A BIAS DEPENDENT HEMT NOISE MODEL

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ABSTRACT

We present a model to describe the noise performance of HEMTs in dependence of the applied gate and drain voltages. The model is based on two uncorrelated noise sources at the intrinsic transistor. Temperatures related to resistors in the intrinsic transistor model are used to model the noise behavior of the device. By using the correlation matrix technique the parameters are extracted from noise parameter measurements in a straightforward manner.

INTRODUCTION

The modeling of the large signal properties of HEMTs is commonly used in the microwave community while the modeling of the noise properties is very often reduced to a few bias points in the saturation region of the device. This is because of the fact that S-parameter measurements can be performed very time efficient while noise parameter measurements require specialized equipment and time. Nevertheless for an accurate prediction of the behavior of MMICs a precise modeling of the signal as well as noise properties of the devices is required.

In this paper we present an analytical model to describe the noise behavior of HEMTs in dependence of the applied bias. Additionally the proposed model allows one to predict the noise behavior of the HEMT at much higher frequencies then those where the measurements for the parameter extraction were taken as well as at extended bias points.

NOISE MODELING TECHNIQUE

For the modeling of the signal and noise properties of the HEMT we use the equivalent circuit shown in figure 1.

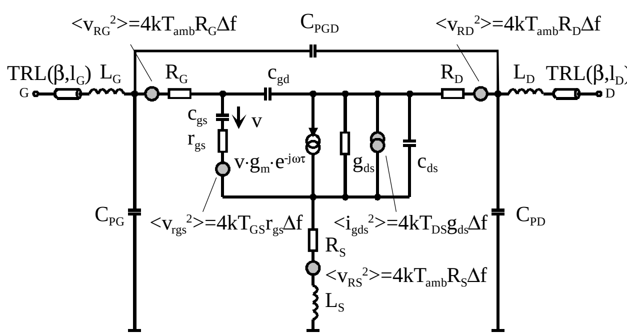

Figure 1 - Equivalent circuit of the HEMT including noise sources

The measurements are taken at the external terminals and include S-parameters and noise parameters (F_{min}, R_n, Γ_{opt}) over the bias field of interest.

If the equivalent circuit elements are determined one can use the correlation matrix technique [1] to determine the associated noise temperatures T_{GS} and T_{DS} [2] related to rgs and gds. All other resistive elements contribute thermal noise only and therefore their noise contribution is known with their ambient temperature.

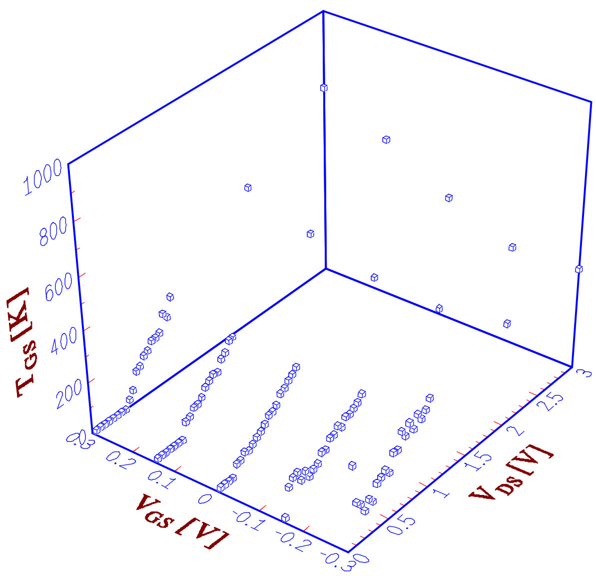

Figure 2 - Bias dependence of T_{GS}

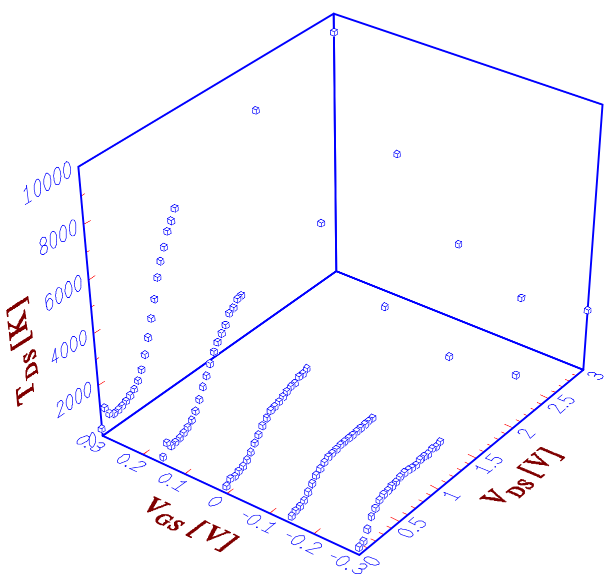

Figure 3 - Bias dependence of T_{DS}

The dependence of the temperatures T_{GS} and T_{DS} (calculated from noise parameter measurements) on the external bias is shown in figures 2 and 3. Commonly T_{GS} is regarded as constant at the ambient temperature. We have found that this is true for the saturation region and small drain currents only. For the first time we introduce a bias dependent model for T_{GS}. To describe the shown behavior we use the following functions for the dependence on the intrinsic voltages:

$$T_{GS} = f(V_{gs}, V_{ds}) = \cdot \left(V_{ds} - \right)^2 + \qquad (1)$$

$$T_{DS} = f(V_{gs}, V_{ds}) = \left(+ \cdot V_{ds}\right) \cdot tanh\left(\cdot \{V_{ds} - \}\right) + \qquad (2)$$

Because small errors in T_{GS} in the linear region (low transconductance) of the HEMT have not such a great influence on the noise performance we used a first order approximation for the modeling. That reduces the number of parameters.

	T_{GS}		
	κ	λ	φ
$m_{\kappa...\varepsilon}$	-94.2	-3.52	1718
$n_{\kappa...\varepsilon}$	0.156	-0.394	0.268
$p_{\kappa...\varepsilon}$	-43.48	3.895	375

Table I - Extracted parameters for T_{GS}

	T_{DS}				
	α	β	γ	δ	ε
$m_{\kappa...\varepsilon}$	25.5	-0.275	11263	7822	11458
$n_{\kappa...\varepsilon}$	-0.1	-0.929	0.218	0.19	0.21
$p_{\kappa...\varepsilon}$	3.58	0.53	674	141	763

Table II - Extracted parameters for T_{DS}

The procedure to find the parameters is the following. At first the extrinsic bias grid (V_{GS}, V_{DS}) must be converted to an orthogonal intrinsic bias grid (V_{gs}, V_{ds}) by using interpolation routines. Then for a set of fixed gate source voltages the functions (1) and (2) are fitted to T_{GS} and T_{DS}, respectively. This results in gate source voltage dependent parameters κ, λ, φ, α, β, γ, δ, and ε. Those parameters are functions of the gate source voltage therefore we introduce so-called secondary functions to model them. Fortunately there is a square dependence of all parameters on the gate source voltage and one can use functions of the following form for all those parameters.

$$\ldots = f(V_{gs}) = m_{\ldots} \cdot \left(V_{gs} - n_{\ldots}\right)^2 + p_{\ldots} \qquad (3)$$

EXPERIMENTAL RESULTS

Following the described procedure one can find a set of 15 parameters for T_{DS} and a set of 9 parameters for T_{GS}. The parameters for the HEMT device (0.25x4x45 µm²) from figures 2 and 3 are shown in table I and II. For clearness the units are left out.

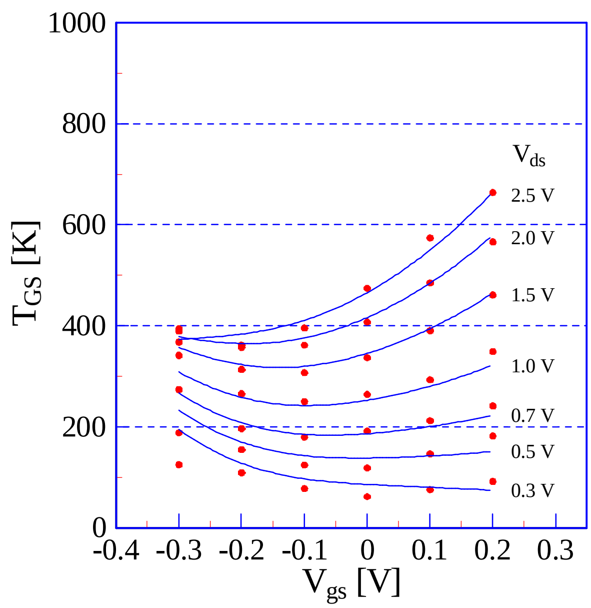

Figure 4 - Comparison between measured () and modeled ( ) T_{GS}

With the parameter sets from table I and II and equations (1) and (2) one can calculate the temperatures T_{GS} and T_{DS} for any bias point. A comparison between measured and modeled temperatures can be seen in figures 4 and 5.

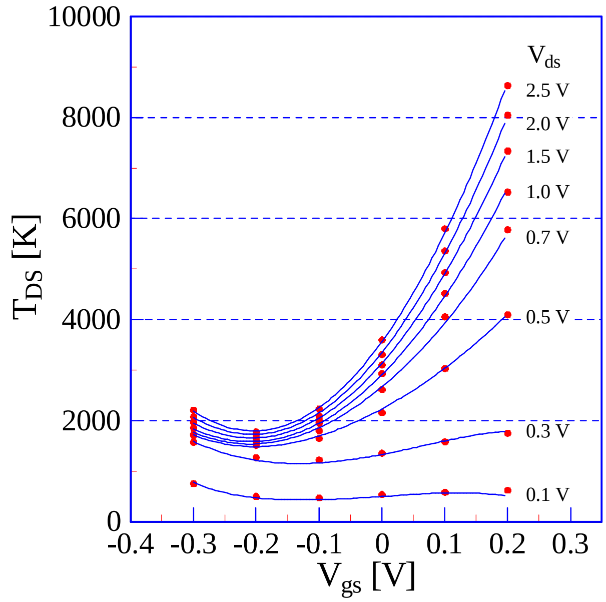

Figure 5 - Comparison between measured () and modeled ( ) T_{DS}

Finally we show the validity of the used temperature noise model by a comparison between measured and simulated noise parameters (F_{min}, R_n, Γ_{opt}) for one bias point. Figure 6 to 9 indicate a good agreement of the prediction by the model and the measurement. A similar result is achieved over the whole bias field.

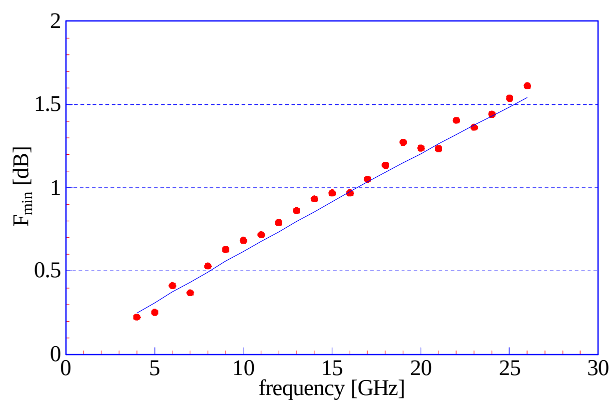

Figure 6 - Comparison between measured () and modeled ( ) F_{min}

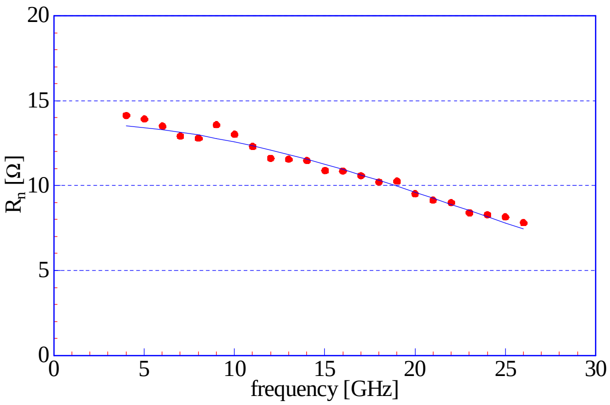

Figure 7 - Comparison between measured () and modeled ( ) R_n

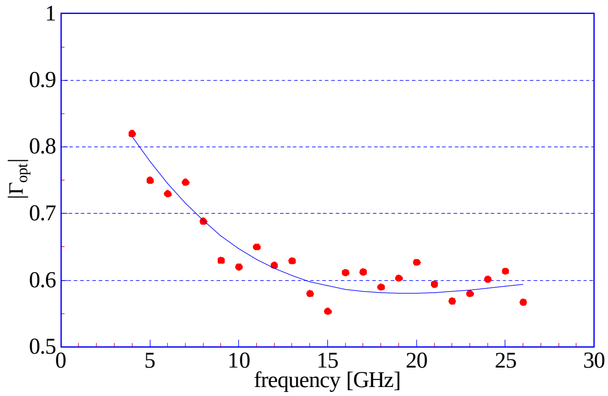

Figure 8 - Comparison between measured () and modeled ( ) magnitude of $_{opt}$

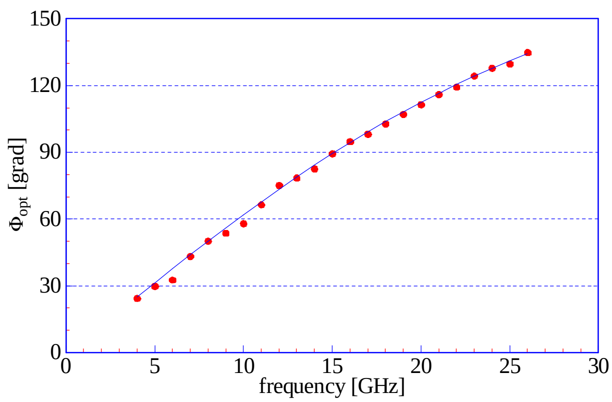

Figure 9 - Comparison between measured () and modeled ( ) phase of $_{opt}$

CONCLUSION

The proposed model can be used for small signal designs (low noise amplifier) as well as large signal designs like mixers and oscillators. Because of the fact that it uses analytical functions it is very fast and no interpolation is required for any bias point. The parameter extraction is straightforward and can be carried out using any mathematical program. It has been shown that the assumption of a constant T_{GS} does not hold over the whole bias field of the HEMT device and accurate modeling needs to account for the variation in T_{GS}.
The proposed model was successfully used for the prediction of the noise figure of a MMIC X-Band gate mixer using the shown HEMT device.

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