THE VOLTAGE LEVELS AND POWER DENSITIES IN TODAY'S EQUIP-
MENT DESIGNS ARE CHANGING MORE RAPIDLY THAN EVER BEFORE,
AND EFFICIENCY IN OFFLINE SUPPLIES AND POINT-OF-LOAD REGU-
LATORS IS A NECESSITY. FREE SOFTWARE PACKAGES CAN TAKE THE
STRAIN OF GENERATING POWER-MANAGEMENT DESIGNS.

# Software holds the key to switching-regulator design

L ET'S FACE IT: Crafting power supplies has never been the fashionable end of circuit design. If you've ever confronted the task of designing a power supply, chances are that it was the last major functional block in the product, and you were left with an awkwardly shaped space in the corner of the case that was just too small. But

in the past, the circuit-design problem was often simpler. You might have needed to provide only two or three dc-voltage rails, and the expected efficiencies were such that linear regulators might have been acceptable. Today, your use of linear regulators might be confined to the last stages of a supply, deriving one dc-voltage rail from another with a low-dropout regulator. More likely, you have to use switching techniques throughout.

Trends in board design are not helping you. As lower supply voltages proliferate, they rarely replace earlier voltages but, rather, must be supplied in addition to all the others. The board that needs 3.3, 2.7, or even 1.8V invariably still requires a 5V line as well. Densely packed designs mandate the lowest possible heat dissipation, and, to add to your difficulties, the use of universal input stages to derive power from any line outlet worldwide is now the most common configuration. Unless you specialize in power design, you will also have to revise subjects that you may not often have to handle.

As always, semiconductor vendors offer a range of options at all stages of the power-management chain—from offline supply-controller ICs to onboard dc-dc converters. Anxious to secure design
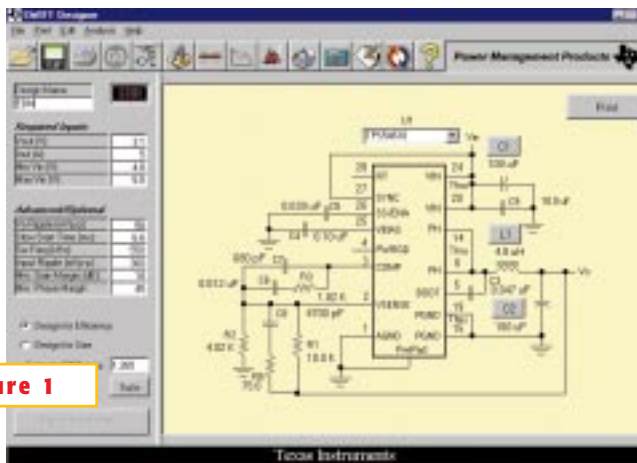


**Figure 1**

**Selecting a nonstandard output voltage causes Texas Instruments' Swift software to opt for the adjustable version of its dc/dc converter IC.**

wins, more and more vendors are now providing support software that is becoming more sophisticated, aiding not only device and component selection but providing circuit simulations, bills of materials, and even thermal analyses. Support is also available for the dedicated-linear-circuit designer who is familiar with the intricacies of Spice or other linear simulators (see **sidebar** "Commercial simulators"). Such support is not the territory this article aims to cover. However, even if you are a Spice specialist, you may find that some of these free software offerings are powerful enough to turn out a quick offline-power-supply or dc/dc-converter design.

Naturally, detailed and powerful free-issue software comes at a nonfinancial cost; the packages invariably focus on the products of one manufacturer, on one range of products, or on a limited number of individual components. But they are becoming more widespread, so your best starting point may be to check with your preferred suppliers of power devices about what is available or due for release. The software packages are usually available on CD-ROM and from vendor Web sites, and their size often permits downloading even over a dial-up modem connection. One of the largest executable files downloaded for this article is slightly more than 12 Mbytes. Surprisingly, though, vendors do not always prominently feature these files on their Web sites, and a scan of related application notes or development-support sections may reveal useful routines.

The most recent introduction to the field is a program from Texas Instruments (www.ti.com) that supports its new series of dc/dc converter ICs with integrated power MOSFETs. You use these chips to provide point-of-load low-voltage supply lines from higher voltage rails of 3 to 6V. TPS5461x devices are synchronous-buck-

## AT A GLANCE

▷ Efficient switch-mode power management is now necessary throughout equipment designs.

▷ Point-of-use regulation to 3V and less, at high currents, rules out linear regulators.

▷ Free software packages offer design support for both offline and dc/dc converters.

▷ Design detail extends to fully specified transformers and transient-response analyses.

▷ You can optimize programs for efficiency, cost, or other parameters.

▷ For more detailed analysis, commercial analog simulators offer power-supply-specific features.

topology ICs with integrated low on-resistance ($R_{DS(on)}$ of 30 m$\Omega$) power FETs rated at 6A continuous or 12A peak. Several variants exist with preset output voltages of 0.9 to 3.3V, and you can set an adjustable-output version anywhere in the same range. Preset-voltage versions are internally compensated and require only six external passive components; the 54610 adjustable version is externally compensated and, therefore, needs several more external components. TI's European market-development manager for power-management solutions, Bernd Krafthofer, says the devices have been introduced to supply low voltages at the point of demand with the minimum board area and maximum efficiency. He notes that telecommunications-equipment design is moving away from deriving multiple voltages from a global 48V rail toward deriving low-voltage supplies at the point of demand from board-level 5V supplies. To help you use the devices in "drop-in" fashion, TI provides the Swift design package.

Swift opens by showing the simplest, six-external-component circuit with a set of default values for input and output conditions. For all of these conditions, you can substitute your own values. Using the default values, the program also computes additional parameters, such as ripple, output-response characteristics, and start-up time. **Figure 1** depicts a request for a nonstandard output voltage of 3.1V at 5A; the software has selected the adjustable version of the chip and has automatically added the additional compensation components. Swift supplies a bill of materials, citing specific manufacturers and part numbers for critical components; an analysis of design performance; stress analysis in terms of peak voltage, current, and power in key components; a graphical plot of output-loop response, gain, and phase margins; and a curve plotting efficiency against output power. The 3.1V, 5A supply claims a peak efficiency of 94.4% and achieves 91.4% at full output. You can also choose to design for minimum board space. Substituting for the components in Swift's library, you can also enter the details of components from your preferred suppliers and recalculate the design to determine the effect on parameters, such as output ripple. You can locate the package using product number TPS54610 at TI's Web site.

In a similar vein, you can quickly design buck-topology dc/dc converters using controller chips from Micrel, using its Buck-It package. You can download the package at Micrel's Web site, www.micrel.com. If you are designing for a board that has limited available clearance, you can design to a maximum height. The software will search its database for components that fit the physical profile, as well as meet the electrical requirements of your circuit.

At the other end of the power-supply

## FINE-TUNING

If you have a taste for the automated approach to power-supply design but require a close tolerance-output specification that manufacturing tolerances don't meet, Xicor (www.xicor.com) suggests one of its products as an option.

Using a digitally controlled potentiometer at a point in the circuit that will set output voltage, you can include a means of automatically setting the output to a precise value. You can completely automate this process using a set of drivers that Xicor released for Lab-View6I from National Instru-

ments (www.ni.com). Either under LabView itself, or from a Windows user interface with LabView, you can create an automated program that measures and sets supplies in production. The digitally controlled potentiometers come in the XDCP family and are 1024-tap

resistive networks; a value stored in a nonvolatile memory sets the connected tap.

Xicor's AN139 details a number of possible circuit configurations to help you use the devices in typical switch-mode power supplies.

chain, Power Integrations (www.powerint.com) has revised its software package PI Expert to version 3.0 (**Figure 2**). This version targets the design of offline supplies, again using ICs with integrated power devices. The new software adds the TinySwitch (23W maximum) devices to the TopSwitch (250W maximum) series that the package previously targeted. The package uses forms for parameter entry and synthesizes circuits using a range of topologies. In an interactive process, you can choose from an ac or dc input, specifying the input-voltage range; select as many as six output voltages, with their associated maximum current demands; and select optimization by cost or by efficiency. For the simplest design process, you can then select AutoDesign, and the program will choose a power device and topology and produce a complete design, again with a bill of materials. In an even more interactive process, you can follow the program as it selects the power device and specifies key components, altering the selections to suit your available components or to adjust performance.

Power Integrations has taken note of the fact that you may rarely be involved with the design of magnetic components and transformers and includes a complete design section addressing this subject. One option is geographic: You select North America, Europe, or Asia, and the program uses libraries of components most commonly available in that territory. As part of the output, the program specifies a complete transformer design, including bobbin, wire and turns count, isolation barriers, and winding windows. It also warns you if your selection is nonideal. A nonideal selection can occur, for example, when the design requires a

transformer turns ratio that you cannot ideally achieve with a small integer number of turns. If you choose the interactive route to specify a supply with PI Expert, all of its table-based design forms recalculate on the fly in a spreadsheet fashion to show the effects of the changes you make. This software is available at the company's Web site.

Supporting its Viper range of single-chip switch-mode power-supply controllers, STMicroelectronics (www.st.com) also provides an interactive software package, which you can download from http://stonline/products/support/smps/smps.htm (**Figure 3a**). You can use Viper series parts—named for the vertically integrated power-transistor that they incorporate on-chip along with a PWM controller—to build offline supplies of as much as 100W. The software includes data sheets and, on initializing, presents you with a generic flyback supply circuit. Once again, this is an "active" circuit diagram that recalculates its results on the fly as you alter configurations and parameters. From its toolbar, you have the choice of setting primary or secondary (with optocoupled-feedback) regulation or selecting transformer-primary clamping by either RC network or by a Transil diode. You can also add extra secondary outputs from the toolbar. The panels marked Input, Transformer, Viper, and Out expand to parametric input forms and show the calculated figures that define, for example, the transformer.

The default input is a universal ac input (88 to 264V), but you can also specify dc; you select the Viper device from ST's range, and warning messages tell you if you exceed any of the limits of your chosen part or if your design is running close to its limits. In this panel, you also set the operating conditions and switching frequency for the chip, the optocoupler gain, and the soft-start time. Each output generates its own specification panel, where you enter required voltage and current with allowable ripple. This panel also gives you feedback on the required parameters (ESR and peak current) of the output-filter capacitors. ST's software provides a comprehensive transformer design, specifying core, wire, windings, and winding order, and giving

a graphical representation of the winding-stack and bobbin-window use (**Figure 3b**).

All of these programs (and others like them—these examples are programs with new releases incorporating significant updates) generally appear to be working, at least in part, on a look-up-table or spreadsheet basis. When you build your circuit with the specified semiconductor devices and passive components, the characteris-



(a)

(b)
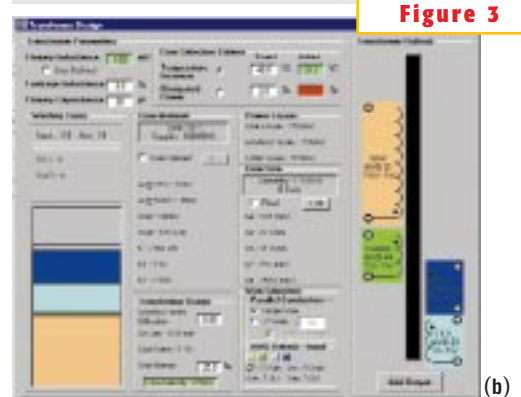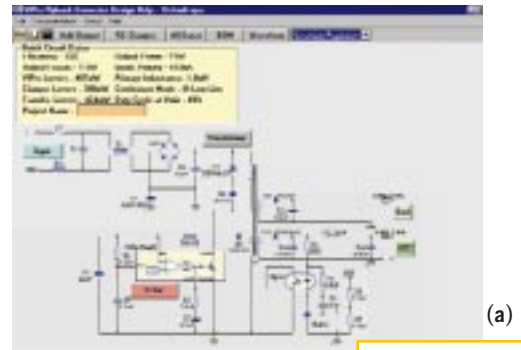
**This design for STMicroelectronics' Viper device specifies secondary regulation, a universal line input, and an extra 3V output (a). The software creates a detailed transformer design including an estimated profile of the windings on the left (b).**

tics of one or more known topologies reduces to an algorithmic representation that operates reasonably accurately within a given design space. If these free design programs are carrying out a simulation, they execute it using a relatively high-level behavioral model of the semiconductor devices. They do not do a comprehensive and detailed transistor-level simulation for an arbitrary design. More than one of the packages carries a disclaimer stating that you should build a prototype to verify performance on the bench. The representations in these packages, for the most part, apply to the steady-state performance of the given circuits; they calculate a start-up time and a transient re-

sponse, but they do so using a higher-level abstraction of the behavior of each device. Still, the results should be satisfactory for most power-supply and dc/dc designs. If you think you need to go beyond the capabilities of free-download software, consider some of the options in the **sidebar** "Commercial simulators."

National Semiconductor has a range of downloadable and Web-hosted software tools for switch-mode power-supply design. Recently updated to version 6.1, Switchers Made Simple generates buck, boost, and flyback circuits for a range of National's Simple Switcher regulator ICs. (If you already have the earlier version, a smaller download will upgrade it and reduce your connection time.) Again, the package accepts your required input and output voltage-range specifications and guides device selection, outputs component lists, and estimates performance.

However, National offers more comprehensive capability with its Web-based service, Webench. You must register for Webench, but it is free of charge. Available at http://power.national.com, it gives you access to a full circuit-simulation package called WebSim and a thermal-modeling facility called WebTherm. When you access these routines, you are using restricted versions of the analysis engines Simplis (from Transim, www.transim.com) and Flotherm (from Flomerics, www.flomerics.com).

Transim's Web-based analysis engine performs a similar task on other vendors' sites, but in each case, it is restricted to those vendors' components and component models. For example, on Fairchild

Semiconductor's site (www.fairchildsemi.com), the device models available to the simulator are of Fairchild MOSFETs (50 in the current release of the software), and you can explore three application circuits, including a synchronous buck converter. The Transim engine also appears on Champion Microelectronic Corp's and Artesyn's Web sites (www.championmicro.com, www.artesyn.com). It analyzes the performance of packaged power supplies and dc/dc converters.

National's Web-site begins with the same design process as the downloadable version. You use a forms-based entry of desired circuit parameters, and the Web-based software synthesizes a suitable circuit. You submit the circuit to the Web-based analysis engine and within a short time you have a comprehensive analysis of the circuit that presents waveforms at any node you choose to probe. You can also call for full transient-response plots of the circuit's performance, which the program returns as a conventional Bode plot. Because the simulator is using more detailed, lower level device models than are possible with the downloadable tools—models that National optimizes to run on this simulation engine—you can achieve greater accuracy.

Using the same operating paradigm, you can then analyze the thermal behavior of your proposed supply circuit. Webench generates a typical layout for the circuit, mounting all components on standard pc- board material, and submits this layout to the Flotherm engine. Flotherm is a general-purpose computational-fluid-dynamics thermal-analy-

sis package, and the version Webench uses will accept your inputs for the board environment in terms of board orientation, edge temperature, and airflow direction and speed. A color-coded plot shows the heat distribution across the board in steady-state conditions, revealing the peak temperatures that will affect each component.

National's most recent addition to this facility is Build-It. Once you have completed your design simulation, you can automatically generate a kit-of-parts order to build a prototype. Distributor Pioneer-Standard (www.pioneer-standard.com) fulfills the order.

Linear Technology (www.linear-tech.com) takes a different approach to precise simulation of switch-mode circuitry with its SwitcherCAD package. SwitcherCAD is one of the longest established packages in this sector, but the newest version that you can currently download—SwitcherCAD III—is a complete rewrite with a new philosophy. This simulator is much more general-purpose and can handle arbitrary analog circuits, as opposed to a design package that finds solutions for only a limited number of predefined circuit topologies. SwitcherCAD III is not a conventional Spice simulator, explains Linear senior software engineer, Mike Engelhardt, but it does contain a Spice engine, along with specially defined logic primitives. These primitives allow you to accurately model the control behavior of the typical switching regulator, alongside its detailed linear operation, while circumventing the problem of disparate time scales (see **sidebar** "Commercial simula-

## COMMERCIAL SIMULATORS

Rather than supply a dedicated software package, some vendors concentrate on making detailed models available for use in Spice-based simulators. Running switch-mode simulations is, however, a notoriously tricky task with a conventional (Spice-based) linear-simulation package and integrated devices containing both linear circuitry and power switches. You need to set a small time-step to accurately model the switching behavior of the circuit as it transitions from one state to another, but as the

simulator works through the linear segments of circuit operation, the same time-step will produce many cycles in which little changes, leading to very long simulation runs. If your models do not accurately represent all the parasitics involved in the devices, deviation from real-world behavior can be significant.

An example of Spice-model support that you might use with a commercial version of the program is FSDMOS.LIB, a library that Fairchild Semiconductor

developed and describes at www.fairchildsemi.com/models/Discretes/spicemanual.html. The library represents Fairchild's power MOSFETs as both switched-capacitor-electrical and empirical-thermal models.

In addition to the general-purpose linear and mixed-signal simulators from suppliers such as Cadence's Pspice (www.cadence.com) and Tanner EDA's T-Spice (www.tanner.com/eda), more specialized tools include those from Intusoft (www.intusoft.com) and Avanti (www.

avanticorp.com). Intusoft's IsSpice4 comes bundled with a package called Power Supply Designer. It includes support for SMPS design and a detailed package for design of magnetic components. You can download an evaluation version of Magnetics Designer from Intusoft's Web site. Avanti's Saber simulator has also gained a reputation for use in the detailed simulation of power-supply circuitry, especially in modeling circuit start-up from initial conditions to steady state.

tors"). Engelhardt has also created new models for elements that are critical to the operation of a switching supply, such as capacitors and MOSFETs. His models for output capacitors have the required ESR but without internal nodes, allowing detailed simulation to proceed more quickly. He takes a similar approach with MOSFETs, again modeling their characteristics without internal nodes. This approach, Engelhardt says, also improves the convergence characteristics of the program and allows you to simulate circuits that have multiple modes of operation. It also offers a new, more accurate way to compute efficiency, based on continuously comparing levels of stored energy in the circuit elements on a cycle-by-cycle basis.

The release notes for SwitcherCAD III describe the program's three modes of operation. Although you can use it as a circuit simulator for an arbitrary circuit design, you can also use it in "cookbook" mode. If you are going to use it to create new designs of your own, numerous warnings indicate the presence of fatal design flaws. Unlike earlier versions of

SwitcherCAD, this version does not have an element of circuit-synthesis capability. Engelhardt says that the software should include this feature by the end of 2001. He adds that the program is evolving and the company posts new versions of it every week or two at www.linear.com. The program comes with a number of demonstration circuits, one of which is a 12 to 5V step-down circuit (**Figure 3**). When you enter a set of initial conditions into SwitcherCAD and start the program, it runs until it achieves a steady state. **Figure 3** shows the circuit and the first 100 $\mu$sec of $V_{OUT}$; not shown is the efficiency report that lists each component with the rms and peak currents it experiences and the power dissipated in it.

Detailed simulation is also a feature of the design process that supports International Rectifier's PowIR devices for dc/dc-converter use. In this case, IR has already completed a detailed study of the flow of charge through the MOSFETs

and associated passive components. IR includes the results in a set of reference designs and design guidelines and says that its precise modeling of device behavior allows you to build circuits with much better efficiencies than would otherwise be possible. The company describes this process at www.irf.com.

And, if you require a fully qualified supply in a short time, you can access Web-based software at Vicor's Web site, www.vicor.com. Vicor's VCAD software will build you a modular supply using second-generation ac/dc and dc/dc modules. It will also select the required hold-up capacitors to meet your specifications. The company's VDAC software will design a dc/dc converter module that meets your specifications (if no standard part exists) and automatically enter it into Vicor's automated manufacturing process. Vicor requires a $3750 NRE charge to place an initial order, but you can explore the software's capabilities without cost.□

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