design ideas

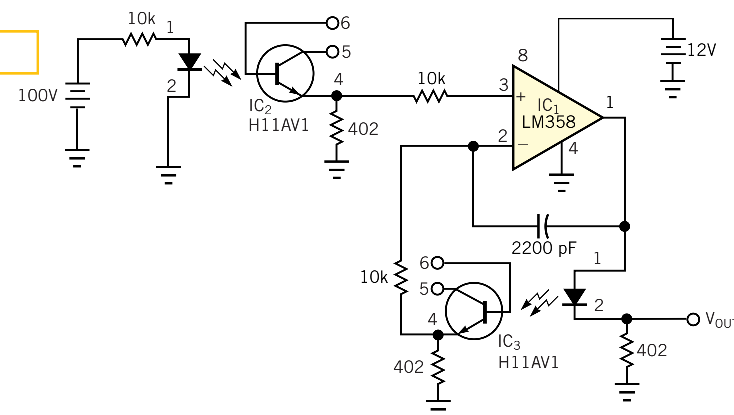
Edited by Bill Travis

Circuit compensates optocoupler temperature coefficient

J Michael Zias, Acme Electric Corp, Cuba, NY

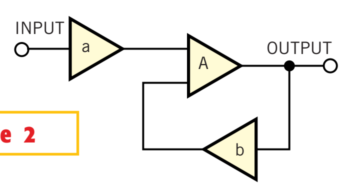
When using an optocoupler in a linear application, you should consider its gain drift with temperature. Traditional single- and dual-transistor-output devices have a notable gain drift with temperature. In recent years, some temperature-compensated optocouplers have appeared. However, another option is to use two optocouplers or a dual optocoupler with appropriate feedback to make the drift of one device cancel the drift of the other. The circuit in **Figure 1** accomplishes that task by using a differential amplifier with the drift treated as a common-mode signal. In operation, it is interesting to apply a dc signal to the input and use digital voltmeters to simultaneously monitor the output of each optocoupler and the differential amplifier. Apply a heat gun and observe the individual outputs change rapidly while the amplifier output moves much more slowly. This result occurs even with optocouplers from different manufacturers. With optocouplers of the same type, you can observe good drift cancellation. Parts from the same manufacturer and dual devices give outstanding results. You can use individual optocouplers instead of dual devices to meet safety-agency spacing requirements.

Figure 1



By using two optocouplers instead of one, you can cancel temperature-dependent gain drift.

Figure 2



Control-system feedback theory explains the operation of the circuit in Figure 1.

To examine the method in control-system terms, consider **Figure 2**, which shows one amplifier, a, in the forward path and another amplifier, b, in the feedback path. Also consider the following **equation**:

$$\mathrm{GAIN} = a\frac{A}{1+Ab} = \frac{a}{b}\bullet\frac{1}{1+\frac{1}{Ab}},$$

where a/b is the ideal closed-loop gain and is multiplied by the loop-gain error term. Given that the error term is small (from the large gain A of the op amp), the gain of the system is seen as the ratio of the gains (current-transfer ratios) of the optocouplers. You can also easily find this same ratio by setting the voltages to the op-amp inputs equal. The input and output signals for this analysis are currents, which precision resistors translate to voltages. The optocouplers in this design are not particularly fast devices, so the phase delays could cause oscillation without a feedback capacitor. You choose its value empirically by applying a pulse at the input and observing the rise time and overshoot at the output.

Is this the best Design Idea in this issue? Vote at www.ednmag.com.

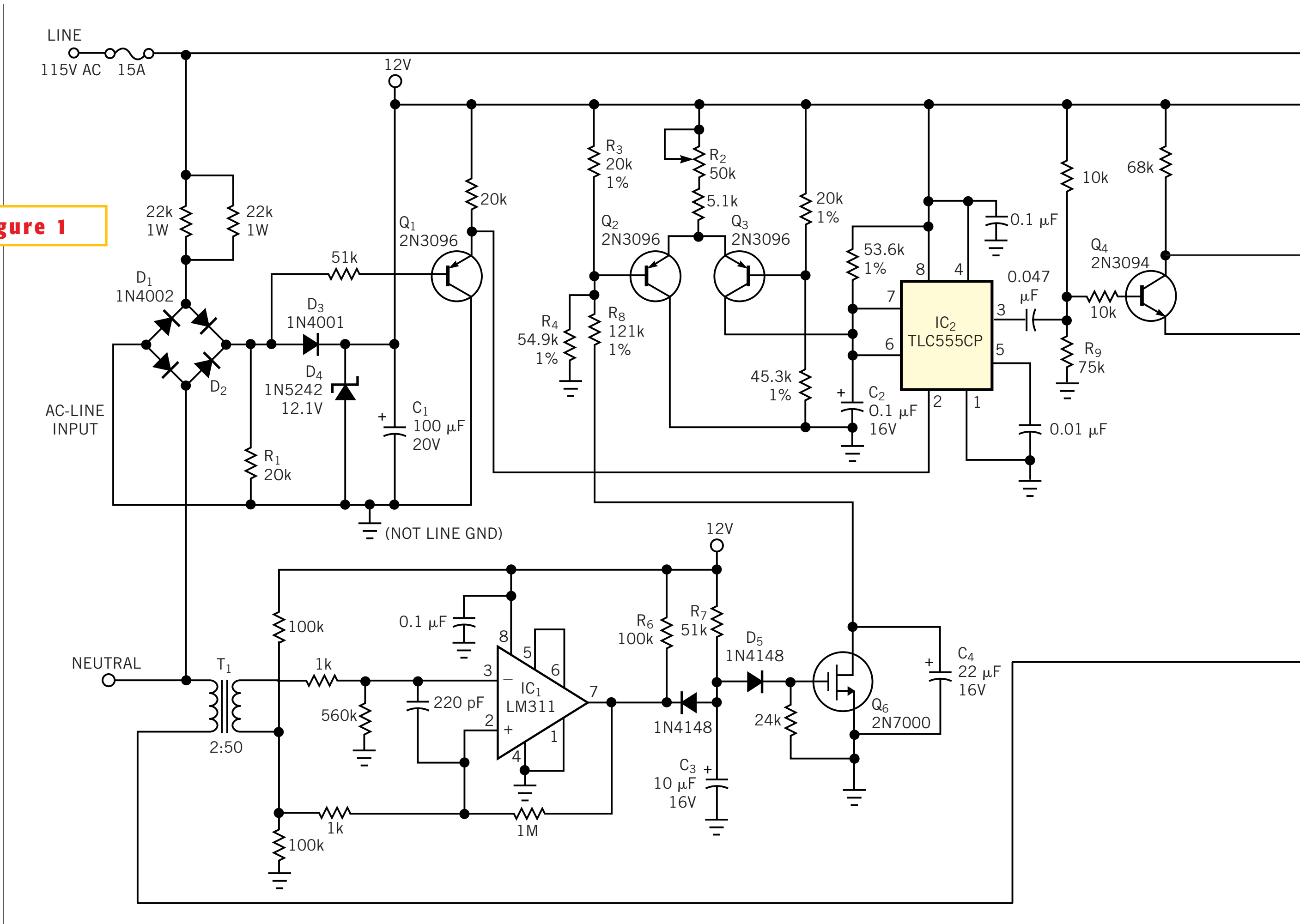
Soft-start controller is gentle on loads

Douglas Sudjian, Resonext Communications Inc, San Jose, CA

The control circuit in **Figure 1** senses a given load and automatically soft-starts the load by synchronously adjusting the power to that load. You can also manually adjust the power delivered to the load by controlling the phase angle of the line voltage across the load. The phase-angle adjustment for every ac half cycle covers 0 to 180°. When the isolation transformer, T_1, senses the load current in the ac ground return, IC_1's output changes state, driving the signal diode, D_5, into and out of conduction. R_6, R_7, and C_3 create a delay such that the voltage at Q_6's gate decays slowly to allow for the load's switch-closure noise or missed ac cycles. Once Q_6 turns off, the voltage at the base of Q_2 rises to a higher reference level, which voltage divider R_3 and R_4 sets. The bias current of transistor pair Q_2 and Q_3 slowly passes through Q_3 as the differential input voltage across Q_2 and Q_3 changes according to the time constant of R_8 and C_4. The additional current that Q_3 sources to C_2 increases the voltage rate of change at pins 6 and 7 of IC_2. IC_2, a TLC555CP, is a low-power timer configured as a monostable multivibrator.

In the monostable mode, the timer issues a positive pulse output every time a negative-going trigger pulse arrives at Pin 2 of IC_2. The output pulse width corre-

Figure 1



This soft-start circuit protects the load from large inrush currents.

sponds to the time it takes the voltage on capacitor C_2 to ramp from 0V to 2/3 V_{CC}. With a constant current essentially charging C_2, the charging is linear, and the output at IC_2's Pin 3 is proportional to the current set by R_2. The full-wave bridge, with D_3 and D_4 and filter capacitor C_1, forms a dc power supply for the timer/controller. The common cathode node for D_1 and D_2 pulls to ground via R_1 every time the line voltage approaches 0V. Q_1 turns on and supplies a negative-going trigger to Pin 2 of

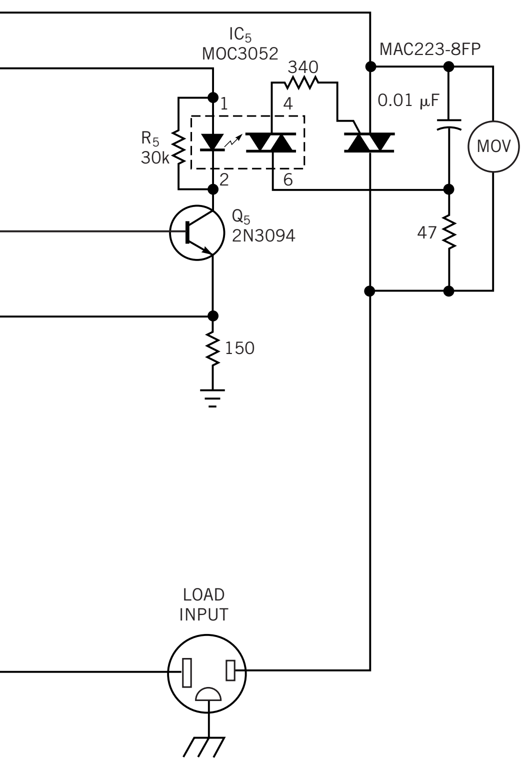
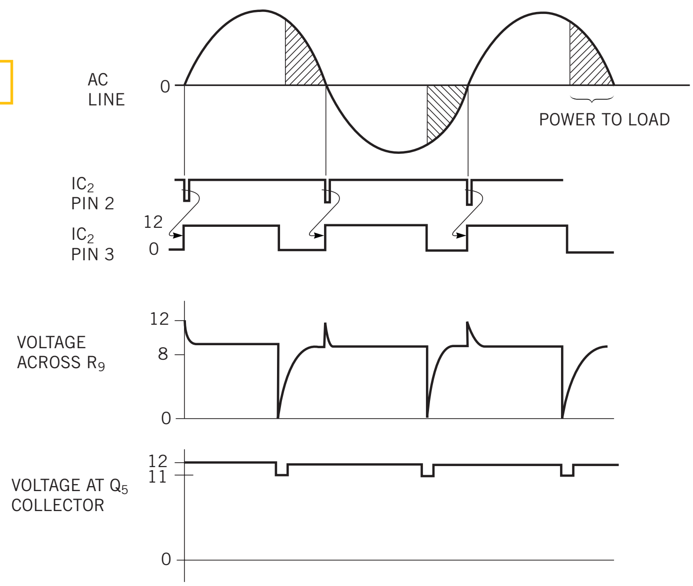


Figure 2



The circuit in Figure 1 provides soft-starting by adjusting the phase angle of the power applied to the load.

IC_2. This pulse uses its negative edge to provide a minimum pulse width of 200 µsec to the base of Q_4. The feedback pair Q_4 and Q_5 provides signal inversion and limits the current drawn from the 12V supply rail through IC_3. When sufficient LED current develops, the MOC3052 triac driver latches on and generates a gate current in the power triac, triggering it into the conducting state. Once the power triac latches on, the triac driver enters its off state, even if the LED current still exists.

The power triac's gate voltage falls below the optocoupler's threshold and cannot hold the optocoupler. The longer the phase delay from the zero-crossing trigger, the smaller the conduction angle and power delivered to the load. R_5 facilitates on-off switching of the triac-driver LED by providing a path for leakage currents. Potentiometer R_2 provides variable power to the load (to provide motor-speed control, for example). R_2 varies the dc-source current that charges C_2 every ac half-cycle. Note that the signal ground with respect to earth ground is floating; you must not tie these grounds together. The design in **Figure 1** has successfully controlled fans and high-amperage universal motors (100 mA to 11A). One example is a router for woodworking. By soft-starting these high-torque motors, the reaction torque (to the input current) that the user feels disappears. Moreover, other soft-start designs need two switches. The design in **Figure 1** needs only one on-off switch (located at the load). Thus, less danger exists for incurring an accidental starting condition. **Figure 2** shows some of the waveforms associated with the circuit in **Figure 1**. T_1 is a signal transformer that you can modify by wrapping two turns of 14-gauge wire around the bobbin to act as the primary winding.

Is this the best Design Idea in this issue? Vote at www.ednmag.com.

Method offers fail-safe variable-reluctance sensors

Phil Levya, Maxim Integrated Products, Sunnyvale, CA

Variable-reluctance sensors are preferred for industrial and automotive environments, because they sustain mechanical vibration and operation to 300°C. In most applications, they sense a steel target that is part of a rotating assembly. Because the unprocessed signal amplitude is proportional to target speed, a sensor whose signal-processing circuitry is designed for high speed ceases to function at some lower rate of rotation. Hall-effect sensors are preferable for speeds of several pulses per second, but they require the attachment of a magnet to the rotating assembly. They're thus prone to failure when the magnet is broken or damaged. Neither variable-reluctance nor Hall-effect sensors offers fail-safe detection of the processed signal in the event of failure in the cable or sensor. The circuit in **Figure 1** is a fail-safe variable-reluctance sensor for low- to medium-speed operation.

The circuit comprises L_1; R_1; and a quad RS-422/RS-485 receiver, IC_1. It provides the complementary, independent output signals V_{OUT} and $\overline{V_{OUT}}$. **Table 1** lists the resulting fail-safe modes. The supply voltage can be 10V, 12V, or the control system's 24V-dc source. Coil L_1 consists of 2600 turns of #32 magnet wire wound on a 0.8-in. steel bar of 0.2-in. diameter, with 0.125 in. protruding from the sensor face. A magnet attached to the back of the steel bar supplies the necessary magnetic flux. The rotating target causes a change in reluctance and, hence, a change in the amount of magnetic flux conducted. This change produces a corresponding change in the current induced in L_1. R_1 converts the L_1 current to a time-varying voltage. This voltage goes to the inputs of IC_1, whose input-voltage range of ±25V, input threshold of ±0.2V, and typical input hysteresis of 45 mV enable the VR sensor to operate at low speeds.

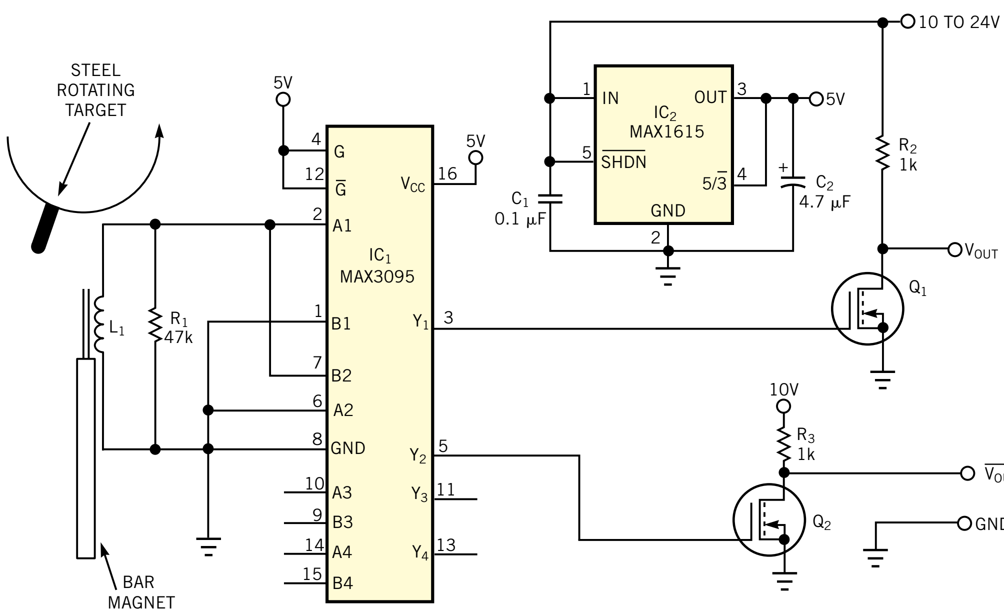
The separate, complementary outputs come from separate, ESD-protected in-

TABLE 1—FAIL-SAFE MODES (TWO CYCLES OF V_{OUT} OR $\overline{V_{OUT}}$)

(V_{OUT}, $\overline{V_{OUT}}$)	Mode
(1,0) then (0,1) or (0,1) then (1,0)	Normal mode, both pulses valid
(1,0) then (0,0) or (0,0) then (1,0)	Failure, valid $\overline{V_{OUT}}$ pulse, V_{OUT} failure, cable failure, or partial sensor failure*
(0,1) then (0,0) or (0,0) then (0,1)	Failure, valid $\overline{V_{OUT}}$ pulse, V_{OUT} failure, cable failure, or partial sensor failure*
Always (1,1)	Short-circuited cables or failure in IC_1
Always (0,0)	Severed cables, failure in IC_1 or failure in Q_1 and Q_2

*System remains functional in failure modes.

Figure 1



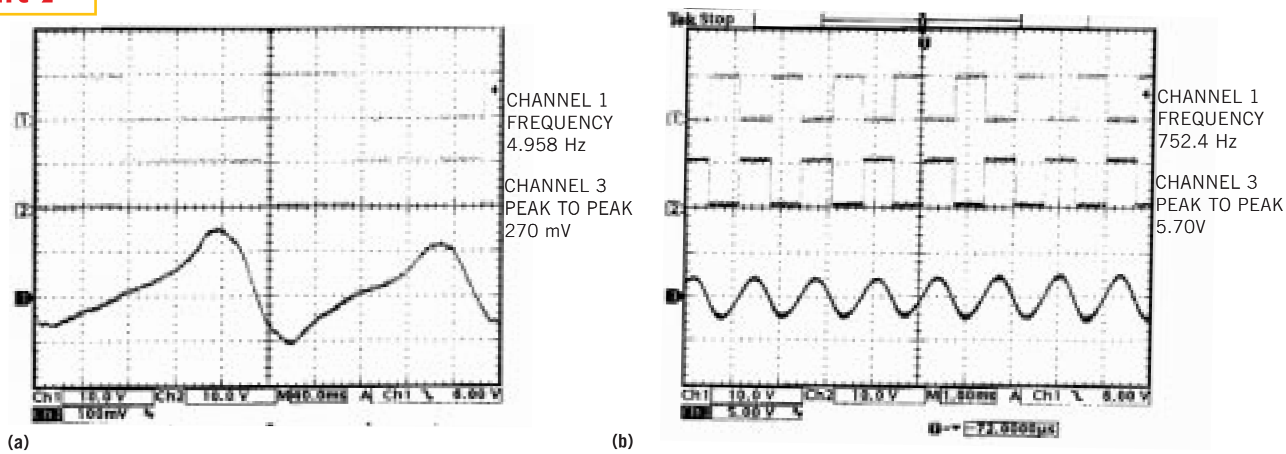
NOTE: Q_1, Q_2 = FAIRCHILD FDV303N.

This circuit provides a fail-safe, low- to medium-speed variable-reluctance sensor.

puts. IC_1's outputs Y_1 and Y_2 can source as much as 10 mA. They alternately switch the logic-level, n-channel MOSFETs Q_1 and Q_2, which in turn provide V_{OUT} and $\overline{V_{OUT}}$. A low-dropout regulator, IC_2, provides the 5V power source for IC_1. **Figure 2** illustrates low- (**Figure 2a**) and medium-speed (**Figure 2b**) operation for the sensor. For 5V-supply applications in which you can locate a microcontroller close to the sensor, you need only L_1, R_1, and IC_1 for a direct interface. For 3V applications, replace IC_1 with a MAX3096 IC.

Is this the best Design Idea in this issue? Vote at www.ednmag.com.

Figure 2



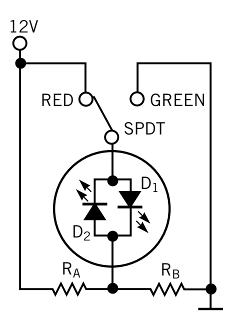
These waveforms represent operation at 4.9 Hz at 2.4 revolutions/sec (a) and 752.4 Hz at 376.2 revolutions/sec (b). Channel 1 is V_{OUT}, Channel 2 is $\overline{V_{OUT}}$, and Channel 3 is the voltage across R_1.

Circuit efficiently switches bipolar LED

Spehro Pefhany, Trexon Inc, Toronto, ON, Canada

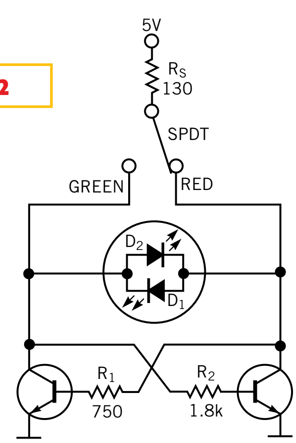
The circuit in **Figure 1** represents one method to switch a bipolar, two-color LED using an SPDT mechanical switch or relay. This circuit wastes power and does not work properly if the power-supply voltage is not substantially more than the sum of the LEDs' forward voltages. The circuit is, therefore, marginal, to the point of being unusable, with a 5V supply and a red or green LED, which typically has a total forward voltage of 4V. You can use a circuit resembling a flip-flop (**Figure 2**) that doesn't suffer the disadvantages of the circuit in **Figure 1**. It adds only one $V_{CE(SAT)}$ voltage to the V_F of each LED, so plenty of headroom exists with a 5V supply and a series resistor to control the LEDs' current. The circuit in **Figure 2** costs less than a dime for the parts, which include three resistors and two inexpensive, general-purpose npn transistors, such as the 2N4401 or the C8050. In this

Figure 1



This switching circuit wastes power and does not work with low supply voltages.

Figure 2



In this "flip-flop" switch, the only losses come from the $V_{CE(SAT)}$ and the base currents of the transistors.

example, D_1 is red (V_{F1}=1.6V), and D_2 is green (V_{F2}=2.4V). Based on D_2, the green LED, you can calculate that R_S=(5V−2.4V−0.1V)/0.02A=125Ω (use 130Ω for 19 mA).

As a result, using a single resistor, D_1 has a current of 25 mA. If it is desirable to have equal or arbitrarily different currents, you can insert an additional resistor in one leg of the switch to increase the effective R_S for that switch position. The base drive is a function of the V_F of the driven LED, so you can calculate the base resistors, using a forced beta of 20, as follows:

R_1=20(V_{F1}−0.7V)/I_{LED1}=720Ω (use 750Ω).

R_2=20(V_{F2}−0.7V)/I_{LED2}=1.8 kΩ.

The base drive reduces the actual LED current by 5%, which is visually negligible. As a bonus, the circuit does not introduce any switching glitches into the power supply. The circuit requires only two connections, rendering it ideal for front-panel use. Because the 130Ω resistor is in series with the power supply, any part of the circuit beyond R_S can short to ground without causing damage.

Is this the best Design Idea in this issue? Vote at www.ednmag.com.

Circuit forms adjustable bipolar clamp

Pautasso Luciano, Nichelino, Italy

The easy way to clamp a signal to a given value is to use two zener diodes, connected back-to-back. This method has several disadvantages. The accuracy of the clamping depends on the tolerance of the zener diodes, and the clamping is not adjustable, except by changing diodes. The circuit in **Figure 1** is a bipolar clamper with a range of ±1 to ±10V, with the clamping level a function of the input V_{CLAMP}. IC_{1A}, IC_{1B}, and IC_{3A} are unity-gain buffers. IC_{2A} is a positive clamper, and IC_{2B} is a negative clamper. **Figure 2** shows the transfer function, with V_{CLAMP} set at −5V. You can change V_{CLAMP} over the range of −1 to −10V and thereby change the clamping level. If V_{IN} is within $-V_{CLAMP}$ to $+V_{CLAMP}$, then V_{OUT}=V_{IN}. If V_{IN} exceeds V_{CLAMP}, then V_{OUT}=V_{CLAMP}.

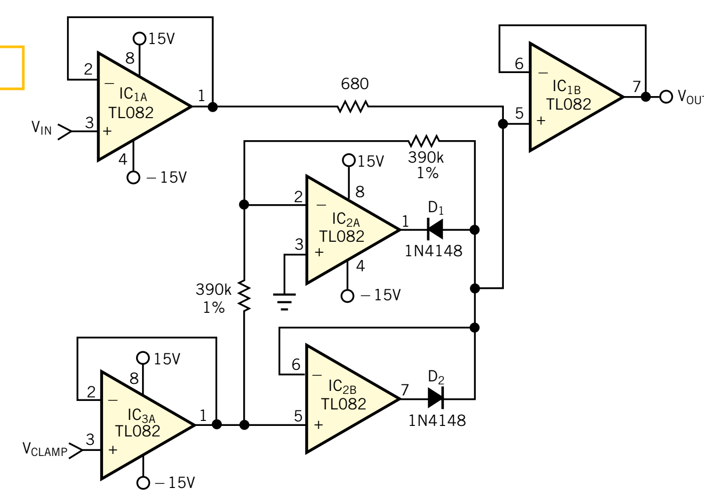
To explain how the circuit works, assume four cases, with four values of V_{IN}. Basically, the circuit works in two modes: the linear mode, in which diodes D_1 and D_2 are open switches, and the clamped mode, in which the diodes are closed switches. **Table 1** gives results for the four cases. In Case A, the input is 7V, V_{CLAMP} is −5V, D_1 conducts, and D_2 is an open switch. The feedback loop around IC_{2A} regulates the anode of D_1 to 5V and the output of IC_{2A} to 4.4V. In cases B and C, both diodes are open switches. In Case D, D_2 conducts, and D_1 is an open switch.

Is this the best Design Idea in this issue? Vote at www.ednmag.com.

TABLE 1—RESULTS FOR CLAMPED AND LINEAR MODES

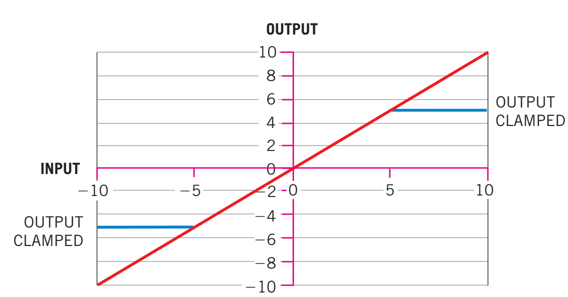
Case	V_{IN} (V)	V_{OUT} (V)	Mode
A	7	5	Clamped
B	3	3	Linear
C	−3	−3	Linear
D	−7	−5	Clamped

Figure 1



This circuit provides adjustable clamping over the range of ±1 to ±10V.

Figure 2



With V_{CLAMP} set at −5V, the output clamps firmly at ±5V.

Analog switch expands I^2C interface

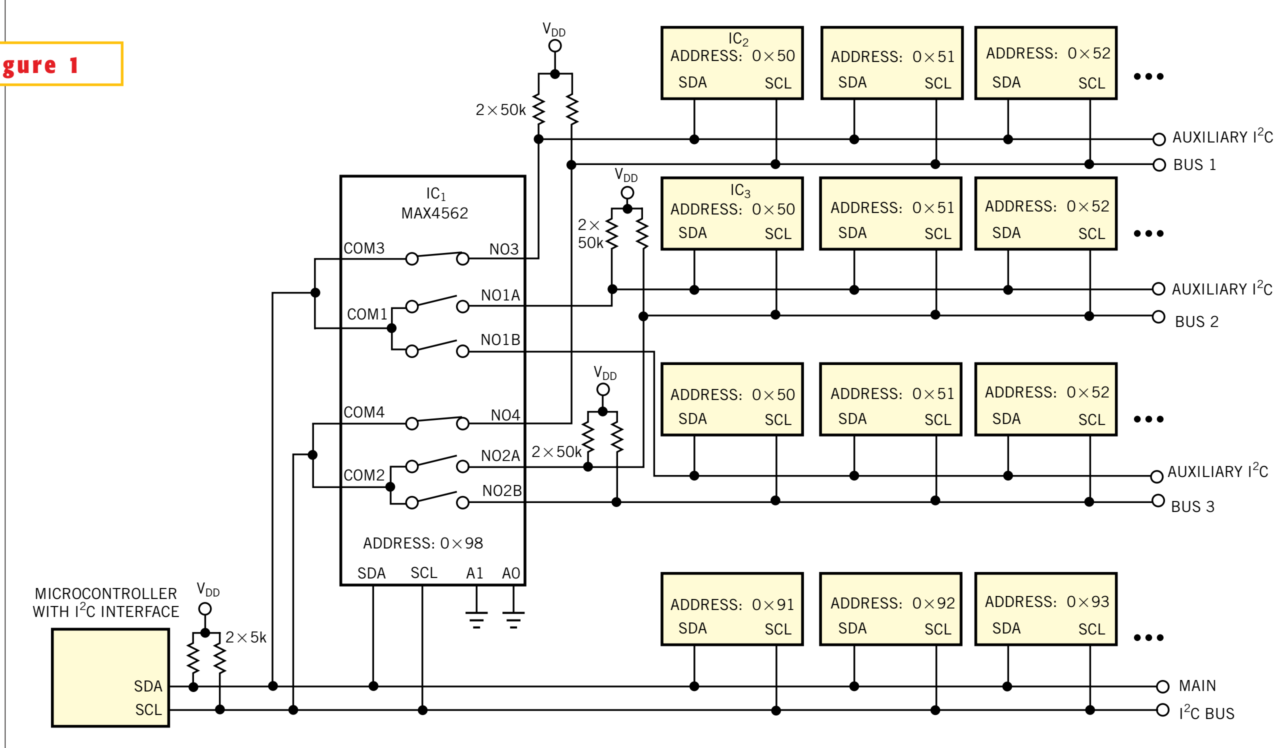
Luca Vassalli, Maxim Integrated Products, Sunnyvale, CA

PERHAPS THE MOST effective way to gain board space and increase component density is to minimize wiring on the board. A widely used architecture that allows such miniaturization is the I^2C bus. Comprising only a bidirectional data line, SDA, and a clock line, SCL, this bus requires no chip selects or other additional connections. Microcontrollers from Philips, Microchip, and other manufacturers include dedicated I^2C interfaces, but you can also implement the interface in software. To complete this task, you associate a 7-bit address with each master or slave transceiver and factory- or pin-program the device with two to four address options. An increasing number of slaves now include the I^2C interface, but some of their 128 address locations are reserved for special functions, so not all locations are available to a designer. Yet, two or more devices could have the same address in some application. In **Figure 1**, analog switch IC_1, which is I^2C-controlled, connects auxiliary branches that contain devices with the same address to the main I^2C bus. IC_2 and IC_3, for example, have the same address but are located on different auxiliary buses.

The arrangement in **Figure 1** prevents the master from addressing multiple slaves at the same time. If that situation occurs, the data becomes corrupted during a master-read protocol, and all slaves may not receive data during a master-write protocol. The analog switch accepts bidirectional signals as required for the SDA line. The switch has low on-state resistance, adds almost no leakage on the lines, and provides four selectable slave addresses. You simultaneously control the switches by using the simple Send-Byte protocol (address plus 8-bit command). You can switch the three auxiliary buses on the fly. Power-up sets the switches to soft mode, an off state with 12-msec switching time. Then, a command byte of 0b11000000 sets the switches to hard mode (400-nsec switching time). Subsequent commands select the desired auxiliary bus. Command 0b1000011, for example, selects auxiliary bus 1. The main I^2C bus includes necessary pullup resistors, and the auxiliary buses include weaker pullups that ensure a high state when you deselect the bus. The circuit in **Figure 1** allows you to add three times more devices on the bus. For a wider selection, you can replace the MAX4562 with a MAX4572, whose 14 switches allow you add as many as seven auxiliary buses.

Is this the best Design Idea in this issue? Vote at www.ednmag.com.

Figure 1



This I^2C-controlled analog switch expands by three the number of devices connected to the bus.

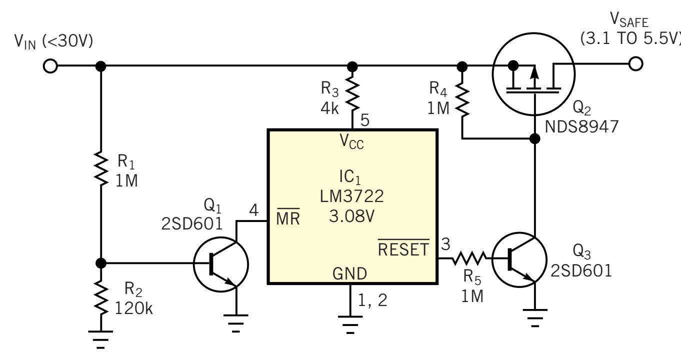
Circuit safely applies power to ICs

Clayton Grantham, National Semiconductor, Tucson, AZ

Supervisory circuits normally monitor a microprocessor's supply voltage, asserting reset to the IC during power-up, power-down, and brownout. In this way, the circuit ensures that the supply voltage is stable before the microprocessor boots, thus preventing code-execution errors. Many analog and digital ICs also need a well-behaved start-up of their supply to avoid latch-up and logic-state errors. In addition to low-supply conditions, low-voltage CMOS circuits need overvoltage protection from any supply runaway. The additional components in **Figure 1** extend IC_1's supervisory functions to connect V_{IN} to V_{SAFE} only when V_{IN} is within set limits. This function protects circuitry at the V_{SAFE} terminal from power-up transients and overvoltage damage. As a supervisory circuit, IC_1 asserts a reset signal that is delayed by more than 100 msec whenever V_{IN} decreases below the precisely trimmed reset threshold. You can custom-select the reset threshold from 2.32 to 4.63V. You can also use a manual input, $\overline{MR}$, to assert the reset signal.

This application uses IC_1's delayed reset signal to control switch Q_2. The delay ensures that V_{IN} is stable before application to V_{SAFE}. Q_3 inverts and isolates IC_1's reset signal to control the gate of Q_2. R_4 is Q_2's pullup resistor; R_5 limits Q_3's base current. Using Q_1 as an inexpensive 0.6V switch, resistor dividers R_1 and R_2 set the overvoltage threshold according to the equation $V_{OV} = V_{BE1}(R_1+R_2)/R_2$. An internal 22-kΩ resistor at IC_1's $\overline{MR}$ input provides Q_2's pullup. Typical V_{BE1} accuracy and temperature-coefficient errors are ±10% and −2 mV/°C, respectively. Adjustment of R_2 for an exact overvoltage value nullifies V_{BE1}'s accuracy error. **Table 1** shows typical setpoints over temperature. If you need further error reduction, you could exchange Q_2 for a comparator and voltage reference. For V_{IN} within the set limits, 3.1 to 5.5V, the circuit draws only 16 μA. A total of 5 μA flows into both the R_1 and R_4 nodes, and 6 μA flows into R_3's node. R_3 protects IC_1 by providing current limiting of less than 6 mA) for high voltages at V_{IN}. The typical IC_1 current of 6 μA through R_3 increases the undervoltage setpoint by 24 mV.

Figure 1



This LM3722 configuration connects only safe voltages to sensitive ICs.

TABLE 1—V_{SAFE} HYSTERESIS OVER TEMPERATURE

V_{SAFE}		0°C	25°C	50°C
On (V)	V_{IN} increasing	3.2	3.2	3.2
Off (V)	V_{IN} increasing	6.1	5.5	4.9
On (V)	V_{IN} decreasing	6	5.4	4.8
On (V)	V_{IN} decreasing	3.1	3.1	3.1

Is this the best Design Idea in this issue? Vote at www.ednmag.com.

Simple circuit forms peak/clipping indicator

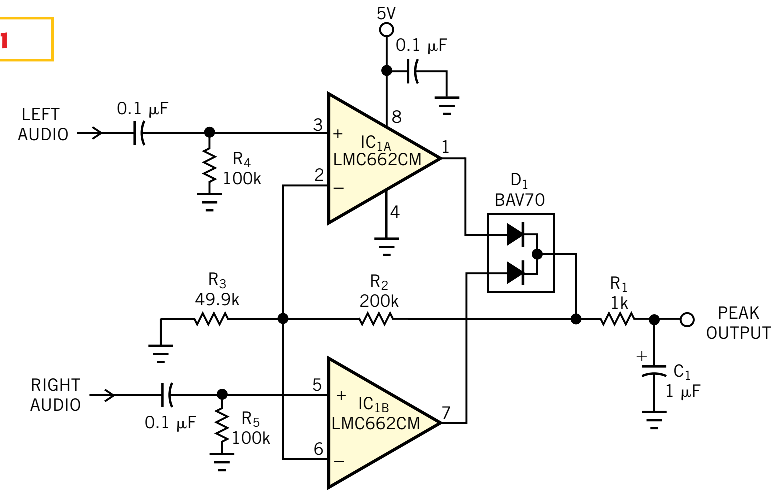
Steven Hageman, Agilent Technologies, Santa Rosa, CA

The simple peak detector in **Figure 1** is the result of a need for a single-5V-supply, level/clipping indicator for a multimedia-PC sound system. The design is unique in that it detects both stereo channels on a single peak-hold capacitor. All the adjustments in the circuit simultaneously apply to both left and right stereo inputs. The output is suitable for driving a bar-graph display or for analog-to-digital conversion and display with a microprocessor. The circuit operates as a dual positive-peak-detector circuit. The dual diode, D_1, serves to allow positive peaks to pass while disconnecting the op amp from the hold capacitor, C_1, on negative peaks. Also, because the diodes have an OR connection, the circuit detects only the larger peak from the left or right stereo input. The values shown in **Figure 1** are for standard 200-

mV-rms line-input levels, such as those you'd find on a PC's sound-card line input. Your personal preference or exact needs might require other performance parameters, and you can easily adjust these values.

The gain for both stereo channels is equal to $1+R_2/R_3$. The circuit as shown has a gain of 5. For a full-scale 200-mV-rms input, this gain produces an output of approximately 1.4V. This value is convenient for this application, which uses three green LEDs, two yellow LEDs, and one red LED to show the relative peak levels of the stereo channels. Nominal, full-scale line input of 200 mV rms lights two of the green LEDs. "Attack time" is the time it takes the peak detector to respond to 69% of an input-signal peak, or one time constant. The time constant R_1C_1 sets the attack time. In this circuit, the attack time is 1 msec. The decay time is the time it takes the peak to decay to 31% of its original value, or one time constant. This time equals $(R_2+R_3)C_1$ (assuming that R_1 is negligibly small compared with R_2+R_3). The decay time in this case is 250 msec, because that value produces a pleasing-looking bar-graph display. Some applications may need different response rates; you can easily obtain them by following the design equations above.

Figure 1



This simple circuit provides peak detection and clipping indication for a PC's stereo channels.

Is this the best Design Idea in this issue? Vote at www.ednmag.com.