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DIs Inside

84 Optical feedback extends white LEDs' operating life

88 Sequencer controls power supplies' turn-on and turn-off order

92 Use dual op amp in an instrumentation amp

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Microcontroller drives logarithmic/linear dot/bar 20-LED display

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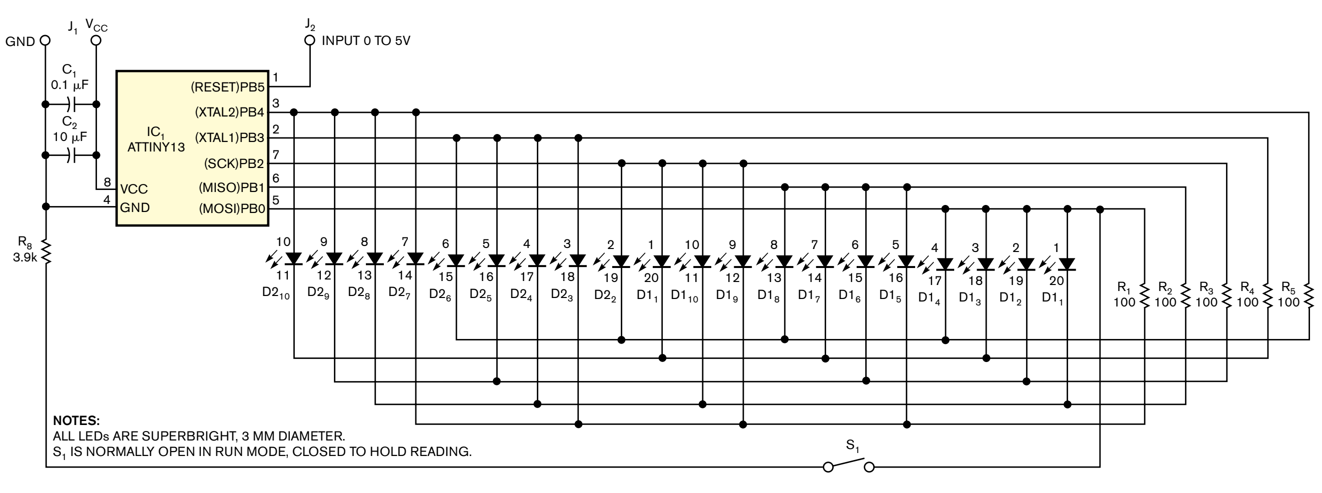
Available for more than 20 years, National Semiconductor's (www.national.com) venerable LM3914 dot/bar-display driver still enjoys wide popularity among designers. The LM3914 can sense an analog voltage level and display it on 10 LEDs by illuminating one of 10 in dot mode or by progressively illuminating LEDs in bar-graph mode. Recently, an application needed an analog-input-voltage display capable of displaying more than 10 levels in linear- and logarithmic-scale formats. According to the LM3914's data sheet, you can cascade multiple 3914s to display more than 10 levels (**Reference 1**), but, even so, the LM3914 offers only linear displays of its input voltage. (**Editor's note:** National Semiconductor also offers the LM3915, a logarithmic, 3-dB-per-step version, and the LM3916, which displays its input in volume units, for audio applications.)

This application required more flexibility than the LM3914 offers, and it uses a circuit based on an Atmel (www.atmel.com) AVR-family ATTiny13 microcontroller, which features 1 kbyte of program memory; a four-channel, 10-bit ADC; and six general-purpose I/O pins. Altering the circuit's firmware allows linear or logarithmic scaling of the 0 to 5V input-voltage range.

The circuit in **Figure 1** continuously displays the input voltage in 20 levels. When closed, switch S_1 freezes the displayed reading at its then-current level. Five of the microcontroller's six I/O pins control all 20 LEDs and the switch. Configured as an ADC-input channel, the remaining I/O pin receives the analog-input voltage. The microcontroller uses Charlieplexing, a method of using I/O lines to drive as many as N×(N−1) LEDs, to drive 20 LEDs with only five I/O pins (**references 2** through **4**).

The firmware is written in C and compiled using AVR-GCC, a freeware C compiler and assembler available in Windows and Linux versions at www.avrfreaks.net. It uses the Tiny13's internal 10-bit ADC operating in free-



NOTES:
ALL LEDs ARE SUPERBRIGHT, 3 MM DIAMETER.
S_1 IS NORMALLY OPEN IN RUN MODE, CLOSED TO HOLD READING.

Figure 1 Based on a low-cost microcontroller, this dot/bar LED driver operates in linear or logarithmic modes.

running, interrupt-driven mode to convert the analog-input voltage into a digital number. Upon completion of each conversion, the ADC generates an interrupt that a subroutine reads; the interrupt stores the ADC's converted output in a shared variable.

To provide a flicker-free display, an internal timer generates a 1875-Hz interrupt derived from the 9.6-MHz system clock to drive the multiplexed LEDs at a rate exceeding 90 Hz. Dividing the ADC count by a constant yields a linear display of the input voltage. A look-up table scales the ADC count to produce a logarithmic display. **Figure 2** shows the logarithmic-conversion curve that defines the look-up table's values. Versions of the ATTiny13's control programs for linear and logarithmic scales are available for downloading from the online version of this Design Idea at www.edn.com/070118di1. You can modify the source code to display only a particular subrange of the input voltage of 0 to 5V. For example, you can specify a linear-display range spanning 1 to 3V or a logarithmic scale for input voltages of 2 to 3V. **EDN**

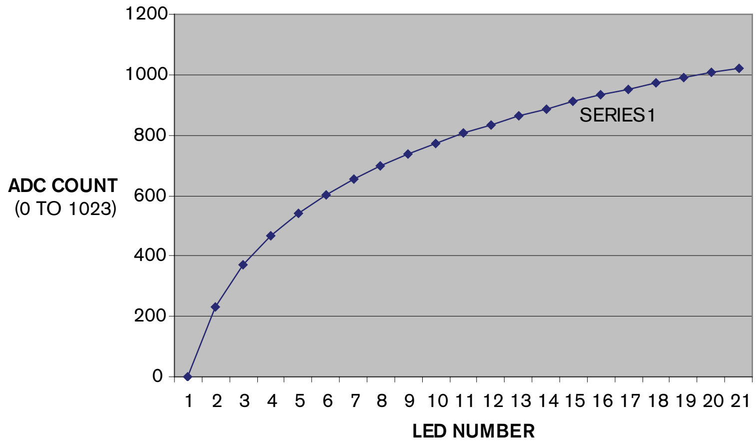


Figure 2 A linear-to-logarithmic-conversion curve defines the input voltage required to illuminate a particular LED.

REFERENCES

1 LM3914 data sheet, www.national.com/pf/LM/LM3914.html.

2 Lancaster, Don, "Tech Musings," August 2001, www.tinaja.com/glib/muse152.pdf.

3 "Charlieplexing: Reduced Pin-Count LED Multiplexing," Maxim Application Note 1880, Feb 10, 2003, http://pdfserv.maxim-ic.com/en/an/AN1880.pdf.

4 Benabadji, Noureddine, "PIC microprocessor drives 20-LED dot- or bar-graph display," *EDN*, Sept 1, 2006, pg 71, www.edn.com/article/CA6363904.

Optical feedback extends white LEDs' operating life

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Regardless of its color, an LED's light output varies as a function of forward current and ambient temperature. As **Figure 1** shows, an LED's light output can vary by as much as 150% over its operating-current range. In response, a designer's first attempt to solve the problem focuses on driving the LEDs with a constant current. The most common white-LED-driver circuits use an inductor-based dc/dc boost-converter topology similar to the circuit in **Figure 2**. A current-feedback controller ensures that the voltage across current-sensing resistor R_1 remains constant. As a result, the controller varies the voltage across the entire string to maintain the LEDs' current constant without regard to

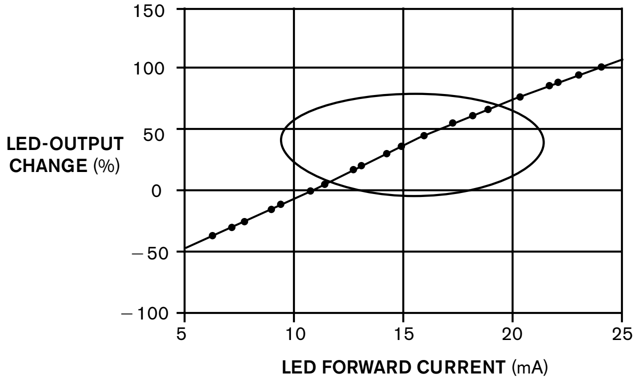

Figure 1 An LED's light output changes considerably as a function of its forward current, even within the sweet spot (oval area) of its nominal operating current.

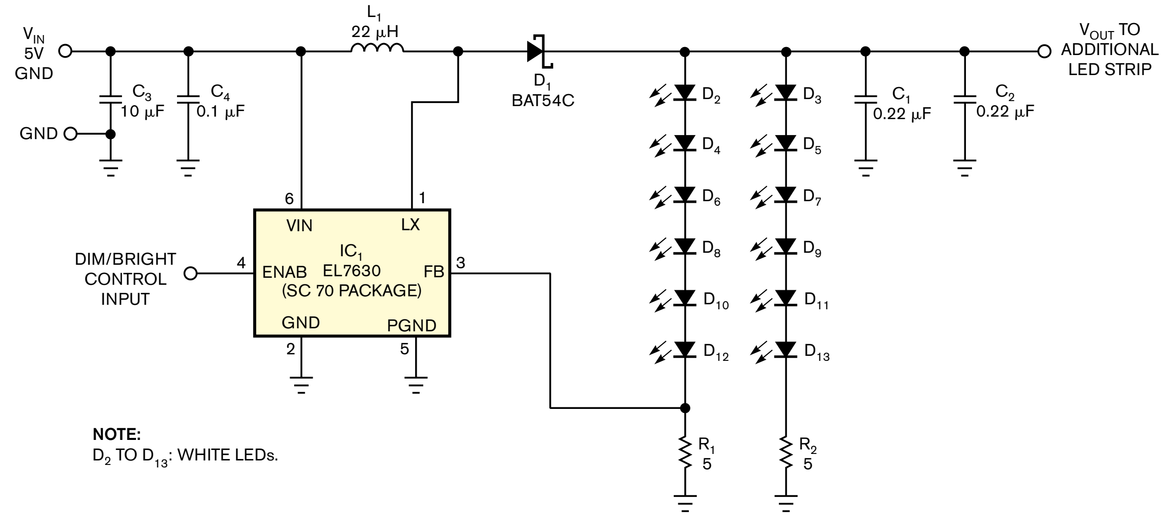

Figure 2 One method of driving an LED illuminator samples current through a string and adjusts the voltage across the entire string to maintain a constant current.

the LEDs' actual light output.

Driving series-connected white LEDs with a current source relies on the assumption that, at constant current, an LED's light output remains constant. Unfortunately, all LEDs exhibit a nonlinear decrease in brightness as a function of operating time. Although less obvious in colored LEDs that find use as indicators, the decrease in brightness of a white-LED-illuminator-array source becomes noticeable over an extended period. Brightness also varies as

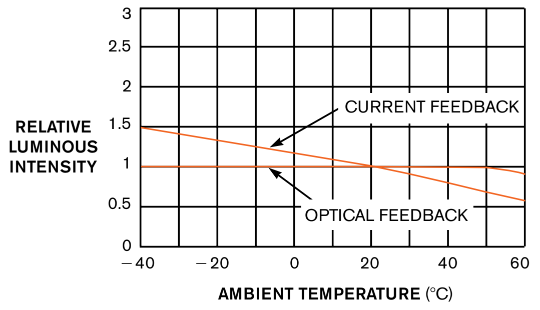

Figure 3 Even at a constant forward current, an LED's light output correlates strongly with temperature and can vary by as much as 100% over the entire operating-temperature range (upper curve).

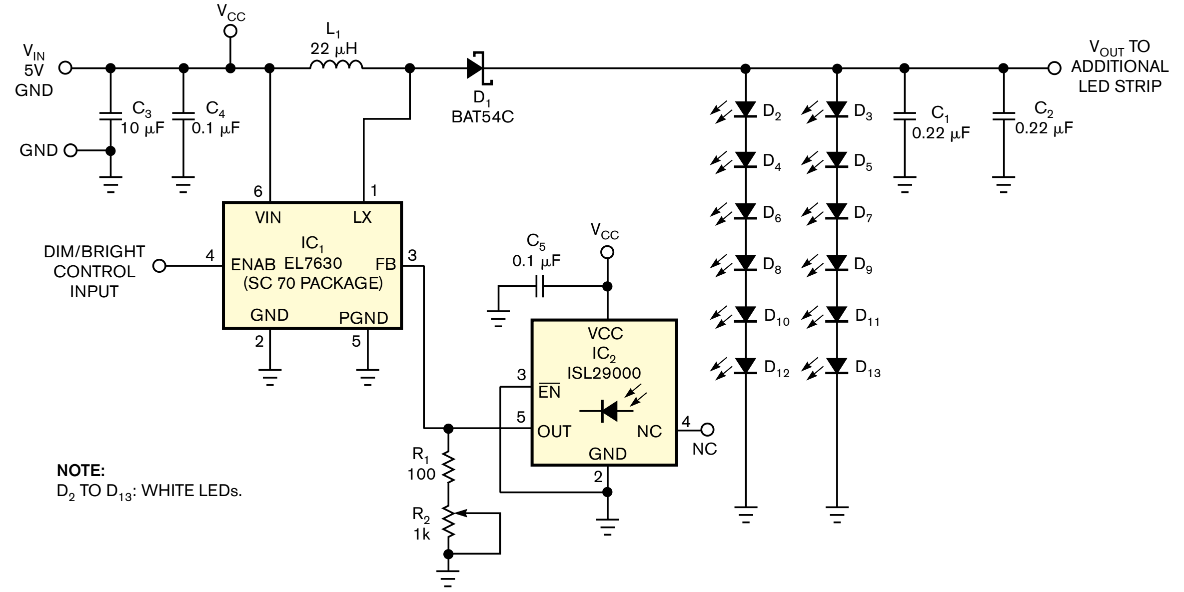

Figure 4 Photosensor IC$_2$, an Intersil ISL29000, resides near an LED to detect brightness fluctuations and provides compensating feedback to IC$_1$, the current controller, which is an Intersil EL7630 pulse-width regulator.

a function of temperature, which can affect an illuminator's performance over an extended-temperature range (upper curve, **Figure 3**).

To compensate for LED-output variations due to aging and temperature fluctuations, the control loop needs more information in addition to voltage or current data. Adding an ambient-light sensor and optical feedback to the control loop can ensure that a white LED's light output remains uniform and consistent over time and temperature variations. An optical sensor can measure the LED's light-output intensity and provide a feedback signal for the control loop, which can adjust the current to produce a relatively constant light output. As the LEDs' light outputs decrease, increased current compensates for aging and temperature-induced variations (lower curve, **Figure 3**).

The circuit in **Figure 4** includes an optical-feedback loop based on Intersil's (www.intersil.com) ISL29000 light-to-current optical sensor, IC_2, which senses changes in the LEDs' light output and decreases the feedback voltage applied to IC_1, the current controller, an Intersil EL7630. The pulse-width-modulated controller then increases the LED-drive current's duty cycle, boosting the LED current until the feedback voltage reaches its nominal value. As ambient temperature decreases, the LEDs' light output tends to increase, and IC_2 delivers a higher feedback voltage to the controller, which responds by lowering the duty cycle to decrease the LEDs' current and thereby compensates for the decrease in temperature.EDN

Sequencer controls power supplies' turn-on and turn-off order

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When a design based on multiple point-of-load dc/dc converters requires a specific power-supply-start-up sequence, wiring each converter's power-good output to the next converter's enable input produces the desired voltage cascade. Although this approach works well for simple designs, it fails to satisfy a requirement of many modern microprocessors and DSPs: that, during shutdown, the power-supply rails switch off in reverse order. Although various vendors provide programmable-sequencing ICs, these components are usually too expensive for cost-sensitive applications.

Offering an alternative to programmable-sequencing ICs, the circuit of **Figure 1** can sequence and cheaply

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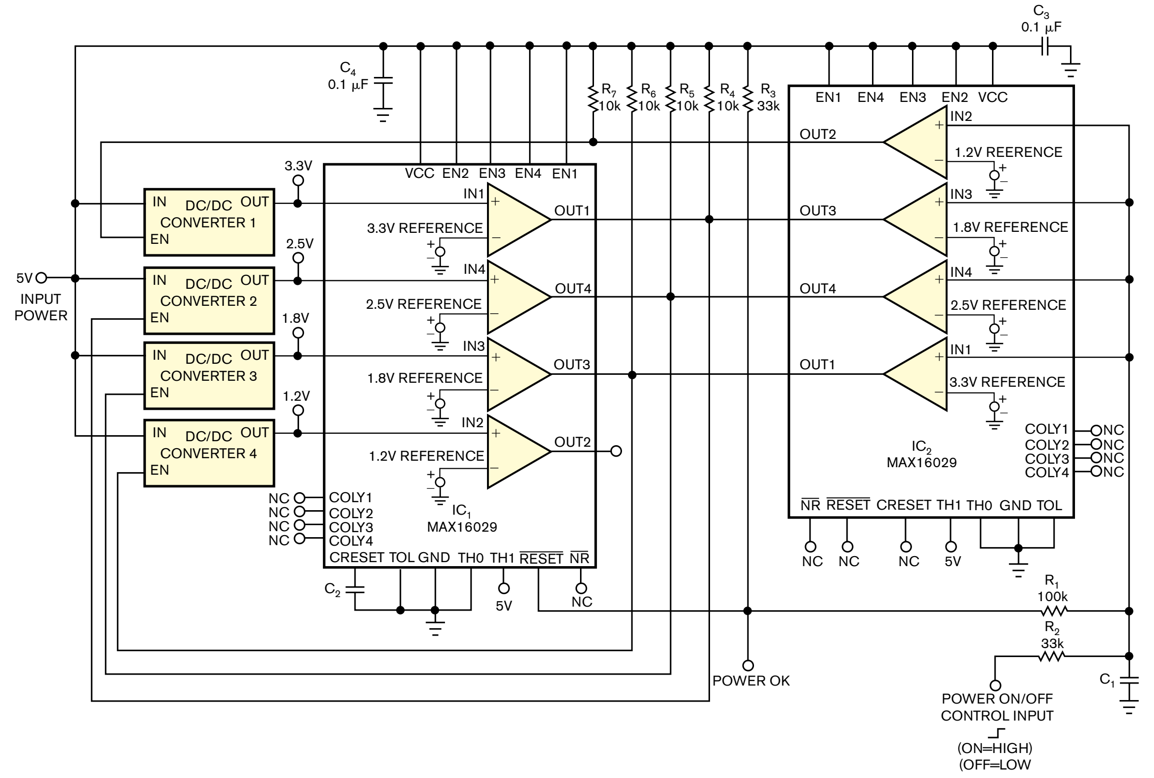

Figure 1 Comprising a pair of inexpensive ICs, this circuit applies four supply voltages in a specified order at power-up and then removes them in reverse order at power-down.

(continued from pg 88)

and effectively monitor four power-supply rails. Four dc/dc power supplies provide the application circuit with 3.3, 2.5, 1.8, and 1.2V. A quad supervisor circuit, IC_1, monitors each rail, generating the master POK (power-OK) signal and ensuring that, during power-up, the next supply in the sequence does not turn on until the preceding supply voltage is valid. Using an RC circuit comprising R_1, R_2, R_3, and C_1, a second quad supervisor, IC_2, creates the power-up and power-down sequences. Each supervisor's internally preset voltage threshold eliminates the need for external resistive-voltage dividers.

Connecting the power-on/off signal to 5V initiates a power-up sequence, which charges C_1 through R_2. As the capacitor's voltage gradually exceeds 1.2, 1.8, 2.5, and 3.3V, each of IC_2's corresponding open-drain outputs floats, thereby allowing the power supplies to turn on in the prescribed sequence. After a time delay, which C_2 sets, and after all four supplies turn on, the POK signal asserts—that is, goes high.

To monitor the supply rails, allow the power-on/off-control input to float. Resistors R_1 and R_3 sustain the voltage across C_1 and maintain the POK signal high to keep the power supplies on. When an output-voltage fault occurs, POK rapidly deasserts, discharging C_1 through R_1 and shutting off all of the power supplies. To remove power in an orderly sequence, connect the power-on/off signal to ground. Capacitor C_1 discharges through R_2 and also through R_1 when POK deasserts, turning off each power supply in reverse order (**Figure 2**).EDN

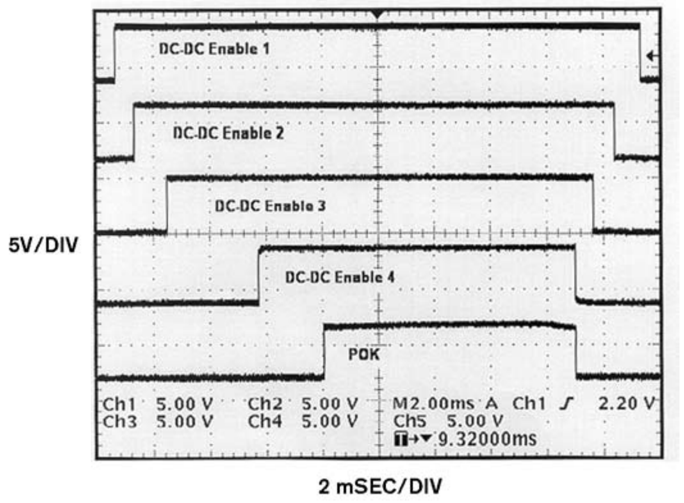

Figure 2 Beginning with a dc/dc converter, the circuit in Figure 1 switches on three additional converters in sequence and generates a POK signal. Pulling the circuit's on/off input low removes the POK signal and switches off all four converters in reverse order.

Use dual op amp in an instrumentation amp

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Editor's note: *Here's an oldie but goodie. EDN editors regularly field requests for copies of articles that predate our online archives (www.edn.com/archives). But this Design Idea from our Feb 20, 1986, issue has generated many more requests than normal. We aren't sure how readers know of this Design Idea, but its enduring popularity has led us to publish it once again, and now it will be available in our online archives.*

Although monolithic instrumentation amplifiers are more cost-effective than their discrete and modular predecessors, the limited variety of monolithic instrumentation amps restricts their use. You can widen your options, however, by deriving the differential response of an instrumentation amplifier from a dual op amp (**Figure 1**). The circuit uses FET-input op amps to provide lower noise and lower input-bias currents than monolithic instrumentation amps can offer.

In **Figure 1**, feedback networks for the two op amps are interconnected to establish IC_{1B} as an inverting amplifier in the feedback path of IC_{1A}. Each amplifier provides an external signal input with the high impedance expected of an instrumentation amplifier. (Input-bias currents for this circuit are 2 pA at 25°C.)

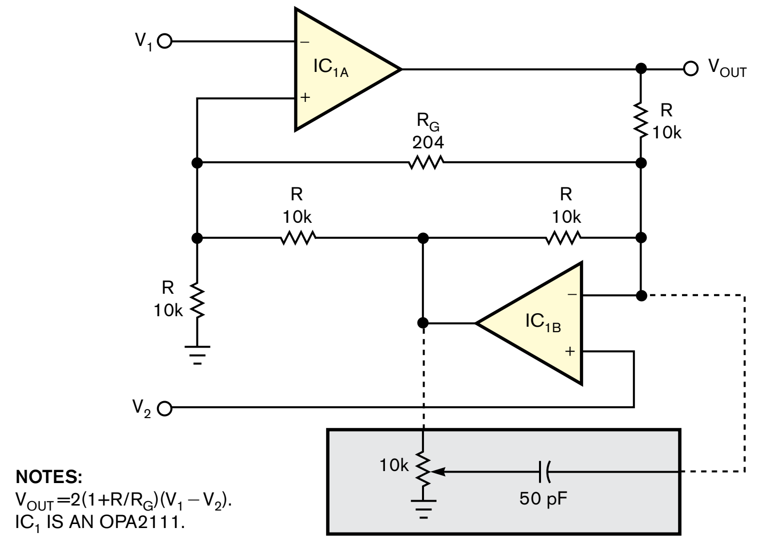
Feedback from each amplifier forces a voltage (V_1-V_2) across the gain-setting resistor R_G. Signal current in the combined feedback path is thus proportional to the differential input voltage and inversely related to R_G. The output voltage, V_{OUT}, equals $G(V_1-V_2)$—that is, $V_{OUT}=2(1+R/R_G)(V_1-V_2)$.

You choose R_G for the desired gain G, which may range from a value of 2 (R_G omitted) to a maximum that is limited only by the op amps' open-loop gain, the allowable gain error, and the required bandwidth. The **Figure 1** circuit provides a 2-kHz bandwidth at a gain of 2000; in general, the bandwidth is about 2 MHz/G. What's more, the output offset equals the difference in op-amp offsets multiplied by G.

The dc CMR (common-mode rejection) is an important spec for instrumentation amps; in **Figure 1**, CMR depends primarily on matching values for the four resistors labeled R. DC CMRR (common-mode rejection ratio) is the reciprocal of the net fractional resistor mismatch; that is, 10,000-to-1 (−80 dB) for a 0.01% mismatch. AC CMR, on the other hand, is limited by the op amps' unequal feedback factors. The network within the shaded region lets you compensate for the effect of unequal feedback factors where necessary—in applications in which the frequency of common-mode voltage exceeds the useful frequency range for signals.

Finally, note that op amp IC_{1B}'s output (the combined differential and common-mode signals) has a wider swing than V_{OUT}. Consequently, this output—equal to $2V_1+(R/R_G)(V_1-2V_2)$—must remain within the op amp's common-mode range to ensure linear operation.**EDN**

Correction: In the print version of the Dec 15, 2006, Design Idea "Magnetic-field probe requires few components," we inadvertently omitted the byline of one of the Design Idea's primary authors: Sandeep M Satav. You can read this Design Idea and see the correct bylines online at www.edn.com/article/CA6399102. We apologize for the error.



NOTES:
$V_{OUT}=2(1+R/R_G)(V_1-V_2)$.
IC_1 IS AN OPA2111.

Figure 1 You can build an instrumentation amplifier by providing a common feedback path for the two sides of a dual op amp.