MODELING OF LOW FREQUENCY NOISE SOURCES IN HEMTS

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Abstract

For amplifier and oscillator applications it is often necessary, to know the low frequency noise behavior of the used HEMT device. In this paper we present the models of two important low frequency noise contributions - the $f^{-\alpha}$ noise and the generation/recombination noise (*g-r* noise). Starting with measurements of the noise power spectral densities at about 100 bias points we can find analytical expressions for the characterization of two noise current sources assumed in the channel of the HEMT. The two low frequency noise current sources are implemented in a large signal physics based HEMT model, which describes the signal and noise properties in the frequency range from 1 Hz to 40 GHz and is used for oscillator phase noise calculations. Also other noise current sources in this model will be discussed.

Introduction

The development of high performance microwave subsystems like low noise amplifiers or low phase noise oscillators requires precise information about the characteristic noise behavior of their components. One of the important parameters is the baseband noise of the active elements. In this paper we present models for two low frequency noise sources in HEMT devices between 1 Hz and 40 MHz - i.e. $f^{-\alpha}$ noise and generation/recombination noise. In oscillators this low frequency noise is upconverted to noise sidebands of the carriers and gives the dominating contribution to the phase noise of oscillators [1,2].

Measurement Setup

Fig. 1 shows the measurement setup we use for the characterization of the baseband noise of active devices up to 40 MHz. The evaluation of the measured drain voltage is done either by a FFT-analyzer or an analog spectrum analyzer.

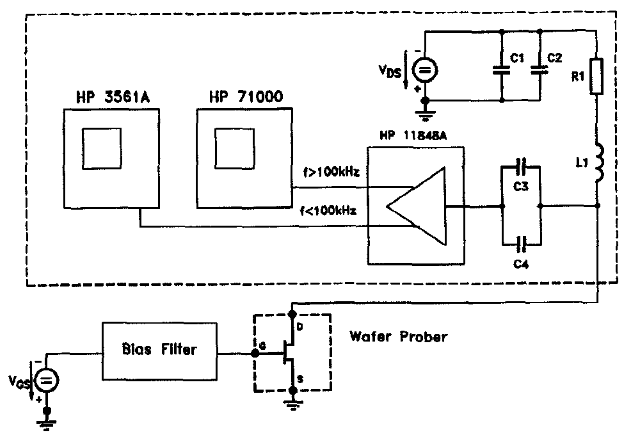

Fig. 1 Baseband noise measurement setup

For comparison in Fig. 2 some low frequency noise power spectra of different active devices are shown. The power spectral density of the voltage fluctuations $S_v(f)$ is given by

$$S_v(f) = 10 \cdot \log \frac{u_{rms}^2}{1\mathrm{V}^2} \quad \text{in} \quad [\mathrm{dBv}].$$

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Therefore a value of -120 dBv corresponds to an effective noise voltage of u_{rms}=1 μV/√Hz. In addition the residual noise contribution of the

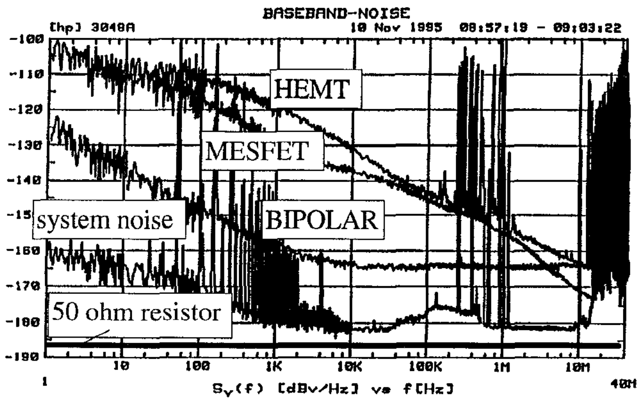

Fig. 2 Low frequency noise power spectra of different active devices (bipolar, MESFET, HEMT, residual noise of measurement setup, thermal noise of 50 ohm resistor)

measurement system and the theoretically thermal noise power spectrum of a 50 ohm resistor also is given. Although the measurements were done in a metal shielded chamber spurious signals can be seen being caused by digital bus and video frequencies and referring to 50 Hz line frequency and its harmonics.

Modeling of Low Frequency Noise Sources

In AlGaAs/GaAs-HEMT devices the measured low frequency noise spectra show different noise contributions. As an example in Fig. 3 we can find a typically fundamental $f^{-\alpha}$ noise at lower drain currents and superimposed an additional generation recombination noise, which appears only at higher drain currents. In literature this additional *g-r* noise is referred to deep level traps in the AlGaAs-layer of the HEMT [3,4]. Both low frequency noise contributions are modeled as noise current sources $In_{1/f}$ and In_{gr} in the channel of the HEMT and combined in the low freqency noise source I_{NF} in the equivalent circuit (Fig. 8). The spectral power density of the low frequency $f^{-\alpha}$ noise source is determined from low frequency noise measurements at about 100 different bias points.

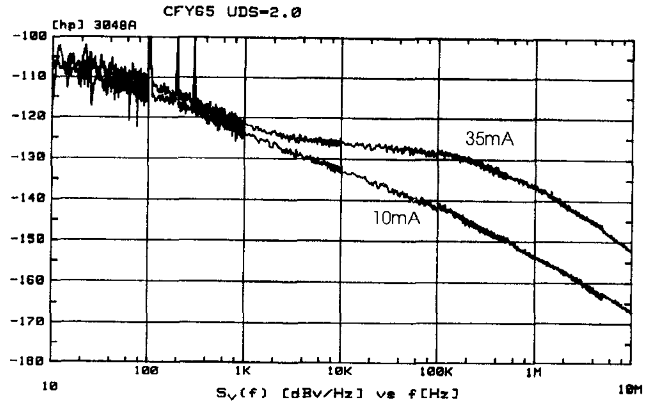

Fig. 3 Low frequency $f^{-\alpha}$ noise measurement results at two different bias points (I_{ds}=10mA, I_{ds}=35mA)

The correlation spectrum of the $f^{-\alpha}$ noise source is given by

$$C(f) = \frac{c_0(U_{gs}, U_{ds}) \cdot (10kHz)^{\alpha}}{|f_m|^{\alpha}}$$

The function $c_0(U_{gs}, U_{ds})$ denotes the spectral noise power at a frequency of 10 kHz in dependence of the gate-source and the drain-source voltage. The exponent α was obtained by averaging the slope of the measured baseband noise between 1 kHz and 100 kHz. For the analytical description of the noise current $In_{1/f}$ we derive the equation

$$In_{1/f} = \left[\left(\left(\frac{a \cdot b^{-\left(\frac{U_{gs}}{g}+1.5\right)}}{d + \frac{U_{ds}}{g}}\right) + c\right) \cdot e\right] \cdot I_{ds}$$

with the parameters

a	0.190813E–01	
b	0.949643E+02	
c	0.934592E–04	
d	0.252189E+01	
e	0.100000E–02	1/√Hz
g	1.0	V

Fig. 4 shows the approximated and measured low frequency noise current versus U_{ds}, normalized to the DC channel current I_{ds}.

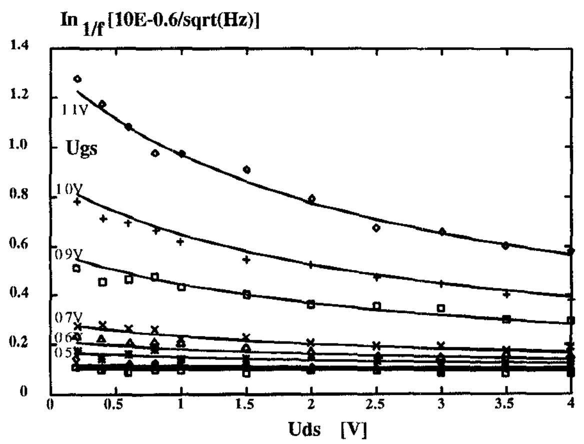

Fig. 4 Measured data and plot of the modelled f^{-a}-noise current $In_{1/f}$ normalized to I_{ds}

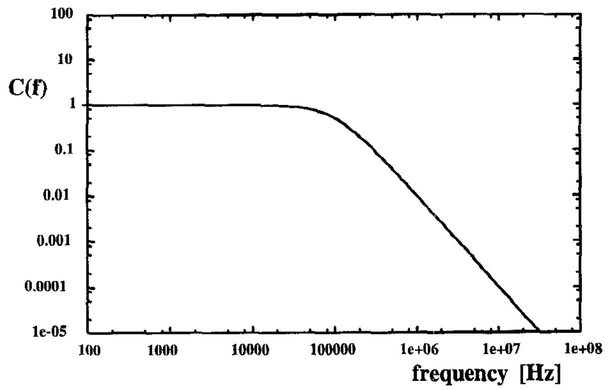

Fig. 5 Lorentzian spectrum of *g-r* noise process

The *g-r* noise shows a Lorentzian spectrum (Fig. 5). From low frequency noise measurements we can extract the term α_{gr} and the time constant of the trap level τ_{gr}. For the evaluated active device we find a corner frequency of 200 kHz which corresponds to τ_{gr}=5μs [5]. This is a first order approximation, because the DX-center consists of more than one deep level trap and should be modeled by more than one *g-r* noise source. Fig. 6 shows measured data and the modeled *g-r* noise current source. As a first order approximation the amplitude of the *g-r* noise current source was determined to be linearly dependent on the DC channel current by

$$In_{gr}=\gamma I_{ds} \qquad \text{with } \gamma=1.64\cdot 10^{-7}.$$

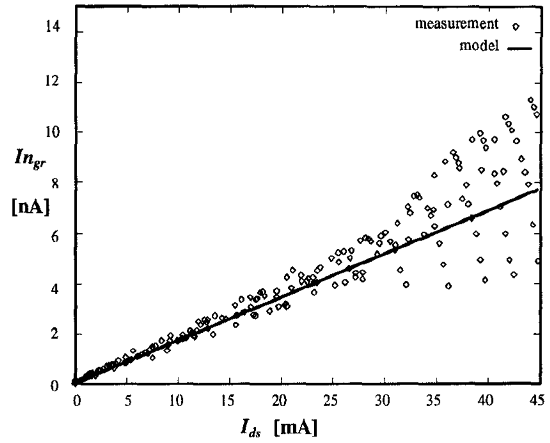

Fig. 6 Measured and modeled data of the *g-r* noise current source (AlGaAs/GaAs-HEMT)

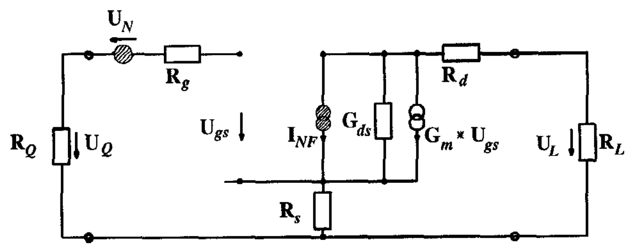

Fig. 7 Low frequency noise equivalent circuit of the HEMT device

Fig. 7 shows the equivalent low frequency circuit of the HEMT we use for the calculation of the noise current sources. The amplitudes of the noise current sources are calculated from the measured noise voltage power spectra due to

$$\sqrt{<I_{NF}^2>}=\sqrt{<V_L^2>}\frac{1}{R_L}\left[1+(R_L+R_d+R_s)G_{ds}\right]$$

The amplitude of the modeled noise current sources is mainly influenced by the value of the output conductance and the load resistance.

Conclusion

The derived models were implemented in a large signal and noise equivalent circuit (Fig. 8), which also contains noise current sources for

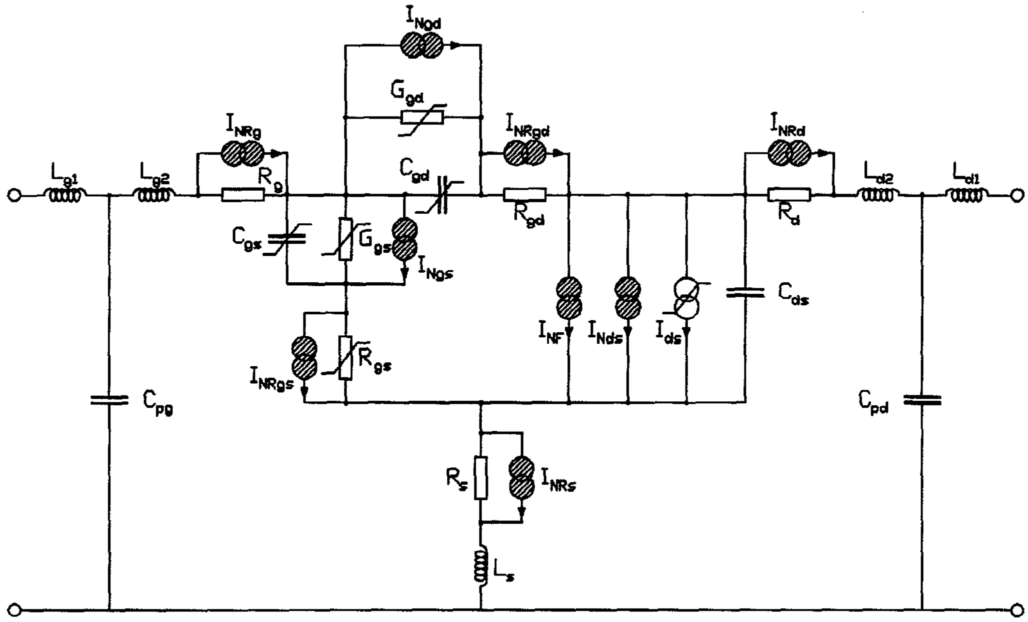

Fig. 8 Large signal and noise equivalent circuit of a HEMT device

the Schottky noise of the diodes and thermal noise of the three resistors in the inner HEMT [6,7]. The $f^{-\alpha}$ - and the g-r noise sources describe with adequate accuracy the low frequency noise behavior of the analyzed HEMT device and allow the phase noise calculation of a 15-GHz-HEMT-oscillator (Fig. 9) with an agreement of ±3dB between measured and calculated data.

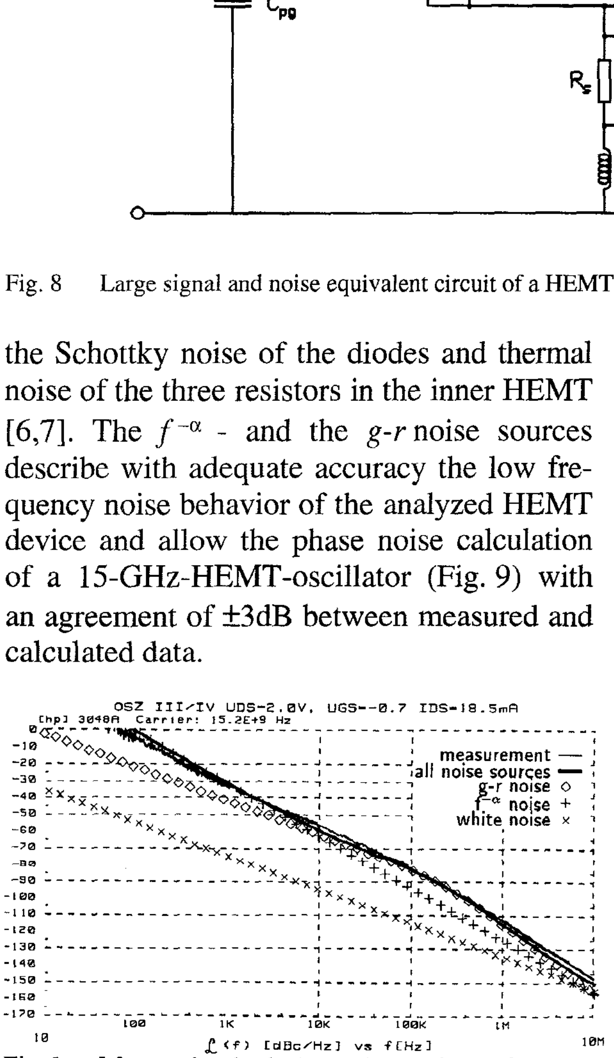

Fig. 9 Measured and calculated phase noise performance of a 15-GHz-AlGaAs/GaAs-oscillator

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