A 2 GHz Fully Balanced Switching HBT Mixer

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Abstract - **This paper describes a highly linear low-voltage 2 GHz AlGaAs HBT fully balanced downconversion mixer. The circuit is designed to operate with a supply voltage from 4.2V down to 3.2V. Both input ports (LO/RF) are single ended and well matched to 50 Ω. Our results show a conversion gain of -7 dB and a third-order intercept point of 7 dBm realized at 3.6 V.**

The mixer utilizes 3 x 30 µm^2 single-finger HBTs fabricated in an Infineon AlGaAs/GaAs bipolar process. The size of the chip is 1 *x* 1 mm^2.

I. INTRODUCTION

AlGaAs Heterojunction bipolar transistors (HBTs) are often used in L-Band low voltage monolithic microwave integrated circuits (MMIC) as power amplifiers for wireless mobile applications. They offer high gain at very small chip size [1]. To obtain compact and cost effective transmitter circuits there is a need to integrate complete receiver circuits with low noise amplifiers (LNA), voltage controlled oscillators (VCO) and mixer circuits on the same die. Besides the high power capability they offer low noise performance which is also needed in LNAs and mixer circuits.

Components with a large dynamic range at low power supply voltages down to 2.8 V are needed in today's wireless communication systems.

With the help of CAD tools in combination with precise large signal models, we designed and processed a monolithically integrated mixer in AlGaAs HBT technology, which offers the advantages of fully balanced mixers at low supply voltages.

II. HBT PROCESS

The HBT Mixer MMIC was fabricated on MOCVD-grown wafers using the Infineon three-inch nonself-aligned production line for HBTs. The epitaxial layers consist of a 100-nm N-Al$_{0.28}$Ga$_{0.72}$As (N_{Si} = 4 x 10^{17} cm^{-3}) layer with 20-nm gradings, a 90-nm p-GaAs ($p+$ = 4x10^{19} cm^{-3}) constant C-doped base, a 700-nm n-GaAs (n = 2x10^{16} cm^{-3}) collector and a 700-nm thick n-GaAs (n = 5x10^{18} cm^{-3}) subcollector. The cross-section of the one-finger transistor with an emitter area of 3 x 30 µm^2 is shown in Fig.1.

The process is the basis of high-performance HBT power MMICs for low voltage applications [1]. The high-frequency HBT performance features f_T and f_{MAX} of 43GHz and 90GHz respectively at a collector current density of 3x10^4 A/cm^2 and a collector-emitter voltage of 3V. The maximum unilateral gain (MUG) at 2 GHz is larger than 32 dB.

Because of process-compatibility reasons the whole mixer MMIC is exclusively composed of 3x30µm^2 one-emitter-finger HBTs.

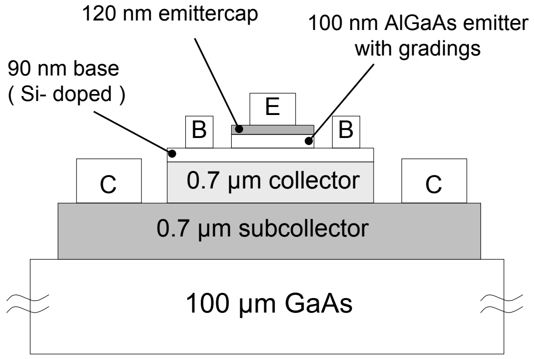

Fig. 1. Cross-section of a 3x30µm^2 HBT-cell

III. HBT MODELING

For a first pass design, an accurate large signal model is desirable. In our design procedure an extended Ebers-Moll model was used (Fig. 2). The dc model-parameter extraction is based on I-V Gummelplots of 3x30µm^2 HBTs. Because of the low thermal conductivity of GaAs and the strong temperature dependence of the transistor DC parameters, modeling of the thermal behavior of the device including self-heating is important. The extraction of the thermal resistance was performed using the DC output characteristics at two different substrate temperatures [2]. The thermal time constant is modeled with an RC-circuit and can be determined from S-parameter measurements below 10MHz [3].

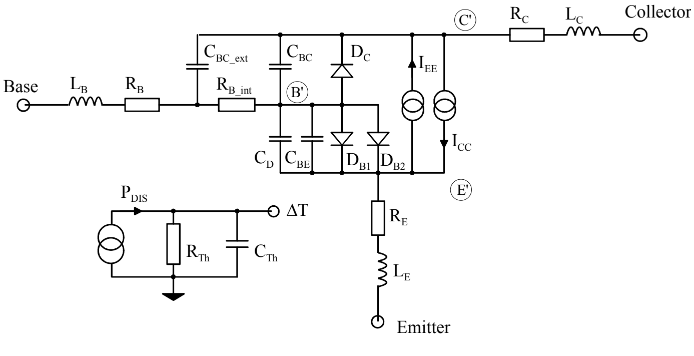

Fig. 2. Topology of the temperature dependent HBT large signal model

The AC model parameters are extracted from S-parameter measurements at various bias points. Because of the parasitic elements describing the contacts (Fig. 3) of the coplanar test environment (not shown in Fig.2), a careful extraction of those elements is needed first. With the help of em-field simulations, the extrinsic circuit elements shown in Fig.4 can be determined and used for de-embedding of the whole parasitic network.

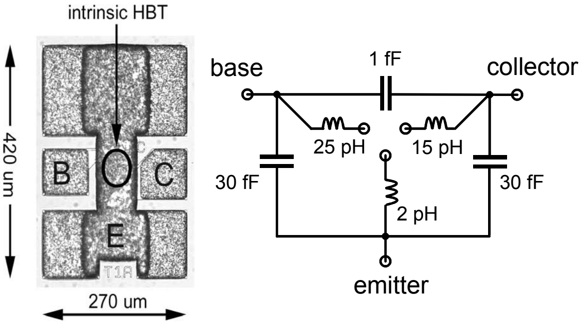

Fig. 3.,4. 3x30µm^2 HBT with GSG Pads and parasitic pad-network

With a direct extraction algorithm for GaAs-HBTs with low intrinsic base resistance [4], the small signal equivalent circuit elements are determined from measured S-parameters of common-emitter HBTs. The intrinsic base resistance R_{int} , which is nearly bias independent, can be directly used for the large signal model. The large signal parameters describing the junction capacitances C_{BC}, C_{BC_EXT}, C_{BE}, the diffusion capacitance C_D and the base transit-time are determined from the bias dependence of the extracted small-signal values. With the help of Symbolically Defined Devices (SDD), the large signal model was implemented in *Agilent's* ADS^{TM}. Fig.5 shows S-parameter simulations of the extracted model, which closely resembles the measurement data.

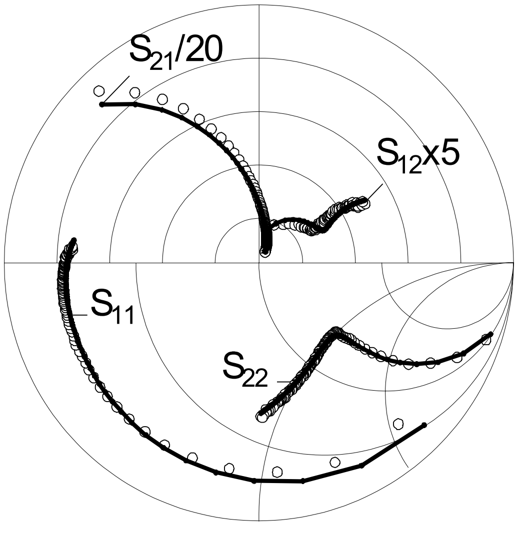

Fig. 5. Comparison of simulated and measured S-parameters for an HBT with an emitter area of 3x30µm^2 (U_{CE} = 3V, I_C = 10mA, 100 MHz to 25 GHz)
symbols : measurements, lines : simulation

III. Circuit Design And MMIC Results

A. Mixer Conception

As a double balanced MMIC mixer we are using a modified Gilbert mixer configuration as shown in Fig.6. The die layout (1.0 x 1.0 mm) can be seen in Fig. 7. The circuit is divided into four parts. The single ended RF and LO input signals are converted into differential currents by an improved transconductance cell [5]. This circuit features an extended linear range compared to the traditional differential transconductance stages and facilitates broadband input-matching [6]. An improved intermodulation behavior is expected because the transconductance stage dominates the third order nonlinearity of the double balanced mixer [7].

The switching core is based on four cross-coupled HBTs which form a fully balanced phase-reversing switch. The IF signal at the mixer core output is available in a differential current form. It is converted to the output voltage by two series resistances connected to Vcc. The differential IF signal is matched to a single ended 50Ω load by an external (off-chip) balun connected via GSGSG probeheads.

B. Simulation and Measurement Results

The presented simulation results of the HBT mixer have been calculated with *Agilent's* ADS^{TM} harmonic balance tool using our presented large signal model.

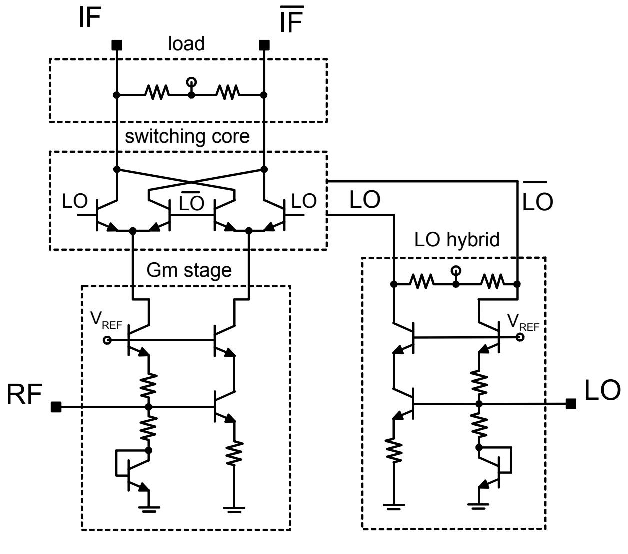

Fig. 6. Circuit schematic of the modified Gilbert mixer

The conversion gain and the linearity measurements of the mixer were based upon the following test conditions :

V_{CC}	**IF freq**	**RF freq**	P_{RF}	P_{LO}
3.6 V	80 MHz	2 GHz	-30 dBm	-5 dBm

TABLE I
MIXER TEST CONDITIONS

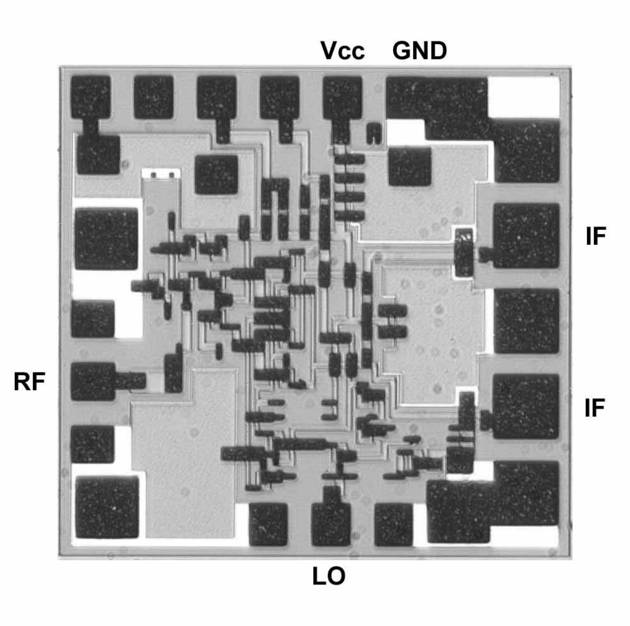

Fig. 7. Die photograph of the HBT mixer

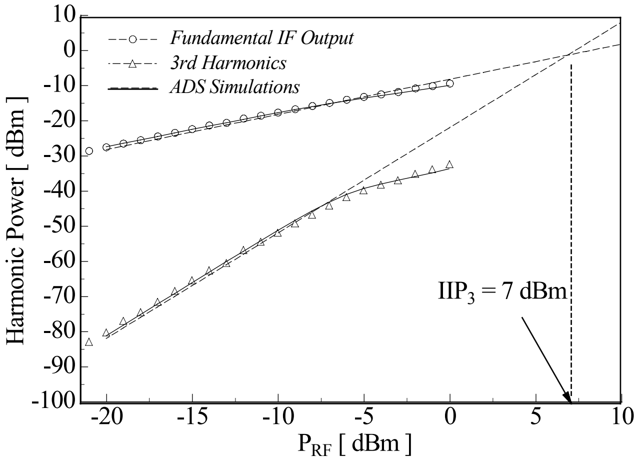

Fig. 8. Third-Order Intermodulation

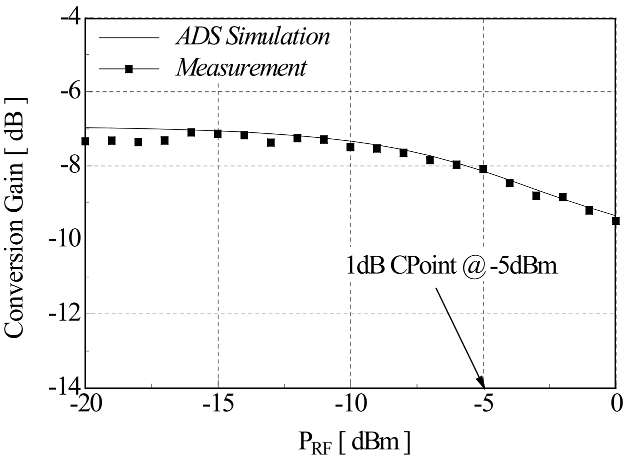

Fig. 9. Conversion Gain versus RF-input-power

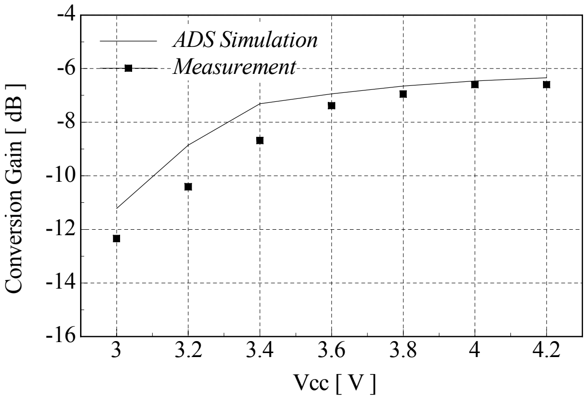

Fig. 10. Conversion gain vs. Vcc

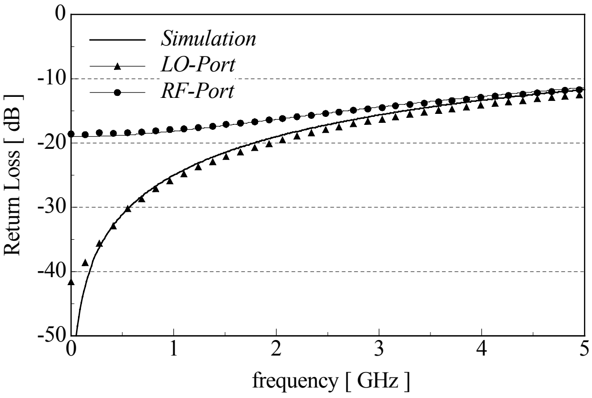

Fig. 11. RF and LO port matching vs. frequency

IV. CONCLUSION

A highly-linear low-voltage fully balanced down-conversion AlGaAs HBT mixer has been developed for low-voltage wireless applications. Both input ports (LO/RF) are single ended and well matched to 50 Ω. The experimental results show a conversion gain of -7 dB and a input third order intercept point (IIP_3) of 7 dBm realized at 3.6 V. The measured results confirm the simulated values calculated by ADS simulations using our large signal model which includes self-heating effects.

The inherent advantage of this approach is the extremely low supply voltage from 4.2V down to 3.2V using AlGaAs HBTs with a forward base-emitter voltage of roughly 1.2 V.

V. ACKNOWLEDGMENT

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