# A Novel Compact Monolithic Active Regulated Self-Biased InP HEMT Amplifier

K. W. Kobayashi, *Member, IEEE,* R. Lai, G. I. Ng, *Member, IEEE,* K. L. Tan, *Member, IEEE,* R. Esfandiari, D. C. Streit, *Senior Member, IEEE,* and J. B. Berenz

***Abstract*— This letter reports on the first results of a monolithic active regulated self-biased HEMT amplifier fabricated in InP technology. The self-bias scheme incorporates an op-amp-based HEMT regulator topology that regulates the bias current to within 6% over a threshold variation of ±0.2 V. The dc yield based on this performance criteria was 75% across a wafer. The InP HEMT amplifier achieves an rf gain of 10-dB and a 3-dB bandwidth of 1–14 GHz. Across a wafer with a total threshold variation of 0.4 V, the gain variation was maintained to less than ±1 dB. The compact integrated HEMT regulated amplifier circuit was realized using area-efficient analog design techniques that consumed less than 1.3 × 1.1 mm². This demonstration has far-reaching implications to the producibility and reliability of InP HEMT MMIC's.**

## I. Introduction

A MAJOR insertion challenge for HEMT MMIC's is the requirement for a self-biasing scheme that is tolerant of threshold voltage variation over process and temperature. Conventional resistive self-bias as well as active current source topologies exist, however they are only capable of regulating the bias current to ±20% over a typical on-wafer threshold variation of ±0.2 V. In addition, the FET current source topology requires a depletion mode device, whereas low-noise HEMT devices are usually enhancement mode at their low-noise bias point.

Previously, a monolithic HEMT active regulated low noise amplifier has been fabricated using InGaAs HEMT's and has demonstrated ±3% current regulation over a threshold variation of 0.5 V [1]. This regulated amplifier also achieved a 1.5% current regulation over a 25–125°C temperature range. Because of the higher transconductance, the sharper threshold characteristics, and the lower breakdown voltages of InP HEMT's, a monolithic InP HEMT regulator design is more challenging.

A new monolithic bias regulation scheme has been adapted to operate with the high transconductance (bias sensitivity) and low breakdown characteristics of InP HEMT's. The regulator design has been integrated with an analog wideband amplifier topology that compacts high performance into a small area. This amplifier topology could be used as a transimpedance amplifier for light-wave applications as well as a generic, low cost gain block for microwave receiver applications. The following sections will describe the performance and design of the active regulated self-biased InP HEMT amplifier chip.

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The authors are with TRW Electronic and Technology Division, Redondo Beach, CA 90278 USA.

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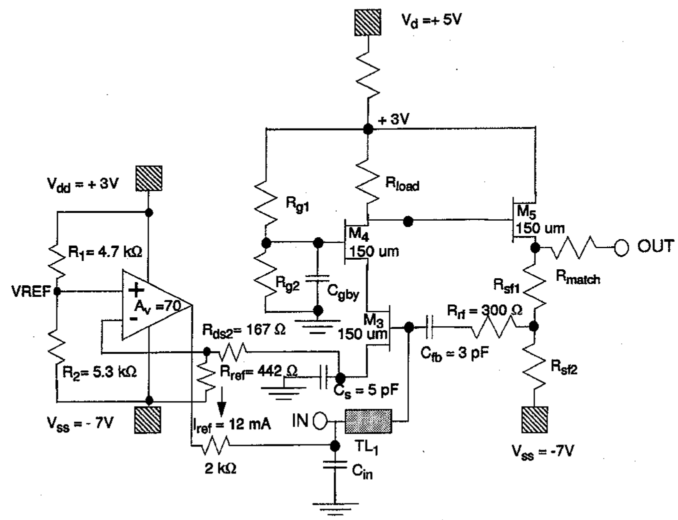


Fig. 1. Schematic of the HEMT regulator integrated with a microwave-analog amplifier.

## II. Monolithic Active Bias-Regulated Amplifier Design

The MMIC amplifier was fabricated using 0.2-μm gate length InGaAs/InAlAs/InP HEMT technology because of its high gain, frequency, and low dc power performance. The 0.2-μm gate length InP HEMT's typically exhibit a transconductance greater than 800 mS/mm and cutoff frequencies greater than 100 GHz. This makes them attractive for wideband and low power amplification. Details of the epitaxial layer design, growth, and fabrication processes are described elsewhere [2].

The design schematic of the integrated HEMT regulator and amplifier is shown in Fig. 1. A patent is pending on this monolithic HEMT regulated self-biased amplifier [3]. The basic amplifier circuit consists of a cascode input stage cascaded with a source follower stage. The cascode stage is made up of transistor pair $M_3$ and $M_4$, load resistor $R_{\mathrm{load}}$, and a bias network for the common gate HEMT. The follower stage consists of HEMT $M_5$, output resistance $R_{\mathrm{match}}$, and biasing resistor $R_{\mathrm{sf2}}$. The output VSWR is controlled by the value of $R_{\mathrm{match}}$. Resistor $R_{\mathrm{rf}}$ and capacitor $C_{\mathrm{fb}}$ provide feedback that is adjusted for rf bandwidth. A transmission line $TL_1$ and input

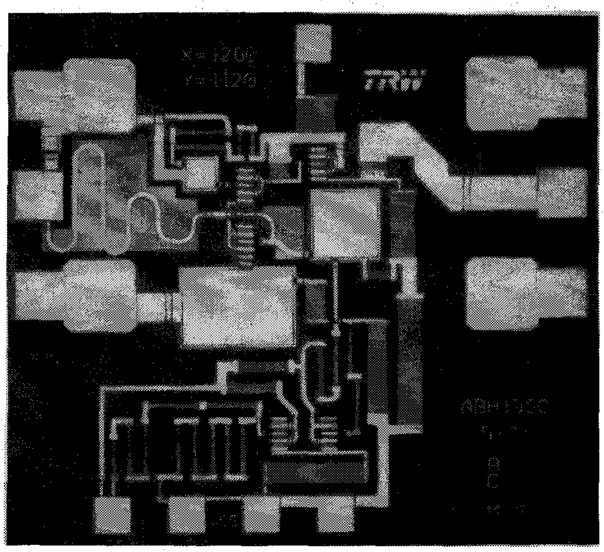

Fig. 2. Microphotograph of the InP HEMT monolithic regulated amplifier. The chip size is $1.3 \times 1.1$ mm$^2$.

shunt capacitance $C_{\text{in}}$ are used to match the cascode input for noise figure and return-loss performance.

The bias current of the cascode pair is regulated using a HEMT differential amplifier (opamp). The opamp mirrors a voltage reference $V_{\text{ref}}$ set up by resistors $R_1$ and $R_2$ across a reference resistor $R_{\text{ref}}$. This sets up a regulated current source on the source terminal of HEMT transistor $M_3$. A current source could also be set up on the drain of HEMT transistor $M_4$, however this scheme requires larger HEMT breakdown voltages which are not characteristic of InP HEMT devices. A bypass capacitor $C_s$ provides an AC ground. The general function of the regulator bias scheme is to provide a fixed current source which is tolerant of threshold variation due to process and temperature. The HEMT regulator requires a HEMT breakdown voltage of greater than 2 V and a threshold voltage uniformity within $\pm 0.5$ V for proper operation.

A microphotograph of the fabricated regulated HEMT MMIC is shown in Fig. 2. The chip layout is very compact and is typical of an analog design. Microwave-microstrip proximity effects were observed to have minimal impact on the performance. The total amplifier chip size is less than $1.3 \times 1.1$ mm$^2$, with the regulator circuit consuming only 25% of the chip. Relative to typical microwave designs, the area consumed by the regulator can be as small as 5–10%.

## III. Measured Results

Fig. 3 shows the typical gain and return-loss response of the monolithic regulated InP HEMT amplifier. The amplifier has a gain of 10 dB and a 3-dB bandwidth from 1–14 GHz. At 10 GHz, the on-wafer variation in gain was less than $\pm 1$ dB. This variation is primarily attributed to rf variations in the HEMT device due to fabrication. The amplifier can be biased with a $+5$ V or a $+3$ V supply and consumes 25 mA. The regulator circuit is biased with $+3$ V and $-7$ V supplies and consumes 12 mA. The regulator can be optimized for lower current and power consumption operation.

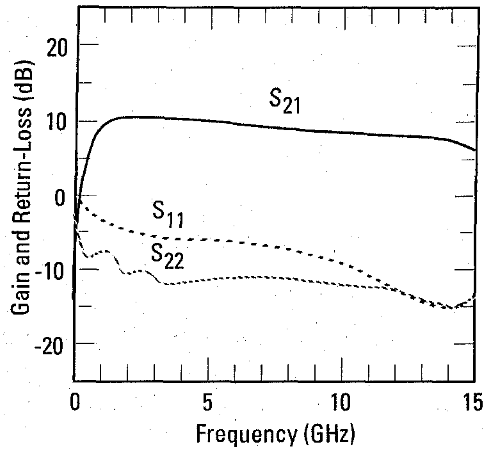


Fig. 3. Wideband gain and return-loss performance.

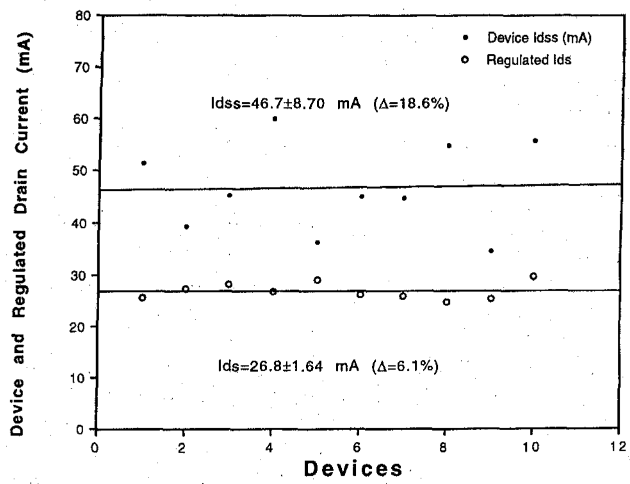


Fig. 4. HEMT device and MMIC bias current across a wafer. (■) $I_{\text{dss}}$ of a 200-$\mu$m HEMT. (o) $I_d$, the actively regulated bias current of the MMIC.

The bias regulation performance of the MMIC is compared to the HEMT device $I_{\text{dss}}$ variation across the wafer. HEMT $I_{\text{dss}}$ variation is representative of the performance variation of an active HEMT current source biasing scheme, where the gate and source of the HEMT are shorted together. Fig. 4 shows the scatter plots of $I_{\text{dss}}$ (at zero gate bias) for a 4-finger 200-$\mu$m InP HEMT and the measured current of the InP HEMT amplifier. The average $I_{\text{dss}}$ of the HEMT is 46.7 mA with a standard deviation of 8.7 mA, which corresponds to 19% deviation. The total InP HEMT amplifier bias current varies much less and is comprised of the regulated current of the cascode ($M3$ & $M4$) and the unregulated current of the source follower ($M5$). The amplifier current ranged from 25.5–29 mA, which corresponds to an average value of 26.8 mA, close to the design value of 27 mA. The standard deviation of the amplifier current is 1.64 mA, only 6% of the average value. The dc functional yield was 75%, while the rf yield was 50% across the wafer. The regulator bias scheme reduces the total bias current variation by a factor of 3 over the active HEMT current source implementation. This improvement would be significantly better if the source-follower stage was also regulated, however the overall amplifier rf performance is not very sensitive to the bias current variations in the source-follower output stage.

## IV. Conclusion

An InP HEMT amplifier incorporating a monolithically integrated InP HEMT active regulator has been demonstrated for the first time. The active regulator can regulate the bias current to 6% over a threshold variation of $\pm 0.2$ V. The rf gain variation is controlled to within $\pm 1$ dB. The HEMT regulator bias scheme can be integrated with other InP HEMT IC's to improve the MMIC performance and reliability, as well as to reduce the cost and weight of the integrated microwave assembly (IMA).

## References


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[3] K. W. Kobayashi, "Compact Monolithic Wideband HEMT Low Noise Amplifiers with Regulated Self-bias," patent pending, TRW docket no. 12-0600.