A Power Efficient Active K Band Mixer

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Abstract — **An energy efficient K band GaAs-HBT mixer applicable in integrated receiver front ends is presented. For pico cell networks, reduction of energy consumption is a central task. This mixer operates with a power as small as 15.6 mW still providing adequate gain making it in some cases unnecessary to use an amplifier. The mixer provides 13.5 dB power gain at 24.5 GHz using 0.5 dBm LO power. Compared to reported K band mixers employing other architectures, this is an excellent performance.**

I. Introduction

Wireless sensor networks are focus of current research of many microwave groups. As systems like these should be highly integrated, self organizing and totally power independent of their environment, new challenging tasks are arising. Rx/Tx architectures and components have to be optimized concerning simplicity and power consumption. RF frequencies are usually in the higher bands, in the presented example in the K band. The need for very low power consumption at these frequencies certainly implicates challenges to the receiver architecture and components as well as to the technologies used. Often GaAs technology is used to reduce substrate losses and provide high f_{max}.

In this context, the AVM (autarkic distributed systems) [1] project was established to build up an independent pico cell network and analyze new challenges coming up in this area.

To realize the miniaturized nodes named "eGrains" the research focuses on ultra low power architectures and components. The eGrain concept and building blocks are described in detail in [2].

In this paper, the mixer as a central part of the RF front-end is discussed. It is realized as a two transistor cascode structure to achieve high conversion gain and RF/LO isolation. The mixer is integrated into the entire front-end architecture as described in [3]. Cascode structures used as mixers built in FET technology are discussed in [4]. We present such a structure realized in HBT technology and discuss their advantages, disadvantages and results compared to other architectures.

II. HBT Technology

The circuits are fabricated using the 4'' GaAs HBT MMIC process of the Ferdinand-Braun-Institute Berlin (FBH). The active elements are GaInP/GaAs HBTs. The transit frequencies are f_t = 45 GHz and f_{max} = 170 GHz. The epitaxial layers are grown with Metalorganic Vapor-Phase Epitaxy (MOVPE). Ledge technology is used to reduce 1/f noise. For the design we used 2x10 µm transistors operable at collector currents down to 2 mA.

III. Mixer Design

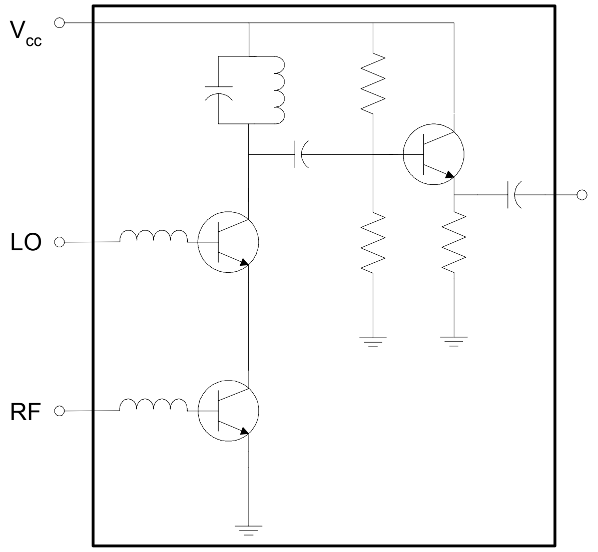

Fig. 1. Schematic of the mixer.

Batteries of an eGrain are very small and provide very limited power. For our application, the most important issue is very low DC power consumption to provide an adequate operating time with the limited battery power available. Consequently, we decided to choose a simple architecture.

Single transistor mixers have the big advantage of simplicity. The overall current consumption of the described circuit is only the collector current. Because of the absence of series stages, low supply voltage is needed. Disadvantages are poor gain and isolation. Especially for the LO suppression at the output, this is an important fact.

Active mixer circuits found in literature are usually Gilbert cell mixers [5]. These are double balanced mixers with excellent performance. To achieve considerable conversion gain, though, current dissipation in such structures is high compared to the approach we are using [6]. The overall current consumption is several times the collector current of one transistor. Furthermore, mostly active baluns which are complex and power consuming have to be realized if the input signals are available unbalanced only.

A new and innovative mixer structure was presented by the authors in [7]. Using a cascade as it is usually known from amplifier design, we are able to use the gain of two transistors in series while dissipating only a DC current equal to the collector current of one transistor.

The given DC voltage in an eGrain of 3 V is sufficient to operate such a structure, which is shown later. The minimum DC voltage is limited approximately by the sum of the base collector voltages of all transistors. The mixer presented in [7] needed a high output impedance to operate adequately and achieve high power gain. Therefore a series resistance of 600 Ω was implemented for test reasons. This was in accordance to the input impedance of the following stage which was used in the specific application.

For general use, a mixer circuit should certainly be matched to 50 Ω. This is done by using an emitter follower. The emitter follower provides a high ohmic resistance to the output of the mixer core and transforms it to 50 Ω at the output of the overall circuit. The emitter follower can be operated with currents down to 1 mA if we use even smaller transistors than used in the mixer core. Furthermore it will increase gain but decrease linearity as shown below. The schematic of the mixer circuit including the emitter follower is shown in Figure 1.

RF and LO signals respectively are applied to the bases of the two transistors and the converted signal is available at the collector of the upper transistor of the series stage. This signal is transformed to 50 Ω at the output by the emitter follower. The mixer was designed and realized using the GaAs HBT process described in section II. Figure 2 shows a chip photo of the corresponding layout.

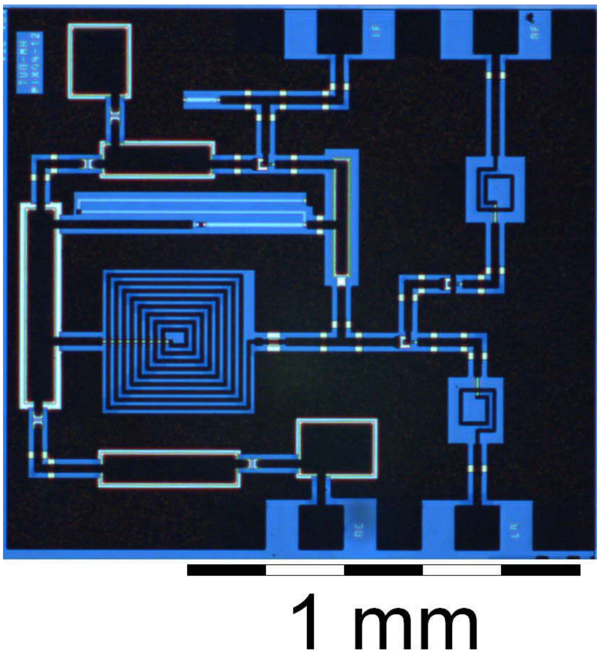

Fig 2. Chip photo of the mixer, realized in coplanar design, upper pads: IF out, RF in , lower pads: Vcc, LO in.

IV. Simulation and Measurement

All following measurements and simulations are based on a supply voltage of 3 V. Measurements are done with a Tektronix 2782 Spectrum Analyzer. Figure 3 shows measured and simulated conversion gain versus RF input frequency of the circuit using a 600 Ω load as it was presented in [7]. The conversion gain was scaled to 50 Ω as described there. DC current consumption is 3 mA using a 3 V supply. LO Power is 4 dBm, IF is fixed at 1.8 GHz. Measurements were made at –35 dBm RF input power. At this low DC power, a conversion gain of about 4 dB can be achieved at the desired input frequency of 24.5 GHz.

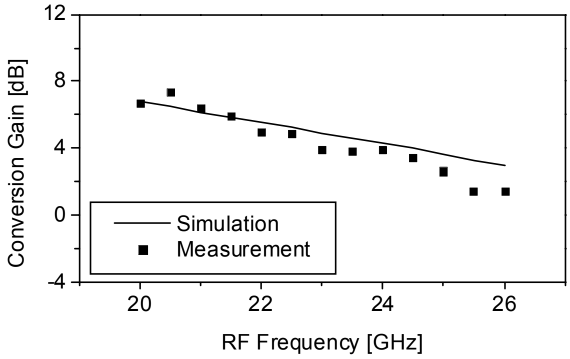

Fig. 3. Conversion gain vs RF input frequency of the mixer with a high impedance load, measured and simulated, f_{IF}=1.8 GHz, P_{DC}=9 mW, P_{LO}=4 dBm, P_{RF}=-35 dBm.

Figure 4 shows the frequency response of the enhanced mixer with emitter follower as shown in Figure 1. IF is kept at 1.7 GHz, RF and LO input frequencies are swept in parallel. Measurements were made with RF input power of -35 dBm, LO power of 0.5 dBm and DC current of 5.2 mA from a 3 V source. Matching of the LO and RF input is done by using just an inductor and is hence very broadband. No significant frequency selectivity can be expected as is affirmed by the data. Good agreement between measurement and simulation can be observed, gain decreases for increasing frequency as expected.

Even if broadband input matching was not a design goal, this is obtained with the presented structure. Output matching certainly is dependent on the IF frequency, which is 1.7 GHz in this case. The parallel LC circuit suppresses out of IF band frequencies strongly.

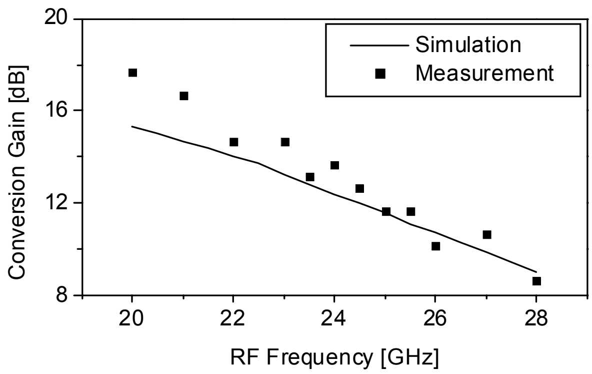

Fig. 4. Conversion gain vs RF input frequency of the mixer measured and simulated, f_{IF}=1.7 GHz, P_{DC}=15.6 mW, P_{LO}=0.5 dBm, P_{RF}=-35 dBm.

Figure 5 shows conversion gain versus RF input power using 15.6 mW DC power from a 3 V source. IF frequency is 1.7 GHz as in all following measurements. A LO power of only 0.5 dBm is sufficient to operate the circuit. This is an important improvement compared to the mixer presented earlier. Even if in the planned application a strong LO is available, for general use of the circuit in a power efficient system, it is favorably not to need a LO power of up to 4 dBm.

TABLE I

COMPARISON WITH PREVIOUSLY REPORTED MIXERS

Technology	Frequency [GHz]	Conversion Gain [dB]	DC Power [mW]	LO Power [dBm]	Input 1 dB Compression [dBm]	IP3 [dBm]	Ref.
GaAs HEMT	17.5-33	-10	n.a.	10	n.a.	n.a.	[8]
GaAs HEMT	21-26	-10	n.a.	10	n.a.	n.a.	[9]
Si 3D	10-30	-7.7	6.6	5	n.a.	9	[10]
SiGe HBT	8-11	1	n.a.	5	0	n.a.	[11]
SiGe BiCMOS	5.8	9.2	32	-12	-3	6	[12]
GaAs HBT	DC-9	12	25	-8	-4	2	[13]
GaAs HBT	24	4	9	4.2	-11	2	[7]
GaAs HBT	**24**	**13.5** **16.5**	**16.5**	**0.5** **6.5**	**-20** **-25**	**n.a.**	**This work**

A power gain greater 13.5 dB can be achieved with an 1 dB compression point better –20 dBm. Compression in this structure is moderate, but we have to keep in mind, that this mixer is used in an energy efficient system which works with very power levels in general. Good accordance between simulation an measurement can be seen.

Using the same parameters but a stronger LO source, conversion gain can even be increased. Measurement and simulations of conversion gain versus RF input power using a LO power of 6.5 dBm are also shown in figure 5. Gain can be increased up to 16.5 dB and is even a little better than expected by the simulation. The input 1 dB compression point decreases due to the higher gain.

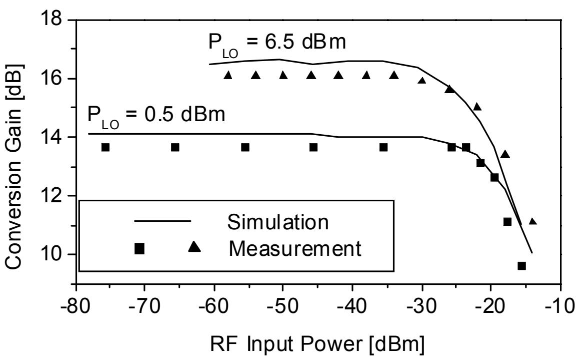

Fig. 5. Conversion gain vs. RF input power, measured and simulated, f_{RF}=24,5 GHz, f_{IF}=1.7GHz, P_{DC}=15.6 mW, P_{LO}=0.5 dBm and P_{LO}=6.5 dBm.

A more detailed analysis of the behavior of conversion gain depending on LO power is given in figure 6. Measurements and Simulation are made with an RF input power of –35 dBm which is definitely in the constant gain domain of the mixer even for high LO power levels. This graph helps to determine the ideal LO power for a power efficient system. The saturation region, where the mixer gain is not increased any longer by increasing the LO power, is at about 7 dBm. At 0.5 dBm as shown in the other graphs the slope decreases which implicates the ideal LO power from an energy efficiency point of view. Because of the poor efficiencies of oscillators, in an overall energy estimation one has to consider the DC power needed to generate higher LO power compared to the DC energy needed to build a mixer with higher gain by changing the structure or using an additional amplifier.

RF-IF isolation was measured at 12 dB, LO-IF isolation at 17 dB.

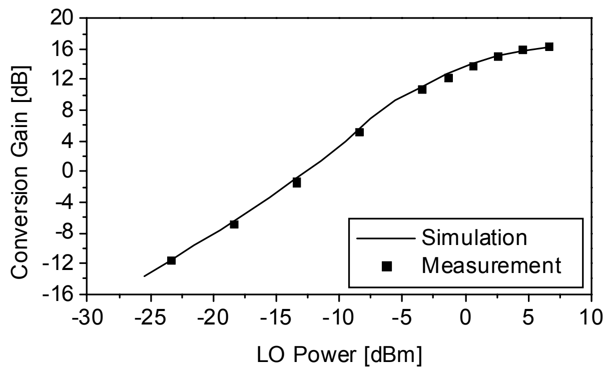

Fig. 6. Conversion gain vs. LO power, measured and simulated, f_{RF}=24,5 GHz, f_{IF}=1.7 GHz, P_{DC}=15.6 mW, P_{RF}=-35 dBm.

Figure 7 shows the mixer performance depending on the applied DC voltage. Measurements were made with -35 dBm RF input power at 24.5 GHz and 0.5 dBm LO power. Conversion gain stays constant from 2.8 V to 3 V. Hence, small variations in battery voltage which have to be expected during the use of an eGrain can be accepted. On the right axis, DC current consumption is shown for the same DC voltage values. From an energy efficiency point of view, 2.8 would be best at first sight. This is because of the biasing of the emitter follower. The base voltage of the emitter follower changes rapidly with supply voltage because a simple voltage divider was used to provide this voltage. Furthermore, the feedback resistance is relatively small which leads to a noticeable increase of the DC current while increasing the applied supply voltage. Measurements were made, where the bias voltage is affected by applying a DC current at the IF output to change the voltage at the emitter of the output transistor. Hence, the operating point of the transistor changes which is equal to a change of the biasing. As we expected, same results as presented above can be achieved even with lower bias. One can conclude, that the emitter follower operates as well at a DC current of only 1 mA without lowering the performance of the circuit. The overall circuit could this way achieve the same results with a DC current dissipation of only 4 mA compared to 5.2 mA which are the case at the moment. This is also done by increasing the resistance of the voltage divider up to the maximum possible with the chip space given by the layout. This will be verified in the next version of the circuit.

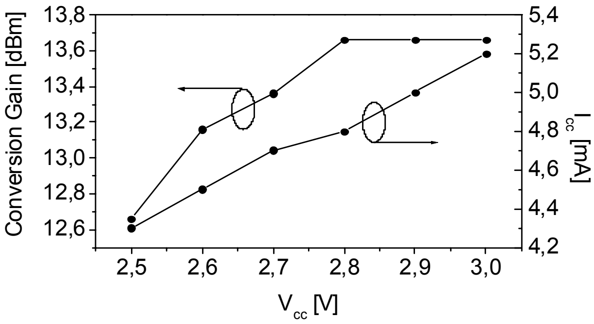

Fig. 7. Measured conversion gain/DC current vs. DC voltage, f_{RF}=24,5 GHz, f_{IF}=1.7 GHz, P_{RF}=-35 dBm, P_{LO}=0.5 dBm.

V. CONCLUSION

We have presented an active unbalanced K-band mixer operating at a DC power of only 16.5 mW. With this low power consumption the circuit provides 13.5 dB gain, using an LO power of 0.5 dBm and 16.5 dB gain using 6.5 dBm LO power, respectively. By further optimization of the emitter follower we expect to see the same performance at 12 mW DC power. Hence, the circuit can be used in energy efficient front ends for pico cell networks.

ACKNOWLEDGEMENT

This work was funded by the BMBF grant 16SV1658 “Autarke Verteilte Mikrosysteme - AVM” [1].

We would like to thank the FBH Berlin for providing the GaAS technology and for valuable discussions and advice.

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