Abstract — High-frequency (h.f.) noise and linearity of advanced SiGe heterojunction bipolar transistor (HBT) cells with common-emitter (CE) and common-base (CB) connections with optimized metallization interconnections between HBT cells were investigated. Noise parameters were measured, simulated and analyzed. The observed low noise and output power linearity for the SiGe HBT in CB operation makes the investigated configuration suitable for low-noise and high-bandwidth applications.

Index-Terms: Compact modeling, heterojunction bipolar transistor, linearity, noise parameters.

I. INTRODUCTION

Recent advances in SiGe HBT performance [1],[2],[3] have enabled the realization of h. f. low noise amplifiers, transceivers and MIMO radars [3]-[12]. Both the power amplifier and the low noise amplifier (LNA) are an important component in RF transceivers. For successful design and optimization of these circuits, an accurate compact model is required, which should account for the measured noise and linearity behavior of SiGe HBTs.

The noise behavior of SiGe HBTs in different operation configurations was investigated in [14],[15]. It was found that the noise of first generation SiGe HBTs in CB configuration is the same as in CE configuration for frequencies below 2 GHz but is higher at higher frequencies (f > 6 GHz), especially at higher collector current density [13]. The difference was explained with the shot noise correlation effect. In addition, the base resistance has significant impact on NF_{min} in the CB case. However, a simplified noise model ignoring the base resistance for the first generation SiGe HBTs yields nearly same NF_{min} [14] in CE and CB configuration, which contradicts [13].

In this work, a fourth generation multifinger high-speed SiGe HBT cell with optimized and reduced base resistance in CE and CB configuration were analyzed and compared using a compact model that includes the impact of base resistance and shot noise correlation. In case of a multifinger HBT structure, the base resistance is smaller for longer emitters, resulting to a better \( f_{\text{max}} \) and noise figure (NF). Measured noise, linearity and the associated analysis of a double-emitter high-speed cell in CE and CB connection are presented.

II. DUT AND MEASUREMENT SETUP

A. SiGe Cell Layout Design

The investigated SiGe cells consisted of two back-to-back connected CBEBEBC devices with an emitter window area of \( A_{\text{e0}} = 2 \times 0.13 \, \mu\text{m} \times 10 \, \mu\text{m} \).

The IHP SG13G2 process offers seven metal layers [15]. The high-speed cell layout was realized with two HBTs, connected and separated by an isolation (shallow) trench and combined into a single shallow trench. The collectors and bases of the individual devices, were connected locally and finally terminated with Topmetal2 of the process at the east and west side respectively. The emitter contacts, which are parallel to each other, were connected towards the vertical direction up to Topmetal2 and finally grounded from both north and south sides.

B. Measurement equipment

On-wafer DC and RF (0.1-67 GHz) characteristics were measured with a PNA-X 5247A and HP4142 SMU. High-frequency noise parameters were measured with a Maury Microwave Automated Tuner System ATS 5.21 07. Circuit simulations were carried out with HICUM/L2 v2.34, including adjunct networks for noise correlation [16] and non-quasi static (NQS) effects [17].

III. RESULTS AND DISCUSSION

A. DC and RF characteristics

The output characteristics for the complete SiGe cell in CE configuration are shown in Fig. 1. Avalanche multiplication at \( V_{\text{BE}} = 0.74 \, \text{V} \) starts at \( BV_{\text{CEO}} = 1.7 \, \text{V} \). For \( J_C(V_{\text{CE}}) \) and \( J_B(V_{\text{CE}}) \) excellent agreement between model and measurement is obtained. Exceeding \( BV_{\text{CEO}} \) with the collector bias turned out to be beneficial in terms of output power and RF performance for cascode power circuits [3],[18].

Fig. 1: Collector current density of the cell versus CE voltage with \( I_B \) drive (1 \( \mu \text{A} \) to 501 \( \mu \text{A} \), 50 \( \mu \text{A} \)). Lines are HICUM.
sent in Fig. 2. The dips in $|J_B|$ at $V_{CE} = 1.8$ V correspond to current reversal due to avalanche multiplication in the base-collector region.

Fig. 2: Forward Gummel plot at $V_{CE} = 1.8$ V, 1.5 V.

The current gain cut-off frequency $f_T$ and maximum frequency of oscillation $f_{max}$ versus current density are given in Fig. 3.

![Image: Current gain cut-off frequency $f_T$ and $f_{max}$ over collector current density for a single CBEBEBC SiGe HBT.]

Fig. 3: Current gain cut-off frequency $f_T$ and $f_{max}$ over collector current density for a single CBEBEBC SiGe HBT.

B. High frequency and power characteristics of common base CB cell

It is well known that CB configuration HBTs yield higher bandwidth at the cost of lower gain. The CB configuration is widely used for mixers and generally in cascode amplifiers. For 200 GHz SiGe HBTs, the CB configuration also exhibited significantly better linearity than the CE configuration [19].

![Image: Output power of fundamental (2 and 10 GHz) and harmonic frequencies versus input power of the CB cell with CBEBCBEBC layout at, $V_{CB} = 0.9$ V and $V_{BE} = 0.93$ V.]

Fig. 4: Output power of fundamental (2 and 10 GHz) and harmonic frequencies versus input power of the CB cell with CBEBCBEBC layout at, $V_{CB} = 0.9$ V and $V_{BE} = 0.93$ V.

In this work we have measured the large-signal behavior of a SiGe HBT CB cell with 2xCBEBCBEBC parallel configuration. The base-emitter voltage was forced during these measurements. The transducer power gain $G_T$ is slightly above $4$ dB at 2 GHz and drops to $2$ dB at 10 GHz (c.f. Fig. 4). The emitter and collector current densities versus input power are given in Fig. 5. Beyond an input power of $2$ dBm a frequency dependence is observed.

![Image: Output power of fundamental (2 and 10 GHz) and harmonic frequencies.]

Fig. 5: $P_{out}(P_{in})$ and $|J_E(P_{in})|$ at 2 and 10 GHz for the CB CBEBCBEBC cell biased at $V_{BE} = 0.93$ V and $V_{CB} = 0.9$ V.

C. High frequency noise behavior

High-frequency noise parameters of the CE and CB cells were measured in a frequency band of 8 to 50 GHz. $NF_{min}$ is presented in Fig. 6. As expected for high-speed devices, very low noise is observed. The corresponding noise resistance is around 10 $\Omega$ over the frequency band. Such low noise resistance enables easy matching of the SiGe power cell for a low noise performance over a wide bias range.

![Image: Minimum noise figure $NF_{min}$ versus frequency for SiGe CE and CB power cells.]

Fig. 6: Minimum noise figure $NF_{min}$ versus frequency for SiGe CE and CB power cells.

The frequency dependence of $NF_{min}$ for CB operation is very close to that of the CE case, and $NF_{min}$ slightly increases with frequency as observed in [13]. HICUM captures the trend, in particular the crossing of $NF_{min}$ data between CB and CE operation, quite well. The second (upper) set of curves in Fig. 6 shows the $f_c$ versus current density dependence of $NF_{min}$. At $J_C$ below the minimum, $NF_{min}$ is higher for the CB case, while towards higher $J_C$ lower $NF_{min}$ is obtained for CB operation.

The final version of the manuscript will include an analysis, based on the compact model, of the noise
parameters and RF linearity performance of the SiGe power cells in CB and CE configuration for a wide variety of measured data.

IV. CONCLUSIONS

A low noise figure along with a low noise resistance allows the use of high-speed SiGe HBTs not only for low noise applications but also for power amplifiers for example in MIMO radar receivers.

ACKNOWLEDGEMENT

This work was supported by the Excel project TARANTO (H2020-ECSEL-2016-1-RIA-two-stage) and the German National Science Foundation (DFG SCHR695/12) Everbeing Inc. is acknowledged for support with its 300 mm probe station.

REFERENCES


