ANALYTIC REPRESENTATION OF NONLINEAR PARAMETERS OF MICROWAVE MESFET's

GiorgioLeuzzi, NicolaMinnaia, FrancoGiannini

Dept. Electronic Engineering, II University of Roma Tor Vergata Roma, Italy

ABSTRACT

A new type of analytic formulae is given for the representation of the bias-voltage dependence of non-linear elements of a MESFET. Accuracy and range of validity make them suitable for non-linear CAD applications.

KEYWORDS: Modelling, MESFET's, Non-linear

INTRODUCTION

Non-linear equivalent-circuit models (Fig. 1) are the standard representation of microwave transistors in CAD programmes for non-linear microwave circuit design (Ref.1). The intrinsic elements of the circuit have voltage-dependent values extracted from microwave measurements at different bias points; the elements' dependence on bias voltages is introduced into the model via analytic functions fitted to the experimental behaviour of the components. The precision of this representation depends both on measurements' accuracy and on fitting functions' aptness to interpolate the results of the measurements. A polynomial of low degree would be accurate enough for relatively smooth curves and a limited range of interpolation voltages (Ref.2,3); however, if large gate and drain voltage swings must be accounted for, as is the case for Class B or C operations, a different class of functions must be used. Transcendental functions (like for instance the hyperbolic tangent) on the other hand may be used in wide ranges, have a good asymptotic behaviour and may easily be made to fit the typical shape of the experimental curves. Therefore formulae based on such functions have been implemented for the various non-linear elements of the equivalent circuit; a fitting procedure for typical curves has also been defined.

THE ANALYTIC FUNCTIONS

A combination of hyperbolic functions and low-degree polynomials has been used to fit the experimental curves. Data come from small-signal measurements of the MESFET repeated at many bias points; the extraction of the equivalent circuit at each bias point has been performed at low frequency after a well-known method (Ref.5). I-V curves come from DC and pulsed measurements. A typical set of curves used to fit the dependence of small- signal gate-source capacitance on gate-source and drain-source voltage is:

$$C_{gs} = C_{gso}\left(V_{gs}\right) + C_0 \cdot tgh\left\{a\left(V_{gs}\right)\left[V_{ds} - b\left(V_{gs}\right)\right]\right\}\sqrt{1 + K \cdot V_{ds}}$$

where

$$C_{gso}(V_{gs}) = C_1 + C_2 \cdot (1 - tgh(C_3 - V_{gs})) \left[1 + C_4 \cdot \frac{V_{gs}}{C_6 - V_{gs}}\right]$$

$$a(V_{gs}) = A_1 \cdot \{1 - tgh[A_2 \cdot (A_3 - V_{gs})]\}$$

$$b(V_{gs}) = B_1 + B_2 \cdot (B_3 - V_{gs})$$

A similar set of curves may be used for gate-drain capacitance:

$$C_{gd} = \frac{C_{gdo}(V_{gs})}{\sqrt{c(V_{gs}) + V_{ds}}} + C_0 \cdot \{1 - tgh[a(V_{gs}) - (V_{ds} - b(V_{gs}))]\}$$

where

$$C_{gdo}(V_{gs}) = C_1 - C_2 \cdot V_{gs}^2$$

$$c(V_{gs}) = C_3 + C_4 \cdot V_{gs}^4$$

$$a(V_{gs}) = A_1 + A_2 \cdot \{1 + tgh[A_3 \cdot (V_{gs} + A_4)]\}$$

$$b(V_{gs}) = B_1 + B_2 \cdot (B_3 - V_{gs})$$

The dependence on gate-source and drain-source voltages has been separated for ease of fitting. The results for a MESFET NE9000 are shown in Figs. 2 and 3 for C_{gs} and C_{gd} respectively: the agreement is good. The formulae hold also for very large negative gate-source voltages, and can be made to be quite accurate near pinch-off. For drain-source current (pulsed measurements) a simple set of curves is:

$$I_{ds} = \beta(V_{gs}) tgh\{\alpha(V_{gs}) \cdot V_{ds}\}[1 + \gamma(V_{gs}) \cdot V_{ds}] + \delta(V_{gs}, V_{ds})$$

where

$$\alpha(V_{gs}) = \alpha_1 \cdot [1 + tgh(\alpha_2 \cdot V_{gs})]$$

$$\beta(V_{gs}) = \beta_1 \cdot [1 + tgh(\beta_2 \cdot V_{gs})]$$

$$\gamma(V_{gs1}) = \gamma_1 \cdot (1 - \gamma_2 \cdot V_{gs})$$

$$\delta(V_{gs1} V_{ds}) = \delta_1 \cdot e^{\frac{V_{ds} - \delta_2}{(1 - \delta_3 V_{gs})}}$$

The results are shown in fig.4. For DC curves, a thermal effect factor must be added, e.g. of the form:

$$F_{term} = 1 + [\epsilon(V_{gs}) \cdot V_{ds} + \varsigma(V_{gs})]$$

The fit can be improved using more complicated functions of the same type, at the expense of the effort required for the fitting procedure. The results are however very good, as shown in fig. 5 (DC curves of a Harris HMF0610)

THE FITTING PROCEDURE

The choice of the coefficients in the formulae can be done by trial-and-error; however, it is best done through an optimisation procedure. For each gate-source voltage, i.e. for each curve of the family, a standard optimisation routine is used to find the best values for the V_{gs}-dependent functions (like a or b) for that V_{gs}; a second optimisation step will find separately for each function of V_{gs} the best values for its coefficients (like A_i or B_i). A final optimisation can be performed on the complete set of curves. This procedure ensures a quicker and safer optimisation with respect to direct optimisation; nonetheless, a careful choice of the starting values in the first step is strongly suggested, in order to avoid convergence to erroneous values.

CONCLUSIONS

A family of analytic functions has been used to fit experimental curves of the dependence of non-linear equivalent-circuit elements on bias voltages; a fitting procedure has been suggested. The results show a good agreement with measurements for a wide range of voltages.

REFERENCES

1. Curtice W.R. 1988, GaAs MESFET modelling and non-linear CAD, IEEE Trans. Microwave Theory Tech., vol.36, pp.228-230

2. Madjar A. 1989, An improved analytical AC large-signal model for the GaAs MESFET, IEEE Trans. Microwave Theory Tech., vol.37, Nr.10, pp.1519-1522

3. Curtice W.R., Ettenberg M. 1985, A non-linear GaAs MESFET model for use in the design of output circuits for power amplifiers", IEEE Trans. Microwave Theory Tech., vol.33, Nr.12, Dec.1985

4. Materka A., Kacprzak T. 1985, Computer calculation of large-signal GaAs amplifier characteristics", IEEE Trans. Microwave Theory Tech., vol.33, Nr.2·

5. Dambrine G. et al. 1988, A new method for determining the FET small-signal equivalent circuit, IEEE Trans. Microwave Theory Tech., vol.36, Nr.7, pp.1151-1159

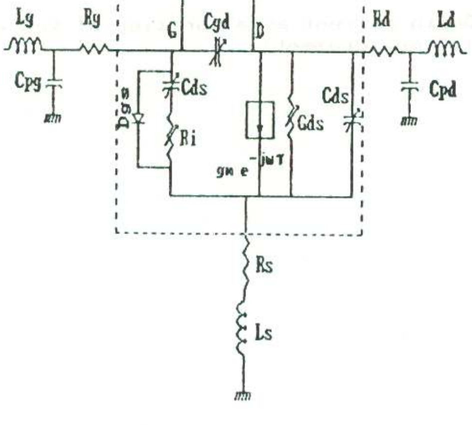

Fig.1 - The non-linear equivalent circuit

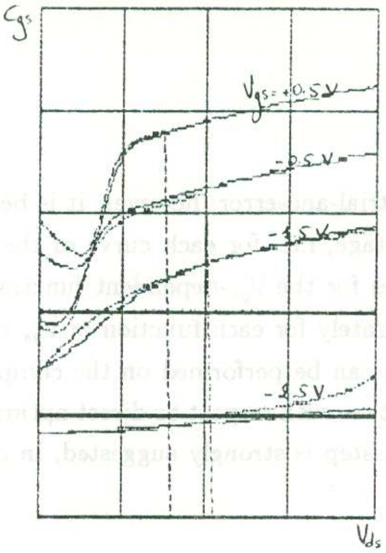

Fig.2 - Gate-source capacitance as a function of Vgs and Vds (measured and modelled)

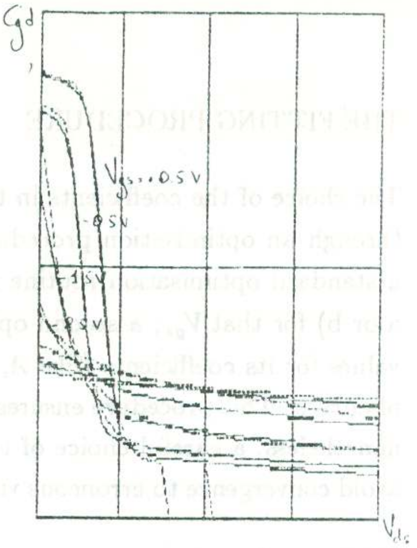

Fig.3 - Gate-drain capacitance as a function of Vgs and Vds (measured and modelled)

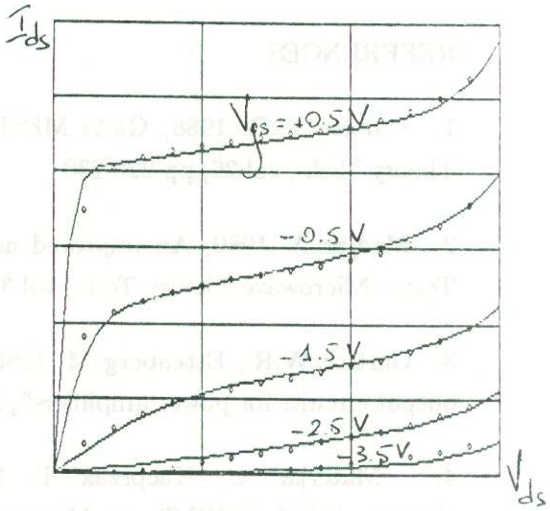

Fig.4 - Drain current as a function of Vgs and Vds (pulsed measurement)

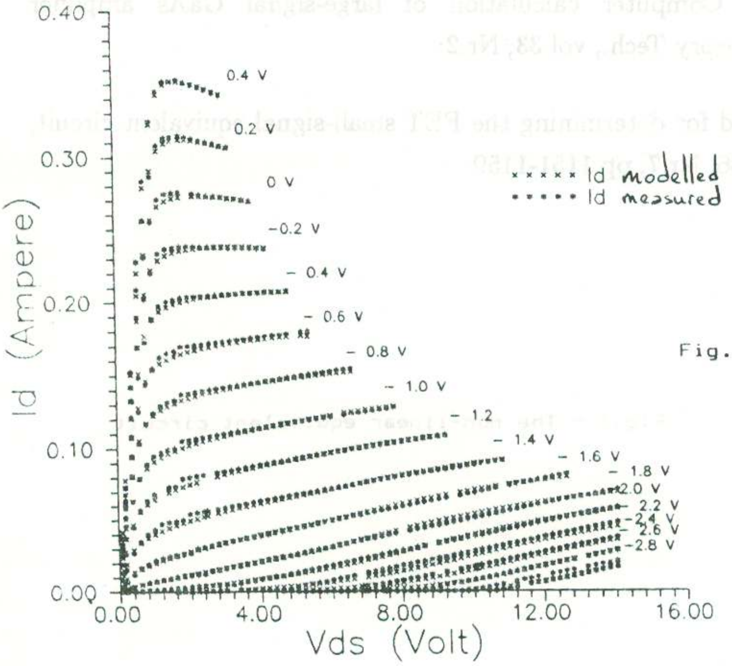

Fig.5 - Drain current as a function of Vgs and Vds (DC measurement)