15 GHz Wideband Amplifier with 2.8 dB Noise Figure in SiGe Bipolar Technology

Herbert Knapp, Dietmar Zöschg, Thomas Meister, Klaus Aufinger,
Sabine Boguth, Ludwig Treitinger

Infineon Technologies AG, Corporate Research, D-81730 Munich, Germany
E-mail: herbert.knapp@infineon.com

***Abstract* — We present a wideband amplifier with 12 dB gain and a 3-dB bandwidth of 15 GHz. The noise figure is 2.8 dB for frequencies up to 10 GHz and 4 dB at 15 GHz. The circuit is manufactured in an advanced SiGe bipolar technology and consumes 7.2 mA from a 3.3 V supply.**

I. INTRODUCTION

Wideband amplifiers are used in a large variety of applications, including wireless systems, instrumentation, and optical communications. Several wideband amplifiers using III-V hetero-junction bipolar transistors (HBTs) [1]-[4] and silicon-germanium HBTs [5] have been presented so far. These circuits have been optimized for very high bandwidth with little emphasis on their noise figure. The reported noise figures are in the range from 5 dB to 7 dB [5], [2].

Silicon-germanium technologies have already shown their potential for narrow-band low-noise amplifiers in the frequency range up to 10 GHz [6], [7]. This work presents a SiGe wideband amplifier which has been optimized for low noise while maintaining a high bandwidth of 15 GHz.

II. CIRCUIT DESIGN

The wideband amplifier consists of a single stage in common-emitter configuration and an emitter follower in the feedback path (fig. 1). Flat frequency response and matching to 50 Ω at the input and output are achieved by emitter degeneration of the common-emitter stage T1 and shunt feedback via T2, R3, and L1. The use of an emitter follower in the feedback path increases the collector-emitter voltage of transistor T1 to approximately 2 V, resulting in a higher f_{max} of the transistor and improved large-signal behavior. The emitter size of T1 is determined by a compromise between low noise and large bandwidth. The effective emitter area of T1 is 10 μm². The emitter follower T2 contributes only little to the output noise and has an effective emitter area of 3.5 μm².

The inductor L1 is used to optimize the frequency response. Large values for the inductance of L1 lead to peaking in the frequency response. While this allows to extend the bandwidth to higher frequencies, excessive peaking is undesirable for broadband communications systems which require a flat group delay. L1 is realized as spiral on-chip inductor. The quality factor Q is only of minor importance in this application and the layout of the inductor was optimized for a high self-resonance frequency.

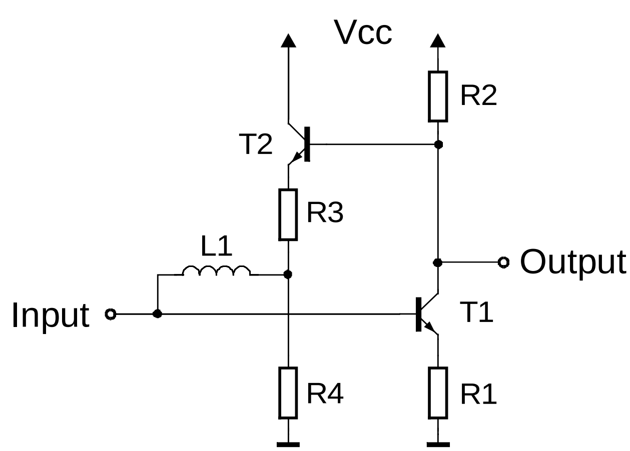

Fig. 1. Schematic circuit diagram of the wideband amplifier.

III. TECHNOLOGY

The wideband amplifier was manufactured in an advanced SiGe bipolar process. This self-aligned double-polysilicon process is an improved version of the technology presented in [8]. It uses selective epitaxial growth (SEG) to achieve a graded SiGe profile in the base with a maximum germanium fraction of 20 %. Figure 2 shows the cross-section of an npn transistor. The cut-off frequency f_T is 80 GHz and the maximum oscillation frequency f_{max} is 97 GHz. The minimum noise figure at 10 GHz is 1.3 dB. The technology uses 0.5 µm lithography and offers three types of polysilicon resistors and four metalization layers.

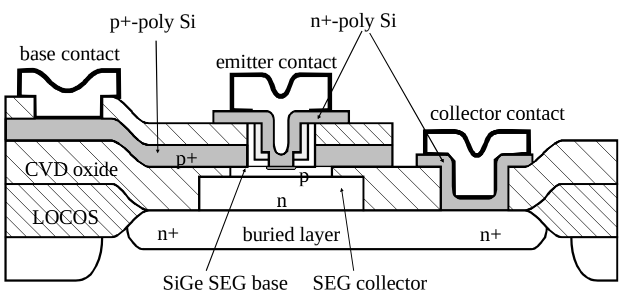

Fig. 2. Transistor cross section.

Figure 3 shows a chip photograph of the wideband amplifier. The die size of 0.55 x 0.45 mm² was dictated by the grid of the shared reticle used for the fabrication of the chip. The amplifier uses only a small fraction of the chip area. The resulting long transmission lines to the input and output pads are realized as microstrip lines in metal 4 over a ground plane of metal 2.

IV. MEASUREMENT RESULTS

The S-parameters and the noise figure of the broadband amplifier were measured on wafer using ground-signal-ground microwave probes. The circuit operates with a supply voltage of 3.3 V and consumes 7.2 mA.

Figure 4 shows the measured gain and noise figure for 50 Ω source and load impedance. The low-frequency gain is 12 dB and the 3-dB bandwidth is 15 GHz. The noise figure is 2.8 dB for low frequencies and rises to 3 dB at 12 GHz and to 4 dB at 15 GHz. The flat gain response indicates that no excessive peaking was used to obtain the desired bandwidth. This is also shown by the linear phase response of S21 (fig. 5). Figure 6 shows the input and output return loss of the wideband amplifier.

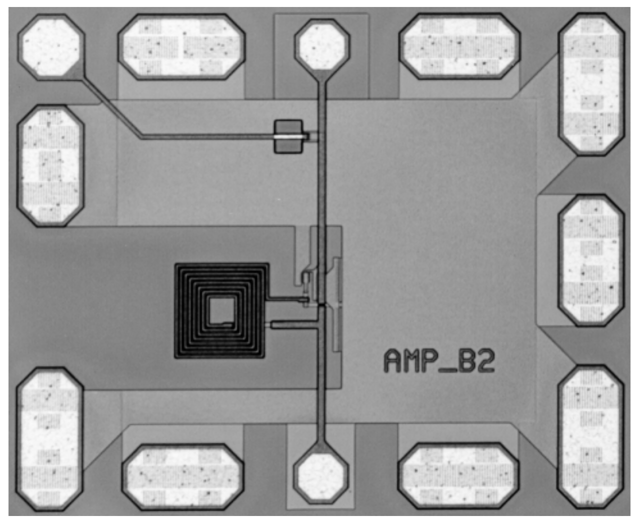

Fig. 3. Chip photograph (chip size 0.55 x 0.45 mm²).

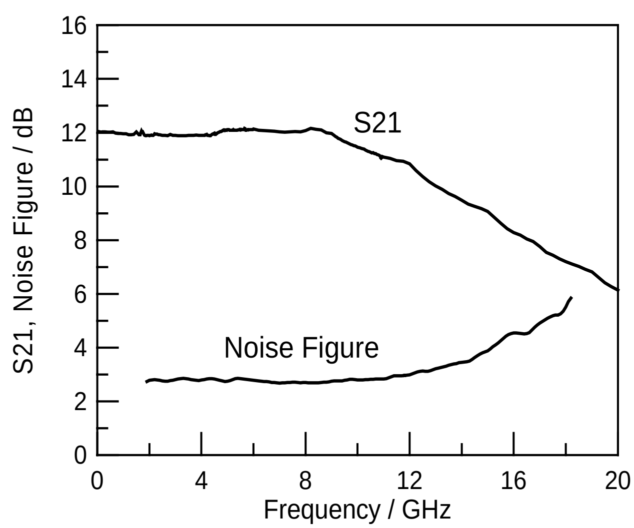

Fig. 4. Measured gain and noise figure versus frequency for a source impedance of 50 Ω.

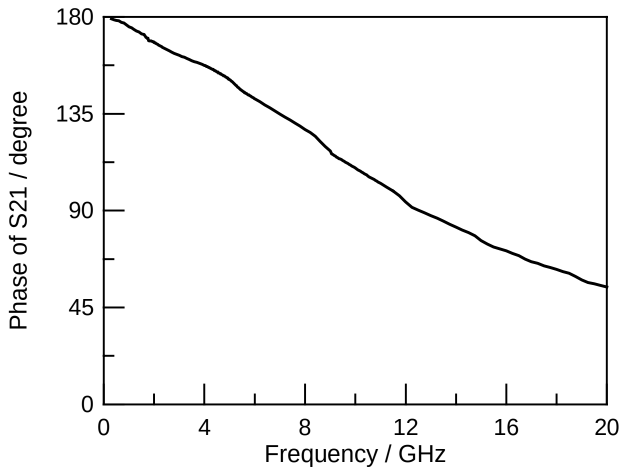

Fig. 5. Measured phase delay versus frequency.

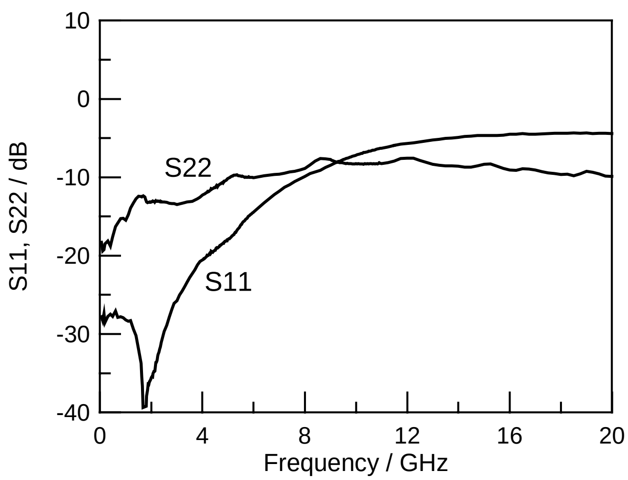

Fig. 6. Measured input return loss (S11) and output return loss (S22).

Operation with reduced supply voltages is possible. With a supply voltage of 2.7 V the current consumption is only 4.4 mA. The gain decreases to 10.8 dB and the 3 dB-bandwidth to 14 GHz.

To evaluate the large-signal behavior of the wideband amplifier the 1-dB compression point and the third-order intercept point were measured. Figure 7 shows the transfer characteristics for an input frequency of 2 GHz and a supply voltage of 3.3 V. The 1-dB compression point is -7.6 dBm referred to the input. Figure 8 shows the third-order intermodulation for input frequencies of

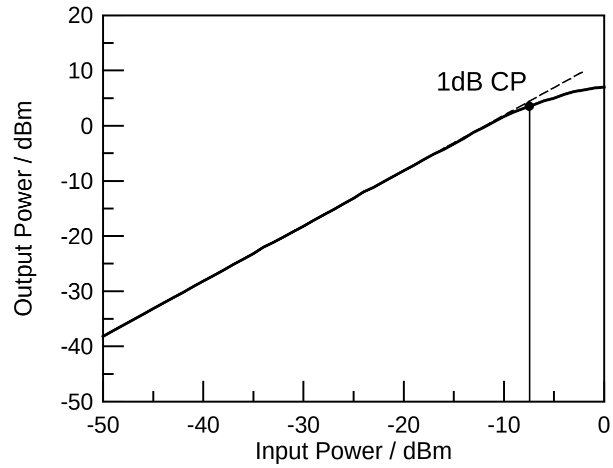

Fig. 7. Measurement of the 1-dB compression point (input frequency 2 GHz, supply voltage 3.3 V).

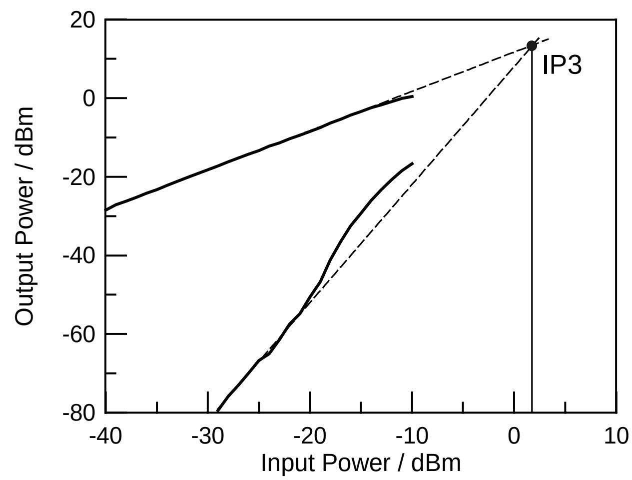

Fig. 8. Measurement of the third-order intercept point (input frequencies 2 GHz and 2.001 GHz, supply voltage 3.3 V).

2 GHz and 2.001 GHz. The input-referred third-order intercept point is 1.9 dBm.

V. CONCLUSION

We have designed a monolithic wideband amplifier in SiGe bipolar technology. The circuit consumes only 24 mW and combines a 3-dB bandwidth of 15 GHz with a noise figure of less than 3 dB. Table 1 gives a summary of the circuit performance.

TABLE 1
SUMMARY OF TECHNICAL DATA

Gain	12 dB
3-dB bandwidth	15 GHz
Noise figure	2.8 dB ($f \leq 10$ GHz) 4 dB ($f = 15$ GHz)
1-dB compression point	-7.6 dBm (input)
Third-order intercept point	1.9 dBm (input)
Supply voltage	3.3 V
Supply current	7.2 mA
Technology	0.5 µm SiGe bipolar
Chip size	0.55 x 0.45 mm^2

REFERENCES

[1] Y. Kuriyama, J. Akagi, T. Sugiyama, S. Hongo, K. Tsuda, N. Iizuka, and M. Obara, "DC to 40-GHz Broad-Band Amplifiers Using AlGaAs/GaAs HBT's", *IEEE Journal of Solid-State-Circuits*, vol. 30, no. 10, pp. 1051-1054, Oct. 1995.

[2] Y. Suzuki, H. Shimawaki, Y. Amamiya, N. Nagano, T. Niwa, H. Yano, and K. Honjo, "50-GHz-Bandwidth Baseband Amplifiers Using GaAs-Based HBT's", *IEEE Journal of Solid-State-Circuits*, vol. 33, no. 9, pp. 1336-1341, Sept. 1998.

[3] B. Agarwal, Q. Lee, D. Mensa, R. Pullela, J. Guthrie, and M.J.W. Rodwell, "Broadband feedback amplifiers with AlInAs/GaInAs transferred-substrate HBT", *Electronics Letters*, vol. 34, no. 13, pp. 1357-1358, June 1998.

[4] A. Huber, D. Huber, C. Bergamaschi, T. Morf, and H. Jäckel, "Lumped DC-50 GHz amplifier using InP/InGaAs HBTs", *Electronics Letters*, vol. 35, no. 1, pp. 53-54, Jan. 1999.

[5] H. Schumacher, A. Gruhle, U. Erben, H. Kibbel, and U. König, "A 3V supply voltage, DC-18 GHz SiGe HBT wideband amplifier", *Proceedings of the 1995 Bipolar/ BiCMOS Circuits and Technology Meeting*, pp. 190-193, Oct. 1995.

[6] H. Ainspan, M. Soyuer, J.-O. Plouchart, and J. Burghartz, "A 6.25-GHz Low DC Power Low-Noise Amplifier in SiGe", *IEEE 1997 Custom Integrated Circuits Conference*, pp. 177-180, May 1997.

[7] D. Zöschg, W. Wilhelm, T.F. Meister, H. Knapp, H.-D. Wohlmuth, K. Aufinger, M. Wurzer, J. Böck, H. Schäfer and A. Scholtz, "2 dB noise figure, 10.5 GHz LNA using SiGe bipolar technology", *Electronics Letters*, vol. 35, no. 25, pp. 2195-2196, Dec. 1999.

[8] T.F. Meister, H. Schäfer, M. Franosch, W. Molzer, K. Aufinger, U. Scheler, C. Walz, M. Stolz, S. Boguth, and J. Böck, "SiGe Base Bipolar Technology with 74 GHz f_{max} and 11 ps gate delay", *IEDM Technical Digest*, pp. 739-742, Dec. 1995.