

design ideas

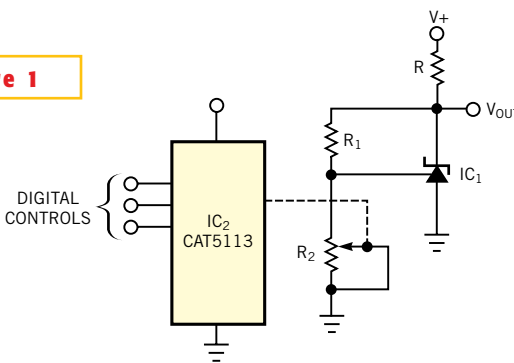
Edited by Bill Travis

Digital potentiometer programs and stabilizes voltage reference

Chuck Wojslaw, Catalyst Semiconductor, Sunnyvale, CA

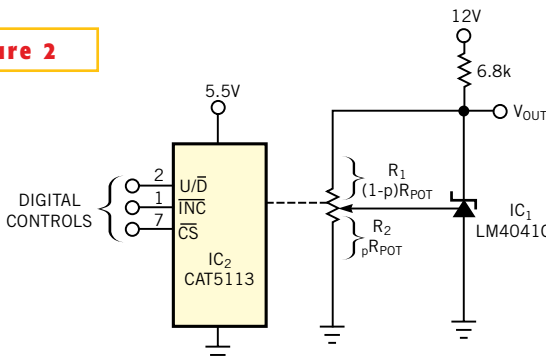
THE POTENTIOMETER PORTION of a mixed-signal, digitally programmable potentiometer adds variability to an analog circuit, and its digital controls provide programmability. You can use a digital potentiometer in two ways in an analog circuit. You can use it as a two-terminal variable resistance, or rheostat, or as a three-terminal resistive divider. Although both ways bring variability to the analog circuit, the three-terminal implementation usually brings other important characteristics as well. For example, a programmable voltage reference has two implementations. The circuit in **Figure 1** is a voltage reference whose output, V_{OUT} , depends on the 1.25V reference of the shunt regulator, IC₁, R₁, and the programmable resistance $R_2 = pR_{POT}$. The value of p varies from 0 to 1; it represents the proportional setting of the wiper from one end, 0, to the other, 1. For this circuit, $V_{OUT} = 1.25V(1 + pR_{POT}/R_1)$. As p varies from 0 to 1, V_{OUT} varies from 1.25V to

Figure 1



In this circuit, the potentiometer's temperature coefficient adversely affects that of V_{OUT} .

Figure 2



This circuit has low component count, low temperature coefficient, and enhanced programming accuracy.

perature stability of R_{POT} has adverse effects on the temperature coefficient of V_{OUT} . The programmable voltage-reference circuit in **Figure 2** uses the potentiometer as a three-terminal device. For this circuit,

$$V_{OUT} = 1.25V \left\{ 1 + \frac{pR_{POT}}{(1-p)R_{POT}} \right\}$$

$$= 1.25V \left(\frac{1}{1-p} \right)$$

This implementation shifts the temperature dependence of V_{OUT} on the potentiometer from the high temperature coefficient of R_{POT} to the potentiometer's low ratio-metric temperature coefficient of 20 ppm/°C. It also reduces component count and cost and increases programming accuracy. The 15% accuracy of R_{POT} is the dominant factor in the accuracy of V_{OUT} in the circuit of **Figure 1**. In the circuit of **Figure 2**, the

some maximum value established by R_1 and the potentiometer's end-to-end resistance, R_{POT} . The temperature coefficient of V_{OUT} is proportional to those of the LM4041CIZ regulator's 1.25V reference, R_1 , and R_{POT} . The temperature coefficient of the reference voltage and a quality resistor are lower than 100 ppm/°C. However, the temperature coefficient of R_{POT} is not guaranteed and can run in the hundreds of parts per million per degrees Celsius. Thus, the tem-

potentiometer's 1% linearity is the dominant factor in the accuracy of V_{OUT} . For the values shown in **Figure 2**, the 100-tap CAT5113 digitally programmable potentiometer provides for a variable, temperature-stable V_{OUT} of 1.25 to 5.5V ($0 \leq p \leq 0.77$). The measured data correlates to better than 1% with the calculated values.

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Add voice command to virtual instrumentation

Alexander Bell, Infosoft International Inc, Rego Park, NY

DEBATES STILL PERSIST in the engineering community about the relative merits of analog and digital controls of instrumentation. Meanwhile, a revolutionary new type of control—voice-command control—is gaining acceptance in many application areas (Reference 1). This Design Idea focuses on the practical implementation of the Voice Commander voice-command interface in a virtual-instrumentation project. The beauty of the method lies in the fact that a single Microsoft Excel file, vScope VC.xls, encapsulates the entire voice-command system. The Excel file comprises two worksheets, vScope and vScopeData; two standard code modules; and a small portion of code in the This Workbook code module. You can download the relevant software from the Web version of this Design Idea at www.edn.com. Using the terminology and the concept of modern multitiered software architecture, the voice-command method embraces the user-interface and the business-logic layers.

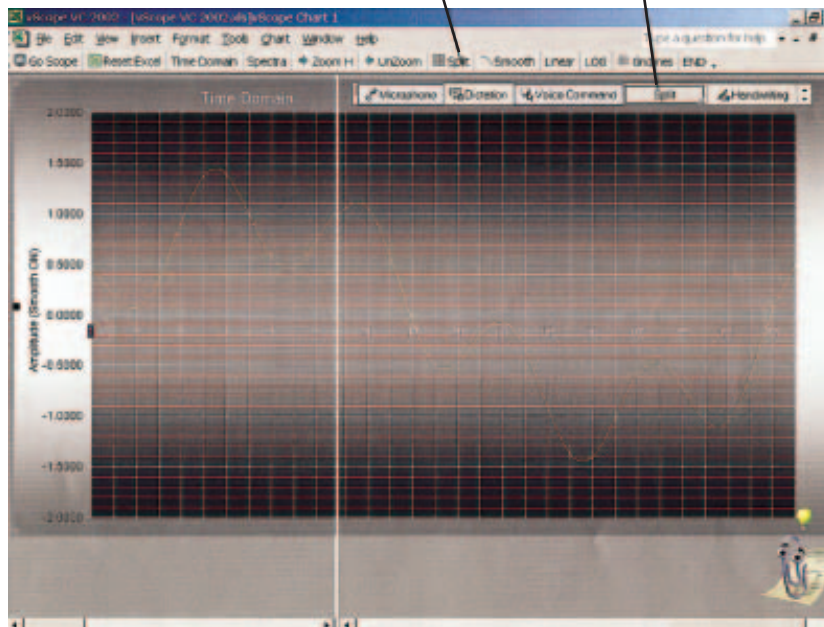
The simulated-data layer is in the vScopeData worksheet. Column A contains the samples' ordinal numbers ($i=1, 2, \dots, 64$), Column B contains simulated signal-amplitude samples ($V = \sin(6.28 \times 2 \times i/64) + 0.5 \cos(6.28 \times 10 \times i/64)$), and columns C and D contain calculated complex-FFT and signal-amplitude spectra, respectively. By adding the actual data source (signal samples captured by a data-acquisition board or database query for historical data analysis) and linking it to Column B, you can expand the technique to a “full-flavored” virtual instrument or analytical tool with voice-command interface.

The vScope worksheet contains the Chart Object (called “Chart1” in the downloadable macros), formatted to emulate the actual oscilloscope screen (Figure 1). A custom toolbar appears at the top of the display, which contains control buttons. The buttons are associated with macros that execute when you press the button or say the com-

LANGUAGE TOOLBAR IN MS EXCEL 2002 IS SHOWN IN A VOICE-COMMAND MODE. (THE USER ENTERED THE “SPLIT” CUSTOM COMMAND.)

Figure 1

TEMPORARY CUSTOM TOOLBAR IS DYNAMICALLY CREATED ON THE FILE_OPEN EVENT.



This screen snapshot uses the time-domain mode with horizontal zoom and split-view on to see signal details at the beginning and end of the scale.

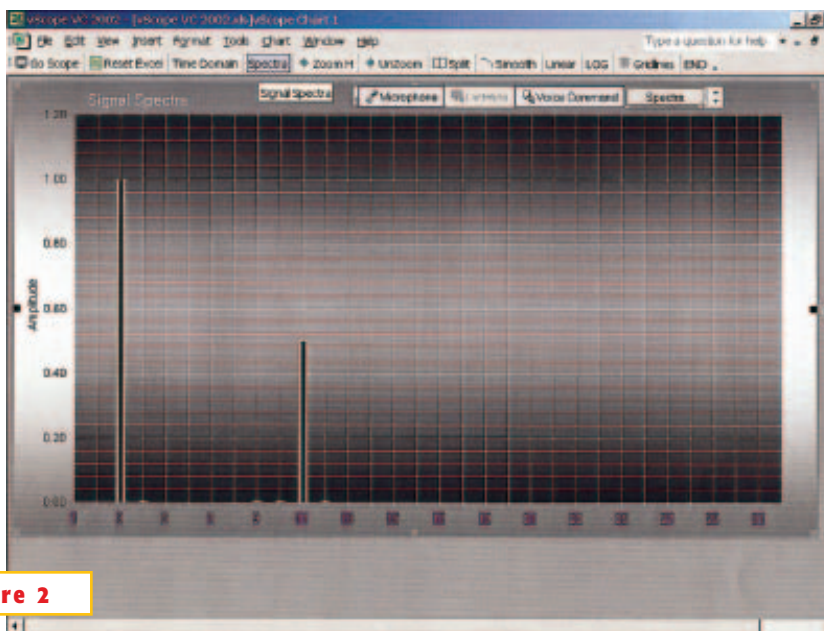


Figure 2

These signal-amplitude spectra correspond to a 64-point FFT with 32 spectral components.

mand, corresponding with button's caption. Note that the voice-command feature is available only in the latest Excel 2002 Office application.

Table 1 shows the list of custom commands. The Chart Object dynamically links via macros to the simulated data in the vScopeData worksheet. The Business Logic portion of the routine is programmed in VBA (macros) and partially in Excel worksheet functions. It contains a 64-point FFT, based on the Excel add-in functions. To use this feature, install Analysis Tool-VBA from the Tools-Add-Ins menu item. You can expand the business-logic and user-interface layers by including different digital-filtering and windowing techniques and by adding multiple channels, for example.

Upon opening the Demo file, a temporary custom toolbar appears at the top of the display (**Figure 1**). In Excel 2002, activate the speech tools: Go to the Tools—Speech—Speech Recognition menu item and then choose the Voice

TABLE 1—VOICE-COMMAND DESCRIPTIONS

Voice command	Description
Go scope	Customize screen settings to maximize viewing area
Reset Excel	Reset standard Excel screen settings
Time Domain	Time-domain mode
Spectra	Show signal-amplitude spectra
Zoom H	Zoom horizontal axis
Unzoom	Unzoom horizontal axis
Split	Toggle split-screen mode on/off
Smooth	Toggle line smoothing on/off
Linear	Use linear scale (vertical axis)
Log	Use logarithmic scale (vertical axis)
Grid lines	Turn major/minor gridlines on/off (three-state logic)
End	Close file without saving and end the vScope session

Command mode. In this mode, you can enter the command either by saying it or by clicking the button on the toolbar. For example, by clicking on or saying “go scope,” you can maximize the view by temporarily removing some standard screen components. You can restore the components by clicking or by saying, “reset Excel.” The Split command allows you to open two pseudowindows with independent horizontal scrolling. This feature lets you see the rising and falling edges of the long, or horizontally “zoomed,”

signal at the same time. When you say, “spectra,” the signal-amplitude spectra screen appears (**Figure 2**). You can use this technique with Excel 95, 97, and 2000, but you must use the custom toolbar instead of voice commands. Note that when you enable macros in Excel or other applications, some macros could perform potentially dangerous and harmful actions, and some

may contain viruses. The code for this Design Idea is on an as-is basis without warranty of any kind. The vScope VC.xls file is for demo purpose only, and commercial use of this file is prohibited.

REFERENCE

1. Bell, Alexander, “Add voice commands to your CAD system,” *EDN*, May 2, 2002, pg 77.

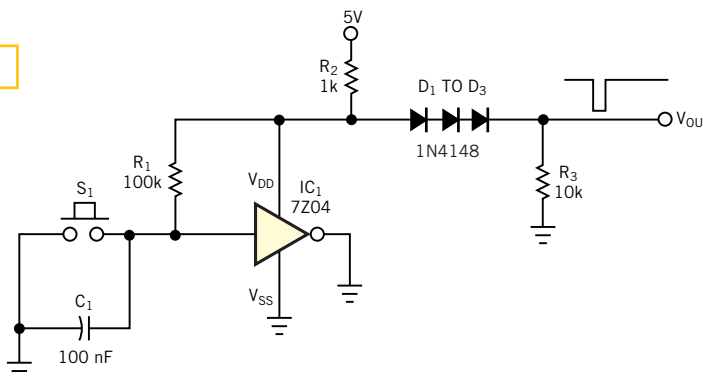
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Switch debouncer uses only one gate

Steven Robertson, Anritsu Co, Morgan Hill, CA

THE CIRCUIT IN **FIGURE 1** produces a single debounced pulse each time you press S_1 . Moreover, the circuit uses only logic power from the remote pull-up resistor, R_2 . You can use the circuit to detect when a key is pressed in a nonenergized device, such as a device in a system that's just coming up from standby. The circuit operates as follows: Assume that you have not yet pressed S_1 and that C_1 is in a charged state. Under these conditions, R_1 drives IC_1 toward V_{SS} (ground), causing the IC to consume virtually no power. This action allows V_{OUT} to remain near 5V. However, when you press S_1 , C_1 rapidly discharges and drives IC_1 toward V_{DD} . Under these circumstances, IC_1 conducts heavily, pulling V_{OUT} near 0V until R_1 charges C_1 enough to again drive IC_1 to-

Figure 1



This switch-debouncer circuit consumes virtually no power.

ward V_{SS} . Once C_1 charges sufficiently, IC_1 goes to V_{SS} and stops drawing power. This action unloads V_{DD} and causes V_{OUT} to return to a high state. D_1 to D_3 , in conjunction with R_3 , shifts the level of

V_{OUT} for improved compatibility with CMOS logic.

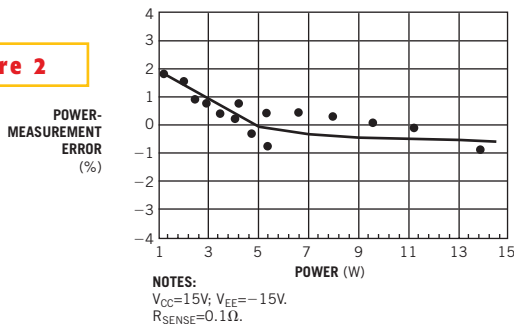
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Power meter is $\pm 1\%$ accurate

Ken Yang, Maxim Integrated Products, Sunnyvale, CA

POWER METERS provide an early warning of thermal overload by monitoring power consumption in high-reliability systems. Power monitoring is especially suitable for motor controllers, industrial heating systems, and other systems in which the load voltage and current are both variable. The power meter/controller in **Figure 1** uses the principle that power is the product of voltage and current. The typical accuracy of the circuit is better than $\pm 1\%$. A current sensor, IC₂, measures output current, and a four-quadrant analog-voltage multiplier, IC₁ and IC₃, generates the product of output voltage and current. An optional unity-gain inverter, IC₄, inverts the inverted multiplier output. This power meter is most accurate for multiplier inputs (J₁ and J₂) of 3 to 15V. Select the current-sense resistor as follows: $R_{SENSE} = 1/P$, where R_{SENSE} is in ohms, and P is the output power in watts. If power delivery to the load is 10W, for example, you would choose $R_{SENSE} = 0.1\Omega$.

Figure 2



The measured power is better than $\pm 1\%$ accurate for power levels of 3 to 14W.

The circuit in **Figure 1** has a unity-gain transfer function, in which the output voltage is proportional to load power. For instance, the output voltage is 10V when the load power is 10W. To change the transfer-function gain, change the sense resistor as follows: $Gain = 10R_{SENSE}$. For the circuit in **Figure 1**, **Figure 2** compares power-measurement error with load power. Note that accuracy is better than $\pm 1\%$ for load power of 3 to 14W. For proper operation, you must first calibrate the analog multiplier according to the following procedure. Remove jumpers J₁ (X input) and J₂ (Y input) before calibration.

- X-input offset adjustment: Connect a 1-kHz, 5V p-p sinusoidal signal to the Y input, and connect the X input to ground. Using an oscilloscope to monitor the output, adjust R_X for an ac null (zero amplitude) in the sinusoidal signal.
- Y-input offset adjustment: Connect a 1-kHz, 5V p-p sinusoidal signal to the X input, and connect the Y input to ground. Using an oscilloscope to monitor the output, adjust R_Y for an ac null (zero amplitude) in the sinusoidal signal.
- Output-offset adjustment: Connect both X and Y inputs to ground. Adjust R_{OUT} until the dc output voltage is 0V.
- Scale factor (gain): Connect both X and Y inputs to 10V dc. Adjust R_{SCALE} until the output voltage is 10V dc.
- Repeat the preceding steps as necessary.

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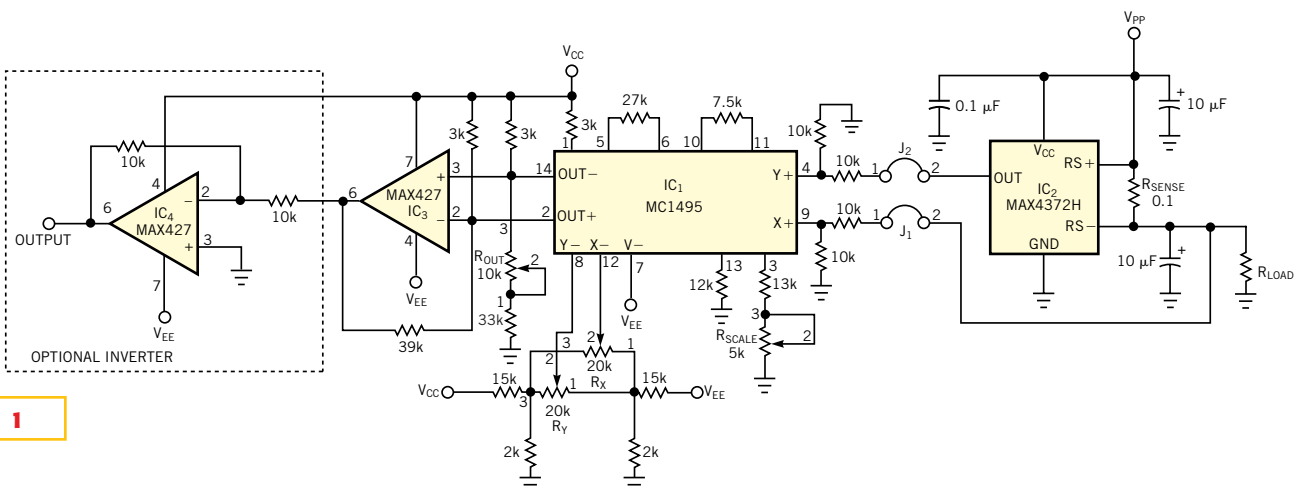


Figure 1

This power meter, whose output voltage is proportional to load power, achieves $\pm 1\%$ accuracy.

Circuit controls brightness of multiple displays

Stephan Goldstein, Analog Devices, Wilmington, MA

RECENTLY NEEDED TO CONTROL nine seven-segment displays for a microcontroller's serial port. The complication I faced was the need to provide a continuous brightness adjustment for all the digits—from completely dark to fully bright. I couldn't easily use the obvious solution of a string of 74HC595 serial-to-parallel converters driving the segments through series resistors, because I would have needed a variable power supply for the displays—an inefficient and inelegant approach. I considered using software to control the duty cycle of the displays' drive signal, but as a long-time analog-circuits guy, I felt honor-bound to find a way that wouldn't require writing any more code. Besides, I'd used up all the I/O pins on my microcontroller, so a software solution would have entailed changing processors. Allegro Microsystems (www.allegromicro.com) offers several parts for driving common-anode displays. Each includes a serial-data interface and an on-chip control loop that sets equal on-currents for all the segments, using a single resistor to ground. I selected the Allegro A6275E (Figure 1), which neatly match-

es up one chip per display digit. Now, I had to simultaneously vary nine resistors.

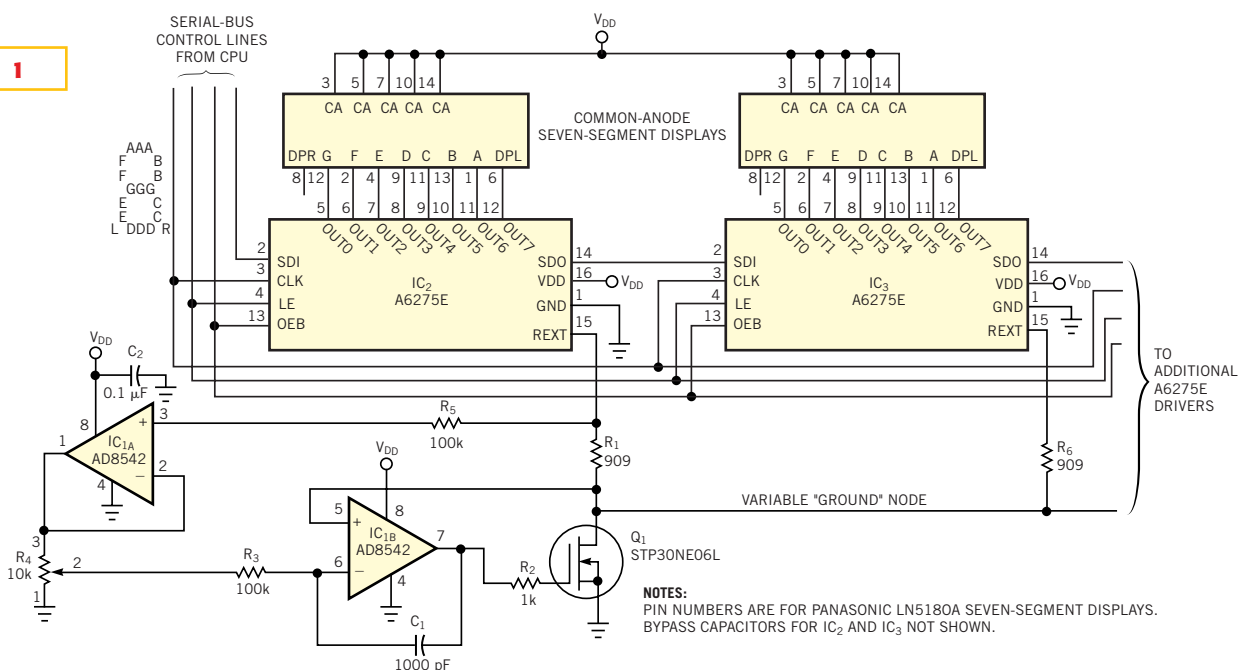
I cheated, of course. Instead of varying the resistors, I moved their apparent ground point with a simple analog control circuit comprising a dual op amp, a power MOSFET, and a few passive components. IC_{1A} provides a buffered version of the A6275's nominal 1.23V reference voltage to the top of the potentiometer, preventing the potentiometer's loading from affecting the segment currents of the "master" A6275. IC_{1B} drives Q₁'s gate and forces Q₁'s drain voltage to be equal to the voltage at the potentiometer's wiper. This action varies the voltage across the 909Ω resistor between (almost) ground and the reference voltage and yields a smooth intensity control from maximum (20 mA for a 909Ω resistor) to zero. The slight variations in A6275 reference voltages and the tolerances of the 909Ω resistors add to the normal variations in intensity from digit to digit, but these variations were unnoticeable in my application.

One important point to note is the connection of IC_{1B}: The feedback from

Q₁'s drain goes to the IC's noninverting input. The MOSFET adds an inversion inside the main loop, so using the op amp's noninverting input as the feedback point results in overall negative feedback. C₁ and R₃ create the loop's dominant pole, and R₂ isolates Q₁'s gate capacitance to ensure that IC_{1B} doesn't oscillate. Allegro cautions against excessive capacitance at the A6275's reference pin, so I used R₅ to isolate IC_{1A}'s input capacitance from this point. IC₁ must have a rail-to-rail output, its input must operate down to the negative rail, and it must operate with a total supply span of 5V. Q₁ needs to have low on-resistance with 5V gate drive. Using the STP30NE06L from ST Microelectronics (www.stmicroelectronics.com) was probably overkill at 0.045Ω, but the price was right at less than \$1. The remaining components are noncritical. You may want to experiment with different potentiometer tapers; in my case, an audio taper gave a pleasing "feel" to the brightness control.

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Figure 1



An analog control loop provides an adjustable "ground" node to control the current flowing through the resistors that set the segment currents.

Difference amplifier uses digital potentiometers

Reza Moghimi, Analog Devices, San Jose, CA

YOU SOMETIMES NEED TO measure a small signal in the presence of a large common-mode signal.

Traditional instrumentation amplifiers that use two or three op amps in their internal structure find common use in these applications. The circuit in **Figure 1** presents an alternative approach that is useful when low cost and low drift are important, but when you don't need high precision. The circuit uses IC₁, a dual 1024-position AD5235 digital potentiometer with nonvolatile memory. It also uses IC₂, an AD8628 autozero amplifier to form a difference amplifier with a gain of 15. The programming capability of the AD5235 allows you to perform gain setting and trimming in a single step. Autozero amplifiers, such as the AD8628 and the AD855x family, are the best choices in these types of applications. They have high dc accuracy and add negligible errors to the output. The long-term stability of the autozero amplifiers eliminates the need for repeated calibration. With a minimum common-mode rejection ratio of 140 dB for the autozero amplifier, the resistor match is the limiting factor in most circuits. The transfer function of the circuit in **Figure 1** is:

$$V_{OUT} = \frac{R_{W1B2}}{R_{W1A2}} \left[\frac{\left(1 + \frac{R_{W1B2}}{R_{W1A2}}\right)}{\left(1 + \frac{R_{W2A1}}{R_{W2B1}}\right)} V_2 - V_1 \right], \quad (1)$$

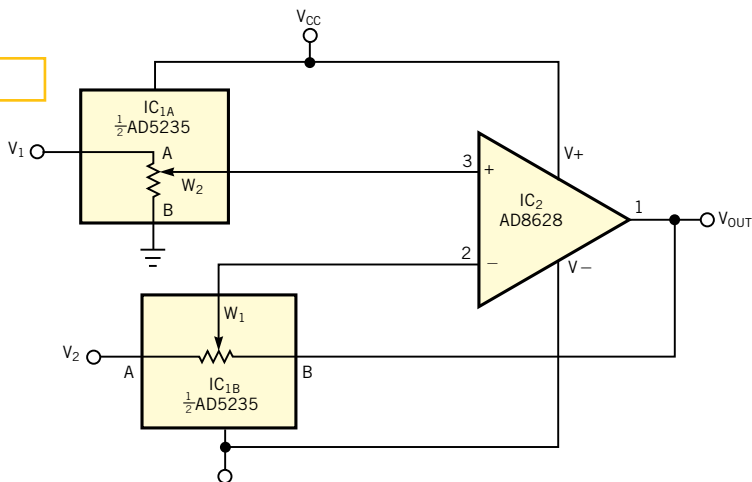
where R_{AnBn} = nominal end-to-end resistance; R_{WnBn} = terminal resistance, W to B; R_{WB} = R_{AB} × D/2^N; R_{WnAn} = terminal resistance, W to A; R_{WA} = R_{AB} - R_{WB} = R_{AB} (1 - D/2^N); D = decimal equivalent of the binary word; and N = number of bits.

A special situation arises when (R_{W1B2})/R_{W1A2} = (R_{W2A1})/R_{W2B1}. The transfer-function equation reduces to

$$V_{OUT} = \frac{R_{W1B2}}{R_{W1A2}} (V_2 - V_1). \quad (2)$$

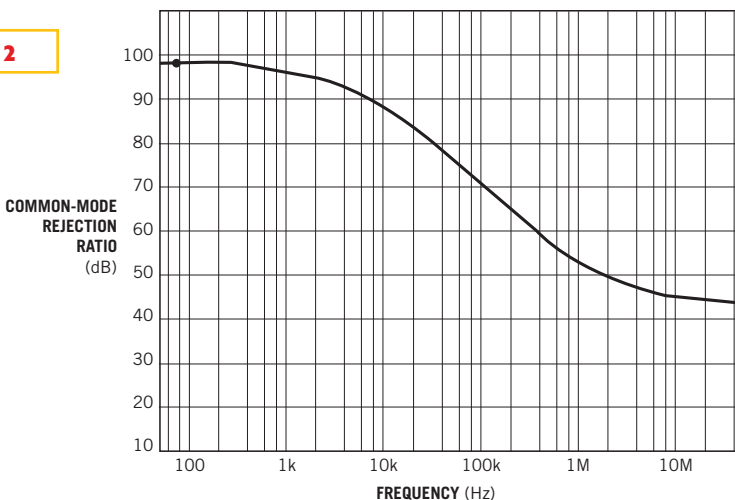
You can see that the output is the dif-

Figure 1



A low-cost difference amplifier uses digital potentiometers to set the gain.

Figure 2



A plot for common-mode rejection ratio versus frequency for the circuit in Figure 1 yields a figure of 98 dB.

ference of the two inputs times a gain factor that you can set to any desired gain, including unity. **Equation 2** holds true because the same chip integrates all the resistors; therefore, their values match tightly. The low-frequency common-mode rejection ratio is approximately 98 dB (**Figure 2**). Because of the tight matching, the circuit can achieve a tem-

perature coefficient of 15 ppm/°C. Although the circuit has lower performance than precision instrumentation amplifiers, it is adequate for many low-cost applications.

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Switching regulator forms constant-current source

Stefan Strozecki, Institute of Telecommunications, Bydgoszcz, Poland

MANY APPLICATIONS REQUIRE current sources rather than voltage sources. When you need a high-current source, using a linear regulator is inadvisable, because of the high power dissipation in the series resistor. To solve the wasted-power problem, you can use a switch-mode regulator.

The circuit of **Figure 1** uses IC₁, an LM2576 adjustable regulator. It needs only a few external elements and has an adjustable sensing input, which you use for controlling the output current. Resistor R_{SC} is a current sensor. IC_{2A}, one-half of a TL082 op amp, operates as a difference amplifier. When R₁=R₂=R₃=R₄, the output voltage is proportional to the current flowing in R_{SC}. Good common-mode rejection and a wide common-mode voltage range are important, because the amplifier works with large, changing common-mode signals.

The second half of the TL082 op amp, IC_{2B}, operates as a noninverting ampli-

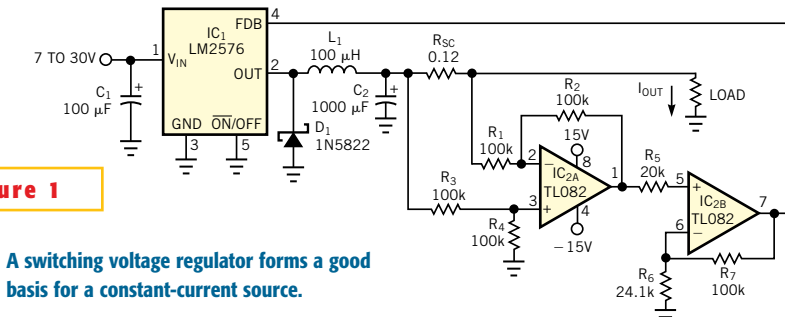


Figure 1

A switching voltage regulator forms a good basis for a constant-current source.

er. The required gain depends on the output current you need: $G = V_{REF} / V_{SC}$, where G is gain, V_{REF} is the voltage on the sensing input of the LM2576, and V_{SC} is the voltage across R_{SC}. Note that $V_{SC} = I_{OUT} R_{SC}$, where I_{OUT} is the output current. For example, if $I_{OUT} = 2A$ and $R_{SC} = 0.12\Omega$, then $V_{SC} = 0.24V$. Typically, for the LM2576, $V_{REF} = 1.237V$. So, you can obtain the gain of the noninverting amplifier from the gain equation: $G = 5.15V/V$. The overall gain of the noninverting amplifier is $G = 1 + R_7/R_6$. If

$R_7 = 100\text{ k}\Omega$ and $G = 5.15$, you can solve for R_6 (24.1 k Ω). When you need a precise output current, you can replace the fixed resistor, R_6 , with a series connection of a fixed resistor and a potentiometer. Tests showed that the output current is practically constant with varying loads. For example, the 2A output current changed less than 1% for an output-voltage range of 0.3 to 15V.

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