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A New 20-element distributed Small-Signal Model and Integrated Intelligent Extraction Method applied to AlGaN/GaN HEMTs up to 40GHz

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1. Introduction

Accurate small-signal equivalent circuit model is vital for circuit design, process evaluation, and device performance optimization. However, due to the high contact resistances in the source and drain region, the standard parameter extraction method for HEMTs cannot be performed directly for GaN-based HEMTs [1]. Previous works [2, 3] on GaN-based HEMT modeling can mainly be classified into two categories: direct extraction method and optimization-based methods. The former usually cannot satisfy very high frequency application for lower accuracy, whereas the latter is often sensitive to the starting point of the optimization and lack of stability.

In this paper, a new 20-element distributed small-signal equivalent circuit (Fig.2) is proposed. Compared with traditional 16-element HEMT SSM [4], two parasitic distributed inter-electrode extrinsic capacitances (Cgsi, Cdsi) account for inter-electrode and crossover capacitances between gate and , source and drain. Moreover, two additional feedback-intrinsic resistances (Rlgd, Rlgs) are added for consideration of the gate leakage current. Correspondingly, we developed a simple but efficient direct extraction technique. This new extraction system is proved to be able to achieve much better agreement between measurement and simulation than the traditional 16-element SSM within the frequency range from 50MHz to 20GHz.

At the higher frequency range (up to 40GHz), we found that the direct extraction method is not so competent. The average scalar error [3] between simulation and measurement is above 25%. To meet higher frequency application (up to 40GHz) we developed a new optimization procedure including modified Differential Evolution (DE) algorithm and a self-adaptive bound technique. After efficiently integrating the direct extraction and the optimization process, we can achieve a good agreement between simulation and measurement in the wide frequency range (50MHz to 40GHz).

2. Direct Extraction

The flow of direct extraction is shown in Fig.1 (in dashed frame). The bias-independent extrinsic elements are extracted from S-parameters at cold conditions (Vds=0). After de-embedding parasitic elements, the bias-dependent intrinsic elements were obtained from intrinsic Y-parameter. Considering that the frequency-dependent effect in the intrinsic elements cannot be neglected, especially in the linear bias condition [3], we adopted an efficient method in which the intrinsic elements are formulated analytically by the intrinsic Y-parameters without any omits. By simple linear data fitting these intrinsic parameters can be determined.

3. DE Optimization Method

Differential Evolution (DE) algorithm is proved to be independent on the starting points [5], which is significant for optimization to escape from local minimum. To improve the efficiency and keep the results' validity, we proposed three modifications to the canonical DE algorithm. First, an initial search bound for each parameter is derived from the results of direct extraction. Second, we normalized the parameter bounds into [0,100], because DE is very effective in [0,100]. Thus, the speed and ability of optimization can be improved. Third, we developed a self-adaptive bound expansion technique in order to search out of the predetermined bounds and achieve better results when there is a conflict between the optimization goal (minimization of the total deviation between the measured and simulated S-parameters) and the predetermined bounds.

Further, we developed a link for data transmission between the coding environment and HSPICE. So we can employ HSPICE for circuit calculation and analysis. The reliability of the optimization enhanced greatly.

A comparison between our procedure and ICCAP (Agilent) Levenberg-Marquardt optimizer [6] was made. The detailed comparison result is shown in follow section.

4. Results and Discussion

The 20-elements distributed model and extraction processes described above has been verified by modeling AlGaN/GaN HEMTs samples (Vth=-6V, gate-length=1μm gate-width=200μm) over a frequency range from 50MHz to 40GHz. Fig.3 shows the scalar errors and gain errors [3] between simulated and measured data of direct extraction from 50MHz to 20GHz. The comparison shows that the average error of 20-element modeling system is only half as that of tradtional16-element modeling system. Fig.4 shows S-parameter comparison between measurement and simulation of DE optimization as well as LM optimization over higher frequency range from 50MHz to 40GHz. It can be realized that the agreement between meas. and DE optimization are much better than that between meas. and LM optimization. The advantages of DE optimization also can be acquired from Fig.6 in which the comparison of errors in different biases condition between DE and LM is shown. the average scalar error and gain error by our procedure are about 8.42% and 1.64% respectively comparing with 15.36% and 5.96% optimized by LM optimizer, at a wide bias and frequency range (Vgs: -5V ~ 0V, Vds: 2V ~10V, frequency: 50MHz ~40GHz). Fig.5 shows the dependence of the main intrinsic parameters on frequency, which reveals that our approach feasible and robust.

3. Conclusions

A new 20-element distributed SSM and a simple direct extract method are proposed for GaN HEMT. Better extraction results are achieved than the traditional lumped SSM. In higher freq. application (up to 40GHz) a modified DE algorithm and self-adaptive bound expansion technique are proposed for optimization. The scalar errors can be achieved within 10% in a wide bias and freq. range.

Acknowledgements

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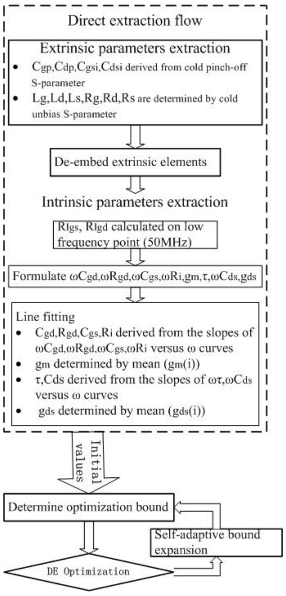

Fig. 1 The flowchart of the whole extraction process

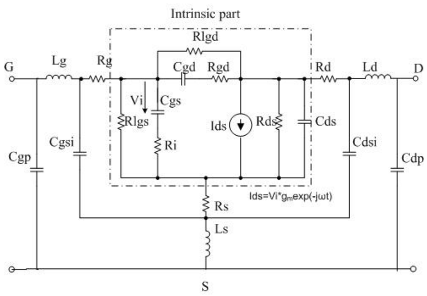

Fig. 2 20-element equivalent circuit

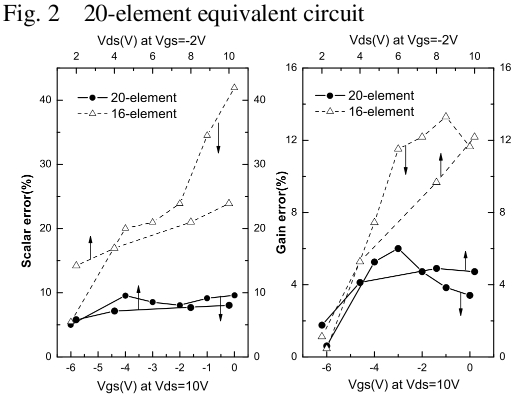

Fig. 3 Comparison of Scalar (square) and Gain (triangle) Errors between 20-element model and 16-element in direct extraction at different biases freq. from 50MHz to 20GHz

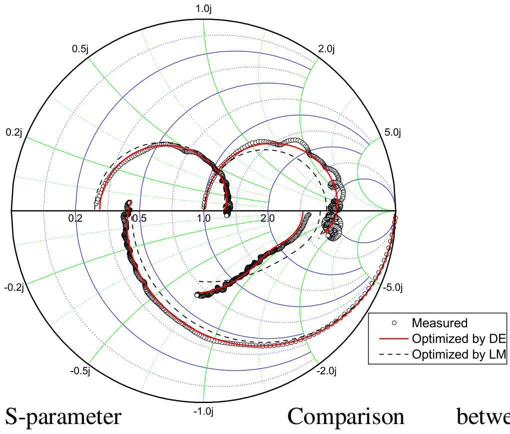

Fig. 4 S-parameter Comparison between measurement (circle) and result of DE optimization (solid line) and result of LM optimization (dashed) for 20-elements model (Vgs=0V, Vds=10V, Freq: 50MHz ~40GHz)

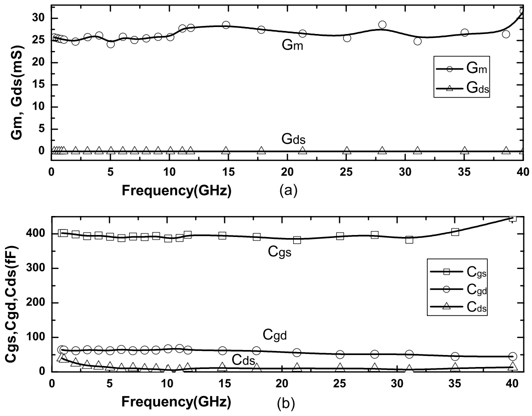

Fig. 5 (a) Extracted gm and gds versus frequency at Vgs=-2V, Vds=10V; (b) Extracted Cgs, Cds and Cgd versus frequency at Vgs=-2V, Vds＝10V

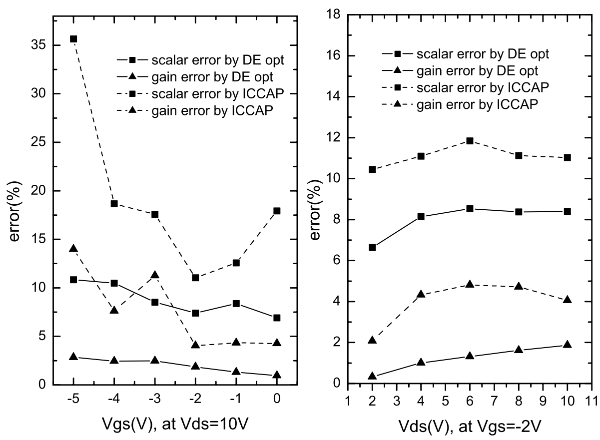

Fig. 6 Comparison of Scalar (square) and Gain (triangle) Errors between DE optimization (solid) and ICCAP L-M optimization (dashed) at different biases freq. from 50MHz to 40GHz