

Edited by Bill Travis

Seven-segment LCD uses two-wire interface

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YOU CAN CONNECT seven-segment LCDs using only a two-wire interface (Figure 1). The two-wire interface may be at the field-effect, direct-drive LCD or at a serial interface (such as I²C) that uses an eight-pin microcontroller. The design in Figure 1 uses an Atmel (www.atmel.com) ATtiny12 microcontroller, IC₁. V_{CC} can range from 2.7 to 5.5V. Each digit receives drive from an 8-bit 74HC164 shift register, which provides seven outputs for each of the segments and one output for a decimal point or a colon. The data input to the shift register drives the LCD's common terminal. Software for the eight-pin microcontroller generates the required symmetrical ac square wave between the segments and the common terminal (Listing 1, which you can find at the Web version of this Design Idea at www.edn.com). This generation entails shifting the seven-segment data and decimal points to the appropriate outputs and setting the shift-register-input/LCD-common-terminal to low at a less-than 1-msec rate. A delay

of 16 msec followed by shifting the same data complemented, as well as the complement of the LCD common terminal with another 16-msec delay, provides the second half of the required ac waveform. Because field-effect LCDs takes tens of milliseconds to respond, the rapid data-shifting and display-common changing does not affect the displayed image. You can use the two 16-msec delays per cycle for application processing.

Directly driving the segments allows the display of not only the numbers zero to nine, but also any combination of segments and decimal points. You can use the eight-pin ATtiny12 with a built-in, 1-MHz clock oscillator to produce the described two-wire signal and to provide a two-wire I²C application interface. The dedicated use of the microcontroller for display control and its I²C interface frees the application hardware and software from timing and resource restrictions. The implemented I²C interface operates at 0 to 40 kbps and is bit-synchronous. One data protocol allows for the input of

a two-byte binary integer, which converts to decimal for display. A third byte in the protocol indicates any decimal points or colons. This data format allows the easiest interface from binary measurement or calculation. A second protocol accepts four bytes that directly control the segments and decimal points, allowing the display of a variety of characters and symbols possible on a seven-segment display. You can download the source code and hex object file for the ATtiny12 from the Web version of this Design Idea at www.edn.com. The code provides a two-wire I²C interface for a four-digit Lumex (www.lumex.com) LCD-S401C-52TR display. □

Seven-segment LCD uses two-wire interface.....89

Open-collector output provides fail-safe operation.....90

Low-battery indicator uses fleapower90

Indicator has "electronic lens".....92

Thermal switches provide circuit disconnect.....98

Buck-boost regulator suits battery operation100

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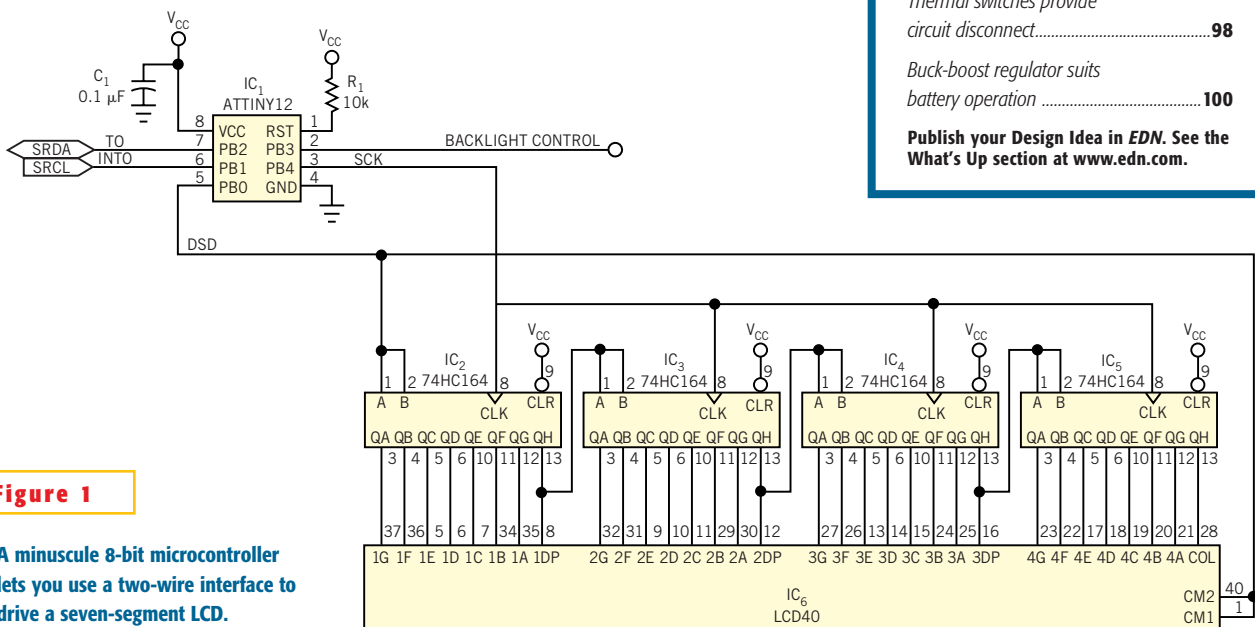


Figure 1

A minuscule 8-bit microcontroller lets you use a two-wire interface to drive a seven-segment LCD.

Open-collector output provides fail-safe operation

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IT IS COMMON PRACTICE to use digital open-collector outputs for control units in industrial applications. Using these outputs, you can switch loads, such as relays, lamps, solenoids, and heaters. One possible problem inherent to this type of output stage is a short circuit from the output to the supply voltage (often, 24V). This condition can destroy the output transistor if it lacks protection. The simplest approach to solving this problem is to use a fuse. This method has a disadvantage, however: You have to replace the fuse after it blows. A PTC (resettable) fuse is often too slow to protect the transistor under the short-circuit condition. Another possibility is to use a current source as the switching element. This approach is safe and simple, but it produces heat during the error condition. If the power rating and the cooling of the transistor are inadequate, the transistor fails because of thermal overload. The circuit in **Figure 1** shows another simple approach to the fail-safe protection of such switching devices.

The principal function of the circuit is to switch off the transistor if the voltage on the collector is higher than a predetermined value. Under normal switching conditions, transistor Q_1 should saturate when it turns on with a voltage lower than 0.2V between the collector of Q_1 and

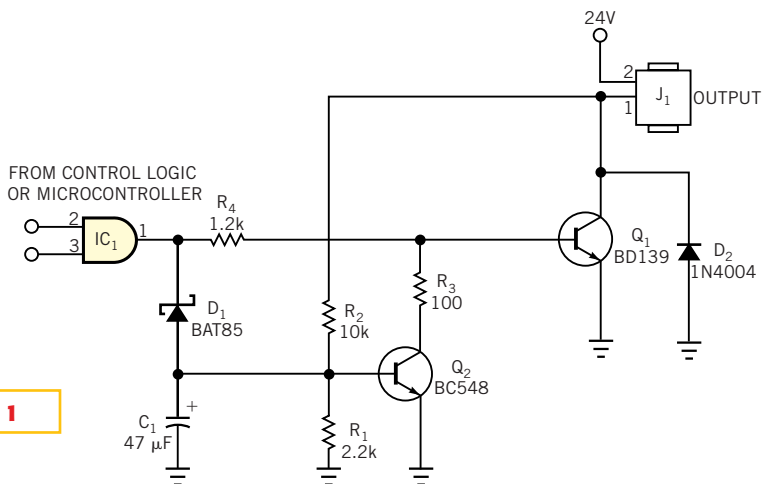


Figure 1

This circuit provides fail-safe protection of an open-collector output stage.

ground. If a short circuit exists on the output J_1 or if the impedance of the load is lower than specified, the voltage on the collector of Q_1 rises because too little base-current feed comes from the control logic (via R_4) to saturate Q_1 . If the collector voltage of Q_1 reaches the switching voltage on the base of Q_2 , Q_2 turns on, and Q_1 switches off. You can adjust this switching point with the R_1 - R_2 voltage divider. Now, the voltage on the collector of Q_1 rises to 24V, and the output stays in the switched-off condition. To reset the circuit, you must switch the steering output from the control logic to low. Now,

the Schottky diode, D_1 , is forward-biased and thus discharges C_1 and switches off Q_2 . If the steering output from the control logic again switches to the high state, Q_2 stays in the switched-off condition during the charging of C_1 . If the output of Q_1 is not overloaded, Q_1 saturates again and stays switched on. If the output has a short circuit to the supply or it is overloaded, then Q_1 switches on only during the charging of C_1 ; after this time, Q_2 switches off Q_1 . The maximum load current depends on the value of R_4 , the output voltage from the control logic, and the current gain of Q_1 . □

Low-battery indicator uses fleapower

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IT IS ALWAYS DESIRABLE to use a low-battery indicator that consumes as little power as possible. For a 9V, 450-mAhr alkaline battery, a 50- μ A low-battery indicator can by itself run the battery down in a little more than a year. Battery-powered devices that need to run continuously for a long time require battery indicators that consume minimal power. The circuit in **Figure 1**, designed for a 9V battery, uses extra-low power. When the battery is at full charge (9V),

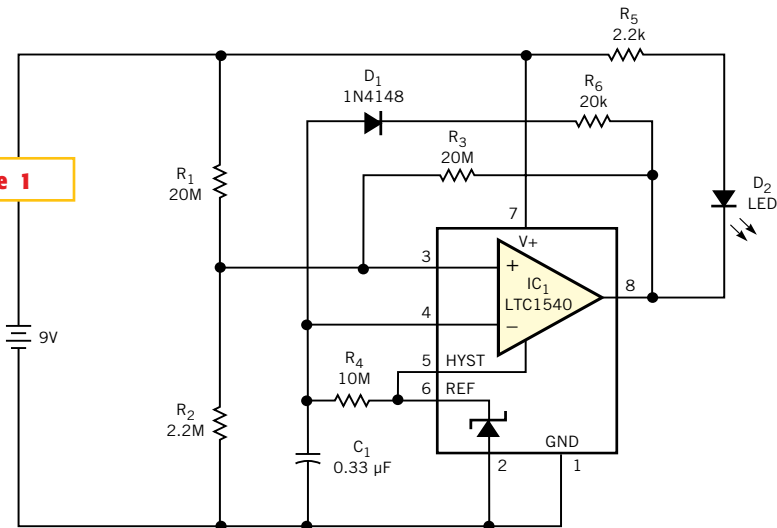
the circuit draws 1.4- μ A current. At the indication-threshold voltage, 6.5V, the circuit draws 1 μ A. Assume that the average operating current is 1.2 μ A. The circuit uses 42 mAhr in a four-year period, less than 10% of the battery's rated energy. A red LED, D_2 , flashes periodically when the battery voltage drops below 6.5V. IC_1 , an LTC1540, is a nanopower comparator with a built-in 1.18V reference. A battery-voltage divider comprising R_1 and R_2 , and a positive-feedback

network, R_3 , feed the positive input of the comparator. The positive feedback generates hysteresis in the comparator. The negative input of the comparator receives bias from the reference voltage, through the R_4 - C_1 delay circuit.

During normal operation, the voltage at the positive input is approximately 1.62V when the battery is at 9V. The output of the comparator is at a high state, such that no current flows through D_1 and D_2 . When the battery voltage drops

below 6.5V, the voltage at the positive input drops below the reference voltage at the negative input. The output of IC₁ switches from high to low, thereby lighting the LED, D₂. The switching changes the voltage at the positive input to 0.58V and causes C₁ to discharge through D₁ and R₆. Because the value of R₆ is much smaller than that of R₄, the voltage at the negative input drops quickly, according to the time constant that C₁ and R₆ set. Once the voltage at the negative input falls below 0.58V, the comparator switches back to a high state. This change sets the voltage at the positive input to 1.18V, turns off the LED, and reverse-biases D₁, so the reference charges C₁ through R₄. When the voltage at the negative input again reaches 1.18V, the cycle repeats. The LED's on-time is a function of C₁ and R₆, and the off-time is a function of C₁ and R₄. With the values in **Figure 1**, the on- and off-

Figure 1



This fleapower low-battery indicator draws just 1.2-µA operating current.

times are 20 msec and 10 sec, respectively, at 6.5V threshold voltage. At this point, the LED's on-state current is (6.5V –

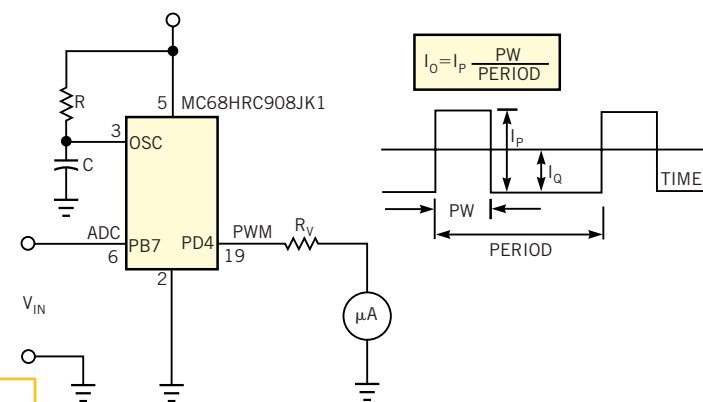
1.8V)/2.2 kΩ = 2.1 mA. The average LED current is (20 msec × 2.1 mA)/10 sec = 4.2 µA. □

Indicator has “electronic lens”

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THE METHOD for implementing an extended-scale meter described in an earlier Design Idea had a conceptual error: The meter impedance must change continuously, not discretely as expressed (**Reference 1**). You could achieve the desired result by using a digital potentiometer controlled by an input voltage via an appropriate interface. But this approach is probably too sophisticated. **Figure 1** shows an alternative approach that needs only a small and inexpensive microcontroller. The method exploits the fact that a dc meter measures the average value of a PWM signal: $I_{AVG} = I_{PEAK} (T_{PULSEWIDTH}) / (T_{PERIOD})$.

Figure 1



An inexpensive microcontroller allows you to expand any portion of the scale of a linear meter.

Therefore, you can control the current through the meter by changing the pulse width of the PWM signal. The PWM-generating software determines the law that governs the change in current in the meter. In the process of creating this software, you can choose expansion of any part of the scale (**Figure 2**).

The transfer function, a, represents a linear meter response; b denotes expansion of the beginning of the scale; c indicates expansion of the middle of the scale;

and d denotes the expansion of the upper end of the scale. The curves with high slopes in the graph of **Figure 2** correspond to expanded scales. You can create the scale patterns by choosing the threshold voltages (breakpoints) and slopes. The circuit resembles an “electronic lens” attached to the meter, which magnifies any chosen part of the scale. The ADC in the microcontroller of **Figure 1** transforms the measured input voltage into its

8-bit hex equivalent. The microcontroller program (**Listing 1** at the Web version of this Design Idea at www.edn.com) reads the hex value and finds a corresponding pulse width from a table in its memory. Finally, the routine generates the PWM signal with the given pulse width. **Figure 3** shows the software flow chart for the process.

As an example of the method, calculate the scale expansion of a 100-µA dc me-

ter with a measured-voltage range of 0 to 5V. You need to magnify the portion of the input from 2 to 3V, from 20 to 70%, leaving 10% at the beginning and 20% at the end of the scale (Figure 2, characteristic c). Table 1 shows the steps of the calculations, which you execute as follows:

1. Choose a number (N) and the values of the measured input voltages, V_{IN} . These parameters depend on the desired accuracy of the meter scale. As an example, assume voltages with increments of 0.5V for the low slope (Figure 2) and 0.1V for the high slope (Table 1, column 2). Therefore, $N=19$.

2. Calculate the 8-bit ADC's digital output, N_{IN} , for the selected input voltages (column 3): $N_{IN} = (256/5)V_{IN} = 51.2V_{IN}$.

3. Transform N_{IN} from decimal to hexadecimal format (column 4). The errors arising from the 8-bit quantization are insignificant for an analog indicator.

4. Choose the PWM period, T. This value depends on the rapidity of the input-voltage change and should be relatively short to prevent needle chatter. Assume $T=10$ msec for easy Table 1 calculations.

5. Calculate the number of timer cycles for the PWM period. The accuracy of any

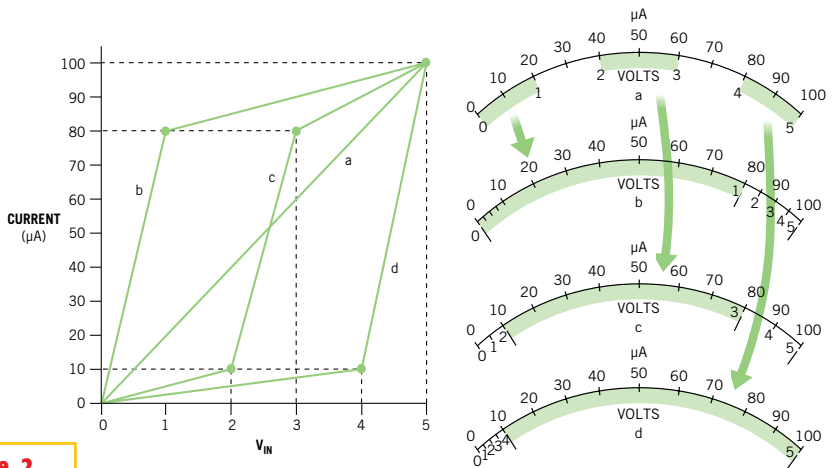


Figure 2

By selecting slopes and breakpoints, you can expand the bottom (b), the middle (c), or the top (d) portions of a linear meter's response.

microcontroller's time intervals is a function of the accuracy of its oscillator frequency, which for the MC68HRC908K1 depends on the external RC circuit. The data sheet for the IC recommends a tolerance of 1% or less for these components to obtain a clock tolerance of 10% or better. But it is difficult to find a 10-pF $\pm 1\%$ capacitor, so this design uses a less expensive 5% capacitor and measures the oscillation frequency. According to the microcontroller manual, the timing com-

ponents $R=20$ k Ω and $C=10$ pF should yield a frequency of approximately 4.5 MHz. The measured frequency is 5.75 MHz. With the timer/counter prescaler set at 64, the timer-clock period is 44.5 μ sec. Hence, you can calculate the number of timer cycles for any time interval as $N_t = (t \text{ in milliseconds}) / (44.5 \times 10^{-3}) = 22.5 \times (t \text{ in milliseconds})$. Thus, for $T=10$ msec, $N_{10} = 225$ or $N_{HEX} = \$E1$.

6. Determine the duty cycle (α) of the PWM signal for each chosen input voltage, V_{IN} , as well as the scale-expansion pattern (column 5); $\alpha = (I_V / I_{MAX}) \times 100\%$. You could either read the current value directly from the diagram in Figure 2 (characteristic c) or calculate it for three linear parts of the scale with the following equation: $I_V = I_{Ti} + S_i(V_{IN} - V_{Ti})$, where I_V is the current for the given input voltage V_{IN} , I_{Ti} is the current for the threshold voltage V_{Ti} ($i = \{1,2,3\}$), and S_i is the slope of each linear portion of the scale in Figure 2 (characteristic c). The expressions for the three piecewise-linear segments are as follows:

$$V_{T1} = 0; I_{T1} = 0; S_1 = \frac{10}{2} = 5 \mu A / V.$$

$$V_{T2} = 2V; I_{T2} = 10 \mu A; S_2 = \frac{80 - 10}{3 - 2} = 70 \mu A / V.$$

$$V_{T3} = 3V; I_{T3} = 80 \mu A; S_3 = \frac{100 - 80}{5 - 3} = 10 \mu A / V.$$

7. Determine the pulse width of the PWM signal: $PW = \alpha T$ (column 6).

8. Calculate the number of timer cycles, N_{OUT} , for this pulse width by using

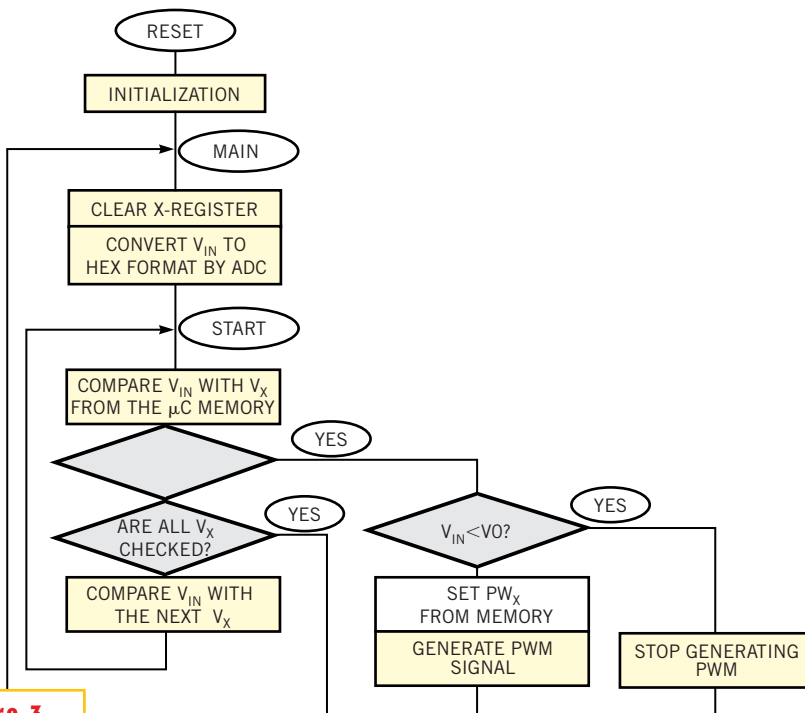


Figure 3

This flow chart shows the steps in the scale-expansion process.

the equation for N_t and transform the number into hexadecimal format (columns 7 and 8).

9. Enter N_{IN} and N_{OUT} **Listing 1**.

You can use any microcontroller with a PWM function and built-in ADC. The one in **Figure 1** has a 12-channel, 8-bit ADC and the capability to generate a PWM signal. This microcontroller has 15 I/O pins, which are necessary for executing other functions. If your application needs only to effect the meter-scale expansion, then the eight-pin 68HC908-QT2 is probably a better choice. This microcontroller has a built-in oscillator and costs less than \$1. You can download **Listing 1** from the Web version of this Design Idea at www.edn.com. □

REFERENCE

1. Raynus, Abel, "Expanded-scale indicator revisited," *EDN*, Aug 8, 2002, pg 112.

TABLE 1—EXAMPLE OF MIDSACLE EXPANSION

1	2	3	4	5	6	7	8
x	V_{IN} (V)	N_{IN}	N_{IN} (hexadecimal)	α (%)	Pulse width (msec)	N_{OUT}	N_{OUT} (hexadecimal)
0	0.04	2	\$2	0	0	0	\$0
1	0.5	25.6	\$1A	2.5	0.25	5.6	\$6
2	1	51.2	\$33	5	0.5	11.2	\$0b
3	1.5	76.8	\$4D	7.5	0.75	16.87	\$11
4	2	102.4	\$66	10	1	22.5	\$16
5	2.1	107.5	\$6C	17	1.7	38.25	\$26
6	2.2	112.6	\$71	24	2.4	54	\$36
7	2.3	117.8	\$76	31	3.1	69.75	\$46
8	2.4	122.9	\$7B	38	3.8	85.5	\$55
9	2.5	128	\$80	45	4.5	101.25	\$65
10	2.6	133.1	\$85	52	5.2	117	\$75
11	2.7	138.2	\$8A	59	5.9	132.75	\$85
12	2.8	143.3	\$8F	66	6.6	148.5	\$95
13	2.9	148.5	\$94	73	7.3	164.25	\$A4
14	3	153.6	\$9A	80	8	180	\$B4
15	3.5	179.2	\$B3	85	8.5	191.25	\$BF
16	4	204.8	\$CD	90	9	202.5	\$CB
17	4.5	230.4	\$E6	95	9.5	213.75	\$D6
18	5	250.9	\$FB	99	9.9	222.75	\$DF

Thermal switches provide circuit disconnect

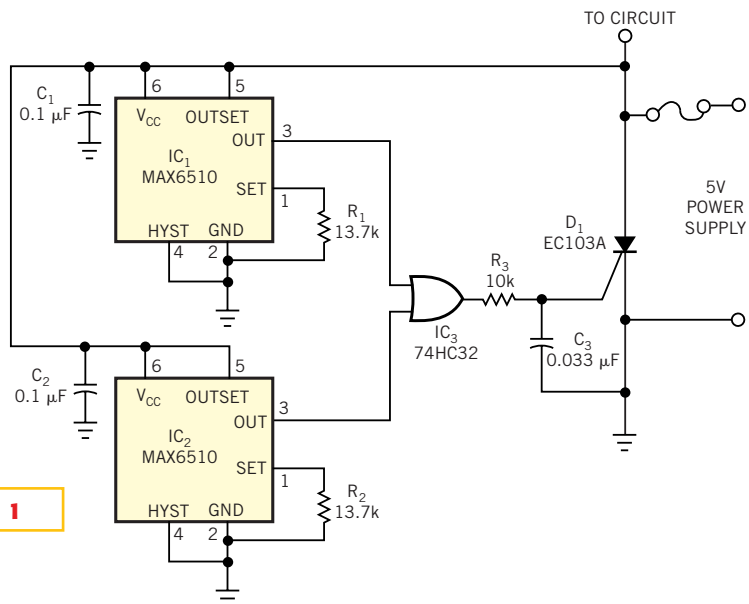
Mark Cherry, Maxim Integrated Products, Sunnyvale, CA

A SINGLE TEMPERATURE sensor can provide an interrupt to a microcontroller when the measured temperature goes out of range. You need multiple temperature sensors when you have to monitor more than one hot spot. A microcontroller implements the proper protective action when one of the temperature monitors detects an overtemperature condition. It is sometimes easier and more cost-effective to simply disconnect the offending circuit from the power supply without involving a microcontroller. A simple thermal-protection circuit (**Figure 1**) includes two temperature switches, IC_1 and IC_2 , with active-high outputs. Temperature thresholds for these switches depend on resistors R_1 and R_2 , and the switch outputs connect to the inputs of a dual-input OR gate, IC_3 . OR gates with more than two inputs are available if you need more than two temperature switches. When excessive temperature drives either input high, the OR gate's output switches high, causing an SCR (silicon-controlled rectifier) to crowbar the power supply and

blow the fuse. You must take precautions to ensure that the SCR does not trigger on a false gate pulse. Power-supply transients can cause a false high signal at the output of the OR gate and

cause the SCR to turn on. Once triggered, the SCR cannot turn off, and the fuse blows. A small RC filter, R_3 and C_3 , suppresses any gate transients that would otherwise turn on the SCR. □

Figure 1



This thermal-protection circuit includes a crowbar device, D_1 , driven by thermal switches IC_1 and IC_2 .

Buck-boost regulator suits battery operation

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A BUCK/BOOST CONVERTER can step a voltage up or down. Such a converter is appropriate for battery-powered applications. One application derives a regulated 14.1V at 1A from 12V solar panels with 9 to 18V variation. In this type of battery application, efficiency is an important factor; hence, this design uses an inexpensive synchronous-rectifier-based MC33166/7 circuit. It is difficult to find a buck-boost controller in the market. It is even more difficult to find an inexpensive one with an integrated high-current switch. One way to build a buck-boost converter is to use a buck regulator with an internal switch, such as the MC33166/7 (Figure 1). The negative-polarity output voltage connects to the IC's ground pin,

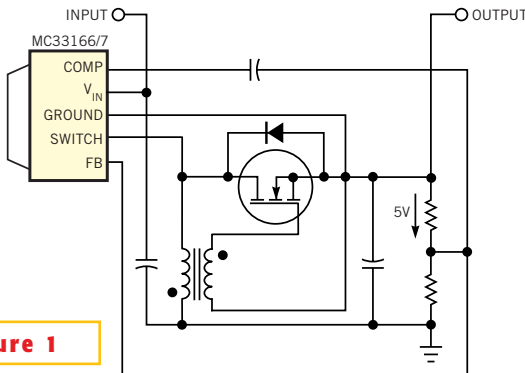


Figure 1

This inexpensive buck-boost controller uses synchronous rectification for high efficiency.

and a resistor pair divides the 14.1V output voltage to 5V for connection to the FB pin of the IC. So, the IC effectively regulates an input of $V_{IN} + V_{OUT} = 18 + 14.1 =$

32.1V to an output of 14.1V.

The MC33166/7 has a 40V maximum switch rating, and it can accommodate 95% duty cycle, so it's adequate for the application. To implement synchronous rectification for better efficiency, the design uses an additional transformer winding and a MOSFET. The auxiliary winding provides bias voltage to turn on the MOSFET when the switching-node polarity turns negative. Note that the synchronous rectifier is an important factor in the efficiency of this circuit, because the input-to-output ratio is approximately 1-to-1. So, the duty cycle is approximately 50%, which means that the MOSFET conducts for half the switching-frequency period. □