Bias-Dependent Low-Frequency Noise Model for Low Phase Noise InP HEMT based MMIC Oscillator Design

H. van Meer[a], D. Schreurs[a], K. van der Zanden[a], W. De Raedt[a], E. Simoen[a] and L. Kaufmann[b]

[a]IMEC
Kapeldreef 75, B-3001 Leuven, Belgium
[b]Electronic Devices Group (EEA), Eindhoven University of Technology
Den Dolech 2, 5600 MB Eindhoven, The Netherlands

Abstract

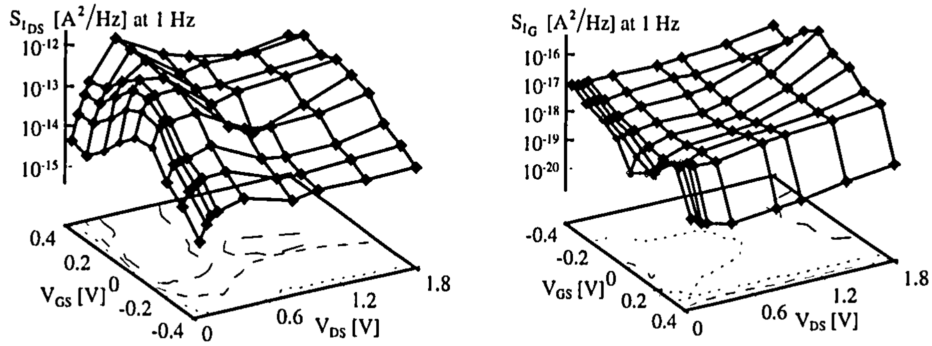
A bias-dependent low-frequency noise model of InP based InAlAs/InGaAs HEMTs has been acquired by direct implementation of low-frequency noise measurements in a circuit simulator in order to enable phase noise simulations of non-linear microwave applications such as mixers and oscillators. A 20 GHz coplanar oscillator has been designed and realised in order to validate the obtained simulation results. The simulated phase noise level at 100 kHz from the carrier is −83.6 dBc/Hz, which agrees well with the measured value of −77.1 dBc/Hz.

1. Introduction

Up to now, InAlAs/InGaAs High Electron Mobility Transistors (HEMTs) grown on InP substrates have shown to be the best performing three terminal devices in terms of noise figures and gain at frequencies up to 100 GHz and above [1]. However, low-frequency (LF) noise in HEMTs has shown to be an important limitation of the microwave device performance in non-linear applications such as mixers and oscillators that suffer from noise up-conversion [2]-[3]. This results in undesired amplitude modulation and frequency modulation or phase noise. Therefore, for the design of non-linear Monolithic Microwave Integrated Circuits (MMICs), it is desirable to model the LF noise of the HEMT. Although detailed noise analysis has been performed on InAlAs/InGaAs HEMTs, none of them has yet resulted in an accurate analytical LF noise model that can be implemented in modern microwave circuit simulators. This paper presents a measurement-based bias-dependent $1/f$ noise model of InP based InAlAs/InGaAs HEMTs, which can straightforwardly be implemented in a commercial microwave simulator.

2. Modelling of low-frequency noise

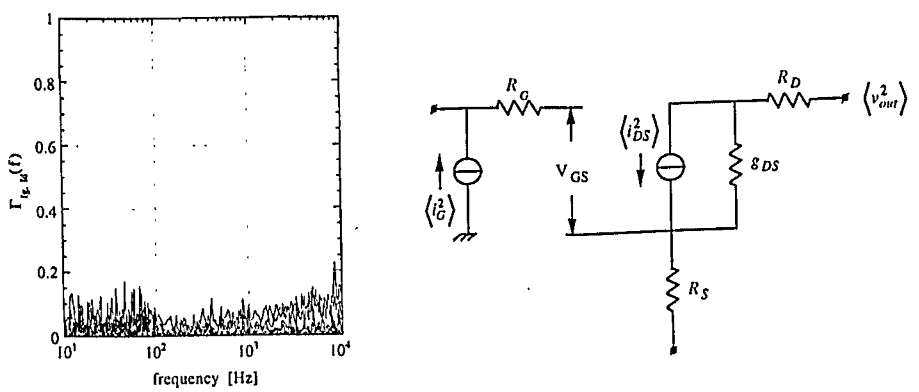
In order to acquire an accurate bias-dependent LF noise model that can be applied in microwave simulators, LF drain and gate current noise measurements have been performed on InP based HEMTs with a gate length and width of 0.15 μm and 50 μm, respectively. The measurements have been carried out in the ohmic as well as in the saturation region for various values of V_{GS} and for spectral frequencies from 1 Hz to 100 kHz. All drain and gate current noise measurements produced merely $1/f$ spectra in the accessible frequency range, which implies that the generation-recombination and thermal noise sources are not dominant below 100 kHz. An overview of the LF noise measurements is given in Fig. 1, which shows the $1/f$ noise in the drain and gate current $S_I(f)$ at the spectral frequency of f = 1 Hz versus the gate voltage V_{GS} and the drain voltage V_{DS}.



(a) (b)

Fig. 1. Spectral current power density of the drain current (a) $S_{I_{DS}}(f)$ and of the gate current (b) $S_{I_G}(f)$ at f = 1 Hz versus V_{GS} and V_{DS} of an InP based HEMT with 0.15 μm gate length and 50 μm gate width.

Besides the separate contributions of the drain current noise $S_{I_{DS}}(f)$ and gate current noise $S_{I_G}(f)$, the coherence between these contributions $\Gamma_{I_G, I_{DS}}(f)$ has been measured at several gate bias points in both the linear and saturation regimes (Fig. 2a). Due to the low coherence value presented in Fig. 2a, the gate noise source can be treated separately from the drain noise source, which facilitates the LF noise modelling considerably. Hence, as shown in Fig. 2b, the LF noise behaviour of the HEMT at both the drain and gate side can be modelled by a spectral current noise source parallel to the intrinsic drain current source as well as parallel to the gate and source contacts. The bias-dependent behaviour of these noise sources is achieved by considering the spectral power densities $S_{I_{DS}}(f)$ and $S_{I_G}(f)$ at f = 1 Hz and the coefficient γ in $S_I(f) = S_I(f = 1\ \text{Hz})/f^{\gamma}$ with $0.8 < \gamma < 1.2$, as variables which are dependent on the drain voltage V_{DS} and gate voltage V_{GS}. The noise data used for implementation have been obtained from a HEMT with a gate width of 50 µm. However, these spectra can also be applied to devices with other gate widths, if the intrinsic current noise sources are scaled to the proper magnitude by using Hooge's relation [4]. Similar to the $1/f$ noise behaviour, the generation-recombination noise can be modelled. However, since in our case the LF noise spectra only showed a $1/f$ dependence, the noise model has not been extended with generation-recombination noise sources.

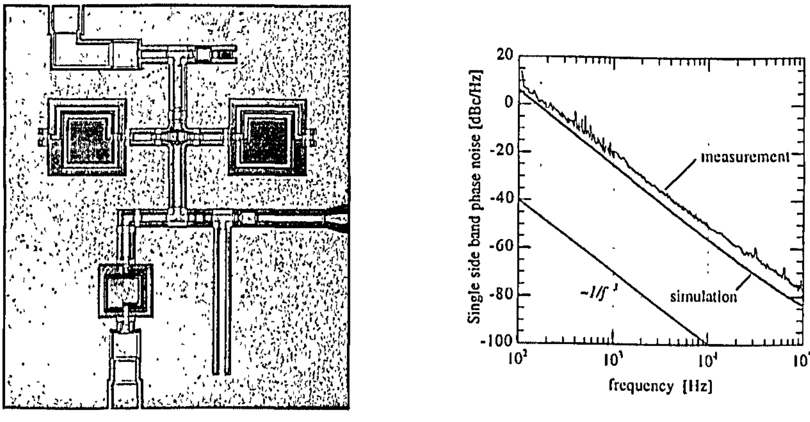


(a) (b)

Fig. 2 . (a) Coherence measurements at several gate bias points in the linear as well as in the saturation regime.
(b) Implementation of the bias-dependent low-frequency noise model in the non-linear HEMT model.

3. Measurement and simulation results

After the LF noise model has been added to an in-house developed non-linear HEMT model [5], implemented in the commercial simulator HP MDS, a coplanar low phase noise MMIC oscillator (Fig. 3a) has been designed and fabricated. Fig. 3b compares the measured and simulated phase noise, calculated with the phase noise analysis tool of HP MDS. The presented phase noise spectra show that the simulated as well as the measured single side band phase noise, located close to the carrier, is proportional to $1/f^3$. The magnitude of the simulated and measured phase noise spectra at f = 100 kHz from the carrier is –83.6 dBc/Hz and –77.1, respectively.



(a) (b)

Fig. 3. (a) Picture of the 20 GHz InP HEMT based coplanar MMIC oscillator, $L \times W = 1.4 \times 1.7$ mm^2.
(b) Measured and simulated phase noise spectra.

4. Conclusions

A scalable bias-dependent low-frequency noise model has been acquired by a straightforward implementation of low-frequency gate and drain current noise measurements. The obtained measurement-based noise model has validity in both linear and saturation regimes.

The phase noise performance of a 20 GHz MMIC oscillator has been simulated and compared to measurement results. The simulated phase noise level at 100 kHz from the carrier is –83.6 dBc/Hz, which agrees well with the measured value of –77.1 dBc/Hz.

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