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Build a complete industrial-ADC interface using a microcontroller and a sigma-delta modulator

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Designers commonly use 0- to 20-mA, 0 to 10V isolated inputs for industrial-application-control signals. A combination of isolated supplies, the built-in isolation of an Analog Devices (www.analog.com) AD7400 sigma-delta modulator, and a Texas Instruments (www.ti.com) MSP430 microcontroller creates a design for industrial designers requiring complete, isolated, and robust analog-signal interfaces. A precise signal-conditioning circuit generates the small differential voltage that the AD7400 requires (**Figure 1**). The circuit generates the required 200-mV differential voltage. For clarity, the **figure** omits overvoltage diodes and protection circuits.

A 0- to 20-mA current loop converts to a voltage through a properly scaled resistor, R_2, and enters a precision operational amplifier. The signal level, which connects to the negative input, gets a positive offset by maintaining constant voltage on the positive input of the amplifier. The 0 to 10V signal, such as that from a potentiometer, also scales to a similar voltage to that of the 0- to 20-mA sig-

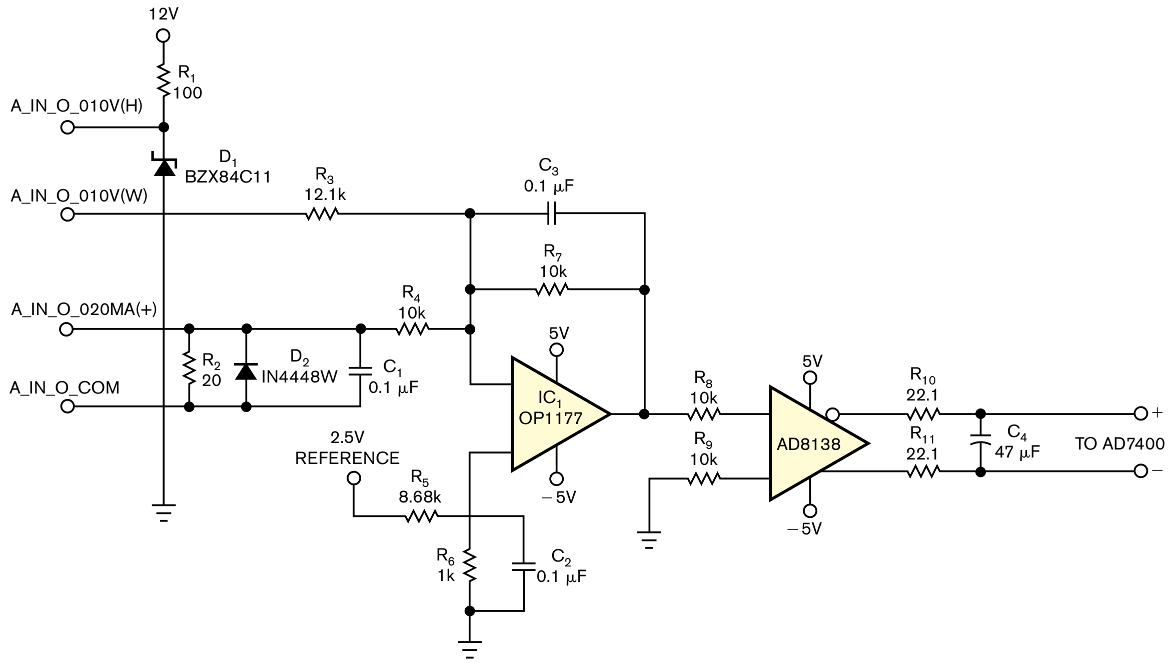

Figure 1 This analog-conditioning circuit filters and level-shifts the input signals, developing the AD7400 ADC's differential input.

nal and gets summed into the negative terminal of the Analog Devices OP1177 amplifier, IC_1.

Shifting the signal above 0V results in a signal that is similar to a positive, single-ended analog signal. A differential ADC-driver amplifier, Analog Devices' AD8138, drives the AD7400. The gain scales such that the resultant signal is within ±200 mV, which the ADC requires. Finally, before connecting to the AD7400, the signal runs through a lowpass filter, which R_{10}, R_{11}, and C_4 create between the positive and the negative terminals. The AD7400 converts this differential signal and processes it using a low-cost microcontroller. Sigma-delta-modulator ADCs, such as the AD7400, commonly interface to an FPGA or a DSP. However, this approach comes at a high price in both cost and complexity. For cost-sensitive applications not requiring advanced filtering, you can use a simple microcontroller.

The AD7400 device has two outputs, MCLKOUT and MDAT (**Figure 2**). MCLKOUT, a 10-MHz clock, synchronizes the modulated data stream, MDAT. The AD7400 interprets MDAT as a percentage of ones over time. Because MDAT changes

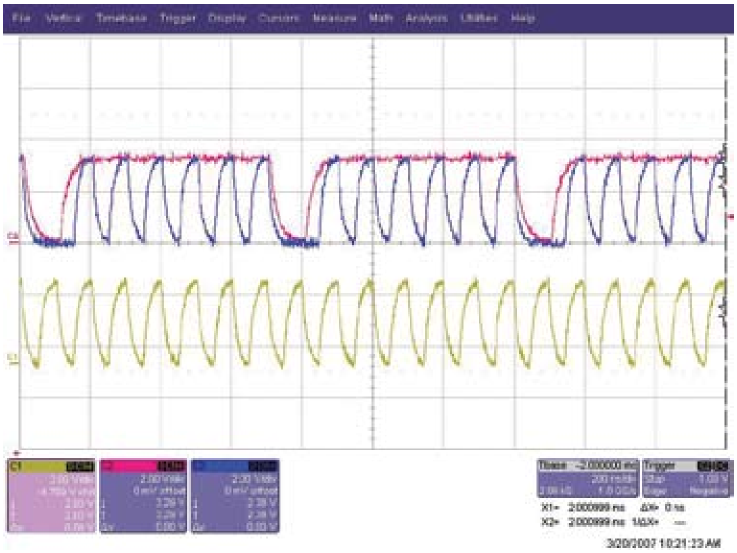

Figure 2 These oscilloscope traces show MDAT, inverted MCLKOUT, and the resulting data stream (courtesy LeCroy).

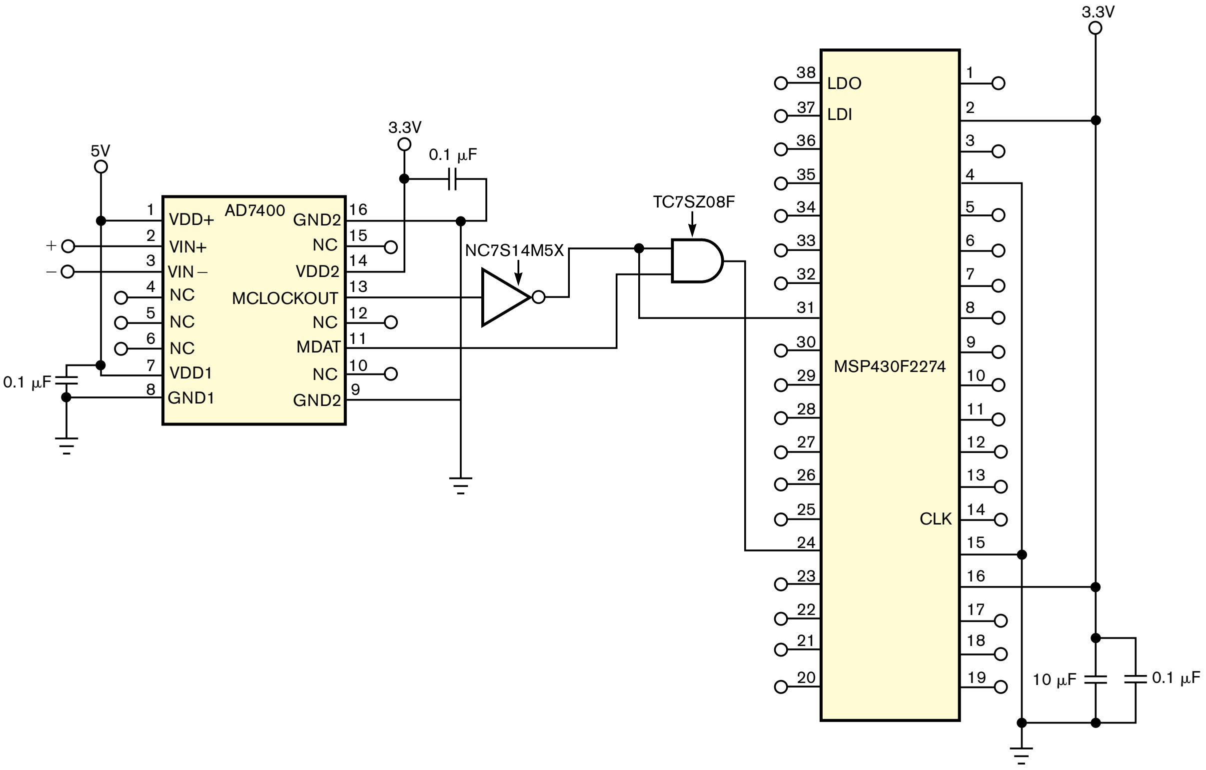

Figure 3 The AD7400 serial ADC digitizes the analog input and feeds the simple, low-cost microcontroller.

only at the rising edge of MCLKOUT, the circuit must AND together MDAT and MCLKOUT to create a stream of pulses that the microcontroller can count. The microcontroller first inverts MCLKOUT to prevent unintentional glitches from being counted at the transition edges of MDAT. The **figure** shows MDAT, inverted MCLKOUT, and the resulting data stream.

The pulsed data signal and the inverted MCLKOUT each feed into a separate timer/counter on the microcontroller (**Figure 3**). The TI MSP430F2274 provides two 16-bit counters and can support operation as fast as 16 MHz. The circuit measures the ADC value by sampling the data counter when the clock counter signals an overflow interrupt. For this application, running an average number of data measurements on a circular buffer may conveniently filter the data.EDN

Circuit guards amplifier outputs against overvoltage

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A universal requirement for automotive electronics is that any device with direct connections to the wiring harness must be able to withstand shorts to the battery voltage. Though brutal, this requirement is necessary for reliability and for safety. One example of the need for this protection is an audio amplifier that produces indicator noises in the automotive interior. Though operating from a voltage of 3.3 or 5V, which is lower than the battery voltage, the amplifier must be able to stand off the full battery voltage. You can also use a protection network appropriate for these amplifiers for other automotive circuits (**Figure 1**). A dual N-channel MOSFET disconnects the amplifier's outputs from the wiring harness in response to a high-voltage condition on either output. The MOSFETs, Q_{1A} and Q_{1B}, are normally on; zener diode D_4 and its bias components drive the MOSFETs' gates to approximately 11V. Dual diode D_3 provides a diode-OR connection to the dc voltage on each output, thereby producing a voltage that controls the output of shunt regulator IC_2. The circuitry protects IC_1, a 1.4W Class AB amplifier suitable for audible warnings and indications for the automotive electronics.

During normal operation, the amplifier outputs' dc components are at

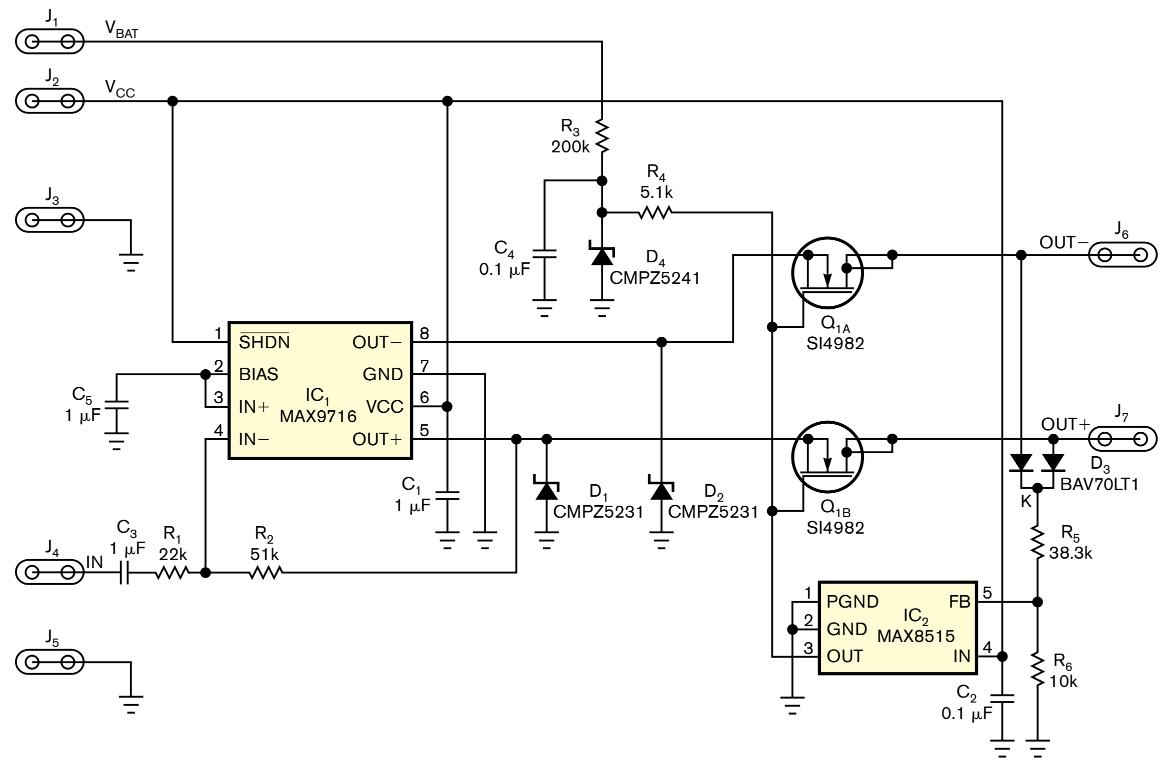

Figure 1 This output-protection circuit provides continuous protection against overvoltage faults.

one-half of the V_{CC} supply—2.5V in this case, for which V_{CC} is 5V. The 11V gate drive fully enhances the MOSFETs, and the shunt-regulator output is off because its feedback input, Pin 5, is below its internal 0.6V threshold. If either output exceeds 5V, current flows through D_3 into the R_5/R_6 divider, pulling the feedback terminal above its threshold. The shunt-regulator output then pulls the MOSFET-gate voltage from 11V almost to ground, which blocks high voltage from the amplifier by turning off the MOSFETs. The MOSFETs easily withstand the continuous output voltage, and the circuit returns to normal operation when you remove the short. Because the circuit does not respond instantaneously, zener diodes D_1 and D_2 provide protection at the beginning of a fault condition.

The waveforms of **Figure 2** represent an operating circuit. One of the amplifier's outputs (Trace 1) is a 1-kHz sine wave biased at a dc voltage of 2.5V. Trace 2 is the signal on the wire harness. It also starts as a 1-kHz sine wave biased at a 2.5V-dc voltage, but, at 200 µsec, it shorts to an 18V supply. Trace 3 is the shunt regulator's output, initially biased at 11V but pulled to ground in response to the overvoltage condition. Trace 4 is current in the wire harness. Initially a sine wave, this current drops to zero in response to the overvoltage condition.

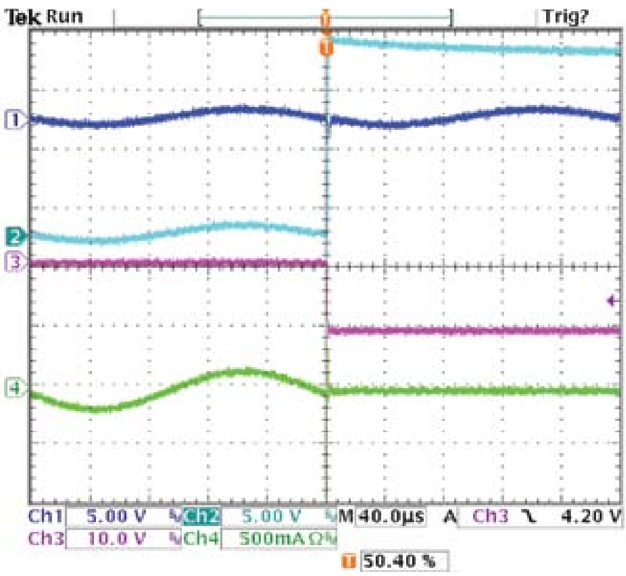

Figure 2 In Figure 1, one of IC_1's two audio outputs (Trace 1) has protection when its external terminal accidentally contacts an 18V supply voltage (Trace 2).

The components in **Figure 1** optimize this circuit for 5V operation. For other voltages, you can adjust the R_5/R_6 resistor values. The shunt regulator must be able to function in saturation and, therefore, requires a separate supply pin in addition to the shunt output pin. The circuit repeatedly withstands 28V shorts without damage.**EDN**

Isolated circuit monitors ac line

David Williams, Millington, MI

The circuit in **Figure 1** provides a low-cost, isolated ac-line monitor that measures ac-line-voltage level and has some other unique capabilities. The analysis of the circuit is straightforward: When the ac input, V_{IN}, is positive relative to neutral, you apply it to the network comprising R_1, R_2, D_1, and the LED in optocoupler IC_1. Current flows in this network when the voltage is high enough to get zener diode D_1 and the diode in the optocoupler to conduct. This diode pair's conducting voltage is the enable voltage, V_E. The zener diode's reverse-breakdown voltage of 47V and the optocoupler's LED forward voltage of 1.2V make the enable voltage 48.2V. Any voltage below this level drives the output of the optocoupler high. When the voltage exceeds the enable voltage, the transistor in the optocoupler becomes saturated, pulling the output low. The output continues to stay low until the input voltage drops below the enable voltage.

The resulting output is a square wave with a fixed time, t_{TOTAL}, based on how long the input voltage is above the enable voltage. If the voltage on the input varies from 120 to 144V, the resulting square-wave waveform becomes wider; if the voltage varies downward, the pulse width decreases. To calculate the formula for this circuit, consider the input waveform as a cosine function. Because the input voltage peaks at time zero, the optocoupler circuit is on, and the output voltage is low. It continues to be low until the input voltage moves below the enable voltage. The following **equation** yields the time when this crossover happens:

$$V_E=V_{IN}\times\cos(2\times\pi\times f\times t_{ON}).$$

Because the cosine function is symmetrical around zero, time t_{ON} is half the total time that the output pulse is high. Because a microprocessor's timer port usually captures the time, the simplest way to calculate the input voltage from the pulse width is to replace the on-time with the total time and then to solve the equation for the input voltage, which gives the result as a function of the measured pulse-width output from the optocoupler:

$$V_{IN}=\frac{V_E}{\cos(\pi\times f\times t_{TOTAL})}.$$

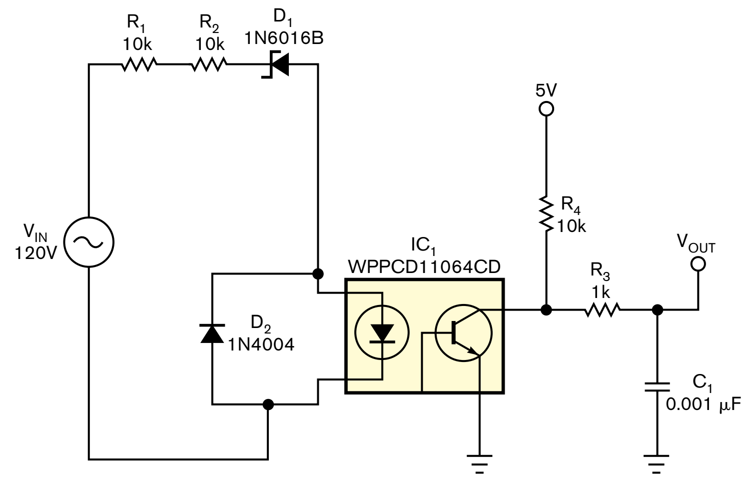

Figure 1 This simple ac-mains voltage monitor's output is a square wave whose width is proportional to the input-voltage level.

You can implement this formula in software or a look-up table that converts pulse width to input voltage. Take note that the input voltage is the peak ac voltage, so you must convert it to the rms value if necessary. You can also use this circuit as a clock line because the output frequency is independent of the duty cycle. The output is consistently 60 Hz, and you can use it for timekeeping. You can also potentially use it for zero-crossing-load driving if you extrapolate the time back to the zero crossing based on the input voltage, because the duty-cycle edge timeshifts from the real zero crossing.

Some other design principles in this circuit require attention. D_2 protects the diode in the optocoupler when the ac input goes negative. In most cases, the optocoupler diode is unaffected because the reverse leakage through the network ensures that the LED does not exceed its maximum reverse voltage. However, bypassing the diode is the best approach for clamping the voltage across this optocoupler using a diode. Adding this diode does more than double the quiescent current in the circuit, and, because you apply this current to the ac line, it may be a concern for both energy consumption and power dissipation in the resistors in the input circuit.

If you need a more accurate estimation of input voltage, some options improve circuit function. The main source of this variation is the 5% tolerance on the zener voltage. A 5% variation on this voltage can result in a significant error in your estimate of the input-voltage amplitude. Specifying a more precise diode or calibrating each board by applying a known input voltage and storing that value in memory as a fixed calibration improve the overall accuracy of this circuit.EDN

I^2C interface has galvanic isolation, wired-OR capability, improved noise margin

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This Design Idea describes a simple and effective way to provide optoisolation for devices connected on the I^2C bus (**Figure 1**). It improves on an earlier version (**Reference 1**). SDA and SCL are on the bus master's side of the I^2C bus; SDA_1 and SCL_1 are on the slave device's side. It is fairly easy to optoisolate the clock line because it is unidirectional, from the master to the slave device. A P-channel MOSFET, Q_3, provides the current for the LED of the fast optocoupler, IC_2, buffering the clock line.

The data line, however, is bidirectional. This section of the circuit is symmetrical. Resistors R_6 and R_7 are the I^2C pullup resistors on the slave device's side of the bus, and R_3 and R_1 are dummy pullups in parallel with the main I^2C pullup resistors on the SDA/SCL side. If both SDA and SDA_1 lines are high—that is, no I^2C devices are pulling them down—Q_1 is off, no current flows into the LED of optocoupler IC_2, IC_2's Pin 7 is high, Q_2 is off, and the LED of optocoupler IC_1 is also off.

THE LED OF IC_1 DOES NOT TURN ON BECAUSE THE VOLTAGE APPLIED ACROSS IT IS BELOW ITS THRESHOLD.

If a device drives the SDA line low, Q_1 and the LED of IC_2 turn off, driving IC_2's Pin 7 low; diode D_2 then starts to conduct. The result is a low level on the SDA_1 line—the low output voltage of IC_2 plus the threshold voltage of Schottky barrier diode D_2. In this situation, it is important to notice that the LED of IC_1 does not turn on because the voltage applied across it is below its threshold. This situation means that the circuit does not latch, and it can recover from this state once you release the SDA line.

Q_3 and the PNP BJT (bipolar-junction transistor), Q_1, effectively buffer the two SDA/SCL lines so that no extra current flows into the open-collector and -drain stages of the I^2C

devices that connect to the bus when they hold the lines down. This configuration allows the optoisolated interface to repeatedly pull low, providing wired-OR capability. Using Schottky barrier diodes for D_1 and D_2 rather than common diodes reduces the low-level voltage on the bus, improving the noise margin. Finally, because of the low propagation-delay times of the Fairchild Semiconductor (www.fairchildsemi.com) HCPL06XX devices that this design uses, this interface has no bus-glitch problems and works well at speeds of 400 kHz or higher (**Reference 2**).EDN

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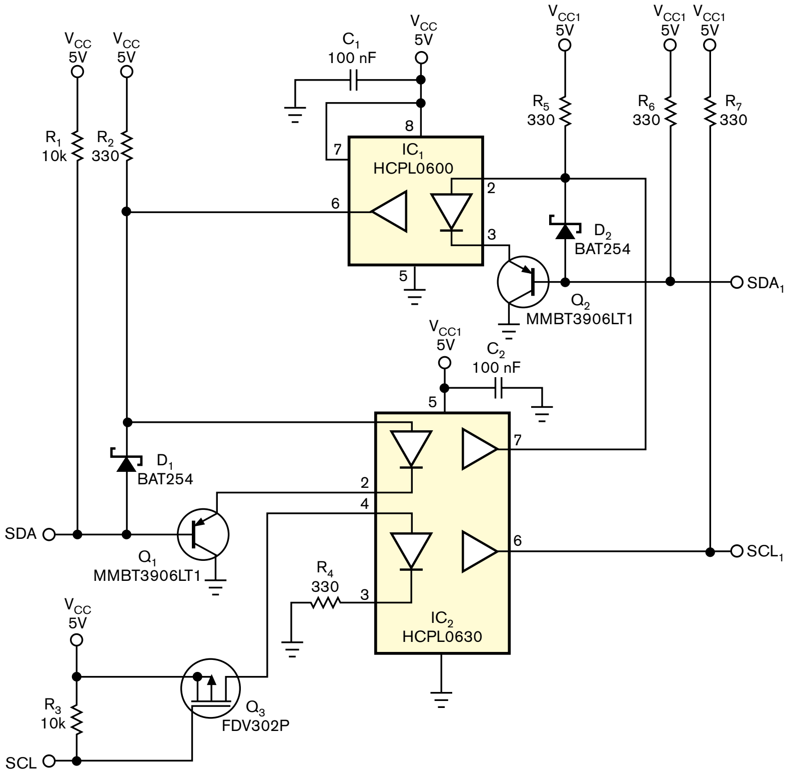

Figure 1 This circuit provides an isolated, bidirectional, wired-OR connection of slave devices to the I²C-bus master.