A dual-polarity, bidirectional current-shunt monitor

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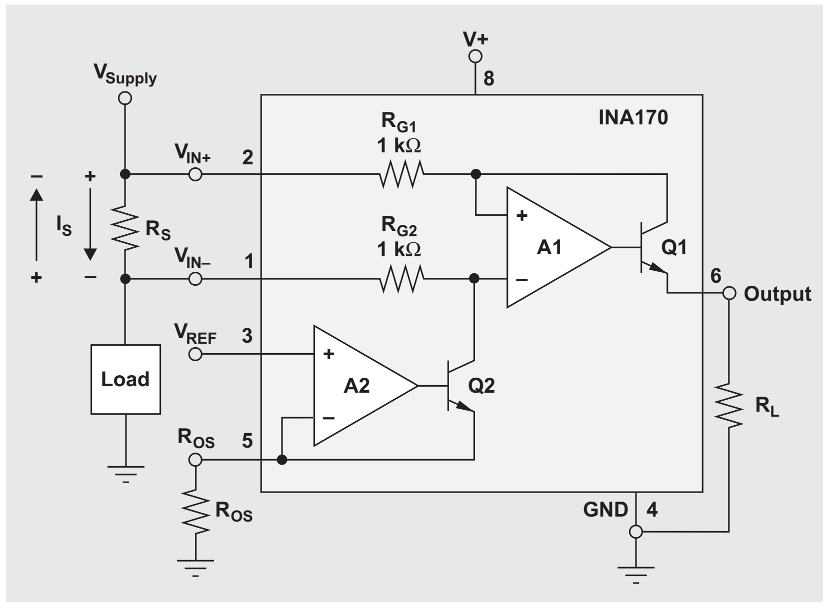
Current-shunt-monitor ICs are an extension of the instrumentation amplifier family of products. They provide an easy method of monitoring circuit current and possess similarities to the sensitive analog voltmeter and external shunt resistor commonly used to measure current in the past. The analog voltmeter registered a small voltage drop that developed when current passed through a shunt resistor. With a current-shunt monitor, the voltmeter has been replaced by a specially adapted instrumentation amplifier that amplifies the voltage developed across the shunt resistor. An output measure is provided that is proportional to the current through the resistor. Analog voltmeters were commonly designed for a full-scale voltage of 50 or 100 mV, and the current-shunt monitor operates with comparable input-voltage levels. Instead of an analog meter-scale indication, the current-shunt monitor provides a voltage or current output level, or a digital output code, that directly corresponds to the measured current level.

Figure 1. The INA170 connected for bidirectional current monitoring



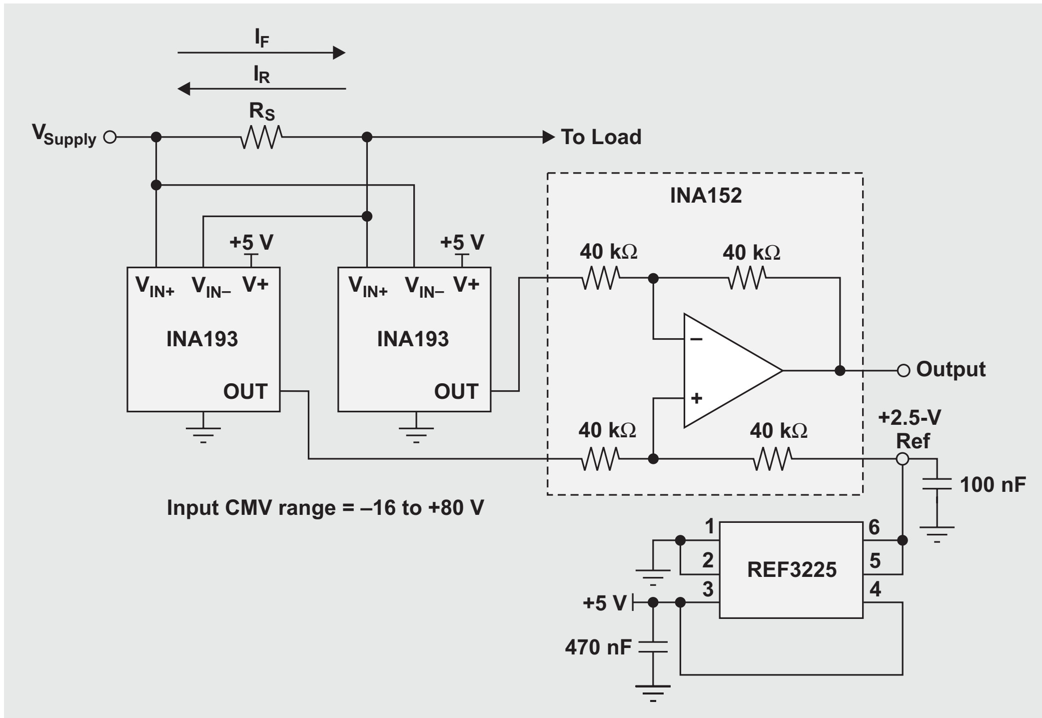
A variety of current-shunt monitors are available that are designed for high-side or low-side circuit connection, with some offering different user functions. Often the voltage ranges of the current-shunt-monitor supply and the common-mode input are independent of each other. This allows the current-shunt monitor to be operated from a convenient supply-voltage level independent of the input voltage. Many applications need only monitor current flowing in one direction, and a current-shunt monitor such as the INA138/168 provides this capability. A monitor intended for single-direction, or unidirectional, current flow is referred to as a unidirectional current-shunt monitor. Other applications require a bidirectional current-shunt monitor where the circuit current can flow and be monitored in either direction.

An example of a bidirectional current-shunt monitor is the INA170. It is powered by a single supply voltage of +2.7 to +40 V, while the input common-mode voltage (CMV) may be any voltage between +2.7 and +60 V. The input CMV is the external voltage that is applied to the current-shunt-monitor input and provides current to the output load. When the current through the shunt resistor is zero, both inputs of the current-shunt monitor are ideally at the same CMV potential; but when a current flows through the shunt resistor, a differential voltage is developed and the inputs become separated by that amount. This voltage difference is amplified by the gain factor of the current-shunt monitor.

The bidirectional property allows the INA170 to monitor current between two voltage potentials that are more positive or negative relative to each other. A simple illustration of a bidirectional-current-flow system is a motor that draws current from a battery when operating at a constant speed or accelerating, but then acts as a generator, returning current to the battery during deceleration. Figure 1 shows the INA170 connected for bidirectional current monitoring.

Thus, two important current-shunt-monitor operating parameters are the unidirectional or bidirectional input voltage characteristic and the CMV range. The operational CMV range often extends from near 0 V to a specified maximum positive voltage, but some current-shunt monitors include a negative voltage range as well. For example, the INA193 through INA198 current-shunt-monitor family provides a CMV range of –16 to +80 V. These devices are unidirectional; so even if the input voltage is a negative voltage, the output has to be more negative for current to

Figure 2. Two INA193 ICs configured as a bidirectional current-shunt monitor



flow in the correct direction. Two of the unidirectional current-shunt-monitor ICs may be interconnected to form a bidirectional current-shunt monitor with a CMV range that extends from –16 to +80 V. The addition of the INA152 instrumentation amplifier and +2.5-V reference completes the circuit. A circuit schematic for the INA193 bidirectional current-shunt monitor is shown in Figure 2.

Recently, a customer described an application where monitoring a DC motor's current was necessary. It was an automotive application, and the system supply was available to power a current-shunt monitor. The customer wanted to know the current levels when the motor was running normally in the forward direction and in reverse where a negative, back EMF developed. The circuit shown in Figure 2 is appropriate for this application; but the customer wanted to keep the number of components and the cost to a minimum, even if some precision had to be sacrificed. This called for a different approach.

Earlier it was mentioned that current-shunt monitors are an extension of instrumentation amplifiers. Also included in the family are difference amplifiers, which consist of an instrumentation-grade operational amplifier and four or more precisely matched resistors. The difference amplifier amplifies the difference in voltages applied to the two inputs by a fixed gain. Gain and common-mode rejection of the difference amplifier are optimized by precise laser trimming of four thin-film resistors included on the integrated circuit die. Difference amplifiers with a fixed gain of 1:1, 10:1, and 100:1 V/V are commonly available; however, there is a unique product—the INA159—that has a fixed gain setting of 0.2 V/V. Its primary role is to serve as a level-translation amplifier between sensors having a bipolar output voltage with a range of ±10 V, and a modern analog-to-digital converter having a unipolar input range of 0 to 5 V. The INA159 is a true difference amplifier that can sense a differential voltage of either polarity. Its input CMV range extends from –12.5 to +17.5 V when powered from a single +5-V supply. These features allow the INA159 to be employed as a dual-polarity, bidirectional current monitor. An additional instrumentation or operational amplifier needs to be included after the INA159 to increase the overall gain of the monitor circuit.

Figure 3. INA159 dual-polarity, bidirectional current-shunt-monitor circuit

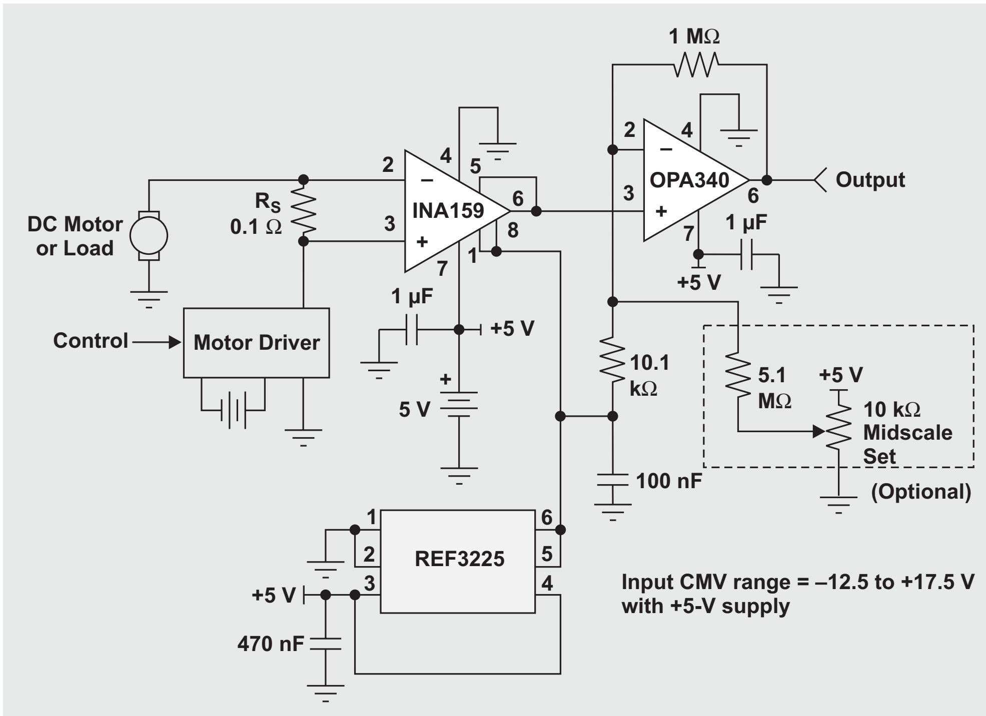


Figure 3 shows the circuit of the INA159 current-shunt-monitor stage, followed by an OPA340 CMOS operational-amplifier gain stage. The OPA340 was selected because its near rail-to-rail input and output swing ranges allow the circuit's output voltage to approach 0 and 5 V at the extremes. The INA159 gain is +0.2 V/V, while the OPA340 gain is set to +100 V/V, for an overall circuit gain of +20 V/V. A higher OPA340 closed-loop gain could be used to increase sensitivity, but the DC errors and bandwidth would suffer. Also, the shunt resistor R_S, could be increased from 0.1 Ω to a larger value. This would increase the INA159 output, but the consequences of the larger voltage drop and higher resistor power dissipation should be evaluated before doing so.

The output voltage delivered from the INA159 current-shunt-monitor circuit is centered at a level of about +2.5 V. This is the approximate voltage level at the OPA340 output when no current is flowing through R_S. Figure 4 shows an oscilloscope image of the INA159 current-shunt monitor's output response when the input circuit is being driven by a 24-V_{PP}, 1-kHz sine wave. This input-voltage waveform is recorded as the upper trace image. The resistive load in the input circuit is 12 Ω, resulting in peak current levels of ±1 A. The lower trace is that of the OPA340 output voltage swinging from 0.5 to 4.5 V, indicating a peak current of approximately ±1 A. A center-scale, manual zeroing circuit is included in the OPA340 stage. It can be excluded if an exact 2.5-V center-scale voltage is not necessary. The INA159 and OPA340 combined exhibit a bandwidth of well over 100 kHz, making this circuit usable for a wide variety of AC-current-monitoring applications.

Figure 4. Input/output waveforms of current-shunt-monitor circuit

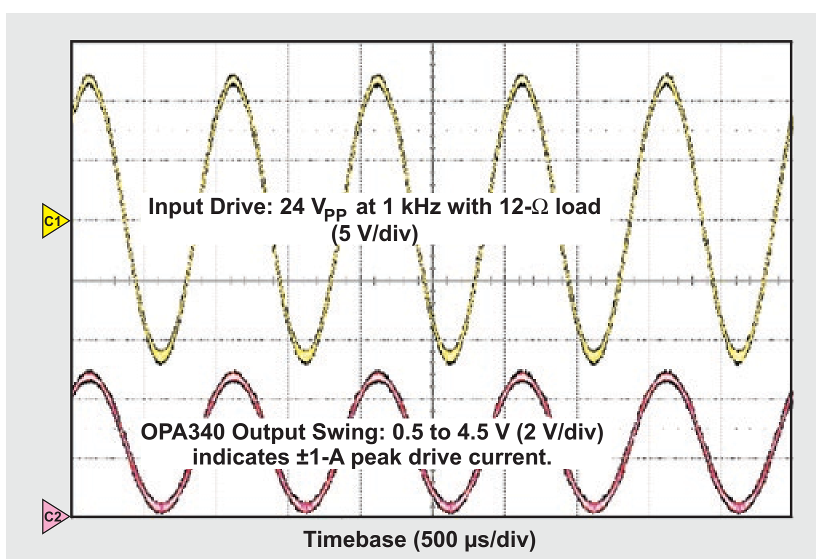


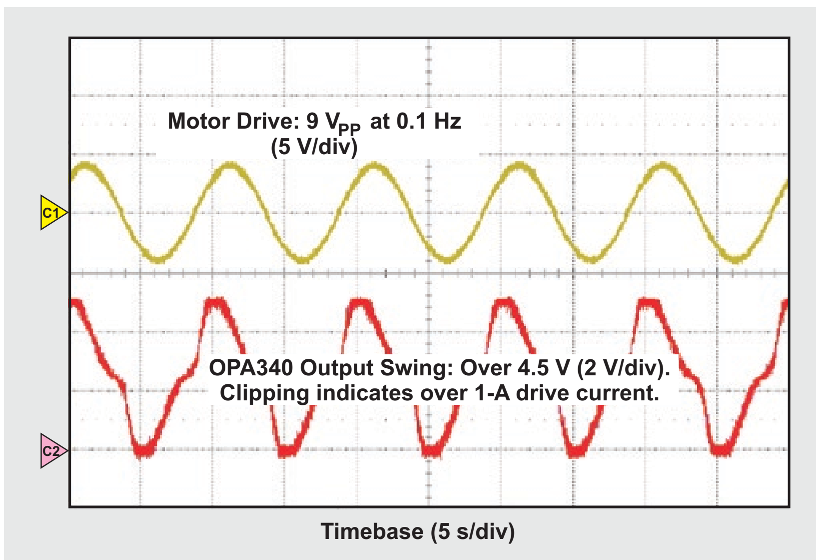
Figure 5 shows oscilloscope images of the INA159 current-shunt monitor monitoring the current of a DC pancake motor under load. The motor is being driven by a slow 9-V_{PP}, 0.1-Hz sine wave such that the armature direction follows the sine function, reversing direction every half cycle. This input drive voltage, shown as the upper trace, had to be adjusted to keep the motor from drawing more than 1 A of current. The lower trace shows the OPA340 output voltage where the peak motor current exceeds 1 A. Some evidence of clipping is seen at the OPA340 output as output-voltage-swing limits. With proper sizing of components, the circuit can be optimized for monitoring this particular motor's current levels. Nonetheless, this illustrates the utility of the INA159 in a motor-current-monitoring application.

Accuracy of the INA159 current-shunt monitor was measured at a little better than 4.5%. Standard 1% resistors were used, with no special selection being made. The circuit accuracy could be improved by replacing the OPA340 circuit with a precision, single-supply instrumentation amplifier such as the INA326. However, the AC bandwidth will decrease and the cost will be higher.

Related Web sites

amplifier.ti.com
www.ti.com/sc/device/*partnumber*
Replace *partnumber* with INA138, INA152, INA159, INA168, INA170, INA193, INA326, or OPA340

Figure 5. Input/output waveforms of current-shunt-monitor circuit of DC motor



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