Comparison of GaAs MESFET DC Models

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ABSTRACT

This paper describes a comparative study of ten GaAs MESFET DC models, including three new variations. The computations have been carried out using a new interactive program for nonlinear parameter extraction and sensitivity analysis (INTERSECT). The study concluded that the Curtice Cubic model, with seven parameters, provide the best fit to the two sets of MESFET DC characteristics used.

INTRODUCTION

Considerable work has been reported on the nonlinear CAD of GaAs MESFET devices and circuits. Many commercial and in-house programs have been developed, all relying for their operation on the mathematical description of the prime nonlinearities within the active device. The main nonlinearity is the relation between gate source voltage, drain source voltage and drain current. Many different equations have been used to curve fit measured DC characteristics, and many subjective assessments of their relative merit have been made. This paper describes the use of a new nonlinear optimisation tool, INTERSECT, to systematically and objectively compare the performance of a number of standard fitting equations with those new equation sets.

Table 1 reviews many of the existing equation sets which are presently employed for MESFET DC curve fitting. Of these "Statz" and "Cubic Curtice" are perhaps the most commonly employed. The table is completed by three new equations. Two of these are extensions of the Statz model to allow for channel length modulation as a function of V_{gs} (New 1), and the drain gate breakdown phenomenon (New 2), and the third due to Brazil.

In order to assess the validity of the alternative equations, two typical MESFET DC characteristics were considered. Each equation in turn was fitted to these measured characteristics using the interactive nonlinear parameter extraction program INTERSECT. For simplicity, the computed I_{ds}-V_{ds} characteristics (o) from only the Curtice cubic model (x) and Materka model (+) are shown in Figure 1 and the results compared with experimental characteristics, which refer to the NE71000 chip device and Plessey Foundry F20 monolithic device.

INTERSECT

INTERSECT has been designed to allow those without detailed knowledge of optimisation techniques to solve nonlinear parameter extraction problems. It seeks to do this by making it possible to explore the problem thoroughly, to simplify it as necessary without reformulation, and to ensure, by a variety of interactive menus, that the solution achieved is significant, accurate, and reliable.

The program computes optimal parameter values, carries out sensitivity analyses, and allows graphical expression of results. Optimisation can be defined in terms of least sum of squares of residual error, least absolute value or minimum maximum value. The optimisation algorithms provided include both modified Gauss-Newton and variable metric methods, and bounds can be placed on the acceptable values of parameters. To increase the scope for exploration, the user of INTERSECT can cause any subset of the set of parameters to be held fixed at any value while the values of the others are optimised. The data can be modified, and selected data points can be ignored during the optimisation.

Sensitivity analysis is based on an eigenvalue analysis of either the Hessian matrix of the sum of squares function, or on the Jacobian matrix. The analysis, which can be based on any point in the search space, is interactive in that the user can make exploratory steps along the eigenvector principle component directions, examining both the actual function values and the quadratic-prediction values at the new points.

RESULTS

Table 2 illustrates the results obtained, showing the equation parameters for best overall fit to the selected transistor characteristics.

Table 3 compares the complexity (in terms of the number of parameters needed) and the accuracy (in terms of an overall RMS error) of the alternative equation sets.

From this table it may be deduced that the Curtice Cubic model, with seven parameters, provided the best solution for both MESFET characteristics. However parameter fitting has been found to be difficult for this model. Moreover, for large negative V_{gs} and small V_{ds}, I_{ds} can go negative in contrast to

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the properties of the real devices.

In contrast, the Materka model, with only four fitting parameters, exhibits an acceptable performance. This model which is easy to parameter fit may therefore be a more acceptable choice for many applications.

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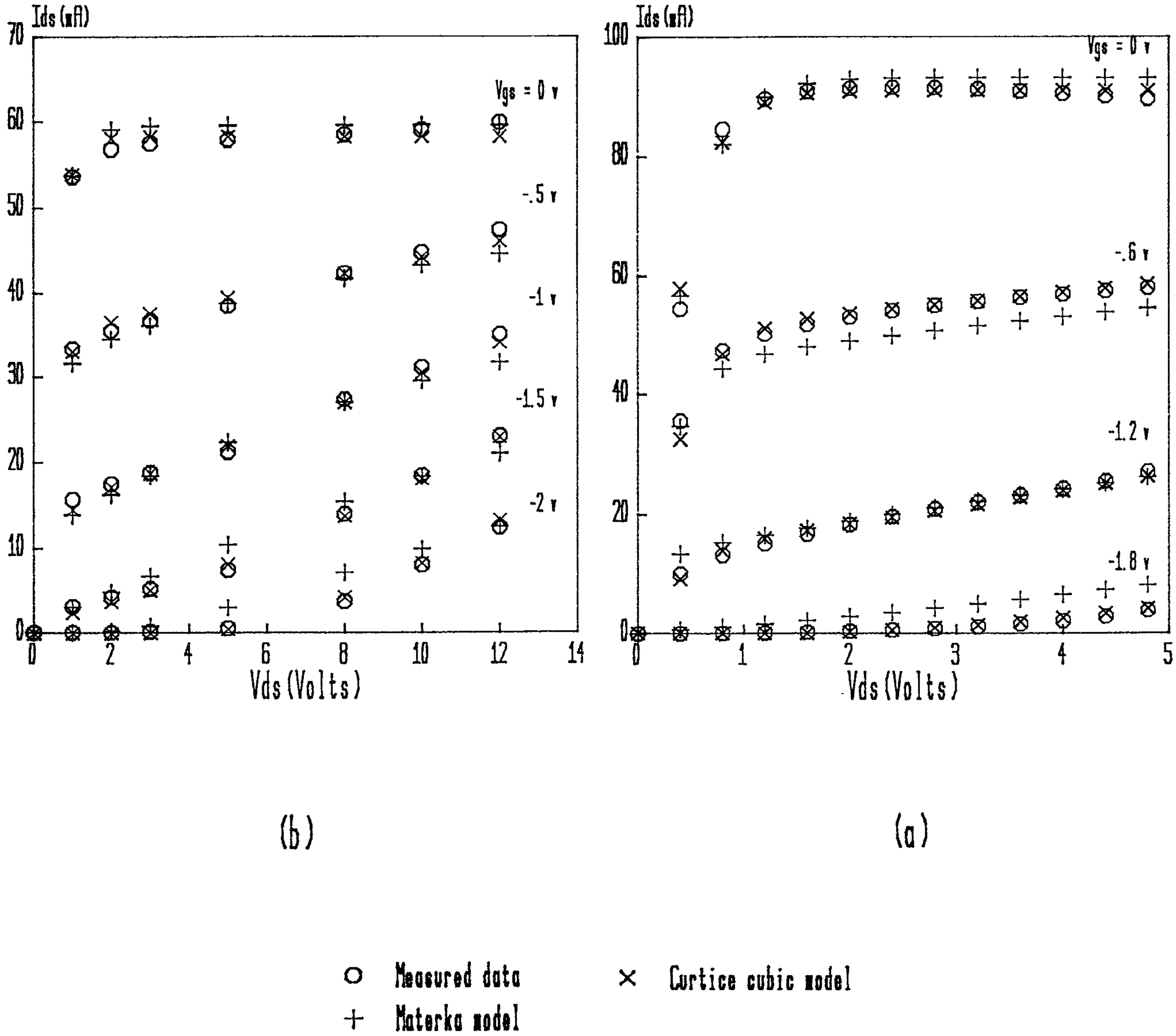

Fig. 1 Comparisons of simulation results and experimental data for MESFETs (a) NE71000 (b) Plessey F 20

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Table 1 Various GaAs MESFET DC Equations

Model Name	DC Equations
Taki [1]	$I_{ds} = I_{dss}(1 - \frac{V_{gs}}{V_{po}})^2 \tanh(\alpha \lvert \frac{V_{ds}}{V_{po} - V_{gs}} \rvert)$
Curtice Quad. [2]	$I_{ds} = \beta(V_{gs} - V_t)^2(1 + \lambda V_{ds})\tanh(\alpha V_{ds})$
Materka [3]	$I_{ds} = I_{dss}(1 - \frac{V_{gs}}{V_p})^2 \tanh(\frac{\alpha V_{ds}}{V_{gs} - V_p})$
Statz [4]	$I_{ds} = \frac{\beta(V_{gs} - V_t)^2}{1 + b(V_{gs} - V_t)}(1 + \lambda V_{ds})\tanh(\alpha V_{ds})$
Curtice Cubic [5]	$I_{ds} = (A_1 + A_2 V + A_3 V^2 + A_4 V^3)\tanh(\alpha V_{ds})$
Tajima 1 [6]	$I_{ds} = I_{d1} I_{d2}$
Tajima 2 [7]	$I_{ds} = I_{dss} F_g F_d + G_{do} V_{ds}$
New 1	$I_{ds} = \frac{\beta(V_{gs} - V_t)^2}{1 + b(V_{gs} - V_t)}(1 + \lambda V_{gs} V_{ds})\tanh(\alpha V_{ds})$
New 2	$I_{ds} = \frac{\beta(V_{gs} - V_t)^2}{1 + b(V_{gs} - V_t)}(N_g + \lambda V_{gs} V_{ds})\tanh(\alpha V_{ds})$
Brazil	$I_d = I_{dss}[1 + \tanh(T_b)]\tanh(\tau V_{ds})$

Notes:

$V_p = V_{po} + \tau V_{ds}$ (Materka)

$V = V_{gs}(1 + \beta(V_{dso} - V_{ds}))$ (Curtice.C)

$$I_{d1} = \frac{1}{k}[1 + \frac{V^*_{gs}}{V^*_p} - \frac{1}{m} + \frac{1}{m}\exp\{-m(1 + \frac{V^*_{gs}}{V^*_p})\}] \quad \text{(Tajima 1)}$$

$$I_{d2} = I_{dsp}[1 - \exp\{-\frac{V_{ds}}{V_{dss}} - a(\frac{V_{ds}}{V_{dss}})^2 - b(\frac{V_{ds}}{V_{dss}})^3\}] \quad (\ \ldots\ )$$

$V^*_{gs} = V_{gs} - V_\Phi$, $V^*_p = V_{po} + pV_{ds} + V_\Phi$ (...)

$k = 1 - 1/m\{1 - \exp(-m)\}$ (...)

$$F_g = \frac{1}{k}(V_{gsn} - \frac{1 - e^{-mV_{gsn}}}{m}) \quad \text{(Tajima 2)}$$

$F_d = 1 - \exp\{-(V_{dsn} + aV^2_{dsn} + bV^3_{dsn})\}$ (...)

$$V_{gsn} = 1 + \frac{V_{gs}}{V_p} , \quad V_{dsn} = \frac{V_{ds}}{V_{dsp}(1 + wV_{gs}/V_p)} \quad (\ \ldots\ )$$

$V_p = V_{po} + pV_{ds}$ (p is equivalent to τ in Materka model)

$N_g = 1 + \mu V_{gs}\exp(\tau V_{gs} V_{ds})$ (New 2)

$$T_b = \mu[1 - \exp(-\frac{\alpha(V_{gs} - V_\Phi)}{V^2_{ds} + V_\Phi})] \quad \text{(Brazil)}$$

Table 2 Results of the parameter extraction performed for NE71000 and Plessey F20 for various DC models.

Model	Taki		Curtice.Q		Materka		Statz		New 1		Brazil		New 2		Curtice.C		Tajima 1		Tajima 2	
Para.	NE	PLESS	NE	PLESS	NE	PLESS	NE	PLESS	NE	PLESS	NE	PLESS	NE	PLESS	NE	PLESS	NE	PLESS	NE	PLESS
I_{dss}	93.32	59.56	-	-	93.21	59.55	-	-	-	-	119.4	75.91	-	-	-	-	-	-	89.76	54.58
V_{po}	-2.281	-2.688	-	-	-1.916	-1.775	-	-	-	-	-	-	-	-	-	-	-	-	-	-
α	3.809	3.327	1.841	2.049	3.484	2.871	1.845	4.5	1.894	4.5	.767	.623	1.863	1.694	1.883	1.619	-	-	-	-
β	-	-	16.88	6.564	-	-	197.5	10.29	33.37	2.93	-	-	3.300	6.867	.0537	.9381	-	-	-	-
V_t	-	-	-2.317	-2.764	-	-	-1.729	-2.573	-1.958	-2.714	-	-	-1.913	-2.314	-	-	-	-	-	-
λ	-	-	.0089	.0273	-	-	.0092	.0294	-.0841	-.1163	.003	.002	.2449	-.0772	-	-	-	-	-	-
b	-	-	-	-	-	-	3.273	.1521	.2076	-.231	-	-	-.4532	-.1594	-	-	-.179	-.7200	6.455	-.7276
A_1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	90.89	58.30	-	-	-	-
A_2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	46.82	20.13	-	-	-	-
A_3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-12.97	-.6536	-	-	-	-
A_4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	- 7.02	-.5074	-	-	-	-
V_{dso}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.38	14.09	-	-	-	-
μ	-	-	-	-	-	-	-	-	-	-	.225	.34	-4.388	-.0195	-	-	-	-	-	-
τ	-	-	-	-	-.1351	-.1602	-	-	-	-	1.92	2.07	-.1333	-.2448	-	-	-	-	-	-
I_{dsp}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	92.19	69.97	-	-
V_{dss}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.6735	-.2200	-	-
V_{dsp}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.2481	-.2287
V_{po}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.633	1.673	1.615	1.591
Φ	-	-	-	-	-	-	-	-	-	-	.8	.8	-	-	-	-	.0211	.3239	-	-
G_{do}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.2017	.4971
a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.230	24.00	-10.57	.2489
m	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.48	2.605	4.125	3.577
p	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.09	.1178	.0951	.0849
w	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.0339	1.117

Note: NE: NE71000;
PLESS: Plessey F20 4x75 IC539A/1.

Table 3 Comparisons of Accuracy of Different Models

Model Names	Number of Parameters	Root Mean Square Error	
		NE71000	PLESS F20
Taki	3	3.66	4.95
Curtice.Q	4	3.36	4.09
Materka	4	2.67	1.48
Statz	5	2.15	4.06
New 1	5	1.38	2.29
Brazil	6	1.51	1.13
New 2	7	1.02	1.17
Curtice.C	7	.845	.649
Tajima 1	8	.848	.929
Tajima 2	9	1.03	.838