A Novel Monolithic Linearized HEMT LNA using HBT Tuneable Active Feedback

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ABSTRACT

For the first time, a novel HBT active feedback circuit is employed with a HEMT LNA which improves linearity (IP3) and gain-bandwidth performance without significantly impacting noise figure. The HEMT and HBT circuits are monolithically integrated using selective molecular beam epitaxy (MBE). The HEMT LNA achieves a nominal gain of 9 dB and noise figure of 2.5-3 dB from 1-11 GHz. By adjusting the bias of the HBT active feedback circuit, positive feedback can be induced which can increase the gain bandwidth from 11 to 16 GHz. In addition, the IP3 can be tuned from less than 20 dBm to > 24 dBm across a 1-11 GHz band with a peak improvement of 10 dB. At S-band, as much as 20 dB reduction in IM3 products has been demonstrated using the HBT active feedback. Compared to an equivalent design which employs resistive feedback only, the active feedback design achieves a 50% improvement in gain-bandwidth and a 4-10 dB improvement in IP3 while maintaining comparable noise figure performance and consuming only 15% additional dc power. This HBT active feedback linearization technique is a cost effective means of improving the linearity of HEMT-based LNA/receiver MMICs for use in multi-carrier wireless communications.

Introduction

In many commercial wireless communication systems where multi-carrier reception is involved, a low noise amplifier with high linearity performance is required. HEMTs provide superior noise figure performance compared to other technologies, however, they fall short of providing the best linearity performance. Several circuit techniques using concepts such as feed-forward linearization and pre-distortion techniques are popular circuit means for improving amplifier linearity performance [1], [2], [3], [4]. However these techniques involve complex methods or systems requiring precise control of phase and amplitude characteristics, are usually limited to narrow band applications, and may require additional hardware which is not economically feasible to employ on a MMIC. Other MMIC linearization techniques employing active and passive FET feedback have been used to improve amplifier IMD performance as well as to provide gain control function [5], [6], [7]. In these applications, FET feedback is used to improve the IMD performance under large signal compressed conditions, but do not lend themselves to good amplifier noise figure performance.

In our work, a novel HBT active feedback circuit is employed with a HEMT LNA which improves both the small-signal gain-bandwidth and linearity (IP3) performance without sacrificing the noise figure performance, or significantly increasing chip size and dc power consumption.

HEMT-HBT IC Technology

The HEMT-HBT monolithic integration was realized using selective MBE and a merged HEMT-HBT process, which has been documented in detail [8]. This technology integrates 0.2 μm gate-length pseudomorphic InGaAs-GaAs HEMTs with 2 μm emitter-width GaAs-AlGaAs HBTs. The HEMT devices achieve a gm > 500 mS/mm with an fT > 60 GHz. The HBT devices achieve a typical ß=60, with an fT and fmax of 23 GHz and 50 GHz, respectively, at a current density Jc = 20 kA/cm ^{2}. The monolithically integrated HEMT and HBT devices have demonstrated dc and microwave performance equivalent to that of the baseline single-technology devices.

HEMT LNA with HBT Active Feedback Design

A schematic of the HEMT low noise amplifier which incorporates HBT tuneable active feedback is given in Fig. 1. Active feedback constructed using bipolar or HBT transistors is preferred over FET or HEMT transistor implementations because they offer lower dc current and power consumption, are easier to self-bias and require no dc blocking capacitors,

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HEMT Low Noise Amplifier with HBT Tuneable Active Feedback

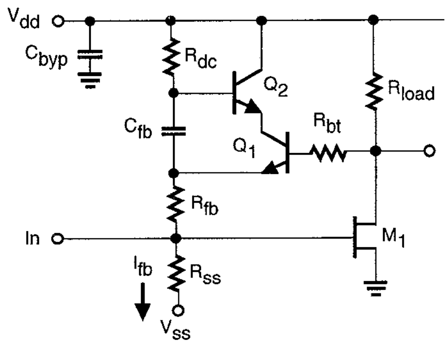

Fig. 1 Schematic of the HEMT low noise amplifier which integrates HBT tuneable active feedback.

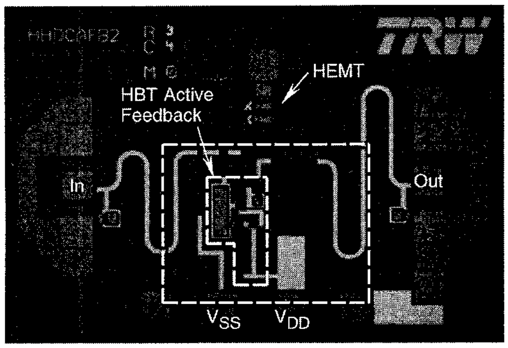

Fig. 2 Microphotograph of the fabricated high linearity-low noise HEMT-HBT MMIC.

and can be implemented in a smaller area [9]. The low noise figure performance of the amplifier is provided by a HEMT device M1. The tuneable HBT active feedback network is comprised of cascode connected HBT transistors Q_1 and Q_2, regenerative feedback tuning resistor R_{bt}, dc bias resistor R_{dc}, and an ac feedback resistor C_{fb}. In a previous demonstration, this cascode HBT active feedback topology was shown to be more effective in achieving regenerative feedback than a single HBT transistor active feedback employment [10], however, its electronic tune-ability and linearity enhancement has not been reported until now. The active HBT feedback is in series with a feedback resistor R_{fb}, which provides a nominal amount of resistive feedback. Resistor R_{bt} can be set to achieve regenerative feedback from the HBT active feedback network. The bias current of the active feedback circuit I_{fb}, can be adjusted by varying the supply voltage V_{SS}. By adjusting V_{SS}, various degrees of positive feedback can be induced by the resultant change in phase and amplitude characteristics of the active feedback network. These characteristics are advantageously used to improve gain-bandwidth as well as linearity performance of the HEMT LNA.

The HEMT-HBT LNA MMIC incorporates a 0.2µm x 200 µm HEMT device which is biased to ≈ 20-25 mA. The HBT transistors Q_1 and Q_2 are 2x10 μm^2 four-finger emitter HBTs

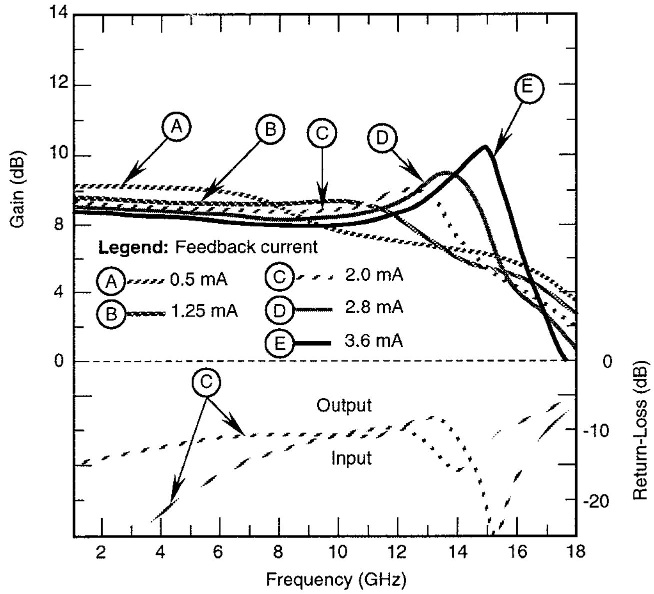

Fig. 3 Measured gain response for different HBT active feedback bias currents I_{fb}, and typical input and output return-loss at the maximally flat gain bias, (I_{fb}= 2 mA).

whose collector bias current (I_{fb}) can vary from 0-5 mA. The supply voltage V_{dd} is 5V and consumes a current between 20.4 and 24 mA. The tuneable active feedback supply voltage V_{SS} varies from 0 to -5 V and consumes 0.5-3.6 mA. Fig. 2 shows a microphotograph of the fabricated proto-type HEMT-HBT LNA MMIC. The HEMT LNA and HBT active feedback consume as little as 300µm x 300µm without bond pads and transmission lines, illustrating the compact size employment of the active feedback technique.

Measured Performance

Fig. 3 gives the measured gain response for different HBT active feedback bias currents I_{fb}, and also a typical input and output return-loss response for the maximally flat gain feedback bias condition, (I_{fb}= 2 mA). The nominal gain is 9 dB with 3-dB bandwidths greater than 11 GHz. As the voltage supply V_{SS} is decreased from -1V to -5V, the feedback bias current increases. This changes the amplitude and phase characteristics through the HBT active feedback network such that more positive feedback is employed. Fig. 3 illustrates the resultant gain peaking which occurs at a Vss of -5V and an Ifb of 3.6 mA. At one extreme (V_{SS}=-5V, I_{fb}=3.6 mA) you get excessive gain peaking, at the other extreme (V_{SS}=-1V, I_{fb}=0.5 mA), the gain has a pronounced roll-off. At a V_{SS} = -3V and a feedback current of 2 mA, the gain has a maximally flat response up to 11 GHz with about 0.5 dB gain peaking at 13 GHz. The corresponding input and output return-loss at this tuning voltage is greater than 10 dB. Fig. 4 gives a plot of

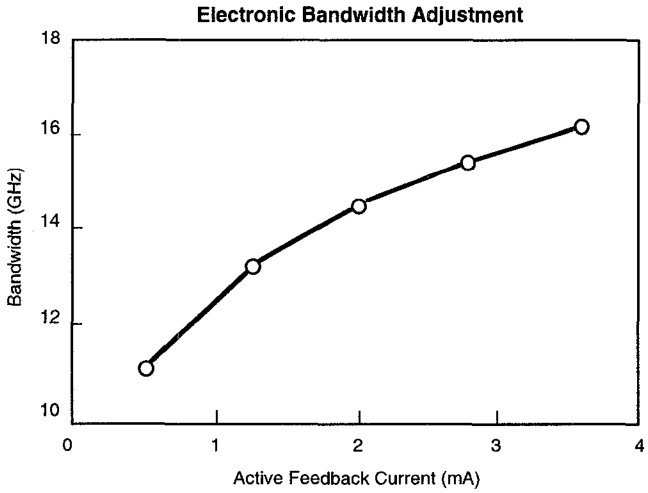

Fig. 4 Plot of 3-dB bandwidth versus active feedback current, I_{fb}.

the 3-dB bandwidth versus active feedback current. This figure illustrates that the 3-dB BW can be improved from 11 GHz to greater than 16 GHz by adjusting the active feedback bias. This corresponds to a 50% BW tuning capability.

The HBT active feedback was also bias-tuned to achieve a radical improvement in IP3. Fig. 5 shows the measured two-tone third-order-intercept-point (IP3) response as a function of active feedback bias (V_{SS}, I_{fb}). Also shown for reference is the IP3 response of an equivalent HEMT LNA design without the HBT active feedback (bold line), which is nominally 20 dBm. This plot shows that as the HBT active feedback bias is increased and positive feedback induced, the IP3 begins to increase at the lower frequencies. As the bias is further increased, the IP3 performance begins to significantly exceed the conventional resistive feedback HEMT LNA with "NO Active Feedback" at the lower frequencies below 8 GHz. For example, at a V_{SS}=-3V (I_{fb}= 2 mA), the IP3 is as great as 27-30 dBm which is an improvement of 7-10 dB over the conventional HEMT LNA for frequencies from 1-3 GHz. As the bias is further increased, the IP3 performance begins to improve at the higher band edge. At a V_{SS}=-5V (I_{fb}= 3.6 mA), the IP3 is 24 dBm across the 1-11 GHz band which is a 4 dB improvement over the conventional HEMT "No active feedback" amplifier. This improvement in IP3 and associated gain-bandwidth performance is at the expense of an additional 3 mA or 15% increase in dc power.

The IP3 is only a figure of merit and may not accurately portray the linearity characteristics of the amplifier circuit. The linear properties of the amplifier can be examined in greater detail in Fig. 6 and 7 which plots the fundamental (single-tone) output power and third order (two-tone) inter-modulation product versus input power at 1 and 3 GHz. These plots compare the conventional resistive feedback HEMT LNA to the HBT tunable active feedback HEMT LNA. At both 1 and 3 GHz, as the HBT active feedback current I_{fb} is

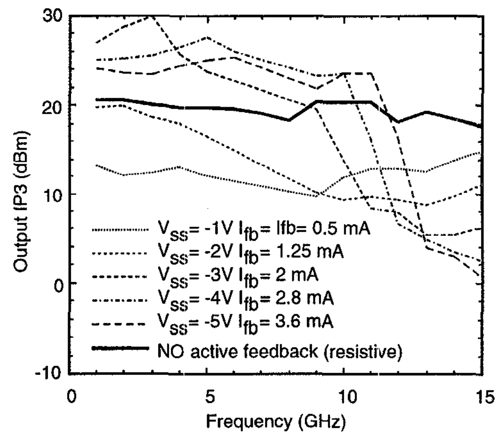

Fig. 5 Measured two-tone IP3 over frequency for various active feedback bias conditions (V_{SS}, I_{fb}). Also shown is the 20 dBm IP3 reference (bold line) of an equivalent HEMT LNA design without the active HBT feedback.

increased, the third order inter-modulation products become suppressed below the conventional resistive feedback design in the input power range where the amplifier is operating linearly (-20 to 0 dBm). As much as 18-20 dB improvement in IM3 suppression can be seen at an input power of -10 dBm. At low I_{fb} bias, the IM3 performance is slightly worse than the pure resistive feedback case due to nonlinearities generated by the HBT active feedback network. Above an I_{fb} of 1.25 mA, the IP3 product level drops well below the conventional resistive feedback case where an IM3:Pin slope of 3:1 is observed. This indicates that the active feedback is effectively canceling out the IM3 products, leaving higher order residual products. Thus, these detailed IM3 vs. input power measurements indicate a large improvement in linearity performance due to the HBT active feedback.

The HEMT LNA noise figure performance was also found to be insensitive to the use of the HBT active feedback. Fig. 8 shows the noise figure response as a function of the active feedback tuning bias. Also shown as a reference, is the noise figure response of the conventional resistive feedback HEMT LNA with "NO HBT Active Feedback." The nominal noise figure of the amplifier is 3 dB and is essentially flat from 1-11 GHz. The noise figure performance is not sensitive to the active feedback bias and is comparable to the conventional HEMT LNA design in this frequency band where the gain was found to be maximally flat. Above 11 GHz where gain peaking is induced at higher I_{fb} feedback bias, the noise figure also begins to abruptly degrade. This illustrates the effect of positive feedback which regenerates the noise amplitude as well as the desired signal, resulting in gain peaking and noise figure degradation. However, this occurs at frequencies beyond the

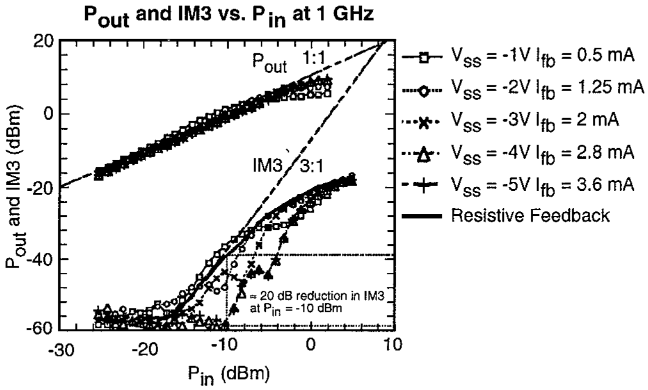

Fig. 6 Fundamental (single-tone) output power (P_{out}) and third order (two-tone) intermodulation product (IM3) vs. input power (P_{in}) at 1 GHz. Also shown is the conventional resistive feedback HEMT LNA.

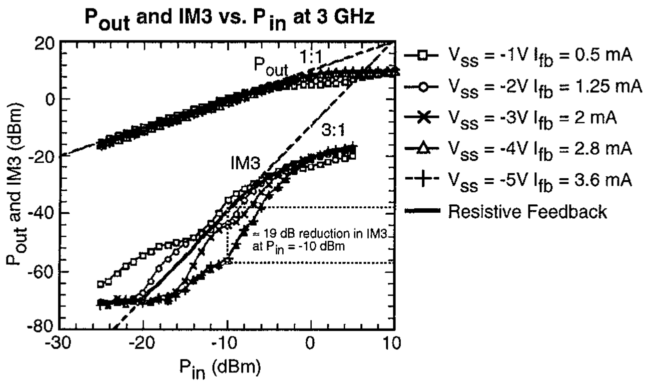

Fig. 7 Fundamental (single-tone) output power (P_{out}) and third order (two-tone) intermodulation product (IM3) vs. input power (P_{in}) at 3 GHz. Also shown is the conventional resistive feedback HEMT LNA.

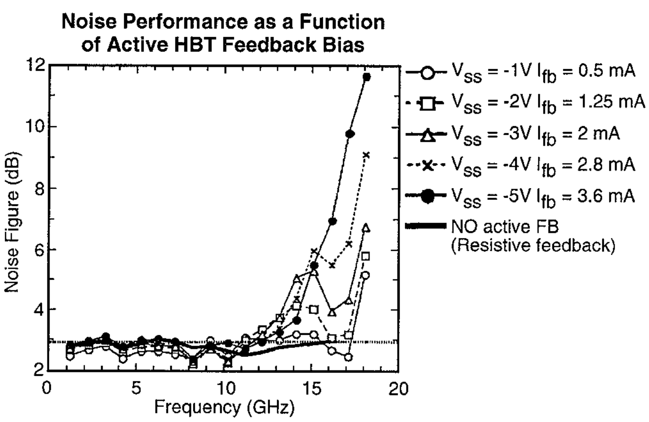

Fig. 8 Noise figure response for the various active feedback bias conditions. Also shown for reference is the noise figure response of the conventional resistive feedback HEMT LNA with "NO HBT Active Feedback".

practical 1-11 GHz bandwidth of the amplifier where a desired flat gain response is achieved.

Conclusion

A novel high linearity-low noise HEMT LNA which integrates HBT tunable active feedback has been presented. The HEMT-HBT MMIC is fabricated using selective MBE technology. The active HBT feedback circuit enhances the gain-bandwidth and linearity performance without compromising the noise figure of the amplifier. The active HBT feedback can be electronically tuned to achieved a 50% improvement in gain-bandwidth and a corresponding 6-10 dB improvement in IP3 (linearity) performance while consuming only 2-3.6 mA of additional current through the active feedback network. Ultimately, this novel circuit technique can be used to improve the bandwidth and linearity performance, as well as recover RF yield after fabrication and packaging of the MMICs for high volume commercial applications.

Acknowledgment

The authors would like to acknowledge T. Naeole for HBT fabrication, M. Iiyama for layout, G. Fisk for RF test support, and special thanks to Dr. P. Liu and the EBL group for HEMT gate processing.

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