EDITED BY CHARLES H SMALL
AND FRAN GRANVILLE

designideas
READERS SOLVE DESIGN PROBLEMS

Filter simplifies software-defined radio

John Wendler and Ray Tremblay, Tyco Electronics,
M/A-Com Wireless Systems, Lowell, MA

SDRs (software-defined radios) provide enormous flexibility, permitting you to change modes or waveforms at will. This Design Idea focuses on the "exciter" portion of a moderate-bandwidth SDR (**Figure 1**). The RF carrier or transmitter IF enters the quadrature modulator, and the modulated output exits for further frequency translation or amplification, depending on the details of the design. The DSP section generally works with analytic signals—in this case, signals with real and imaginary parts—at baseband. These signals may have started out as a voice speaking into a microphone that attaches to an ADC, or they may have started out as data from a computer. Regardless of the signals' origin, the DSP performs calculations on the stream of numbers, performing filtering, perhaps adding signaling tones or packetizing the data, and converting the stream into the final I and Q modulating signals. For moderate bandwidths, a stereo sigma-delta DAC or codec provides the conversion to analog signals and performs some additional filtering on the signal. Such filtering is often necessary because the quadrature modulator comprises a pair of mixers. These mixers translate any noise at baseband frequencies directly to the modulator's output.

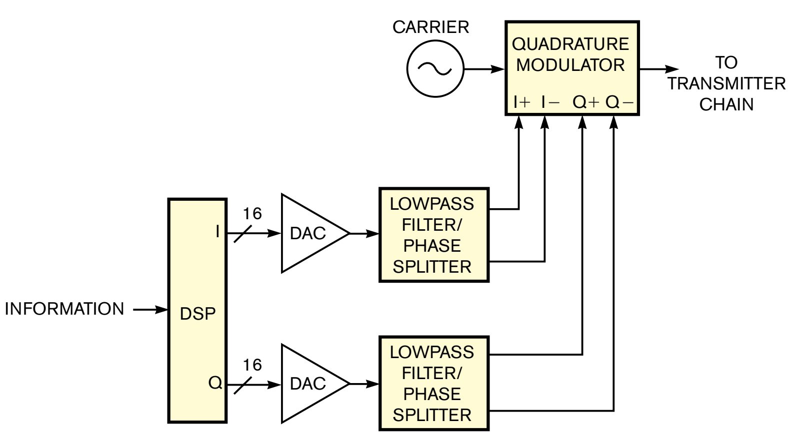

Figure 1 A pair of DACs converts the baseband signal from a DSP into I and Q signals for the quadrature modulator of a software-defined radio.

Output noise is problematic. The FCC (Federal Communications Commission) sets spectral masks or adjacent-channel-power-ratio requirements on some services, such as land mobile radio. These requirements govern the allowed spectrum of a transmission and vary according to the bandwidth of the channel and the frequency of transmission. Their function is always the same, however: They limit the interference to other users on nearby channels to the transmitter. Meeting the spectral mask is a regulatory requirement; you cannot certify a radio without proving that it meets this requirement, and, without this certification, you cannot legally sell it. **Figure 2** shows a sample spectral mask, 47 CFR 90.210 G, with a normalized X axis to show the offset from the center of the channel and a normalized Y axis to show the unmodulated carrier output. This mask applies to the 800-MHz SMRS (specialized-mobile-radio service) in which channels are 25 kHz apart but signals can occupy only 20 kHz.

The unmodulated carrier first transmits at the center of the mask, and the top of the mask adjusts to correspond with the output power of the transmitter. You then turn on the modulation, thereby spreading the spectrum. The resulting spectrum must fall below the mask line in all places.

DIs Inside

▶What are your design problems and solutions? Publish them here and receive $150! Send your Design Ideas to edndesignideas@reedbusiness.com.

A close examination of **Figure 2** shows some interesting features. On the carrier trace, the sampling-frequency spurs appear at ±19.2 kHz away from the center. The modulated spectrum is also interesting. The filter in the sigma-delta DAC causes the nearly vertical roll-off at approximately ±10 kHz. The mounds that appear around ±12 kHz and gradually roll off are spectral regrowth, which nonlinearities in the high-power amplifier cause.

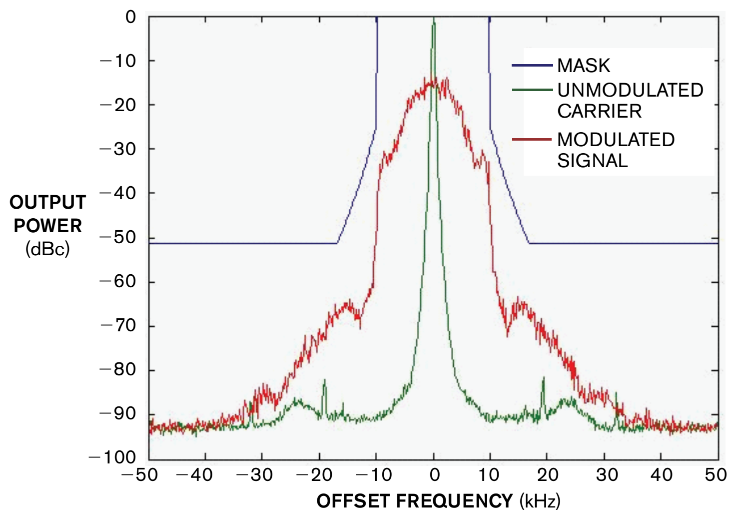

Figure 2 A sample spectral mask, 47 CFR 90.210 G, has a normalized X axis to show the offset from the center of the channel and a normalized Y axis to show the unmodulated carrier output.

Many moderate-bandwidth SDRs need a translator between the sigma-delta DAC's single-ended output and a typical balanced-input quadrature modulator. It is frequently desirable to follow up the DAC output with a hardware filter that removes the DAC's high-frequency noise and ensures compliance with spectral-mask requirements. Further complicating things, the optimal common- and differential-mode output voltages of the DAC are likely to differ from those that the modulator requires. An easy scaling factor does not relate common- and differential-mode voltages.

Handling all of these considerations with a conventional approach can require as many as four operational amplifiers with multiple filter sections per I or Q channel. The filters require close component matching to guarantee that carrier and single-sideband suppression—key measures of quadrature-modulator ideality—do not degrade as a function of baseband frequency. The Linear Technology (www.linear.com) LTC1992, on the other hand, addresses the problem in a single section. Linear shows a fully balanced approach to the problem in its data sheet (**Reference 1**).

It turns out, however, that a fully balanced approach is unnecessary. The circuit in **Figure 3** has excellent phase and amplitude balance between the output channels and eliminates some critical component-matching requirements. Pin 2 is set for the desired common-mode output voltage, and the DAC's midpoint voltage connects through an input resistor to Pin 8. Note that any mismatch between the input voltage and the midpoint voltage appears at the outputs and causes asym-

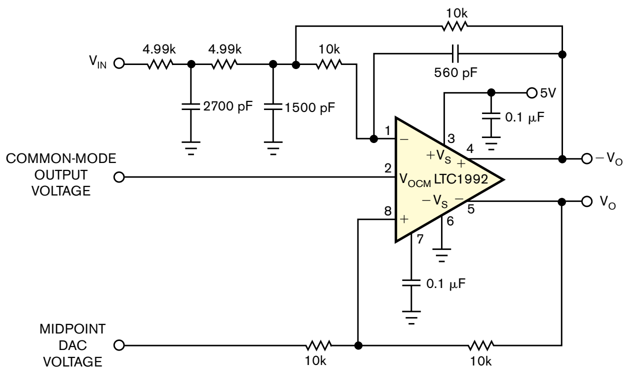

Figure 3 This circuit has excellent phase and amplitude balance between the output channels and eliminates some critical component-matching requirements.

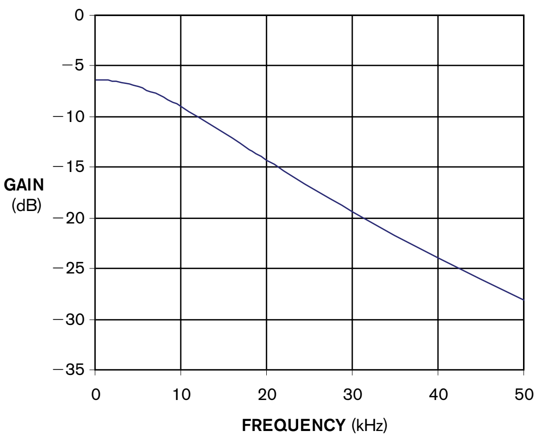

Figure 4 The measured frequency response of the positive channel with respect to ground shows an apparent 6-dB loss as a result of looking at only half the differential-output voltage; when you examine the full balanced output, the net gain is 0 dB.

metrical swing. This application bypasses Pin 7. The filter is a passive single-pole circuit cascaded with an inverting Sallen-Key filter, but other topologies are feasible.

Figure 4 shows the measured frequency response of the positive channel with respect to ground. The apparent 6-dB loss is a result of looking at only half the differential-output voltage; when you examine the full balanced output, the net gain is 0 dB. **Figure 5** shows the measured deviation from an ideal equal-amplitude, 180° phase shift between the positive and the negative outputs. The agreement in the critical 300-Hz to 3-kHz range is less than 0.1 dB and 0.1°. Even at 50 kHz, the error is less than 0.5 dB and 1°.**EDN**

REFERENCE

1 "LTC1992: Fully Differential Input/Output Amplifier/Driver," Linear Technology, July 2003, www.linear.com/pc/downloadDocument.do?navId=H0,C1,C1154,C1009,C1126,P2348,D3455.

ACKNOWLEDGMENT

The authors gratefully acknowledge the assembly assistance of Deb Girard.

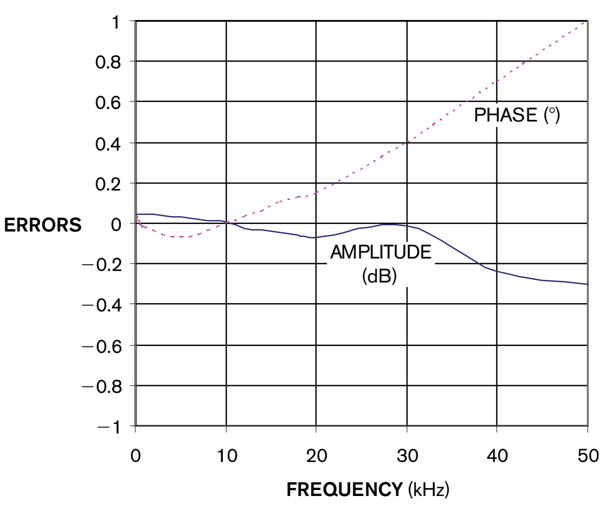

Figure 5 The measured deviation from an ideal equal-amplitude, 180° phase shift between the positive and the negative outputs shows agreement of less than 0.1 dB and 0.1° between 300 Hz and 3 kHz.

Thermoelectric-cooler unipolar drive achieves stable temperatures

W Stephen Woodward, Chapel Hill, NC

Most engineers know about the solid-state refrigerators called Peltier devices or, more commonly, TECs (thermoelectric coolers) and how they can actively cool temperature-sensitive electronic components, such as optical detectors and solid-state lasers. It's also common knowledge—although perhaps less so—that TECs are bidirectional heat pumps and can therefore both heat and cool, depending on the direction of the supplied drive current. TECs can therefore serve as the basis for precision microthermostats, maintaining a predetermined temperature against ambient-temperature excursions that range both above and below the setpoint.

The rub is that bidirectional-TEC drive tends to be an inconvenient design problem. It requires either dual bipolar power supplies or relatively complex H-bridge-drive output circuits involving arrays of power transistors that selectively reverse the TEC excitation as the required direction of heat flow dictates. But an alternative method offers advantages whenever simplicity matters more than efficiency. This Design Idea presents a novel approach to bidirectional-TEC-temperature control that avoids both the inconvenience of dual power supplies and the complexity of bidirectional drive. It works by exploiting a little-known quirk of all TECs: the inherent reversal of net heat flow at unconventionally high levels of drive current.

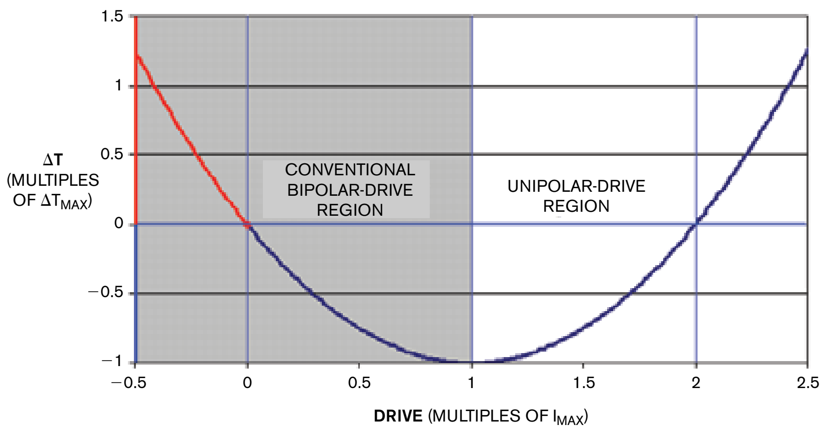

Figure 1 This plot of temperature versus maximum current shows that operating a TEC at high currents achieves heating and cooling from a unipolar drive.

The specifications of every TEC include I_{MAX}, the drive current that results in maximum net cooling. Plotting heat transfer versus drive current relative to I_{MAX} results in a typical parabolic curve (**Figure 1**). The left-hand, gray half of the plot in the **figure** shows the usual bipolar TEC's operating region, which confines drive current to the range of $-0.5\times I_{MAX}<I<I_{MAX}$. The right-hand half shows the region of interest, in which the same bipolar-temperature excursion results from unipolar-current drive: $I_{MAX}<I<2.5\times I_{MAX}$. Operation of the TEC in this second operating region thus allows bidirectional temperature control without the complexity of bidirectional-current drive.

Figure 2 shows an implementation of the concept in a high-performance PID (proportional-integral-derivative)-feedback loop. The component count is less than one-fourth that of a comparable bipolar-drive design. Feedback stability is robust, and settling time is short. The downside is a current draw as much as 150% higher than that for a conventional bipolar driver, which limits the technique to applications in which power consumption and heat dissipation aren't critical priorities and small TECs are adequate.EDN

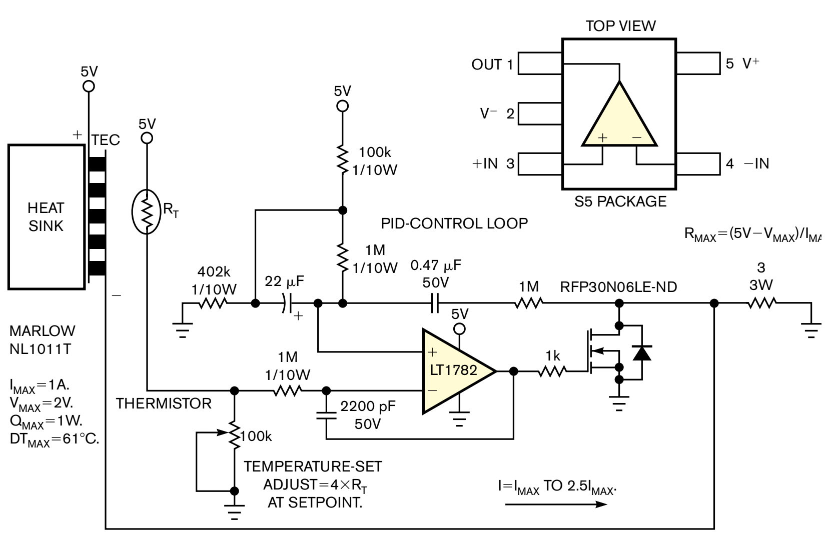

Figure 2 This circuit puts unipolar drive in a PID-feedback loop to stabilize the temperature of the target device.

Transimpedance synchronous amplification nulls out background illumination

Stefano Salvatori and Gennaro Conte, University Roma Tre, Rome, Italy

Light sensors find use in a host of important applications, spanning from consumer electronics, such as ambient-light measurements and exposure control for cameras, to scientific instruments, such as optical-absorption spectroscopy, IR (infrared) detection for thermography, and two-color pyrometry. For example, in optical spectroscopy, a correct intensity measurement of the probe beam is fundamental during material and device characterization. You must eliminate any influence that dc or very-low-frequency background light induces. Also, to increase the SNR (signal-to-noise ratio), you can apply narrowband, phase-sensitive, or lock-in detection techniques to mechanically chopped or otherwise modulated probe-light sources.

In this Design Idea, the reference signal from the light chopper as a square wave of frequency, f_{CHOP}, modulates the gain of an op-amp-based inverting amplifier (**Figure 1**). The amplifier input is a voltage proportional to the photocurrent signal produced by a photodiode, which is irradiated by a modulated light beam at the same chopper frequency. In this case, because the gain and input are at the same frequency content, a dc component, which a low-pass filter can easily detect, is present at the amplifier's output.

Op amps A_{1A} and A_{1B} convert the photogenerated current into a voltage including only the ac components. You can change the value of R_1 depending on the light level you want to detect. Neglecting A_{1A}'s input capacitance, the value of C_1 strongly depends on the terminal capacitance of the input photodiode, and you must select the value to ensure the stability of the transimpedance circuit (**Reference 1**).

The heart of the system, op amp A_{1C}, includes photoresistor R_{PR}, which represents the feedback element that determines the gain of the stage. The value of R_{PR} depends on the light that D_1 emits. A_{2B}, a voltage-to-current converter, drives D_1. The converter has a fixed voltage, V_B, and a ΔV signal through A_{2A} and A_3. A_{2A} determines the dc value of R_{PR}, whereas A_{2B} and ΔR_{PR} change at the same frequency as the reference signal. The A_3 Schmitt trigger converts any TTL/CMOS level of the reference signal into a balanced ±4.6V square wave attenuated to ±0.5V to generate an LED current change of approximately 1.8 mA p-p. For the photoresistor, R_{PR}, and LED elements, a Silonex (www1.silonex.com) CdS (cadmium-sulfide) NSL-19M51 cell couples to a red LED and resides in a black box to ensure the absence of background light on the optocoupler.

To calibrate the circuit, first disconnect or obscure the input photodiode so that A_{1A} converts no ac signal. Then, switch S_1 to the "measure" position and adjust R_{T2} to null any voltage offset referred to the output voltage. When the A_{1B} buffer generates the known approximately 300-mV test voltage and S_1 is in the calibrate position, adjust R_{T1} to fix the output voltage at 0V. In such a case, V_B voltage can set the $R_{PR}/R_C=R_A/R_B$ condition. **EDN**

REFERENCE

1 Wang, Tony, and Barry Erhman, "Compensate Transimpedance Amplifiers Intuitively," Application Report SBOA055A, Texas Instruments, 1993, focus.ti.com/lit/an/sboa055a/sboa055a.pdf.

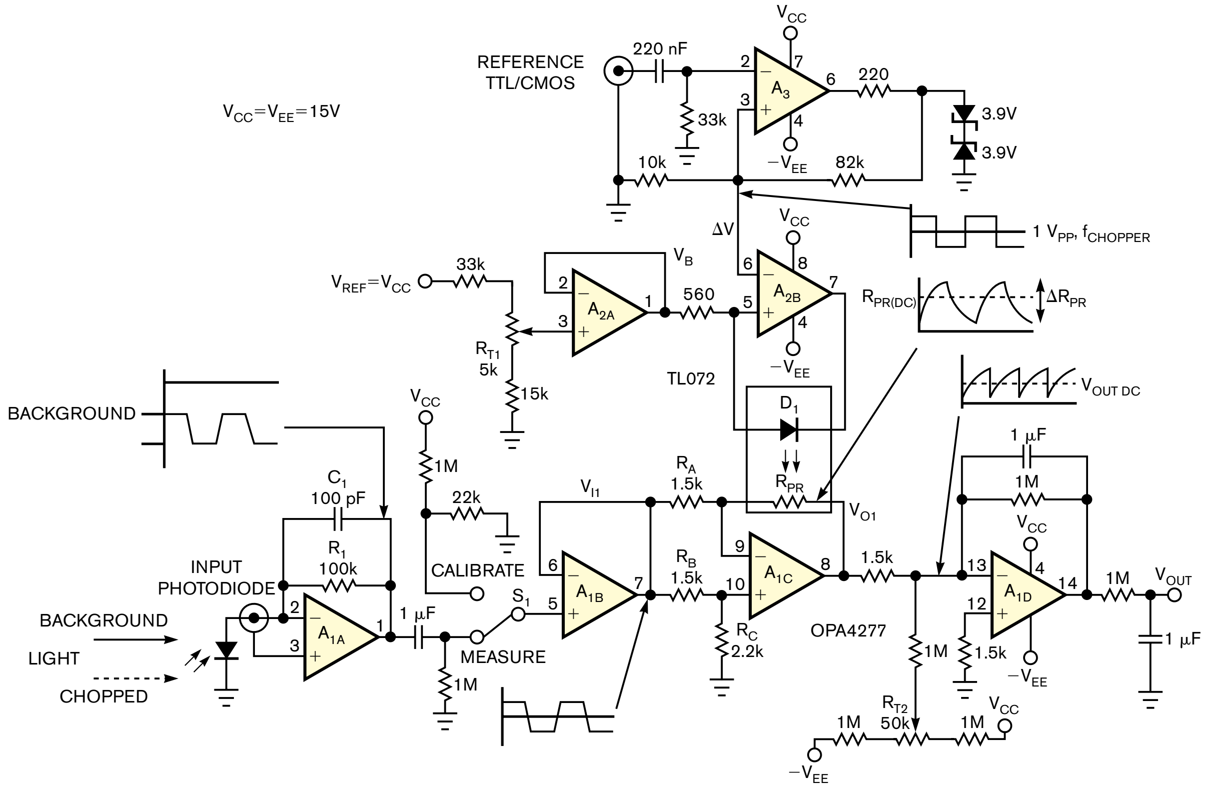

Figure 1 The reference signal from a light chopper acts as a square wave of frequency and modulates the gain of an omp-amp-based inverting amplifier.

Microcontroller drives LCD with just one wire

Noureddine Benabadji,
University of Sciences and Technology, Oran, Algeria

HD44780 LCDs are the most popular alphanumeric displays in embedded systems. The only downside is that they use six I/O pins in 4-bit nibble mode and as many as 11 pins in 8-bit mode. Earlier Design Ideas have described many approaches to saving or expanding I/O pins (**references 1**, **2**, and **3**). In driving an HD44780-compatible LCD, it would be better to use a baseline microcontroller instead of logic chips, because the microcontroller is lower cost, uses less board space, and has programming features. Microchip (www.microchip.com) has introduced the smallest PIC10F microcontroller family, which comes in a six-pin SOT-23 package.

The circuit in **Figure 1** proves useful for any pin-limited embedded system that must interface with an HD44780-compatible display through a one-wire serial link using an asynchronous, simplified RS-232 protocol at 9600 baud. It uses a PIC10F202, but any member of the PIC10F family is suitable, because the highly optimized source code in **Listing 1**, which is available with the Web version of this Design Idea at www.edn.com/071203di1, allows the program code to take fewer than 256 words. It is useless to try higher baud rates than 9600, because the PIC10F202 uses an RC internal oscillator with 1%-frequency tolerance, and the LCD requires a delay as long as 1.6 msec for some instructions, such as "clear display."

Listing 1 is the fully commented assembler source code for the LCD232 module; the main routine consists of the display of a 2-sec-delay "splash screen," and then it enters an endless loop to wait for 1 byte as a command for the LCD, a maximum of 16 bytes as data for the LCD, and an ASCII zero. For test purposes with an external PIC microcontroller embedded system, **Listing 2**, also available at www.edn.com/071203di1, is a simple assembler source code, which sends another splash screen.**EDN**

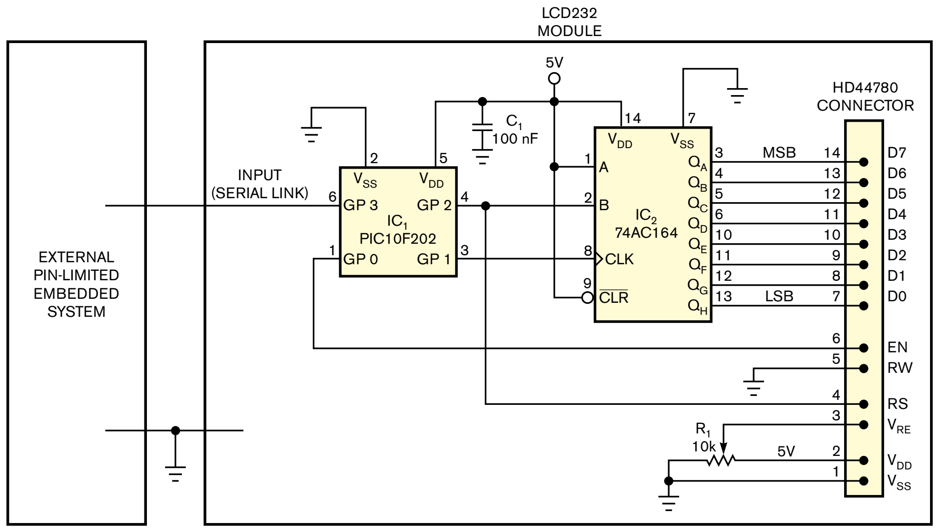

Figure 1 This circuit interfaces a pin-limited embedded system with an HD44780-compatible display through a one-wire serial link using an asynchronous, simplified RS-232 protocol.

REFERENCES

[1] Raynus, Abel, "Squeeze extra outputs from a pin-limited microcontroller," *EDN*, Aug 4, 2005, pg 96, www.edn.com/article/CA629311.

[2] "Microcontroller provides low-cost analog-to-digital conversion, drives seven-segment displays," *EDN*, May 10, 2007, pg 80, www.edn.com/article/CA6437954.

[3] Niven, Rex, "RC lowpass filter expands microcomputer's output port," *EDN*, June 21, 2007, pg 74, www.edn.com/article/CA6451248.