A 60 GHz Broadband Amplifier in SiGe Bipolar Technology

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Student Paper

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Abstract. A broadband amplifier with 16 dB gain and a 3-dB bandwidth of more than 60 GHz is presented. This amplifier exhibits a 1-dB compression point of -9.5 dBm and a third-order intercept point of +2.1 dBm referred to the input. The maximum differential output voltage swing is 1.5 V_{PP}. Clear output eye diagrams have been measured up to 100 Gbit/s. The chip is manufactured in an advanced SiGe bipolar technology and consumes a power of 770 mW at a supply voltage of -5.0 V.

I. INTRODUCTION

Broadband amplifiers are important building blocks for a large variety of applications, including wireless transceivers and optical communication systems. In general, they are based on a lumped or on a distributed concept.

Broadband amplifiers based on lumped elements are presented in [1], [2], and [3]. In [1] an amplifier using SiGe hetero junction bipolar transistors (HBTs) is presented which exhibits a gain of 36 dB and a bandwidth of 26 GHz. An InP HBT amplifier is presented in [2] with 21 dB gain and 38 GHz bandwidth. Another InP HBT based wideband amplifier with bessel transfer function, a gain of 11 dB, and a bandwidth of more than 50 GHz is presented in [3].

Broadband amplifiers based on distributed concepts using InP high electron mobility transistors (HEMTs) are presented in [4] and [5] and exhibit a bandwidth of more than 110 GHz and 92 GHz, respectively. A distributed amplifier using SiGe HBTs reaches a bandwidth of 80 GHz [1].

In this paper a broadband amplifier based on lumped elements using an advanced SiGe bipolar technology is presented. Key design aspects are high bandwidth and a high output voltage swing. The amplifier is intended as driver circuit for both sinusoidal signals up to high frequencies and very high data rate signals.

II. TECHNOLOGY

The amplifier is fabricated in a preproduction state-of-the-art SiGe bipolar technology [6]. The transistors have a double-polysilicon self-aligned emitter-base configuration with a minimum effective emitter width of 0.14 μm. A TEM cross section of the emitter-base complex is given in Fig. 1. The SiGe:C base of the transistors has been integrated by selective epitaxial growth. The emitter contact exhibits a monocrystalline structure. The transistors manufactured in this technology offer a transit frequency f_T of 200 GHz, a maximum oscillation frequency f_{max} of 275 GHz and a ring oscillator gate delay of 3.5 ps. Current density for maximum f_T and f_{max} is at about 8 mA/μm^2. Some important parameters of a tran-

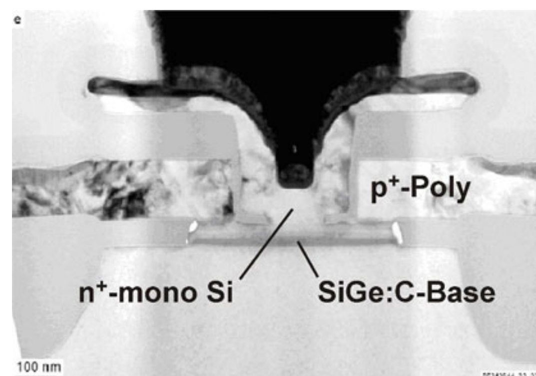

Figure 1: TEM cross section of the emitter-base complex of a transistor with effective emitter width of 0.14 μm

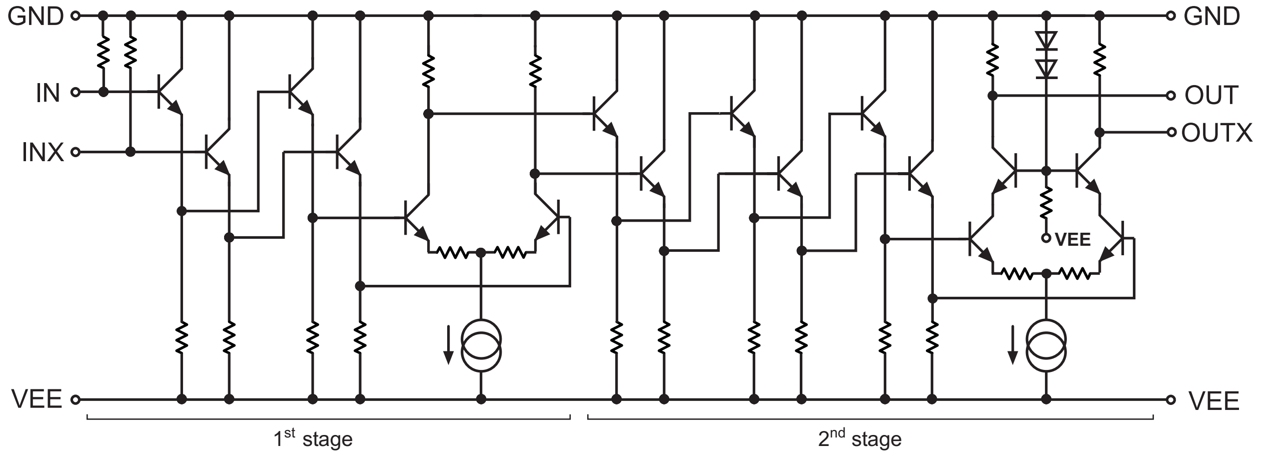

Figure 2: Schematic of the broadband amplifier

sistor with an effective emitter size of $0.14\,\mu m \times 2.6\,\mu m$ are: $C_{BC} = 5.5$ fF, $C_{EB} = 6.3$ fF, $C_{CS} = 3.7$ fF, $R_B = 50\,\Omega$, $R_E = 3.5\,\Omega$, $R_C = 7.5\,\Omega$. The collector-emitter breakdown voltage BV_{CE0} is 1.7 V.

The technology provides four copper metallization layers, two different types of polysilicon resistors, a TaN thin film resistor and a MIM capacitor.

III. CIRCUIT DESIGN

The circuit diagram of the broadband amplifier is shown in Fig. 2. The broadband amplifier is based on a fully differential design and consists of two stages. The first stage consists of two emitter follower pairs and a differential amplifier. The second stage consists of three emitter follower pairs and the differential amplifier at the output. $50\,\Omega$ on-chip resistors are provided at the input and the output for broadband matching. In order to achieve a high output swing, high currents in the differential amplifiers are necessary. In addition, emitter degeneration and low load resistors are used for increasing the 3-dB bandwidth at a well-defined gain. Emitter degeneration resistors also improve the linearity of the circuit. As an adequate dimensioning for the first stage we obtained load resistors of $30\,\Omega$ and emitter degeneration resistors of $10\,\Omega$ each. In the second stage emitter degeneration resistors of $5\,\Omega$ are used. Carefully adjusted transistor sizes and currents enable a flat transfer function and a high bandwidth. The differential amplifier of the second stage is implemented as cascode configuration in order to prohibit avalanche breakdown of the output transistors. The cascode stage additionally minimizes the Miller effect, thereby bandwidth is increased.

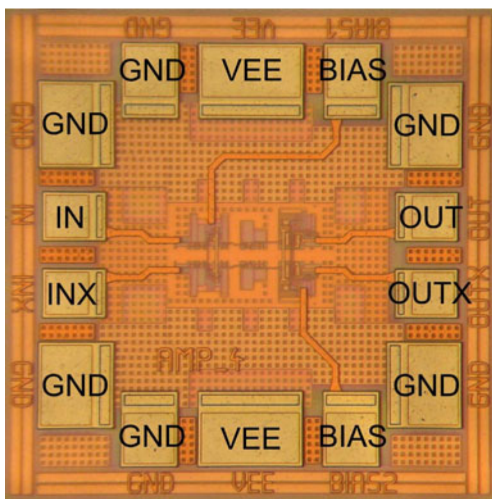

Figure 3: Chip photograph (chip size: $550\,\mu m \times 550\,\mu m$)

IV. EXPERIMENTAL RESULTS

In Fig. 3 a chip photograph of the broadband amplifier is shown. The die size is $550\,\mu m \times 550\,\mu m$. The amplifier has been carefully characterized by S-parameter and large-signal measurements. All measurements have been performed at a supply voltage of -5 V with a current consumption of 155 mA.

S-parameter measurements have been performed single-ended, on-wafer using an Anritsu 360B vector network analyzer with 67 GHz GS and SG probes, respectively. Fig. 4 shows the single-ended measured gain and the input and output return loss at $50\,\Omega$ source and load impedance. The single-ended low-frequency gain

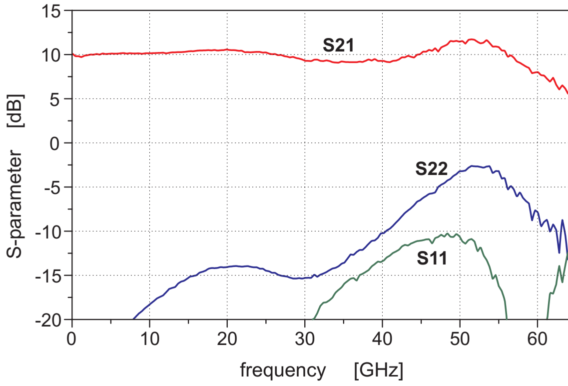

Figure 4: Single-ended on-wafer measurement of the S-parameters

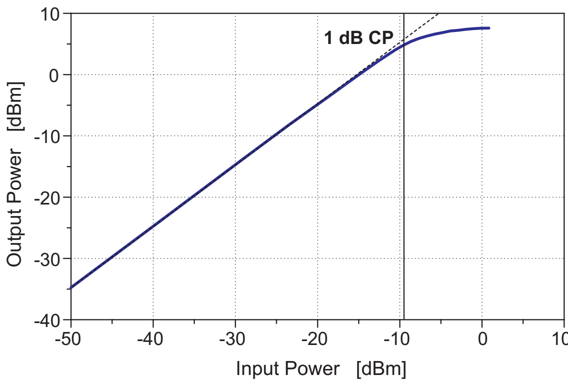

Figure 5: Differential on-wafer measurement of the 1-dB compression point (input frequency: 40 GHz)

is 10 dB and the 3-dB bandwidth is 62 GHz. The differential gain is 16 dB. Degradation of S_{22} at about 50 GHz can be observed. In the case of a single-ended excitation together with an inductance in the supply path this behavior can be verified by simulations. In differential operation such an inductance would have no effect.

The large-signal behavior of the broadband amplifier is analyzed on-wafer with 40 GHz GSSG-probes using differential signals. In Fig. 5 the 1-dB compression point of the amplifier is shown. It results to -9.5 dBm referred to the input, measured at a signal-frequency of 40 GHz. Fig. 6 shows the third-order intermodulation for a two-tone excitation with input frequencies of 40 GHz and 40.002 GHz. The input-referred third-order intercept point is +2.1 dBm.

Further measurements have been performed by excitation with high data rate signals. Therefore a PRBS-generator chip [7] and the broadband amplifier chip have been mounted closely on a substrate. Short bond wires

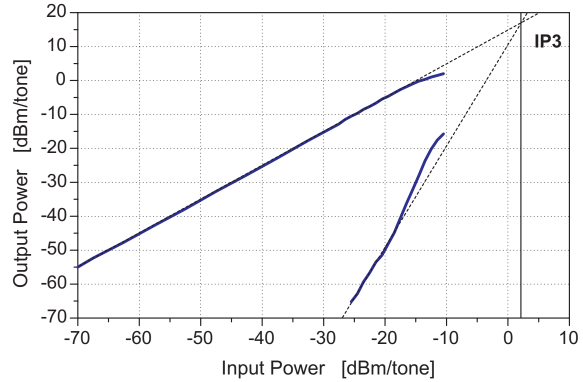

Figure 6: Differential on-wafer measurement of the third-order intercept point (input frequencies: 40 GHz and 40.002 GHz)

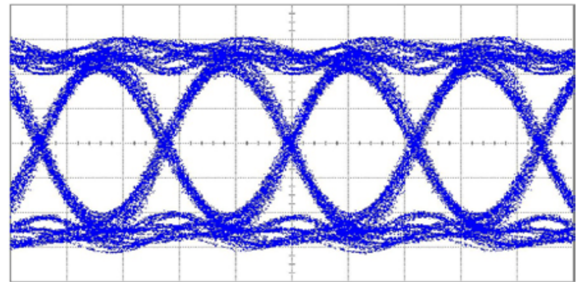

Figure 7: Measured 80 Gbit/s differential output eye diagram (250 mV/div, 5.6 ps/div)

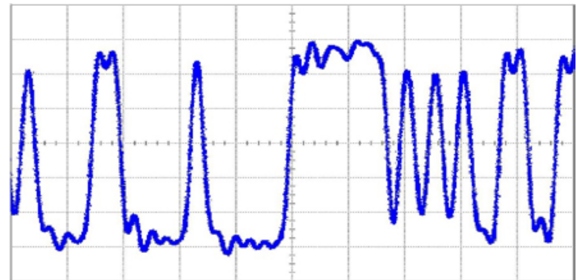

Figure 8: Measured 80 Gbit/s differential output signal (250 mV/div, 50 ps/div)

connect the outputs of the PRBS-generator and the amplifier inputs. The output signal has been measured with a 40 GHz GSSG-probe and a 70 GHz sampling oscilloscope 86100B from Agilent. Fig. 7 shows the differential 80 Gbit/s output eye diagram. The amplitude is $2\times750\,\mathrm{mV_{PP}}$ and the eye opening is about 1 V. In Fig. 8 the bit pattern of the same signal is shown. The amplitude of the input signal is about $2\times150\,\mathrm{mV_{PP}}$. In Fig. 9

Table 1: Summary of technical data

Technology	200 GHz f_T SiGe bipolar
Supply voltage	-5.0 V
Supply current	155 mA
Differential gain	16 dB
1-dB compression point	-9.5 dBm (input)
Third-order intercept point	+2.1 dBm (input)
Chip size	550 μm $\times$ 550 μm

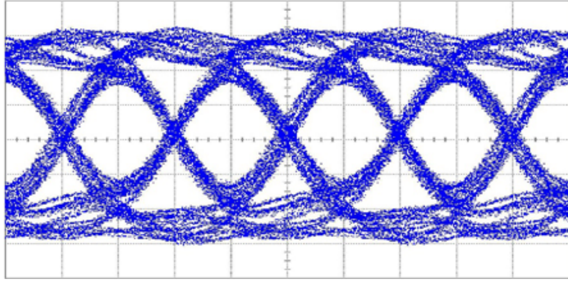

Figure 9: Measured 100 Gbit/s differential output eye diagram (250 mV/div, 5 ps/div)

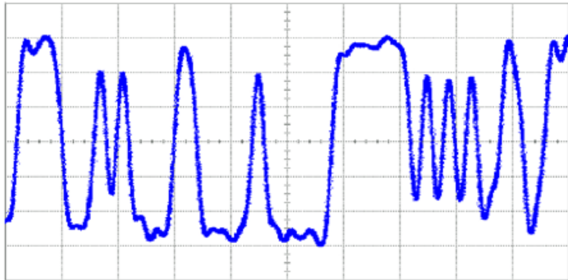

Figure 10: Measured 100 Gbit/s differential output signal (250 mV/div, 50 ps/div)

and Fig. 10 the output eye diagram and the output bit pattern for a 100 Gbit/s excitation signal are shown. At this data rate both the input signal and the limited bandwidth of the measurement equipment degrade the measured output signal.

V. SUMMARY

In this paper a monolithic integrated broadband amplifier in SiGe bipolar technology is presented. The circuit exhibits a differential gain of 16 dB, a bandwidth of 62 GHz and it consumes 155 mA at a supply voltage of -5 V. Tab. 1 gives a summary of the circuit performance.

To the author's knowledge, this is the highest bandwidth for lumped broadband amplifiers reported so far. The clear output eye diagrams at a data rate of 80 Gbit/s and beyond demonstrate the feasibility for high data rate communication.

VI. REFERENCES

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