A 30 GHz Bandwidth AlGaAs–GaAs HBT Direct-Coupled Feedback Amplifier

N. H. Sheng, W. J. Ho, N. L. Wang, R. L. Pierson, P. M. Asbeck, and W. L. Edwards

Abstract—**A dc to 30 GHz broadband amplifier based on the Darlington connected transistors with series and shunt resistive feedback was implemented with self-aligned AlGaAs–GaAs heterojunction bipolar transistor (HBT) technology. The measured performance shows 7.8 dB of gain with −3-dB roll-off bandwidth of 30 GHz. Measured at 1 GHz, the noise figure was 5.7 dB, 1-dB compression power was 11 dBm and the third-order intermodulation product intercept point (IP3) was 23.9 dBm.**

I. Introduction

AlGaAs/GaAs HBT technology is now sufficiently advanced to demonstrate a variety of integrated circuits covering high speed digital circuits, small signal analog MMIC's and high efficiency microwave power sources for system insertion applications [1], [2]. In most cases, HBT circuit design can take advantage of Si bipolar circuit topologies and experiences because there are few differences between the two (the base-emitter turn-on voltage is different and the HBT has much higher f_T and f_{MAX} to achieve better performances). Excellent performance of broadband amplifiers based on Darlington or cascode topology have been demonstrated with HBT technology [3] [4]. In this letter, we report an AlGaAs–GaAs HBT broadband amplifier with ultra-wide bandwidth due to the superior device performance using a self-aligned technology. The amplifier shows 7.8 dB of gain with 3-dB bandwidth of 30.5 GHz. The measured input and output VSWR are better than 2:1 across the whole bandwidth. The ultra-wide bandwidth amplifiers will find applications as general purpose gain blocks in advanced microwave modules, lightwave communication systems and testing/measurement equipments.

II. Device Technology

The direct-coupled broadband amplifiers were fabricated using AlGaAs–GaAs HBT technology with MBE grown epitaxial layers on semi-insulating substrates. The base layer was Be doped to $4 \times 10^{19}/\text{cm}^3$ with thickness of 700 Å. The emitter layer was lightly doped to $5 \times 10^{17}/\text{cm}^3$ with a heavily doped cap layer to facilitate emitter ohmic contact formation. The collector thickness was 7000 Å with doping concentration 3 to $6 \times 10^{16}/\text{cm}^3$. Self-aligned processing as described in a previous paper [5] was applied in the fabrication to reduce the base resistance. The gap between base contact and emitter was 0.2 μm, which lowers the base resistance by 30%–50% compared with a representative 0.8-μm gap using a nonself-aligned process. The extrinsic base area was implanted with protons to reduce the extrinsic base-collector capacitance. Typically, this capacitance was reduced to half of its value without implant. High-frequency characteristics of the fabricated transistors show measured f_T of 60 GHz and f_{MAX} of 120 GHz. The detailed process characteristics were shown in a previous publication [6].

III. Circuit Design and Measurement Results

The circuit topology of the HBT broadband amplifier is shown in Fig. 1, which consists of the Darlington connected transistors as the active elements. The single emitter finger size is 1.4 μm × 8.5 μm and the emitter area ratio of Q2 transistor to Q1 transistor is 3 to 1. One of the design requirements for microwave broadband amplifier is that the input and output impedances should match the system impedance, typically 50 ohm. The resistive feedback makes the input and output impedance determined primarily by the feedback resistance R_F and R_E, as analyzed in detail in [7], which are more controllable in comparison with broadband matching or distributed amplifier designs. Resistor R_{Bias} is used to bias transistor Q2, while R_E is the emitter degeneration resistor to optimize the bandwidth and output impedance. The noise figure of the amplifier is mainly determined by the feedback resistors R_F, R_E and base resistance of the input transistor Q1. The typical values for R_F and R_E are 250 ohm and 10 ohm, respectively. The resistor R_{BB} determines the collector voltage of Q1 and Q2, which in turn determines the microwave output power capability of the circuit. The circuit layout was designed to fit into the general purpose 70 mil microwave package, which has only input, output and two ground pins. External resistor R_{cc} was used for biasing; a single power supply was used to bias the whole circuit such that the collector voltage of Q1 and Q2 transistors is 3.4 V and the total current is 33 mA. Total power consumption of the chip is about 115 mW. Fig. 2 shows microphotograph of the fabricated circuit with dimension of 211 μm × 490 μm including the bonding pads. This size is extremely small in comparison with MESFET distributed amplifiers. Fig. 3 shows the measured transmission power gain and input, output return loss as a function of frequency. The flat power gain of 7.8 dB was measured from dc to 16 GHz that rolls off by 3 dB at 30.5 GHz. The input and output VSWR's are better than 2:1 from dc to 30 GHz. In comparison with the

Manuscript received March 21, 1991.
N. H. Sheng, W. J. Ho, N. L. Wang, R. L. Pierson, and P. M. Asbeck are with Rockwell International, Science Center, 1049 Camino Dos Rios, Thousand Oaks, CA 91360.

W. L. Edwards is with Rockwell International, Collins Avionic Group, Cedar Rapids, IA 52498.
IEEE Log Number 9101737.

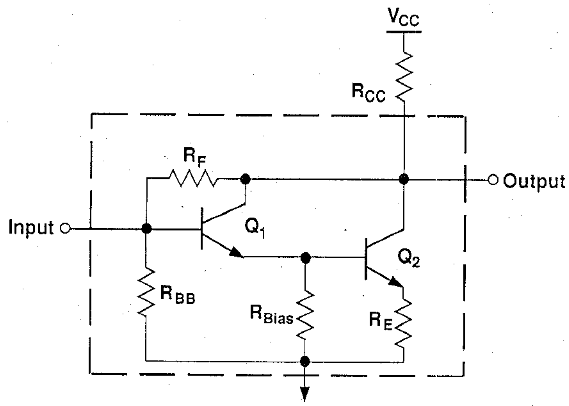

Fig. 1. Circuit schematic of the Darlington feedback amplifier.

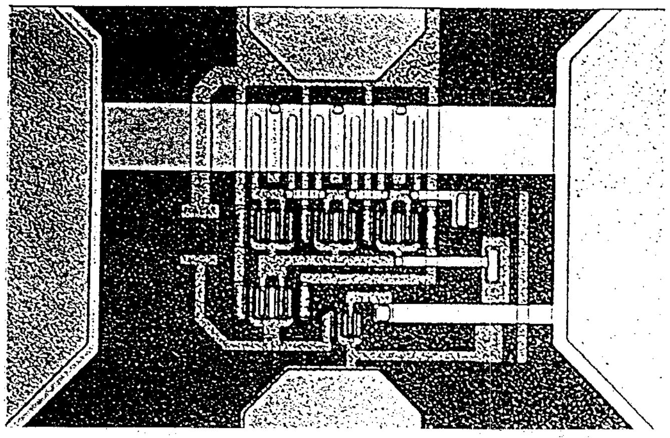

Fig. 2. Microphotograph of fabricated HBT broadband amplifier. Chip size including the bonding pads is 211 μm $\times$ 490 μm.

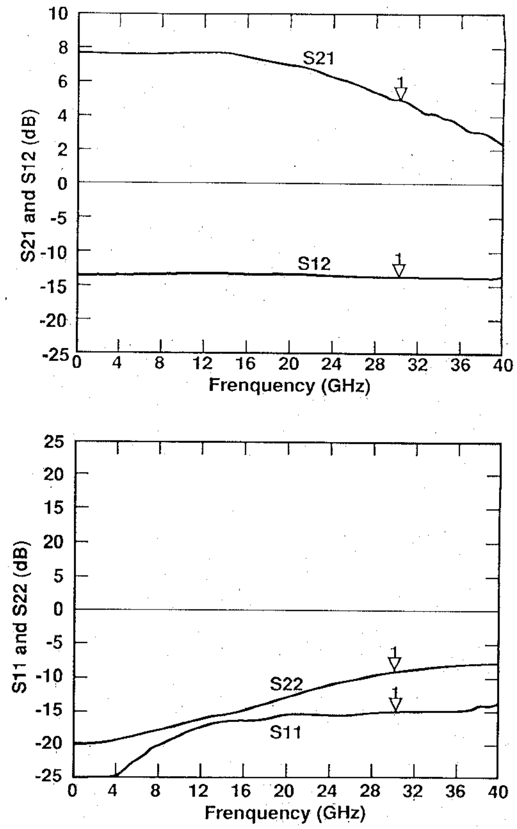

Fig. 3. Measured transmission gain S21, input return loss S11 and output return loss S22 as a function of frequency.

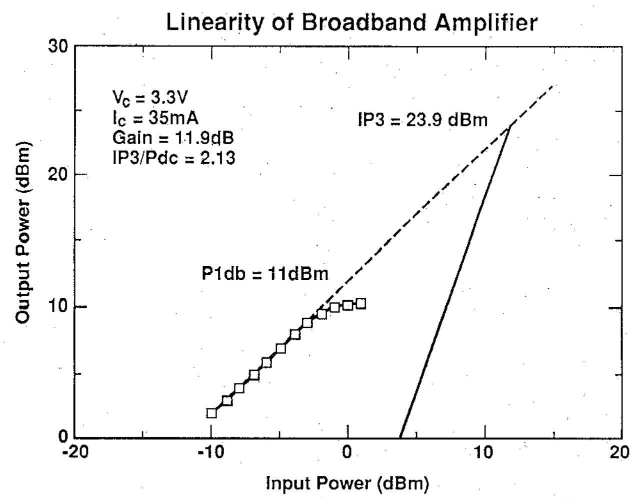

Fig. 4. Output power of fundamental frequency and third-order intermodulation product (IP3) intercept plot for the HBT feedback amplifier.

previously reported cascode HBT feedback amplifier [4], the bandwidth of input and output return loss are much better. The noise figure measured at 1 GHz was 5.7 dB, which is comparable to the previous reported results [3]. The measured output power as a function of input power, as shown in Fig. 4, has very good linearity with 1-dB compression output power of 11 dBm and third-order intercept point (IP3) of 23.9 dBm.

IV. Conclusion

A dc to 30 GHz broadband feedback amplifier implemented with AlGaAs-GaAs HBT technology was reported. The performance of this amplifier presents significant improvements over previously reported GaAs-based HBT wideband amplifiers. This high performance is achieved by the advanced device technology and optimization of circuit element value. The bandwidth of this amplifier is comparable to the cascode feedback design based on the AlInAs-GaInAs HBT technology. However, using shunt-series resistive feedback offers much better input and output matching to the 50-ohm systems than the cascode approach. Only one single-power supply is used to bias the whole circuit. In coupling with the extremely small size, this circuit could easily be inserted in various microwave and lightwave communication systems and instruments.

Acknowledgment

The authors thank G. I. Sullivan and C. W. Farley for material growth, and K. Steckbauer and E. Peterson for their contributions in processing. The circuit and system application inputs from Network Transmission System Division and Collins Avionic Division are gratefully appreciated.

References

[1] P. M. Asbeck, M. F. Chang, J. A. Higgins, N. H. Sheng, G. J. Sullivan, and K. C. Wang, "GaAlAs-GaAs heterojunction bipolar transistors: Issues and prospects for application," *IEEE Trans. Electron Devices*, vol. 36, no. 10, p. 2032, Oct. 1989.

[2] M. E. Kim, A. K. Oki, G. M. Gorman, D. K. Umemoto, and J. B. Camou, "GaAs heterojunction bipolar transistor device and IC technology for high performance analog and microwave applications," *IEEE Trans. Microwave Theory Tech.*, vol. 37, no. 9, pp. 1286-1303, Sept. 1989.

[3] K. W. Kobayashi, D. K. Umemoto, R. Esfandiari, A. K. Oki, L. M. Pawlawicz, M. E. Hafizi, L. Tran, J. B. Camou, K. S. Solt, D. C. Streit, and M. E. Kim, "GaAs HBT MMIC broadband amplifiers from dc to 20 GHz," in *IEEE Microwave and Millimeter-Wave Monolithic Circuits Symp. Dig.*, p. 19, 1990.

[4] M. Rodwell, J. F. Jensen, W. E. Stanchina, R. A. Metzger, D. B. Rensch, M. W. Pierce, T. V. Kargodorian, and Y. K. Allen, "33 GHz monolithic cascode AlInAs-GaInAs heterojunction bipolar transistor feedback amplifier," in *IEEE Bipolar Circuits and Technol. Meeting Dig.*, p. 252, 1990.

[5] M. F. Chang, P. M. Asbeck, K. C. Wang, N. H. Sheng, G. J. Sullivan, and D. L. Miller, "AlGaAS-GaAs heterojunction bipolar transistors fabricated using a self-aligned dual-lift-off process," *IEEE Electron Device Lett.*, vol. EDL-8, p. 303, 1987.

[6] W. J. Ho, M. F. Chang, N. H. Sheng, N. L. Wang, P. M. Asbeck, K. C. Wang, R. B. Nubling, G. J. Sullivan, and J. A. Higgins, "A multifunctional HBT technology," in *IEEE GaAs IC Symp. Dig.*, p. 67, 1990.

[7] C. T. Armijo and R. G. Meyer, "A new wide-band Darlington amplifier," *IEEE J. Solid-State Circuits*, vol. SC-16, p. 634, Dec. 1981.