A Novel Heterojunction Bipolar Transistor Active Feedback Design

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Abstract—**This paper reports on the results of a novel active feedback amplifier design using Heterojunction Bipolar Transistors. The design incorporates positive feedback to increase the gain bandwidth response by as much as 50 %. The active feedback amplifier achieves a gain of 13.8 dB and a 3-dB bandwidth of 15.6 GHz. The active feedback is economical in size in comparison to a spiral inductor implementation. In addition, the active feedback network includes a means for electronically tuning the active feedback circuit in order to adjust the bandwidth response. A two-stage design achieves a tuneable bandwidth from 4–10 GHz with a fixed gain of 20 dB. The tuneability that this design offers is a convenient means for recovering from gain and bandwidth degradation due to process variation and fixture parasitics.**

I. Introduction

Active-inductor topologies have previously been developed in order to economically implement monolithic inductive elements [1], [2]. These developments have lead to amplifier circuits that incorporate frequency dependent active loads. The active loads provide gain peaking in amplifier circuits that enhance the gain-bandwidth performance. However, the use of these active networks has not been demonstrated in an amplifier feedback loop.

This work describes an HBT amplifier that uses an active feedback circuit based on the active impedance circuits previously developed. The frequency dependence of the active feedback provides positive feedback to the amplifier circuit, increasing its bandwidth performance. Furthermore, the active feedback design of this work has the additional capability of electronically shaping the gain response through a tuning voltage, which is convenient for in-hybrid tuning of the circuit.

The following sections will describe the performance and design techniques of the active HBT feedback amplifier, which was fabricated using InAlAs/InGaAs HBT technology.

II. InAlAs/InGaAs HBT Process

The InAlAs/InGaAs HBT process and MBE growth have been previously described in detail elsewhere [3], [4]. The MBE profile incorporates a base thickness of 1000 Å, uniformly doped to 2x10^{19} cm^{-3}, an n^- collector 7000 Å thick and lightly doped to 5x10^{15} cm^{-3}, and an n+ subcollector doped to 2x10^{19} cm^{-3}. The base-emitter junction is compositionally graded using a quarternary layer of In_{1-x-y} Ga_x Al_y between the base and the emitter. A 1-μm fully self-aligned HBT process was used to fabricate the transistors. The resulting HBT's achieve an f_T and fmax of 60 and 110 GHz, respectively, for a 1x10 μm^2 single-emitter HBT device at a $J_c \simeq 40 - 50kA/cm^2$.

Manuscript received January 26, 1994.
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IEEE Log Number 9401066.

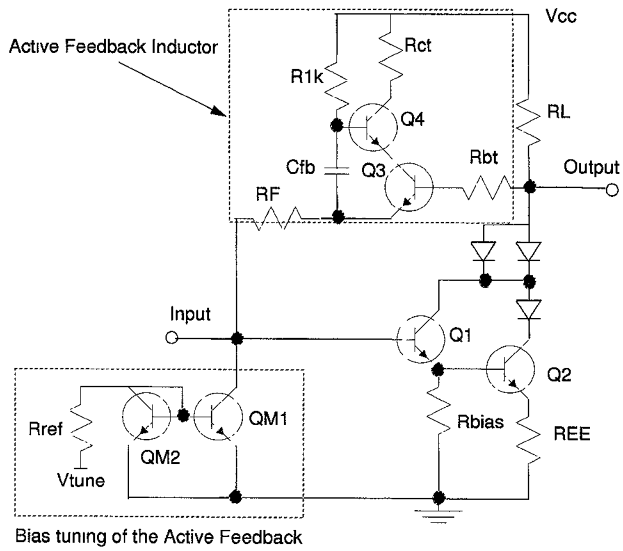

Fig. 1. Schematic of the Active feedback Darlington amplifier.

III. Active Feedback Design

The circuit schematic of the newly developed single-stage HBT active feedback amplifier is shown in Fig. 1. This design uses a patented active feedback network [5]. The basic amplifier consists of a Darlington stage made up of transistors Q_1, Q_2, series feedback resistor Ree, bias resistor Rbias, and level shifting diodes. The shunt feedback is comprised of the active feedback network. This network consists of cascode connected transistors Q_3 and Q_4, which provide the active impedance characteristics, and feedback resistors R_F and R_{bt}. Additional blocking capacitor C_{fb}, and resistors R_{1k} and R_{ct} complete the active feedback network. Feedback resistor R_F provides the basic resistive impedance of the feedback loop, while resistor R_{bt} is instrumental in setting the frequency dependent characteristics of the active feedback network. A current source mirror comprised of transistors Q_{m2} and Q_{m3}, and resistor R_{ref} is used to bias the active feedback network. It can be shown that the active feedback characteristics are dependent on the quiescent current flowing through transistors

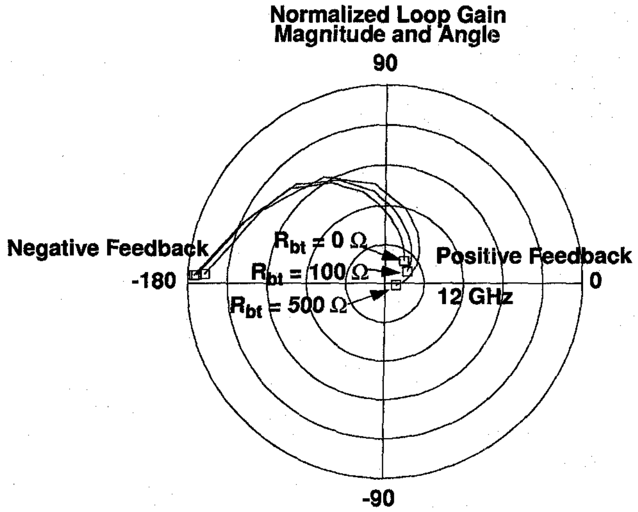

Fig. 2. Normalized loop gain magnitude and phase response for three values of R_{bt}: R_{bt} = 0 Ω, R_{bt} = 100 Ω, and R_{bt} = 500 Ω.

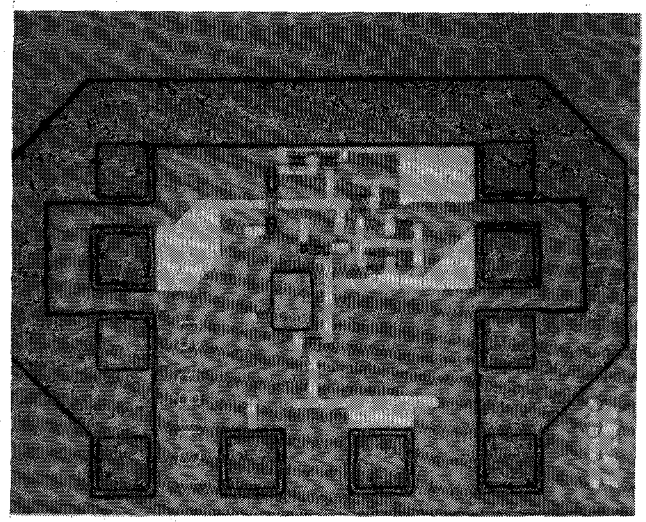

Fig. 3. Micro-photograph of the fabricated active feedback amplifier. The chip size is 0.73x0.5 mm^2.

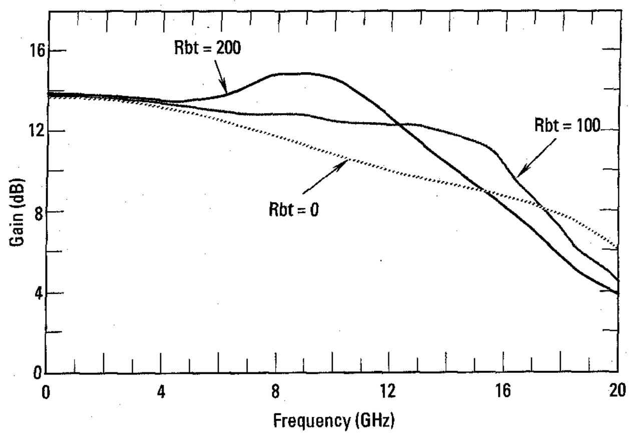

Fig. 4. Measured gain response for three values of tuning resistor R_{bt}: R_{bt} = 0 Ω, R_{bt} = 100 Ω, and R_{bt} = 200 Ω.

Q_3 and Q_4. By employing this currrent mirror bias scheme for the active feedback network, the circuit has the additional capability of adjusting the bandwidth electronically. This gives the degree of freedom to adjust the gain response, which might have been degraded by process variations or stray package parasitics that were not accounted for in the MMIC design.

By adjusting the value of R_{bt} of the active feedback circuit, the amount of positive feedback can be adjusted. Fig. 2 shows a polar plot of the normalized voltage gain (S_{21}) magnitude and phase of the active feedback network for various values of R_{bt}. Positive feedback on this chart is represented by a magnitude of normalized voltage gain (S_{21}) that is in phase (0°) with the incident voltage at the input of the amplifier. For larger R_{bt}, the effective positive feedback is enhanced. This is illustrated by the phase of the active feedback network, which approaches 0° at the upper band edge (12 GHz) for larger R_{bt}.

A microphotograph of the fabricated HBT active feedback amplifier is shown in Fig. 3. Due to the implementation of the active feedback, an optimal bandwidth response can be realized without the use of area-consuming spiral inductors. The total chip size of the prototype design is 0.73x0.5 mm^2. However, this can significantly be reduced to 0.45x0.4 mm^2 by eliminating the on-wafer R_F probe pad configuration. In comparison, a 2-3 nH square-inductor consumes an area of as much as 0.18x0.18 um^2.

IV. Measured Results

The gain response of three different active feedback amplifiers, each employing different values of R_{bt}, was measured. The amplifiers are biased with a 7-V supply and consume 33.7 mA each. The tuning voltage was fixed at 5 V for all three cases. Fig. 4 shows the measured wideband gain response for R_{bt} equal to 0 Ω, 100 Ω, and 200 Ω. In all three cases, the nominal low frequency gain was about 13.8 dB. The three cases show that the shape and bandwidth of the gain response can be adjusted by varying tuning resistor R_{bt} of the active feedback network. For an R_{bt} = 0 Ω, the gain rolls off linearly with frequency above 4 GHz, and the 3-dB bandwidth is about 9.5 GHz. For R_{bt} = 100 Ω, the gain response is wider and flatter with a 3-dB bandwidth of 16 GHz. This is an improvement of greater than 50% over the case where R_{bt} = 0 Ω. For an R_{bt} = 200 Ω, positive feedback is more pronounced and peaking is observed at about 10 GHz with a gain peak of about 1 dB. The 3-dB bandwidth in this case is 14 GHz.

In addition, a 2-stage amplifier was also measured. Fig. 5 shows the gain response of the amplifier at various tuning voltages, V_{tune}. The tuning voltage ranged from 2–7 V. This plot shows the electronic tuneability of the gain bandwidth response that is a function of bias current through the active feedback network. The nominal low frequency gain is 20 dB, while the upper band-edge can be tuned from 4 GHz to above 10 GHz. The bandwidth tuning capability is attractive for multi-stage amplification that is especially sensitive to gain roll-off due to cascading stages.

V. Conclusion

A novel active feedback technique was developed that can economically enhance the bandwidth performance of Si-BJT and HBT feedback amplifiers. A single-stage HBT

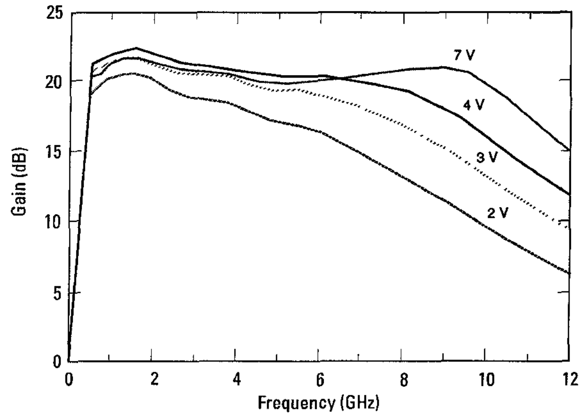

Fig. 5. Measured two-stage amplifier gain response for various values of tuning voltage, V_{tune} = 2, 3, 4, and 7 V.

active feedback amplifier was fabricated and measured, and it exhibited 50% bandwidth improvement by using the new technique. A 2-stage amplifier demonstrated the electronic tuning capability of the active feedback network. The active tuneable feedback can be attractive for in-hybrid gain response tuning of multi-stage cascaded amplifiers.

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