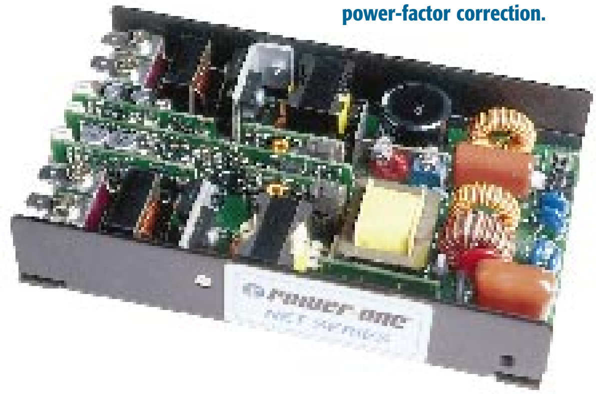
 By Bill Travis, Senior Technical Editor

The NET1 power-supply series from Power-One uses active power-factor correction.



POWER-FACTOR CORRECTION IS A MAJOR ISSUE IN SWITCHING POWER SUPPLIES. REGULATOR ICs EFFECT THE CORRECTION AND SUPPLY MANY OTHER FUNCTIONS TO BOOT.

Devices clean up power factor in ac/dc supplies

SWITCHING POWER SUPPLIES have become the norm in almost all electronic systems. The switchers' excellent line and load regulation, high conversion efficiency, and compactness all contribute to their popularity. Low-loss power MOSFETs and IGBTs (insulated-gate bipolar transistors), coupled with low-drop rectifiers, are at the heart of these switching supplies. A potential problem with some of these supplies is power factor, a measure of the effect the supply and the load have on the ac line. Some of you might remember from engineering school that the term "power factor" applied to the out-of-phase line current accruing from reactive loads. But the term also applies to harmonics injected back into the line. Stringent norms, especially in Europe, govern how much a system and its power supply are allowed to mess up the ac line with harmonics and out-of-phase signals. A variety of preregulator ICs and other products helps keep the line clean by providing power-factor correction.

Consider the definition for power factor. It's the quotient of the real power in the load in kilowatts and the total kilovolt-amps in the load. "Real power" means the in-phase volts and amps product. "Total kilovolt-amps" means the product of volts and amps, regardless of phase, plus any power contributed by harmonics. The term "kVAR" in **Figure 1** applies to reactive power, the product of out-of-phase volts and amps (**Reference 1**). Distortion is the result of harmonics. The diagonal line in the parallelepiped represents the total kilovolt-amps in the load, including harmonics. The accurate way to measure power factor is to use true-root-mean-square meters to measure the voltage and current and multiply the readings to obtain the total kilovolt-amps in the above quotient. The objective of power-factor correction is to make the input of a power supply look resistive. A power-factor corrector performs this task by controlling the input current in response to the input voltage. With a constant voltage/current ratio, the input appears resistive, and the power factor is 1.0. When the ratio deviates from a constant, it means that the in-

AT A GLANCE

- ▷ Stringent specs, specially in Europe, govern power factor.
- ▷ Boost regulators are amenable to IC-based PFC
- ▷ Soft-recovery diodes greatly reduce EMI.

put contains phase displacement, harmonic distortion, or both.

BOOST PREREGULATOR PROVIDES ACTIVE PFC

A cleverly designed IC from Texas Instruments' Unitrode division uses a boost topology to provide power-factor correction. The UC3854 (**Figure 2**) contains a voltage amplifier, an analog multiplier/divider, a current amplifier, and a fixed-frequency pulse-width modulator. In addition, the device contains a power-MOSFET gate driver, a 7.5V reference, a line anticipator, a load-enable comparator, a low-supply detector, and an overcurrent comparator. The UC1854 uses average-current-mode control to provide fixed-frequency current control. The block diagram in **Figure 3** shows the principles involved in active power-factor correction (**Reference 2**). In the average-current-mode-control method, an amplifier in the feedback loop around the boost power stage makes the input current track the input voltage with little error.

Note that an active power-factor corrector must control both the input current and the output voltage. In **Figure 3**, the rectified line voltage programs the current loop so that the input to the boost converter appears to be resistive. The UC3854 controls the output voltage by changing the amplitude of the current-programming signal. An analog multiplier creates the current-programming signal by multiplying the rectified line voltage by the output of the voltage-error amplifier, such that the current-programming signal has the waveshape of the input voltage and an average amplitude that controls the output voltage. IMO in **Figure 2** is the current-programming signal. **Figure 2** shows a squarer and a divider as well as a multiplier in the loop. The circuit divides the output of the voltage-error amplifier by the square of the average input voltage before multiplying it by the rectified input voltage. This extra circuitry keeps the gain of the voltage loop constant; without it, the gain of the voltage loop would change as the square of the average input voltage.

The circuits that keep the loop gain constant make the output of the voltage-error amplifier a power controller; this output actually controls the power delivered to the load. An example proves this premise. If the output of the voltage-error amplifier is constant and you double the input voltage, the programming signal doubles but the multiplier/divider divides it by the square of the feedforward voltage (four times the input). The result is an input current that's reduced to half

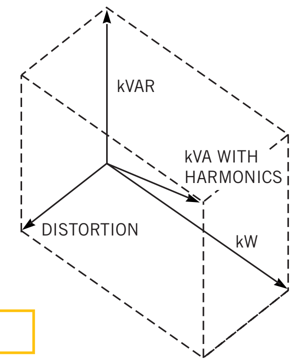
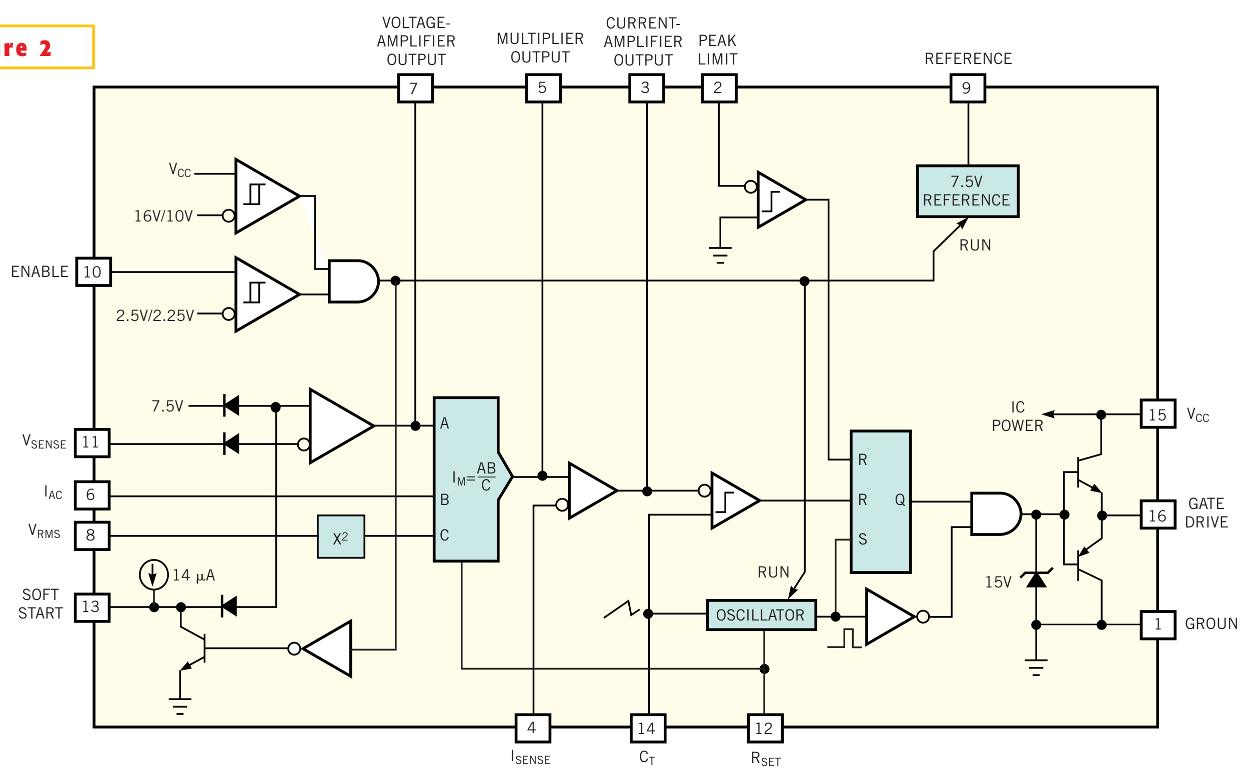


Figure 1

This parallelepiped shows the factors that contribute to the power factor of an ac line.

Figure 2



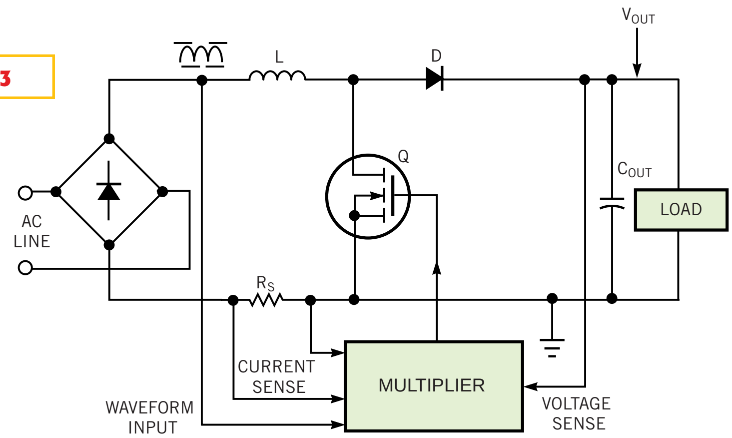
The UC3854 from Texas Instruments uses a clever multiplier/divider arrangement to correct power factor.

its original value. Twice the input voltage times half the input current results in the same total power as before. The output of the voltage-error amplifier, then, controls the input-power level of the power-factor corrector.

A boost-regulator topology is a good choice for the power stage of an active power-factor corrector, because the input current is continuous. Continuous current produces low levels of conducted noise and the best input-current waveform. However, the disadvantage of the boost architecture is the high output voltage. The output voltage must be greater than the highest expected peak input voltage. Texas Instruments uses this boosted voltage to drive a dc/dc converter in another PFC circuit, the UCC38500 (**Figure 4**). This IC provides all the control functions necessary for an active PFC preregulator and a second-stage dc/dc converter. The PFC stage is much like that of the UC3854, except that the gate-drive output stages in the UCC38500 use MOSFET instead of bipolar totem poles. The UCC38500 uses leading-edge modulation for the PFC stage and trailing-edge modulation for the dc/dc-converter stage. This feature reduces ripple current in the output capacitor by reducing the overlap in conduction time of the PFC and dc/dc-converter switches.

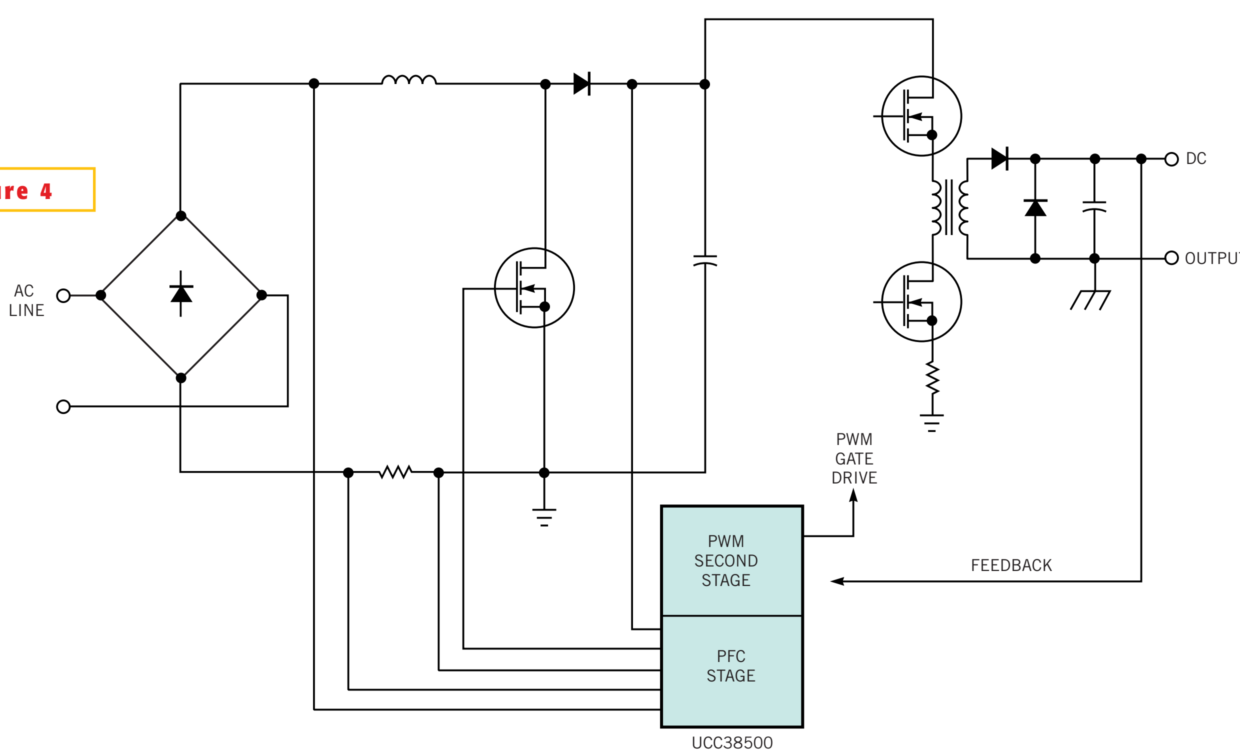
The dc/dc-converter section of the UCC38500 relies on an error signal generated on the secondary side of the converter's step-down transformer. The IC processes the error signal using peak-current-mode control. The dc/dc section also includes current limiting, a controlled soft start, a selectable operating range, and 50% maximum duty cycle. One of the main challenges in designing systems with a PFC front end is coordinating the turn-on and turn-off of the dc/dc converter. If the dc/dc converter turns on before the boost converter is operational, the dc/dc converter must operate at a greatly reduced voltage and, therefore, can present a large current

Figure 3



A feedback loop enables power-factor correction in TI's UC3854.

Figure 4



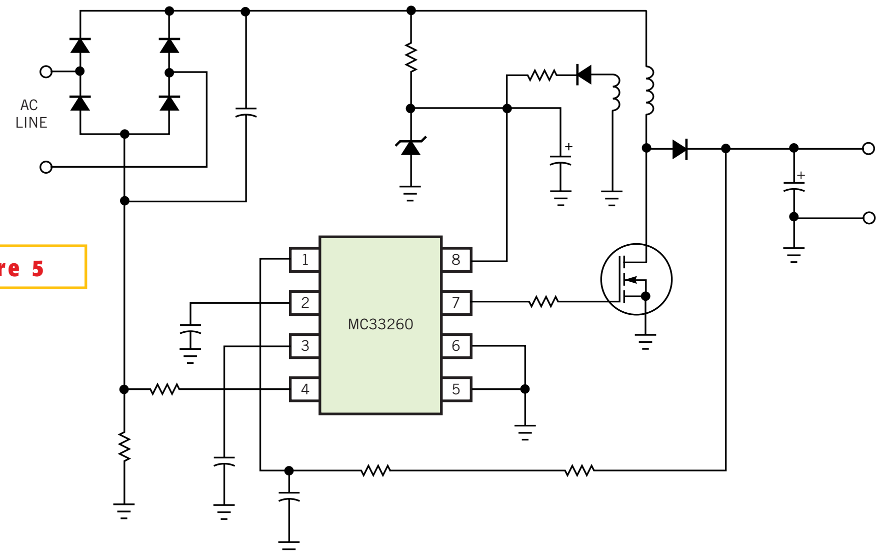
The UCC38500 combines power-factor correction with a PWM-based dc/dc converter.

draw to the boost converter. The UCC38500 monitors the output voltage of the PFC converter and holds the dc/dc converter off until the voltage is within 10% of its regulation point. Once the output of the boost converter reaches this point, the dc/dc converter goes through a soft-start sequence for a controlled, low-stress start-up. Similarly, if the output voltage drops too low, the dc/dc converter shuts down.

PFC CIRCUIT IN MULTIPLE MODES

Another boost preregulator that offers active PFC is available from On Semiconductor. The MC33260, designed to drive a free-running-frequency regulator in discontinuous mode, is also capable of synchronous operation. **Figure 5** shows a typical application circuit. This configuration is a "follower-boost" circuit. In this topology, the voltage output from the PFC preconverter doesn't stay at a constant regulation level but rather assumes a value dependent on the ac-line amplitude. The company claims that the use of this mode significantly reduces the size of the inductor and the conduction losses of the power MOSFET. Discontinuous mode, also called "critical-conduction mode," presents two major advantages in PFC applications (**Reference 3**). First, the inductor current must fall to zero before the start of the next cycle. This feature results in high efficiency and eliminates boost-rectifier reverse-recovery loss, because the MOSFET cannot turn on until the inductor current reaches zero. Second, because no dead-time gaps exist between cycles, the ac-line current is continuous, thus limiting the peak switch current to twice the average input current. Safety features in the MC33260 include overvoltage and undervoltage protection, as well as overcurrent protection. Each pin has ESD protection. The IC incorporates a totem-pole output for MOSFET gate drive.

Figure 5



The MC33260 power-factor corrector from On Semiconductor operates in either free-running or synchronized mode.

As stated, the MC33260 can operate synchronously, or bimodally. In free-running, discontinuous mode, the power switch turns on as soon as the current in the inductor drops to zero. Synchronization mode ensues when a feedback signal from the load to Pin 5 (shown grounded in **Figure 5**) crosses a 1V threshold. In this mode, free-running operation can resume only after a new circuit start-up. The power switch needs two conditions to turn-on: It must detect zero current in the inductor, and the preceding turnon must have been followed by a synchronization rising edge (on Pin 5) that crossed the 1V threshold. In other words, the synchronization acts to prolong the power switch's off-time.

An application note from Intersil shows how to configure a 360W, power-factor-corrected off-line power supply, using the company's HIP5500 MOSFET driver (**Reference 4**). **Figure 6** shows a block diagram of the supply. You can use one of several available boost-preregulator ICs for the "power-factor-correction" block. **Reference 4** uses an MC34262 PFC device from On Semiconductor. The supply generates an intermediate voltage of 36V for use with distributed dc/dc converters throughout a system. In driving the MOSFETs, the HIP5500 derives its voltage from the well-regulated boost-converter output. The 36V output derives its regulation simply by its duty cycle and the transformer turns ratio. As a result, the HIP5500 driver runs open-loop with no need for loop compensation, thereby reducing the expense and

FOR MORE INFORMATION...

For more information on products such as those discussed in this article, go to our information-request page at www.rscahners.ims.ca/ednmag/. When you contact any of the following manufacturers directly, please let them know you read about their products in *EDN*.

International Rectifier Corp
www.irf.com
Enter No. 311

Intersil Corp
www.intersil.com
Enter No. 312

On Semiconductor
www.onsemi.com
Enter No. 313

Power-One Inc
www.power-one.com
Enter No. 314

Texas Instruments
www.ti.com
Enter No. 315

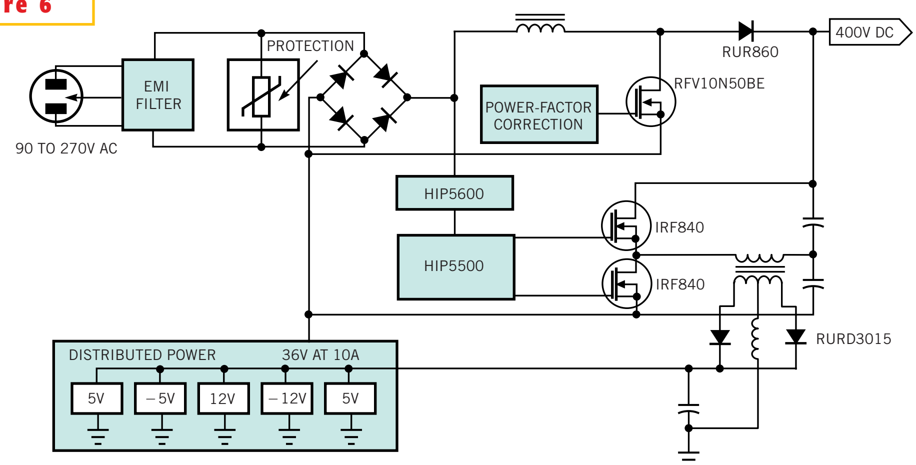
Vicor Corp
www.vicr.com
Enter No. 316

SUPER INFO NUMBER
For more information on the products available from all of the vendors listed in this box, enter No. 317 at www.rscahners.ims.ca/ednmag/.

complexity of crossing the isolation boundary twice.

The heart of the power supply in **Figure 6** is the HIP5500 MOSFET driver. It includes a user-programmable on-chip oscillator, dead-time control, a user-programmable soft-start function, and a buffered oscillator output. The IC specs a blocking voltage of 500V, a 2A output-drive capability, and a set of complementary gate-drive outputs. **Reference 4** gives a detailed schematic diagram of the supply. Measurements show that, at 50% load, the power supply exhibits a 0.990 power factor at 60-Hz line frequency and 84.8% conversion efficiency.

Figure 6



A 360W power-factor-corrected supply uses Intersil's gate driver to switch the MOSFETs.

DIODE, IGBT HELP KEEP AC LINES CLEAN

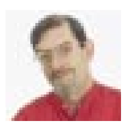
A recent European CENELEC (Comité Européen de Normalisation Electrotechnique) directive, Amendment A14 to the EN 610002 standard, specifies limits for harmonic-current emissions. Intersil offers a switching device and a rectifier that make it easier to comply with the directive. According to the company, the switch-mode-power-supply IGBT and the Stealth diode yield a low-cost, efficient way to meet the new testing requirements. The IGBT improves power factor by enabling high-speed switching with minimal power loss. The device can operate at five times the current density of a standard power MOSFET. The Stealth diode combines high speed and soft-recovery characteristics with resulting low EMI (electromagnetic interference). Power circuits can generate severe EMI if a diode's recovery characteristic is too sudden or abrupt. The Stealth diode's "softens" the reverse-recovery response, greatly reducing EMI. International Rectifier also offers controlled-recovery diodes, dubbed QuietIR, that feature low forward-conduction losses and a soft recovery-current shape.

Intersil offers several mated IGBT/Stealth-diode pairs, optimized for switch-mode power supplies with power outputs from less than 500W to greater than 1500W. The company is promoting IGBTs as alternatives to MOSFETs in switch-mode power supplies. Newer, faster IGBTs have raised practical switching frequencies to greater than 100 kHz in switching supplies. At these frequencies, the IGBTs use much less silicon and exhibit greater conversion efficiency than comparably rated MOSFETs. Once plagued with latch-up problems, the new generation of IGBTs yields trouble-free and safe operation.

Two examples of ready-made power supplies incorporating active power-factor correction are Vicor's PFC Mini series and Power-One's NET1 supply. The PFC Mini is a low-profile supply that can accept ac input voltages of 85 to 380V and provide output power to 1500W. The family specs a power factor of 0.99 at a 115V ac, 800W load and 0.95 at a 230V ac, 1200W load. The PFC Mini can provide as many as six isolated outputs. The NET1 series from Power-One uses active power-factor correction that complies with the European line-harmonics standard EN-61000-3-2 and specs 0.95 power factor at full load. The NET1 family provides current outputs exceeding 100A in a 1U-size chassis.

For those contemplating building their own ac/dc power supplies, power factor is a major consideration. To disregard this aspect is to invite disaster in the form of phase displacements and harmonic distortion introduced in the ac line. Thankfully, a number of ICs and switching devices are available to make the design task easier. □

You can reach Senior Technical Editor Bill Travis at 1-617-558-4471, fax 1-617-558-4470, e-mail b.travis@cahners.com.



References

1. Kennedy, Barry, *Power Quality Primer*, McGraw-Hill, 2000, pg 61.

2. Todd, Philip, *UC3854 Controlled Power Factor Correction Design*, Application Note U-134, Texas Instruments.

3. Chew, Ming Hian, *Design of Power Factor Correction Circuit Using Greenline Compact Power Factor Controller MC33260*, Application Note AND8016/-D, On Semiconductor.

4. Hamo, David, *A 360W, Power Factor Corrected, Off-Line Power Supply, Using the HIP5500*, Application Note AN9417, Intersil Corp.