EDITED BY BRAD THOMPSON
AND FRAN GRANVILLE

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Op amp can source or sink current

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When you design for electronics applications, such as sensor or amplifier bias supplies or special waveform generators, a controlled constant-current source or sink circuit can serve as a useful building block. These circuits exhibit high dynamic-output impedance and deliver relatively large currents within an allowed range of compliance voltage. You can implement a constant-current circuit with an op amp and a discrete external transistor, but you can also design a bipolar version of a current source or sink around a single op amp and a few resistors (**Figure 1**). The constant-current sink circuits in **Figure 1a** through **Figure 1c** offer various compromises between precision, dynamic impedance, and compliance range.

The circuit in **Figure 1d** describes a bipolar current source with a simpler feedback configuration than that of the usual Howland-current pump, which requires positive feedback and presents variable input impedance. **Figure 1e** shows a constant-current source. All of these circuits exhibit excellent linearity of output current with respect to input voltage.

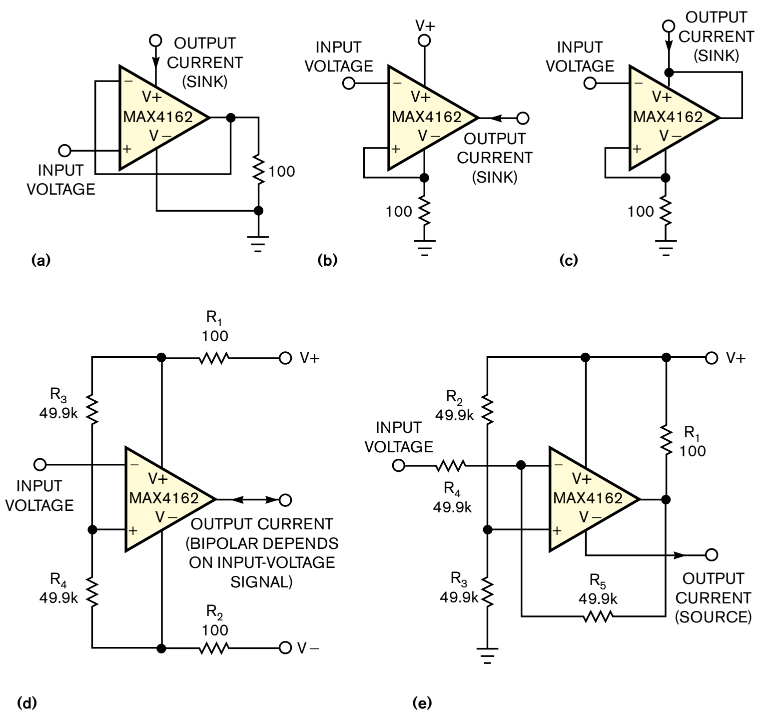

Figure 1 This compendium of constant-current circuits includes current sinks (a, b, and c), a bipolar sink or source (d), and a current source (e).

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The output from the circuit in **Figure 1a** includes an uncertainty due to the op amp's quiescent current, which adds to the calculated output current. For example, in most applications, you can neglect the MAX4162 op amp's quiescent current of approximately 25 μA. The circuit in **Figure 1b** behaves similarly, but its quiescent current subtracts from the ideal output-current value. The circuit in **Figure 1c** provides a current sink with no quiescent-current error, and the circuit in **Figure 1d** presents a bipolar output—that is, it sinks or sources current—depending on the polarity of the input voltage. Its performance depends on close matching for the resistor pairs R_1 and R_2 and R_3 and R_4 and good tracking of the positive- and negative-power-supply voltages. Any difference between the absolute values of the supply voltages appears as an offset current at 0V input voltage. To achieve insensitivity to power-supply-voltage variations, the current-source circuit in **Figure 1e** requires close matching of resistor pairs R_2 and R_3 and R_4 and R_5.

You can use the following equations to calculate output currents for the circuits in **Figure 1**. Note that $R_{LOAD}=100\Omega$ in these examples. In **Figure 1a**, $I_{OUT}=-V_{IN}/R_{LOAD}+25\ \mu A$; in **Figure 1b**, $I_{OUT}=-V_{IN}/R_{LOAD}-25\ \mu A$; in **Figure 1c**, $I_{OUT}=-V_{IN}/R_{LOAD}$; in **Figure 1d**, $I_{OUT}=-2\times V_{IN}/R_{LOAD}$; and, in **Figure 1e**, $I_{OUT}=V_{IN}/R_{LOAD}$. The equation for circuit **1d** assumes perfect matches—that is, $R_3=R_4$, $R_1=R_2$, and V+=V−. It also assumes that R_4 is much greater than R_1.

For a fixed value of output current in each of the five circuits in **Figure 1**, the graphs of **Figure 2** show the circuits' dynamic impedance and range of useful output voltage (current compliance). The graphs show a high nominal output current of 5 mA to better display the higher end of the current-amplitude range. Depending on your application, you can optimize each circuit's dynamic impedance and current range through a judicious choice of op amps and resistor values.**EDN**

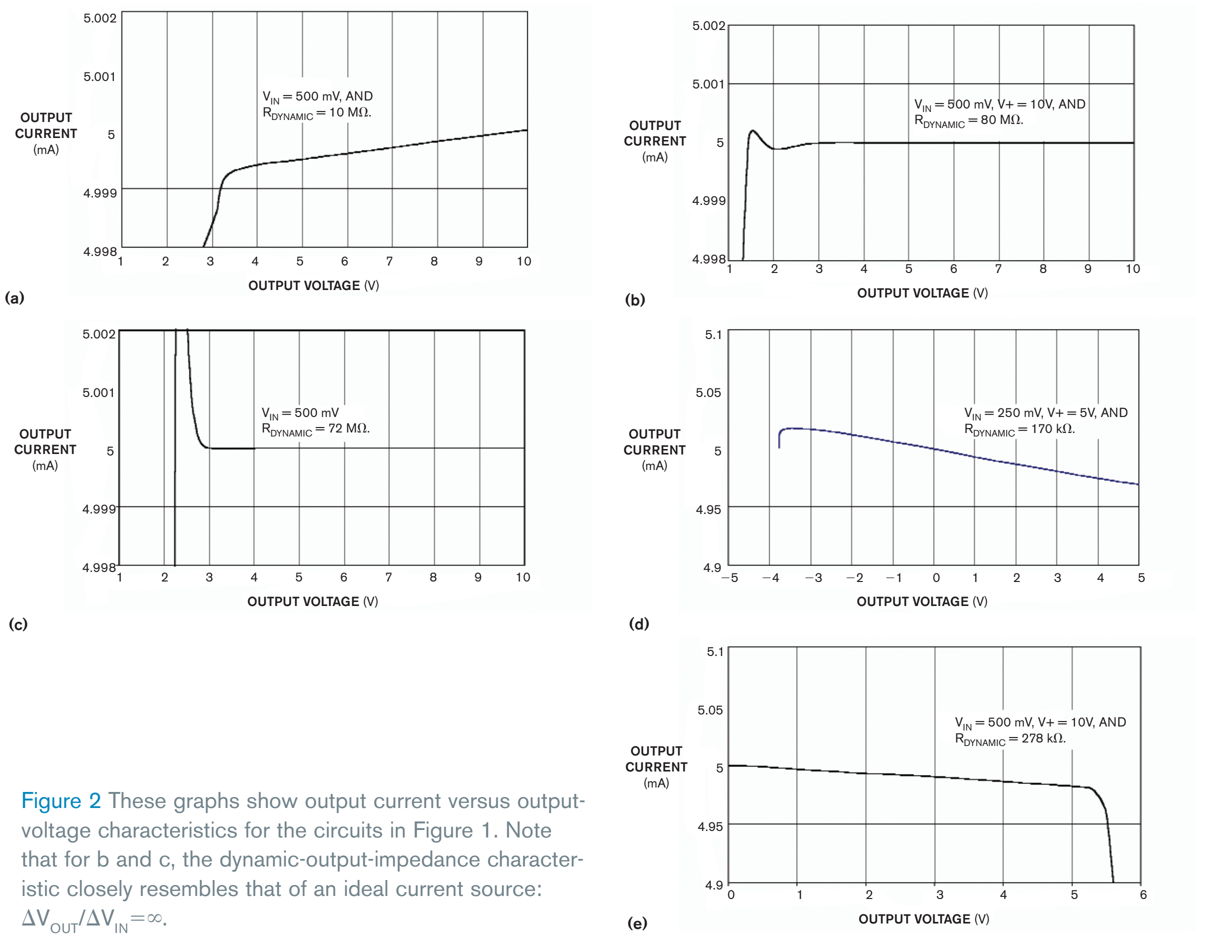


Figure 2 These graphs show output current versus output-voltage characteristics for the circuits in Figure 1. Note that for b and c, the dynamic-output-impedance characteristic closely resembles that of an ideal current source: $\Delta V_{OUT}/\Delta V_{IN}=\infty$.

Simple digital filter cleans up noisy data

Richard Rice, Oconomowoc, WI

Many systems use an ADC to sample analog data that temperature and pressure sensors produce. Sometimes, system noise or other factors cause the otherwise slowly fluctuating data to "jump around." To reduce higher frequency noise, designers often install an analog RC (resistor-capacitor) lowpass filter between the sensor and the analog-to-digital-conversion stage. However, this approach is not always ideal or practical. For example, a long time constant of minutes would require very large values for R and C.

Figure 1 shows an analog RC lowpass filter and its design equations. As an alternative, you can clean up noisy signals that remain within the ADC's linear range by using the digital equivalent of an analog RC lowpass filter. The filter's software comprises only two lines of C code: $LP_{OUT}=LP_{ACC}/K$, where the output value of the filter is LP_{ACC} divided by a constant, and $LP_{ACC}=LP_{ACC}+LP_{IN}-LP_{OUT}$, where you add the difference between input and output to update LP_{ACC}. You specify all variables as integers.

Each time the analog-to-digital conversion acquires a new input sample, LP_{IN}, the software produces an output value, LP_{OUT}, which comprises a lowpass-filtered version of the input samples. Calculate the value of the constant, K, based on the sampling rate of the system and the desired time constant for the filter as follows: $K=T\times SPS$, where $K>1$, and SPS is the system's sampling rate. For example, for a system-sampling rate of 200 samples/sec and a desired time constant of 30 sec, the constant K would equal 6000 samples. Applying a step change to the routine's input requires 6000 samples to reach approximately 63% of its final value at the output.

The lowpass accumulator, LP_{ACC}, can grow large for large time constants and large input values. It can grow as large as K times the largest possible LP_{IN} value. Under these conditions, you need to make sure that LP_{ACC} does not overflow, and you may need to specify a larger data type to contain LP_{ACC}. To avoid a long settling time during start-up, before the start of the sampling loop, you can initialize LP_{ACC} to a value of K times the current input value.

You can extend the basic filter concept presented to accommodate higher order filters with greater high-frequency rejection by executing multiple filter code segments in sequence. Also, you can use an array of variables for LP_{ACC} and an array of values of the constant K to filter signals that multiple data channels acquire. **EDN**

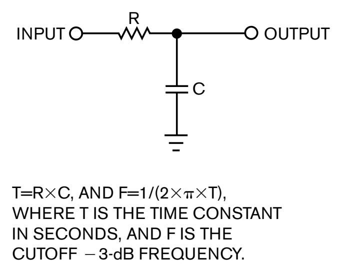
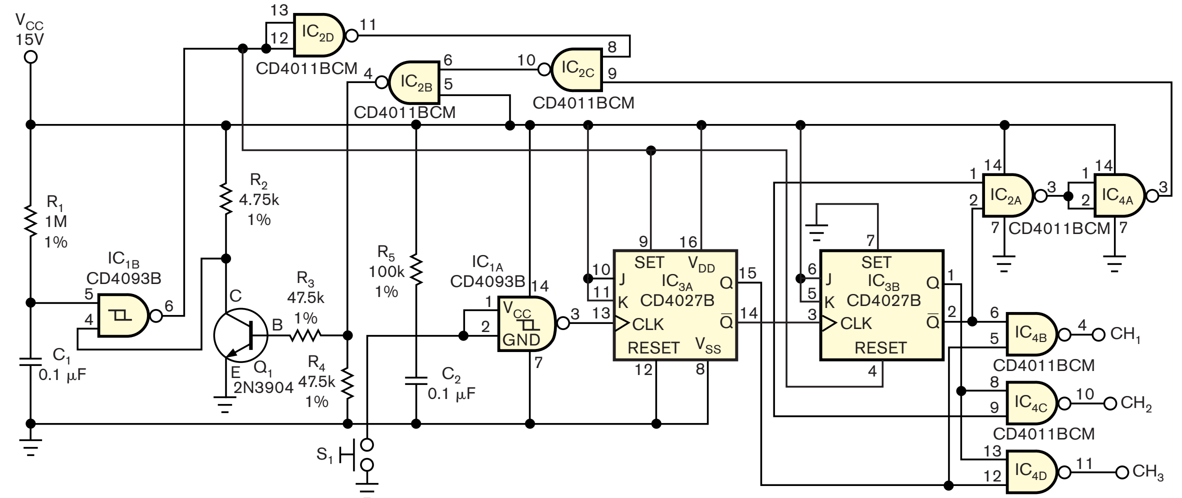


Figure 1 In some circumstances, a classic RC lowpass filter does an adequate job of removing noise from signals.

Single switch selects one of three signals

Felix Matro, JL Audio Corp, Phoenix, AZ

This Design Idea shows how you can use a single-pole momentary-contact switch to select one of three signal sources by scrolling through three output states. The circuit in **Figure 1** comprises commonly available components from the CD4000 CMOS-logic series, along with a general-purpose NPN transistor. The total cost of the components doesn't exceed \$1. Only one of circuit's three outputs, CH_1, CH_2, or CH_3, goes low at any given time, and you can use these outputs to control analog switches, relays, or the gates of JFET switches. As long as you apply power, the



NOTE: S_1 IS AN SPST NORMALLY OPEN PUSHBUTTON SWITCH.

Figure 1 A handful of active and passive components form a one-of-three selector switch. Press switch S_1 once to advance to the next channel and twice more to revert to Channel 1.

selected output does not change, making the circuit a good choice for applications requiring nonvolatile operation. Quiescent-current consumption averages only about 15 µA at room temperature, 25°C, a low value even for battery-powered applications.

The heart of the circuit comprises a dual JK flip-flop, IC_3, that's configured as a 2-bit ripple counter. Without additional circuitry, the counter would allow selection of four signal sources. Upon initial application of power, a reset circuit comprising R_1, C_1, and IC_{1B} always sets the CH_1 output to a logic-low level.

When the $\overline{Q}$ outputs of IC_3, pins 2 and 14, both go to logic zeros, the feedback chain comprising IC_{2A}, IC_{2B}, IC_{2C}, and IC_{4A} pulls Q_1's base to a logic-high level, which in turn pulls one input of IC_{1B} to a logic low. This action causes the counter to skip the 00 state and advances the count to the 01 state. Components R_5, C_2, IC_{1A}, and normally open momentary-contact switch S_1 constitute a debounced switch that provides clock pulses for both sections of the counter, IC_3. When a user pushes S_1, the counter advances to the 10 state, and a subsequent push advances the counter to the 11 state. A third push restarts the cycle. To summarize, IC_{4B} decodes the counter's 01 state and pulls CH_1 low, IC_{4C} decodes the counter's 10 state and pulls CH_2 low, and IC_{4D} decodes the counter's 11 state and pulls CH_3 low. The layout of the circuit should be noncritical, but use a low-leakage capacitor for C_1. Connect unused logic inputs to ground or V_{CC} as appropriate. **EDN**

R_5, C_2, IC_{1A}, AND NORMALLY OPEN MOMENTARY-CONTACT SWITCH S_1 CONSTITUTE A DEBOUNCED SWITCH THAT PROVIDES CLOCK PULSES FOR BOTH SECTIONS OF THE COUNTER.

Low-cost audio filter suppresses noise and hum

Richard M Kurzrok, RMK Consultants, Queens Village, NY

The low-cost composite passive filter in this Design Idea requires no dc power and can enhance the performance of audio equipment and instrumentation by rejecting power-supply hum and spurious pickup from AM, FM, and low-band VHF transmissions (**Figure 1**). The composite filter comprises a cascade of three simple filters: a T-section highpass filter to reject power-source hum and two π-section lowpass filters to reject spurious RF signals. As a starting point, the three filter sections present a lossless 0.01-dB Chebyshev response at a 50Ω impedance level, but you can scale the components' values to meet other impedance requirements.

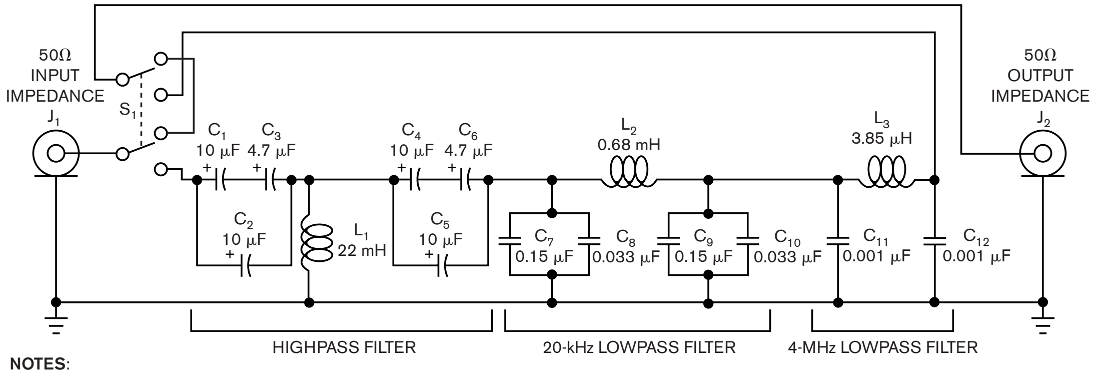
Table 1 lists the components the prototype filter uses. With the exception of inductor L_3, all the components are standard values that are available off the shelf. Switch S_1 provides a bypass mode that permits rapid frequency-response measurements without connection and disconnection of the prototype's BNC connectors. To construct the prototype, wire all components to a section of perforated breadboard stock supported by metal spacers that mount inside a die-cast aluminum enclosure. This method of shielded construction has proved its worth in other laboratory-accessory applications (**Reference 1**). **Table 2** lists the filter's measured insertion loss over a range of 40 Hz to 200 MHz.

Low-cost polarized electrolytic capacitors C_1 through C_6 provide reasonable performance, but observe input polarity for signals with a dc component. For a modest increase in cost and assembly time, you can enhance filter performance and reproducibility by selecting the values of these capacitors to meet a 10% or better tolerance. For best results, use nonpolarized film-dielectric capacitors for C_1 through C_6. For noncritical applications, you can relax the tolerances for the remaining capacitors and use off-the-shelf inductors for 22-mH L_1, 0.68-mH L_2, and 3.9-µH L_3.

Redesigning the filter to match the 600Ω impedance that you find in classic audio circuits would increase the

TABLE 1 COMPONENTS IN THE PROTOTYPE FILTER

Reference designators	Values	Description
C_1, C_2, C_4, C_5	10 µF	50V electrolytic capacitor, ±20% tolerance
C_3, C_6	4.7 µF	50V electrolytic capacitor, ±20% tolerance
C_7, C_9	0.15 µF	Polypropylene capacitor, ±2% tolerance
C_8, C_{10}	0.033 µF	Polypropylene capacitor, ±2% tolerance
C_{11}, C_{12}	0.001 µF	Polypropylene capacitor, ±2% tolerance
L_1	22 mH	Inductor, ±5% tolerance
L_2	0.68 mH	Inductor, ±10% tolerance
L_3	3.85 µH	Inductor, 27 turns of AWG #28 magnet wire hand-wound on T37-2 mixture (Carbonyl E) toroidal core
S_1	NA	DPDT panel-mounted toggle switch
J_1, J_2	NA	50Ω BNC panel jack
NA	NA	Hammond 1590H-BK die-cast aluminum enclosure



NOTES:
BOTH GROUNDS CONNECT TO CHASSIS.
WHEN S_1 IS IN THE UP POSITION, IT BYPASSES THE FILTER; WHEN IT IS IN THE DOWN POSITION, IT INSERTS THE FILTER.

Figure 1 A highpass filter and two lowpass filters help reduce or eliminate low-frequency hum and high-frequency noise from audio signals.

inductors' values by an order of magnitude, which would increase the inductors' dimensions and costs. An alternative design approach could use cascaded active-RC filters, which would pave the way for their inclusion into completely integrated composite-audio filters. **EDN**

REFERENCE

1. Kurzrok, Richard M, "Simple Lab-Built Test Accessories for RF, IF, Baseband, and Audio," *High Frequency Electronics*, May 2003, pg 60.

TABLE 2 FILTER INSERTION LOSS

Frequency (kHz)	Insertion loss (dB)	Frequency (MHz)	Insertion loss (dB)
0.04	45.2	0.1	42.3
0.07	35.4	0.3	60
0.1	29.4	0.5	60
0.2	17.3	1	55.5
0.3	10.9	2	52.2
0.5	5.5	3	51.1
1	2.7	4	56.2
2	2	5	60
5	1.9	10	46.5
10	2.1	25	44
15	2.7	50	40.5
20	4.5	100	39.5
30	11.7	150	45
50	24.5	200	44

Microprocessor's single-interrupt input processes multiple external interrupts

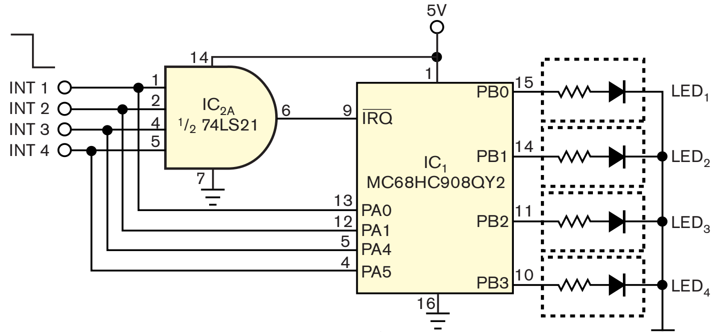
Abel Raynus, Armatron International Inc, Malden, MA

On the lower end of the performance spectrum, many widely available and inexpensive microcontrollers pay for their small pc-board footprints by omitting functions. For example, most low-end processors provide only one external-interrupt input pin and only one address vector in memory for the service routine that processes external IRQs (interrupt requests). However, a project occasionally requires that several interrupt-service programs must process multiple external interrupts from various sources. Cost and inventory constraints may make it undesirable to choose another microcontroller whose only advantage is the availability of a few more interrupt pins.

For example, Freescale Semiconductor's (www.freescale.com) popular Nitron family of flash-memory microcontrollers, such as the MC68HC908QT and QY, offer only one IRQ input pin. You can use one-time-programmable versions of the family, such as the MC68HC705KJ1 or MC68HC705J1A, that offer five external-interrupt inputs but omit some of the family's valuable functions, such as flash memory, built-in analog-to-digital conversion, and an advanced instruction set. You could also select a larger microcontroller, such as the MC68HC908JL3, from the same product family to gain eight external-interrupt inputs at the expense of significant increases in cost and pc-board area.

This Design Idea offers an alternative that retains the small processor and adds extra interrupt inputs. The technique involves applying the interrupt signals to an AND gate to generate an IRQ signal and using the microcontroller's inputs to recognize the interrupt's source. For example, consider the four external-interrupt sources in **Figure 1**. If you apply no interrupt signals and if all of the AND gate's inputs rest at logic ones, the IRQ level also remains at logic one. Applying an interrupt signal (a logic-zero level) to any one of four inputs, INT1 through INT4, drives the gate's output to a low level and triggers the interrupt. The interrupt-service routine recognizes the interrupt's source by testing the levels of input pins PA0, PA1, PA4, and PA5 and executing the corresponding interrupt-service routine.

The MC68HC908QY2 microcontroller, IC_1, includes built-in pullup resistors that eliminate the need for external resistors, and you can use an inexpensive and readily available 74LS21 for IC_2. For demonstration purposes, this circuit displays the address of an incoming interrupt by lighting one of four corresponding LED indicators for 3 sec. The software routine in **Listing 1** that assigns a priority to each interrupt uses the standard set of assembler instructions and can apply to any microcontroller. You can download **Listing 1**, as well as the sample's assembler code and its accompanying table of equations (**Listing 2**), from www.edn.com/060302di1. **EDN**



NOTE: LED_1 TO LED_4 ARE KINGBRIGHT CORP'S W934GD-5V WITH BUILT-IN RESISORS FOR OPERATION AT 5V.

Figure 1 An external AND gate plus a software routine expand a microcontroller's single interrupt input into four inputs.