design ideas

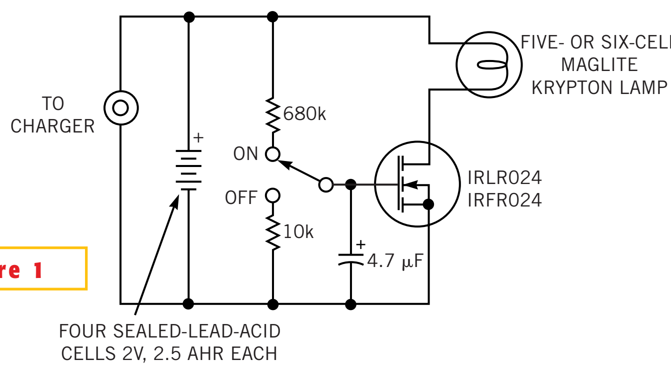
Edited by Bill Travis

Rechargeable flashlight obsoletes lantern battery

Fran Huffart, Linear Technology, Milpitas, CA

This Design Idea describes a high-intensity, rechargeable flashlight system that you can build from a 6V lantern-type flashlight. The rechargeable battery comprises four 2V, 2.5-Ahr (ampere-hour) SLA (sealed lead-acid) cells, similar in size to a standard D-sized battery. SLA cells are especially well-suited to powering flashlights because of their low self-discharge rate. NiCd (nickel-cadmium) or NiMH (nickel-metal-hydride) cells can lose as much as 1% of their charge per day, compared with less than 0.2% per day for SLA cells. SLA cells are also easy to charge and can withstand abuse. The flashlight in this design uses a krypton high-intensity lamp. Maglite (www.maglite.com) makes this lamp as a replacement lamp for its line of flashlights. The lamps are extremely bright; have a standard miniature-flange-base, built-in lens; and are available in five- or six-cell versions. (Manufacturers typically rate flashlight lamps by the number of alkaline cells the flashlight uses.) The lamp's operating voltage is approximately 1.25V per cell, which makes the lamp voltage of a six-cell lamp equal to 7.5V. This design uses a six-cell lamp for this flashlight, although you could also use a five-cell, 6.25V lamp. A five-cell lamp provides approximately 30% more light output but has a shorter lamp life. To increase lamp life, this flashlight includes the soft-start circuit in **Figure 1**.

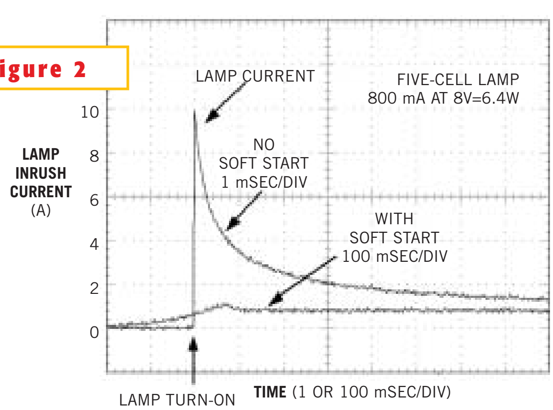
Figure 1



This soft-start circuit reduces inrush current, thereby prolonging lamp life.

Incandescent lamps inherently draw large start-up currents because of the filament's relatively low resistance when it is cold. A tungsten filament's resistance is typically 10 times lower when cold than it is when at normal operating temperature. When the full battery voltage suddenly hits a cold filament, the inrush current is typically 10 times the normal operating current, and this instant is when a lamp is likely to fail. Adding a soft-start circuit nearly eliminates this large inrush current, allowing for a higher power lamp and reducing the probability of the lamp's failure at turn-on. The soft-start circuit consists of an n-channel MOSFET in series with the lamp, which ramps the lamp voltage up at a controlled rate to reduce the inrush current. A gate-to-source capacitor controls the ramp speed. The lamp turns on in approximately 2 sec. **Figure 2** shows the dramatic reduction in lamp inrush current when you use the soft-start circuit.

Figure 2



Using the soft-start circuit in Figure 1 provides a dramatic decrease in inrush current.

The charger is a 200-kHz step-down switching regulator using current-limited constant voltage to charge the battery (**Figure 3**). When a discharged battery connects to the charger, the charge cycle starts in a 1A constant-current mode. As the battery accepts charge, the battery voltage increases until it reaches the programmed charge voltage of 2.5V/cell (10V total). At this point, the charge cycle enters constant-voltage mode. During constant-voltage mode, the charge current drops exponentially. When the charge current reaches approximately 10% (100 mA) of the programmed current, the charge voltage drops to a float voltage of 2.35V/cell

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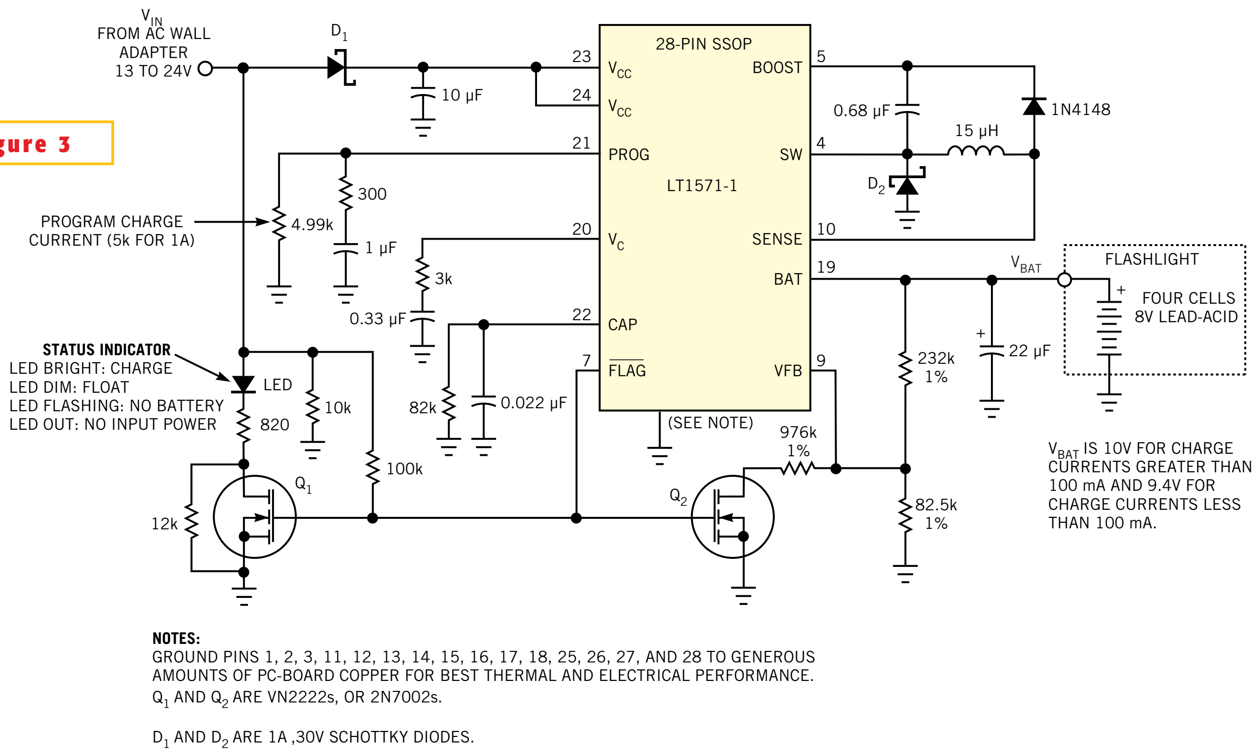
Figure 3



This battery charger uses current-limited constant voltage to charge the lead-acid cells in the flashlight.

(9.4V total). This dual-voltage approach provides a faster charge and also provides an LED indication when the battery is nearly fully charged. The charger keeps the battery at this float voltage, thus keeping the battery in a fully charged condition. You can leave the charger indefinitely connected to the battery without damage to the battery, although battery damage can result if it is fully discharged—when the battery voltage is less than 1.8V/cell—either through use or self-discharge. The $\overline{\text{FLAG}}$ pin is an open-collector output that indicates when the charge current has dropped to approximately 10% of the full programmed charge current.

A wall adapter with an output from 13V, 1A to 26V, 0.5A provides power to the charger. This design uses all surface-mount components to reduce the overall size of the charger. The pc-board layout should include wide ground traces that expand to larger copper areas to minimize the possibility of overheating the IC. The flashlight housing features a 3- to 4-in. reflector and has a handle on top; it is readily available from Radio Shack (www.radioshack.com) and other electronics outlets. The light is designed for a 6V lantern battery, but this design replaces the lantern battery with four D-sized, SLA cells. The cells leave enough room for the soft-start circuitry. Other modifications include replacing the switch with a high-quality SPDT switch and soldering all the connections for increased reliability. A dc power jack connects the flashlight to the charger.□

Single cell flashes white LED

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Many portable appliances and other products that must operate from a single cell are restricted to working at very low voltages. It is thus difficult to drive white LEDs that typically have a forward voltage of 3 to 5V. The ability to flash the LED with a supply voltage as low as 1V presents additional complications. The circuit in the **Figure 1** provides a discrete approach to these problems and allows a white LED to flash at a rate set by an RC time constant. Components Q_1, Q_2, R_3, R_4, and R_5 form a simple Schmitt trigger that, together with R_1, R_2, and C_1, controls the flashing of the LED. Q_4, Q_5, L_1, and associated components form a voltage booster that steps up the single-cell voltage, V_S, to a level high enough to drive the LED. Transistor Q_3 functions as a switch that gates the booster on and off at a rate determined by the Schmitt-trigger section.

To understand how the booster section works, assume that Q_3 is fully on, such that Q_4's emitter is roughly at the battery-supply voltage, V_S. Q_4 and R_8 provide bias for Q_5, which turns on and sinks current,

I_L, through inductor L_1. The inductor current ramps up at a rate determined mainly by V_S and the value of L_1; during this time, LED_1 and series diode D_1 are reverse-biased. The current continues to ramp up until it reaches a peak value, I_{LPEAK}. Q_5 can sustain no further increase, and the voltage across the inductor at this point reverses polarity. The resulting "flyback" voltage raises LED_1's anode to a positive voltage higher than V_S, sufficient to forward-bias LED_1 and signal diode D_1. The flyback voltage is also coupled through C_3 and R_{10} to Q_4's base, thus causing Q_4 and, hence, Q_5 to turn off rapidly.

The inductor current now circulates around L_1, LED_1, and D_1, and, as the energy stored in L_1 decays, the current ramps down to zero. At this point, the inductor voltage again reverses polarity and the negative-going change is coupled through C_3, rapidly turning on Q_4 and, in turn, Q_5. Current again begins to ramp up in L_1, and the process repeats. The booster section oscillates at a rate determined by several factors. The important factors determining the rate of oscillation include the values of V_S, L_1, and R_8; the forward-current gain of Q_5; and the forward voltage of LED_1. With the component values in the **figure**, the oscillation frequency is typically 50 to 200 kHz. On each cycle, a pulse of current with a peak value equal to I_{LPEAK} flows through LED_1 and, because this scenario occurs thousands of times every second, LED_1 appears to be continuously on.

The low-frequency oscillator formed around the Schmitt trigger turns the booster section on and off at a low rate. To understand how this works, assume that Q_1 is off and Q_2 is on. Provided that Q_2 has reasonably large forward-current gain, you can ignore the effects of its base current and say that V_S and the R_3-R_5 voltage divider set Q_2's base voltage, V_{B2}. With the values of R_3 and R_5 in **Figure 1**, V_{B2} is approximately 800 to 900 mV when V_S=1V. This voltage produces approximately 300 to 400 mV across R_4, resulting in a collector current of at least 15 µA in Q_2 with R_4=20 kΩ. Q_2's collector current provides base drive for Q_3, which saturates, turning on the booster section and illuminating LED_1. When LED_1 is forward-biased, C_4 charges to a positive voltage, V_P, roughly one diode drop above V_S.

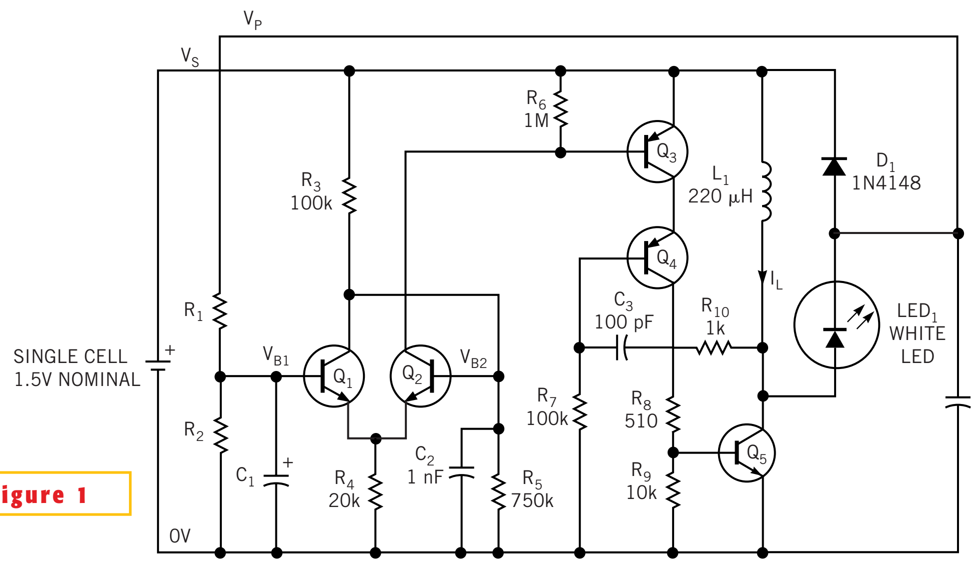


Figure 1

This circuit provides boosted voltage and flashes a white LED from a single cell.

Timing capacitor C_1 now charges via R_1 at a rate determined mainly by the values of V_P, R_1, R_2, and C_1. Provided that you carefully choose the ratio of R_1 to R_2, Q_1's base voltage, V_{B1}, eventually exceeds the quiescent level of V_{B2} (roughly equal to the Schmitt trigger's upper threshold voltage, V_{TU}), causing Q_1 to turn on and Q_2 to turn off. At this point, Q_3 also turns off, thereby disabling the booster section and turning off LED_1.

With LED_1 off, V_P rapidly decays, and C_1 begins to discharge at a rate determined mainly by the values of R_2 and C_1 and by Q_1's base current. The LED remains off until V_{B2} has fallen below the Schmitt trigger's lower threshold voltage, V_{TL}, at which point Q_1 turns off, Q_2 turns on, and the booster section again activates, illuminating LED_1. Provided that R_1, R_2, and C_1 are large enough, LED_1 can flash at a low rate. For example, if R_1 and R_2 have values of approximately 1 MΩ each and C_1 has a value of 1 µF or greater, a rate of less than one flash per second is possible. Remember, however, that R_1 and R_2 form a voltage divider that sets Q_1's base voltage, V_{B1}; therefore, R_2 must be sufficiently larger than R_1 to ensure that V_{B1} can cross the Schmitt trigger's upper threshold voltage as C_1 charges. With this fact in mind, you can with some trial and error fairly easily find the optimum values of R_1, R_2, and C_1 necessary for a given flash rate.

The value of V_P significantly influences the charging and discharging of C_1, and V_P's value hence varies according to the prevailing battery supply voltage, V_S. However, changes in V_{B2}, which also varies with V_S, somewhat balances this dependence. Nevertheless, the flash rate and duty cycle do vary somewhat as the battery voltage falls. For example, with R_1=2.2 MΩ, R_2=10 MΩ, and C_1=1 µF, the test circuit's flash rate at V_S=1.5V is approximately 0.52 Hz with a duty cycle of 66%. With a V_S of 1V, the flash rate increases to approximately 0.75 Hz but with a lower duty cycle of 44%. The Schmitt-trigger thresholds, V_{LT} and V_{TU}, are typically approximately 0.7V and 1.2V at V_S=1.5V, falling to approximately 0.6V and 0.8V when V_S is 1V.

The LED's intensity is proportional to

its average forward current and is thus determined by the peak inductor current, $I_{L\text{-}PEAK}$, and by the duration of the current pulse through the LED. Provided that L_1 is properly rated such that it does not saturate, the peak current depends largely on the maximum collector current that Q_5 can sustain. For a given supply voltage, this figure depends primarily on Q_5's forward-current gain, and on the value of R_8 that you can select to give optimum LED brightness at the lowest supply voltage. Experiment with different values of R_8 to get the best intensity for a given LED type. Take care, however, that the peak current does not exceed the LED's maximum current rating when V_S is at a maximum. The actual value of L_1 is not critical, but values in the range 100 to 330 μH should provide good performance and reasonable efficiency. The transistor types in the circuit are not critical; the test circuit works well with general-purpose, small-signal devices having medium to high current gain. If possible, select low-saturation types for Q_3, Q_4, and Q_5. C_2 is not essential to circuit operation but helps to decouple any switching noise at Q_2's base.

C_4 acts as a charge reservoir and ensures that R_1 can charge C_1 from a stable voltage source (V_P) when LED_1 is on. Because the charging current is likely to be low, C_4 can be fairly small; a value of 10 nF should be adequate. Note that C_4 must connect to the junction of D_1 and LED_1 as shown, rather than being charged, via a rectifying diode, from the flyback voltage at Q_5's collector. The reasons for this caveat are, first, that this approach ensures that V_P is only a diode drop above V_S, thereby minimizing the value of R_1 necessary for a given C_1 charging current. Also, and more important, this approach places the forward voltage of the LED in the path from V_S through L_1 and R_1 to Q_1's base. Because the forward voltage of a white LED is usually at least 3V, this connection prevents Q_1 from being turned on via this route, which could otherwise cause the circuit to lock in the "off" state.

At first sight, it might appear that you can turn the booster section on and off by gating current to Q_4's base, thus obviating the need for Q_3. However, under certain conditions, once you activate the booster section, the feedback to Q_4's base via C_3 and R_{10} is sufficient to maintain oscillation without feeding any dc bias to Q_4's base. Therefore, the only reliable way to gate the booster on and off is via Q_3, as shown. The test circuit starts up and operates with V_S as low as 0.9V, although the LED is dim at this voltage. The LED's intensity is good at V_S=1.5V (equivalent to a fully charged alkaline cell) and remains acceptable with V_S as low as 1V. The circuit should find applications in toys, security devices, miniature beacons, and any other products that must provide a flashing visual indication while operating from a single cell.□

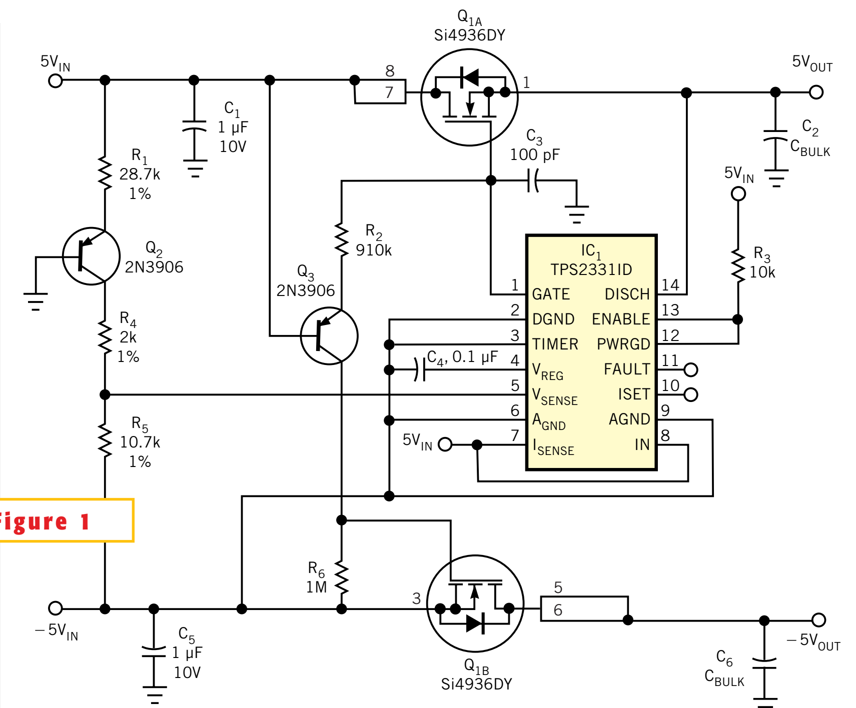
Hot-swap controller handles dual polarity

Dan Meeks, Texas Instruments, Manchester, NH

SOME APPLICATIONS REQUIRE a hot-swap controller, a circuit-breaker function, or both for dual-polarity, dc-input power-supply rails. In some hot-swap cases, the requirement is based only on inrush-current considerations. Control of the inrush current is necessary to eliminate connector stress and glitching of the power-supply rails. Other applications may have issues when one of the supplies fails for some reason. A good example is a bias supply for a gallium-arsenide FET amplifier. If you remove the negative gate bias, then you must also remove the positive drain supply; otherwise, the device may destroy itself because of the resulting high drain current. You can meet both these requirements by using a single-channel, hot-swap controller.

The circuit in **Figure 1** uses a TPS2331, IC_1, in a floating arrangement. The circuit references the IC's ground to the negative input voltage. If the voltage on the positive rail is too low or the voltage

Figure 1

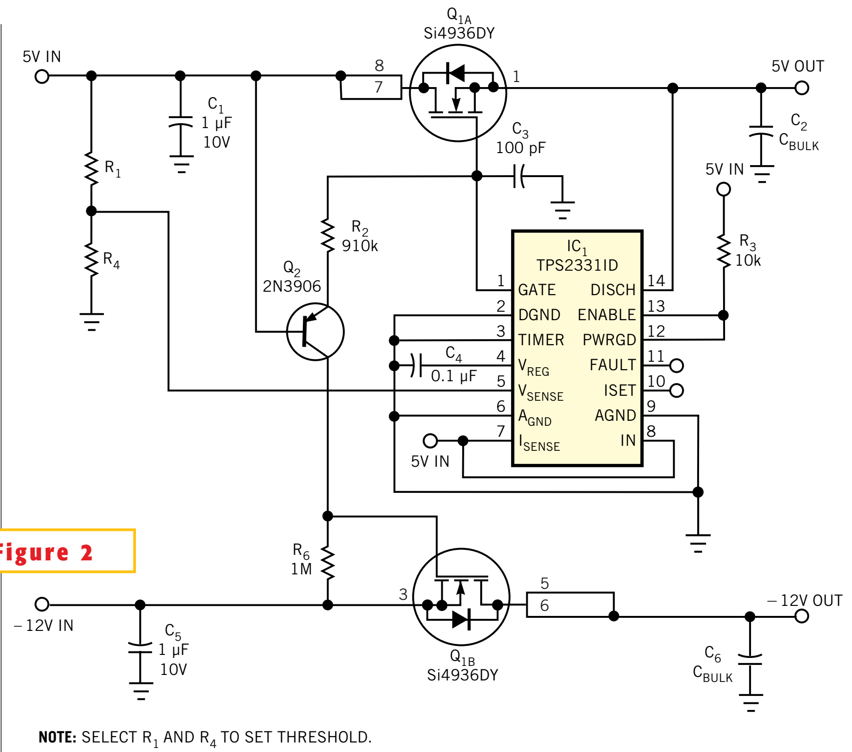


This circuit is a dual-polarity voltage sequencer for low-voltage applications.

on the negative rail is too high, the circuit cannot attain the 1.225V threshold at the V_{SENSE} pin, and the IC turns off. The V_{SENSE} pin incorporates approximately 30 mV of hysteresis to ensure a clean turn-on with no chatter.

When both supplies are beyond their respective thresholds, IC_1 turns on, providing a controlled-slew-rate ramp-up of the two FETs. Note that the circuit uses only n-channel FETs, which have lower on-resistance for a given size and cost than p-channel devices. To turn on Q_{1A} on, the TPS2331 has a built-in charge pump that generates a voltage above the positive rail, thus enhancing the FET. As the gate voltage builds, Q_3 acts as a linear level translator, so that Q_{1B} also ramps on. The turn-on speed is a function of the TPS2331's 14-μA output current and the value of C_3. The design uses the FETs based on the maximum resistance allowed in the dc path and the FETs' power-dissipation figures. You can use virtually any size FET, depending on the current you want to control. Take care that the total voltage span across the TPS2331 does not exceed the maximum rating of 15V. If IC_1 does not float between the input rails, the negative input may be larger.

Figure 2



This variation on Figure 1's circuit can handle higher voltages.

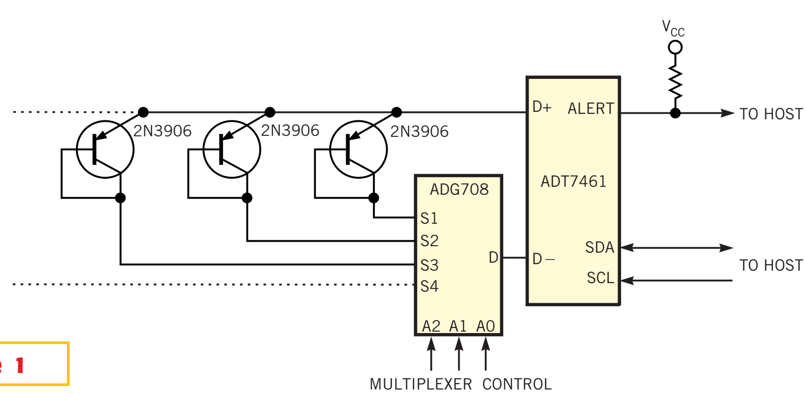
Figure 2 shows such an application, in which 5V and −12V are the input supplies. The main requirement is that the level-shifting transistor, Q_3, be able to handle the higher voltage. This circuit also allows you to use a positive input voltage as high as IC_1's maximum rating of 15V.□

Temperature monitor measures three thermal zones

Susan Pratt, Analog Devices, Limerick, Ireland

You can use an ADT7461 single-channel temperature monitor; an ADG708 low-voltage, low-leakage CMOS 8-to-1 multiplexer; and three standard 2N3906 pnp transistors to measure the temperature of three separate remote thermal zones (**Figure 1**). Multiplexers have resistance, R_{ON}, associated with them; the channel matching and flatness of this resistance normally result in a varying temperature offset. This system uses the ADT7461 temperature monitor, which can automatically cancel resistances in series with the external temperature sensors, allowing its use as a multichannel temperature monitor. The resistance automatically cancels out, so R_{ON} flatness and channel-to-channel variations have

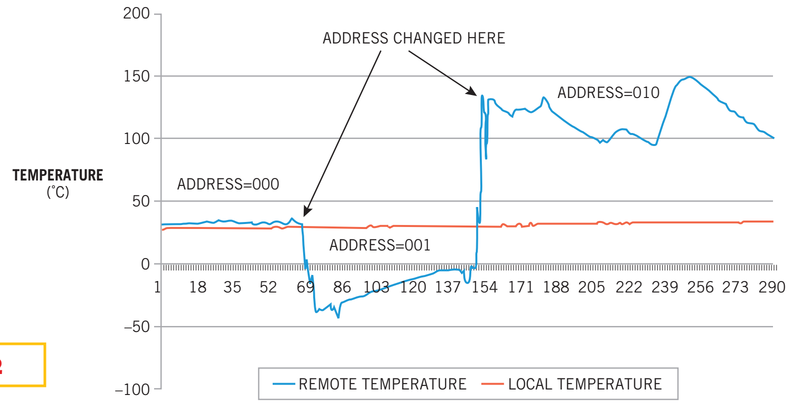
Figure 1



This system measures the temperature of three remote thermal zones.

no effect. Resistance associated with the pc-board tracks and connectors also cancels out, allowing you to place the remote-temperature sensors some distance from the ADT7461. The design requires no user calibration, so the ADT7461 can connect directly to the multiplexer. The ADT7461 digital temperature monitor

Figure 2



The system in Figure 1 measures ambient (address 000), cold (address 001), and hot (address 010) temperatures.

can measure the temperature of an external sensor with ±1°C accuracy. The remote sensor can be a monolithic or a discrete transistor and normally connects to the D+ and D− pins on the ADT7461. In addition to the remote-sensor-measurement channel, the ADT7561 has an on-chip sensor.

The diode-connected transistors have emitters that connect and then connect to the D+ input of the ADT7461, and each of the base-collector junctions connects to a separate multiplexer input (S1 to S3). You connect the selected remote transistor to the D− input on the ADT7461 by addressing the multiplexer, which address bits A2, A1, and A0 digitally control. The ADT7461 then measures the temperature of whichever transistor is connected through the multiplexer. The ADT7461 measures the temperature of the selected sensor without interference from the other transistors. **Figure 2** shows the results of measuring the temperature of three remote temperature sensors. The sensor at address 000 is at room temperature, the sensor at address 001 is at a low temperature, and the sensor at address 010 is at a high temperature. When you select no external sensor, the "open-circuit" flag in the ADT7461 register activates, and the Alert interrupt output asserts. You can expand the system to include as many external temperature sensors as your design requires. The limiting factor on the number of external sensors is the time available to measure all temperature sensors. If your design requires two-wire serial control of the multiplexer, you can use an ADG728 in place of the ADG708.□