The circuit in Figure 1 converts a ±10V analog voltage representing an angle between $\theta_{\text{MIN}}$ and $\theta_{\text{MAX}}$ and emits a voltage equal to 10 cos$\theta$. This circuit can have an accuracy of better than 1% over ±120° or better than 0.2% over ±90°. These figures represent an order-of-magnitude improvement over a Taylor-series estimate for the same range and for the same number of multiplications. The Taylor-series definition for a cosine (with $\theta$ in radians) is:

$$\cos \theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \frac{\theta^6}{6!} + \cdots$$

The series works well for high values of $n$ or small angles. Generally, for $n=4$, significant errors start to accumulate for angles exceeding ±45°. When you use a Taylor-series expansion for better accuracies at larger angles, the number $n$ becomes larger and demands more resources from the design. The Taylor series for $n=4$ has the form of $f(\theta)=a-b\theta^2+c\theta^4$, where $a=1$, $b=0.5$, and $c=0.041667$ (for angles in radians). By using a least-squares curve fit to optimize this function at $n=4$, you can find coefficients that allow you to obtain significantly better accuracies over the desired input range without raising the value of $n$ to more than 4. The circuit in Figure 1 embodies this least-squares approach.

Choosing the resistor values for the circuit is relatively simple. Set $R_1$ and $R_2$ equal to each other (for 10V maximum input and $a\approx1$), and determine values for $R_3$ and $R_4$ by applying the following equations:

For angles greater than ±90°, the revised coefficients in Figure 1 yield significant accuracy improvements in calculating cosines.
Reference stabilizes exponential current
Tom Napier, North Wales, PA

In an antilog converter, the difference between the base voltages of two transistors sets the ratio of their collector currents:

\[ \frac{I_1}{I_2} = \frac{e^{V_{IN}/kT}}{e^{V_{IN}/kT}} \]

The use of matched transistors balances the first-order temperature coefficient but leaves a temperature-dependent gain term, q/kT. Classic antilog circuits use a thermistor in the drive circuitry to correct this temperature dependency. However, if the control input is a fraction of some reference voltage, as when you use a manual potentiometer or a DAC, you can achieve an exact temperature correction by adding a second reference transistor. Figure 1 shows three of the five transistors in a CA3046 array. \( Q_1 \) is the exponential current source, \( Q_2 \) is the conventional reference transistor. \( Q_3 \) forces \( Q_1 \)'s collector to ground so its collector current, 1 mA in this example, is simply the reference voltage divided by \( R_2 \). Typically, this current equals the maximum output required from \( Q_1 \); lower currents result from negatively driving the transistor’s base.

The attenuator on the base of \( Q_1 \), \( R_1 \), and \( R_2 \), and \( R_3 \) reduces the effects of \( Q_1 \)'s offset voltage. \( IC_1 \) drives the base of \( Q_1 \) via a second attenuator, \( R_3 \) and \( R_4 \), forcing its collector to ground. The reference current through \( Q_1 \) is a fraction of the main reference—one-tenth in this example. Despite the chip temperature, the base voltage of \( Q_1 \) is exactly the voltage you need to generate a 1-to-10 current ratio. Because \( IC_1 \)'s output supplies the reference voltage for the potentiometer, the ratio of the two attenuators defines the full-scale-current-adjustment range. If the ratio is 4 to 1, the output current has a four-decade tuning range that’s independent of temperature. The circuit in Figure 1 is dynamically stable, using either low-power or fast op amps.

Microcontroller becomes multifunctional
Abel Raynus, Armatron International, Melrose, MA

A microcontroller, by default, can execute only one program at a time. What do you do if, in a given project, you need to perform more than one operation at a time? Add more microcontrollers to the design? In certain cases it’s unnecessary. Consider a real-life situation (Figure 1). The microcontroller constantly generates on its Pulse output pin a sequence of pulses with 25-msec duration and a repetition rate of 1 or 4 sec, depending on the state of the Rate input pin. LED illumination accompanies the pulse generation. Suppose that the microcontroller must simultaneously and independently perform some other functions using the rest of its six I/O pins. You can benefit from the fact that the pulse duration is much smaller than the repetition period. During this relatively long period, the microcontroller may not just wait for the generation of the next pulse, but, instead, it may perform some other operation. You organize the pulse-generating program as an interrupt-service routine and the rest of the program as a main program. To avoid any interference between these parts of the software, the interrupt-service routine execution time should be shorter than the smallest period of pulse repetition.

Listing 1 is the assembly routine for multifunctional operation. To make the interrupt program repeatable after the predetermined time interval, the best choice is to use the microcontroller’s internal timer. This microcontroller has two timing options: timer-overflow interrupt and RTI (real-time interrupt). For a 2-MHz operating frequency, the timer overflow occurs every 0.51 msec.

Listing 1—Routine for Multifunctional Operation

```
1 ************ Multifunctional operation ************
2 $include "std-ja.s" ;
3 $PAGEWIDEN 160
4 org H'00100000 ;
5 ?? /O PORT BITS ***********
6 ??
7 ??
8 ??
9 ??
10 ??
11 ??
12 ??
13 ??
14 ??
15 ??
16 ??
17 ??
18 ??
19 ??
20 ??
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25 ??
26 ??
27 ??
28 ??
29 ??
30 ??
31 ??
32 ??
33 ??
34 ??
35 ??
36 ??
37 ??

Listing 1—Routine for Multifunctional Operation
```

Figure 1
Between pulses, the microcontroller can perform other tasks using the software in Listing 1.
You can program the RTI period to be as long as 65.5 msec (with RT1-to-RT0 = 1-to-1). To simplify the counters, it is reasonable to choose the largest value: 65.5 msec. Then, to make the repetition periods equal to 1 and 4 sec, you create the counters modulo 16 and 62 accordingly in the RTI routine (Listing 1). You can see in Listing 1 that the microcontroller waits for a high level on its Start pin to begin pulse generation and LED lighting. During the interval between pulses, it performs the other operations, continuously checking the state of its Start pin. After receiving a low level on the Start pin, the microcontroller stops pulse generating and switches off the LED. You can download the software for multifunctional operation from the Web version of this article at www.ednmag.com.


Circuit converts pulse width to voltage
James Mahoney, Linear Technology Corp, Milpitas, CA

The circuit in Figure 1 converts pulse information to a clean dc voltage by the end of a single incoming pulse. In another technique, an RC filter can convert a PWM signal to an averaged dc voltage, but this method is slow in responding. Converting low-duty-cycle pulse information is slower yet. The circuit in Figure 1 uses two low-input-bias-current LT1880 op amps, IC2 and IC3, and an LTC202 quad analog switch, IC1A, IC1B, IC1C, and IC1D, to configure the integrator and sample-and-hold stages to convert a single pulse to a dc voltage. The circuit’s output is stable after a single pulse. This example shows the conversion of a low-duty-cycle positive pulse, whose width varies from 1 to 2 msec with a period of 25 msec, to a clean dc voltage. The input pulse starts, stops, and resets the integrator and controls the input to the sample-and-hold stage. After the reset operation, the positive pulse level-triggers the integrator, comprising R1, C1, and IC2. The sample-and-hold stage, comprising IC1B, C2, and IC3, is in the sample mode, sampling the output of the integrator, while the incoming pulse is high.

When the incoming pulse goes low, the circuit disconnects the input to the sample-and-hold stage, putting it into hold mode. The integrator then stays in the reset state until the next positive pulse arrives. During reset, analog switch IC1A opens to disconnect the integrator’s input, switch IC1C closes to reset integration capacitor C1, and switch IC1D opens to disconnect the input to the sample-and-hold stage, placing the stage in hold mode. Analog switch IC1B inverts the on/off states of switch IC1C. The circuit yields a clean dc voltage that indicates the width of an incoming pulse.

This circuit linearly converts a pulse width to a dc voltage.
Short dc power-line pulses afford remote control

Tom Hornak, Portola Valley, CA

If you face the challenge of adding a second, independently controlled light source to an existing ceiling lamp controlled by a wall switch, you may find that stringing a second power line is impossible. First, you can replace the wall switch by the circuit in Figure 1. Pushing the on switch $S_1$ or $S_2$ for approximately 1 sec inserts the 12V zener diodes $D_1$ or $D_2$, in series with the hot wire of the power line. During the push, the polarity-dependent conduction of the zener diodes creates a small positive (negative for $D_2$) dc component across the line and only slightly reduces the line’s 120V-ac component. A control circuit at the lamps’ site reacts selectively to the polarity of this dc pulse and controls the power to the two lamps. The required power rating of the two zener diodes depends on the load current. The short duration and low duty cycle of the activation are helpful. The 1N2976 diodes in Figure 1 are rated for continuous dissipation of 10W.

Figure 2 shows the first part of the control circuit located at the lamps’ site, including the two leads of the power line, $W_1$ and $W_4$. Current through capacitor $C_1$ and resistor $R_1$ creates a 60-Hz square wave across the 6V zener diode, $D_3$. Diode $D_3$ and filter capacitor $C_2$ generate a dc supply voltage of $V_{dd} = 5V$ for the control circuit’s active elements. Two two-stage RC filters connected to $W_1$ create $V_1$ and $V_2$, with reference to $W_1$. The filters attenuate the 120V-ac voltage between $W_1$ and $W_2$ to a subvolt level in $V_1$ and $V_2$. An extra zener diode, $D_4$, creates a positive 5V dc bias in $V_2$. The filter outputs $V_1$ and $V_2$ drive inverting Schmitt triggers IC$_1$ and IC$_2$. Inserting zener diode $D_1$ by pushing $S_2$ in Figure 1 changes $V_1$ from 0V to 5V and $V_2$ from 5V to 10V. Inserting $D_1$ in Figure 1 by pushing $S_1$ changes $V_1$ from 0V to −5V and $V_2$ from 5V to 0V. Note that the input-protection diodes of IC$_1$ and IC$_2$ limit the voltage swings of $V_1$ and $V_2$. The output $V_1$ of IC$_1$ responds to pushing $S_1$ by a positive transition and has no response to pushing $S_2$. The output $V_2$ of IC$_2$ responds to pushing $S_2$ by a positive transition and has no response to pushing $S_1$.

Figure 3 shows the second part of the control circuit located at the lamps’ site. Signals $V_1$ and $V_2$ in Figure 2 drive the clock input of toggle flip-flops IC$_1$ and IC$_2$, respectively. For clarity, Figure 3 doesn’t show the connections of the flip-flops of $Q_1$ to $D$ and the Set terminal to $V_{pp}$. When you push switch $S_2$ in Figure 1, the positive transition in $V_2$ toggles flip-flop IC$_2$. Similarly, when you push $S_1$, the positive transition in $V_1$ toggles flip-flop IC$_1$. Thus, you can independently control the states of flip-flops.

The circuit operates with pulse-width information and not duty-cycle values. The sample-and-hold stage is an analog-memory element that reveals the dc-voltage equivalent for this pulse width.


LT1880 op amp is a good choice for the integrator and sample-and-hold stages because of its maximum input-bias current of 900 pA at 25°C and maximum of 1500 pA maximum over the full −40 to +85°C ambient-temperature range. Another benefit of the LT1880 is its maximum input-offset-voltage drift of 1.2 µV/°C. Integrator capacitor $C_1$ and resistor $R_1$ set the integration gain.

You should use polypropylene, poly-styrene, or Teflon capacitors for $C_1$ and $C_2$ to minimize integrator drift and sample-and-hold droop rate. The voltage ratio that resisters $R_1$ and $R_2$ set establishes the dc level at the positive pulse’s midrange value: 1.5 msec in this example. Figure 2 shows input pulse width versus output voltage. You can easily modify the circuit in Figure 1 to yield different conversion gains, output levels, and swings for different pulse widths.

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flops IC₁ and IC₂ by pushing S₁ and S₂, respectively. To drive the two lamps, the Q outputs of the flip-flops drive the gates of triacs TR₁ and TR₂ via coupling resistors R₂ and R₃. The MT2 terminal of each triac drives the lamps, L₁ and L₂, respectively. Pushing S₁ changes the state of lamp L₁; pushing S₂ changes the state of lamp L₂. Thus, you have independent control of both lamps on a single power line. In this application, you want to keep each lamp’s terminals safely connected to the hot and neutral wires. Therefore, you make W₁ the hot wire and W₂ the neutral wire.

With the control circuit, the state of the flip-flops becomes uncertain if, after an interruption, the ac power returns. This situation is unacceptable because the lamps could turn on and stay on for an uncontrollable length of time. Therefore, you add a power-up reset circuit (Figure 3). To guarantee a safe reset also for short interruptions, the reset circuit must quickly pull down the flip-flops’ Reset terminal, which is independent of VDD’s slowly dropping level. Diode D₂ (driven by the 60-Hz square wave across zener diode D₄), capacitor C₃, and resistor R₄ act as an auxiliary rectifier supplying voltage V₅. When power experiences an interruption, V₅ drops to 0V much faster than VDD. V₅ drives the cascade of inverting Schmitt triggers IC₄ and IC₅, which then quickly pull down the flip-flops’ Reset terminals via diode D₃. When power returns, the Reset terminals pull up slowly via resistor R₅. The R₅C₄ time constant guarantees that the flip-flops’ Reset does not release before VDD reaches its full value.

Note that you can use this Design Idea in other applications. For example, if you omit the circuit in Figure 3, the transitions in V₃ and V₄ can drive an up/down counter that can perform an auxiliary control function for a device that the ac line powers. If you insert an additional conventional switch in series with the circuit in Figure 1, it can turn on and off the power to the device. If the application requires control signals near ground level, wire W₁ should be the neutral lead of the power line, and W₂ should be the hot lead. However, make sure that the powered device is not an inductive load because it can short out the controlling dc pulses.