

Math-analysis packages Minerr function aids Spice modeling

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Almost any Spice package employs .model statements to describe elements it considers primitives. That statement defines the mathematical representations for each primitive element. Examples include diodes, capacitors, resistors and transistors. Yet generating a Spice model for even a simple device becomes quite complex due to the number of variables that describe a typical component. However, you can simplify the process by tapping into the functionality of a general-purpose scientific analysis package like MathSoft's Mathcad.

The modeling process typically begins either by manually taking measurements with a device or finding datapoints on a spec sheet. Once the datapoints are established, several options exist to obtain a "best correlation" model.

Least squares

Once a popular option, a linear least-squares solution uses specialized

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curve-fitting software that takes XY coordinate pairs from the datapoints and calculates several curves along with regression coefficients for each curve. While this method can provide adequate mathematical solutions, the resulting equations aren't consistent with the specific mathematical representations of the primitive element. The best equation that a curve fitter finds might, for example, be a hyperbolic function, which is nothing like the logarithmic function that represents the behavior of a diode.

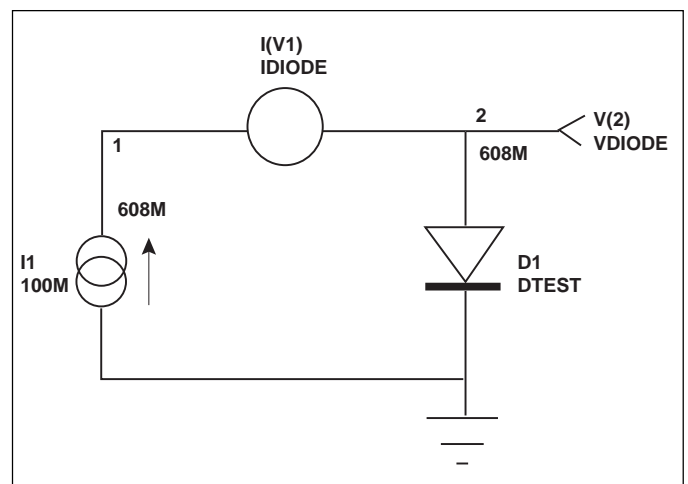
Some engineers have found a degree of success using linear programming routines such as the Solver function in Microsoft Excel. The advantage of this method over curve fitting is that the user specifies the form of the equation that the solver works with. Then, this approach iteratively

adjusts equation coefficients in a spreadsheet and compares the numerical result of this user-defined equation (with computer-generated coefficients) with the original datapoints to obtain the best solution. This method requires the user to determine the error function. Additionally, it works best for systems of linear equations, but many complex components are distinctly non-linear.

Basic method

After weighing the pros and cons of the two previous approaches, I've come to the conclusion that the simplest and most reliable method to derive models employs Mathcad's Minerr function. This powerful function solves a system of simultaneous

Fig 1—The circuit for finding the Spice model for a diode parallels the device's physical parameters.



equations for minimum error. Much like a solver function, it returns a solution that provides the minimum error if it doesn't find an exact solution.

The following example shows how to use Minerr to solve for variables that describe the room-temperature forward characteristics of a silicon diode. The equation Spice uses to represent this parameter is

$$VD = \ln\left[\frac{(ID + IS)}{IS}\right] \cdot N \cdot VT + ID \cdot RS$$

where ID is the diode current at the diode voltage VD, IS represents the saturation current and N equals the emission coefficient and is a function of the diode type. Further,

$$VT = K \cdot \frac{T}{q}$$

where K is Boltzmann's constant (1.38×10^{-23}) and q equals the magnitude of the electron charge (1.60×10^{-19}). Solving the equation results in a VT of approximately 0.026V at room temperature. The unsolved variables for VD are N, IS and RS, while ID and VD define the original datapoints.

Because three variables remain,

you need at least three equations to solve for them. The Minerr function starts with an estimated value for each variable. The solution isn't particularly sensitive to these initial values unless multiple solutions exist, in which case the estimates help determine which solution it converges towards. The initial values for this example are RS = 0.022, N = 1.62 and IS = 11.7×10^{-12} , which were the results of the last diode I modeled. In practice, you can pick any number you want, because there is only one solution for a diode equation.

The Minerr function block (Listing 1) starts with the command Given and continues with the equation set. The three original datapoints equal 0.511V at 10 mA, 0.608V at 102 mA and 0.716V at 1A. Note that these datapoints are not close to each other. Instead, the currents for each are a decade apart. The

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0.511 = ln((0.010 + IS) / IS) * N * 0.026 + 0.010 * RS
0.608 = ln((0.102 + IS) / IS) * N * 0.026 + 0.102 * RS
0.716 = ln((1.0 + IS) / IS) * N * 0.026 + 1.0 * RS

minerr(IS, N, RS) = [ 4.057 * 10^-8
                    1.583
                    0.016 ]
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Listing 1—The Mathcad Minerr function invocation for finding the model of a diode requires only three datapoints.

function completes the block and provides the best-fit solution for these datapoints using the Spice form of an equation for a diode. Using the resulting solution to solve for the three measured points results in VD(0.01) = 0.511, VD(0.102) = 0.608 and VD(1.0) = 0.717. These results match the original data to within 1 mV.

Increasing the number of datapoints and of equations can increase the accuracy of the result where data are more scattered. Although for the case of the diode, three datapoints are generally sufficient. If you then enter the results into a Spice diode-model statement for verification, the schematic in Fig 1 results in the VI curve of Fig 2.

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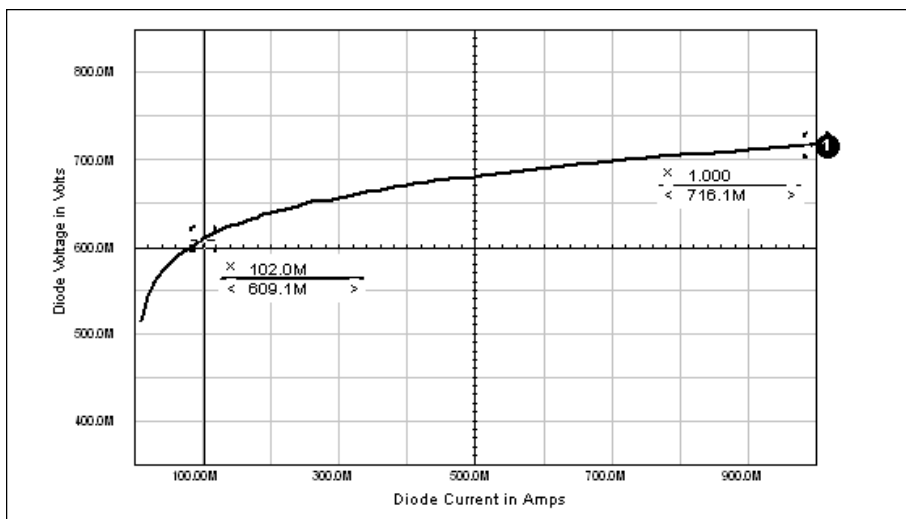


Fig 2—The VI curve for the diode model tracks the actual diode within a millivolt at three current datapoints

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