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Impact of 1/f noise in Ka-Band InGaP/GaAs HBT Frequency Sources

M. S. Heins, T. Juneja, D. Caruth, M. Hattendorf, and M. Feng

Department of Electrical and Computer Engineering
University of Illinois at Urbana-Champaign
Urbana, IL 61801

Abstract

A measurement system was constructed to evaluate the 1/f noise of InGaP/GaAs HBTs. Our standard InGaP/GaAs HBTs have 1/f noise that is at least 10 dB less than reported AlGaAs devices and comparable to other InGaP devices. Experiments and simulations highlight the contributions of both device noise and circuit elements to the resultant oscillator phase noise in our particular Ka-band VCO circuits at 100 kHz offset.

I. Introduction

Lately, there has been a great demand for MMIC components for use in millimeter-wave (MMW) transceivers. Most of the chips, such as the LNA, PA, and mixer have the ability to meet the performance requirements for these systems with existing advanced device processes. The frequency source, however, is often not realized in a MMIC due to the need for low phase noise. To achieve low phase noise, external resonators or DROs are used. However, this technique is not amenable to low-cost, high volume production.

Researchers have designed completely monolithic Ka-band oscillators with phase noise less than -90 dBc/Hz at 100 kHz offset [1-2]. These results are encouraging, but there still exists little confidence in predicting the phase noise of these type of oscillators. Simple empirical models such as Leeson's cannot be applied to most negative resistance MMW designs.

To experimentally determine device and circuit contributions to oscillator phase noise, we fabricated oscillators processed with HBT devices having differing 1/f noise characteristics. One HBT wafer is processed normally, while the other uses emitter ledge passivation. The phase noise comparison was performed using two circuit topologies, and the results are corroborated with simulations from HP-MDS.

II. Low frequency noise measurement of HBTs

A description of the standard HBT process and 3x10 μm^2 device performance is given in [3]. The devices having passivated emitter ledges are discussed in [4]. The emitter ledge width is 500 nm. The passivated devices had significantly higher current gain than the standard devices.

Figure 1 shows a schematic of the low frequency noise measurement system. Potentiometers allow for bias adjustment, and along with a switching capacitor, can provide a variety of input impedances to the device. Filters insure the device is stable at frequencies higher than those used for noise measurement. The voltage density of noise, S_{vc}, is measured across a load resistor R_c.

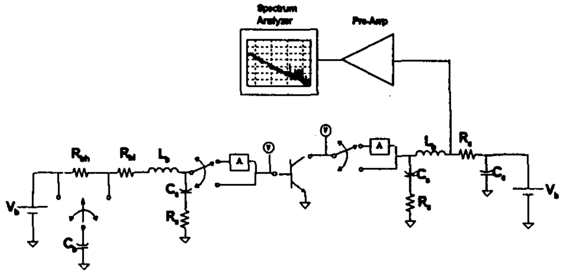

Figure 1: Low frequency measurement setup

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We compared HBTs in terms of input noise current density, S_{ib}. This is easily found by referring the output noise to the input, knowing the current gain of the device. Figure 2 shows low frequency noise in a standard HBT at various collector currents. The current gain is relatively constant in this region. It is evident that the noise current increases with collector current with an exponent greater than 2. This behavior has been witnessed in other HBT devices.

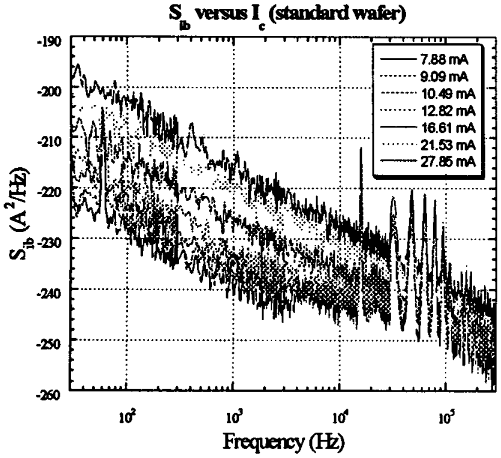

Figure 2: Input referred noise spectral density versus collector current for standard wafer

Figure 3 shows noise power versus collector current density at 100 Hz. Shown in the figure are results taken from reports [5-9]. The values are obtained assuming 1/f behavior when 100 Hz data was not reported. Our measurements were taken with a termination having high input impedance (> 10 kΩ). It is seen that InGaP devices are superior to AlGaAs devices by at least 10 dB. The passivation ledge further improves input referred noise for a given current density, in this case by at least 8 dB.

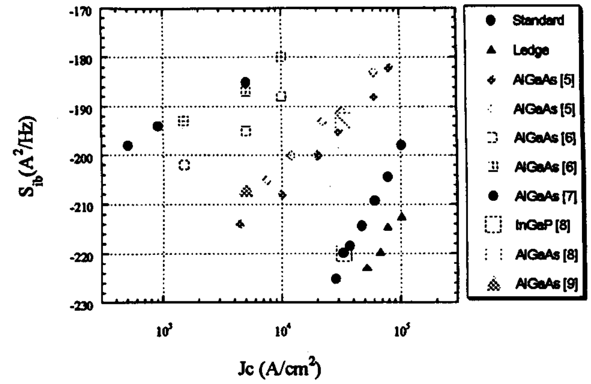

Figure 3: Literature comparison of low frequency noise in HBTs at 100 Hz

III. Simulation and oscillator measurement

From the low frequency noise measurements, a worst case value of the noise current was selected. The MDS simulator represents the noise current in the base of a bipolar device as $S_{ib}=2qI_b+K_f*(I_b\wedge A_f)/f$. The noise thus consists of a shot term and a 1/f component. Ignoring the bias dependence of the 1/f noise, a value of $K_f=5x10^{-17}$ is used for the simulations. This is a conservative estimate based on Figure 3, scaled to 1 Hz, at the oscillator bias point $I_c=10$ mA. This level of noise yields a 1/f corner frequency, f_c, of 78 kHz. It is important to realize that the 1/f corner frequency need not be the offset frequency at which that noise influences the oscillator spectrum. However, the noise level at a given frequency is a good reference to compare devices for potential use in low-noise circuits.

Simulations were performed using standard and ledge HBT models. The noise for both devices was kept constant, using $K_f=5x10^{-17}$ from above. The simulations were performed on common-emitter (CE) and common-base (CB) topologies that were designed at 38 GHz, similar to those discussed in [1]. The simulated and measured phase noise at 100 kHz offset are shown in Figure 4. The simulated phase noise spectrum is fit to Leeson's empirical model [10] to obtain a circuit Q and corner frequency for the influence of 1/f noise, $f_{c,osc}$. The measured data was taken from an average of a few samples on each wafer. A large-signal model for each type of device was used.

Osc. Type	Simul. 100 kHz	Meas. 100 kHz	Q	$f_{c,osc}$ (Hz)
CE-Std	-97	-89	19	46
CE-Ledge	-91	-82	7.6	5
CB-Std	-94	-85	14	78
CB-Ledge	-84	-80	3.5	468

Figure 4: Table of MDS phase noise simulations of Ka-band oscillators

Of note in the measured results is the fact that the circuits using ledge devices did not have better phase noise, despite having lower 1/f noise. The simulations predict that 1/f noise is an influence at frequencies less that a few hundred Hz for most cases. Thus it is not expected that low frequency noise will play a role in VCO phase noise at frequency offsets less than 100 kHz, and that circuit considerations such as the Q, should be the focus for design.

A confounding factor in this study is that the DC and RF performance of the ledge processed devices was significantly different than the standard devices. The change in the resulting high-frequency circuit can affect the overall Q. The simulated phase noise spectrum reflected a change in circuit Q for the two device types. The predicted phase noise was optimistic for these designs.

In these free-running MMW oscillators, phase noise can only be estimated reliably as close in as 100 kHz using direct spectrum measurements. It is often impossible to determine the influences of low frequency noise from measurement by identifying the 20 and 30 dB/decade regions in the oscillator phase noise spectrum. Therefore, with our capabilities the only way to investigate these influences is through simulation. Here, the simulated phase noise deviated from the measured noise by as much as 10 dB.

V. Conclusions

The input referred low frequency noise of our 3x10 μm^2 InGaP/GaAs HBTs has been benchmarked and found to be less than -220 dBA^2/Hz at 100 Hz at a bias of 10 mA. Emitter ledge passivation can further improve the 1/f noise. These devices are very attractive for use in low-phase noise oscillators.

Ka-band oscillators fabricated with each type of these devices showed little conclusive difference in phase noise at offsets greater than 100 kHz. Simulations predict that the influence of 1/f noise is only apparent at very low offset frequencies and also highlight the low circuit quality factor.

To fully utilize the excellent 1/f noise of these devices, both the frequency selectivity of the oscillation condition and its sensitivity to current fluctuation must be considered. The optimization of these parameters may require a search of numerous circuit topologies, device size and bias. This methodology is necessary because these parameters can not be individually optimized. Another acceptable approach is to establish planar elements with higher Q. Either method would require accurate simulation capability and measurement verification to very close-in frequencies.

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