Noise Optimization of a GaAs HBT Direct-Coupled Low Noise Amplifier

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ABSTRACT

This work describes a GaAs HBT direct-coupled (inductor-less matched) MMIC LNA which was optimized for noise figure by careful selection of HBT device size, bias, and thorough consideration of its gamma opt characteristics. An optimum HBT device size and bias was determined which offers a device minimum NF (NF_{min}) of 0.9 dB at 2 GHz. The resulting HBT LNA achieves minimum noise figures of 1.5 dB, 1.6 dB, and 2.1 dB at 1 GHz, 2 GHz, and 3 GHz, respectively, while consuming only 6 mA of dc current through a 5 V supply. These NF's are believed to be the lowest reported for Si-BJT or GaAs HBT-based LNA MMICs in this frequency range. In addition, the LNA also achieves a gain of 22.4 dB, a 3.5 GHz bandwidth, and an IP3 greater than 8 dBm at 2 GHz. The design optimization revealed here gives insight into the noise performance trade-offs associated with GaAs HBT-based MMIC LNAs for low dc power wireless applications.

Introduction

From baseband to 6 GHz, conventional Si-BJT and GaAs-HBT bipolar technologies can provide an optimum combination of high linearity and low noise figure with very little dc power dissipation. These properties are attractive for portable battery operated wireless applications.

The noise figure performance summary of previously reported Si-BJT and GaAs-HBT MMIC LNAs is given in Fig. 1. The Si-BJT LNAs achieve 1.7 dB NF at 1 GHz, however at 2 GHz they achieve NFs of ≈ 3 dB [1] due to their limited f_T performance. Several GaAs HBT LNAs achieve similar NFs but at about twice the frequency [3,4,5], with a previous benchmark of 1.9 dB NF @ 2 GHz and only 2 mA of bias current. This previous design was matched for minimum noise using

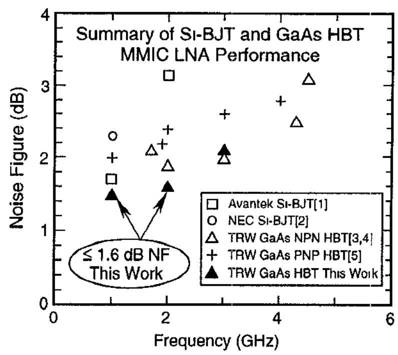

Fig. 1 Summary of Previously reported BJT and HBT LNAs.

monolithic spiral inductors and capacitors. In that demonstration, it was determined that as much as 0.5 dB NF degradation was contributed by the lossy spiral inductors comprising the gamma opt matching circuit, preventing the design from taking advantage of the HBT's device minimum NF (NF_{min}). Other upcoming technologies such as Si-Ge HBTs can provide excellent device NFmin at high frequencies[6] also, but whose passive matching components constructed on the more lossy Si semiconductor substrate, can also profoundly limit the Si-Ge MMIC LNA from realizing its potential device NF_{min}.

In this work, noise optimization of a broadband direct-coupled LNA design which does not use passive inductors or capacitors for noise matching, was realized by careful device size and bias selection. The resulting amplifier achieves minimum noise figures of 1.5 dB and 1.6 dB at frequencies of 1 GHz and 2 GHz, representing the lowest NFs so far reported for a Si-BJT or GaAs HBT-based MMIC LNA.

AlGaAs/GaAs HBT Device Noise Characteristics

The low noise amplifier in this work was fabricated using our standard GaAs HBT production

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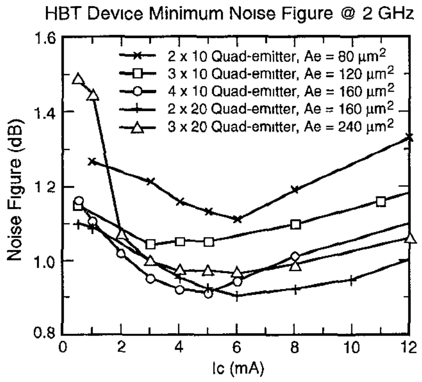

Fig. 2 HBT device NFmin @ 2 GHz as a function of I_C for various devices sizes (A_e).

process technology which has been described in detail elsewhere[4]. On-wafer noise parameters of several HBT device emitter areas were taken as a function of bias over a 0.3-3 GHz frequency. Fig. 2 gives the device minimum NF @ 2 GHz as a function of I_C for various device sizes. The total emitter area A_e, is defined by the dimension of the emitter stripe times the number of fingers. For example, a 4x10 μm^2 quad-emitter HBT is defined as four (quad) 4x10 μm^2 emitter stripes in parallel with a total emitter periphery, Ae = 160 μm^2. Fig. 2 shows that as the total emitter area, Ae increases, the device NFmin decreases by as much as a 0.3 dB when scaling up from a 2x10 μm^2 quad-emitter HBT to a 2x20 μm^2 quad-emitter HBT. An NF_{min} of 0.9 dB @ 2 GHz is achieved from a 2x20 μm^2 quad-emitter HBT under a bias of 6 mA. Based on Fig. 2, any of the three largest devices could provide sub-dB NF_{min}. *However, in order to achieve the best noise figure performance from a direct-coupled LNA design which does not rely on an optimum reactive noise matched input, the location of the device gamma opt in relation to the 50Ω source impedance will heavily determine the LNA's ultimate NF performance.*

Figs. 3-7 give the gamma opt loci from 0.3-3 GHz for the various device sizes at biases of Ic=1,2,4, and 16 mA. In general, for a given device size, the lower the current, the more inductive reactance and the higher the real impedance (> 50Ω) required to achieve minimum noise. For high bias currents, the less inductance and the lower the real impedance (---> 50Ω) required. *For direct-coupled amplifiers, a higher bias current is more desirable in order to obtain a gamma opt which is closer to the 50 Ω source impedance, however, higher*

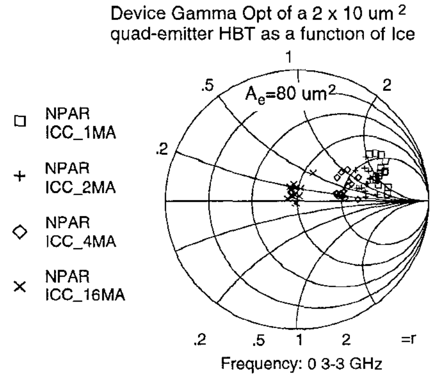

Fig. 3 Gamma opt of a 2x10 μm^2 four-finger HBT as a function of bias.

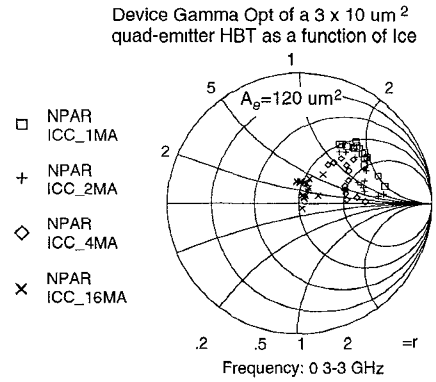

Fig. 4 Gamma opt of a 3x10 μm^2 four-finger HBT as a function of bias.

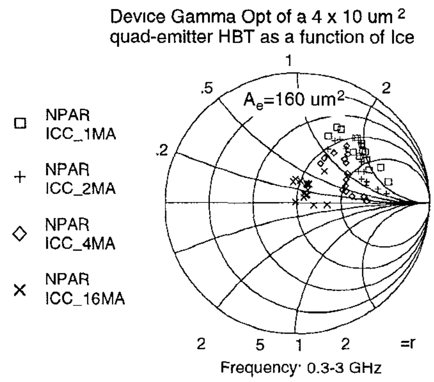

Fig. 5 Gamma opt of a 4x10 μm^2 four-finger HBT as a function of bias.

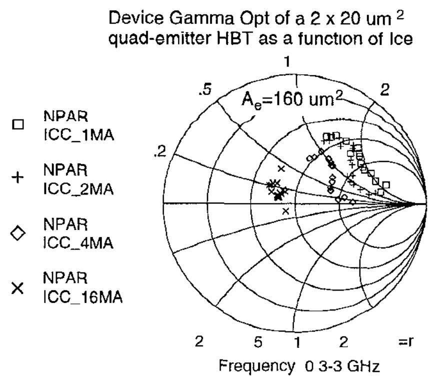

Fig. 6 Gamma opt of a 2x20 μm^2 four-finger HBT as a function of bias.

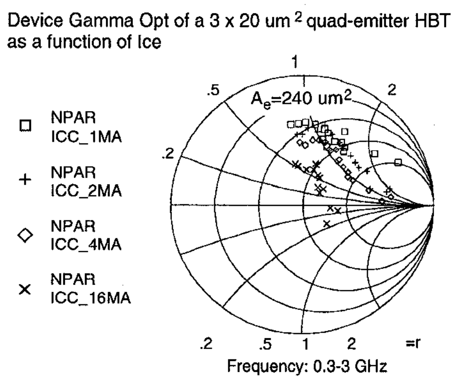

Fig. 7 Gamma opt of a 3x20 μm^2 four-finger HBT as a function of bias.

bias current (Fig. 2) results in an increase in NF_{min}. This is an important design trade for direct-coupled HBT amplifiers. Considering the device size, as one goes to larger HBT device total emitter area A_e, the gamma opt's real impedance becomes smaller (closer to 50 Ω) while the imaginary part becomes less inductive. *For direct-coupled LNAs, the larger device size resulting in lower real part of gamma opt is more desirable for the low frequency noise match.* However, the larger size may limit the bandwidth performance.

HBT LNA Design and Measured Performance

Fig. 8a gives the schematic of the direct-coupled LNA design. This design has been discussed in detail elsewhere[3]. In this schematic, the first HBT transistor Q1, was optimized in terms of size and bias in order to achieve low noise figure under low dc operation. Fig. 8b shows a microphotograph of the LNA illustrating its compact 0.27x0.3mm^2 size. The small size is a result of using a direct-coupled amplifier design which achieves low NF without the use of passive components for noise matching.

A comparison of the measured noise figure performance of the HBT LNA which implements the various size HBTs for Q_1, is given in Fig. 9. The LNA with a 2x20 μm^2 quad-emitter achieved the best noise performance across the band, and is consistent with the desire to have a larger emitter area HBT device in order to obtain lower NF_{min}, and a corresponding gamma opt whose real part is more closely matched to 50 Ω. Fig. 10 gives the HBT LNA with Q1 = 2x20 μm^2 quad-emitter HBT, as a function of supply bias. As the bias voltage and current is increased, the noise figure dramatically improves due to the movement of the gamma opt loci closer to the 50 Ω source impedance.

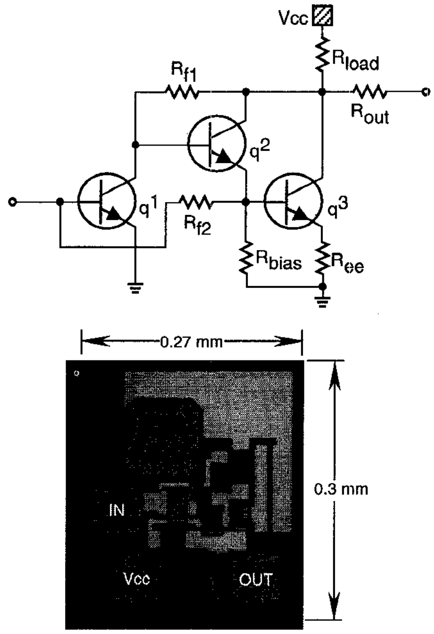

Fig. 8 a) Schematic and, b) microphotograph of the GaAs HBT LNA. The production chip is 0.27x0.3 mm^2 in size.

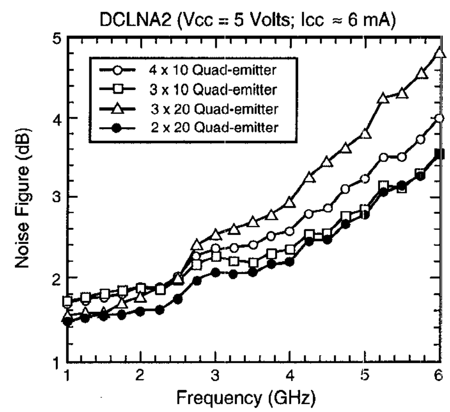

Fig. 9 Direct-coupled LNA noise figure performance comparison implementing various size HBTs for Q_1.

An improvement of > 0.5 dB in the LNA can be seen over bias which exceeds the HBT device NFmin variation over bias (Fig. 2). This indicates that matching the device gamma opt to the 50 Ω source impedance by size and bias selection has a greater impact on the direct-coupled LNA NF performance than just employing the device with the lowest NFmin alone. Fig. 11 gives the wideband gain and return-loss response of the HBT LNA at a supply voltage of 5V and 6 mA of current. At this bias the LNA achieves 22.4 dB gain with a 3.5 GHz bandwidth, and good return-losses exceeding 12 dB in this band. The broadband IP3 performance as a function of supply bias is also given in Fig. 12. At the optimum LNA NF bias of 5V and 6 mA, the LNA achieves an IP3 of > 8 dBm @ 2 GHz.

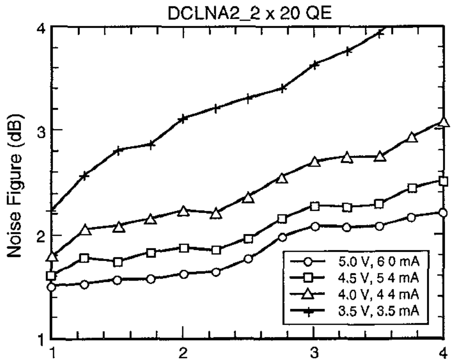

Fig. 10 Direct-coupled LNA (with 2x20 μm^2 quad-emitter) noise figure performance as a function of supply bias.

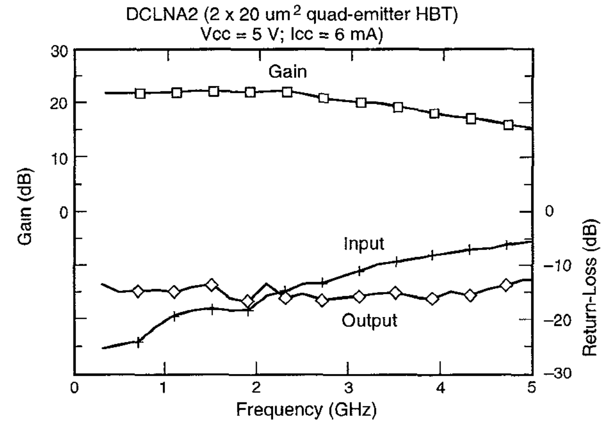

Fig. 11 Gain and return-loss response of the HBT direct-coupled LNA (with 2x20 μm^2 quad-emitter).

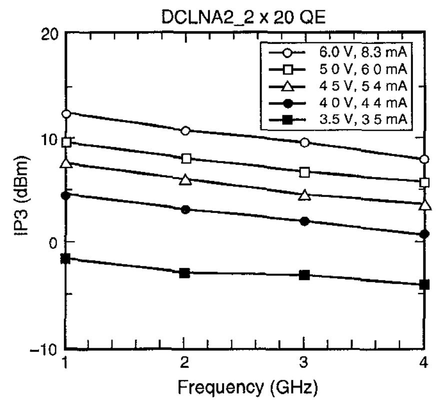

Fig. 12 IP3 performance as a function of supply bias of the HBT direct-coupled LNA (with 2x20 μm^2 quad-emitter).

Conclusion

The noise figure performance of an HBT direct-coupled MMIC LNA was optimized by careful selection of HBT device size, bias, and examination of the device gamma opt characteristics. The resulting HBT LNA achieves minimum noise figures of 1.5 dB, 1.6 dB, and 2.1 dB at 1 GHz, 2 GHz, and 3 GHz, respectively, while consuming only 6 mA of dc current. These NFs are believed to be the lowest reported for Si-BJT or GaAs HBT-based LNA MMICs. In addition to the excellent NF, the LNA also achieves 22.5 dB gain, a 3.5 GHz bandwidth, and an output IP3 greater than 8 dBm at 2 GHz. A combination of high linearity and state-of-the-art noise figure was achieved without the use of passive matching components.

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