Extracting Transistor Charges from Device Simulations*

W. M. Coughran, Jr.
AT&T Bell Laboratories†

W. Fichtner
Eidgenössische Technische Hochschule‡

Eric Grosse
AT&T Bell Laboratories§

Abstract

We show how to use conventional device simulations to produce charge models suitable for circuit simulation. In particular, we demonstrate the use of gradient fitting of transient simulation data to produce tensor-product splines representing the charges. We contrast this with results from small-signal analyses and discuss the relation between small- and large-signal charges.

Extended Abstract

Conventional circuit simulators make use of compact analytical or table models to represent the behavior of a MOSFET. Moreover, the models are often based on the so-called quasi-static assumption so that the constitutive relation may be written in terms of charges as

$$\begin{pmatrix} i_{ds} \\ i_{gs} \\ i_{bs} \end{pmatrix}(v) = f(v) + \frac{d}{dt}q(v)$$

where $v \stackrel{\text{def}}{=} (v_{ds}, v_{gs}, v_{bs}) \stackrel{\text{def}}{=} (u_d - u_s, u_g - u_s, u_b - u_s)$ represents the branch voltages, f represents the static (DC) current response, and q represents the

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†Murray Hill, New Jersey 07974, USA. `research!wmc` or `wmc@research.att.com`.

‡Institut für Integrierte Systeme, CH-8092 Zürich, Switzerland. `mcvax!eiger!fw` or `fw%ethz.ch@relay.cs.net`.

§Murray Hill, New Jersey 07974, USA. `research!ehg` or `ehg@research.att.com`.

charges, respectively. This *ansatz* is a fundamental assumption made by a number of existing circuit simulators, although it is known to break down when the voltages $v(t)$ vary too rapidly [1,2].

Previous approaches have been based on small-signal analysis [2] and Fourier analysis of transient responses [3]. Our approach is based on fitting techniques applied directly to data obtained from transient simulations, which we will now briefly outline.

For simplicity, ignore the bulk current and the dependence of the currents on v_{bs}; moreover, take $u_b = 0$. We will assume without loss of generality that $u_s \equiv 0$. We can then write the terminal currents in quasi-static form

$$\begin{pmatrix} i_s \\ i_d \\ i_g \end{pmatrix} (u_d, u_g) = f(u_d, u_g) + \frac{d}{dt} q(u_d, u_g). \tag{1}$$

Let us consider fitting one component of the current in (1) and let $x \equiv u_d$ and $y \equiv u_g$ to simplify notation. First, we do a series of static device analyses to produce values of f on a regular rectangular grid $\{\,(x_i, x_j)\,\}_{ij}$ so an approximation to f over the domain may be constructed. A series of transient device simulations can then be used to compute the pointwise residual

$$r(u(t)) = i(u(t)) - f(u(t))$$

for a voltage ramp applied to one terminal, holding the other voltages fixed. (One possible approach is to then use a quadrature to approximate $\int r$ and, thereby, q; however, it has been noted that this procedure is path dependent [2].) Transient simulation data can be transformed into $\partial_x r$ and $\partial_y r$ on the rectangular grid $\{\,(x_i, x_j)\,\}$ and then a least-squares gradient-fitting technique can be used to generate a tensor-product form for q

$$q(x, y) = \sum a_{ij} B_i(x) B_j(y)$$

where $B_\star$ are appropriate B-spline basis functions.

We have simulated a number of devices on a variety of time scales and computed the associated large-signal quasi-static charges. We will contrast these results with values obtained using small-signal analysis and discuss the range of validity of the quasi-static assumption.

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References

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