A Novel Method for the Higher Order Components Extraction of the Channel Current in GaAs MESFET

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ABSTRACT

We propose a new simple and accurate method for the higher order Taylor coefficient extraction of the channel current in GaAs MESFET. In this method, the nonlinear channel currents are directly measured through a hole current sensor and spectrum analyzer. Taylor coefficients up to 3rd order have been successfully extracted from the measured currents of the low frequency(4MHz, 25MHz) two-tone test, and a resonator is added to the load to remove the gate frequency component from the drain voltage, which makes the problem simple. The proposed extraction procedure is simple and straightforward.

INTRODUCTION

Volterra series analysis has been the common technique used for the prediction of distortion properties of weakly coupled nonlinear circuits. This analysis is superior, in terms of conversion efficiency in numerical simulation, to the harmonic balance or the time-domain methods [1]. In Volterra series, all nonlinear components must be represented by the Taylor series expansion form. In GaAs MESFET, the channel current, I_{ds}, is known as the most significant nonlinear source[1-2]. The Taylor expansion form of the channel current is given by equation (1). In this equation, all the Taylor coefficients of the channel current are dependent on the bias voltages.

$$\begin{aligned} i_{DS}(v_{GS}, v_{DS}) &= I_{DS}(V_{GS}, V_{DS}) \\ &+ G_m \cdot v_{gs} + G_d \cdot v_{ds} \\ &+ G_{m2} \cdot v_{gs}^2 + G_{md} \cdot v_{gs} v_{ds} + G_{d2} \cdot v_{ds}^2 \\ &+ G_{m3} \cdot v_{gs}^3 + G_{m2d} \cdot v_{gs}^2 v_{ds} \\ &+ G_{md2} \cdot v_{gs} v_{ds}^2 + G_{d3} \cdot v_{ds}^3 \\ &+ \cdots \end{aligned} \tag{1}$$

where I_{DS} is the bias current and v_{GS}, v_{DS} are $V_{GS} + v_{gs}$, $V_{DS} + v_{ds}$ respectively. v_{gs}, v_{ds} are small signal gate and drain voltage, respectively, and V_{GS}, V_{DS} are the DC bias points of the device.

Many works for extracting the high order Taylor coefficients of $I_{ds}(v_{gs}, v_{ds})$ in equation(1) have been reported [1-6]. The coefficients of the equation (1) have been extracted by a least-square fit of the measured S-parameters at several bias points [4] or of the microwave two-tone test data [5]. These methods are inaccurate due to the measurement error and insufficient data in the fitting process. Recently, more advanced methods based on the low frequency harmonic measurements were proposed [1-3]. These methods have merits that the measurement errors are small and the coefficients can be analytically extracted. However, Maas method [1] cannot represent the cross terms of I_{ds}, i.e., a transconductance variation with v_{ds} and an output conductance variation with v_{gs}. To extract the cross terms, there should be sufficient independent measurement. Pedro [2] reported a method of the more accurate harmonic component measurement technique. In this method, the independent measurement was performed by applying a signal to gate side and the other one to drain side. But Pedro method is very complex. Because the measurement system should have a high power source at the drain side and a very high performance duplexer to reject the leakage of harmonics generated from the large signal source. In the article [3], a low frequency two-tone test is used, but the load impedance should be carefully designed to extract the accurate coefficients through the Volterra series analysis.

In this work, a direct method for extracting the Taylor coefficients of the channel current is proposed based on the nonlinear current measurement method.

NONLINEAR CURRENT MEASUREMENT METHOD

Fig. 1 shows an equivalent circuit model of a GaAs MESFET. In that circuits, the intrinsic capacitors and the channel current are nonlinear elements. But all the intrinsic capacitances(C_gd, C_ds, and C_gs) are almost open in low enough frequency. Therefore, only the channel is the nonlinear source.

The nonlinear channel current was directly measured using Textronic AM503 current amplifier and A6305 current probe, and the output of the current amplifier is applied to spectrum analyzer to obtain each harmonic components. In this measurement, it is not so easy to find the absolute current level, but it is very easy to obtain the relative level between other frequency components. Since the fundamental components could be found from small signal measurement, each current level could be obtained from the relative levels. If each current components are obtained, the Taylor coefficients of the channel current can be directly extracted from the measured currents. This is a simple and direct method to measure the Taylor coefficients of the channel current.

The experimental setup is shown in figure 2. A resonator is added at the drain, and its resonance frequency is 25MHz as shown in figure 2, which shows the $|S21|$ of the resonator. In this experiment, the input signal frequencies are selected 25MHz(ω_g) for the gate, and 4MHz(ω_d) for the drain, respectively. At this low frequencies, the C_{gs}, C_{ds}, and C_{dg} are almost open, so that the FET can be assumed as an unilateral device. Because of that, the drain signal does not come out at the gate (v_{gs}). And the resonator is designed to be short at 25MHz by resonance, and open at 4MHz as shown in figure 2, so that the drain voltage (v_{ds}) does not have ω_g frequency component. Therefore, the $v_{ds}(\omega_d)$ is dominant at the drain node, and the $v_{gs}(\omega_g)$ is dominant at the gate node. Actually, these facts have been confirmed from the gate and drain voltage measured through an oscilloscope and spectrum analyzer. Therefore, the gate and drain voltage can be approximate as following.

$$\begin{aligned} V_{gs} &= V_{gs}(\omega_g) + V_{gs}(\omega_d) + \cdots \simeq V_{gs}(\omega_g) \\ V_{ds} &= V_{ds}(\omega_g) + V_{ds}(\omega_d) + \cdots \simeq V_{ds}(\omega_d) \end{aligned} \quad (2)$$

From the equations (1) and (2), the second order coefficients(G_{m2}, G_{md}, G_{d2}) are obtained from the measured nonlinear 2nd order currents of $I_n(2\omega_g)$, $I_n(2\omega_d)$, $I_n(\omega_g + \omega_d)$, and $I_n(\omega_g - \omega_d)$.

$$\begin{aligned} I_n(2\omega_g) &= G_{m2} \cdot V_{gs}^2 \\ I_n(\omega_g + \omega_d) &= G_{md} \cdot V_{gs} \cdot V_{ds} \\ I_n(\omega_g - \omega_d) &= G_{md} \cdot V_{gs} \cdot V_{ds} \\ I_n(2\omega_d) &= G_{d2} \cdot V_{ds}^2 \end{aligned} \quad (3)$$

In the same way, the third order coefficients, G_{m3}, G_{m2d}, G_{md2}, and G_{d3} are obtained from the measure 3rd order nonlinear currents.

$$\begin{aligned} I_n(3\omega_g) &= G_{m3} \cdot V_{gs}^3 \\ I_n(2\omega_g + \omega_d) &= G_{m2d} \cdot V_{gs}^2 \cdot V_{ds} \\ I_n(2\omega_g - \omega_d) &= G_{m2d} \cdot V_{gs}^2 \cdot V_{ds} \\ I_n(\omega_g + 2\omega_d) &= G_{md2} \cdot V_{gs} \cdot V_{ds}^2 \\ I_n(\omega_g - 2\omega_d) &= G_{md2} \cdot V_{gs} \cdot V_{ds}^2 \\ I_n(3\omega_d) &= G_{d3} \cdot V_{ds}^3 \end{aligned} \quad (4)$$

From the above equations, each nonlinear coefficients can be directly obtained and the polarity of each coefficient is easily guessed based on the measured results.

RESULT

In this experiment, OKI KGF-1284 MEFET is used at the bias point of V_{GS} from -2.7 to -1.3 V and V_{DS} = 3.6 V. The extracted second and third order harmonic channel current coefficients in equation (1) are shown in figure 3 - 5. The extracted coefficients The main advantage of this technique is that the measurement method is very simple and straightforward, and because of the low frequency, the transistor equivalent circuit can be simplified for analysis.

CONCLUSION

In this article, we have proposed a very simple and straightforward method to measure the higher order Taylor series coefficients of the channel current of GaAs MESFET. A resonator added at the drain to remove the gate frequency component from the drain voltage, and the nonlinear channel currents are directly measured by the current probe and spectrum analyzer. That makes all the problems simple. From this method, the harmonic components up to 3rd order are successfully extracted.

REFERENCES

[1] S. A. Maas and D. Neilson, "Modeling GaAs MESFET's for intermodulation distortion analysis," *Microwave Journal,*, vol. 34, pp. 295 - 300, May 1991.

[2] J. C. Pedro and J. Perez, "Accurate Simulation of GaAs MESFET's Intermodulation Distortion Using a New Drain-Source Current Model," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-42 pp. 25 - 33, Jan. 1994.

[3] Tae Moon Roh, Youngsik Kim, Youngsuk Suh and Bumman Kim, "A new simple extraction method for higher order components of channel current in GaAs MESFET," *27'th European Microwave Conf. Dig.,* Jerusalem, Israel, Sept 1997.

[4] Robert A. Minasian, "Intermodulation Distortion Analysis of MESFET Amplifiers Using the Volterra Series Representation," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-28 pp. 1 - 8, Jan. 1980.

[5] Rodney S. Tucker, "Third-Order Intermodulation Distortion and Gain Compression in GaAs FET's," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-27 pp. 400 - 408, May 1979.

[6] S. A. Maas and D. Neilson, "Modeling GaAs MESFET's for intermodulation analysis of Mixer and Amplifiers," *IEEE Trans. Microwave Theory Tech.,*, vol. MTT-38, pp. 1964 - 1971, Dec 1990.

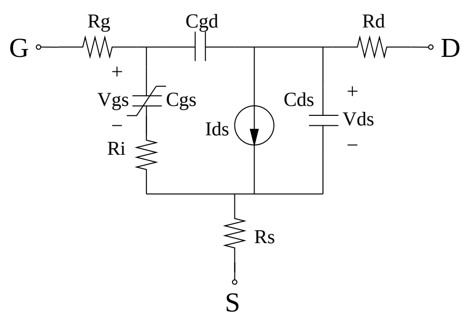


Fig. 1. Equivalent circuit of a GaAs MESFET

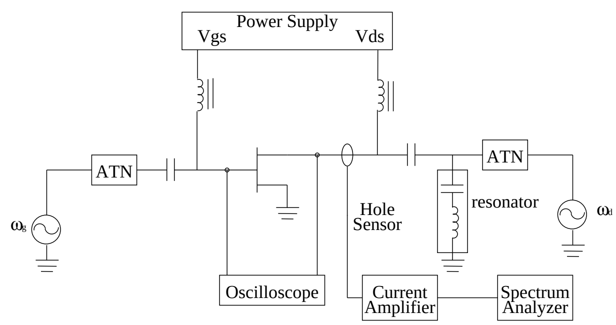
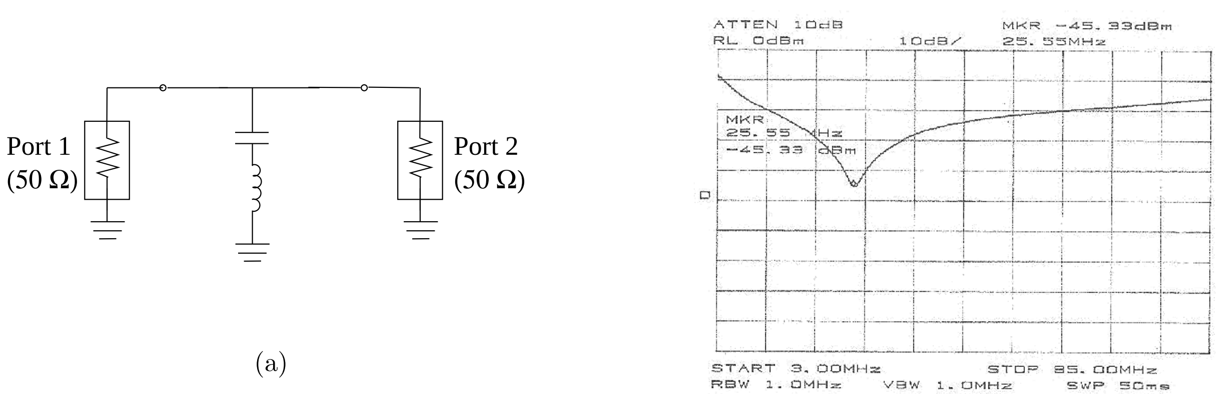


Fig. 2. Experimental setup used for the low frequency harmonic measurement



(a)

(b)

Fig. 3. Resonator(a) and the measured response of the resonator(b)

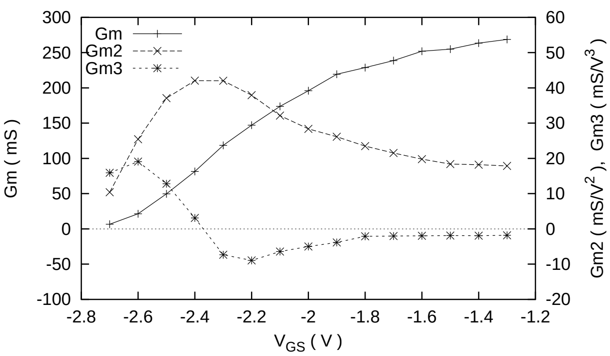


Fig. 4. Measured Gm, Gm2, and Gm3 of the KGF-1284 for V_{GS} = -2.7 -1.3 V. V_{DS} = 3.6 V

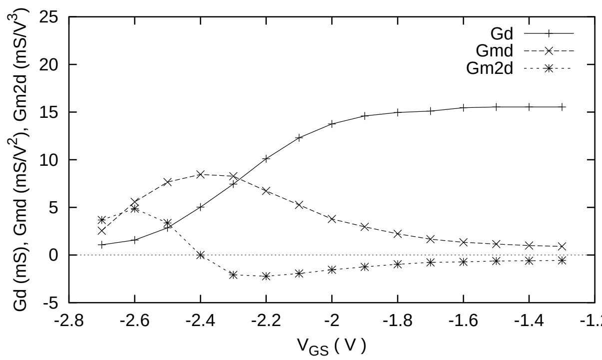


Fig. 5. Measured Gd, Gmd, and Gm2d of the KGF-1284 for V_{GS} = -2.7 -1.3 V. V_{DS} = 3.6 V

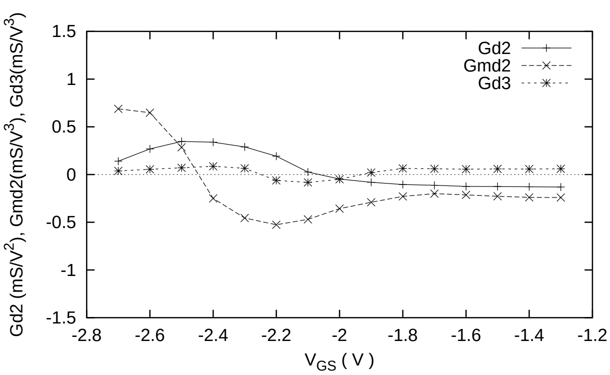


Fig. 6. Measured Gd2, Gmd2, and Gd3 of the KGF-1284 for V_{GS} = -2.7 -1.3 V. V_{DS} = 3.6 V