Broadband Feedback Amplifiers with AlInAs/GaInAs Transferred-Substrate HBT

B. Agarwal, Q. Lee, R. Pullela, D. Mensa, J. Guthrie, and M. J. W. Rodwell

Abstract— **We report two broadband amplifiers with AlInAs/GaInAs transferred-substrate HBTs. A simple Darlington configuration with resistive feedback has 50 GHz 3-dB bandwidth, 10 dB gain. A variation of this basic amplifier, with a cascode output stage, has greater than 50 GHz 3-dB bandwidth, 10 dB gain. This high bandwidth is due to the high device bandwdith of transferred-substrate HBTs.**

Keywords— **HBT, transferred-substrate, InP, broadband, amplifiers.**

I. Introduction

HETEROJUNCTION bipolar transistors (HBTs) are used in a wide variety of medium-scale integrated circuits (ICs). For high performance circuits, the transistor cutoff frequencies must be larger than the circuit bandwidths by a factor varying from ∼ 5:1 for fiber-optic ICs to ∼ 1000:1 for high resolution ADCs. In particular, 100 Gbit/s optical systems will require devices with 200-300 GHz bandwidth and above. HBT bandwidths are increased by both vertical (epitaxial) and lateral (lithographic) scaling. The transferred-substrate HBT IC technology has demonstrated devices with very high bandwidths [1]. In addition to high device bandwidths, the technology incorporates a wiring environment with low capacitance, low ground-return inductance and efficient heat-sinking for closely spaced HBTs operating at high current densities. These features make this technology suitable for high performance ICs operating above 50 GHz.

Wideband amplifiers are used in fiber-optic transmission systems as pre-amplifiers and as gain blocks in the main AGC/limiting amplifier. High gain and high bandwidth are required for systems operating at high data rates. Simple feedback amplifiers with one or two stages and 50 Ω input/output impedances can be used [2]. These amplifiers are easy to design, build and test, and usually consume small die areas and power. A number of such amplifiers have been demonstrated in several different HBT technologies [3], [4], [5], [6]. The first demonstration circuit in the AlInAs/GaInAs transferred-substrate HBT IC technology, a Darlington feedback amplifier, was presented in [7]. In this paper we present two amplifiers. The first amplifier is a Darlington amplifier with series and shunt resistive feedback and 50 Ω input/output impedance. The measured gain of the amplifier is 10 dB and the 3-dB bandwidth is 50 GHz. The second amplifier is similar to the first, but has a cascode stage at the output which gives a small improvement in the bandwidth of the amplifier. The measured gain of this amplifier is 10 dB, and the 3-dB bandwidth is greater than 50 GHz.

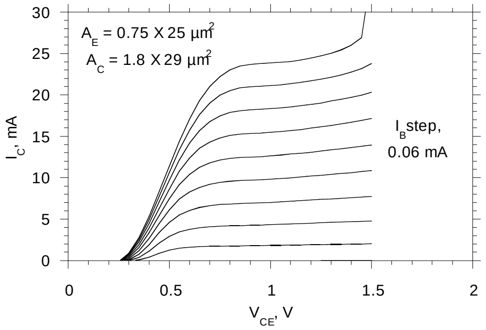

Fig. 1. DC common-emitter characteristics of device.

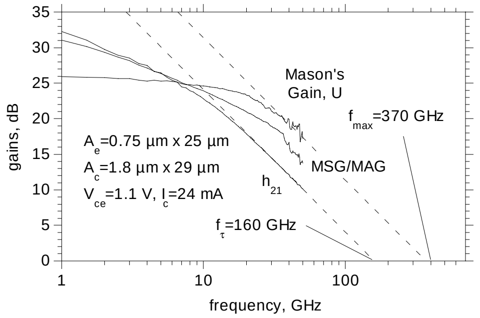

Fig. 2. RF characteristics of device.

II. Technology

The device technology used here is described in [1], where devices with 164 GHz f_τ and > 400 GHz f_{max} were reported. The MBE layer structure is similar but with a thinner base layer (400 Å). Devices with 0.75 μm wide emitters and 1.8 μm wide collectors were fabricated on this wafer. The common-emitter DC characteristics of the devices are shown in fig. 1. The small signal current gain at DC, β is 50. Fig. 2 shows the RF characteristics of the device. The extrapolated f_τ and f_{max} are 160 GHz and 370 GHz respectively, at the bias conditions shown.

III. Circuit Design

Figs. 3(a) and (b) show schematic circuit diagrams of the two amplifiers. The dotted line shows the chip boundary. In the first amplifier (fig. 3(a)), Q1-Q2 form the Darlington pair. The emitter stripe lengths of Q1 and Q2 are selected to maximize bandwidth. If the emitter stripe length of Q1 is large, its input capacitance is large, degrading bandwidth; if it is too small, its base and emitter resistances are large, increasing the driving impedance for Q2 and degrad-

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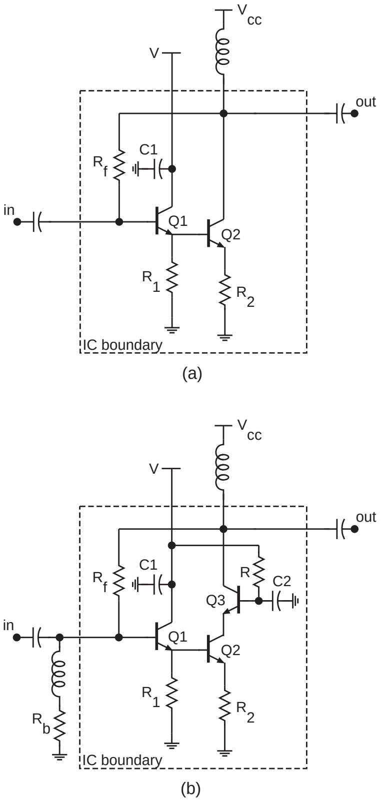

Fig. 3. Schematic circuit diagram of (a)Darlington feedback amplifier and (b)Darlington-cascode feedback amplifier.

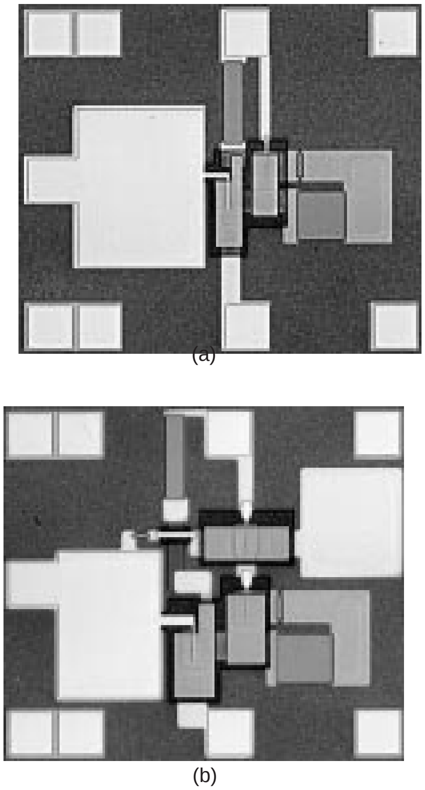

Fig. 4. Photograph of (a)Darlington amplifier IC and (b)Darlington-cascode amplifier IC (0.35 mm × 0.40 mm).

ing bandwidth. Large Q2 emitter stripe length increases its Miller-multiplied base-collector capacitance whereas a small emitter stripe length increases the base resistance, through which the (degenerated) device input capacitance must be charged. Hence, there are optimum emitter stripe lengths for Q1 and Q2. R_f, the shunt feedback resistor, is chosen to provide an input impedance of 50 Ω. R_1 is the series feedback resistor in the emitter of Q1 and sets the Q1 emitter current density close to peak f_τ bias. R_2 sets the degenerate transconductance of Q2 (and hence of the circuit) to provide the desired gain and 50 Ω output impedance.

The circuit is biased with V_{CC} and an off-chip resistor connected through a bias-tee at the output. The collector of Q1 is not connected to the output, but is biased with and independent supply to eliminate Miller multiplication of its base-collector capacitance. C1 is a bypass capacitor for the collector of Q1. The amplifier was designed for 10 dB gain and 50 GHz bandwidth.

The second amplifier (fig. 3(b)) has an additional transistor Q3, cascode connected with Q2 at the output. This configuration reduces the effect of the Miller-multiplied C_{cb} of Q2 and hence improves bandwidth. The base of Q3 is biased through the same supply as the collector of Q1. R_b forms a voltage divider network with R_f, to bias the base of Q1 at the desired voltage. It is externally connected because of the limited current capacity of on-chip resistors. The amplifier was designed for 10 dB gain and 65 GHz bandwidth. The power consumption of the two ICs are 40 mW and 64 mW respectively. Fig. 4 shows photographs of the amplifiers. The chip dimensions are 0.35 mm × 0.4 mm for both amplifiers.

IV. RESULTS

The amplifiers were characterized using a 45 MHz - 50 GHz network analyzer and microwave wafer probes. Fig. 5 shows the forward gain s_{21} of the amplifiers. The Darlington amplifier has a low frequency gain of 10 dB and a 3-dB bandwidth (relative to the low-frequency gain) of 50 GHz. The Darlington/cascode amplifier has similar gain but showed severe gain peaking. Fig. 6 shows the input and output return losses and reverse isolation of the Darlington amplifier. It is observed that both amplifiers exhibit strong gain peaking and poor input return losses at

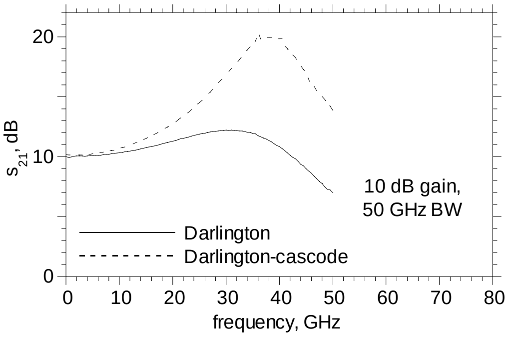

Fig. 5. Measured forward gain s_{21} of the amplifiers.

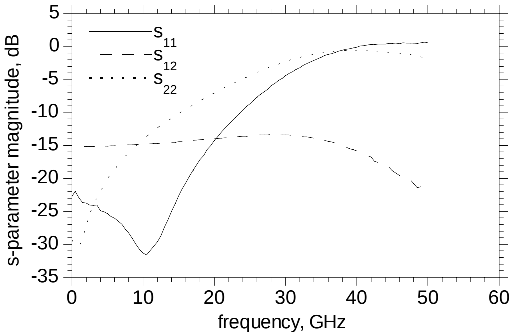

Fig. 6. Measured input return loss s_{11}, output return loss s_{22}, and reverse isolation s_{12} of the Darlington amplifier.

high frequencies. This is a result of the parameters of the transferred-substrate HBT. Q1, an emitter follower driving the input capacitance of Q2, has an input impedance whose real part is negative at some frequencies. The resulting resonance - observed in both gain (s_{21}) and input impedance (s_{11}) - becomes progressively more severe as the base resistances (r_{bb}) of Q1 and Q2 are reduced. The low base resistance and collector-base capacitance of transferred-substrate HBTs strongly enhance this negative-resistance peaking. Recent design studies indicate that the gain peak can be suppressed - and the bandwidth increased - by the use of f_τ-doublers [8] or mirror-Darlington [5] configurations. ICs based on these topologies are now in fabrication.

V. Conclusions

We have demonstrated resistive feedback amplifiers with AlInAs/GaInAs transferred-substrate HBTs. Both a simple Darlington stage and a Darlington-cascode stage achieve 10 dB gain and 50 GHz or greater bandwidth. Strong resonances in the gain and the input impedance arise from the high f_{max}/f_τ ratio of the transferred-substrate HBTs, and limit the usable bandwidths. For HBTs with a high f_{max}/f_τ ratio, resonances are suppressed by the use of the f_τ-doubler configurations. This is expected to improve bandwidth to the 100 GHz range. Applications are in wideband microwave and digital communication systems.

Acknowledgments

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