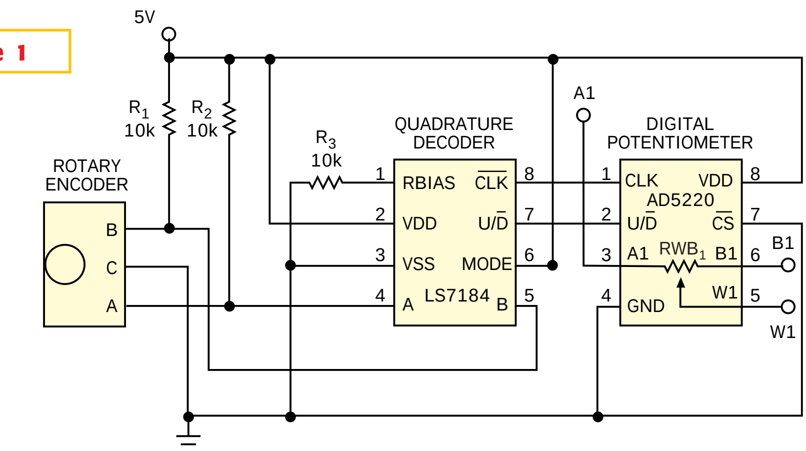
Rotary encoder mates with digital potentiometer

Peter Khairolomour, Analog Devices, San Jose, CA

In developing electronic systems, designers look for products or ideas that may benefit from the better performance, smaller size, lower cost, and improved reliability that an IC can offer. Toward that end, the digital potentiometer emerged as an alternative to its mechanical counterpart, the mechanical potentiometer. The digital potentiometer offers most of the cited advantages but falls short for users of mechanical potentiometers, who require a simple rotary interface for front-panel adjustment or calibration without external controllers. The circuit in **Figure 1** represents an attempt to combine the best of both worlds: the simplicity of a rotary interface and the performance of a digital potentiometer. The rotary encoder in this circuit is the RE11CT-V1Y12-EF2CS from Switch Channel (www.switchchannel.com). This type of rotary encoder has one ground terminal, C, and two out-of-phase signals, A and B (**Figure 2**). When the rotary encoder turns clockwise, B leads A (**Figure 2a**), and, when it turns counterclockwise, A leads B (**Figure 2b**).

Figure 1

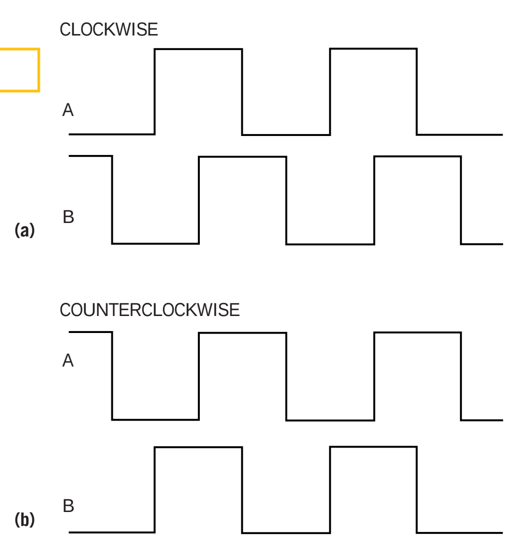


A quadrature decoder and a digital potentiometer form a simple rotary-encoder interface.

Signals A and B of the rotary encoder pass through a quadrature decoder (LS7184 from LSI Computer Systems, www.lsisci.com), which translates the phase difference between A and B of the rotary encoder into a compatible output, $\overline{CLK}$ and U/$\overline{D}$, that the AD5220 can accept. The AD5220 from Analog Devices (www.analog.com) is a 128- step, pushbutton digital potentiometer. It operates with a negative-edge-triggered clock, CLK, and an increment/decrement direction signal, U/$\overline{D}$. When B leads A (clockwise), the quadrature decoder provides the AD5220 with a logic-high U/$\overline{D}$. When A leads B (counterclockwise), the quadrature decoder provides the AD5220 with a logic-low U/$\overline{D}$. The quadrature decoder also produces a clock in synchronism with its output, which also connects directly to the AD5220. You linearly vary the clock's pulse width by adjusting RBIAS.

Aside from decoding the quadrature output of the rotary encoder and providing a clock signal, the LS7184 also filters noise, jitter, and other transient effects. This feature is important for this type of application. Unlike optical encoders, the RE11CT-V1Y12-EF2CS is a low-cost electrical encoder, in which each turn can create some bounce or noise issues because of the imperfect nature of the metal contacts within the switch. The LS7184 prevents such erroneous signals from reaching the AD5220. The operation of the circuit in **Figure 1** is simple. When the rotary encoder turns clockwise, the resistance from the wiper to terminal B1 of the digital potentiometer, RWB_1, increments until the device reaches full scale. Any further turning of the knob in the same direction has no effect on the resistance.

Figure 2



In clockwise rotation, signal B leads A (a); in counterclockwise rotation, A leads B (b).

Likewise, a counterclockwise turn of the knob reduces RWB_1 until it reaches the zero scale, and any further turning of the knob in the same direction has no effect. One example of the flexibility and performance this circuit offers becomes apparent when you consider systems with front-panel rotary adjustment. You can lay out the compact digital potentiometer and quadrature decoder anywhere in the system. All the ICs need are two digital control signals routed to the front panel where the rotary encoder is located. This setup proves impervious to interference, noise, and other transmission-line effects that arise in traditional designs with mechanical potentiometers. These designs force the sensitive analog signal to travel all the way to the front of the panel to be processed and then back to its destination.

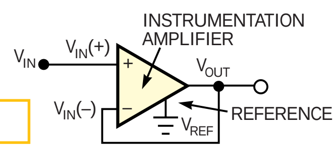
Is this the best Design Idea in this issue? Select at www.edn.com.

Amplifiers perform precision divide-by-2 circuit

Glen Brisebois and Jon Munson, Linear Technology Corp, Milpitas, CA

The classic implementation of a voltage-halving circuit uses two equal-value resistors. Using 1% resistors provides a divider output with 2% accuracy. For most applications, this performance is cost-effective and more than adequate. However, when you need extreme precision, this approach requires correspondingly accurate resistors and can become expensive. Putting feedback around a finite-gain instrumentation amplifier yields a divide-by-2 circuit with the added benefit of a buffered output (**Figure 1**). The operation of the circuit is straightforward. The instrumentation amplifier has unity gain, so the voltage it sees across its inputs appears between V_{REF} and V_{OUT}: $V_{OUT}-V_{REF}=V_{IN}(+)-V_{IN}(-)$. But, considering the circuit in **Figure 1**, note that $V_{OUT}=V_{IN}(-)$, and $V_{REF}=0$. Substituting in the first equation, you obtain $V_{OUT}=V_{IN}(+)-V_{OUT}$, $2V_{OUT}=V_{IN}(+)$, or $V_{OUT}=1/2\ V_{IN}(+)$. Thus, you have a divide-by-2 circuit. One of the interesting features of this approach is that the input and the output offsets of the instrumentation amplifier are divided by 2 as well.

Figure 1

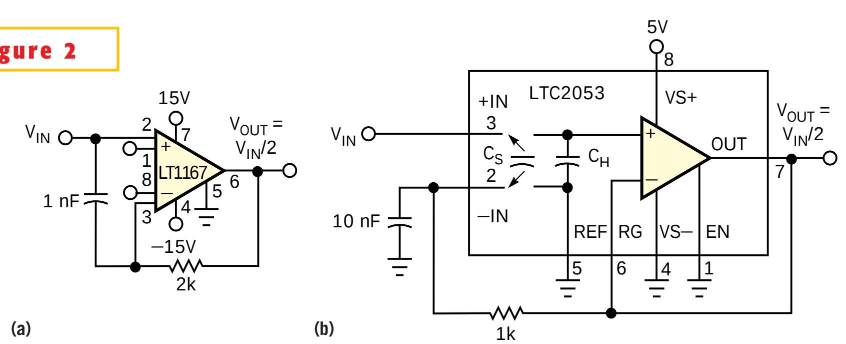


An instrumentation amplifier makes a simple divide-by-2 circuit.

You can implement the circuit on the bench using the LT1167 or the LTC2053 instrumentation amplifiers (**Figure 2**). Although benchtests are unnecessary, you can introduce an RC network into the feedback path for noise shaping and to guarantee dominant-pole behavior. To test for LT1167 offset, set $V_{IN}(+)$ to 0V and alternate $V_{IN}(-)$ between 0V and V_{OUT}. This test confirms that the feedback halves the total offset voltage. Dividing 10V to 5V, the LT1167 shows an error of 100 μV. With the more precise LTC2053, the output error in dividing 2.5V to 1.25V is an almost-immeasurable 2.5 μV. Using cold spray and a heat gun, you can degrade this error to 15 μV. However, perhaps equally important are the calculated worst-case results.

Worst-case calculations for the LT1167 show a maximum 1.12-mV error over 0 to 70°C with 10V input and 5V output. This figure constitutes a total error of 224 ppm over temperature. Resistors that guarantee this accuracy would need a maximum tolerance of 112 ppm each over temperature. The error budget of a resistor-divider solution would require an initial ratio match of approximately 50 ppm with a temperature-coefficient match better than 1 ppm/°C. Worst-case calculations for the LTC2053 with 2.5V input and 1.25V output show a maximum 80-μV error over 0 to 70°C. This figure constitutes a total error of 64 ppm over temperature. Resistors that guarantee this accuracy would need a maximum tolerance of 32 ppm each over temperature. The error budget of a resistor-divider solution would require an initial ratio match of approximately 15 ppm (0.0015%) with a temperature-coefficient match better than 0.25 ppm/°C. In either case, resistors of this caliber would be extraordinarily expensive if available at all. Also, the amplifiers provide the additional benefits of high input impedance and output buffering. Moreover, the error calculations include the effects of input offset voltage, bias current, gain error, and common-mode rejection ratio, which a resistor op amp would still have to add.

Figure 2



Practical implementations of the circuit in Figure 1 use the LT1167 (a) and the LTC2053 (b).

Is this the best Design Idea in this issue? Select at www.edn.com.