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A Smallsignal Databased HEMT Model for Nonlinear Time Domain Simulation

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Abstract

Accurate and simple nonlinear modeling of semiconductor devices for use in nonlinear CAD is of significant importance, especially at higher frequencies. In this paper we present a nonlinear HEMT model, which is directly based on measured data. Therefore time consuming optimization techniques during the modeling process are eleminated. The values of the equivalent circuit elements are derived from DC and smallsignal RF measurements and are stored in a twodimensional lookup table. Using this model we calculate the harmonics generated by the nonlinear elements of the device. For the verification of this model we compare the results with measured data and results obtained by conventional empirical HEMT models [1], [2], [3]. The measured and calculated data deviate less than 1.5 dB.

1. Nonlinear Databased Model

The nonlinear model is based on DC and S-parameter measurements of the transistor at all bias points of interest. At operating points in the region near pinch-off a higher density of data points is choosen than in areas with much more linearity (Fig. 2). The data obtained from S-parameter measurements are deembeded from the extrinsic elements using techniques described in [4] and [5]. The next step is to calculate the value of all the intrinsic nonlinear elements at each bias point. Therefore the voltage drop at the extrinsic resisitive elements R_s and R_d has to be taken into acount. The values of the nonlinear elements are stored in a twodimensional lookup table as functions of the two independent controlling voltages V_{gs} and V_{ds} at the intrinsic HEMT. No optimization process is performed to calculate this table. Because there are no functional approximations to fit the measured data no information gets lost and the modeling process works quite fast.

The databased model is used in nonlinear time domain CAD programs. The values stored in the twodimensional lookup table are used directly by the simulation program. The description of the equivalent circuit of the transistor (Fig. 1) in the time domain is done by a system of differential equations.

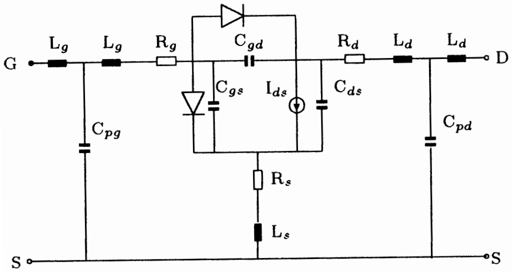

Figure 1: HEMT Equivalent Circuit

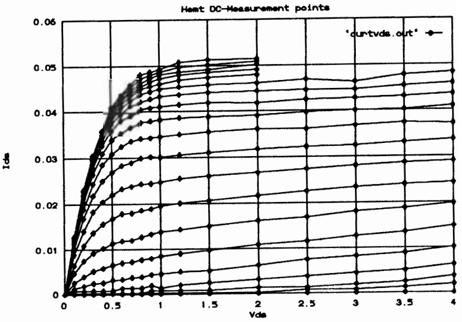

Figure 2: I_{ds} vs. V_{ds} (parameter V_{gs})

The values for untabulated points are obtained by interpolation. Two different interpolation methods -the bilinear interpolation and the bicubic spline interpolation- were tested for calculation. Both interpolation methods show little difference. So the faster bilinear interpolation was used. Two capacitors (C_{gs} , C_{gd}) and the nonlinear current source I_{ds} are considerd to depend on the bias voltages V_{gs} and V_{ds}. In addition the parameters of the two diodes were seperatly determinated and applied to the model.

To verify the nonlinear model the output power at the fundamental frequency and its harmonics were measured. Measurements take place in a 50 Ω system using a wafer prober. The measured results are compared with calculations. A time domain simulator is used to compute the output power at the fundamental frequency and its harmonics.

The modeling process was performed on a standard GaAs/GaAlAs MODFET CFY 65. The semiconductor chip was mounted on a carrier Al_2O_3-substrate and bonded to coplanar waveguide interconnections. The S-parameters were measured in the frequency range 0.1 to 40 GHz at more than 200 bias points using a wafer prober and a computer controlled measurement setup. The verification of the model was done at a fundamental frequency of 5 GHz. In Figures 4 and 5 the empirical Curtice and Materka HEMT model given in [1] combined with the Meyer capacitance-voltage relationship [6] are compared with results from measurement and from the databased HEMT model. The results obtained from the different models agree within 2 dB; however the databased model describes best the measured results of the fundamental frequency and its higher harmonics compared to the measured data.

The nonlinear databased HEMT model was primarily developed for use in CAD software for the simulation of oscillators in the time domain and combined time/frequency domain using FATE [7]. As an example the simulated and measured results of a 16 GHz coplanar HEMT oscillator build on an Al_2O_3-substrate are presented. Figure 6 shows output power versus normalised frequency for different models and measured results with V_{gs} as parameter. Figure 7 shows the same quantities with V_{ds} as parameter. Only the databased model can describe the measured tuning characteristic. These results show the significant advantage of this model concerning especially the accurate modeling of the capacitances (Fig. 3).

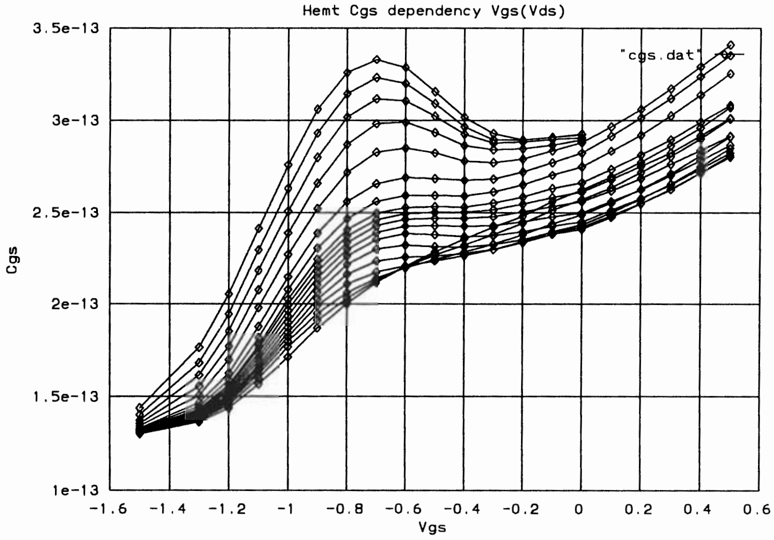

Figure 3: C_{gs} vs. V_{gs} (parameter V_{ds})

2. Conclusion

An accurate and simple nonlinear model for use in nonlinear CAD has been presented. The model was applied to a GaAs/GaAlAs-HEMT, but it is also applicable to MESFEFTs. Because of the greater nonlinearities in HEMTs the use of the databased model is more advantageous. The model, that is directly based on measured data, is used for the time domain simulation of amplifiers and oscillators. The model has been proved to give more accurate results than conventional empirical models.

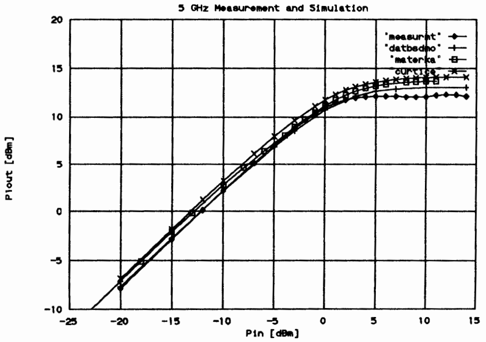

Figure 4: Fundamental Power

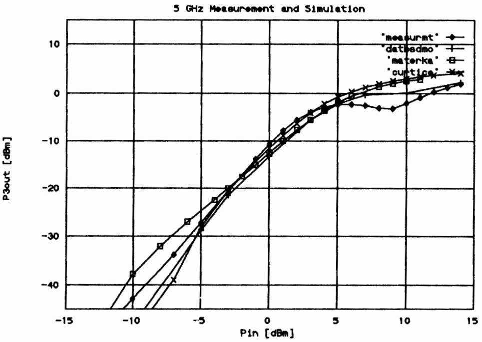

Figure 5: Third Harmonic Power

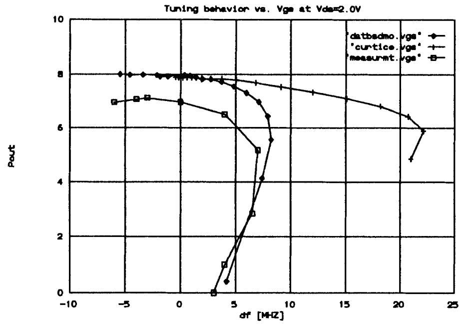

Figure 6: Oscillator output power vs. normalized frequency (parameter Vgs)

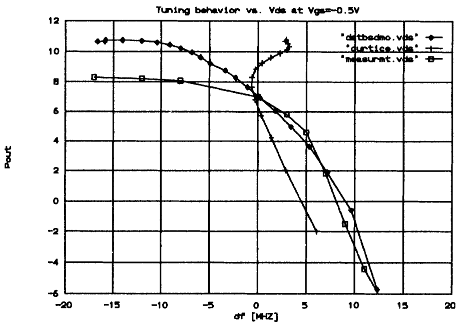

Figure 7: Oscillator output power vs. normalized frequency (parameter Vds)

Acknowledgement

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