NOISE BEHAVIOR OF A 15-GHZ-ALGAAS/GAAS-HEMT-OSCILLATOR

T. Felgentreff, G.R. Olbrich

Lehrstuhl fuer Hochfrequenztechnik, Technische Universitaet Muenchen
Arcisstraße 21, 80333 Muenchen, Germany

Abstract

In this paper the noise behavior of a HEMT oscillator is analyzed theoretically and experimentally. We present a large signal equivalent circuit of the HEMT device which describes also the low and high frequency noise behavior in the considered frequency range. Calculations of oscillator phase noise using this large signal and noise model are compared with results of phase noise measurements.

Introduction

Because of the high and different noise contributions in HEMT devices we analyzed such a device in an oscillator application. Our interest was to get information about the upconversion of the different noise contributions to noise sidebands of the carrier. In the first part of this paper we present a model which describes the large signal and noise properties of HFET devices. In the second part we will concentrate on the consideration of the different noise sources which are implemented in the model and determine the over all noise behavior of the oscillator. In the third part of the paper we will apply a time domain phase noise calculation method and will demonstrate the influence of the different noise sources to the phase noise of the oscillator.

Modeling of the HEMT device

The simulation of oscillator phase noise requires large signal models for the active devices which describe not only the signal but also the noise behavior in the considered frequency range from 1 Hz to 20 GHz. Fig. 1 shows the large signal and noise equivalent cir-

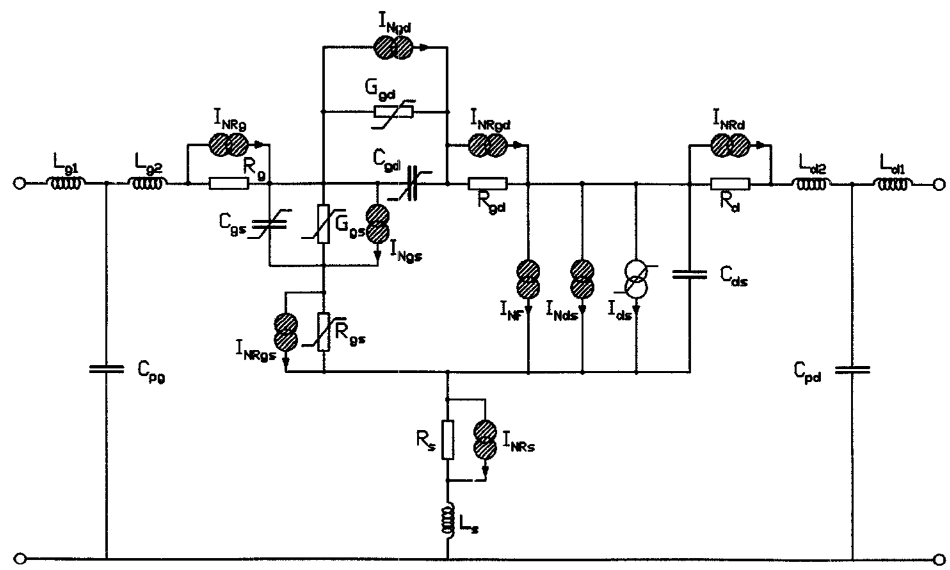

Fig. 1 Large signal and noise equivalent circuit of the HEMT

0-7803-3246-6/96/$5.00 © IEEE

cuit of the HEMT we use for our investigations. The linear and not bias dependent extrinsic elements L_g, L_d, L_s and R_g, R_d, R_s are extracted from small sig-nal S-parameter measurements using hot and cold modeling techniques. To determine the nonlinear elements of the inner transistor (R_{gs}, R_{gd}, C_{gs}, C_{gd}, C_{ds}, G_m, G_{ds}, τ) we apply a deembedding procedure to the measured small signal S-parameter data of 200 different bias points [1,2]. This has to be done for all interesting frequencies. The nonlinear elements can be modeled either by analytical functions or by interpolation using look-up-tables [3]. The two dimensional look-up-tables contain the data of the nonlinear elements as function of the two independent controlling voltages V_{gs} and V_{ds} at the intrinsic HFET. Both approaches are based on a quasistatic approximation. The non-linear diode admittances G_{gs} and G_{gd} are given by their I/V-characteristics whereas the parameters have been determined by DC measurements. To model the channel current I_{ds} we use the DC I/V-characteristic (Fig. 2) and the dynamic output I/V characteristic we get by an integration of the differential small signal RF admittances G_m and G_{ds} (Fig. 3). So dispersion effects of G_{ds} are included.

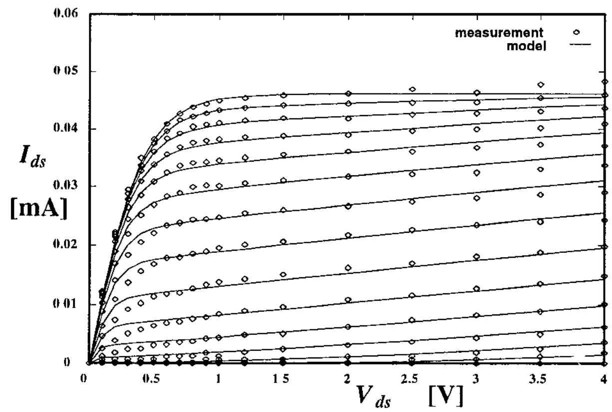

Fig. 2 DC characteristic $I_{ds} = f(U_{ds})$

Discussion of the noise sources

The high frequency noise performance of the HFET is described by the model given in [4,5] which uses three uncorrelated white noise current sources (I_{Nds}, I_{NRgs}, I_{NRgd}) allocated to the resistive elements of the intrinsic transistor. The parameters of these noise sources are determined from noise parameter measurements using the correlation matrix method. Baseband noise

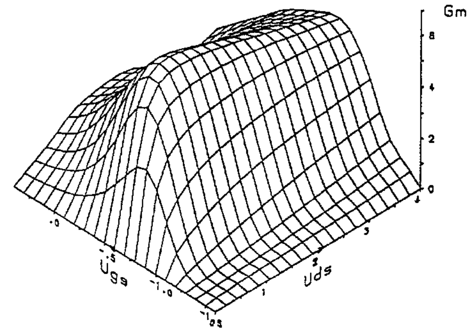

Fig. 3a Transconductance $G_m = \left.\frac{\partial I_{ds}}{\partial U_{gs}}\right|_{\partial U_{ds}=0}$

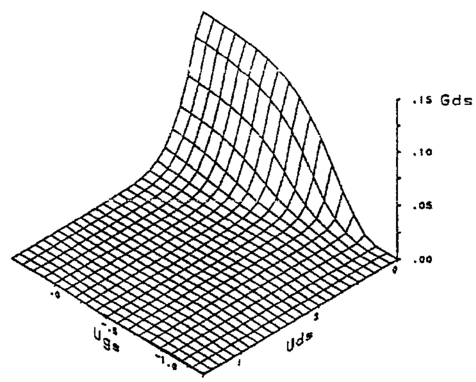

Fig. 3b Output admittance $G_{ds} = \left.\frac{\partial I_{ds}}{\partial U_{ds}}\right|_{\partial U_{gs}=0}$

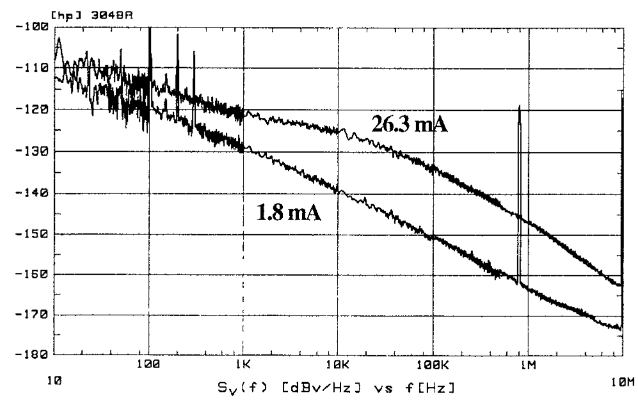

Fig. 4 Measured baseband noise of an AlGaAs/GaAs-HEMT showing $f^{-\alpha}$ - and g-r noise at different bias points

measurements were done to determine the bias dependent low frequency noise power spectra (Fig. 4). The low frequency noise contribution is modeled as a noise current source I_{NF}, which includes the fundamental $f^{-\alpha}$ noise source and the g-r noise source showing an Lorentzian spectrum [6]. Besides of the

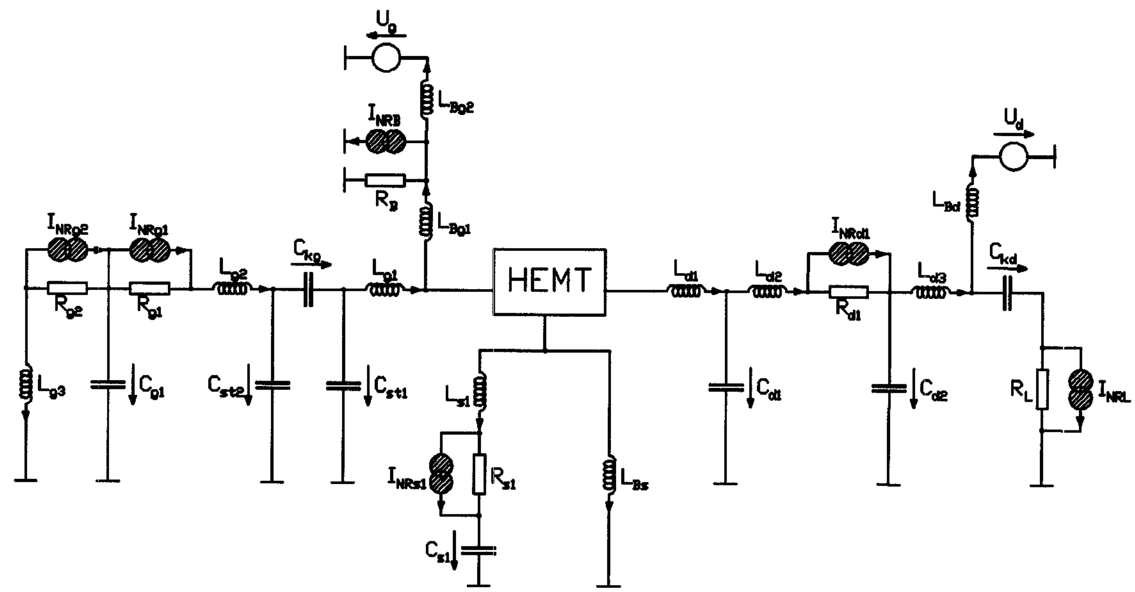

Fig. 5 Lumped element equivalent circuit of the HEMT oscillator

three white noise current sources I_{Nds}, I_{NRgs} and I_{NRgd} in the intrinsic HEMT the large signal and noise model also includes noise sources for the shot noise of the Schottky diodes (I_{Ngs}, I_{Ngd}) and the thermal noise of the parasitic resistances (R_g, R_d, R_s). The noise source I_{Nds} describes the diffusion noise of the channel current I_{ds} (hot electrons).

In general the diffusion noise of the channel current dominates all other noise contributions. Usually the Schottky noise of the diodes can be neglected. This is not applicable if the diodes show high leakage currents. The Nyquist noise of the resistances is responsible for the minimum noise figure of the HEMT and we have to take it into consideration.

Design of the oscillator

The modeling process was performed on a standard AlGaAs/GaAs-HEMT CFY65. The oscillator is fabricated as hybrid circuit on Al_2O_3-substrate using coplanar lines. The design is done using the reflection coefficient method. The oscillation frequency is determined by a short circuited coplanar resonator connected to the gate of the HEMT. Two parallel coplanar lines provide a capacitive load to the source of the transistor and cause the instability for oscillation. The oscillator power is coupled out at the drain of the HEMT.

Phase noise calculation

For the application of the time domain phase noise simulation (TDPNS) method [6,7,8], the oscillator circuit is approximated by a lumped element circuit model (Fig. 5). The lines connected to gate and source of the HEMT are also modeled with lumped elements. This is due to the fact that the calculation method we apply is done in time domain. The Langevin equations - a set of ordinary first order nonlinear differential equations - describe the deterministic and stochastic behavior of the oscillator. A perturbation formulation allows the consideration of the noise contributions. As a result of the calculation we get the phase noise spectrum $L(f_m)$ of the oscillator given by

$$L(f_m) = \frac{\Delta f_{3dB}}{\pi \cdot f_m^2} \quad \text{white noise}$$

$$+ \sum_{k=1}^{K} \left|g_{1,0}^{k}\right|^2 \frac{\omega_0^2 \, c_k}{\left|2\pi f_m\right|^{2+\alpha}} \quad f^{-\alpha} \text{ noise } (1<\alpha<2)$$

$$+ \sum_{l=1}^{I} \left|r_{1,0}^{l}\right|^2 \frac{\omega_0^2}{\left|2\pi f_m\right|^2} \frac{\alpha_{gr}}{1+\left(f_m \tau_{gr}\right)^2} \quad g\text{-}r \text{ noise}$$

While the first term results from the white noise sources in the circuit, the second and the third term are caused by low frequency $f^{-\alpha}$ and g-r noise contributions. In Fig. 6 and Fig. 7 this different contributions are separately displayed and compared with the measured oscillator phase noise. Evaluating the result we can find that up to 10 kHz the phase noise of the oscillator is dominated by the *1/f* noise behavior of the active element corresponding to a slope of 30dB/decade. In the offset frequency range 10 kHz to 8 MHz the phase noise is determined by the *g-r* noise contribution and above 8 MHz the white noise sources will dominate the phase noise behavior.

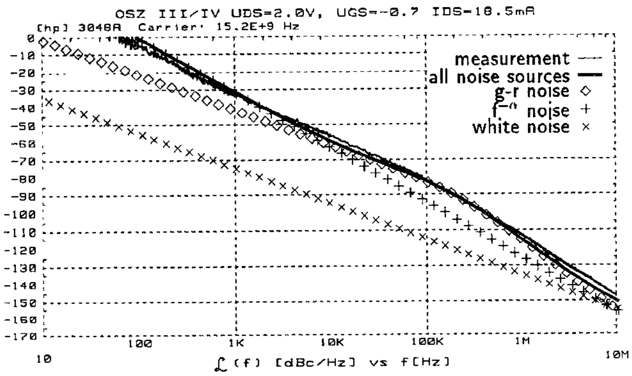

Fig. 6 Measured an calculated phase noise performance of the coplanar HEMT oscillator

Conclusion

In general we find that the phase noise of this oscillator with -30dBc/Hz at an offset frequency of 1 kHz is very high. This is first due to the fact that the HEMT element shows very high f^{-a} noise. Another reason lies in the loaded Q factor of the coplanar resonator which is in the order of 10 and very low. The analysis shows in a clear manner how the different noise sources contribute to the over all noise behavior of the oscillator.

	L(f_m) [dBc/Hz]
R_{g2}	-158.7
I_{Nds}	-159.2
R_L	-164.6
R_{g1}	-165.7
R_s	-167.6
R_{gd}	-167.8
R_g	-168.4
R_B	-168.7
R_{gs}	-170.2
R_d	-175.0
R_{s1}	-179.0
R_{d1}	-183.5
I_{Ngd}	-246.4
I_{Ngs}	-249.2
Summe	**-154.2**

Fig. 7 Contribution of the different noise sources to the phase noise at f_m = 10 MHz

Acknowledgement

This research project has been financially supported by the Deutsche Forschungsgemeinschaft (SFB 348).

References

[1] Dambrine, G. et al: A new method for determining the FET small signal equivalent circuit. IEEE Trans. MTT, Vol.36, 1988, No.7, pp. 1151-1159.

[2] Berroth, M.; Bosch, R.: Broad band determination of the FET small signal equivalent circuit. IEEE Trans. MTT, Vol.38, 1990, No.7, pp. 891-895.

[3] Felgentreff, T.; Olbrich, G.; Russer, P.: A small signal databased HEMT model for nonlinear time domain simulation. -In: Simulation of Semiconductor Devices and Processes, Vol. 5, Eds.: S. Selberherr, H. Stippel, E. Strasser. Wien: Springer-verlag Wien New York, 1993, pp. 269-272.

[4] Felgentreff, T.; Olbrich, G.; Russer, P.: Noise parameter modeling of HEMTs with resistor temperature noise sources. IEEE MTT-Symposium Digest 1994, pp. 853-856.

[5] Pospieszalski, M.: Modeling of noise parameters of MESFETs and MODFETs and their frequency and temperature dependence. IEEE Trans. MTT, Vol.37, No.9, pp.1340-1350

[6] Felgentreff, T.; Anzill, W.; Olbrich, G.; Russer, P.: Analysis of g-r noise upconversion in oscillators. IEEE MTT-Symposium Digest 1995, Vol.2, pp. 947-950.

[7] Kärtner, F.X.: Analysis of white and f^{-a} noise in oscillators. Internat. Journal of circuit theory and applications, vol.18, 1990, pp. 485-519.

[8] Filleböck, M., Anzill, W.; Russer, P.: Low phase noise design of microwave oscillators. IEEE MTT-Workshop Digest "Advances in microwave and mm-wave synthesizer technology", Orlando, 19. May 1995.