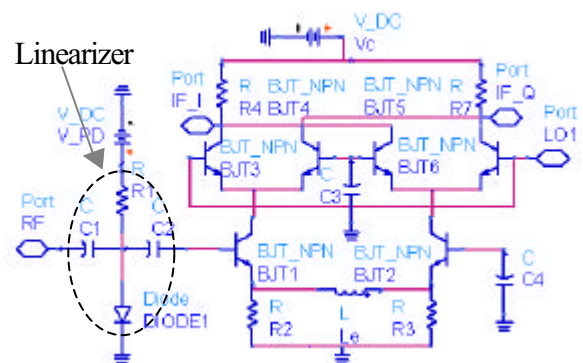


Fig. 1 Mixer and linearizer circuit schematics

B. Diode linearizer

Shown also in Fig.1 is a linearizer [6] applied to the RF input port to improve the linearity. It consists simply of a shunt diode and a bias feed resistor and is ac-coupled to the active mixer. The diode serves as a nonlinear generator that compensates to some extent the nonlinearity generated by the mixer itself, thus, reduces nonlinear distortion of the whole circuit. To illustrate this, the transducer power gain of the linearizer versus the RF input power is simulated and is plotted in Fig. 2. Instead of compression, gain expansion is clearly seen as RF input power increases.

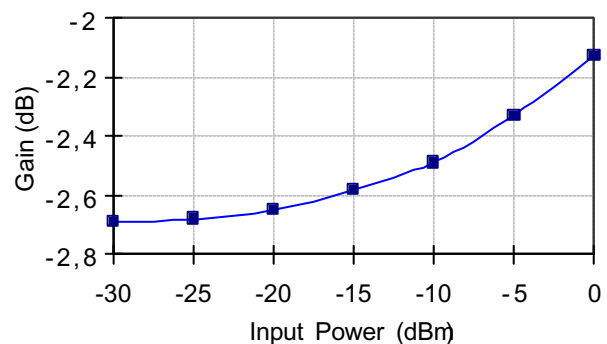


Fig.2 Simulated gain of the linearizer vs. RF input power.

The bias voltage of the diode is set to be 0.7-0.8V at which the RF impedance of the shunt diode is large and the insertion loss of the linearizer is consequently small. The linearizer itself consumes almost no power.

A die photo of the mixer with linearizer is shown in Fig.3. The physical size is 0.55x0.77 mm².

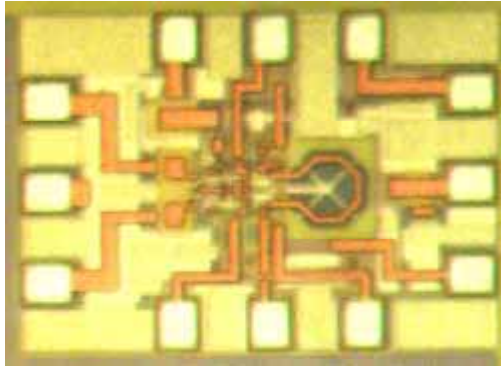


Fig. 3 A die photo of the mixer with linearizer.

III. MIXER PERFORMANCE

The mixer circuits are fabricated in STMicroelectronics' 0.25μm SiGe BiCMOS process. The SiGe HBT in use has an emitter width of 0.4μm (drawn size), featuring 70GHz f_T and 90GHz f_{max} [7]. The process offers 5 metal layers for interconnect, MIM capacitors of 2fF/μm², various kinds of resistors and inductors, all scalable.

Simulations are carried out in ADS environment using Harmonic Balance analysis. ADS built-in transmission line models are used for modeling of long RF paths.

Conversion gain is measured using spectrum analyzer and the DSB noise figure is measured using noise figure meter. The measured results are plotted and are compared with simulation in Fig. 4 and 5 for the mixers with and without the linearizer, respectively. Notably, the optimum performance is achieved for LO power from 2 dBm to 6 dBm in terms of conversion gain and noise figure.

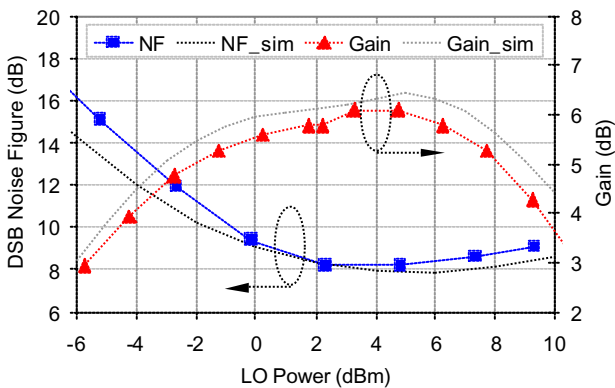


Fig.4 Conversion gain and DSB noise figure vs. LO power for the mixer without the linearizer.

Mixer IIP3 performance is determined by two-tone measurements. Fig. 6 plots the measured and simulated IIP3 as a function of LO power for the mixers with and without the linearizer.

Peak IIP3 is obtained in the measurement for LO power around 2dBm and is improved by more than 6 dB when the linearizer is used. The cost for this improvement, as can be seen from Fig. 4 and 5, is about 4 dB lower gain and 2 dB higher noise figure. It is therefore recommended when high linearity is a more crucial parameter than large gain, which is the case here.

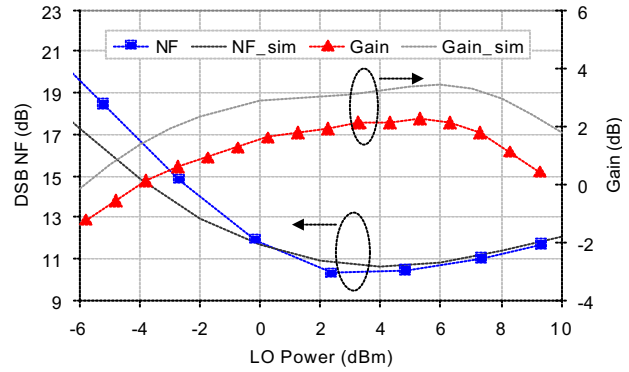


Fig.5 Conversion gain and DSB noise figure vs. LO power for the mixer with the linearizer.

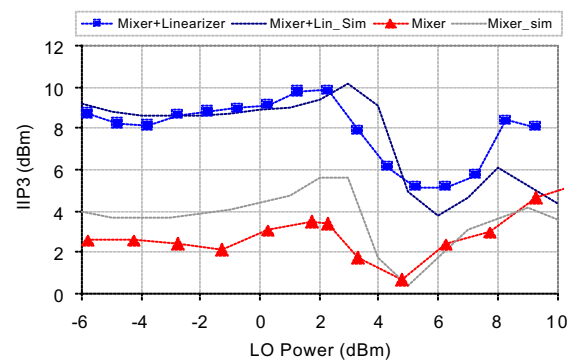


Fig.6 Measured and simulated IIP3 vs. LO power for the mixers with and without the linearizer.

The mixer performance is summarized in Table I. In general simulation and measurement agree excellently in gain, noise figure and IIP3. Even the detailed features of the curves shown in Fig. 4-6 are reproduced by simulation.

P _{LO} =2.0 dBm V _{cc} =3.9V I _c =36mA	Mixer		Mixer with Linearizer	
	Meas.	Sim.	Meas.	Sim.
Gain (dB)	5.8	6.1	2.0	3.0
IIP3 (dBm)	3.5	5.7	9.8	9.4
DSB NF (dB)	8.2	8.2	10.3	10.8

Table I. Summary of Simulated and Measured Results.

It should be pointed out that the IIP3 may be increased by decreasing conversion gain. The improvement in IIP3 by applying the linearizer is partly due to the gain degradation. In order to exclude the impact from this gain variation, the output-referred 3rd-order intercept point

(OIP3) is calculated which equals to IIP3 plus the conversion gain. The obtained OIP3 for the mixers with and without the linearizer are 11.8 dBm and 9.3 dBm, respectively, a 2.5dB improvement in terms of OIP3.

It is noted here that except for the degeneration inductor the mixer has no frequency sensitive reactive components and, thus, is wide-band in nature. Preliminary measurement shows that the mixer operates properly for RF signals from at least 20GHz up to 33 GHz.

For purpose of comparison, the output-referred 3rd-order intercept point, the DSB noise figure, as well as the operating frequency are given in Fig. 7 for SiGe mixers operating at 20 GHz and above. A desired mixer should have its performance appearing at the upper-left corner of the figure, where low noise and high linearity would be achieved simultaneously. Clearly, the mixer with the linearizer demonstrates a reasonable balance between linearity and the noise performance, though not to the best degree yet.

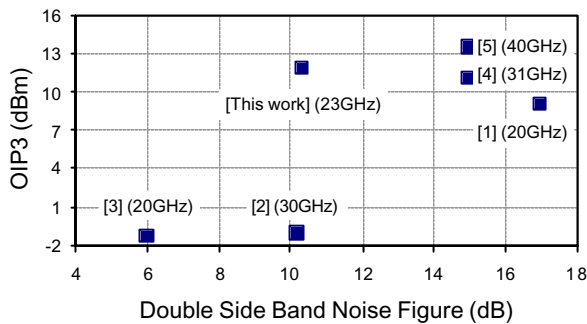


Fig.7 OIP3, DSB NF and operating frequency (>20 GHz) for SiGe active mixers collected from recent publications.

IV. CONCLUSIONS

SiGe active mixers at 23 GHz have been designed. Measurement and simulation agree excellently in general. In order to improve the linearity, an integrated diode linearizer is applied prior to the active mixer. Compared with using large bias approach, this method causes less degradation in noise performance. Thus, the linearization

technique present in this work is a desirable solution for achieving both low noise and high linearity.

ACKNOWLEDGMENTS

The authors would like to thank Mattias Ferndal and Dr. Bertil Hansson for their assistance with measurement. This work was carried out under MEDEA+ project T204 and funding from French Public Authority is acknowledged.

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