A TABLE BASED BIAS AND TEMPERATURE DEPENDENT SMALL SIGNAL AND NOISE EQUIVALENT CIRCUIT MODEL

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Abstract

A new algorithm is presented for construction of an accurate table-based bias and temperature dependent FET small-signal and noise model. The algorithm provides orders of magnitude data reduction over the alternate approach of storing multiple S-parameter and noise parameter data files (to represent different bias and temperature conditions). The algorithm performs 2-D linear interpolation on a single stored data table to quickly produce accurate bias and temperature dependent model simulations.

I. INTRODUCTION

Microwave circuits using FETs are subjected to thermally induced performance changes due to internal power dissipation in the FET and/or changes in the ambient temperature. To observe thermally induced variations in circuit performance, the conventional modeling approach is to extract small-signal models of the FET at the biases and temperature of interest, and then insert these models one at a time into the design simulation. This conventional method, although useful, is cumbersome, and does not allow enough flexibility for efficient investigation of bias and temperature effects on circuit performance. Such investigation, for example, would be needed to efficiently design on-chip temperature compensation circuits [1].

One solution to this problem is to use a temperature-dependent non-linear model. Unfortunately, a temperature-dependent non-linear model requires an extensive modeling effort and may prove inadequate due to failure of the empirical model equations to represent the device under small signal conditions [2]. Also bias and temperature dependent noise models are typically not integrated into these non-linear models. Although work on a bias dependent noise model has been presented by Hughes, et. al. [3].

An alternate approach is to use a table-based model, which avoids the approximation errors assumed by an empirical equation based non-linear model. In this paper, we present a simple algorithm for a table-based, bias and temperature dependent, small-signal and noise model. Linear interpolation of the data table efficiently produces accurate model simulations and improves the conventional approach in three ways: 1) It allows automated analysis, 2) It allows circuit optimization with respect to bias and (if desired) temperature and 3) It provides for data reduction (one model table file represents each device over a wide range of conditions).

II. MODELING METHODOLOGY

a. Procedure for Bias and Temperature MESFET and HEMT Modeling

The small signal/noise model used in this work is shown in Figure 1. For this work, the extrinsic Equivalent Circuit Parameters, or ECPs, (i.e., Rs, Rd, Rg, Ls, Ld, Lg, Cpg, and Cpd) are considered to be dependent on temperature but independent of bias. The intrinsic ECPs (i.e., Gm, Gds, Cgs, Cgd, Cds, Ri, τ, P, R, and C), on the other hand, are considered to be both temperature and bias dependent. P, R, and C are noise parameters which characterize eg and id, the gate and drain noise sources [4].

We begin by modeling the ECPs as a function of temperature at each bias point. Over the considered temperature range of 25 °C to 125 °C, the ECPs can be modeled by a linear function of temperature [4-6],

$$ECP = ECP_0 \cdot \left[1 + \beta(T - T_0)\right] \tag{1}$$

where $T_0 = 300K$. From our previous assumption about the small-signal model, the ECP_0's and β's for the intrinsic ECPs are bias dependent but the ECP_0's and β's for the extrinsic ECPs are bias independent . Since the ECP_0's and β's for the extrinsic ECPs are not bias dependent there is no need to discuss them further, we now concentrate on modeling the ECP_0's and β's for the intrinsic ECPs over bias.

For each intrinsic ECP, ECP_0 and β are tabulated versus bias. An algorithm for piecewise, 2D linear interpolation, included in the model, is used to calculate the values of ECP_0 and β for each ECP at the desired bias. Thereupon Eq. (2) can be used to calculate the values of the ECPs.

b. A Method for 2-D Linear Interpolation

Given a set of n numbered points $P_n(V_{gsn}, V_{dsn})$, the surface formed by the points can be approximated as a series of connecting triangular facets (see Figure 2). P_n here can represent either $ECP_0(V_{gsn}, V_{dsn})$ or $\beta(V_{gsn}, V_{dsn})$. For a triangular facet with vertices P_1, P_2, and P_3, the equation for points on the surface is by

$$P(V_{gs}, V_{ds}) = -\frac{a}{c}(V_{gs} - V_{gs1}) - \frac{b}{c}(V_{ds} - V_{ds1}) + P_1 \tag{2}$$

where

$$a = (V_{ds2} - V_{ds1})(P_3 - P_1) - (V_{ds3} - V_{ds1})(P_2 - P_1), \tag{3}$$

$$b = (P_2 - P_1)(V_{gs3} - V_{gs1}) - (P_3 - P_1)(V_{gs2} - V_{gs1}), \tag{4}$$

and

$$c = (V_{gs2} - V_{gs1})(V_{ds3} - V_{ds1}) - (V_{gs3} - V_{gs1})(V_{ds2} - V_{ds1}). \tag{5}$$

Note that Eq. (2) is actually the equation of a plane through points P_1, P_2, and P_3 and is only valid for points whose projection onto the $V_{gs} - V_{ds}$ plane is in or on triangle (P_1, P_2, P_3). Therefore, it is necessary that the triangle (P_1, P_2, P_3) which contains the desired point, P_4, be found.

To determine whether a desired point P_4 is in a triangle, a two step procedure is used. First, in the $V_{gs} - V_{ds}$ plane, a search is made to find four points that form the smallest quadrilateral containing P_4 (see Fig. 2). Once the quadrilateral is found, it is subdivided into two triangles. All that is necessary now is to find which triangle P_4 lies in.

The determination of whether a point is inside or outside a triangle is a classic problem in the area of computer science [7]. Given the three vertices of a triangle and the desired point, numbered clockwise as 1, 2, and 3 with point 4 being the desired point (see Fig. 2), we define the following quantities:

$$a=\begin{vmatrix}V_{gs1} & V_{ds1} & 1\\ V_{gs2} & V_{ds2} & 1\\ V_{gs3} & V_{ds3} & 1\end{vmatrix}, b=\begin{vmatrix}V_{gs4} & V_{ds4} & 1\\ V_{gs1} & V_{ds1} & 1\\ V_{gs2} & V_{ds2} & 1\end{vmatrix},$$
$$c=\begin{vmatrix}V_{gs4} & V_{ds4} & 1\\ V_{gs2} & V_{ds2} & 1\\ V_{gs3} & V_{ds3} & 1\end{vmatrix}, d=\begin{vmatrix}V_{gs4} & V_{ds4} & 1\\ V_{gs3} & V_{ds3} & 1\\ V_{gs1} & V_{ds1} & 1\end{vmatrix}. \quad (6)$$

In Eq. (6) we are only concerned with the sign of a, b, c, and d, and not their magnitudes. A point is inside the triangle if: 1) the quantities *a*, *b*, *c*, and *d* have the same sign, or 2) either b, c, or d is zero, in which case the point lies on a side of the triangle and is also considered inside. Once the triangle is found, Eq. (2) is used to calculate the temperature parameters at the desired bias point. Then, Eq. (1) is used to calculate the value of each ECP. Once the ECPs are known, two-port S-parameters and noise figure can be calculated easily from the appropriate two-port equations of the model in Figure 1.

III. RESULTS

The active device used in this work is a 0.25 μm x 300 μm MESFET. S-parameters and noise parameters were measured over a regularly spaced grid of bias (i.e., Vgs from 0 V to -1.2 V in 0.4 V increments and Vds from 1 V to 6.0 V in 1.0 V increments) and temperature points (i.e., 25°C, 50°C, and 75°C). ECPs were extracted over bias and temperature [4, 8] and the above modeling procedure applied. Using the tabulated data from above, the model was implemented within HP-EEsof's Libra 4.0™. A user-define element was programmed to perform the interpolation.

Comparisons of model to data are very good. Fig. 3 highlights the ability of the model to interpolate a point not used in the modeling. If further accuracy is required a smaller grid spacing could be used or a higher order interpolating polynomial could be used, i.e., quadratic. One advantage of this model is the ability to easily simulate important device figures of merit over bias and temperature. For example, Fig. 4 shows the modeled Gmax as a function of bias. Other figures of merit such as minimum noise figure, NFMIN, or optimum noise match, GammaOpt, can also be simulated by the model. These noise data will be presented at the conference.

IV. CONCLUSION

A novel table based small signal and noise model has been described. The model includes bias and temperature dependence, and it is shown to be accurate at points not tabulated in a coarse grid of data points, such as that used in this work. The model is a very useful and efficient tool for studying the effects of temperature on circuits, and for designing temperature compensated small signal FET amplifiers.

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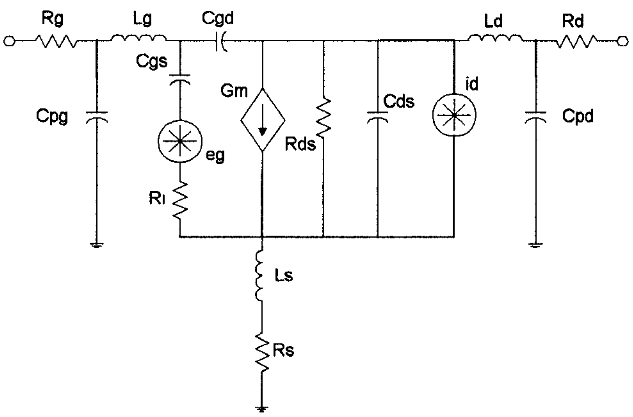

Figure 1: Schematic of the small signal model.

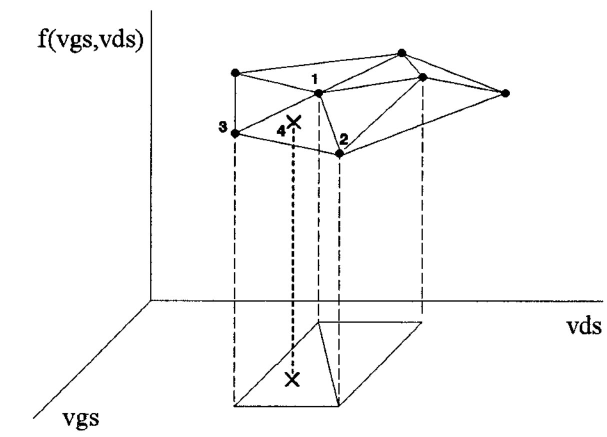

Figure 2: Surface formed by the data points is approximated as a series of connecting triangular facets.

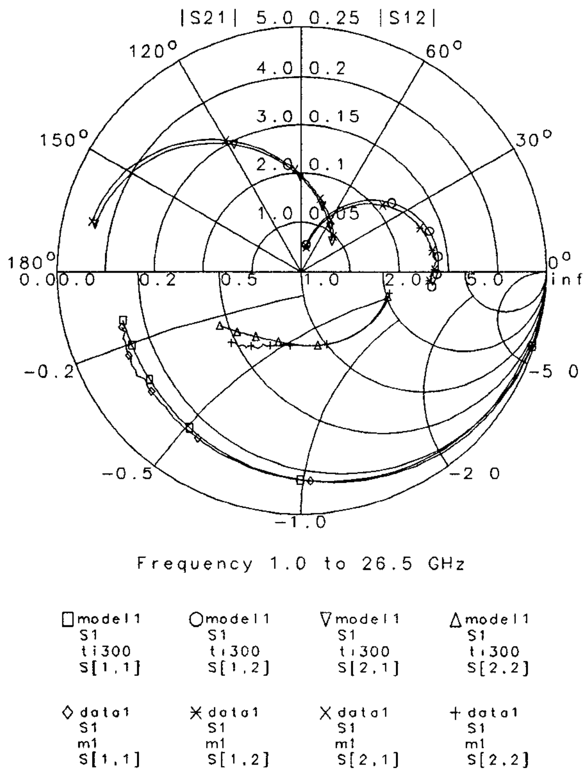

Figure 3: Model versus measure S-parameter data at a point not used in the modeling (Vgs=-0.4, Vds=1.2, T=50 °C).

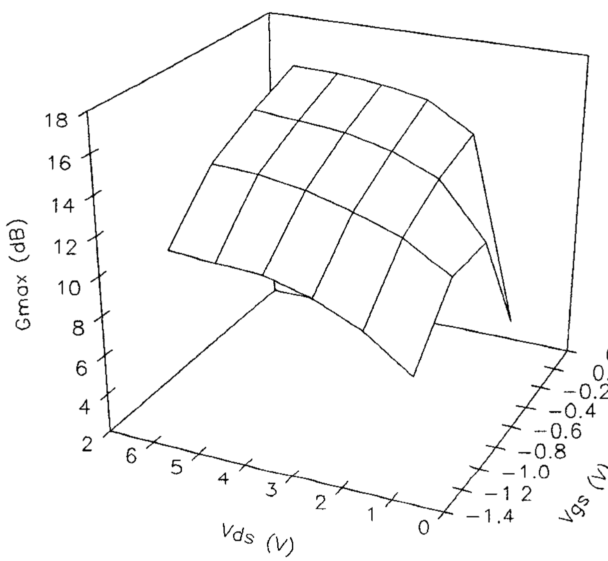

Figure 4: Modeled Gmax as a function of gate and drain bias.