design ideas

Edited by Bill Travis and Anne Watson Swager

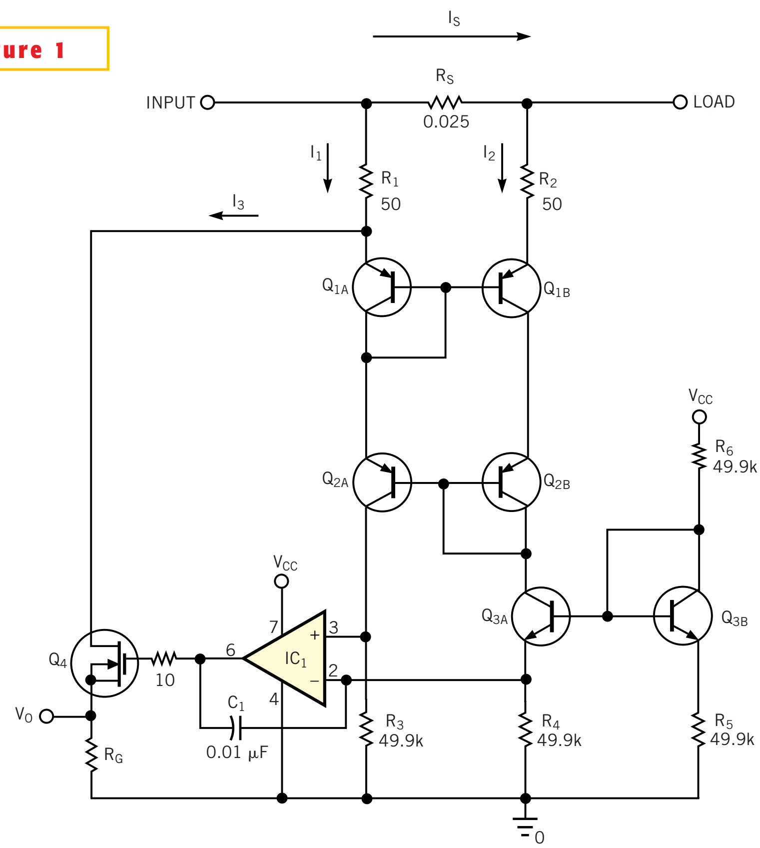
Circuit senses high-side current

Bob Bell and Jim Hill, On Semiconductor, Phoenix, AZ

The accurate, high-side, current-sense circuit in **Figure 1** does not use a dedicated, isolated supply voltage, as some schemes do. Only the selected transistors limit the common-mode range. The circuit measures the voltage across a small current-sense resistor, R_S. The operation of the circuit revolves around the high-side current mirror comprising Q_1 and Q_2. All the circuit components have one overall function: to make the collector currents equal in Q_1 and Q_2. The additional current mirror using Q_3 sets the values of the collector currents. The collector current is $(V_{CC}-0.7)/(R_5+R_6) \simeq 100\ \mu A$. You can best calculate the gain of the circuit by analyzing the loop formed by R_1, R_S, R_2, Q_{1B} (emitter base), and Q_{1A} (base emitter). In **Figure 1**, the currents are I_S, the high-side measurement current; I_1 and I_2, the mirror currents of Q_{1A} and Q_{1B}; and I_3, a branch current from the emitter of Q_{1A}.

When you sum the currents around the loop, $(I_S \cdot R_S) + (I_2 \cdot R_2) + VQ_{1B}(e-b) - ((I_1+I_3) \cdot R_1) = 0$. Because $I_1=I_2$, $R_1=R_2$, and the emitter-base voltages are equal, $I_3=I_S \cdot R_S/R_1$. Looking at the remaining circuitry, the op amp keeps the transistors' collector currents equal by controlling I_3 through Q_4. Therefore, the overall transfer function is $V_{OUT}=I_S \cdot R_S \cdot R_G/R_1$. For $R_G=1\ k\Omega$, the transfer function is $V_{OUT}=0.5 \cdot I_S$. The circuit can operate over a common-mode input range of approximately 10V to several hundred volts, limited by the selected transistors.

Figure 1



NOTES: IC_1 IS AN MC33202 RAIL-TO-RAIL OP AMP.
Q_1 AND Q_2 ARE SC-88 MBT3906 DUAL PNPs.
Q_3 COMPRISES MBT3904 SC-88 DUAL NPNs.
Q_4 IS A 2N7002 SOT-23 FET.

This circuit measures high-side currents without the need for auxiliary power supplies.

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Adjustable filter provides lowpass response

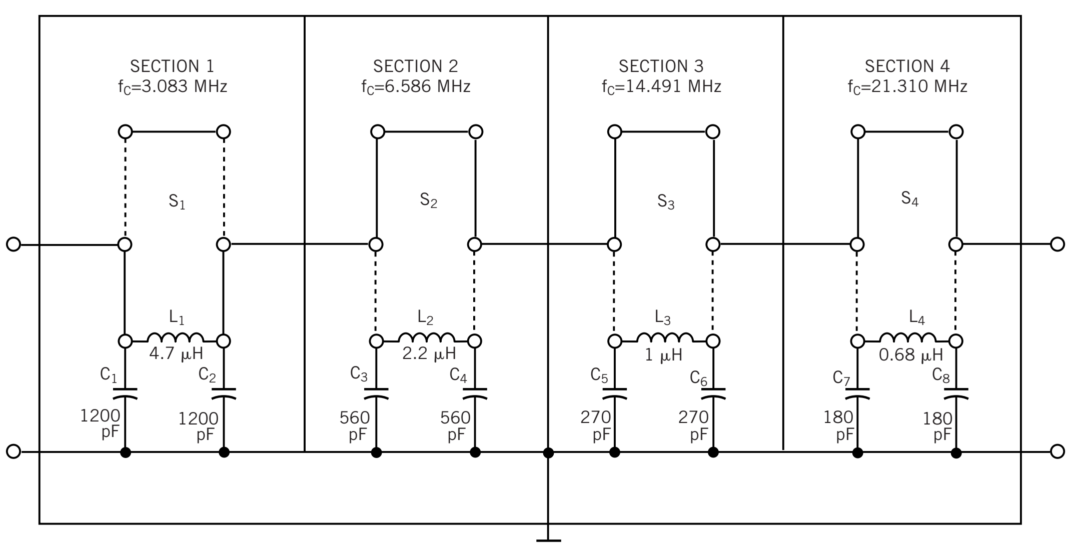
Richard Kurzrok, Queens Village, NY

You can configure simple lowpass filters as pi sections with nominal three-pole, 0.1-dB Chebyshev response to provide a moderate amount of stopband selectivity. You can put four of these filters into one enclosure and then select discrete-filtering steps by using toggle switches. Manufacturers of commercially available stepped attenuators and adjustable baseband equalizers commonly use this technique (**Reference 1**). In an adjustable lowpass filter, each filter section uses commonly available components (**Figure 1**). This example uses filter-section cutoff frequencies for standard

TABLE 1—MEASURED AMPLITUDE RESPONSE OF ADJUSTABLE LOWPASS FILTER

Frequency (MHz)	Box insertion loss (dB)	Filter 1 insertion loss (dB)	Filter 2 insertion loss (dB)	Filter 3 insertion loss (dB)	Filter 4 insertion loss (dB)
1	<0.1	0.1	<0.1	<0.1	<0.1
2	<0.1	0.3	0.1	0.1	0.1
2.5	<0.1	0.6	0.1	0.1	0.1
2.9	<0.1	1.7	0.1	0.1	0.1
3.1	<0.1	2.5	0.15	0.1	0.1
3.3	<0.1	3.3	0.15	0.1	0.1
4	<0.1	7.3	0.2	0.1	0.1
5	<0.1	13	0.45	0.2	0.1
6	<0.1	17.9	1.3	0.25	0.15
6.5	<0.1	20	2.1	0.25	0.2
7	<0.1	21.8	3.1	0.25	0.2
9	<0.1	28.2	8.3	0.4	0.2
12	<0.1	33.4	15.3	1.3	0.25
14	<0.1	34.8	19.4	2.9	0.4
17	<0.1	35.2	24.5	6.4	0.9
20	<0.1	35.3	26.4	10.2	2.1
23	<0.1	>35	28.8	14.5	4
30	0.1	>35	31.7	19.2	9.9
50	0.2	>34	>34	23.5	20
100	0.5	>28	>28	>24	>24

Figure 1



NOTE: ALL SWITCHES ARE DOUBLE-POLE, DOUBLE-THROW TOGGLE SWITCHES.

A switchable lowpass filter provides a choice of four distinct cutoff frequencies.

inductors and capacitors without the need for any extra components in series or parallel. Fixed inductors are Coilcraft 90 series axial-lead chokes with ±10% tolerance. Fixed capacitors are polypropylene units, available from any distributor, with ±2% tolerance for the 1200-pF devices and ±5% tolerance for the other values.

The adjustable lowpass filter is in a 3.625-in.-long×1.5-in.-wide×1.0625-in.-high Bud CU-123 die-cast aluminum box with input and output BNCs. Miniature toggle switches for the individual filter sections are accessible at the enclosure's exterior. Internal ground returns use solder lugs. The four filter sections have 50Ω characteristic impedance and nominal 3-dB cutoff, from left to right in **Figure 1**, of 3.083, 6.586, 14.491, and 21.310 MHz. **Table 1** shows the measured amplitude response for the box alone and for the four individual filter sections. The low-cost, adjustable lowpass filter delivers reasonable performance. As the frequency approaches 100 MHz, the transmission performance of the enclosure deteriorates with all filter sections switched to the off position. The interconnections between switched sections use available bus wire without any precautions to minimize parasitic circuit elements. Stray series inductance, estimated at approximately 55 nH, arises from the 3.5-in. physical length of the enclosure, plus 2 in. for the four switches.

REFERENCE

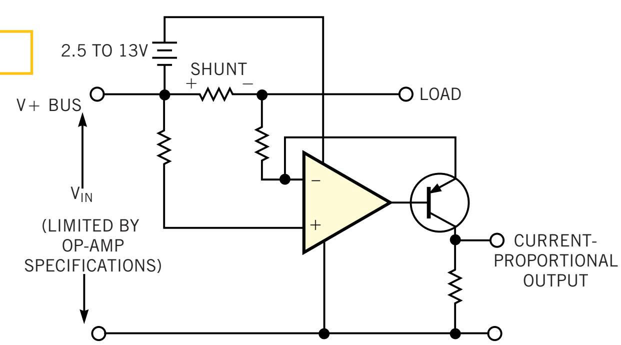
1. Kurzrok, Richard, "Adjustable-amplitude equalizer provides small discrete steps," *Electronic Design*, May 31, 1999, pg 76.

Monitor high-side current without an external supply

Vijay Damle, Digitronics, Pune, India

Typical high-side current-sensing circuits require a dc source that is 2.5 to 13V greater than the V+ high-bus voltage (**Figure 1**). Generating this supply is painful in many situations. For example, in power supplies for TV transmitters, the main SMPS (switch-mode power supply) output supplies the power amplifier, and a series switching regulator steps down the main SMPS output to drive the exciter. The system must remotely display the currents of both of these supply outputs, with 0 to 50A corresponding to 0 to 5V referred to sense V−. Because of the presence of a series switch, the V− lines of both outputs are common. Thus, you cannot use shunts in the V− line and amplify. Shunts are necessary on the positive bus of both the outputs. The main output supplies 30 to 45V at 30A, and the exciter supply outputs 22 to 26V at 10A. You need costly Hall-effect sensors to achieve the proportional output, though isolation is not required.

Figure 1



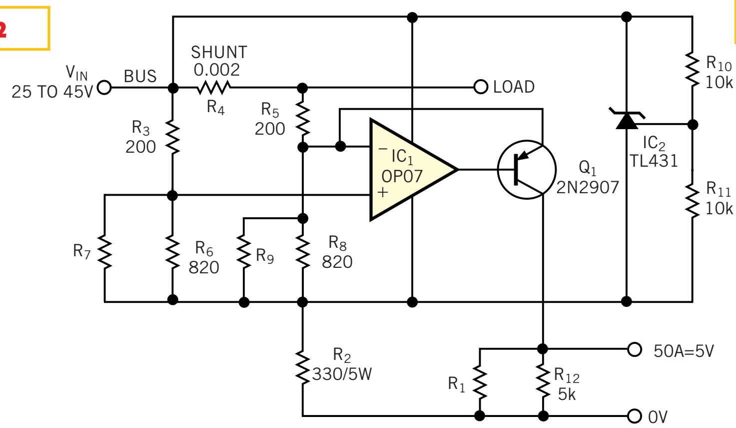
Typical high-side current-sensing circuits require a dc source that is 2.5 to 13V greater than the V+ high-bus voltage; generating this supply can be difficult.

An alternative approach for this application takes advantage of low-offset op-amp characteristics to design a circuit that works with a wide voltage range and needs no other supply. The V+ and inverting and noninverting terminals of the OP07 op amp need a minimum of approximately 2 to 2.5V to function properly. Thus, you can pull the op amp's inputs by more than 2.5V below the positive-supply connection and tie the op amp's V+ pin to shunt V+ (**Figure 2**).

In the circuit, IC_2 with R_{10} and R_{11} generate a 15V output. The R_3 and R_6 pair and R_5 and R_8 pair form dividers such that the op amp's inverting and noninverting inputs are approximately 3V less than the V+ supply of the op amp. You can use R_7 and R_9 to trim the offset to avoid the need for potentiometers. Op amp IC_1 and Q_1 generate a current that is proportional to the shunt voltage. R_{12} generates a voltage that is proportional to the drop across shunt R_4. R_1 trims the gain.

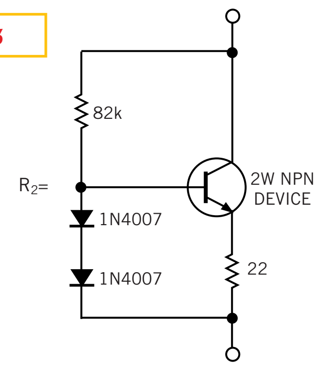
If you use this circuit at less than 25V, then you can delete IC_2, R_{10}, and R_{11}. You should also ground IC_1's V− pin by shorting R_2, and you can replace R_2 with a constant-current source to reduce the power due to bus-voltage variation (**Figure 3**.)

Figure 2



A modified current-monitoring circuit pulls the op-amp inputs below the positive supply voltage.

Figure 3



At voltages less than 25V, you can replace R_2 with a constant-current source.

This circuit was tested for 0 to +55°C, and it maintained proportional output within ±1% for a bus-voltage variation of 25 to 45V over this temperature range.

This approach has many advantages. An external supply is unnecessary. The circuit is suitable for bus voltages of 5 to 60V with component changes. Other circuits have limitations due to op-amp absolute-maximum voltage ratings. The circuit acts as the minimum load that SMPS outputs normally require, which eliminates or reduces high-wattage resistance across the output. You can easily scale the circuit for different proportional outputs. You can add a buffer amplifier to reduce the output impedance, and the buffer can derive its supply across R_2, which increases its operating supply range by 15V or more. One limitation is that, in the case of a short circuit, the current-proportional output drops to zero.

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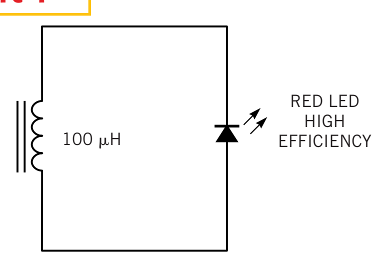
Noncontact device tests power supplies

Alberto Ricci Bitti, Eptar, Imola, Italy

THE PROBELIKE DEVICE in **Figure 1** comes in handy as a quick go-no-go test for step-down power supplies. You can build it using a very bright surface-mount LED and an inductor of the same type as in the power supply, which in this case is 100 μH. Placing this probe close to a working step-down power-supply coil lights the LED. The probe lights when the distance from the step-down coil is as much as 1 cm, making the probe capable of testing even plastic-encased or epoxy-filled power supplies. Industrial engineers will particularly appreciate the capability of not touching the circuit, which is also a useful feature when testing boards that operate without insulation from the mains.

Figure 1



An LED and an inductor make a simple probe for testing power-on of the supply.

For optimum performance, use a very bright-red LED. Other colors feature greater forward voltages, which reduce the sensitivity. You are not restricted to surface-mount LEDs, although this type helps by keeping the probe small and rugged.

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Single chip detects optical interruptions

Frederick M Baumgartner, FM Broadcast Services, Parker, CO

Setting up a light beam and detector to count objects on a conveyer belt, sense security intrusions, or drive a tachometer is simple. However, the task is no longer trivial if you add ambient light or multiple beams, limit optical power, or extend the distance of the light beam more than a few inches. You can use optical lenses and filters and high-power optical sources on the light-path side to improve performance. On the electronic side, servo-bias control of the detector and electronic modulation and filtering of the light beam can add considerable range. The circuit in **Figure 1**, which you can use with these performance improvements, economically provides a minimal-parts-count circuit with negligible power requirements to achieve approximately a foot of useful range even under varying ambient-light conditions.

The venerable LM567 PLL is the only IC in the circuit. The 567's oscillator directly drives an infrared LED on the optical-transmitter end. When the pulsed light returns to the IR phototransistor, a single-stage 2N2222 transistor amplifies the resultant signal to drive Pin 3 of the LM567. Thus, the circuit essentially directs the PLL to lock to itself, which makes Pin 8 go low. The values of R_1 and C_1 provide operation of approximately 3 kHz, and the filters set by C_2 and C_3 provide a clean output from the 567. Operation from 2 to 5 kHz works best. Lower frequencies require more conditioning and thus larger and more critical values of C_2 and C_3, resulting in longer response times and possible jitter. Higher frequencies result in lower efficiencies for the cheap LED and phototransistor. However, tachometers may require higher frequencies. IR components are unnecessary. Two same-color LEDs (one for the photo detector) also work to a degree.

Ambient light or another beam breaker's IR light doesn't false-trigger the circuit unless significant near-frequency light content exists. However, ambient light can swamp the detector, so you may need to adjust the R_2 bias for your application. Of course, using a self-adjusting module with IR filters can easily increase the range by two orders of magnitude.

One interesting variation of the circuit is to use two or more devices on the same frequency, forming a ring. All devices lock, and both ends detect a break in any beam or a modulation of the frequency of any device for communication.

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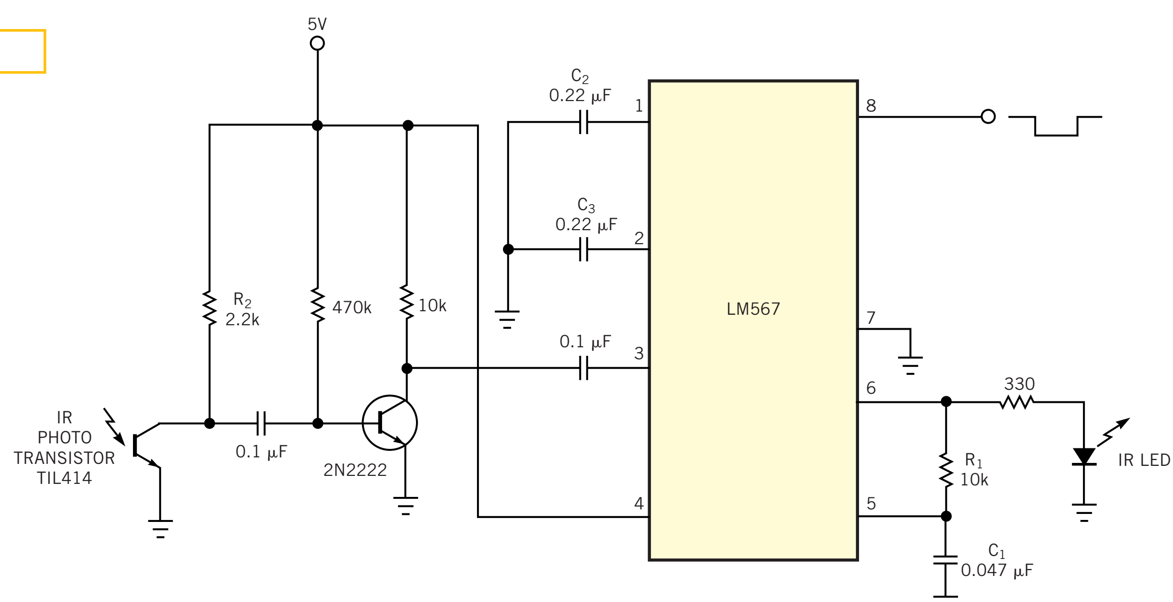
Figure 1



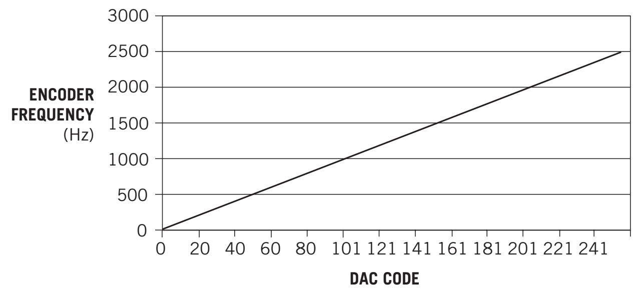
A light-beam-breaker detector uses just one IC and a few external components.

Programmable source powers dc micromotors

VK Dubey, JP Rao, and P Saxena, Centre for Advanced Technology, Indore, India

THE CIRCUIT in **Figure 1** is a simple, economic, compact, and tricky way of using the LM723 as a programmable voltage source to drive dc micromotors. Because of the μPs' accurate positioning and control, these motors are useful in applications such as optical mounts and flexible shaft control, which take advantage of the higher speed and fast movement of servo controls compared with stepper motors. These designs require a stable, programmable dc-voltage source.

Figure 2



The DAC-code versus encoder-frequency, or speed, curve is linear.

The LM723 is a fixed linear regulator, but this application configures the regulator as a programmable voltage source. You can set the output to a value of 200 mV to 6V. The output, an emitter-follower type, provides low output impedance. The circuit limits the maximum output current to the load, or the motor, at 75 mA. The output of an 8-bit DAC and a current/voltage converter provide a variable reference voltage. At the noninverting input of the LM723, you need to adjust the value of R_1 so that the maximum reference voltage does not exceed 8.5V. Because the reference voltage comes from an external source, the circuit doesn't use the internal voltage reference of the LM723. The circuit also incorporates short-circuit current limiting and remote shutdown. Varying the output voltage changes the speed of the motor that connects across the output.

You adjust the minimum output voltage of 200 mV by offsetting the DAC output with zero data, and successive DAC input codes increase the voltage-source output to 6V. You can use a single-chip μC for controlling the speed through the DAC, the direction, and the brake. The no-load maximum speed is 15,100 rpm. By attaching a reduction gear-head with a ratio of 529-to-1, the maximum frequency from the magnetic encoder in response to maximum speed is 2.8 kHz. The circuit feeds back this signal to the μC to measure the speed. The linearity of the voltage source is good over a voltage, temperature, and speed range (**Figure 2**). With only slight modifications in component values and ratings, you can use this same LM723 configuration in other similar applications for higher output voltages.

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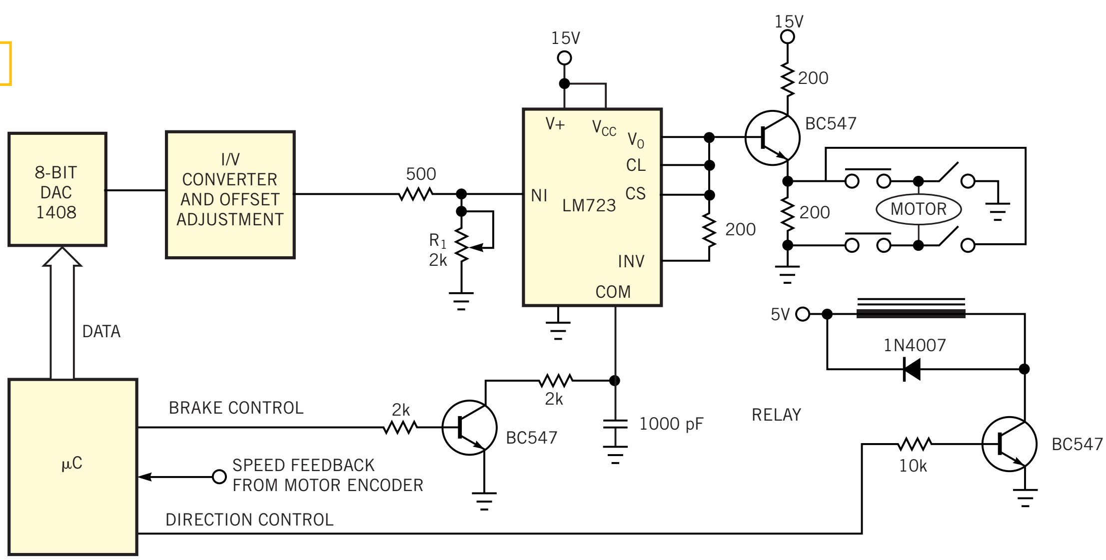
Figure 1



NOTES:
RELAY=TWO-CHANGEOVER REED RELAY.
MOTOR=FAULHABER DC MICROMOTOR TYPE 1219-006 G, MICRO-ENCODER TYPE 30B.

Configuring an LM723 as a programmable voltage source provides a variable dc source for driving dc micromotors.

Optocoupler extends high-side current sensor to 1 kV

Roger Griswold, Maxim Integrated Products, Sunnyvale, CA

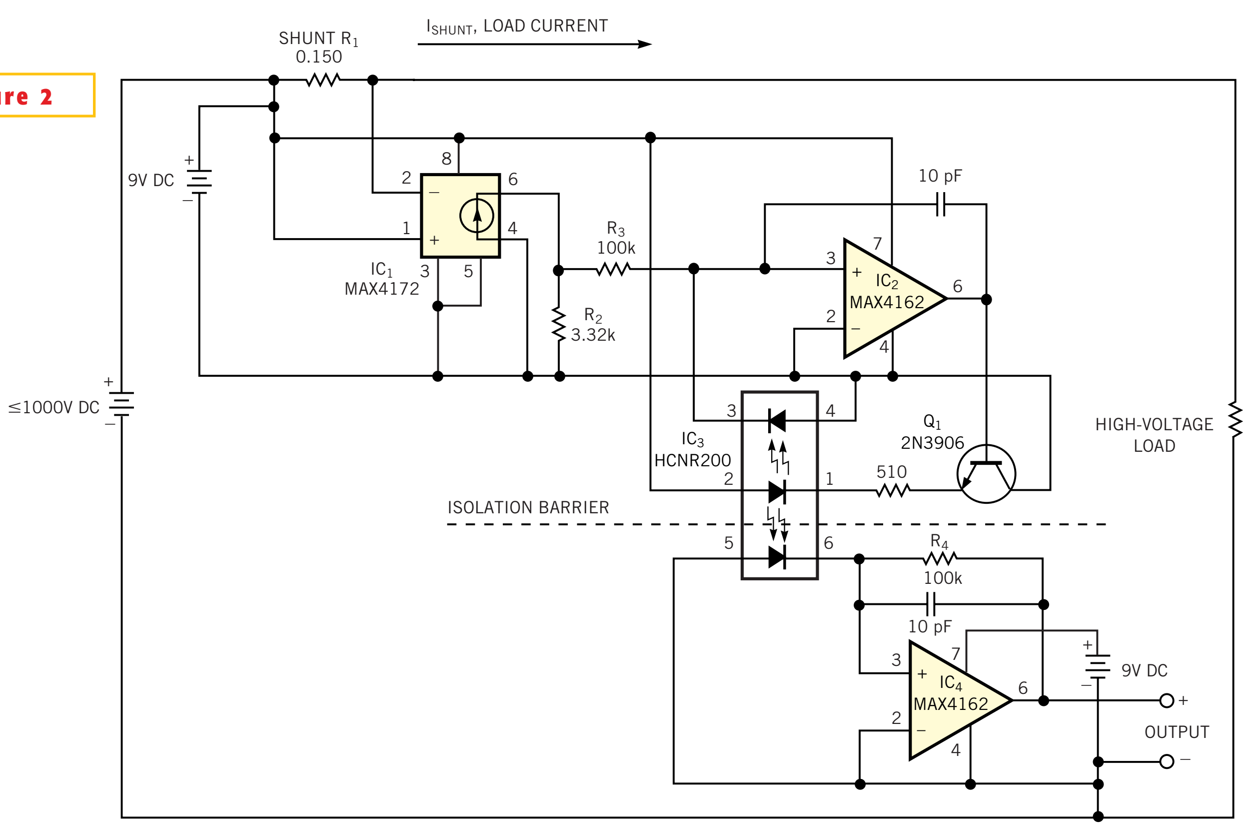
The task of sensing dc current at high voltage is often problematic. Most high-side current-sensing ICs available off the shelf are good only to 30 or 40V. Combining an optocoupler with such an IC yields a sensing circuit in which the only limitation of the high-side voltage is the optocoupler's standoff voltage (**Figure 1**).

A precision, high-side current-sense amplifier, IC_1, and a high-linearity analog optocoupler, IC_3, extend the high-side working voltage to 1000V dc. IC_3 supports a continuous 1000V dc. Its UL rating is 500V rms for 1 minute, and its transient surge rating is 8000V dc for 10 seconds. You should follow all proper safety precautions when working with high voltage.

The circuit has a floating section and a grounded section, each requiring a local low-voltage supply. The floating section detects load current and drives the high-voltage side of the optocoupler. The grounded section monitors the optocoupler's low-voltage side and outputs a voltage proportional to the high-side load current. IC_3 has a feedback photodiode on the high-voltage side that virtually eliminates the LED's nonlinearity and drift characteristics. In addition, IC_3's two closely matched photodiodes ensure a linear transfer function across the isolation barrier.

During operation, the load current passes through shunt R_1 and produces a small voltage. IC_1 monitors this voltage and outputs a proportional current of 10 mA/V. This proportional output current routes through R_2, which produces a voltage proportional to the main load current. The rest of the circuit generates a copy of the voltage across R_2 but on the low-voltage side of the optocoupler. IC_2 monitors the voltage across R_2 and drives the optocoupler's LED via Q_1. The LED generates light that impinges equally on the high- and low-side photodiodes. IC_4 monitors the low-side photodiode and outputs a voltage proportional to the high-side load current. A graph shows the

Figure 2



The ground-referenced output voltage, $V_{OUT} = I_{SHUNT}$ (4.80V/A), is proportional to the high-side load current. As configured, the circuit measures load currents to 1A.

output voltage as a function of shunt current (**Figure 2**).

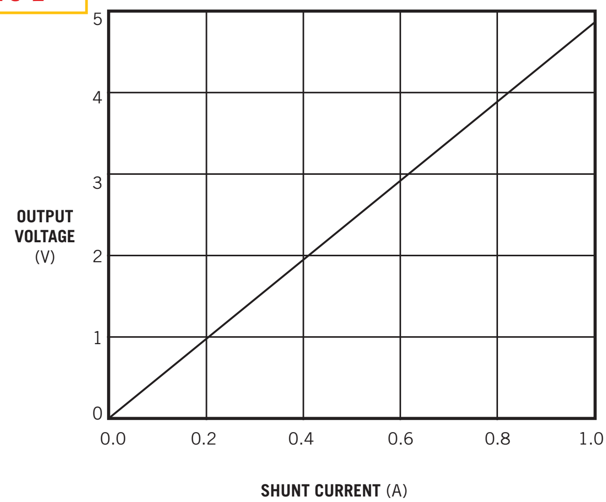
If R_3 and R_4 are equal, the overall transfer function is:

$$\frac{V_{OUT}}{I_{SHUNT}} = 0.01 \bullet R_1 \bullet R_2.$$

Three parameters let you modify the circuit to monitor other maximum load currents and output a different voltage range. The maximum IC_1 output current is 1.5 mA, so the maximum allowed shunt voltage is 150 mV. Also, the maximum allowed photodiode current is 50 μA. Choose an R_1 value that produces 150 mV at the maximum load current that the circuit monitors. Then, choose an R_2 value that produces the desired corresponding maximum output voltage at 1.5 mA. Match R_3 and R_4, and choose a value that allows less than 50 μA through the photodiode at the maximum desired output voltage, or

$$R_3 \geq \frac{V_{OUT\_MAX}}{50 \times 10^{-6}}.$$

Figure 2



The output voltage versus shunt current is linear.

The circuit output then faithfully reproduces the voltage across R_2. The MAX4162 op amp is a good choice for this circuit because of its input-bias current of 1 pA, its rail-to-rail input and output swings, and its ability to operate from one 9V battery. With R_1=150 mΩ and R_2=3.32 kΩ, the output voltage for I_{SHUNT} =1A is 4.80V using the given transfer function. Experimental results at I_{SHUNT}=1.00A give V_{OUT}= 4.84V with an error less than 1%.

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