

Spreadsheet modeling tool helps analyze power- and ground-plane voltage drops to keep core voltages within tolerance

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Introduction

The trend toward smaller geometries in processor cores drives requirements for lower-voltage power supplies. For example, DSPs from Texas Instruments (TI) such as the TMS320TCI648x series require a 1-V core. As processor-core voltages drop, clock frequencies are typically increased to match the thermal capabilities of the packaging and of the overall cooling systems. That means higher currents in the power structures of printed circuit boards (PCBs). It is not uncommon to see 50- to 100-A current requirements for a 1-V rail when multiple processors are distributed on a single PCB. This article addresses the impact of these higher currents on the power- and ground-plane design and on the core-voltage-tolerance budget and describes a spreadsheet model that may be used to calculate voltage gradients.

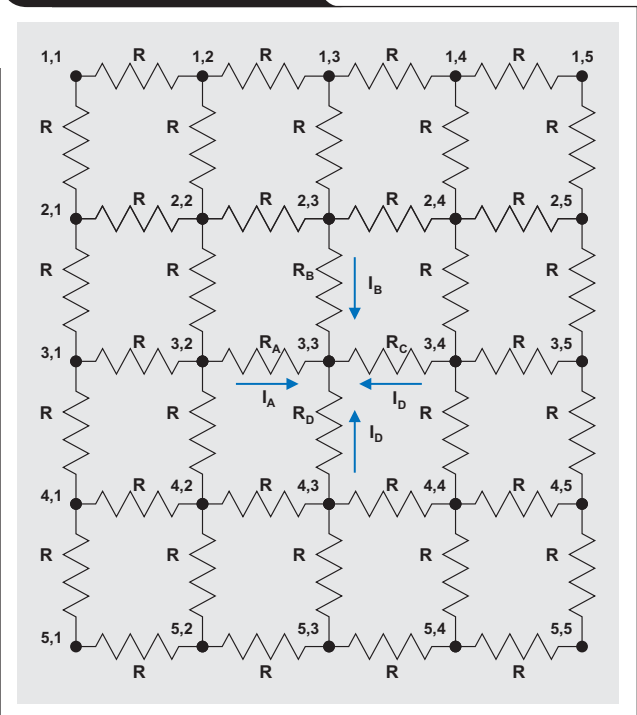
Requirements for processor-core voltage

The typical voltage-tolerance budget for the processor core is 3% for a 1-V rail, which equates to 30 mV for the total static and dynamic response of the power supply. TI's new power devices such as the PTH TurboTrans™ series (T2) modules, and new synchronous buck controllers such as the TPS40140, have been designed with internal references that allow for 1.5% tolerance under static line, load, and temperature conditions. The current guidance allocates the remaining 1.5% tolerance for the transient response of the supply. This, in combination with the bandwidth of the switching power supply, determines the amount of capacitance required to meet the core-voltage requirements. Local bypassing counteracts the inductive nature of large ground planes. Little attention is typically paid to the DC voltage drop in the power planes. As currents continue to increase and core voltages decrease, power- and ground-plane DC voltage drops will become a more significant portion of the total tolerance budget.

Power- and ground-plane voltage-drop considerations

Power- and ground-plane copper thickness is the primary attribute that impacts the voltage drop. Another major factor is the placement of the processor loads relative to the power-supply output pins. Power converters such as the PTH series allow for remote sensing to mitigate board voltage drops, but there are few tools to aid the designer in the placement of these remote sensing lines. Most designers use an ohms-per-square figure for different

Figure 1. Resistor sheet



copper thicknesses to calculate an equivalent resistance and to determine the required copper weight. This technique works well for simple configurations; but when multiple processors or significant plane discontinuities are present (due to vias or other features), the simple ohms-per-square method may not be adequate to model the voltage drop in the power and ground planes.

Commercial software

Commercial software for finite-element analysis may be used to compute the plane voltage drops for arbitrary geometries, but the software is expensive and requires a developed expertise. There is no simple tool to generate a PCB model and quickly assess the plane voltage drops.

SPICE modeling

A model of the PCB may be constructed with an equivalent sheet resistance model (see Figure 1), with sources and loads connected to the appropriate nodes. The PCB

model can then be solved with a SPICE-based simulator. The difficulty in the SPICE method is that the schematic is unwieldy and the results are difficult to visualize.

A spreadsheet-based model

This article details a method that uses Microsoft® Excel® spreadsheet software to determine plane voltage distribution on a PCB with arbitrary geometry and source/load placement. A little-used feature of Excel, circular references and iteration, is used to solve the network matrix. The method may also be used with other mathematical software. This article also develops the necessary equations and provides step-by-step instructions to calculate power/ground-plane voltage drop for arbitrary source and load conditions.

Node equations for sheet resistance

Figure 1 is a schematic model of PCB node voltages interconnected by equivalent sheet resistances, R , with nodes expressed as *row, column*. This model divides the PCB into 25 nodes. Increasing the number of squares will provide more resolution. This array is sufficient to illustrate the general node equations applicable to larger models. The voltage at any node is determined by using Kirchoff's current law, which states that the sum of all currents into a node must equal zero. One of three equations is required to determine node voltage, which depends on the node location—central, edge, or corner.

Central-node equations

For central node 3,3 in Figure 1, the current equation is

$$I_A + I_B + I_C + I_D = 0. \tag{1}$$

Using Ohm's law yields

$$\frac{V_{3,2} - V_{3,3}}{R_A} + \frac{V_{2,3} - V_{3,3}}{R_B} + \frac{V_{3,4} - V_{3,3}}{R_C} + \frac{V_{4,3} - V_{3,3}}{R_D} = 0. \tag{2}$$

Solving Equation 2 for $V_{3,3}$ yields

$$V_{3,3} = \frac{R_B R_C R_D V_{3,2} + R_A R_C R_D V_{2,3} + R_A R_B R_D V_{3,4} + R_A R_B R_C V_{4,3}}{R_B R_C R_D + R_A R_C R_D + R_A R_B R_D + R_A R_B R_C}. \tag{3}$$

Equation 3 is the general form of the equation for a central node with arbitrary sheet resistance. This equation accommodates variations in square resistance that are due to localized heating or other nonuniformities. In the case of uniform sheet resistance, Equation 3 simplifies to

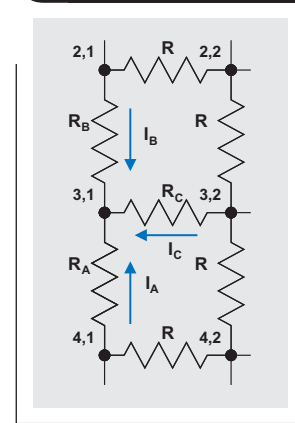
$$V_{3,3} = \frac{V_{3,2} + V_{2,3} + V_{3,4} + V_{4,3}}{4}. \tag{4}$$

Edge-node equations

For edge node 3,1, Figure 2 depicts the currents flowing from the three adjacent nodes. The current equation for an edge node is

$$I_A + I_B + I_C = 0. \tag{5}$$

Figure 2. Edge node



Using Ohm's law yields

$$\frac{V_{4,1} - V_{3,1}}{R_A} + \frac{V_{2,1} - V_{3,1}}{R_B} + \frac{V_{3,2} - V_{3,1}}{R_C} = 0. \tag{6}$$

Solving for $V_{3,1}$ yields

$$V_{3,1} = \frac{R_B R_C V_{4,1} + R_A R_C V_{2,1} + R_A R_B V_{3,2}}{R_B R_C + R_A R_C + R_A R_B}. \tag{7}$$

Equation 7 is the general form of the equation for an edge node with arbitrary sheet resistance. In the case of uniform sheet resistance, Equation 7 simplifies to

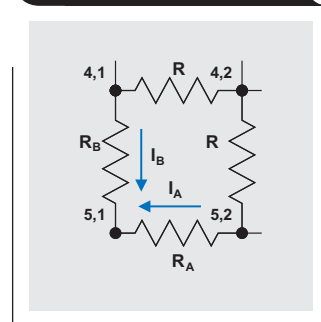
$$V_{3,1} = \frac{V_{4,1} + V_{2,1} + V_{3,2}}{3}. \tag{8}$$

Corner-node equations

For corner node 5,1, Figure 3 depicts the currents flowing from the two adjacent nodes. The current equation for a corner node is

$$I_A + I_B = 0. \tag{9}$$

Figure 3. Corner node



Using Ohm's law yields

$$\frac{V_{5,2} - V_{5,1}}{R_A} + \frac{V_{4,1} - V_{5,1}}{R_B} = 0. \quad (10)$$

Solving for $V_{5,1}$ yields

$$V_{5,1} = \frac{R_B V_{5,2} + R_A V_{4,1}}{R_B + R_A}. \quad (11)$$

Equation 11 is the general form of the equation for a corner node with arbitrary sheet resistance. In the case of uniform sheet resistance, Equation 11 simplifies to

$$V_{5,1} = \frac{V_{5,2} + V_{4,1}}{2}. \quad (12)$$

Source nodes

The outputs of power supplies are modeled as fixed values (voltages) at the geometrically relevant nodes. Many power supplies utilize differential remote sensing. In the model, the fixed-voltage nodes may represent the local sense points, and the power-supply output is varied to set the desired voltage at those remote sensing points.

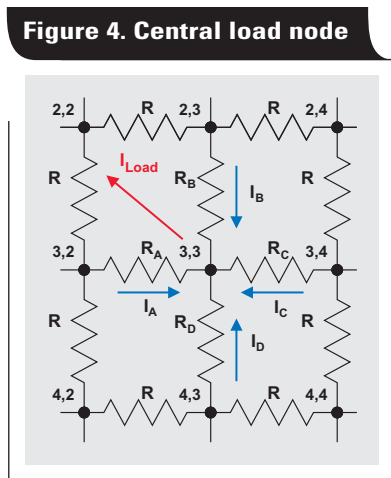
The remaining equations solve for node voltages where a load is present at the node.

Load equations

Central-node equations

In the case of a central node with a load (Figure 4), the current equation is

$$I_A + I_B + I_C + I_D = I_{Load}. \quad (13)$$



Using Ohm's law yields

$$\frac{V_{3,2} - V_{3,3}}{R_A} + \frac{V_{2,3} - V_{3,3}}{R_B} + \frac{V_{3,4} - V_{3,3}}{R_C} + \frac{V_{4,3} - V_{3,3}}{R_D} = I_{Load}. \quad (14)$$

Solving Equation 14 for $V_{3,3}$ yields

$$V_{3,3} = \frac{R_B R_C R_D V_{3,2} + R_A R_C R_D V_{2,3} + R_A R_B R_D V_{3,4} + R_A R_B R_C V_{4,3} - R_A R_B R_C R_D I_{Load}}{R_B R_C R_D + R_A R_C R_D + R_A R_B R_D + R_A R_B R_C}. \quad (15)$$

Equation 15 is the general form of the equation for a central node with arbitrary sheet resistance and a load current. In the case of uniform sheet resistance, Equation 15 simplifies to

$$V_{3,3} = \frac{V_{3,2} + V_{2,3} + V_{3,4} + V_{4,3} - R I_{Load}}{4}. \quad (16)$$

Edge-node equations

For the case where load current is sourced from an edge node (node 3,1 in Figure 2), the node voltage equation is

$$V_{3,1} = \frac{R_B R_C V_{4,1} + R_A R_C V_{2,1} + R_A R_B V_{3,2} - R_A R_B R_C I_{Load}}{R_B R_C + R_A R_C + R_A R_B}. \quad (17)$$

For uniform sheet resistance, Equation 17 simplifies to

$$V_{3,1} = \frac{V_{4,1} + V_{2,1} + V_{3,2} - R I_{Load}}{3}. \quad (18)$$

Corner-node equations

For the case where load current is sourced from a corner node (node 5,1 in Figure 3), the node voltage equation is

$$V_{5,1} = \frac{R_B V_{5,2} + R_A V_{4,1} - R_A R_B I_{Load}}{R_B + R_A}. \quad (19)$$

For uniform sheet resistance, Equation 19 simplifies to

$$V_{5,1} = \frac{V_{5,2} + V_{4,1} - R I_{Load}}{2}. \quad (20)$$

The previous equations may be used to model the power- or ground-plane voltage map of a PCB with arbitrary source, resistance, and load arrangements.

Example problem

PCB voltage-drop modeling presents two challenges. The first is to build the representative model with a number of voltage sources, path resistances, and loads distributed across the PCB; the second is to solve the simultaneous equations. Excel spreadsheet software provides a convenient means to quickly build a model and solve the nodal equations. Following is a simple example that illustrates this. A PCB power plane with uniform sheet resistance is modeled and the voltage at every node is calculated for a given set of load conditions.

For this example, a 10 × 15-cm copper board with a 1-V/1-oz power plane and a 1-oz ground return plane is assumed. A single power supply with 1 output pin provides the voltage source, and distributed across the PCB are 10 loads drawing 5 A each. The goal is to determine the steady-state voltage at each load with a 65°C board temperature.

Worksheet model construction step-by-step

To model the PCB, a worksheet is used where a range of cells is assigned to represent the node voltages on the PCB. Each cell corresponds to a square of copper on the PCB. The size of each square is chosen for a desired geometric resolution. For instance, if 1-mm geometries (such as slots or via holes) are desired, then 100×150 squares (cells) would be required to model a 10×15 -cm PCB. For this simple example, 5-mm squares are selected to model a 10×7.5 -cm PCB, so an array of 20×15 cells is used in the spreadsheet (see Figure 5). The 300 cells are highlighted green to identify the PCB outline.

Circular references

To build this model, a few non-intuitive steps must be followed, because circular references are required to solve the nodal equations. “Circular reference” refers to the condition where the value of a cell is a function of its own value in some way. This situation may be resolved by allowing Excel to iterate the value in the cell (by increasing or decreasing the value) until some tolerance level is met and the interrelated equations converge. There are instances when Excel will not be able to resolve circular references—particularly

evident when the model is being built or is undergoing major changes. For this reason, manual calculation is used in the spreadsheet model.

Initialization

To build the model, it is first assumed that the voltage distribution is ideal; that is, there is 1 V in every cell. A “1” is entered in each cell to start (see Figure 6). Note that it is convenient to label the boundaries of the PCB model with an index grid to aid in placing the sources and loads.

Figure 5. Model of 10×7.5 -cm PCB with 5-mm squares

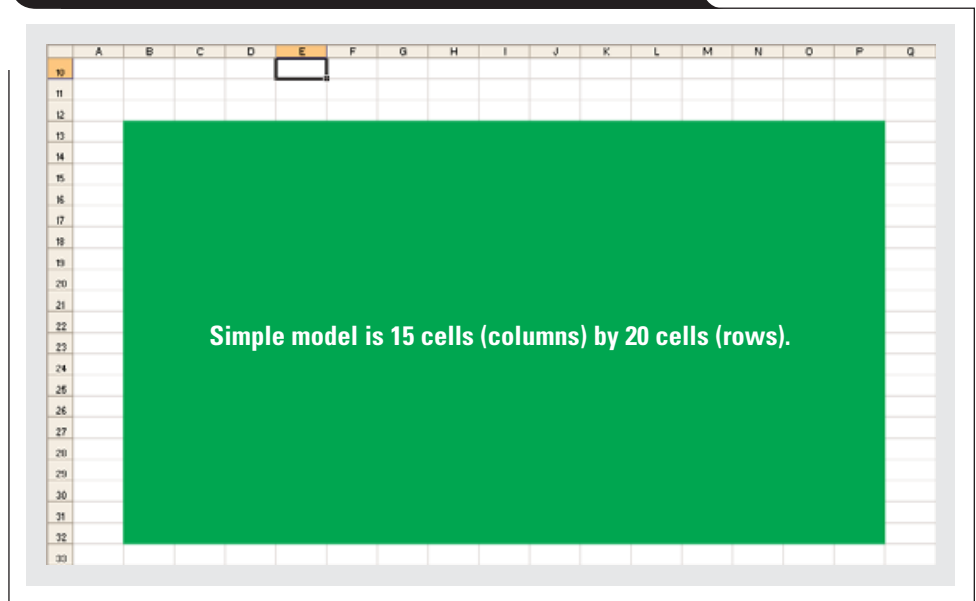


Figure 6. Model of ideal voltage distribution

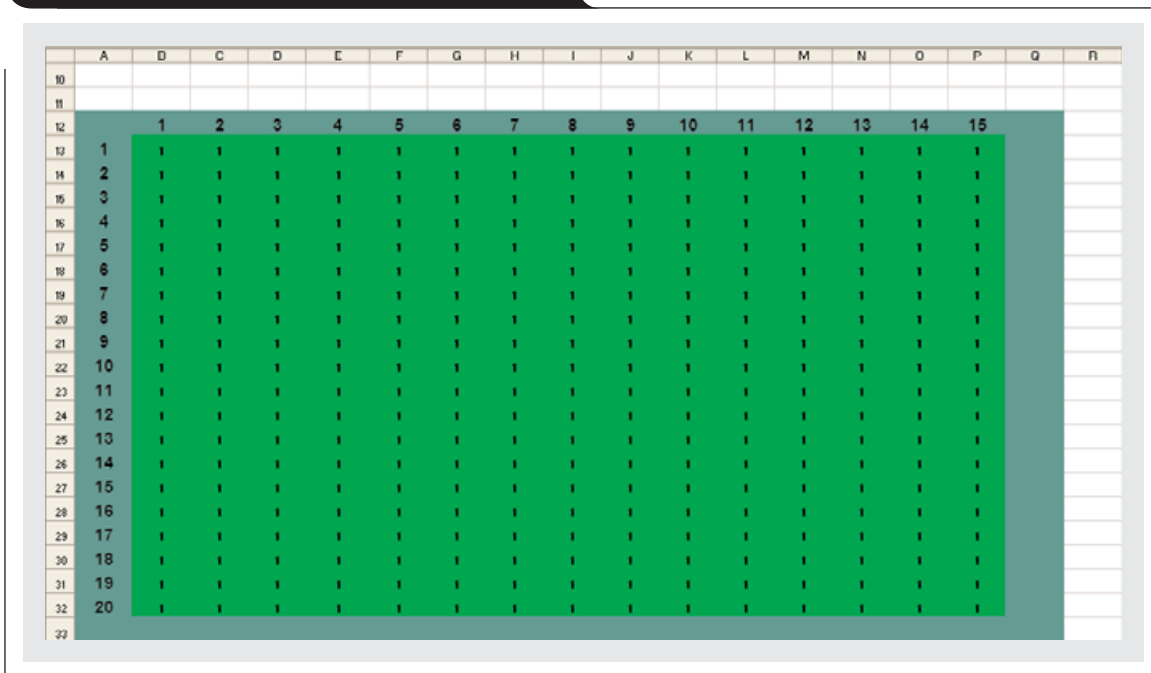
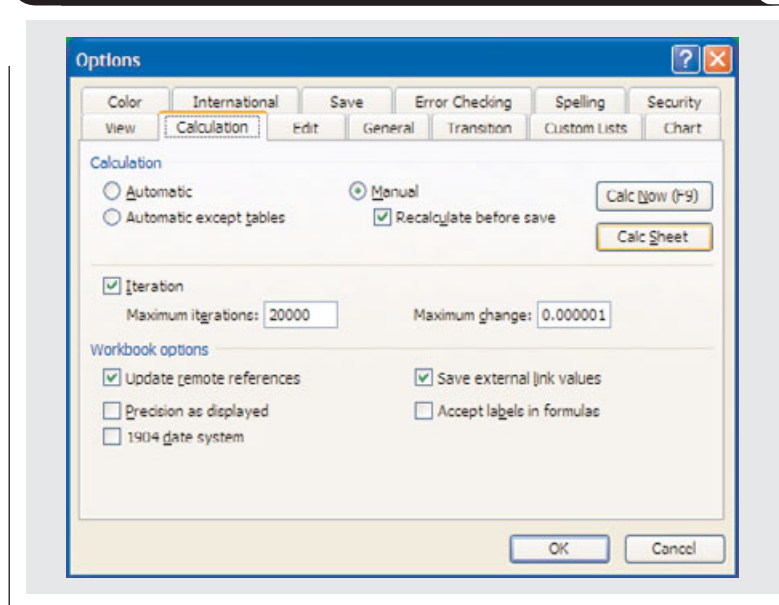


Figure 7. PCB model settings entered in *Calculation* menu

The next step is to disable automatic calculation by checking the *Manual* “radio button” in the *Tools > Options > Calculation* menu (Figure 7). When a change is made, the F9 key recalculates the worksheet. While this menu is open, the *Iteration* box should be checked, and the parameters *Maximum Iterations* and *Maximum Change* should be set to 20000 and 0.000001, respectively. This sets the parameters for the solution engine so that iterations occur up to 20,000 times or until the solution converges to within 1 μV . These preliminary settings are required to enable iterative calculations and to avoid convergence errors while the PCB model is being built and modified.

A simplifying assumption

For this example, the sheet resistance is assumed to be uniform in the power and ground planes so that a simplifying assumption can be made. The ground- and power-plane resistances are combined, and the “return” path is assumed to have zero resistance. That assumption makes the voltage at each cell representative of the differential voltage (plane to ground) at every location on the PCB. The resistance of the power plane is simply doubled to account for the return path.

Copper-sheet resistance

The sheet resistance of copper is given as

$$\rho = \frac{\rho_{20} [1 + \alpha(T - 20)]}{h}, \quad (21)$$

where ρ is the sheet resistance of copper in ohms per square (Ω/\square); ρ_{20} is the resistivity of copper at 20°C equal to 17.241 $\text{m}\Omega/\mu\text{m}^\dagger$; α is the temperature coefficient of resistance for copper equal to 0.393%/°C † ; T is the PCB

temperature in degrees Celsius at the square of interest; and h is the thickness of the copper plane in micrometers (1 oz $\sim 35.6 \mu\text{m} \pm 10\%$). Equation 21 is implemented with the following Excel equation inserted into cell E2 (see Figure 8):

$$=(0.017241*(1+0.00393*(\$D\$8-20)))/(17.8*(IF(\$B\$3,1,IF(\$B\$4,2,IF(\$B\$5,4,IF(\$B\$6,6,0)))))$$

The temperature is located in cell D8, and one of the copper thicknesses in cells B3 through B6 (1/2, 1, 2, or 3 oz) is exclusively selected with a “TRUE.” The resulting sheet resistance value in ohms per square is in cell E2. The value for twice this resistance (accounting for the combined power- and ground-plane resistances), located in cell E5, is used for the simplifying assumption.

Figure 8. Implementation of Equation 21 in Excel

	A	B	C	D	E	F
1						
2		Copper Thickness			0.00114	
3		TRUE	1/2 oz		Ohms/sq	
4		FALSE	1 oz			
5		FALSE	2 oz		0.00228	
6		FALSE	3 oz		2*Ohms/sq	
7						
8		Temperature		65	C	
9						

† CRC Handbook of Chemistry and Physics, 58th edition (CRC Press, Inc., 1977), Section E-84.

Adding radio buttons to select copper thickness

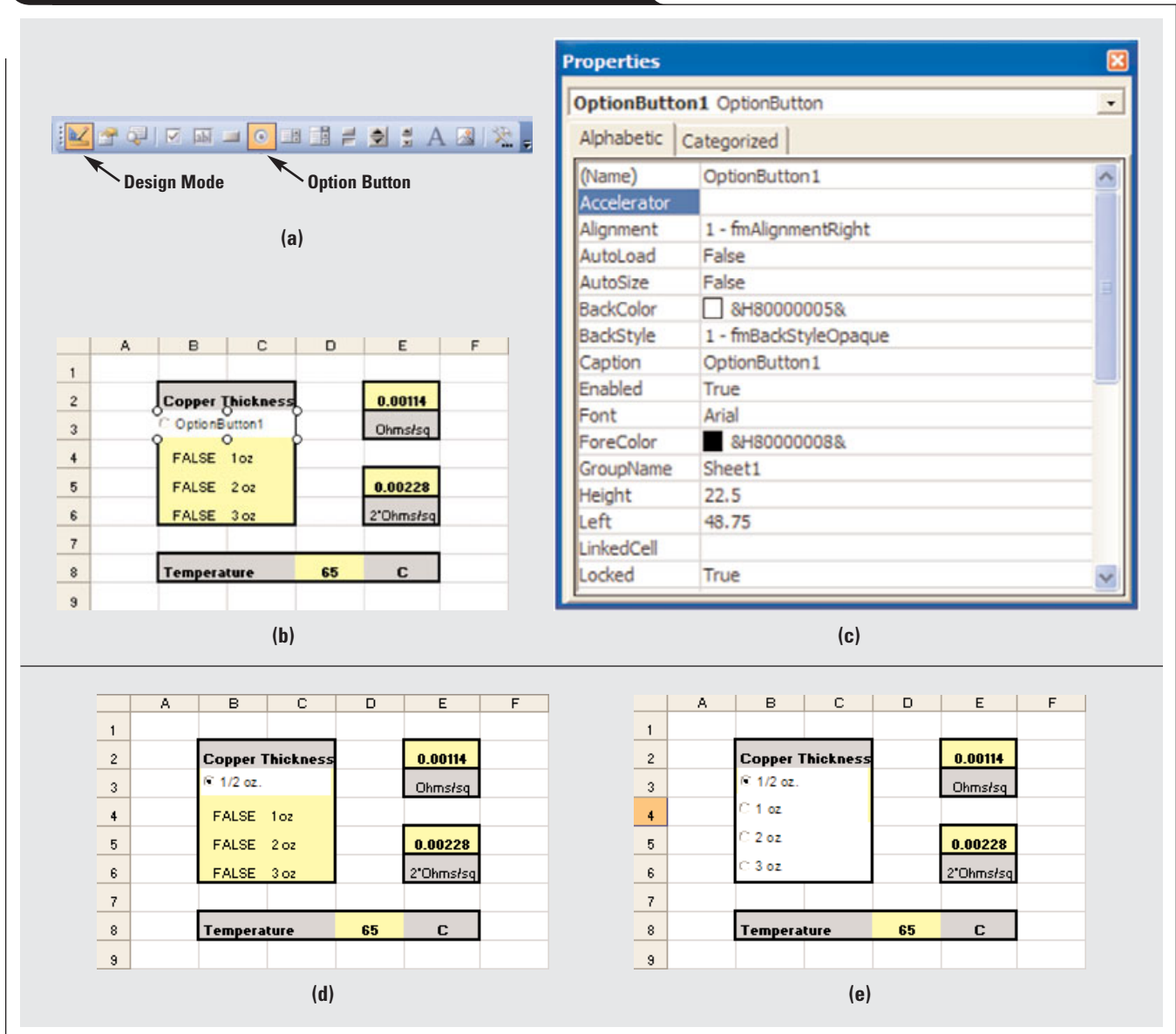
The copper thicknesses of 1/2, 1, 2, and 3 oz are arranged as shown in Figure 8 to allow for the convenient use of radio buttons to select them. To place a radio button, turn on the *Control Toolbox* toolbar (*View > Toolbars > Control Toolbox*) and select *Design Mode* and *Option Button* (Figure 9a). In this mode, use the cursor to draw a box over cells B3 and C3 as shown in Figure 9b. Right-clicking in the new *OptionButton1* area and selecting *Properties* makes the dialog box in Figure 9c appear. Change the *Caption* field from “OptionButton1” to “1/2 oz” and enter “B3” into

the *LinkedCell* field, then close the dialog box. The radio button now appears as shown in Figure 9d. With these settings, cell B3 will be true when this radio button is selected.

Repeat the process for 1, 2, and 3 oz, linking their radio buttons to cells B4, B5, and B6, respectively. The results appear as shown in Figure 9e.

Because the *GroupName* field (*Sheet1*) is common to all the radio buttons, only one thickness may be selected at a time. The radio buttons will not work until the design mode is exited, but there is one more task to complete before exiting.

Figure 9. Adding radio buttons to select copper thickness



Adding a command button for recalculation

While design mode is still active, it is advantageous to create a reminder button to initiate recalculation. Select the *Command Button* on the *Control Toolbox* toolbar (see Figure 10a), then click on some empty cells and drag to create a *CommandButton1* box as shown in Figure 10b. Right-clicking on the *CommandButton1* box and selecting *Properties* makes the dialog box in Figure 10c appear. Change the *Caption* field from “CommandButton1” to “Recalculate” and close the dialog box. Now a *Recalculate* button is displayed as shown in Figure 10d. Exit design

mode the same way you entered, by clicking the *Design Mode* button on the *Control Toolbox* toolbar (Figure 10e).

To cause the *Recalculate* button to force a recalculation, a simple macro must be assigned to the button. Select *Tools > Macro > Visual Basic Editor* to open Visual Basic, then select *View > Code* to open a window similar to the one shown in Figure 10f. Type in the code shown in Figure 10g and close the window. Now, as the copper thickness and temperature are changed, clicking the *Recalculate* button will update the ohms-per-square values appropriately (see Figure 10h).

Figure 10. Adding a command button for recalculation

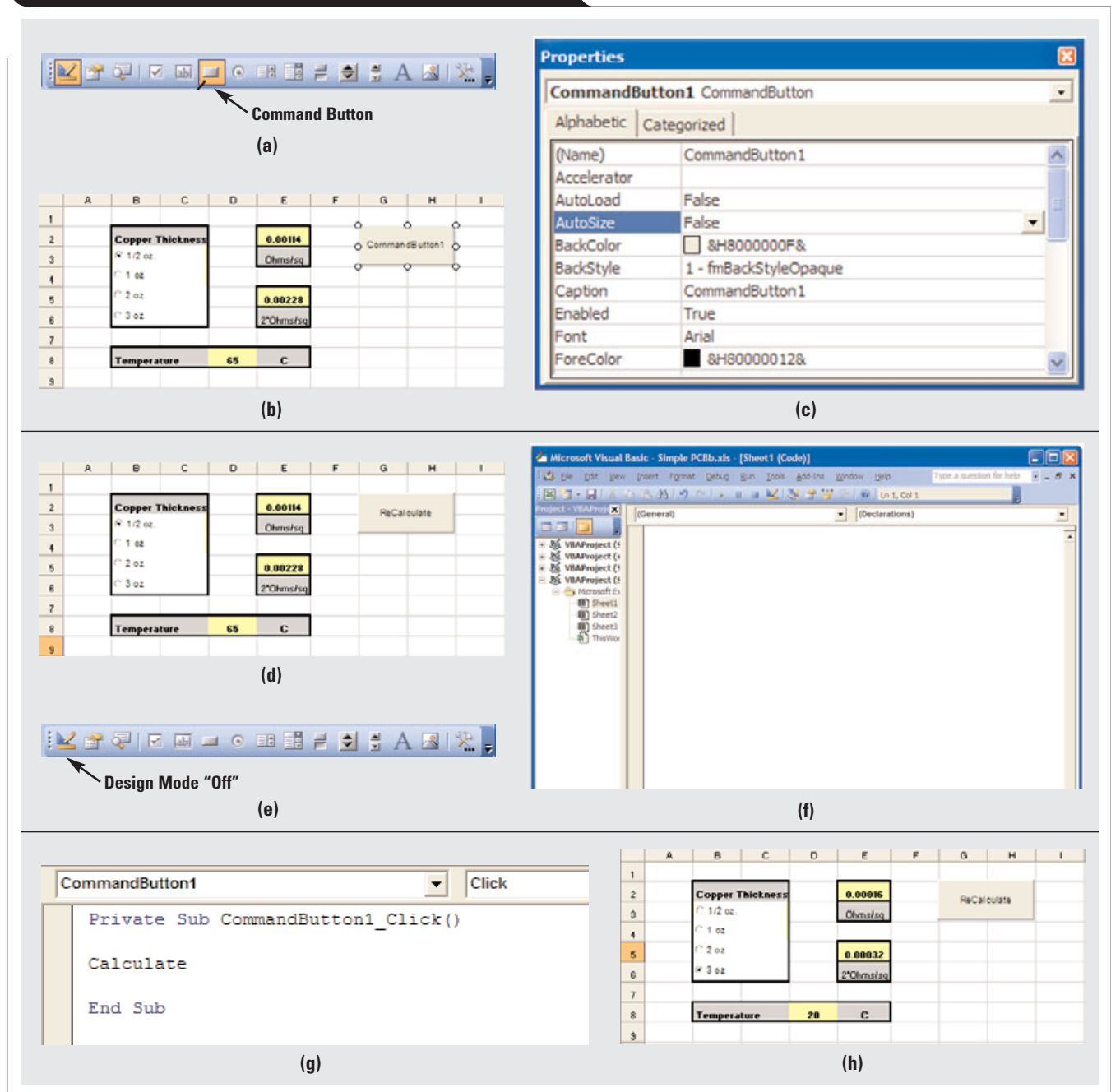
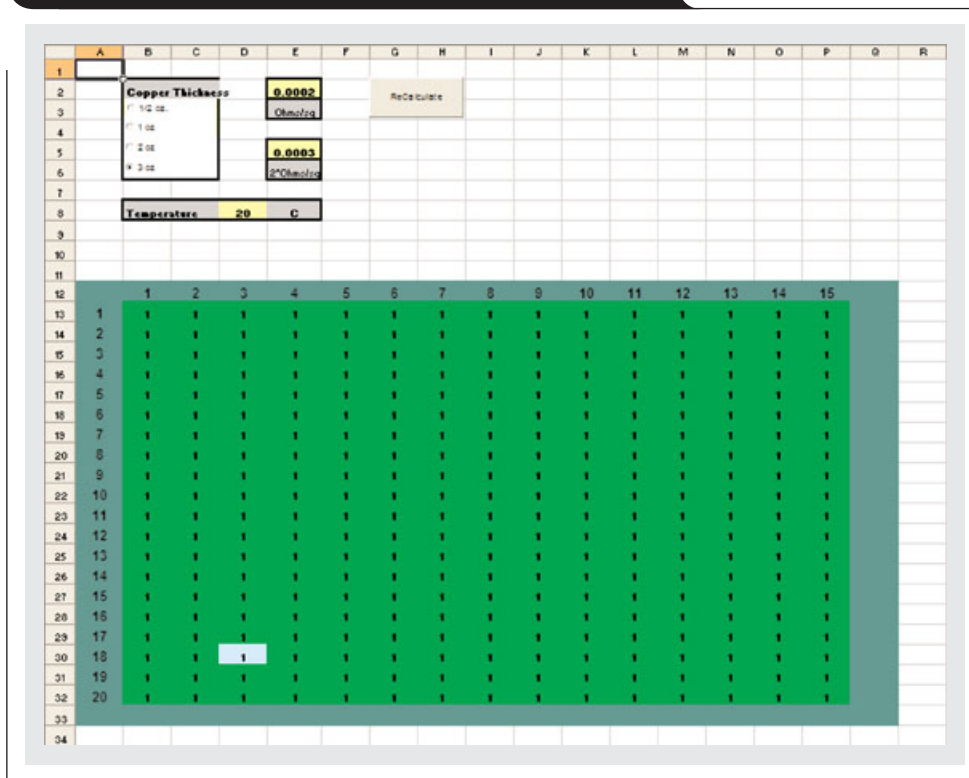


Figure 11. Model with 1-V source entered in cell D30



Building the node-voltage model

To build the node-voltage model, an equation for each node must be entered into the appropriate cell in Excel. Note that for each node, “adjoining cells” refers to those found either above, below, left, or right—not at a diagonal.

Corner nodes: Enter the Excel expression for Equation 12, “=(Sum of the 2 adjoining cells)/2”.

Example: For cell B13, enter “=(B14+C13)/2”.

Edge nodes: Enter the Excel expression for Equation 8, “=(Sum of the 3 adjoining cells)/3”.

Example: For cell F32, enter “=(F31+E32+G32)/3”.

Central nodes: Enter the Excel expression for Equation 4, “=(Sum of the 4 adjoining cells)/4”.

Example: For cell K23, enter “=(K24+J23+K22+L23)/4”.

Fill in all cells with the equations as described and click the *Recalculate* macro button. All voltages remain at 1 V, as there are no sources or loads. It is advisable to save the spreadsheet at this point and to create a backup. New form factors may easily be constructed at this stage by recopying the equations in the desired resolution and form factor.

Adding sources to the model

Sources represent the output of the power supply at the point of regulation. Positioning a source is easily done by placing a fixed numeric value in the cell that corresponds (geometrically) to the location of the actual power-supply output on the PCB. It is convenient to give the cell a contrasting color for ease of identification. Figure 11 shows a

1-V source that was placed in cell D30 by simply entering “1” in place of the equation.

Adding loads to the model

Loads represent current sinks geometrically located on the PCB. Enter a location for a load current in cell H5 and enter “10” in that cell (see Figure 12). Then type the Excel expression for Equation 16 into cell M17 as “=(M18+L17+M16+N17-\$E\$5*\$H\$5)/4”.

“\$E\$5” and “\$H\$5” are absolute (versus relative) references to the copper resistance and load current, respectively, and will not change as this equation is copied into other cells. The remaining factors should change as the load equation is copied into other cells.

Figure 12. Model with load current of 10 added in cell H5

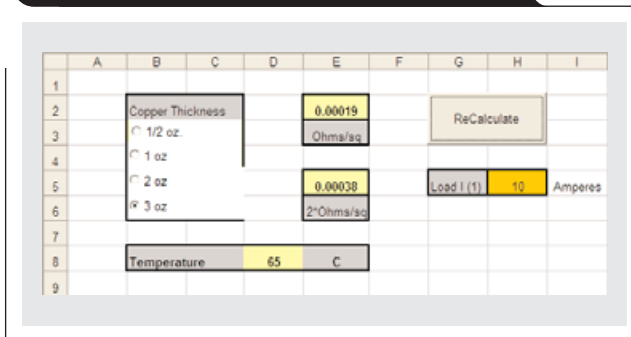
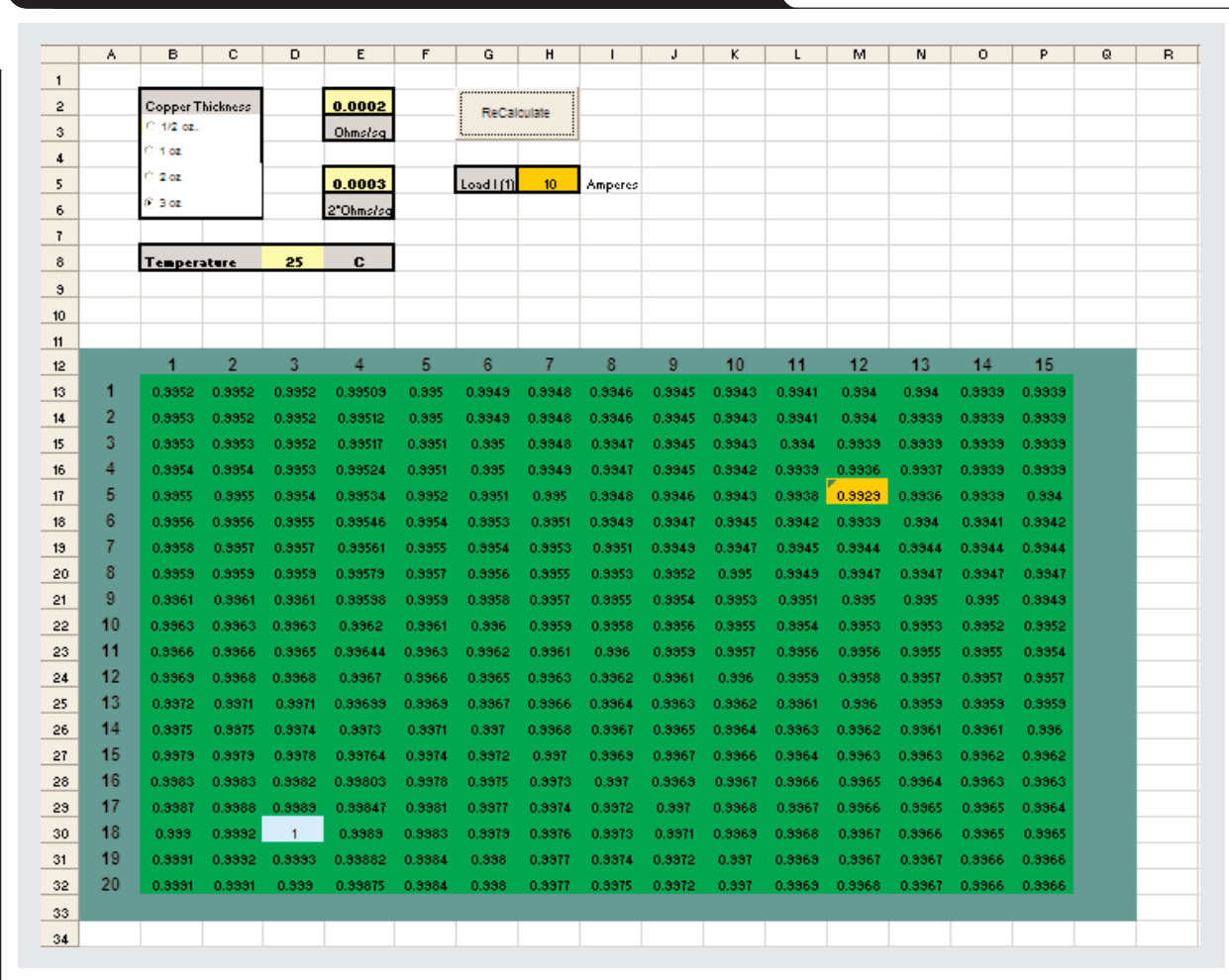


Figure 13. Voltage distribution calculations using 3-oz copper at 25°C with 1 source and 1 load

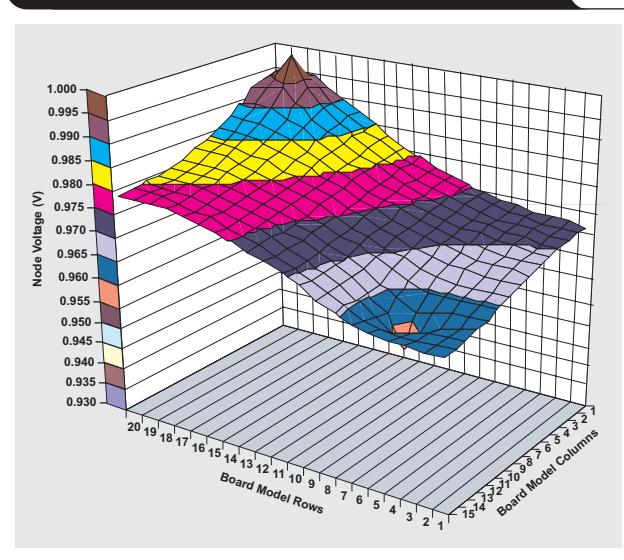


Putting it all together

For the load equation just described, the sheet resistance (actually two times the sheet resistance to account for the return path) is in cell E5, and the load current is in cell H5. Set the temperature to 25°C and select 3-oz copper, then click the *Recalculate* button. When the iterations are complete, the screen appears as shown in Figure 13. Each cell now contains the calculated voltage on the PCB (differential voltage to ground at the load point) for the given copper thickness, source voltage, temperature, and load current. The cells model voltages at the corresponding geometric locations on the PCB.

For a visual representation of voltage distribution using lightweight copper, change the copper thickness to 1/2 oz and the temperature to 65°C and click *Recalculate*. Selecting the voltage results and applying a surface chart creates the voltage map shown in Figure 14.

Figure 14. Voltage map of recalculated data with 1/2-oz copper at 65°C



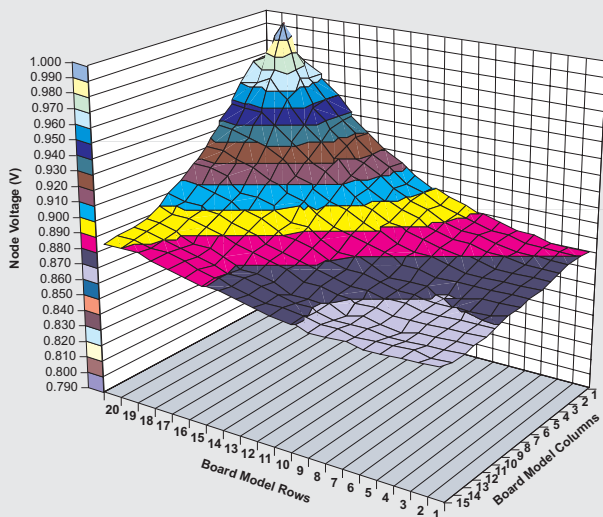
To see an example with multiple loads, reset the copper thickness to 1 oz, the load current to 5 A, and the ambient temperature to 65°C. Then copy the load equation in cell M17 into 9 additional locations on the PCB and click *Recalculate*. The results are shown in Figure 15a. Figure 15b shows the new voltage gradient.

The 50-A total load with 1-oz copper planes causes a worst-case drop of 136 mV—much more than the typical requirement of ± 30 mV—and that doesn't include transient response. Obviously, thicker copper planes are required, so the copper thickness should be adjusted back to 3 oz (Figure 15c). In this case, the maximum drop is 23.4 mV—a much better situation.

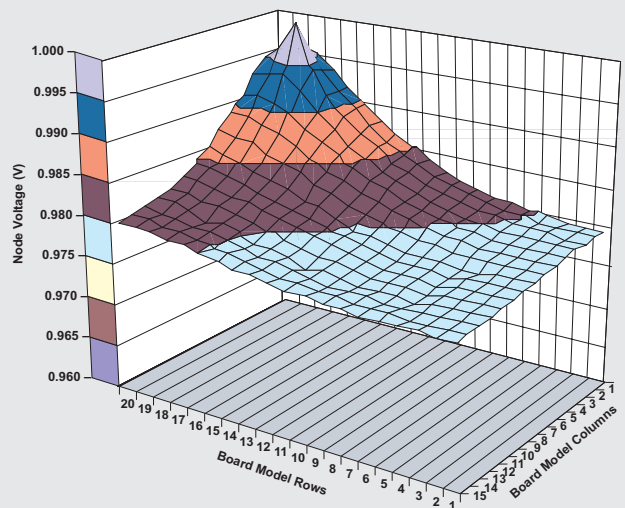
Figure 15. Calculated voltage distribution with 1 source and 10 loads

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	
10																			
11																			
12		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
13	1	0.8803	0.88	0.8792	0.87821	0.8763	0.8754	0.8733	0.8724	0.871	0.8693	0.8683	0.8682	0.8677	0.8675	0.8674			
14	2	0.8807	0.8803	0.8796	0.87847	0.8771	0.8755	0.8738	0.8722	0.8708	0.8697	0.8687	0.8679	0.8675	0.8673	0.8673			
15	3	0.8814	0.881	0.8802	0.87901	0.8775	0.8757	0.8737	0.8718	0.8705	0.8693	0.8682	0.8673	0.8671	0.8671	0.8671			
16	4	0.8826	0.8821	0.8812	0.87989	0.8781	0.876	0.8735	0.8709	0.8699	0.8688	0.8674	0.8661	0.8664	0.8668	0.8669			
17	5	0.8842	0.8837	0.8827	0.88119	0.8792	0.8767	0.8734	0.8685	0.8693	0.8685	0.8667	0.8633	0.8657	0.8666	0.867			
18	6	0.8863	0.8857	0.8846	0.88297	0.8808	0.8781	0.8743	0.8717	0.8705	0.8692	0.8676	0.866	0.8665	0.8671	0.8674			
19	7	0.889	0.8883	0.8871	0.88529	0.8829	0.8793	0.8765	0.8731	0.8716	0.8701	0.8684	0.8668	0.8672	0.8677	0.868			
20	8	0.8922	0.8916	0.8902	0.88819	0.8855	0.8822	0.8781	0.8725	0.8727	0.8713	0.8691	0.8654	0.8677	0.8687	0.869			
21	9	0.8962	0.8955	0.8939	0.89172	0.8888	0.8853	0.8813	0.8773	0.8753	0.8734	0.8714	0.8694	0.8697	0.8701	0.8704			
22	10	0.9003	0.9001	0.8984	0.89594	0.8927	0.8889	0.8845	0.8802	0.8773	0.8757	0.8734	0.8713	0.8714	0.8718	0.872			
23	11	0.9065	0.9055	0.9037	0.90088	0.8973	0.8929	0.8877	0.881	0.8803	0.8781	0.8752	0.871	0.8729	0.8736	0.8739			
24	12	0.913	0.9119	0.9098	0.90665	0.9026	0.8978	0.8925	0.8873	0.8841	0.8813	0.8784	0.8759	0.8757	0.8758	0.8759			
25	13	0.9206	0.9194	0.917	0.91333	0.9086	0.9031	0.8972	0.8913	0.8877	0.8845	0.8813	0.8785	0.8781	0.8781	0.8781			
26	14	0.9293	0.9281	0.9254	0.92106	0.9154	0.9089	0.9017	0.8932	0.891	0.8876	0.8837	0.8787	0.88	0.8803	0.8804			
27	15	0.9393	0.9383	0.9355	0.93009	0.9231	0.9154	0.9076	0.9002	0.8954	0.8912	0.8873	0.8833	0.883	0.8828	0.8827			
28	16	0.9503	0.9501	0.9482	0.94473	0.9395	0.932	0.923	0.913	0.9047	0.8993	0.8945	0.8902	0.8866	0.8855	0.885	0.8849		
29	17	0.9616	0.9638	0.9663	0.96321	0.958	0.9528	0.9475	0.9405	0.9323	0.925	0.9175	0.9095	0.9067	0.9073	0.9071	0.9069		
30	18	0.9705	0.973	1	0.96584	0.961	0.9554	0.9497	0.943	0.9354	0.9273	0.9191	0.9105	0.9067	0.9073	0.9071	0.9069		
31	19	0.9726	0.9749	0.977	0.9731	0.9688	0.9633	0.9568	0.9493	0.9413	0.9329	0.9245	0.9155	0.9107	0.9113	0.9111	0.9109		
32	20	0.9726	0.9725	0.9701	0.96672	0.9619	0.9554	0.9479	0.9394	0.931	0.9226	0.9142	0.9052	0.9004	0.901	0.9008			
33																			
34																			

(a) With 1-oz copper



(b) With 1-oz copper



(c) With 3-oz copper

The voltage-gradient information provided by the model is very helpful in determining the optimal placement of the remote sense lines relative to the power supply or power module.

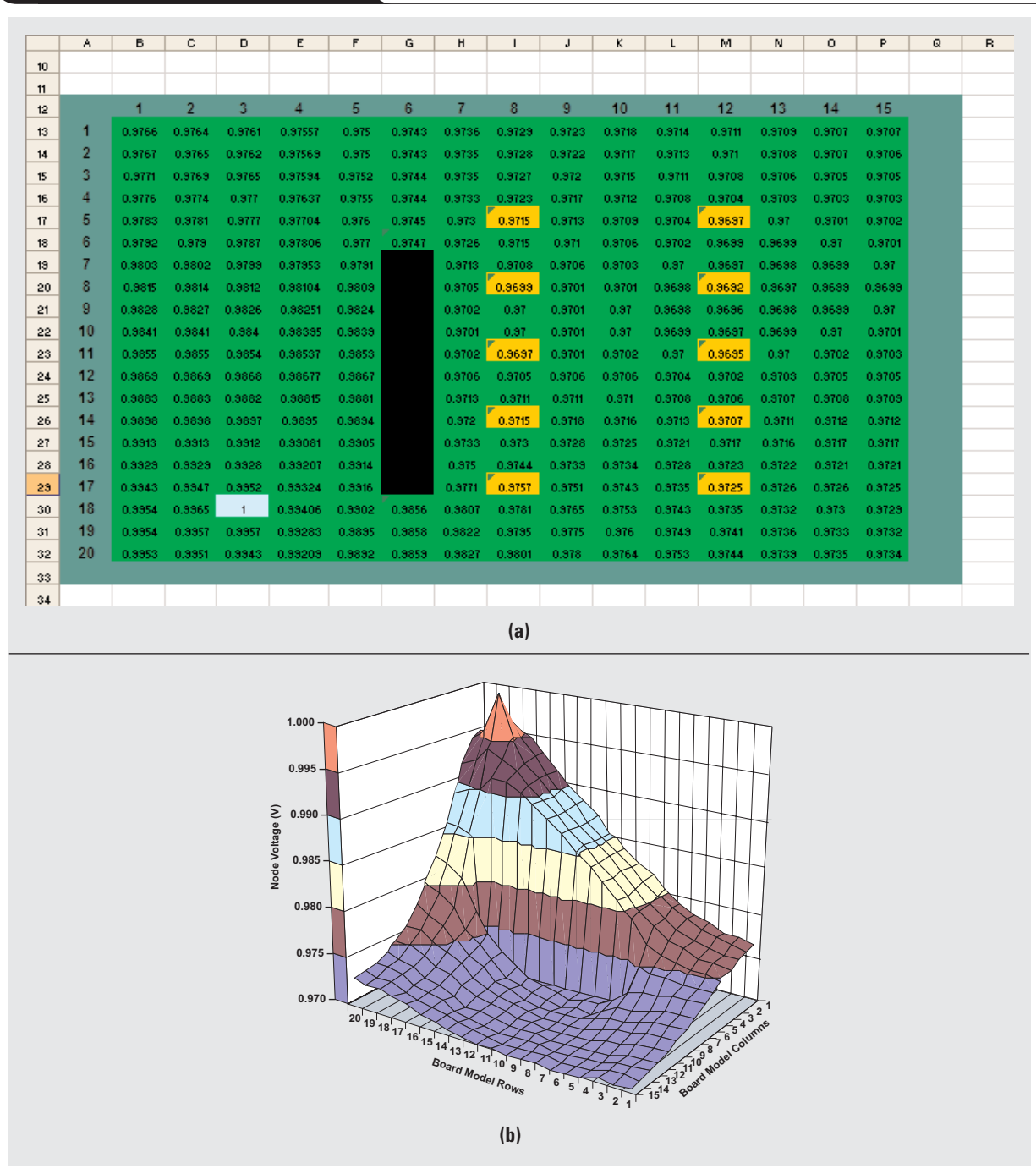
Adding slots or vias

Slots or rows of vias may be modeled by inserting edge and corner nodes into the appropriate locations in the worksheet and placing a "0" in the cells that represent the

slots (Figure 16a). With the slots included in the calculation, the voltage plot looks as shown in Figure 16b. The slot changes the worst-case voltage drop to 30.3 mV.

Many situations may be modeled with this simple example. Additional accuracy is expected as more cells are used to model the sheet resistance. The maximum number of columns in Excel is limited to 256, which sets the limitation for the minimum resolution (for one dimension of the PCB). Note that the three-dimensional graphing capability

Figure 16. Model with slots added



of Excel is limited to about 25 cells, so graphs are not available for higher resolutions. However, this is not a serious limitation, since the cell values are displayed in the table. Simple conditional formatting may be used to color-code the results directly on the spreadsheet without the need for a separate graph.

Further applications

The technique described may be used to construct more complicated geometries. In general, plane thicknesses are not always the same, as ground planes are typically thicker than power planes. Further, power planes may be split rather than uniform, or the “power plane” may be simply a very wide trace on a signal layer. With the described technique, a model for each plane may be constructed and a “difference” sheet created to examine the voltage difference at different load points. Separate temperature and resistance sheets can also aid in constructing more complicated geometries.

One common concern is the voltage drop that occurs due to the “Swiss-cheese” effect of having many vias located in and around high-density ICs. This problem may be addressed by inclusion of the nonuniform resistive effects described in Equations 3, 7, 11, and 15 in the spreadsheet model. Model the resistance of the square by taking the ratio of the copper area to the “empty” area (where vias occur) and increasing the resistance for that square by the ratio.

Including local temperature effects

The copper resistance is a function of temperature, as noted previously. Localized heating due to FPGAs or DSPs will increase the temperature and thus the resistance of the copper around the load points. This variable may be included in models by creating an expected temperature map of the PCB and adjusting the effective resistance for each square according to the local temperature on the board. Again, this requires the inclusion of the nonuniform resistance equations.

Conclusion

The voltage drop of PCB power and ground planes can be a significant contributor to the total voltage-tolerance budget for processor cores. Excel and other spreadsheet software with circular reference /iteration capabilities may be used to construct a model of the PCB that can greatly assist the designer in selecting copper thickness and remote sensing locations, proportioning the voltage-tolerance budget, and optimizing the bypass capacitance necessary to meet transient requirements. The spreadsheet results also provide guidance for power-supply and processor placement.

Related Web sites

dsp.ti.com

www.ti.com/sc/device/TPS40140

A copy of the finished spreadsheet is available for download at: www.ti.com/lit/zip/slyt274

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