A Novel Monolithic LNA Integrating a Common-Source HEMT with an HBT Darlington Amplifier

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***Abstract*—Here we report on the results of a novel HEMT-HBT LNA MMIC fabricated using selective molecular beam epitaxy (MBE) techniques. This unique circuit monolithically integrates a low-noise common-source HEMT with an HBT Darlington feedback amplifier to achieve high gain, low noise figure, and wide bandwidth utilizing a compact direct-coupled topology. The miniature direct-coupled MMIC is $0.9 \times 0.7\,\mathrm{mm}^2$ in size and obtains 1–8 GHz bandwidth, greater than 17.5 dB gain, and a minimum noise figure of 2.5 dB. The maximum IP3 is 18 dBm with a saturated output power $(P_{sat}) >$ 12 dBm. The HEMT-HBT amplifier achieves comparable P_{sat} performance to the conventional HBT-only Darlington amplifier while achieving over 2-dB reduction in noise figure across the band. This work benchmarks the first HEMT-HBT MMIC that illustrates microwave performance advantages when compared to an HBT-only design.**

I. Introduction

The capability of integrating HEMT and HBT devices on the same substrate offers MMIC designers the flexibility to take advantage of the unique performance characteristics of FET and bipolar devices. While HEMT's offer low noise figures, HBT's offer low $1/f$ noise and high linearity and output drive capability. Thus, the monolithic integration of HEMT's and HBT's allows the realization of optimal MMIC performance and will ultimately result in custom high complexity mixed-signal MMIC's.

We have recently reported on the first functional HEMT-HBT and HEMT-HBT-PIN MMIC's using a previously developed selective epitaxy process. An HBT current regulated HEMT LNA benchmarked the first published reports of a functional HEMT-HBT MMIC [1], [2] while a HEMT LNA incorporating HBT active feedback and p-i-n diode gain control benchmarked the first functional HEMT-HBT-p-i-n MMIC demonstration [3]. The details of the selective regrowth process used to realize these unique MMIC's have recently been published in detail [4]. These previous works have demonstrated that the performance of the integrated HBT and HEMT devices were equivalent to the device performance of those using single-technology fabrication. However, the MMIC results demonstrated only a few key functional advantages of the HEMT-HBT integrated IC technology.

In this work we describe a HEMT-HBT MMIC that employs a low-noise common-source HEMT that is directly coupled to an HBT Darlington feedback output stage. The HBT Darlington amplifier is attractive for its wide bandwidth and output drive capability. Its good return-loss performance is realized using resistive feedback in conjunction with the Darlington's high input and output impedances. This design requires no area-consuming passive matching networks. The net result is a high performance microwave amplifier in a very compact area. However the noise figure performance is poor because of its feedback nature. By integrating the HEMT as a common-source pre-amp stage, the overall noise figure and gain can be significantly improved compared to the single-technology HBT Darlington amplifier, without significantly compromising bandwidth or saturated output power performance. We describe here the HEMT-HBT MMIC LNA and compare its microwave results to the single-technology HBT Darlington amplifier.

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II. Common-Source HEMT-HBT Darlington LNA

Fig. 1 shows the schematic of the HEMT-HBT low noise amplifier. A HEMT common-source pre-amplifier is directly coupled to an HBT Darlington feedback amplifier. The HEMT transistor M1 is a $0.2 \times 200\,\mu\mathrm{m}^2$ pseudomorphic InGaAs-GaAs device nominally biased at 14 mA of current. The HEMT transistor provides low noise figure and $\approx$10 dB of gain to reduce the high noise figure of the HBT Darlington stage. The common-source HEMT is directly coupled to the HBT Darlington stage to accommodate self-biasing. Feedback resistors R_{f1} and R_{f2}, load resistor R_{load}, and dc bias resistor R_{ss} set up the self-biasing of the HEMT transistor stage. The Darlington stage is mainly comprised of HBT's Q_1 and Q_2, rf feedback resistors R_{f1} and R_{ee}, and bias resistor R_{bias}. HBT's Q_1 and Q_2 are $2 \times 10\,\mu\mathrm{m}^2$ four-finger AlGaAs-GaAs HBT devices that are both biased with 13 mA of collector current. R_{out} is used to obtain good output return-loss match. The chip is self-biased through a single 12-V supply and draws $\approx$40 mA of current. Fig. 2 shows a microphotograph of the HEMT-HBT MMIC that measures $0.9 \times 0.7\,\mathrm{mm}^2$ in size. The compact direct coupled layout consists of 1 HEMT, 2 HBT's, several thin-film-resistors, and one metal-insulator-metal capacitor. The design uses feedback and HBT active devices to obtain good input and output return-losses as well as broadband noise match without relying on large area consuming passive spiral inductors and commensurate matching components.

The measured gain and return-loss of the HEMT-HBT LNA MMIC is shown in Fig. 3. The amplifier achieves greater than 17.5 dB of gain over a bandwidth from 1–8 GHz. The input

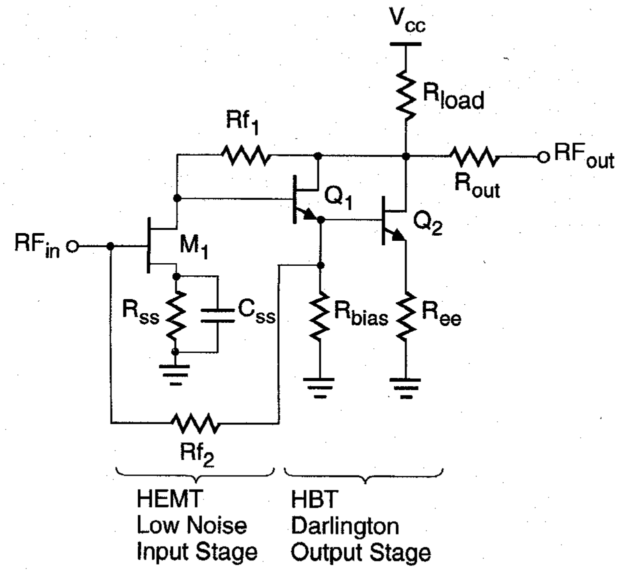

Fig. 1. Circuit schematic of the HEMT-HBT low noise amplifier.

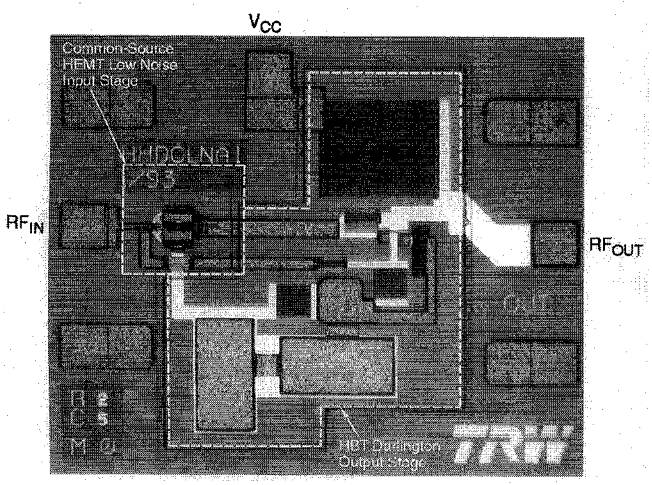

Fig. 2. Microphotograph of the HEMT-HBT MMIC. The chip size is $0.9 \times 0.7\,\mathrm{mm}^2$.

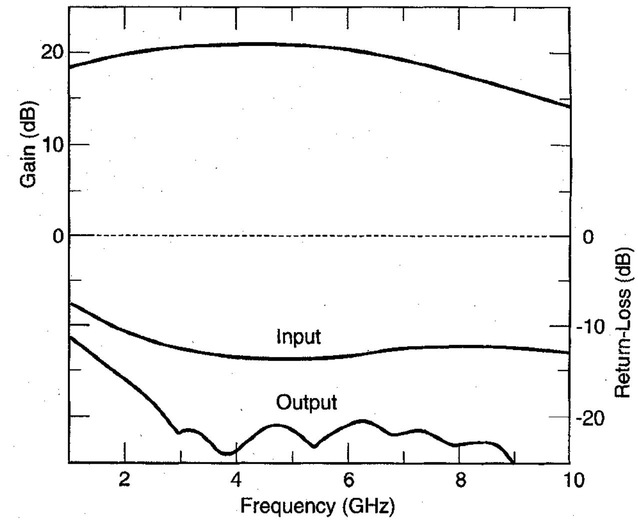

Fig. 3. Measured gain and return-loss of the HEMT-HBT LNA MMIC.

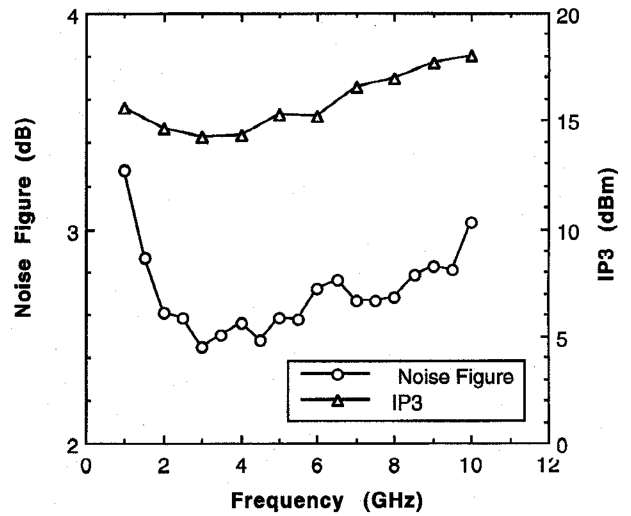

Fig. 4. Measured noise figure and IP3 of the HEMT-HBT LNA MMIC.

return-loss is better than 12 dB and the output return-loss is better than 20 dB through most of the band. Fig. 4 shows the broad band noise figure and IP3 response. The noise figure is <2.6 dB in the 2–5.5 GHz range, between 2.6–2.8 dB from 6–9.5 GHz, and is 3 dB at 10 GHz. The IP3 is between 14–16 dBm from 1–6 GHz, and then increases to 18 dBm at 10 GHz. The measured saturated output power is greater than 12 dBm at midband. Compared to an HBT single-technology Darlington amplifier [5] that achieved 11 dB nominal gain, 10 GHz bandwidth, and 5–6.5 dB noise figure, the low-noise HEMT-HBT direct-coupled amplifier achieves greater than 2 dB improvement in noise figure and 10 dB increase in gain without compromising bandwidth or output power capability.

III. Conclusion

The performance of a unique HEMT-HBT low noise direct-coupled amplifier MMIC has been demonstrated. The MMIC integrates both HEMT and HBT devices using selective MBE regrowth techniques. Combining a low-noise HEMT with an HBT Darlington pair results in improved noise figure and gain performance compared to the single-technology HBT Darlington amplifier. In addition, the integration of HEMT's and HBT's in a direct-coupled topology allows good broad band return-loss and noise figure matching without the use of large area consuming passive microstrip components and also enables HEMT self-biasing. The resulting MMIC achieves high performance in a compact area and demonstrates the functional utility and microwave performance advantage of monolithically integrating both HBT's and HEMT's on the same substrate.

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