design ideas

Edited by Bill Travis

Buck IC boosts battery voltage for white LED

Robert Kollman, Texas Instruments, Dallas, TX

WHITE-LIGHT LEDs are finding their way into many markets that incandescent bulbs once served. Flashlights are among the newer applications in which reliability, ruggedness, and ability to control the power draw of the LEDs make these devices attractive. With incandescent bulbs, the power management for the device is a simple on-off switch. However, the LEDs cannot operate directly from the two cells you typically find in most flashlights, because their required voltage is 2.8 to 4V, compared with a battery voltage of 1.8 to 3V. The power management has a further complication because the light output of the LED relates to current, and the LED's characteristics are extremely nonlinear with voltage. One approach to this problem is to boost the power supply with a current limit. A number of devices for LED applications are available; however, their current ratings are typically too low for the 1 to 5W that flashlight applications need.

Publish your Design Idea in *EDN*. See the What's Up section at www.edn.com.

Figure 1 presents an alternative to the typical boost power regulator. A buck-converter IC, IC_1, generates the higher voltage that the white-light LED needs. An internal buck power stage connects between VIN and PGND, sourcing current to output Pin L. This circuit operates by turning on the high switch, thereby connecting the battery voltage across inductor L_1. Once inductor L_1 stores sufficient energy, the high-side switch turns off. The inductor current drives the switching node negative, and energy transfers through the low side into output capacitor C_1, creating an essentially lossless switching event. Also, because the high- and low-side switches are MOSFETs, voltage drop is lower than that of a diode implementation; therefore, efficiency can be high. The converter IC

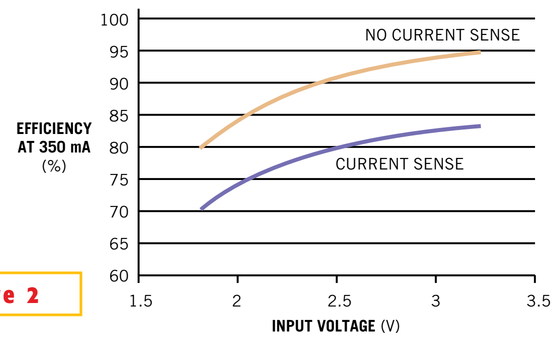


Figure 2

Resistive current sensing has an adverse effect on the efficiency of the circuit in Figure 1.

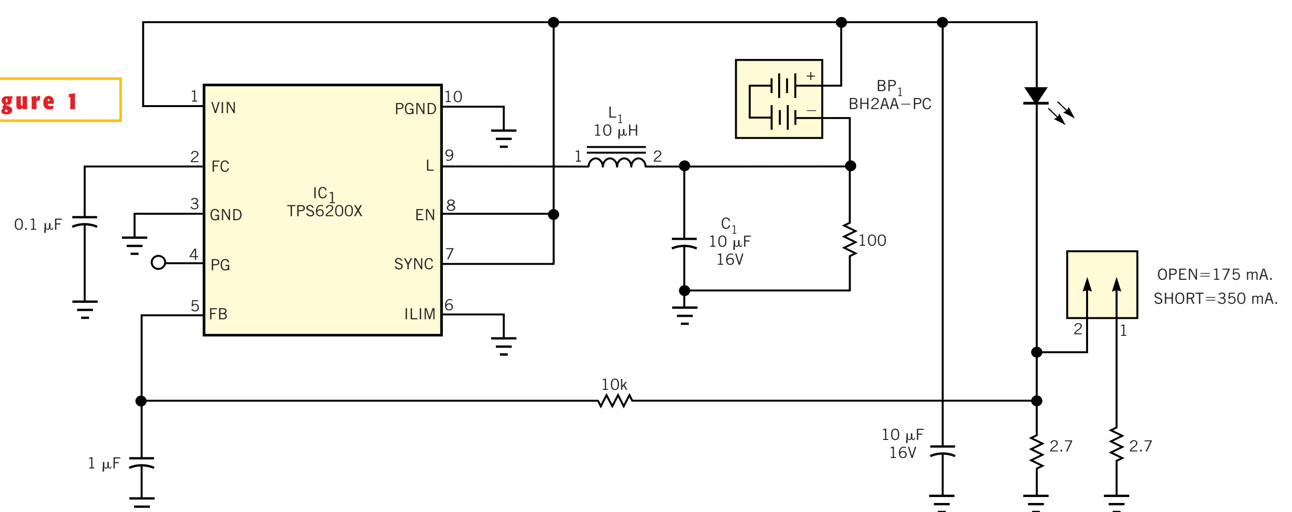


Figure 1

A buck-converter IC is a good choice for boosting voltages for white-LED drive.

monitors the current through the LED via a current-sense resistor and compares the current-sense voltage with an internal 0.45V reference within the converter IC to achieve regulation. Current and, therefore, illumination are functions of the current-sense resistor voltage. Although the internal reference voltage of the IC is lower than that of most other ICs, it does cause an appreciable power loss. With the LED voltage of 2.8 to 4V, it degrades efficiency by 10 to 14%. Reducing the resistor's value and using an amplifier to sense the current at a lower voltage could reduce this loss.

Figure 2 shows load-current regulation and boost voltage at a 350-mA current setpoint. Efficiency is 80% or better over the normal battery-voltage range but falls as battery voltage drops to end-of-life values. Also, the **figure** shows the impact of the resistive-current sensing. At high input voltages, the efficiency approaches 95%, and, at low input voltages, it falls to 80%. The trend for the curves stems from two interrelated effects: At high input voltage, input current and, hence, switch current are low. Therefore, conduction and switching losses are low. Second, much like an autotransformer, the boost power stage does not handle the total output power. The amount of power that the power stage handles relates to the boost voltage, or the difference between the input voltage and the LED voltage. In this design, the LED voltage is approximately 3.7V, so that at high line of 3.2V, the power stage handles only 13% ((3.7−3.2)/3.7) of the power. At low line, in which the currents are much higher, the power stage handles almost four times as much, or 50%, of the power. Although a buck controller is not an obvious choice for this application, it provides low-cost, low-input-voltage operation and good efficiency over a wide input-voltage variation.

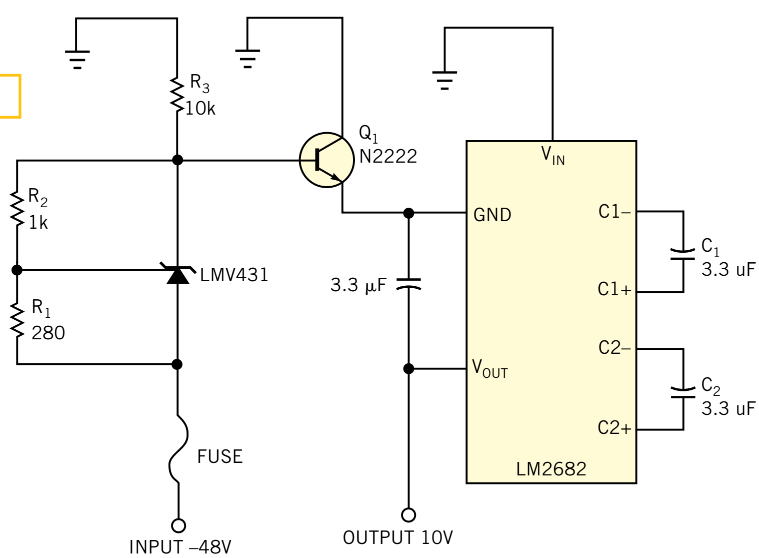
Is this the best Design Idea in this issue? Select at www.edn.com.

Switched-capacitor IC and reference form elegant −48 to +10V converter

Wallace Ly, National Semiconductor, Santa Clara, CA

A system designer must almost always face a trade-off in choosing the right part for an application. The trade-off usually involves performance, price, and function. An example is the issue of powering circuits from a telecom-voltage source. Telecom systems almost exclusively use high-potential negative rails, such as −48V. Digital circuits typically in use in such applications usually operate from a "brick"-type power supply. However, analog circuits rarely require enough power to justify using a costly brick. At the heart of these bricks is nothing more than a specialized switching converter in tandem with an isolated flyback-transformer coil. But some applications neither require nor can tolerate the use of a coil-based approach. **Figure 1** depicts a way to address the problem. The circuit provides a small amount of power to analog/digital circuits, such as the LMH6672 DSL op amp.

Figure 1



This simple circuit provides a 10V power source from −48V telecom power rails.

The LMV431 voltage reference, along with the voltage-setting resistors sets the output voltage to approximately (1+1 kΩ/280Ω)×1.24V~−5.7V. This output voltage then goes to the base of Q_1, the 2N2222 transistor. The configuration of the transistor causes a V_{BE} drop of approximately 0.7V, resulting in a net voltage of −5V for the next stage. The purpose of the transistor is to provide additional current to the LM2682 switched-capacitor converter. Note that the converter has a −5V reference (GND pin). Small capacitors C_1 and C_2 enable the pumping and inverting action required to convert the −5V to 10V. Furthermore, the MSO-8 package of the LM2682 and the SOT-23-3 package of the LMV431 allow the circuit to consume little board space. In roughly the size of a small transformer, the proposed circuit does an elegant job of powering low-power circuits from a negative high-voltage source.

Is this the best Design Idea in this issue? Select at www.edn.com.

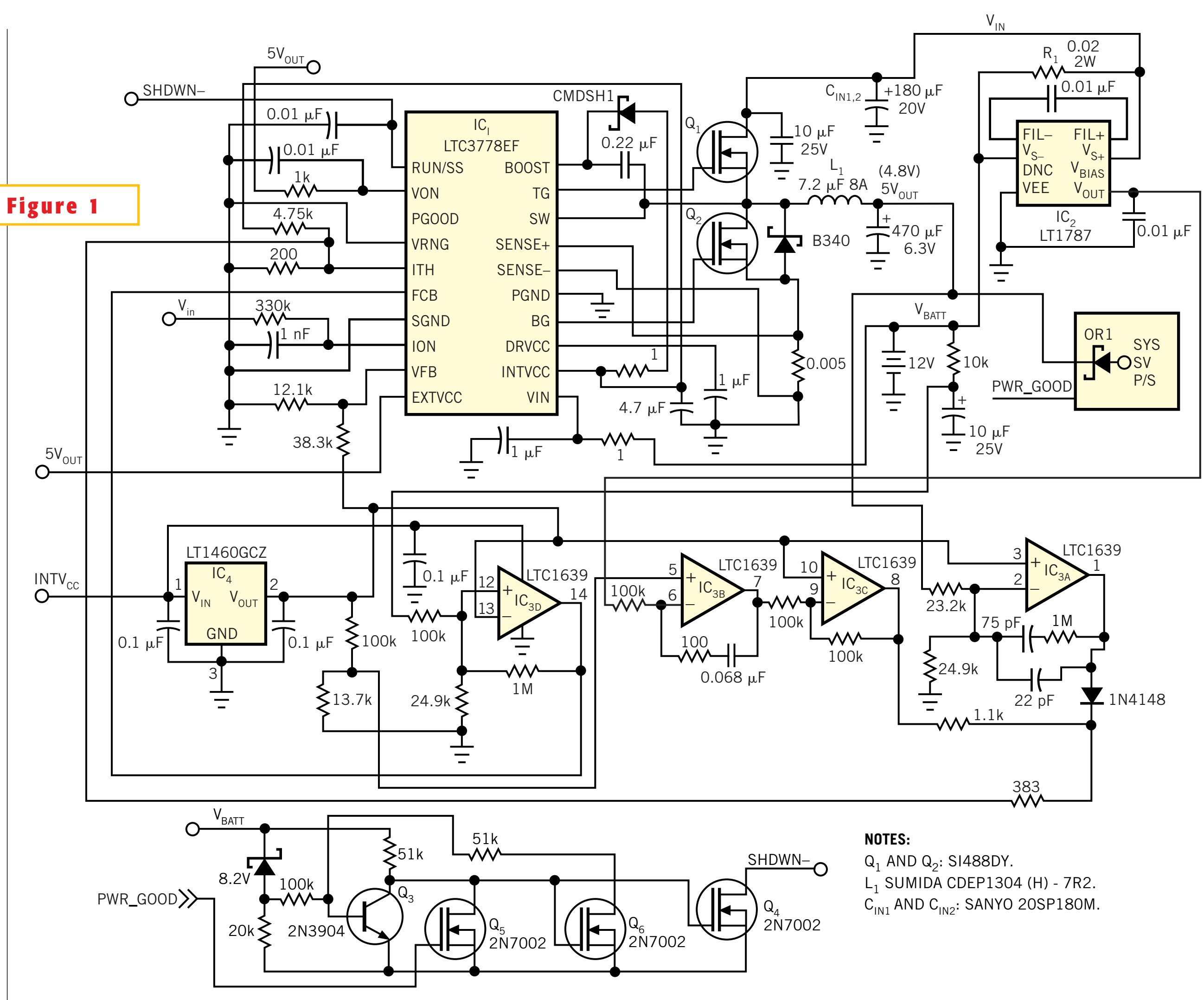
Buck converter handles battery-backup system

Haresh Patel, Linear Technology Corp, Milpitas, CA

A synchronous buck converter is inherently bidirectional. That is, it transfers energy from input to output as a buck regulator when the output voltage is low, but, when the output voltage is *high*, the converter acts as a boost regulator, transferring power from output to input. This Design Idea shows how to use this bidirectional energy transfer to automatically recharge a battery when the main 5V supply is available in a battery-backed 5V system. The circuit in **Figure 1** provides as much as 7A current at 5V output set at 4.8V and recharges a 12V sealed lead-acid battery with a current as high as 2A. The basic concept is that the ITH-pin voltage of the LTC3778 controls the L_1 inductor current, or the valley level. Above approximately 0.7V at the ITH pin, the net inductor current is positive from input to output. Below that level, the inductor current becomes increasingly negative, resulting in a boost function that transfers energy from output to input. When the FCB pin of the LTC3778 is high, the IC inhibits negative inductor current and the boost function by turning off the bottom MOSFET.

Figure 2 shows a 5V power supply backed up by a battery-powered, LTC3778-controlled power supply. The synchronous, bidirectional LTC3778 buck circuit acts as a battery-to-5V converter if the main 5V supply is off and as a battery charger when the 5V supply is alive. As **Figure 1** shows, in the charging mode, the circuit regulates the battery current by sensing the charge current through R_1 by means of an LT1787 current-sense

Figure 1



This bidirectional converter automatically recharges a battery when the 5V main supply is active.

amplifier, IC_2. An error amplifier, IC_{3B} and IC_{3C}, compares the current-sense signal with a reference voltage from the LT1460GCZ, IC_4, and drives the ITH pin of IC_1. When the ITH-pin voltage falls lower than approximately 0.7V, the circuit forces the average inductor current to a negative value, causing reverse power flow from the output to the input of the LTC3778, thereby charging the battery. The lower the voltage at the ITH pin, the higher the charge current.

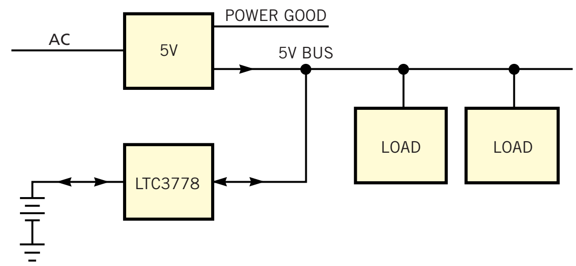


Figure 2

The battery charges when the 5V main supply is alive and provides 5V power when the main supply goes down.

At the beginning of the charge cycle, a constant current charges the battery. When the battery voltage reaches 13.8V, IC_{3D} pulls the FCB pin of IC_1 high, thereby not allowing Q_2 to turn on. So, the circuit inhibits boost mode regardless of the level at the ITH pin. The interruption in charging current causes the battery voltage to drop below 13.2V to restart charging. This action results in pulse charging with the pulse frequency gradually decreasing until the battery fully charges. In the backup mode, IC_{3A} senses the output-voltage drop to 4.8V and drives the ITH pin to maintain the output voltage at 4.8V. The recharging resumes when the system's 5V power returns and the 5V bus goes higher than 4.8V. In this scheme, the main supply voltage must be slightly higher than the backup-supply voltage for proper switchover. Approximately 100 to 200 mV should be adequate to prevent unnecessary mode switching attributable to ripple.

If the lower voltage in the backup mode is objectionable, then you can use a power-good signal from the main supply to change the reference voltage to the desired value when the power-good signal is low. Q_3 through Q_6 prevent low-battery discharge by shutting down IC_1 when the battery voltage is low and the power-good signal from the main supply is inactive. You could implement more sophisticated charging algorithms using a system microcontroller or analog circuitry that sets the charge current as a function of battery voltage. You can implement float charging by reducing the charge current to approximately 100 mA when the battery is nearly fully charged. A gradually tapering charge current can mimic constant-voltage charging as a alternative to pulse charging. The circuit can use a three-cell (in series) lithium-ion battery if you set the maximum voltage to 12.6V.

Is this the best Design Idea in this issue? Select at www.edn.com.

Circuit disconnects load from low-voltage supply

Steve Caldwell, Maxim Integrated Products, Chandler, AZ

Power supplies often include a circuit that disconnects the load when the supply voltage drops too low, such as when a battery is nearly discharged. A p-channel MOSFET connected between supply and load is the typical approach. However, a 1.5V single-cell battery or other low-voltage supply is insufficient to fully turn on the MOSFET. For such low-voltage systems, consider the circuit of **Figure 1**. A small inverting charge pump, IC_1, generates a negative voltage approximately equal to the input supply, V_{CC}. That voltage connects to the ground terminal of a microprocessor supervisor, IC_2, which monitors the voltage difference between its own V_{CC} and ground pins. As long as this difference is greater than the supervisor's internal trip-voltage threshold, the reset output voltage assumes the charge-pump output voltage of approximately $-2V_{CC}$, which provides a gate-source voltage adequate to keep the MOSFET on. When the monitored voltage drops below the threshold of the supervisor, its reset output goes up to V_{CC} and turns off the MOSFET. The supervisor has a threshold of 2.6V. Because the voltage it detects is twice the supply voltage, this circuit disconnects the load when the supply voltage drops below 1.3V, making it suitable for use with a typical 1.5V battery. Other internal threshold voltages are available.

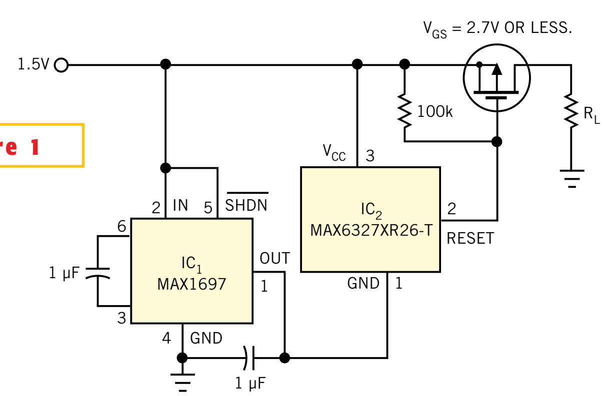


Figure 1

This low-voltage circuit disconnects the load when the supply voltage drops below a predetermined threshold of 1.3V in this case.

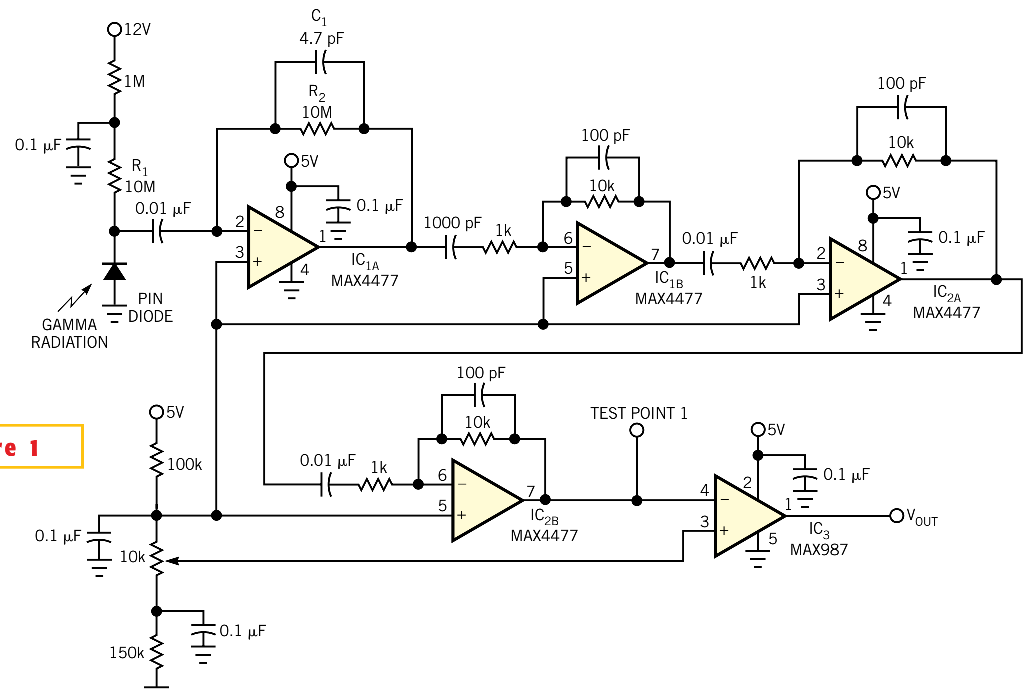
Is this the best Design Idea in this issue? Select at www.edn.com.

Circuit forms gamma-photon detector

Bruce Denmark, Maxim Integrated Products, Sunnyvale, CA

THE CIRCUIT of **Figure 1** includes a PIN photodiode that detects individual photons of gamma radiation. The reverse bias on the photodiode sometimes creates a depletion region. When such a photon strikes this depletion region, a small amount of charge develops. This charge is proportional to the photon's energy. Four amplifiers following the PIN photodiode amplify and filter the resulting signal. A final comparator distinguishes between the signal and the noise. Thus, the comparator's output pulses high each time a gamma photon with sufficient energy strikes the photodiode. Small signal levels make this design an interesting challenge. The design requires very-low-noise circuitry because the individual gamma photons generate a small amount of charge and because lowering the overall noise level allows the circuit to detect lower energy gamma photons. You must pay special attention to the first stage, which is the most noise-critical.

Figure 1



When a single gamma photon with sufficient energy strikes the PIN photodiode in this circuit, the output of the comparator pulses high.

The most critical component is the PIN photodiode, whose selection often involves conflicting considerations. Detector sensitivity (the number of photons detected for a given radiation field), for example, depends on the size of the depletion region, which in turn depends on the area of the diode and the reverse bias applied to the diode. To maximize sensitivity, therefore, you should choose a large-area detector with high reverse bias. Large-area detectors tend to have high capacitance, which increases the noise gain of the circuit. Similarly, a high bias voltage means high leakage current. Leakage current also generates noise. The circuit in **Figure 1** includes the QSE773 PIN photodiode from Fairchild (www.fairchildsemi.com). Though readily available and inexpensive, it is probably not the optimal choice. Certain PIN diodes from Hamamatsu (www.hamamatsu.com) can work nicely in this application. Choosing a detector with 25- to 50-pF capacitance with reverse bias applied provides a fair compromise between sensitivity and noise.

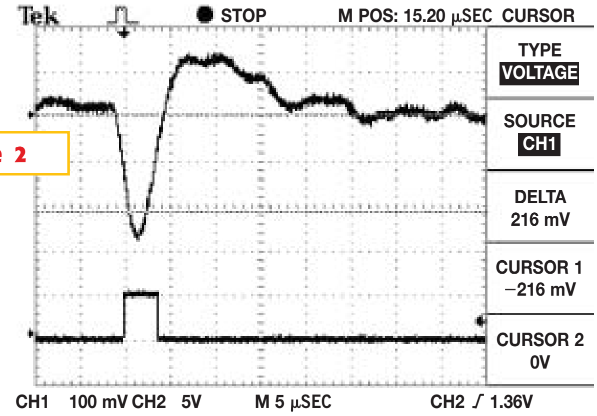
Important considerations for the first-stage op amp include input-voltage noise, input-current noise, and input capacitance. Input-current noise is directly in the signal path, so the op amp should keep that parameter to a minimum. JFET- or CMOS-input op amps are a must. Also, if possible, the op amp's input capacitance should be smaller than that of the PIN photodiode. If you use a high-quality PIN photodiode and an op amp with low current noise and pay careful attention to design, the limiting factor for noise should be the first-stage op amp's input-voltage noise multiplied by the total capacitance at the op amp's inverting node. That capacitance includes the PIN-photodiode capacitance; the op-amp input capacitance; and the feedback capacitance, C_1. Thus, to minimize circuit noise, minimize the op amp's input-voltage noise. The op amp in this circuit, IC_{1A}, a MAX4477, well suits this design. It has negligible input-current noise and low input-voltage noise of 3.5 to 4.5 $nV/\sqrt{Hz}$ at the critical frequencies of 10 to 200 kHz. Its input capacitance is 10 pF.

R_1 and R_2 contribute equally to noise because they are directly in the signal path. Resistor-current noise is inversely proportional to the square root of the resistance, so use as large a resistance value as the circuit can tolerate. Keep in mind, though, that leakage current from the PIN diode and first-stage op amp place a practical limit on how large the resistance can be. The MAX4477's maximum leakage current is only 150 pA, so R_2 could be much larger than the 10 MΩ shown. R_1 can also be substantially larger when the circuit operates with a high-quality

PIN photodiode. C_1 affects the circuit gain, and smaller values benefit both noise and gain. Use a capacitor with low temperature coefficient to avoid gain changes with temperature. This capacitance value also affects the requirement for gain-bandwidth product in the op amp. Smaller capacitance values require a higher gain-bandwidth product.

To ensure that the circuit measures gamma radiation and not light, cover the PIN photodiode with an opaque material. To block radiated emission from power lines, computer monitors, and other extraneous sources, be sure to shield the circuit with a grounded enclosure. You can test the circuit by using an inexpensive smoke detector. The ionizing types of smoke detectors use americium 241, which emits a 60-keV gamma photon. (The more expensive photoelectric smoke detectors do not contain americium.) A 60-keV gamma is close to the circuit's noise floor but should be detectable. A graph shows the result of a typical gamma strike (**Figure 2**). The top waveform is from Test Point 1, and the bottom waveform represents the comparator's output. A possible improvement would be to replace C_1 with a digitally trimmable capacitor, such as the MAX1474, which provides the circuit with digitally programmable gain. Similarly, replacing the mechanical potentiometer with a digital potentiometer, such as the MAX5403 allows digital adjustment of the comparator threshold. Finally, driving the comparator's noninverting input with a reference instead of the 5V supply improves the comparator's threshold stability.

Figure 2



These waveforms from the Figure 1 circuit show the signal at Test Point 1 (top trace) when a gamma photon strikes the PIN photodiode, and the resulting comparator output (bottom trace).

Is this the best Design Idea in this issue? Select at www.edn.com.

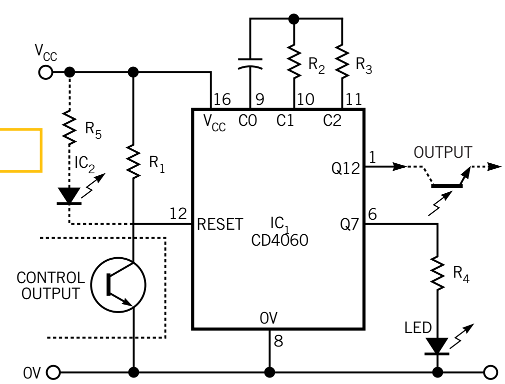
Circuit ensures safety in power-on operation

Jean-Bernard Guiot, DCS AG, Allschwil, Switzerland

COMPUTERS FIND universal use in industrial-control systems. During power- and start-up sequences (booting), the outputs of such control systems may yield uncontrolled pulses before the software defines the correct status. If these outputs control the power-on state of a system, these uncontrolled pulses could have dramatic consequences. Safety regulations forbid such erratic behavior. The circuit in **Figure 1** is a cost-effective approach to the spurious-pulse problem. The circuit costs approximately 10 times less than other available timers. The open-collector output of the controlling device connects to the reset input of the CD4060 counter, IC_1. You can easily adapt this circuit to other controller-output configurations, such as an optocoupler. As long as R_1 pulls the reset input high (controller-output off), the counter's clock stays disabled and all outputs are low. C, R_2, and R_3 are the timing components for IC_1. With $R_2=R_3=10$ kΩ and C=0.1 µF, the measured clock frequency is approximately 360 Hz.

The output of the circuit is Q12. The reset input must stay low longer than $T=(2^{n-1})/f=(2048)/360=5$ sec for the output to turn on (n is the output number, 12). Any spurious pulse from the controller's output that is shorter than 5 sec has no effect on the output of the circuit. Output Q13 of the counter turns on after 11 sec, Q14 after 23 sec, and so on. The LED, connected to Q7 through R_4, flashes during the timing period. With V_{CC}=12V and an LED current of 10 mA, $R_4=(V_{CC}-2)/10=1$ kΩ. For safety reasons, you can add the optocoupler, IC_2. If output Q12 of the counter fails (shorted to V_{CC}), the output turns on only if the controller's output is on. Choose the value of R_1 depending on the controller's output and the noise level; in this design, $R_1=10$ kΩ. Note that V_{CC} should have a maximum value of 15V for the CD4060 and 6V for the 74HC4060.

Figure 1



This simple timing circuit ensures that a controller's spurious pulses do not affect a system's start-up operation.

Is this the best Design Idea in this issue? Select at www.edn.com.