Circuit senses high-side current

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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 $(V_{CC} - 0.7)/(R_5 + R_6) = 100 \mu A$. 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, $(I_S - R_S) + (I_1 - R_2 + V_{Q1B}(e-b)) - ((I_1 + I_2) - R_1) = 0$. Because $I_1 = I_2$, $R_1 = R_2$, and the emitter-base voltages are equal, $I_3 = I_1 \cdot R_S / R_1$. Looking at the remaining circuitry, the op amp keeps the transistors' collector currents equal by controlling $I_2$ through $Q_4$. Therefore, the overall transfer function is $V_{OUT} = I_1 \cdot R_3 \cdot R_5 / R_2$. For $R_5 = 1 \text{k} \Omega$, 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.

Adjustable filter provides lowpass response
Richard Kurzrok, Queens Village, NY

You can configure simple lowpass filters as π 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 values.

### TABLE 1—MEASURED AMPLITUDE RESPONSE OF ADJUSTABLE LOWPASS FILTER

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Box Filter 1</th>
<th>Filter 2</th>
<th>Filter 3</th>
<th>Filter 4</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Insertion loss (dB)</td>
<td>Insertion loss (dB)</td>
<td>Insertion loss (dB)</td>
<td>Insertion loss (dB)</td>
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<td>1</td>
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<td>0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
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<td>0.3</td>
<td>0.1</td>
<td>0.1</td>
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<tr>
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<td>&lt;0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
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<td>&lt;0.1</td>
<td>1.7</td>
<td>0.1</td>
<td>0.1</td>
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<td>&lt;0.1</td>
<td>2.5</td>
<td>0.15</td>
<td>0.1</td>
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<tr>
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<td>3.5</td>
<td>0.15</td>
<td>0.1</td>
</tr>
<tr>
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<td>0.1</td>
<td>0.1</td>
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<tr>
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<td>0.45</td>
<td>0.1</td>
</tr>
<tr>
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<td>&lt;0.1</td>
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<td>1.3</td>
<td>0.25</td>
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<td>2.1</td>
<td>0.25</td>
</tr>
<tr>
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<td>&lt;0.1</td>
<td>21.8</td>
<td>3.1</td>
<td>0.25</td>
</tr>
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<td>28.2</td>
<td>8.3</td>
<td>0.4</td>
</tr>
<tr>
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<td>33.4</td>
<td>15.3</td>
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<td>19.4</td>
<td>2.9</td>
</tr>
<tr>
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<td>&lt;0.1</td>
<td>35.2</td>
<td>24.5</td>
<td>6.4</td>
</tr>
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<td>&gt;34</td>
<td>&gt;34</td>
<td>23.5</td>
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<tr>
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<td>0.5</td>
<td>&gt;28</td>
<td>&gt;28</td>
<td>&gt;24</td>
</tr>
</tbody>
</table>

**Figure 1**

Section 1: $f_c=3.083$ MHz
Section 2: $f_c=6.586$ MHz
Section 3: $f_c=14.491$ MHz
Section 4: $f_c=21.310$ MHz

**NOTE:** All switches are double-pole, double-throw toggle switches.

A switchable lowpass filter provides a choice of four distinct cutoff frequencies.
Monitor high-side current without an external supply

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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.

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 input 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, IC1 with R7 and R8 generate a 15V output. The R4 and R5 pair and R6 and R7 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 R1 and R2 to trim the offset to avoid the need for potentiometers. Op amp IC1 and Q1 generate a current that is proportional to the shunt voltage. R12 generates a voltage that is proportional to the drop across shunt R4. R1 trims the gain.

If you use this circuit at less than 25V, then you can delete IC3, R9, and R10. You should also ground IC3’s V− pin by shorting R9, and you can replace R4 with a constant-current source to reduce the power due to bus-voltage variation (Figure 3.)
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.

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.

Noncontact device tests power supplies

Alberto Ricci Bitti, Eptar, Imola, Italy

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 R₁, 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.

Single chip detects optical interruptions

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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 R1 and C1 provide operation of approximately 3 kHz, and the filters set by C2 and C3 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 C2 and C3, 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 R2 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.

A light-beam-breaker detector uses just one IC and a few external components.
**Programmable source powers dc micromotors**

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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.

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 non-inverting input of the LM723, you need to adjust the value of R1 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.

**Figure 2**

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

![Figure 1](image-url)

**Figure 1**

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, IC1, and a high-linearity analog optocoupler, IC3, extend the high-side working voltage to 1000V dc. IC3 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. IC3 has a feedback photodiode on the high-voltage side that virtually eliminates the LED’s nonlinearity and drift characteristics. In addition, IC3’s two closely matched photodiodes ensure a linear transfer function across the isolation barrier.

During operation, the load current passes through shunt R1 and produces a small voltage. IC1 monitors this voltage and outputs a proportional current of 10 mA/V. This proportional output current routes through R2, which produces a voltage proportional to the main load current. The rest of the circuit generates a copy of the voltage across R2 but on the low-voltage side of the optocoupler. IC2 monitors the voltage across R2, and drives the optocoupler’s LED via Q1. The LED generates light that impinges equally on the high- and low-side photodiodes. IC1 monitors the low-side photodiode and outputs a voltage proportional to the high-side load current. A graph shows the

The ground-referenced output voltage, $V_{out} = I_{SHUNT} \times 4.80V/A$, 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 $R_1$ and $R_4$ are equal, the overall transfer function is:

$$V_{OUT} = 0.01 \cdot R_1 \cdot R_2.$$  

Three parameters let you modify the circuit to monitor other maximum load currents and output a different voltage range. The maximum IC1 output current is 1.5 mA, so the maximum allowed shunt voltage is 150 mV. Also, the maximum allowed photodiode current is 50 $\mu$A. 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 $\mu$A through the photodiode at the maximum desired output voltage, or

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

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 $R_1=150$ m$\Omega$ and $R_2=3.32$ k$\Omega$, the output voltage for $I_{SHUNT} = 1$A is 4.80V using the given transfer function. Experimental results at $I_{SHUNT} = 1.00$A give $V_{OUT} = 4.84$V with an error less than 1%.