Distortion Analysis of GaAs MESFETs Based on Physical Model using PISCES-HB

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Abstract

Distortion simulations of GaAs MESFETs based on physical model and applying harmonic balance method have been demonstrated. Simulation of circuit configurations with components such as blocking capacitors and RF chokes feeding 50 ohm terminations was performed. Good agreement has been obtained between simulation and measurements for harmonic distortion and two-tone inter-modulation distortion characteristics.

Introduction

GaAs MESFETs with low distortion characteristics are strongly demanded in multi-channel communication systems. A device simulator that can predict the distortion characteristics only from the physical and structural parameters is also desired for optimizing the device structures such as doping profiles of donors and the length and width of the gate. The harmonic balance (HB) method is a popular technique in circuit simulation for non-linear frequency domain analysis (1)(2). This method was previously implemented in the device simulator PISCES-HB (Harmonic Balance version of PISCES (3)) which solves drift-diffusion transport equations in frequency domain and allows simulation of distortion components such as harmonically fluctuating local electron density, quasi-Fermi level and total drain current (4)(5)(6).

In this paper, we demonstrate first-time quantitative distortion analysis of GaAs MESFETs based on a physical model using a two-dimensional device simulator PISCES-HB. Power of harmonics were directly simulated for MESFETs in circuit configurations with components such as blocking capacitors and RF chokes feeding 50 ohm terminations. It has been shown that the simulation gave a reasonable results in the analysis of harmonic and inter-modulation distortion characteristics.

Simulation

In order to directly compare the device performance between simulation and experiments, the PISCES-HB has been improved so that it can handle simulations of GaAs MESFETs in circuit configuration as shown in Fig.1. The power of harmonics and inter-modulation distortion dissipated in 50 ohm terminations are directly calculated just as a virtual spectrum analyzer. The feedback circuit consisting of serial resistor of 330ohm and capacitor of 1000pF has been attached in order to perform a distortion simulation for a practical wide-band feedback amplifier operating from 70MHz to 1000MHz.

The GaAs MESFET used in the experiment and simulation was fabricated on a epitaxial wafer grown by MOCVD and has a channel layer consisting of a n-GaAs and undoped GaAs as shown in Fig.2. The gate length and the gate width are 1μm and 1.2mm, respectively.

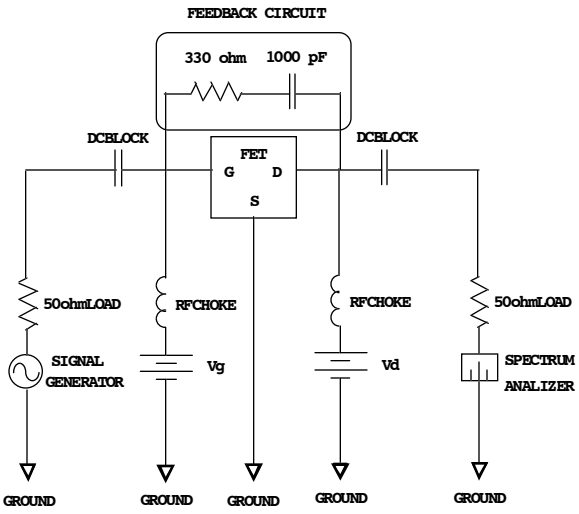

Fig. 1. Simulated circuit configuration with a feedback circuit, blocking capacitors and RF chokes feeding 50 ohm termination.

Result

A. DC and RF characteristics

The measured and simulated current - voltage characteristics for this MESFET are shown in Fig.3. In this simulation, hyperbolic tangent mobility model was used. The semi-insulating GaAs substrate and the undoped GaAs layer were assumed to be a p-type GaAs with an acceptor density of 10^{15} cm^{-3} to fit the threshold voltage. As compared with the measured result, the simulation gave lower knee voltage and higher drain saturated current in the higher drain and gate voltage region. These disagreements are considered to be caused by the fact that parasitic effect such as contact resistance of electrodes and thermal effect which occurs in the case of a wide channel FET are not considered in the simulation.

The comparison of frequency dependence of gain between simulation and measurement is shown in Fig. 4. Circle symbols represent the gain of a MESFET with feedback circuit and triangle symbols represent that of a MESFET without feedback circuit at Vgs=-2.5V, Vds=3V and Pin= -10dBm. Good agreement between simulation and measurement has been obtained in the case of without feedback circuit. The simulated MESFET with feedback circuit, however, showed smaller gain than the measurement at high frequency region. This is probably due to the inductance elements which exists in a real feedback circuit. This is supported by the fact that the same disagreement has also been found in the frequency dependence of gain using circuit simulation.

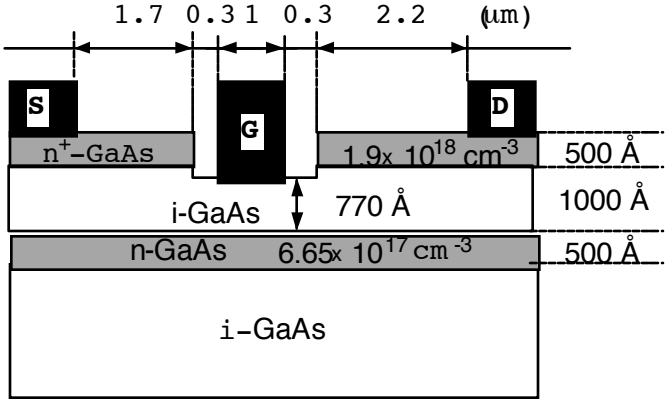

Fig. 2. A cross-section of 1 μm gate-length and 1.2mm gate-width epitaxial GaAs MESFET used in simulation and experiment.

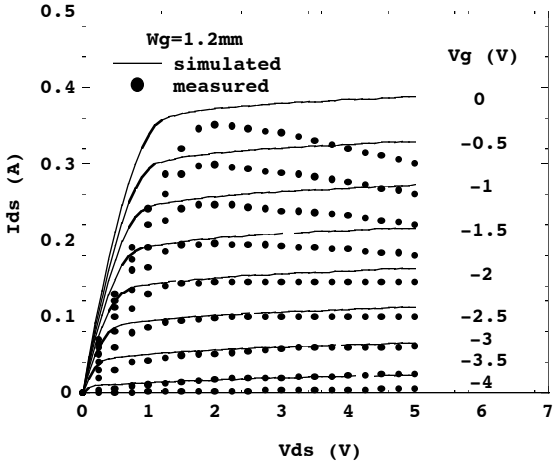

Fig. 3. Comparison of current - voltage characteristics between simulation and measurement for a MESFET shown in Fig. 2.

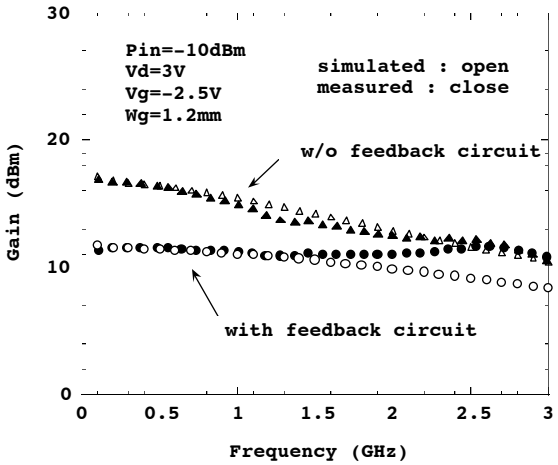

Fig. 4. Comparison of frequency dependence of gain between simulation and measurement for a MESFET shown in Fig. 2.

B. Harmonic Distortion

The measured and simulated harmonic distortion for this MESFET are shown in Fig. 5. The simulation has been performed in the circuit configuration as shown in Fig. 1 with feedback circuit. The input tone has a frequency of 400MHz and its power was swept from -30dBm to 0dBm. The drain current was set to a quarter Idss. Good agreement between simulation and measurement has been obtained for the bias condition of Vds=3V and Vgs=-2.5V.

Further improvements in dynamic range have been confirmed by applying tighter convergence creteria, at the expense of greater computational efforts.

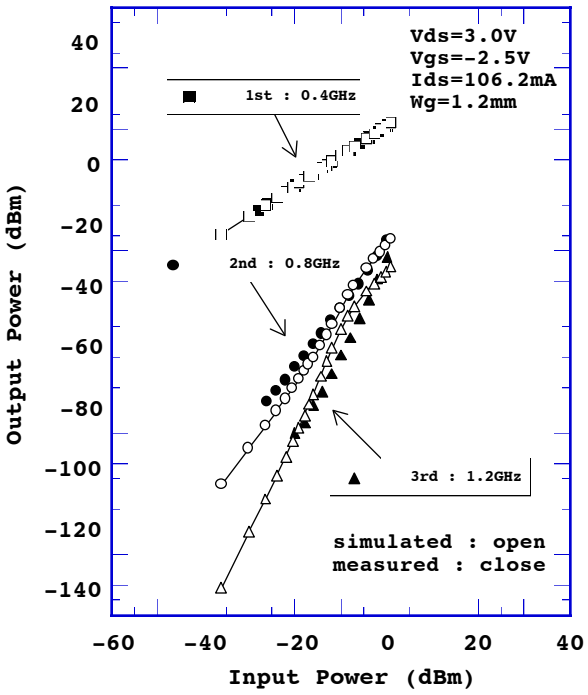

Fig. 5. Comparison of output power of harmonic distortion between simulation and measurement for a MESFET shown in Fig. 2

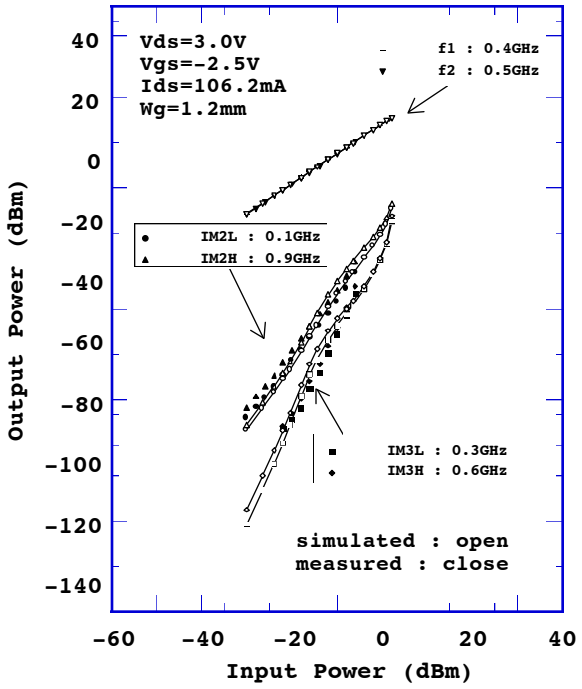

Fig. 6. Comparison of output power of two-tone inter-modulation distortion between simulation and measurement for a MESFET shown in Fig. 2

C. Inter-modulation Distortion

The measured and simulated two-tone inter-modulation distortion for this MESFET with feedback circuit are shown in Fig. 6. The input two tones have a frequency of 400 MHz and 500 MHz and the drain current was set to a quarter Idss. Good agreement between simulation and measurement has been obtained for the input power from -30dBm to -5dBm and the bias condition of Vds=3V and Vgs=-2.5V.

The gate bias dependence of output power, gain, output second and third order inter-modulation intercept point, IP2 and IP3 are also compared between simulation and measurement. Simulated and measured results at Vds=3V are shown in Fig. 7 and Fig. 8, respectively.

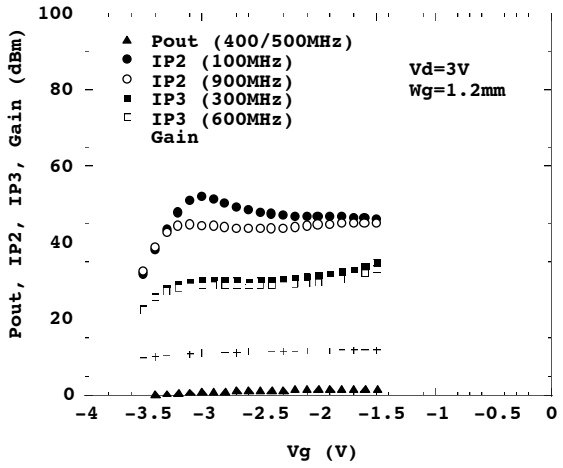

Fig. 7. Simulated gate bias dependence of output power, gain, and output second and third order inter-modulation intercept point, IP2 and IP3 for a MESFET shown in Fig.2.

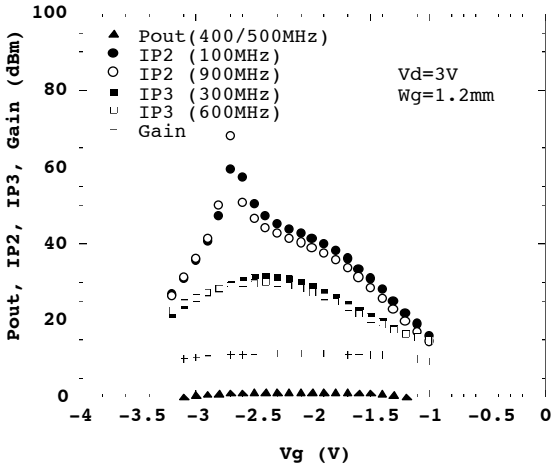

Fig. 8. Measured gate bias dependence of output power, gain, and output second and third order inter-modulation intercept point, IP2 and IP3 for a MESFET shown in Fig.2.

It is seen that measured IP2 has a peak at Vgs around -3V, which is well reproduced in the simulation. The measured IP2 and IP3, however, rapidly decreased in the higher gate voltage region, and the disagreement with simulation became quite large. This is probably caused by the disagreement of current - voltage characteristics as shown Fig.3 due to the thermal effect. Although quantitative comparison was not possible owing to such disagreement, we have confirmed the simulation gave qualitatively reasonable result at various drain bias condition. For example, at Vds=4.5V, IP2 shows two peaks at Vgs around -0.9V and -1.8V in the simulation and Vgs around -1.3V and -2.4V in the measurement. Therefore, it is concluded that our simulation by PISCES-HB gives reasonable distortion characteristics at least in the low gate and drain bias conditions and still more improvements are expected by taking thermal effects into account.

Conclusion

First-time quantitative distortion analysis of GaAs MESFETs based on physical model using two-dimensional device simulator PISCES-HB has been demonstrated.

The input power - output power characteristics of harmonic distortion and two-tone inter-modulation distortion and the gate bias dependence of IP2 and IP3 have been compared between simulation and measurement. Although in this simulation, a parasitic effect and a thermal effect have not been considered and the fitting of current - voltage characteristics was not enough at higher gate bias conditions, the simulation gave qualitatively reasonable distortion characteristics compared with the experiment. Especially good agreement has been obtained between simulation and measurement for the bias region where DC characteristics agreed well between simulation and measurement. These results clearly show the validity and usefulness of distortion simulation using PISCES-HB.

Acknowledgment

Authors would like to thank Mr. Kawashima of Matsushita Electronics Corporation for fabricating of devices, and Dr. Inada and Dr. Kano of Matsushita Electronics Corporation for their encouragement to this work.

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