cādence®

A Nonlinear Capacitor Model for Use in the PSpice Environment

December 2009

THEORY

The charge and current formulas for a linear capacitor are:

$Q = C * V$ **(1a)**

$I = C * dV(t)/dt$ **(1b)**

For a nonlinear (voltage-dependent) time-independent capacitor these formulae become:

$Q = C(V) * dV$ **(2a)**

$I = C(V) * dV/dt$ **(2b)**

This applies to cases where the capacitance has been measured at different bias voltages.

Some would argue that for a nonlinear capacitor,

$Q = C(V) * V$ **(3a)**

where V is a function of time. Therefore,

$I = dQ/dt = C(V(t)) * dV(t)/dt + dC(V(t))/dt * V(t)$ **(3b)**

This is not correct. The flaw in this argument is equation (3a). Although (1a) holds true for linear capacitors, the generalized definition of charge is (2a). Capacitance is the partial derivative of Q with respect to v; which means

$I = dQ/dt = Q/V * dV/dt = C(V) * dV/dt$ **(4)**

Given this relationship between the current through a nonlinear capacitance and the voltage applied to it, analog behavioral modeling can be used to model any nonlinear capacitor whose capacitance, $C(V)$, is a function of the voltage applied to it.

THE MODEL

The nonlinear capacitor is modeled by using ABM (Analog Behavioral Modeling). The capacitor is replaced by a controlled current source, Gout, whose current is defined by (2b). The time derivative, $dV(t)/dt$, is modeled by using the DDT( ) function in the Cadence® PSpice® environment. A voltage dependent capacitance can be specified by using a look-up table, or by using a polynomial.

LOOK-UP TABLE EXAMPLE

If a Capacitance vs. Voltage curve is available, a look-up table can be used in the ABM expression. This table contains (Voltage, Capacitance) pairs picked from points on the curve. The voltage input is nonlinearly mapped from the voltage values in the table to the capacitance values. Linear interpolation is used between table values. This voltage dependent capacitance is the multiplied by the time derivative of
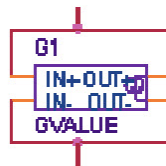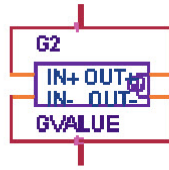

`TABLE(V(%IN+, %IN-), 0v,1e-6, 20v,1.24e-6, 40v,1.56e-6, 60v,1.96e-6 )* DDT(V(%IN+,%IN-) )`

the voltage to obtain the output current.

Figure 1: Nonlinear capacitor with look-up table expression

POLYNOMIAL EXAMPLE

$$(C0 + C1*V(\%IN+,\%IN-) + C2*PWRS(V(\%IN+,\%IN-),2))*DDT(V(\%IN+,\%IN-))$$

Figure 2: Nonlinear capacitor with polynomial expression

The value of the nonlinear capacitor model in this example has a second order polynomial dependence on its voltage. This is equivalent to the standard PSpice capacitor model, whose linear and quadratic coefficients, $VC1$ and $VC2$, can be defined in a .MODEL statement. This model is parameterized so that users can specify the polynomial coefficients in a parameter block (the PARAM symbol), or on the symbol in the schematic editor.

Example Simulation

A transient analysis can be run to verify the model.
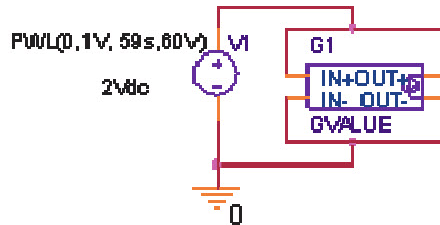
$$TABLE(V(\%IN+, \%IN-), 0v,1e-6, 20v,1.24e-6, 40v,1.56e-6, 60v,1.96e-6)*DDT(V(\%IN+, \%IN-))$$

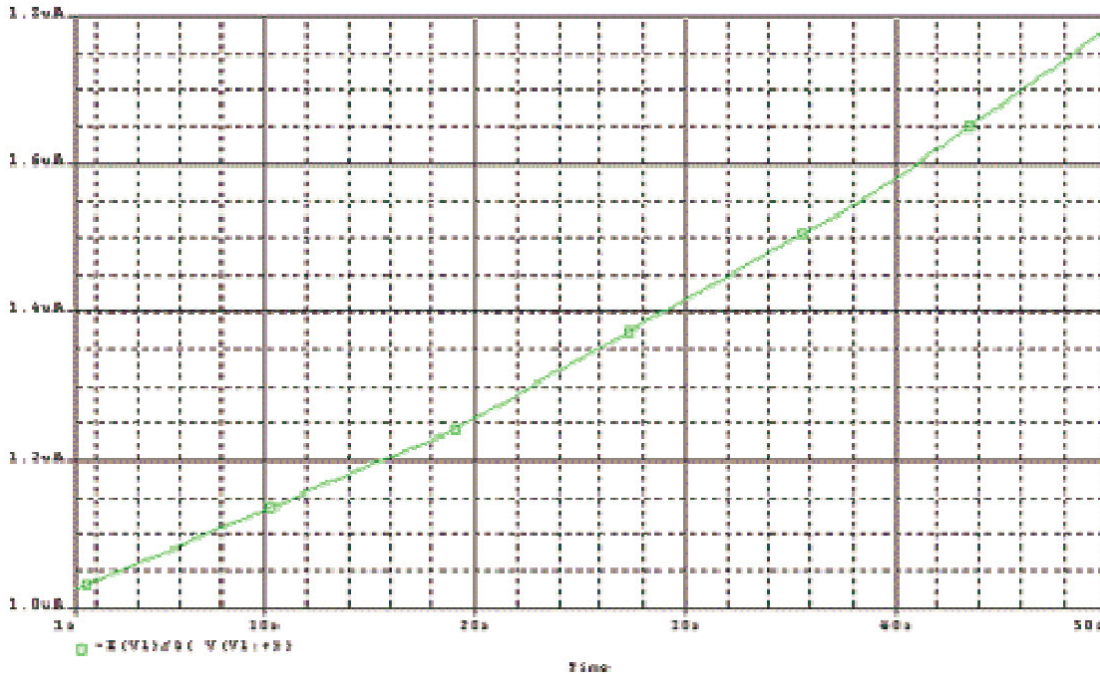*Figure 3: Test circuit for voltage-controlled capacitor*

Figure 4: PSpice plot of transient analysis results

The transient analysis slowly varies the voltage across the capacitor from 1V to 50V. The effective capacitance can be viewed in PSpice as the expression: `- I(V1)/D(V(V1:+))`, which is derived from equation (2b). `D( )` is the derivative with respect to time. The minus `(-)` sign is required because PSpice measures voltage source currents as flowing from the positive node to the negative. PSpice will show that the capacitance varies from `1.02u(F)` to `1.78u(F)`.

SETTING INITIAL CONDITIONS

The IC1 and IC2 symbols in `special.olb` (or the `.ic` statement in an Include file) can be used to specify initial conditions for the capacitor.

APPLICATION NOTE