

## Precision voltage-controlled current sink tests power supplies

Luca Bruno, ITIS Henseberger Monza, Lissone, Italy

▶ To discover potential power-supply problems, you must run dynamic and static tests. This simple current sink tests low- to medium-power supplies and voltage sources. In this application, the current sink can draw current of 0 to 1.5A for an input-voltage range of 0 to 5V with a supply voltage as high as 20V. The basis of the circuit is precision op-amp IC<sub>1</sub>, an OPA277 from Texas Instruments (www.ti.com), which features a maximum input-offset voltage of only 100  $\mu$ V, maximum input-bias current of 4 nA, and low drift over the temperature range of -40 to +85°C (Figure 1). The op-amp IC compares its positive input voltage with the voltage across sense resistor R<sub>SENSE</sub>.

IC<sub>1</sub>'s output drives an enhancement-mode N-channel power-MOSFET, Q<sub>1</sub>, an STMicroelectronics (www.st.com) IRF530, such that the voltage across

the sense resistor equals the positive-input voltage. The voltage across the sense resistor is proportional to the load current from the power supply under test and is independent of its output voltage. Q<sub>1</sub> features a maximum current of 14A at a case temperature of 25°C with drain-to-source voltage of 100V, low gate charge, and maximum on-resistance of 0.16 $\Omega$  at a gate-to-source voltage of 10V and a drain current of 7A.

The MOSFET can dissipate a finite amount of maximum power—to 30W with the heat sink's thermal resistance of 1°C/W or less and an ambient temperature of 40°C or less in still air. The maximum power depends on the thermal resistance of the heat sink you use and the ambient temperature, so, when you increase the supply voltage, you must accordingly reduce the load current. By pulsing the input voltage,

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you can increase the supply voltage to several 10s of volts because the average power dissipation is lower and depends on the average load.

The precision resistive divider, R<sub>1</sub> and R<sub>2</sub>, allows you to convert the input-voltage range of 0 to 5V into 0 to 0.495V at the positive input of IC<sub>1</sub>, resulting in an output-current range of 0 to 1.5A. In addition, the values of resistors R<sub>1</sub> and R<sub>2</sub> provide 100 k $\Omega$  of input resistance, which is adequate for most voltage-function generators having a source impedance of 50 or 75 $\Omega$ , allowing them to drive the circuit's input without using an input-op-amp buffer.

Analyzing the circuit yields the following relationships:  $I_{LOAD} = G V_{IN}$ , with  $G = 1/(\alpha R_{SENSE}) = 0.3A/V$ , where G is the conductance,  $\alpha$  is the attenuation factor, and  $\alpha = 1 + R_1/R_2 = 10.09$ . You can change the attenuation factor of the input-voltage divider to adjust

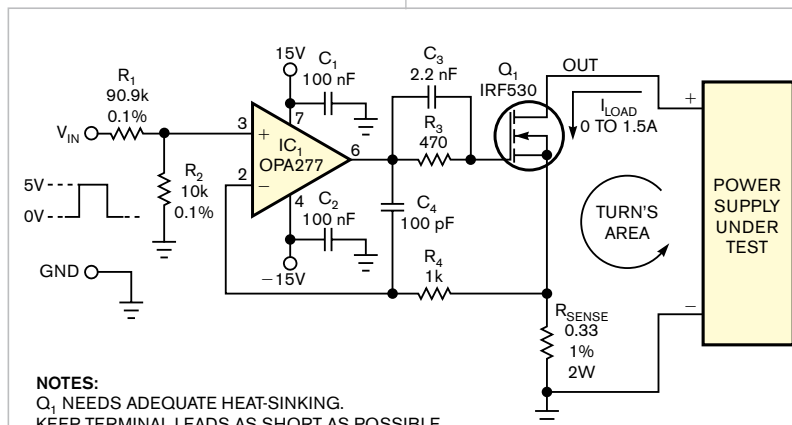


Figure 1 This simple current sink allows you to test both the static and the dynamic behavior of power supplies.

the upper limit of the output current to several amperes, which allow you to test low-voltage power supplies with high output current.

Capacitors  $C_3$  and  $C_4$  and resistors  $R_3$  and  $R_4$  ensure loop stability, yielding a circuit with a rise time of 1.4  $\mu\text{sec}$  for an input step voltage of 0 to 5V. So, you can test power supplies in either static conditions, applying a dc input voltage, or dynamic conditions, applying, for example, a pulsed input voltage to simulate fast load transients.

Also, you can test power supplies or voltage sources as low as 1V because of the low channel resistance of  $Q_1$  and the  $R_{\text{SENSE}}$  resistor; the lower limit is  $1.5A(R_{\text{SENSE}} + R_{\text{DS(ON)}}) = 735 \text{ mV}$ , where  $R_{\text{DS(ON)}}$  is the on-resistance.

You can also test multiple regulated outputs of power supplies such as a  $-5$  or a  $-12\text{V}$  supply voltage. In this case, you must connect the ground of the power supply to the output of the current sink—that is, the drain terminal—and the negative output with

the ground of the circuit. For accuracy, when you perform dynamic tests, such as load regulation, recovery time, and transient response, you must take care when connecting the power supply under test with the circuit to reduce the turn's area. The pulsed load current produces radiated emissions, which are proportional to this area, to the value of the current, and to the square of the current frequency, and they may disturb the circuit itself and the measuring equipment. **EDN**

## Red LEDs function as light sensors

Geoff Nicholls, Glinde, Germany

Ordinary red LEDs normally function as light emitters, but they can also function as photosensors. A single LED can even function as both a light emitter and a light detector in the same circuit (**Reference 1**). The basic idea is to pulse the LED, using the on-time to light it and the off-time to sense the photovoltaic current from the ambient light that the LED sees.

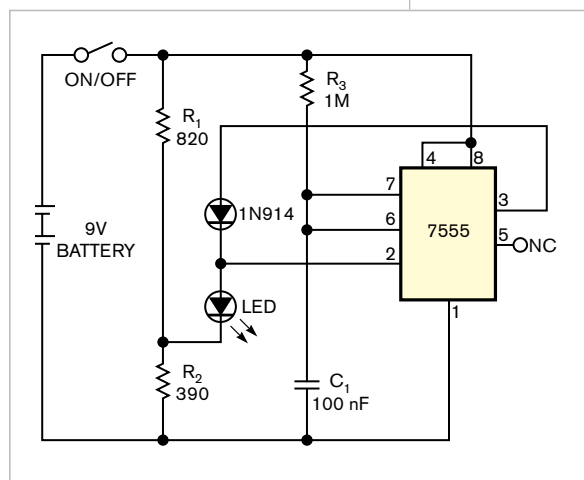
**Figure 1**'s circuit functions as a night-light. The LED stays off during daylight and turns on when the ambient-light level drops. The 7555 CMOS

timer is a monostable one-shot, which triggers when Pin 2's voltage is less than one-third of the supply voltage.  $R_1$  and  $R_2$  form a voltage divider, which keeps the cathode of the LED just below the trigger voltage. When the ambient-light level is sufficient, the LED develops several hundred millivolts, which add to the  $R_1/R_2$ -junction voltage and keep Pin 2 above the one-third-trigger level. In this state, the Pin 3 output of the 7555 approaches 0V, and the 1N914 diode becomes reverse-biased, allowing the LED's photovoltaic current to flow into Pin 2's trigger input.

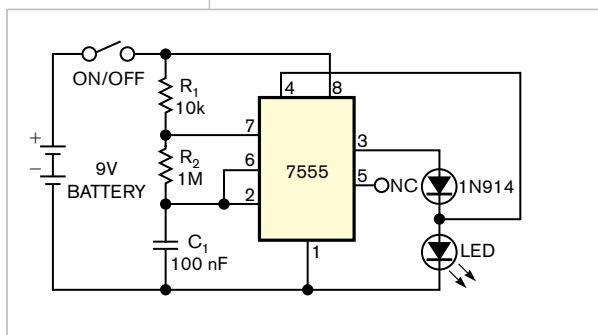
When the ambient-light level drops low enough, the LED voltage falls, and Pin 2 goes

below the trigger level. The 7555 then generates a one-shot pulse, the 1N914 becomes forward-biased, and the LED lights up. At the end of the timing period, which  $R_3$  and  $C_1$  set, the monostable resets and discharges  $C_1$ . The monostable is then ready for another cycle. The LED then briefly turns off during this interval, which allows it to again sense the ambient light.

The circuit in **Figure 2** functions as a day-light; the LED flashes in bright light and stays off in low ambient light. The 7555 provides astable operation and slowly flashes the LED through the 1N914 diode as long as Pin 4's reset input is greater than approximately 600 mV. If the ambient light is too low, the LED cannot generate enough voltage at Pin 4, and the 7555 output remains near 0V, preventing the LED from turning on. The LED operates as a light emitter when Pin 3's output is high and as a sensor when Pin 3's out-



**Figure 1** This circuit functions as a night-light. The LED stays off during daylight and turns on when the ambient light level drops.



**Figure 2** The LED in this circuit flashes slowly when the ambient-light level is high and turns off when the light level drops.

put is low.

These circuits require no current-limiting resistor. The timer IC must be a CMOS type because, to operate correctly, the circuit design requires low input currents. The prototypes use Intersil's ([www.intersil.com](http://www.intersil.com)) ICM7555 devices. **EDN**

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## White-noise generator has no flicker-noise component

Alfredo Saab and Randall White,  
Maxim Integrated Products, Sunnyvale, CA

White-noise generators generate a flat graph of output-power density versus frequency. These generators are useful for testing circuits that have an extended low-frequency or dc response. However, the presence of pink, or flicker, noise complicates the design of white-noise generators for frequency ranges that extend to a few hertz or below. A semiconductor device generates noise that always has the characteristic signature of pink noise: Its output-power-density amplitude increases as frequency decreases, with a corner frequency of 10s of hertz to a few kilohertz. A high-value resistor generates noise with its own flicker-noise component, whose value and characteristics vary with the resistor's technology. If, on the other hand, the resistor has a low value and the de-

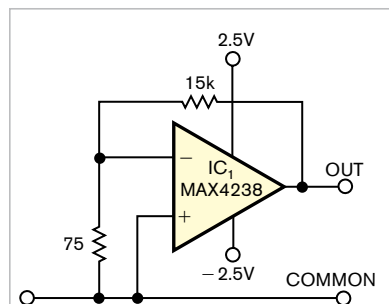
vice uses low-noise technology, then the noise is almost completely white with power density that is constant with frequency. Unfortunately, a low-value resistor also yields a low value of noise-power-density amplitude, and any device you introduce to amplify that level adds pink noise of its own.

You can find amplifiers whose input-voltage noise includes no pink-noise component, but their input-current noise has a flicker-noise component, which appears at the amplifier output if the resistance that any amplifier input

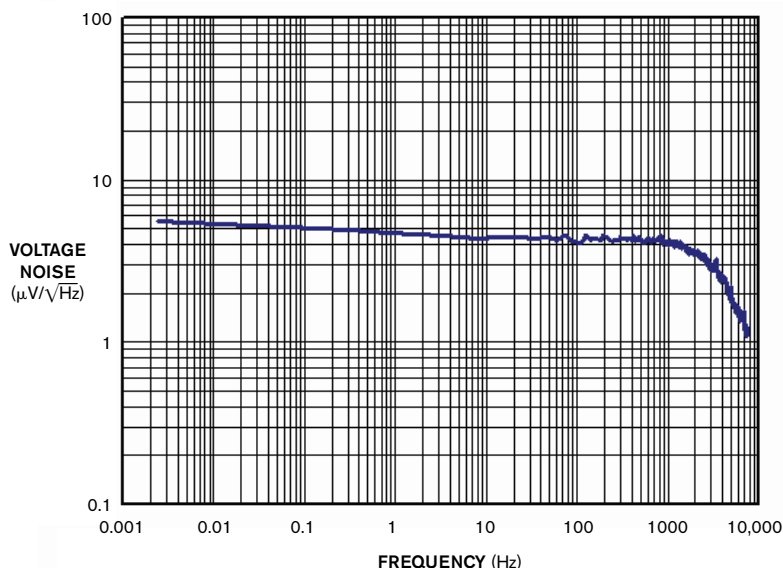
encounters has a significant value.

In the noise-generator circuit of **Figure 1**, IC<sub>1</sub>, a MAX4238 amplifier from Maxim ([www.maxim-ic.com](http://www.maxim-ic.com)) has no flicker-noise component in its input-voltage noise. It amplifies its own input-voltage noise with a feedback network comprising low-value resistors to avoid adding noticeable flicker-component noise from either the resistors or the amplifier's input-noise current.

A plot of the circuit's output voltage as a function of frequency is almost flat from 0.01 Hz to 3 kHz (**Figure 2**). The voltage-density amplitude is 4 to 5  $\mu\text{V}/\sqrt{\text{Hz}}$ . The noise-density amplitude also depends on temperature, so you should keep the circuit at constant temperature while making measurements. **EDN**



**Figure 1** Built with an amplifier whose input voltage noise has no flicker-noise component, this white-noise generator produces an output with no flicker-noise component.



**Figure 2** The circuit's output voltage as a function of frequency is almost flat from 0.01 Hz to 3 kHz.

## Analog voltage controls digital potentiometer

Hrishikesh Shinde, Maxim Integrated Products, Dallas, TX

This Design Idea describes an analog voltage that controls a digital potentiometer through the device's I<sup>2</sup>C interface. An ADC in the Microchip ([www.microchip.com](http://www.microchip.com)) PIC12F683 microcontroller converts the analog voltage to the I<sup>2</sup>C stream that controls the Maxim ([www.maxim-integrated.com](http://www.maxim-integrated.com)) DS1803 digital potentiometer (**Reference 1**). Of the microcontroller's six general-purpose I/O pins, two control the SDA (system-data) and SCL (system-clock-line) output signals, one controls an LED, and one accepts the analog input. SDA and SCL connect directly to the digital potentiometer's SDA and SCL pins with 4.7-k $\Omega$  pull-up resistors to V<sub>DD</sub>. By adding or removing jumpers, you can separate the shared V<sub>C</sub> and V<sub>DD</sub> and isolate SDA and SCL.

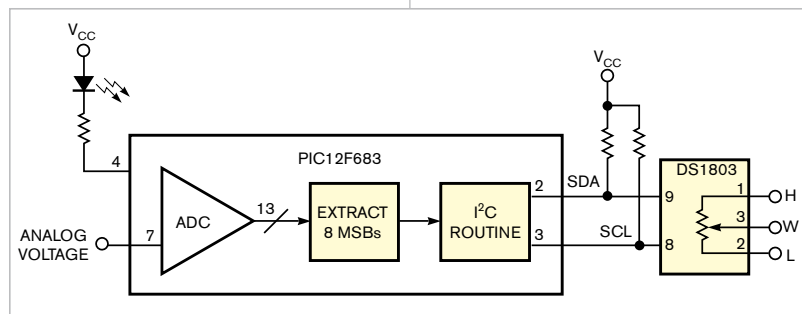
The firmware is in assembly language, which was assembled using Version 7.40 of the MPLab IDE (in-

tegrated development environment), which is currently available free from Microchip at [www.maxim-integrated.com/tools/other/appnotes/4051/AN4051.zip](http://www.maxim-integrated.com/tools/other/appnotes/4051/AN4051.zip). The program comprises fewer than 450 bytes in flash memory and 8 bytes in RAM. The program first initializes various configuration bits in the PIC, including the ADC and the internal oscillator. It configures the ADC to accept input from the analog input and sets the conversion clock to use the internal oscillator at 125 kHz.

The firmware runs in a loop, causing the 10-bit ADC to continuously convert the analog-input voltage. When a conversion is complete, the 8 MSBs form a data byte that transmits over the I<sup>2</sup>C bus, and this I<sup>2</sup>C-signal stream controls the digital potentiometer. The program controls both potentiometers in this dual device. With a change in firmware, however, you can independently control the potentiometers,

using separate analog inputs on the PIC12F683. The program enables you to control the potentiometer by varying a voltage at the GP1 input of the PIC12F683. A change at GP1 causes a corresponding change in the potentiometer's resistance:  $R_{OUT} = ((\text{Input Voltage})/V_{CC}) \times 50 \text{ k}\Omega$ , where the end-to-end resistance of the digital potentiometer is 50 k $\Omega$ , the allowable V<sub>CC</sub> range is 2.7 to 5V, and the input-voltage range is 0 to V<sub>CC</sub>. You can troubleshoot an application by checking that the device's address is correct and that the I<sup>2</sup>C bus is connected. The LED blinks constantly while the ADC is running, but remains on when an I<sup>2</sup>C error occurs. After you correct the error, the LED resumes its normal function.

You can extend this design approach to other applications for which an analog voltage must control a device with an I<sup>2</sup>C interface. You can, for example, implement a nonlinear-transfer function, such as gamma correction, using the DS3906 variable resistor, and implement the transfer function in embedded look-up tables (**Reference 2**). Or, by connecting a thermistor at the input, you can vary the output of an I<sup>2</sup>C-controlled current DAC in response to changes in the ambient temperature. **EDN**



**Figure 1** This circuit allows an analog-voltage input to select the digital potentiometer's resistance.

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## Harvest energy using a piezoelectric buzzer

Carlos Cossio, Santander, Spain

Energy-harvesting, or "scavenging," systems extract energy from the ambient environment. Unfortunately, these power generators supply much less energy than do

standard batteries. However, thanks to the decreasing size and low-power requirements of today's wearable devices, it is feasible to replace batteries in some low-power systems with pow-

er generators that capture energy from the user's environment, such as the vibration energy a user produces during walking or running. This Design Idea uses the piezoelectric effect of a standard and easy-to-find piezoelectric buzzer to turn mechanical vibrations into electrical energy. Although piezoelectric buzzers generate sound waves when you apply an ac voltage,

you can use them in the opposite way: You obtain the maximum ac peak voltage that the piezoelectric buzzer generates when the vibration frequency matches the resonant frequency of the piezoelectric buzzer.

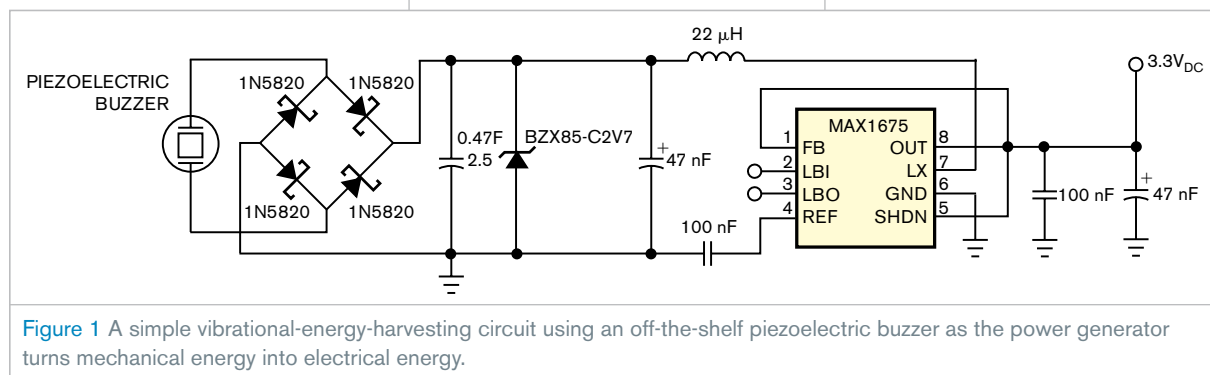
The power generator in **Figure 1** is a simple circuit. The piezoelectric buzzer produces an ac voltage when it is under vibration; therefore, you must convert this voltage to a dc voltage before charging the capacitor. The four Schottky diodes form a bridge rectifier to perform this task. For a reliable and efficient operation, select Schottky diodes, such as the 1N5820 rectifier diode from On Semiconductor ([www.onsemi.com](http://www.onsemi.com)), that exhibit

low forward-voltage drop and low reverse leakage.

Energy harvesters typically capture small amounts of energy over long periods, so harvesters usually contain an energy-storage subsystem in the form of a supercapacitor, such as the PowerStor 0.47F, 2.5V capacitor from Cooper Busmann ([www.bussmann.com](http://www.bussmann.com)). The larger the capacitor, the longer it takes to charge it. On the other hand, a large capacitor provides power for a longer time for the same load. Because a supercapacitor often has a much lower voltage than standard electrolytic capacitors, you must connect a zener diode, such as the BZX85-C2V7, to prevent the voltage across the supercapacitor

from increasing beyond its maximum voltage rating. As soon as you apply a load, the supercapacitor starts discharging, and the voltage across the supercapacitor starts dropping. To guarantee a fixed voltage at the output, you must use a dc/dc-voltage-converter IC, such as the MAX1675 from Maxim ([www.maxim-ic.com](http://www.maxim-ic.com)) as a step-up converter working at 3.3V.

As an additional benefit, if the supercapacitor's voltage drops below the required voltage of operation, the circuit continues to provide regulated output voltage as long as the supercapacitor voltage does not drop below the lower limit of the dc/dc converter. This limit is 0.7V for the MAX1675.**EDN**



**Figure 1** A simple vibrational-energy-harvesting circuit using an off-the-shelf piezoelectric buzzer as the power generator turns mechanical energy into electrical energy.

## Retriggerable monostable multivibrator quickly discharges power-supply capacitor

Jordan Dimitrov, Tradeport Electronics, Vaughan, ON, Canada

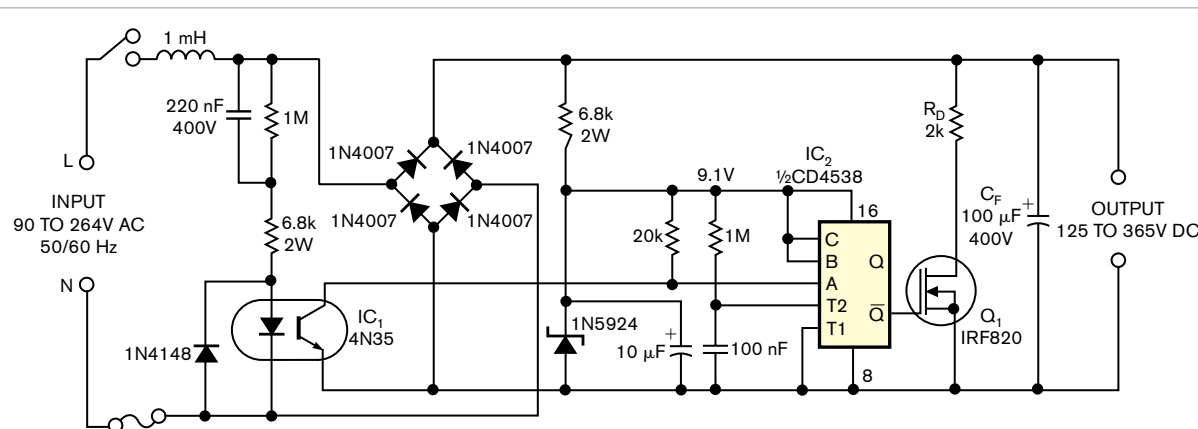
Universal power supplies must work from mains power lines ranging from 90 to 264V ac at 50 or 60 Hz. Directly rectifying the input voltage charges the filter capacitor to 120 to 370V dc. Such voltages present a serious threat to personnel who are prototyping or repairing the power supply. It is desirable to discharge the filter capacitor when mains power is off so workers can safely deal with the power supply. An intuitive solution is to use an ac relay. However, relays cannot operate in a wide range of input voltages, they consume significant power and

space, and they have a limited number of cycles. **Figure 1** shows an alternative circuit, which you can apply to a filter capacitor of almost any value. It

**THE TRICK IS TO USE A RETRIGGERABLE MONOSTABLE MULTIVIBRATOR TO CONTROL THE MOSFET.**

uses a MOSFET,  $Q_1$ , and a current-limiting resistor,  $R_D$ , to discharge the high-voltage filter capacitor,  $C_F$ , within one second after you switch off the mains power. The trick is to use a retriggerable monostable multivibrator to control the MOSFET.

While the mains power is on, optocoupler IC<sub>1</sub> and the associated passive components continue to generate symmetrical square pulses that they apply to the A input of multivibrator IC<sub>2</sub>. Each pulse triggers the circuit, forcing the Q output to the low level. The multivibrator generates a 100-msec negative pulse; then,  $\overline{Q}$  should turn high. However, because triggering pulses arrive before the multivibrator's pulse is complete, the Q output never turns high, the MOSFET is always off, and the rectifier works as usual. When you turn off mains power, the  $\overline{Q}$  output stays low for 100 msec after the last triggering pulse;



**Figure 1** Because of the retriggerable feature of the CD4538 IC, the discharge network,  $Q_1$  and  $R_D$ , remains off when mains power is present; otherwise, it turns on and quickly discharges high-voltage filter capacitor,  $C_F$ .

it then turns high. The MOSFET turns on and quickly discharges the output capacitor to a safe level.

The circuit underwent testing at both limits of the input voltage: 90 and 264V ac. The filter capacitor is of moderate value, 100  $\mu$ F, and so is

the peak-discharge current of 0.06 to 0.18A. The MOSFET's peak current is 8A; hence, the circuit can readily work with much larger-value capacitors. If this current is still not enough, you must use a MOSFET with a higher peak current rate. You need to change

only  $R_D$  to fit the desired discharge time,  $t_D$ . The  $t_D = 3 \times R_D \times C_F$  relationship is a good guideline. It ensures that the output voltage drops to 95% of its initial value, which is well below the user-touchable safety limit for any value of the output voltage. **EDN**