A 74-GHz Bandwidth InAlAs/InGaAs-InP HBT Distributed Amplifier with 13-dB Gain

Y. Baeyens, R. Pullela, J. P. Mattia, H.-S. Tsai, and Y.-K. Chen

***Abstract*— To date, distributed amplifiers based on heterojunction bipolar transistors (HBT's) have consistently shown lower gain-bandwidth products than their high electron mobility transistor (HEMT) counterparts. By using improved design techniques, we report in this letter a single-stage distributed amplifier with 13-dB gain and 74 GHz 3-dB bandwidth, based on InAlAs/InGaAs-InP HBT's with 160-GHz fT and 140-GHz $f_{\max}$. The high gain and bandwidth results in a gain-bandwidth product of 330 GHz, which is, to our knowledge, the highest reported for HBT-based amplifiers and rivals that of the best InP HEMT distributed amplifiers with e-beam written gate of 0.1–0.15 μm dimension.**

***Index Terms*— Distributed amplifiers, HBT, millimeter-wave bipolar transistor amplifiers, MMIC's.**

I. Introduction

Ultra-wideband amplifiers find various applications as baseband amplifiers in high-speed lightwave systems and as gain blocks in millimeter-wave communication and sensor systems or in wideband instrumentation. By incorporating the active device capacitances into artificial transmission lines, distributed amplifiers provide for these applications the largest gain-bandwidth (GBW) products, together with a lower input and output reflection.

To date, the highest gain-bandwidth products for distributed amplifiers have been obtained using InP-based high electron mobility transistors (HEMT's) with ultrashort gatelengths. Pusl *et al.* demonstrated a capacitive-division 0.15-μm-gate-length InAlAs/InGaAs/InP HEMT distributed amplifier with 11-dB gain up to 96 GHz, resulting in record gain-bandwidth product of 340 GHz [1]. Kimura *et al.* reported a 90-GHz bandwidth amplifier with 10-dB gain (GBW $=$ 300 GHz) using 0.1-μm-gate-length InAlAs/InGaAs/InP HEMT's, optimized for application in high-speed optical data transmission [2].

Circuits based on heterojunction bipolar transistor (HBT) technology are attractive for lightwave systems, as they allow baseband operation without level shifting diodes or multiple threshold voltages. Additionally, InP HBT technology provides an easy way to integrate long-wavelength p-i-n photodiodes [7], enabling fully integrated optoelectronic integrated circuit (OEIC) receivers. However, distributed HBT amplifiers which were reported in literature have consistently shown lower gain bandwidth products then their HEMT counterparts. The main reason for this is the lower $f_{\max}$ of HBT's leading to increased attenuation along the in- and output artificial transmission lines. Kobayashi *et al.* reported a 55-GHz bandwidth amplifier with a midband gain of about 6 dB (GBW $=$ 110 GHz) [3]. More recently, Agarwal *et al.* reported a 6.7-dB gain distributed HBT amplifier with a 85-GHz 3-dB bandwidth using a transferred substrate HBT technology with 400-GHz $f_{\max}$ [4], resulting in a for HBT's record gain-bandwidth product of 183 GHz.

In this letter, we report a distributed HBT amplifier with both a high gain and bandwidth and show for the first time that, using improved design techniques such as an *RC* emitter degeneration network, HBT distributed amplifiers can have comparable gain-bandwidth products as HEMT versions.

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II. Circuit Design

The schematic circuit diagram of the distributed HBT amplifier is shown in Fig. 1. The amplifier consists of four identical cells. Each active cell is composed of a cascode gain stage consisting of a common-emitter HBT (Q1 in Fig. 1) and a common-base HBT (Q2). Both HBT's have 1 μm by 5 μm emitter dimensions. While cascode stages are often used in the design of HEMT distributed amplifiers to reduce the output attenuation caused by the relatively high output conductance of the short gatelength HEMT's [5], in distributed amplifiers based on HBT's, the cascode topology mainly helps to lower the effect of the base–collector Miller capacitance on the total input capacitance.

To lower the attenuation of the resistive input impedance of the HBT on the artificial input transmission line and to improve linearity, resistive emitter degeneration was applied for the common-emitter HBT. The emitter degeneration resistor (R1 in Fig. 1) is shunted with a small MIM capacitor (C1) to extend the bandwidth of the amplifier by reducing the input line attenuation.

Peaking lines at the output of the active cells were used to further improve the amplifier bandwidth and roll-off characteristic. Two different circuits were fabricated: one with long peaking lines (L_{peak} in Fig. 2 equal to 200 μm) and one with relatively short lines (L_{peak} is 100 μm). For the circuit with the longest peaking lines excessive gain and group delay peaking near the output line cutoff frequency was observed. As this peaking would lead to a strong degradation of the digital signals, only the amplifier with $L_{\text{peak}} = 100$ μm will be discussed.

Fig. 2 shows a chip photograph of the distributed amplifier. Low-inductance grounding is important for the amplifier bandwidth. Therefore, the circuit is implemented using coplanar

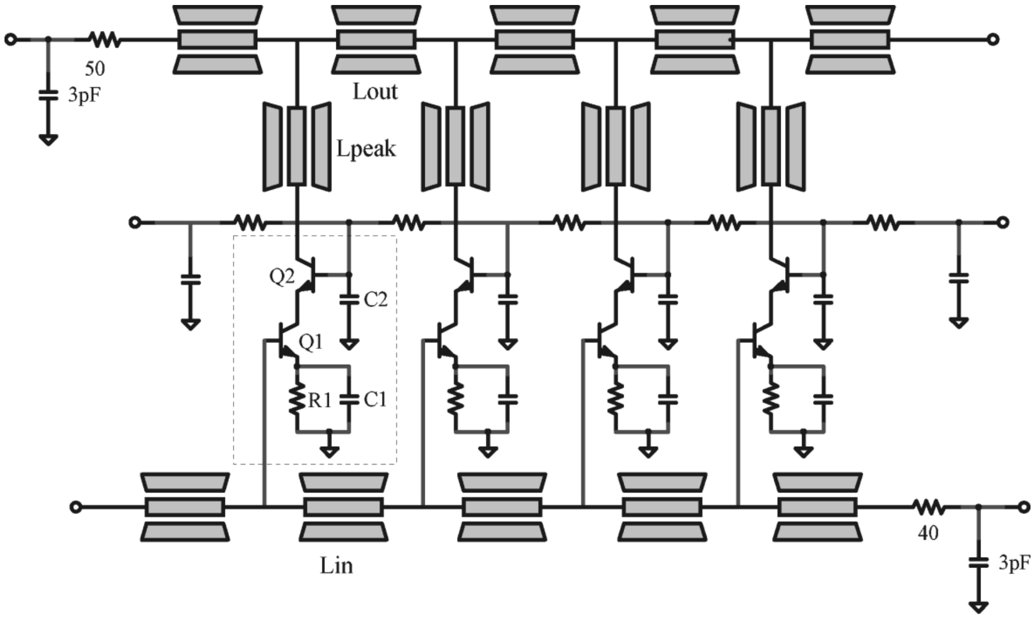

Fig. 1. Circuit diagram of the four-stage distributed HBT amplifier.

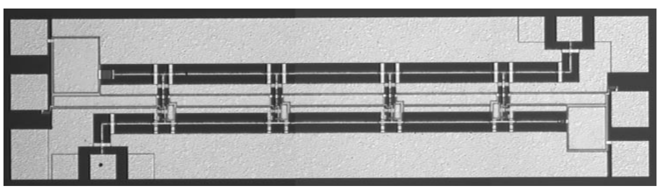

Fig. 2. Chip photograph of the coplanar distributed amplifier.

waveguide lines with a narrow ground-to-ground spacing of 60 μm and a conductor width of 10 μm. As any series inductance between the input line and the input of the active cell would seriously degrade the bandwidth of the amplifier, the active cell including emitter degeneration network was placed as close as possible to the center conductor of the coplanar transmission line. The total chip size including radio frequency (RF) and dc pads and bias networks is 1.7 mm $\times$ 0.45 mm.

The output line was terminated by the combination of a 50-Ω resistor and a 3-pF on-chip shunt capacitor. A slightly lower value of 40 Ω was chosen for the input line termination resistor. When using this circuit as an optical preamplifier coupled with a photodiode, a lower input impedance will increase the *RC* bandwidth.

III. Results and Discussion

The distributed amplifier was realized in a all-optical lithography single-heterojunction AlInAs/InGaAs HBT foundry process developed and fabricated at HRL Laboratories in Malibu, CA [6]. HBT's with 1 μm by 3 μm emitter dimensions, measured on the same wafer as the amplifier, show a maximum cutoff frequency f_T of 160 GHz and a maximum oscillation frequency $f_{\max}$ of 140 GHz.

On-wafer measurements on the amplifier were performed using a single-sweep 45 MHz–110 GHz HP8510XF network analyzer and 1-mm coaxial probes. The measured

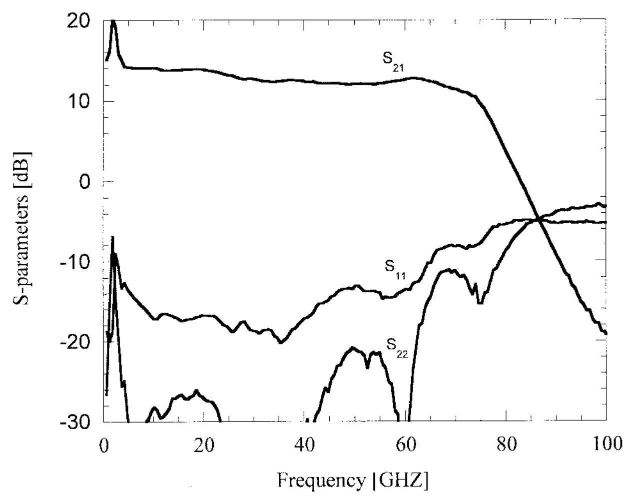

Fig. 3. Measured S-parameters of the distributed amplifier for a total bias voltage of 3 V and a bias current of 40 mA.

S-parameters for a total bias voltage of 3 V and a total bias current of 40 mA are shown in Fig. 3. This bias current corresponds to an emitter current density of 200 kA/cm^2. A gain of 13 dB with a flatness of about 1 dB is obtained up to 70 GHz. The 3-dB bandwidth of the amplifier is 74 GHz. Additionally, a low in- and output reflection is obtained across the band. The output reflection coefficient is lower than -20 dB up to 60 GHz . Due to the input impedance of 40 Ω, the input reflection coefficient is slightly higher, but still lower than -10 dB up to about 70 GHz. Large-signal characterization in a 50-Ω system, performed up to 40 GHz, shows a maximum saturated output power for the distributed amplifier of about 10 dBm.

A small resonance peak around 3 GHz can be observed in the on-wafer measurements. This peak is caused by a parallel resonance between the 3-pF on-chip shunt MIM capacitances, used for ac grounding the 50-Ω termination resistors, and the inductance of the dc-needles. This was verified both by simulation using a model for the dc probes provided by the vendor and by lifting the dc needles and measuring the amplifier directly through the RF probes using a bias network. The low-frequency resonance could be avoided by a low-inductance packaging of the chip, by inserting a small series resistor between the on- and off-chip capacitors or by using active loads, demonstrated in [3].

IV. Conclusions

Using a coplanar layout and *RC* emitter degeneration networks, a compact InP-based HBT distributed amplifier with a high gain-bandwidth product of 330 GHz was realized. This amplifier will find a useful application as a pre-amplifier in future lightwave systems. While lightwave systems currently under development are operating at 40 Gb/s, next-generation systems will operate at data rates up to 80 or even 160 Gb/s. Typically, a bandwidth of at least 70% is needed to amplify nonreturn-to-zero (NRZ) signals without significant degradation of the pulse shape. Based on this ratio, the amplifier should be capable of amplifying 100-Gb/s NRZ data.

Only optical lithography was used in the fabrication of this amplifier, making it potentially cost-effective compared to HEMT technology with e-beam written gate. Integration of the long-wavelength photodiode using the HBT base–collector capacitance could further increase the functionality [7]. Simulations predict a transimpedance of 45 dBO with 70-GHz bandwidth, when using the amplifier in combination with a p-i-n photodiode having a parasitic capacitance of 50 fF, clearly showing the potential of the amplifier for optoelectronic integration.

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