BY DAVID MARSH • CONTRIBUTING TECHNICAL EDITOR

Linear regulators face extinction

AMERICANS CALL THEM "WALL-WARTS"–LOW-POWER OFFLINE PLUGTOP SUPPLIES THAT POWER SO MANY CONSUMER DEVICES. NEW INITIATIVES TO REDUCE STANDBY POWER NOW THREATEN THE TRADITIONAL TRANSFORMER/LINEAR REGULATOR MODEL, FORCING DESIGNERS TO CONSIDER SWITCH-MODE ALTERNATIVES–BUT AT WHAT COST?

Regardless of the soundness of the science behind global warming, the case for energy conservation has never been stronger in any peacetime economy. With the price of a barrel of crude oil way over $60—and peaking over $70 in the wake of Hurricane Katrina, which immobilised around 25% of the US domestic oil supply—governments everywhere are nervously watching their energy stocks. And while it's obvious that fossil fuels will eventually run out, alternative mass-generation technologies that rely on nuclear fission are evermore unpopular with a politically vociferous public-at-large. Recognising that sustainable resources such as wind and tidal power are unlikely to bridge the growing energy gap, economies as diverse as the European Union, Korea, Japan, the People's Republic of China, Russia, and the US appear to be placing their long-term faith in nuclear fusion, having come together in the multibillion-dollar ITER project (iter being Latin for "the way").

Meantime, the only way to stop the lights from going out is to adopt stringent energy-saving measures, some of which are beginning to appear on the statute books. At present, programmes such as Energy Star in North America and similar initiatives in places as far apart as the European Union and Australia are voluntary. But in response to the rolling blackouts that swept the US in 2003 and similar outages that continue to threaten its electricity supplies, agencies such as the California Energy Commission (CEC) are introducing energy-saving measures that have global repercussions for appliance and equipment makers (see **sidebar** "World wakes up to energy waste"). The immediate target for most initiatives concerns standby-power reduction in everything from mobile-phone chargers that draw a few VA to multi-kW server farms. At the low-power end, switch-mode supplies are virtually mandatory to meet efficiency targets, effectively killing off linears in a huge range of applications. Because it's currently impractical to reduce the standby-power consumption of devices such as silver-box supplies to the levels that energy-saving initiatives demand, there's also huge demand for low-power auxiliary supplies.

But whether it's PCs, wall-warts, or virtually any consumer or office equipment, the common thread is the need to convert a small amount of energy from ac line as efficiently as possible, and at as low a cost as possible. As anyone who has investigated this issue knows, an advantageous cost/efficiency balance is difficult to achieve. Magnetic components are not cheap, and the cost of an offline supply can easily spiral beyond economic reason—helped along by the amount of support circuitry that can be necessary, such as surge-protection devices. Moreover, it's imperative to meet EMC specifications, which is also a non-trivial exercise, but one that semiconductor vendors increasingly detail within their application examples.

AT A GLANCE

- Energy-reduction measures reach the statute books.
- Linear topologies are all but dead for wall-warts
- Simple switchers compete for lowest-cost nonisolated supplies.
- Isolated supplies benefit from low-power chips.
- Free software simplifies magnetics design.

NONISOLATED SUPPLY ICs

The traditional method for deriving nonisolated offline supplies employs a resistor and capacitor connected in series to form an RC dropper (see **sidebar** "Prying Eyes"). The circuit exploits the capacitor's effect of shifting the voltage and current phases by 90°, such that the capacitor ideally works as a loss-less resistor. It dates back to valve-heater supplies from the early days of radio, and an excellent expansion of the technique's operation—together with an Excel spreadsheet for component calculations—appears at the UK Vintage Radio's website. Today, variations of this circuit commonly appear in white goods such as washing-machine controllers, but these suffer from poor off-load efficiency due to the Zener shunt regulator that's necessary to stabilise the supply to a microcontroller or other sensitive components. Capacitor size and the resistor's power dissipation also typically limit such circuits to 30 mA or less in contemporary designs, examples of which appear within Philips Semiconductors' application notes (**Reference 1**).

At current levels of only a few mA, dispensing with voltage regulation enables size, cost, and efficiency gains in a less obvious example of an offline dropper circuit (**Figure 1**). In this example—the front-end of a digital temperature-setpoint controller—the op-amp and resistor bridge form the lower arm of what's effectively a resistive divider across ac line. Fusible resistor R1 and half-wave rectifier D1 bleed current into smoothing capacitor C1, which supplies a dual op-amp and ancillary circuitry to control a triac (this explains the unusual-looking use of ac live as analogue common, phasing trigger current to exploit the most sensitive quadrants of triac operation). Measurements show that off-load current is around 1 mA, rising to an average of almost 3 mA when the driver stage (not shown) pulses the triac's gate. Taking the triac's on-state as circuit active and off as standby, this equates to an efficiency figure of some 66%, during which the analogue Vcc supply ranges from 21V (standby) to 13V (active)—adequate for a huge variety of analogue circuitry.

Nonisolated circuits that require regulation and a power level that's similar to most RC dropper supplies can benefit from chips such as the unique SR03x from Supertex. Available in 3.3 or 5V regulated output versions, these 8-pin devices build a universal-input, inductor-less, dual-output supply that suits applications up to 1.5W (**Figure 2**). The unregulated rail is nominally 12V, and by floating the chip's ground via a Zener, it's possible to set arbitrary output voltages that can approach the input line level. Using the SO-8 package option with its integrated heat slug, either chip delivers up to 30 mA from the regulated outputs and as much as 50 mA from the unregulated rail on European supplies, or 100 mA from 120V/60Hz. The company's European sales manager Nic Houslip explains that in operation, the SR03x takes unfiltered dc from a bridge rectifier, from which it derives its internal power supply. The chip then functions as a conventional linear regulator with a comparator controlling the unregulated rail, turning on an external IGBT or N-channel MOSFET whenever the input rail is less than about 45V; above this level, the pass device is off. It's thus important to adequately size the only storage capacitor that the circuit needs, typically lying in the 100 to 470 μF range.

Houslip notes that optimum efficiency approaches 40% when using the company's GN2470, as this IGBT has a lower forward voltage than competing MOSFETs. Because IGBTs are slower than MOSFETs, it's possible to dispense with an optional RC filter in the pass element's gate circuit that constrains conducted EMI. And dispensing with inductors enables significant savings—at least superficially. Budgetary pricing for a supply similar to the figure using main distributor and catalogue supplier data suggests a bill-of-material cost of around €1.40. By comparison, a design that uses the Supertex HV9910 and three inductors to double-downconvert ac line to derive a constant current for a single high-power LED costs about €4—of which inductors account for €1.77. This design—for which Supertex offers the HV9910DB5 demo board, in itself an exercise in clever packaging—originates from a client request to manufacture in China, where inductors are available very cheaply. Increasingly today, the implicit message is to prototype with catalogue components but go offshore for bulk purchases. One company that combines European design expertise with offshore-manufacturing capabilities is Swedish concern Toroid International, which also has a design and marketing presence in the UK.

Suiting current levels from 80 to 360 mA, the LinkSwitch-TN family from Power Integrations tackles nonisolated designs using a single storage inductor and a small line-input choke. Capable of 170 mA in continuous conduction mode, the LNK304 benefits from a reference design and evaluation board (EP48) that implements a universal-input, 12V/120 mA output buck converter. The chip integrates a 700-V MOSFET with control circuitry that switches the pass element at a fixed 66-kHz rate, allowing a standard 1-mH inductor to supply up to 120 mA. The chip regulates the output voltage by skipping switching cycles in response to a feedback signal, with the internal current limit setting peak inductor current. This scheme differs from conventional PWM controllers that vary the duty cycle of the switch. In the absence of any feedback for over 50 msec, the chip enters its 800-msec auto-restart cycle that provides overload and short-circuit protection until the fault condition recedes. Cost-wise, estimates using mainstream distributor pricing suggest less than €2 for this design in 5,000-unit quantities, with the inductors accounting for almost €0.75 of the total.

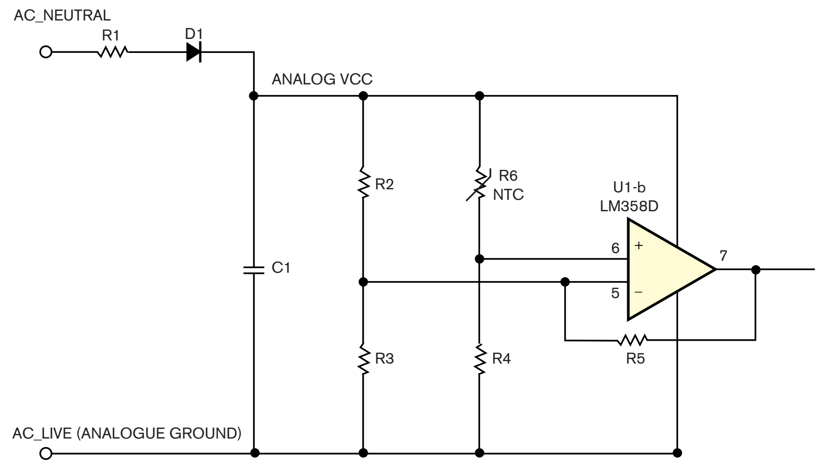

Figure 1 Dispensing with voltage regulation permits this minimum-cost offline supply to source several mA.

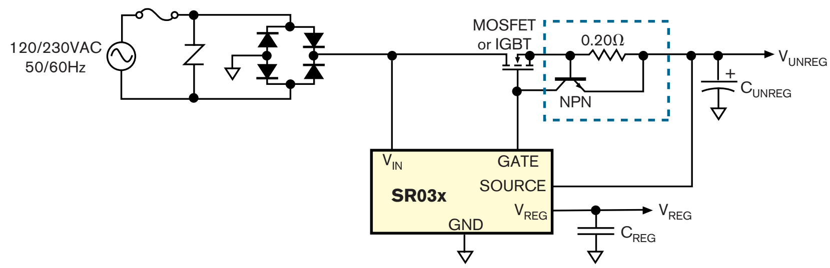

Figure 2 The SR03x from Supertex requires no inductors to build a nonisolated 1.5-W supply.

WORLD WAKES UP TO ENERGY WASTE

The amount of energy that the typical household or business wastes in standby-power consumption is truly staggering. The European Commission (EC) predicts that across Europe, standby losses for external offline power adapters will increase from about 8 TW hours in 1996 to about 14 TW hours next year. For now, the EC simply urges manufacturers to meet minimum offload-efficiency metrics for such supplies in the 0.3- to 150-W range. It believes that its voluntary code-of-conduct can help conserve about 5 TW hours from 2010, saving some 500 million euros per year (Reference 1). But the code-of-conduct document continues with what many see as a thinly disguised statement of intent, stating "Further savings can be expected from the application of efficient power supplies in electronics appliances, such as TVs, VCRs, microwave ovens, etc." It concludes by noting that power quality is another important factor in the energy-consumption equation, and that improved efficiency alone must not compromise the energy supply (for more on this, see Reference 2). Elsewhere, various initiatives seek to reduce the standby-power consumption of IT equipment below 1W–and observers see this too as a bridgehead into appliances and equipment in general. For instance, back in 2001 the Bush Administration mandated all federal agencies to select IT equipment that meets Federal Energy Management Program standards. By far the majority of these equipment categories fall into a 1-W maximum and as of next January, none are allowed more than 3W in standby mode (http://oahu.lbl.gov/). In a complementary move, the 80 Plus programme (www.80plus.org) that's active in California, the Pacific Northwest and some US eastern seaboard states rewards computer makers with $5 for each PC and $10 for each server sold that includes power supplies with a true power factor of at least 0.9 and that meets 80% or greater efficiency at 20%, 50%, and 100% of its nameplate power rating. The computer industry expects 80 Plus to form the basis of new Energy Star (www.energystar.gov) specifications within the next two years, while other equipment makers see the initiative as the precursor of far wider regulation.

But it's the wall-warts that will experience the biggest immediate regulatory changes, with the California Energy Commission (www.energy.ca.gov) mandating that as from 1st July 2006, all single-output ac-ac and ac-dc external power supplies shall meet minimum efficiency criteria at 25%, 50%, 75%, and at full load (Figure A). Already adopted by Arizona, Rhode Island, and Washington State–and voluntary in China today, while being mandatory in Australia as from next April–the CEC's regulations have a major impact on the no-load and light-load operation of a huge variety of low-power offline supplies, effectively making linear supplies obsolete in these roles. Regarding its early adoption, the view from industry observers is that Australia has decided to tackle the issue so aggressively because it has no power-supply industry to protect. Because it imports virtually all such products from the Far East, the knock-on effect to Asian producers is immense.

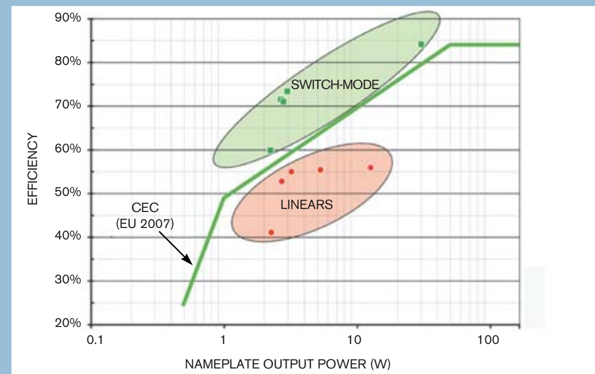

Figure A California's impending legislation obsoletes linear supplies in low-power applications.

Closer to home, the UK Government estimates that appliances not actually in use consume 760 million kW hours per month–equivalent to 1 GW of continuous output, or about 2.25% of the country's total electricity consumption (Reference 3). This report highlights what it terms "market transformation" as an adjunct to regulation, which refers to bringing together various interested parties to develop strategies for future efficiency improvements. The report cites set-top boxes as a key example, stating that the average power consumption has fallen from 27W to 12 – 15W over the past few years as a result of market transformation. Significantly, it notes that this result is "purely mitigating a poor situation" and describes market transformation as "a damage-limitation exercise"–the implication being that designers can increasingly expect regulation to enforce efficiency standards.

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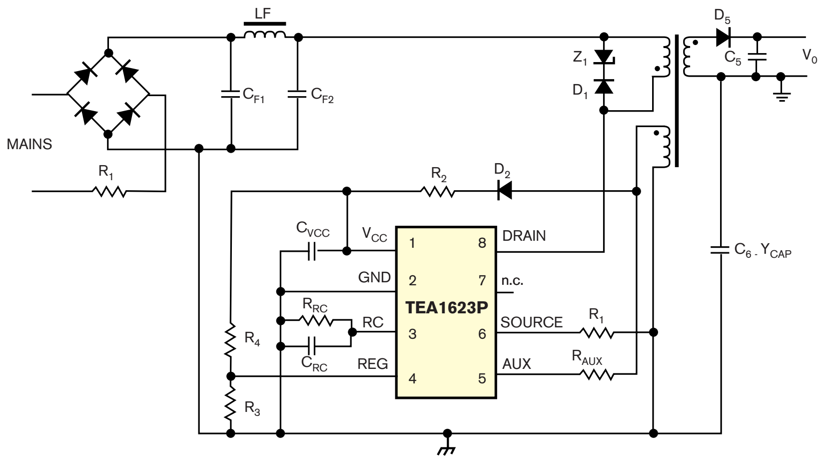

Figure 3 The TEA1623 from Philips forms the heart of this 10-W universal-input, isolated supply.

ISOLATION DEMANDS SMPS

Whether it's a few Watts for a charger or as much as 120W for a notebook PC, external-supply applications invariably demand safety isolation. Vendors that are active in this arena include ASIC Advantage, Fairchild Semiconductor, Philips Semiconductors, Power Integrations (PI), STMicroelectronics (ST), and Texas Instruments (TI). The IPS 18 is the latest isolated SMPS controller from ASIC Advantage, which markets its offline products under the In-Plug trademark. This device targets ultra-low standby-power applications and features a wide operating-frequency range from 30 to 150 kHz with a 0 to 66% duty cycle. It implements what the company calls "hiccup-mode" regulation—effectively a special case of overload protection—whereby the chip monitors the current on the primary side of an external MOSFET to control power delivery to the SMPS's isolation transformer. Cycle-skipping under low-load conditions reduces circuit power, and it's also possible to shut down the primary circuit by pulling the chip's Vcc pin to ground via a 100-Ω resistor.

Fairchild has recently introduced low standby-power versions of its FPS (Fairchild Power Switch) series that now spans 4.8 to 170W. At the low end of the range, the FDS200/210 accommodate the 5-W area that typifies chargers and auxiliary supplies. These two chips are very similar, save for the FDS200's dispensing with the need for a transformer bias winding at the expense of a slight increase in power consumption for its internal 7-V shunt regulator. The FDS210 also implements burst-mode operation under no-load conditions to reduce its standby consumption to under 0.1W. Both chips feature a fixed 134-kHz operating frequency with ±4 kHz frequency modulation, easing EMC issues by spreading emissions over a wider bandwidth. The control mechanism is PWM with a 0 to 65% duty cycle using optocoupler feedback. There's also an internal start-up switch for soft-start operation, and several protection mechanisms including undervoltage lockout with hysteresis, pulse-by-pulse current limiting, and thermal shutdown. The chips have an auto-restart mode and come in a 7-pin DIP that modifies the conventional 8-pin outline by omitting pin 6, thereby increasing the creepage distance between supply pins.

Software and application notes are often the best way to get started with real-world designs. Fairchild's application note AN-4138 provides step-by-step design instructions that include transformer layout, with software support coming from the company's free Design Assistant package. The 5.3-Mbyte download supports flyback and quasi-resonant topologies, and usefully includes a design kit section that introduces magnetics and ac-dc topologies before describing the company's PWM controllers and its integrated power switches—a great source of tutorial material.

Edwin Kluter, product line manager for integrated power at Philips Semiconductors, says that although some official requirements are tough, Japanese consumer-goods manufacturers are demanding standby consumption figures as low as 50 mW from a cellphone charger—twice as low as any impending legislative demands. "The consumer company saving the most energy in their products is awarded first in the 'green ranking' by the government. This status is very important in Japan," Kluter explains. With his company's massive presence in consumer electronics, it's scarcely surprising that its components division principally designs for internal consumption, but it's interesting to learn that LCD screens will shortly swamp the CRT-based TV market: "Prices are falling to the point that everyone will use LCDs." Commenting on higher-power supplies for such applications, Kluter notes that the present architecture for systems exceeding 75W comprises three supplies—the main one plus an auxiliary standby supply, with the power-factor correction stage upfront. This arrangement, he says, must change to reduce costs, and is thus a major integration challenge for today's power-system IC designers.

At the low-power end, the TEA1623P—a member of Philips' STARplug series—caters for universal-input offline supplies with standby consumption below100 mW. The chip integrates a 650-Vdc, 6.5-Ω MOSFET with a 0 to 75% duty-cycle PWM controller and all the ancillary logic necessary to build a low-component-count flyback supply of up to about 10W output (**Figure 3**). Adding optocoupler feedback to augment the indirect voltage-mode sensing from the transformer's sense winding that also provides the chip's power improves regulation from the basic 8% level. Typically running at 100 kHz, the operating frequency is adjustable from 10 kHz using an external RC combination. The chip is notable for using what Philips terms "valley switching", a technique for enabling the next switching cycle at the minimum value of the primary voltage reflection. Relying on the fact that the chip operates permanently in discontinuous conduction mode, this strategy reduces switching losses and minimises the integrated power MOSFET's turn-on stresses. Like many other ICs, the TEA1623P uses leading-edge blanking to limit peak primary-side current to further constrain switch-element stress. Protection mechanisms guard against overvoltage, overtemperature and overcurrent on a cycle-by-cycle basis, as well as short-circuit transformer windings. Output efficiencies of over 75% are possible at the 10-W level.

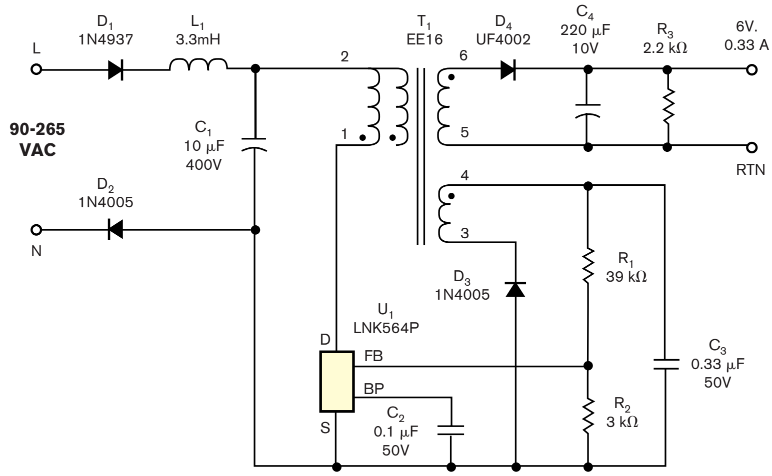

Figure 4 The LNK564 builds a minimum component-count 2-W supply with standby power below 150 mW.

Power Integrations too has recently extended its range of devices that now span 2 to 290W. Tests here recently demonstrated the ease-of-design and creditable circuit performance that its trademark LinkSwitch series offers, using the LNK500 as the example (**Reference 2**). Now, the company is tackling the latest round of low-power wall-adapter efficiency requirements that will be shortly taking effect in Europe, the US, Australia, China, and other areas with two new product families: the LinkSwitch-LP that comprises the LNK562/563/564 for ≤2W, and the LinkSwitch-XT family comprising the LNK362/363/364 for ≤4W (enclosed) or 6W (open frame). As is its normal practice, Power Integrations offers a wide range of reference designs that are—for these chips—fully characterised to meet global efficiency goals, while minimising component count and build cost. The topology is isolated flyback, with optocoupler feedback for tighter regulation where necessary. It's worth noting that the company's application support extends to its Green Room, which provides updates and guidance regarding effective and impending regulations from a variety of agencies around the world.

Suiting applications such as linear transformer replacements where the voltage- and current-regulation performance is relatively loose, a LNK564 circuit sources up to 2W from universal-input ac line at an average efficiency of 60% with a no-load consumption below 150 mW (**Figure 4**). While the LNK36x series uses a common switching frequency of 132 kHz and varies its current limits to suit alternative power levels, the LNK56x series shares a common 136-mA current limit but varies the switching frequencies between 66, 83, and 100 kHz to achieve output power levels of 1.3, 1.7, and 2W. Ben Sutherland, the company's European sales director, notes that this strategy enables designers to use a single transformer design for the whole family and dispense with clamps across the transformer's primary winding: "Careful transformer design and the silicon's tight ±7% current limit constrain voltage reflections and make clamp protection unnecessary, while the transformer design also dispenses with the Y-capacitor that's normally essential to meet EMC targets." This latter step reduces primary-to-secondary leakage current to less than 1µA. Sutherland notes that on 120-V supplies, it's also possible to dispense with the redundant-looking diode (D2 in the figure) that improves EMC performance at higher voltages by presenting another block to reverse currents, while jittering the switching frequency by about 5% helps meet EMC specifications. Other interesting cost-reduction strategies include rating the input inductor L1 appropriately and sleeving it in heatshrink to serve double-duty as a fuse.

The new chips feature enhanced safety features, such as overtemperature shutdown with a very wide hysteresis of 75°C. Sutherland says that this precaution is essential to allow the use of very low-cost SRBP (synthetic resin-bonded paper) pc boards that will only tolerate average temperatures below 100°C. It helps designers to reduce the build cost of a typical 3-W well-regulated supply using the midrange LNK363 below $2 in high volume. By contrast, Sutherland notes that the self-oscillating ringing-choke-converter (RCC) designs that traditionally dominate lowest-cost offline applications have virtually no protection at all. Furthermore, RCC designs can't reduce their offload consumption to acceptable limits, as they increase their switching frequency at light loadings to the detriment of efficiency (see **sidebar** "Prying Eyes").

MAGNETIC DESIGN IS CRUCIAL

Stressing the importance of transformer design, Sutherland says that with careful layout using balance and cancellation shields in the transformer, it's possible to meet EMC standards without common-mode chokes or Y-capacitors in many applications up to about 10W. He cites the typical cost of an EE-16 transformer as around $0.20/500,000 and points to the company's partnerships with Kaschke and Vogt Electronic in Germany and Hical Magnetics in India, all of which specialise in supplying transformers to suit PI's designs. The PI Expert Suite design software now includes a transformer designer that generates detailed instructions for construction, including shield selection to meet EMC requirements and exact lay-up for the windings on the bobbin. Other enhancements to the circuit-design software include support for negative-polarity outputs, diode-bridge forward-current and reverse-voltage ratings, and the ability to export design results to formats including Word and html.

Maurizio Giudice, power MOSFET marketing manager at STMicroelectronics (ST), says that efficiency and cost factors apart, size and weight are key differentiators in the offline-charger marketplace: "Consumers just don't like heavy, bulky stuff. It would be stupid to buy a phone when the charger is heavier than the phone!" He also estimates that in the multimillion unit-builds that these supplies enjoy, a switch-mode design in the 5- to 7-W arena will soon cost as little as one-half that of an equivalently rated linear version. To address this market, ST's Viper family comprises a range of integrated PWM controller and power MOSFET ICs with maximum output currents that range from 0.352 to 3A at dc input voltages of 600 to 700V. Giudice sees the 600-800V level as being the "sweet spot" for today's offline universal-input MOSFET applications, with his company selling discrete devices from 400V to 1kV to suit high-

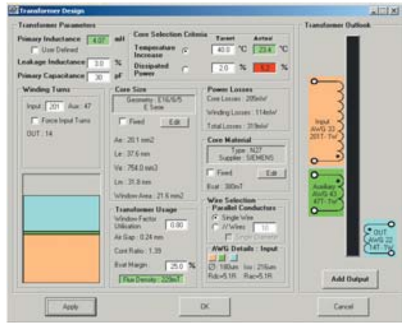

Figure 5 ST's Viper Design Software suite automates transformer design.

power supplies that today's process technologies can't integrate alongside the control logic—for thermal management as well as cost reasons, he observes.

ST's lowest-power Viper12A targets power levels up to about 5W from universal-input ac line in an SO-8 package, or slightly more (8W) in a DIP. Moreover—and in recognition of the European Union's best-practice requirements for wall-adapter supplies into 2006 and beyond—the chip can reduce its standby power consumption to under 100 mW, thereby suiting most offline charger applications worldwide. It can also address lowest-cost nonisolated configurations within applications such as white goods. Internally, the device comprises a fixed-frequency 60-kHz oscillator together with a central logic block that controls the MOSFET. The chip's current-mode PWM topology encompasses inputs from internal circuits that monitor conditions including supply-line under- and over-voltage, chip overtemperature, and current in the output-driver stage. A current-sensitive feedback pin provides overall setpoint control, automatically switching the chip into burst-mode when supplying low output currents. This arrangement effectively makes just four connections to the 8-pin package—drain and source for the MOSFET, and feedback and Vdd for the control logic—with the Vdd supply typically coming from an auxiliary transformer winding and diode-capacitor circuit. The loose 9- to 38-V operational margin further reduces implementation costs.

As an aid to configuring an SMPS using the flyback topology, ST's freely downloadable Viper Design Software suite enables engineers to assess variations in circuit performance, highlighting issues such as conduction losses, thermal considerations, and efficiency estimates for a set of input variables. Soft panels allow users to modify key parameters including the ac or dc line-input parameters, transformer configuration, Viper device selection, and output specification. Importantly, the software automates transformer design for a user-selectable number of outputs, providing details such as recommended core materials and winding configuration along with calculating the power dissipation and core-temperature rises that will result (**Figure 5**). There's also an impressive waveform simulator that plots traces for parameters such as MOSFET drain voltage and current, circuit gain and phase, and overall power dissipation and efficiency versus input voltage and output power. A bill-of-materials listing readies the design for hardware prototyping.

Absent from active competition in the offline SMPS market for some while has been Texas Instruments. Aung Tu, an applications engineer in TI's system power management group, says that his company's UCC3581 was the first "green chip" SMPS controller. Dating back to 1996/97, this chip's micropower consumption results from the need to draw its power from an ISDN (integrated-services-digital-network) phone line. TI now plans a new generation of green controllers for power levels from 50W upwards to suit applications that must meet Energy Star and similar evolving requirements. Tu notes that there's a natural barrier at the 75-W level, above which European legislation demands active power-factor correction (for an update on this issue, see Joshua Israelsohn's recent feature in *EDN*—**Reference 3**). Tu observes that while it's relatively easy to meet Energy Star's 84% efficiency in a 50-W supply, designers find it far more difficult to meet efficiencies much beyond 80% in high-power silver-box supplies because the power-factor correction circuit is typically only 90 to 95% efficient.

Possible solutions include substituting variable-frequency quasi-resonant topologies for the fixed-frequency flyback designs that predominate due to their low cost. Tu comments, "Flyback is cheap because it can use a single-ended driver with only one MOSFET, so it has less components than, say, a forward converter. The quasi-resonant converter has

PRYING EYES–HOW DO THEY DO IT AT THE PRICE?

In keeping with *EDN*'s new "Prying Eyes" strip-downs, it's always instructive–and a bit of fun–to dismantle other designers' work to uncover how they managed to achieve their set of goals. Here, let's take a look at variations on supplies that serve the lowest-cost market.

The RC dropper circuit in Figure A comes from a night light that plugs into a 230-V, 50-Hz socket, demonstrating some of the techniques that designers of truly cost-sensitive designs use. Components R1 and C1 feed about 9 Vac to the bridge rectifier, which supplies the control section with an unfiltered rail that measures about 7.5V (ac+dc, off-load). Together with fusible resistor R1, class-X safety-rated capacitor C2 provides elementary surge protection, while R2 and R3 ensure safe discharge paths for the capacitors. This step limits the unpleasant «tingle» from leakage currents that users may receive if they inadvertently touch the pins when removing the device from a wall socket.

The Zener clips the raw dc to a safe value for Q2's collector to source current to the single amber LED, an Osram PowerTOPLED that withstands continuous currents of as much as 70 mA at a typical forward voltage of 2.2V. Fixed-value R5 and light-dependent resistor R6 form a resitive divider whose ratio varies with the ambient light level to modulate the conduction of Q1, such that Q2 varies the current into the LED from zero to a measured 27 mA. The overall circuit loading spans 38.54 mA with the LED off to 38.64 mA at full intensity. Assuming that powering the LED is the circuit's objective, efficiency is abysmal at 0.26% while consuming almost 9W with a power factor of just 0.14–this politically-incorrect performance being an inevitable consequence of the RC dropper approach but unimportant for such low-power supplies–while the finished product appears for less than €4 on a retailer's shelf!

As the main text reports, the Supertex SR03x chips compete with RC dropper circuits. So what can they achieve? Measurements using the SR036-DB2 demo board reported 3.93 mA off-load with a power factor of 0.25 and voltage levels of 3.35 and 17.4V. Sadly, the demo board blew the top off the SR036 at the next power-on, for no immediately apparent reason. But a technical bulletin titled "SR03x power-on surge protection" reveals that the failure condition most often occurs on 230-Vac supplies when turning the device on at the peak of the sinewave. The IGBT or MOSFET's gate-to-drain parasitic capacitance then injects this step charge into the device's gate, turning it hard on into the output storage capacitor–instantaneously a short circuit–destroying both the pass element and the chip. The solution costs a transistor and a resistor to limit the current peak to about 3A for long enough to let the SR03x take control of the pass element–the dotted area in the main text's Figure 2.

This experience serves as a reminder that handling ac line voltages isn't trivial, even at apparently small power levels. It also highlights the propensity for isolation transformers and variacs to generate large back-emfs at turn-on that reflect into the devices that they power.

The demo-board instructions warn against using any such transformers, saying their "high inductance interferes with the normal operation of the SR036"–a fact that this user overlooked in the desire to normalise all measurements to 230V. But in other circumstances, the experience suggests that a transformer's potentially destructive voltage reflections may be useful as a crude transient generator to assess the effectiveness of surge-protection measures.

A second set of measurements with a direct 238-V, 50-Hz input indicated the SR036's offload input current at 5.1 mA with a power factor of 0.3–or about 1.2W and 5 VA. Offload voltage levels were 3.38V with about 1V peak-to-peak of 50 Hz ripple, and 16.48V with about 750 mV of line-frequency breakthrough. The circuit's action as a low-frequency modulator ensures that there's no perceptible high-frequency energy content. Loading the regulated output by 20 mA increased overall consumption to 25 mA, while the output fell to 3.35V with 750 mV, suggesting that sensitive circuits may benefit from further filtering. Adding a 25-mA load to the unregulated output increased ac-line current demand by another 5 mA while dropping the unregulated output level to 11.6V, containing about 1V peak-to-peak of 100-Hz sawtooth waveform. After stabilisation in 20°C ambient under these load conditions, the

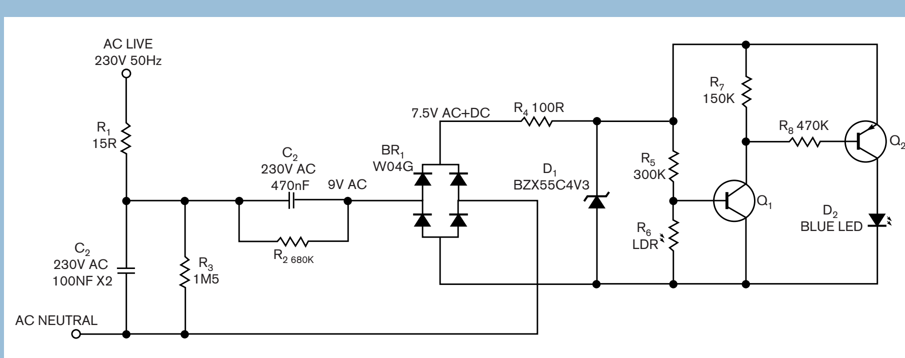

Figure A An RC dropper supply powers a night light that retails for under Œ4.

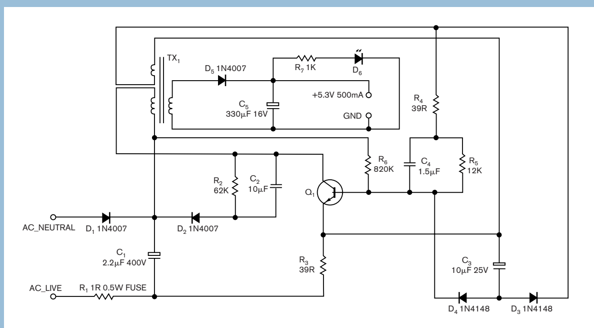

Figure B This Chinese-made RCC-based mobile-phone charger retails for about €1.40.

surface temperature of the SR036 rose to 48°C—courtesy of its heatslug package and two 14×6.5-mm areas of pc board that serve as a heatsink—while the GN2470's double-sided 16×34-mm heatsink constrained its case-temperature rise to 21°C. These results show that the SR03x can better an RC dropper's performance and is very easy to design with, at the cost of about €1.40 in low volume and a few square centimetres of board space.

So what of an isolated consumer-device supply? Available on eBay (www.ebay.com) for just £0.99 (about €1.40), a brand-new Chinese-made, DuoCai-branded charger for a Nokia phone illustrates the traditional single-ended ringing-choke-converter (RCC) that today's energy-conscious agencies disparage. This universal-input design rectifies incoming ac to stimulate a transformer-coupled relaxation oscillator, which then delivers current to its load via an isolation transformer (design details appear in a classic paper from the mid-1950s—Reference 1). In today's context, the key cost-reduction element is the use of one transistor in place of an IC (Figure B). The circuit's main problem is its inability to adapt to low-load conditions—as the load level falls, its switching frequency increases to consume more power relative to its output delivery. In practice, this example outputs 6.79 Vdc offload at 90 Vac, reaching 7.27 Vdc at 253 Vac (the maximum European norm) while drawing 1 to 5 VA with a power factor of 0.27 to 0.11. On-load, its power consumption ranges from 1 to 8 VA at a power factor of about 0.33 across the input-voltage range. And don't be fooled by the price on eBay—according to the vendor, these items come from a UK-based dealer for £0.99 + VAT, making her profit from postage & packing charges. Interestingly, the originating UK dealer's website reveals the same items on sale for £9.90, while enquiries to the suspected Chinese source remained unanswered.

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a natural advantage in that its switching frequency depends on the current in its inductor, so it's far more adaptable to the wide range of operating current that equipment like PCs takes." The controller also needs the facility to disable the power-factor circuit at low load levels to minimise standby power consumption, and include features such as soft-start control to minimise circuit stress. Pointing to Energy Star's standby demands of less than 500 mW for external supplies up to 10W and—crucially—below 750 mW for supplies up to 180W, Tu sees standby as the real bogey that designers are now facing: "No one can currently meet the requirement in high-power supplies without resorting to a separate low-power keep-alive circuit that works in parallel with the main supply."

Keeping a watching brief away from TI, Tu is also a member of the Power Supply Manufacturers Association, a special interest group that's currently lobbying for what it considers more achievable standards. Echoing the views of his peers at other companies, Tu considers that global regulatory trends are currently following the technology. There's no commercial sense in adding unnecessary cost to power supplies unless there are trade barriers or other incentives, and—as PI's Sutherland points out—attempts to mandate uneconomic energy-saving measures will simply result in well-intentioned regulations failing. **EDN**

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CONTACT THE AUTHOR

You can reach Contributing Technical Editor David Marsh at forncett@btinternet.com.

FOR MORE INFORMATION

ORGANISATIONS AND AGENCIES:

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