A Wideband HEMT Cascode Low-Noise Amplifier with HBT Bias Regulation

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***Abstract*—We have achieved broadband low-noise performance and dc bias regulation in a single compact HEMT-HBT MMIC. The self-biased MMIC achieves greater than 13 dB gain from 1–8 GHz with a noise figure of less than 1.9 dB across the band and a minimum noise figure of 1.6 dB. The MMIC consists of a HEMT cascode first stage and a source-follower output stage, with shunt feedback between the stages to obtain good broadband noise figure and gain performance. Bias regulation is realized by monolithically integrating an HBT current regulator with the HEMT LNA using selective MBE. This is the first microwave demonstration of key monolithic HEMT-HBT circuit functionality combined with state-of-the-art low-noise figure performance, realized in a miniature 0.9×1.0 mm^2 MMIC.**

I. Introduction

The development of selective molecular beam epitaxy has allowed the monolithic integration of HEMT and HBT devices on the same chip without degrading the performance of either device [1]. A complex integrated microwave assembly (IMA) consisting of multiple MMIC's, wirebonds, dc regulators, and silicon components can now be replaced by a single HEMT-HBT MMIC chip. A 25:1 reduction in size and a 30:1 reduction in part count can be obtained by monolithically integrating dc regulation with HEMT low-noise amplifiers [2]. This significantly reduces the cost of hybrid integration and assembly. It also increases the reliability of the hardware due to the reduced number of discrete components and the simplified reliability qualification process. The end result is a smaller, lighter, less expensive, and more reliable IMA, which in turn leverages the performance of satellite electronic payloads using HEMT-HBT MMIC's.

Monolithic integration of an HBT current regulator with a HEMT LNA has been previously reported [3]. This benchmarked the first functional HEMT-HBT MMIC and demonstrated the advantages of HBT bias regulation. The LNA used parallel feedback and passive matching to achieve respectable noise figures of 2.5–3.5 dB from 1–10 GHz. We report here a compact HBT-regulated HEMT cascode LNA that achieves state-of-the art performance, with greater than 13 dB gain and 1.6–1.9 dB noise figure from 1–8 GHz. This is the best performance yet reported for this new HEMT-HBT technology, and is comparable to other HEMT-only self-biased MMIC's of equivalent frequency performance [4], [5].

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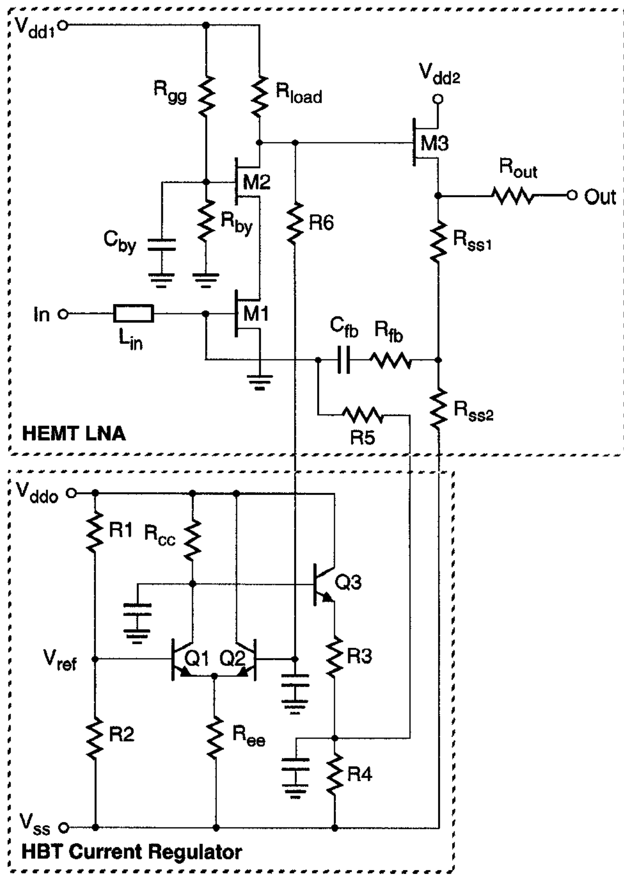

Fig. 1. Schematic of the HBT-regulated HEMT cascode low-noise amplifier.

II. Selective MBE and Merged HEMT-HBT Process

The HEMT-HBT monolithic integration was realized using selective MBE and a merged HEMT-HBT process, which has been documented in detail [1]. This technology integrates 0.2 μm gate-length pseudomorphic InGaAs-GaAs HEMT's with 2 μm emitter-width GaAs-AlGaAs HBT's. The HEMT devices achieve $g_m > 500$ mS/mm with $f_T \sim 60$ GHz. The HBT devices achieve $\beta = 60$, with f_T and $f_{\max}$ of 23 GHz and 50 GHz, respectively, at a current density $J_c = 20$ kA/cm^2. The monolithically integrated HEMT and HBT devices have demonstrated dc and microwave performance equivalent to that of baseline single-technology devices.

III. HBT Regulated HEMT Cascode LNA

The schematic of the HBT regulated HEMT cascode low-noise amplifier is shown in Fig. 1. The core of the HEMT LNA

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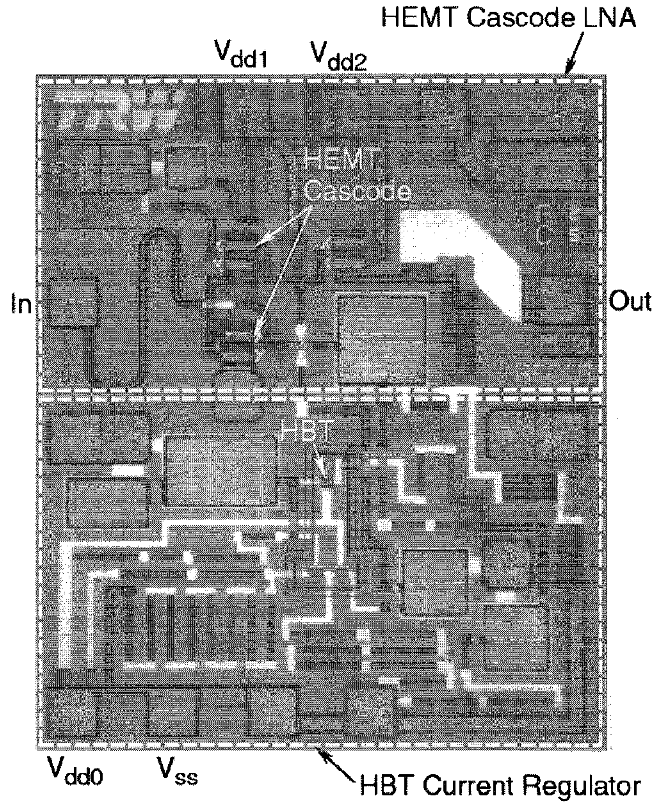

Fig. 2. Microphotograph of the HBT regulated HEMT LNA. The total chip size is 0.9×1.0 mm^2.

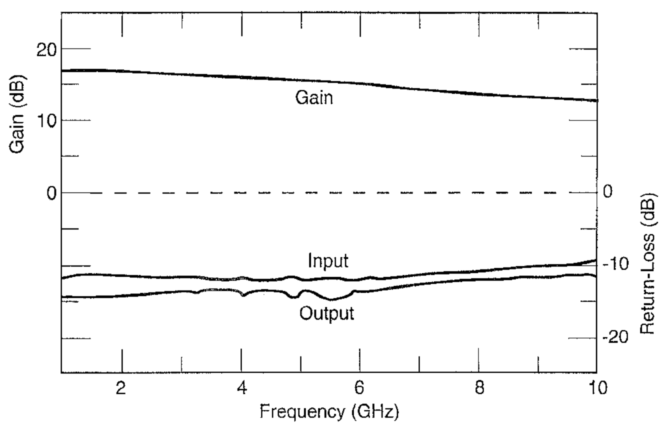

Fig. 3. Measured broadband gain and return-loss performance.

consists of cascode connected HEMT's M1 and M2, which are $0.2 \times 150\,\mu\text{m}^2$ pseudomorphic InGaAs-GaAs devices biased at an Ids of 18 mA. A +5 V (V_{dd1}) supply provides bias to the cascode HEMT through load resistor, R_{load}. The value of this load resistor, which is connected to the drain of M2, sets the open loop gain of the cascode stage while a source-follower HEMT, M3, buffers this high impedance load from the output. This source-follower draws 11.5 mA and is biased from a +5 V supply V_{dd2}. Output resistor R_{out} is used to match the output to 50 Ω. Shunt feedback consisting of R_{fb} and C_{fb} is coupled to the input of the cascode stage to adjust the gain and return-loss for broadband performance. A small input transmission line in series with the gate of M1 is used to match the amplifier for noise figure at the high band edge.

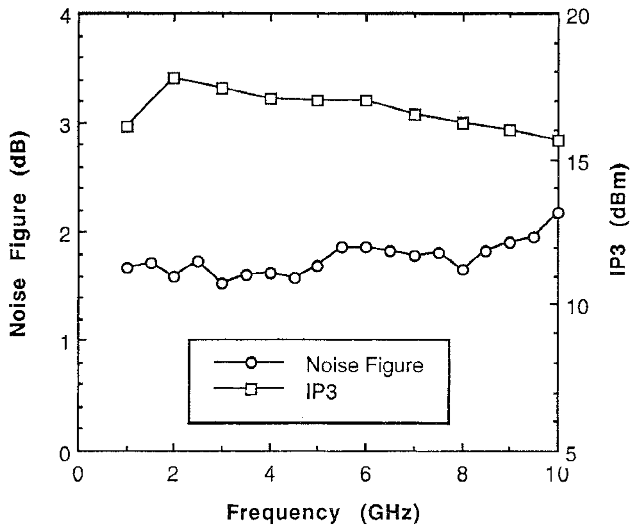

Fig. 4. Measured noise figure and IP3 performance.

An HBT current regulator is integrated with the cascode stage of the LNA because the low-noise performance of the cascode input stage is more sensitive to bias than the source-follower output stage. The regulator is comprised of a high gain differential amplifier consisting of transistors Q1, Q2, and Q3, which are $2 \times 10\,\mu\text{m}^2$ single-emitter HBT's. Each HBT device is biased at $Ic \approx$ 1–2 mA. The HBT regulator uses load resistor R_{load} to set up a positive current source for the HEMT cascode.

The HBT regulator has an open loop voltage gain of 70. Less than 2% change in current is predicted over a 0.5 V HEMT threshold variation, with less than 1% change over a 100°C temperature range. The regulator operates off of a ±5 V supply ($V_{ddo} = 5$ V, $V_{ss} = -5$ V) and draws 4.6 mA, consuming about 16% of the total 250 mW dc power of the chip. The regulator could be re-designed for ≈4% of the dc power at the expense of regulation performance. Fig. 2 shows a microphotograph of the HBT-regulated HEMT LNA. The total chip size is 0.9×1.0 mm^2, half of which is consumed by the HBT regulator and dc bond pads.

The amplifier broadband gain and return-loss performance is shown in Fig. 3. Greater than 13 dB of gain is obtained over a 1–8 GHz bandwidth. The input and output return-losses are greater than 10 and 12 dB across the band. The broadband noise figure and IP3 performance are shown in Fig. 4. A noise figure of less than 1.9 dB is achieved across the 1–8 GHz bandwidth. A minimum noise figure of 1.6 dB is achieved for frequencies below 4 GHz. This is comparable to noise figures of 1.7 dB and 1.5 dB which have been reported for conventional single-technology HEMT self-biased MMIC's with equivalent frequency capability [4], [5]. An IP3 of >15.5 dBm is obtained across the 1–8 GHz band, with a maximum IP3 of 17.5 dBm at 2 GHz. These results show that excellent amplifier noise figures and respectable IP3 can be maintained from selectively re-grown HEMT MBE material.

IV. Conclusion

A compact HEMT low-noise amplifier with HBT bias regulation has been achieved using selective MBE and a merged HEMT-HBT process technology. The design uses direct-coupled cascode and source-follower stages to implement wideband high-gain low-noise performance in a compact area. A minimum noise figure of 1.6 dB has been achieved from 1–4 GHz. A noise figure of less than 1.9 dB and gain of greater than 13 dB has been achieved from 1–8 GHz.

This performance benchmarks the lowest noise figures reported for a HEMT-HBT MMIC and is comparable to single-technology HEMT self-biased LNA's. This HBT-regulated HEMT LNA demonstrates the functional utility and excellent microwave performance that can now be achieved in a compact HEMT-HBT MMIC. This new monolithic HEMT-HBT technology will benefit satellite systems by improving the size, cost, weight, reliability, and performance of their electronic payloads.

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