Application Brief

Low-Power, Small-Size, High-Side Current Monitoring

Many systems utilize current sensing to verify nominal system operation and that the system or a load is not consuming an unexpected level of power which may indicate a faulty system. One of the lowest-power, smallest size and most accurate current sensors is an amplifier configured for high-side sensing. This configuration is especially useful in power- or space-constrained systems where thermal dissipation and layout may be difficult to accommodate a large or complex solution, such as in PC Power Supply Units (PCU), Merchant DC/DC and Flow Transmitter systems.

High-side or low-side?

The first question to answer when designing a current-sensing circuit is: high-side or low-side sensing? While both methods measure current under normal operation a high-side sensor is often preferred for its ability to measure a short between the system and ground which may otherwise bypass a low-side sensor. Additionally, multiple high-side current sensors can be used to accurately monitor independent loads without the ground reference errors that may affect multiple low-side current sensors.

In high-side current sensing the operational amplifier (op amp) is configured as a difference amplifier to measure the voltage drop across the shunt resistor. With this design it is important to keep in mind the input common-mode (Vcm) range of the amp. It is helpful for the Vcm of the amp to extend to the positive rail for high-voltage gain circuits to avoid an input signal limitation when the amp is powered from the system supply or bus voltage. Additionally, the output of the amp should be able to extend very close to the negative rail to maintain high accuracy for low input currents. Figure 1 shows a typical configuration

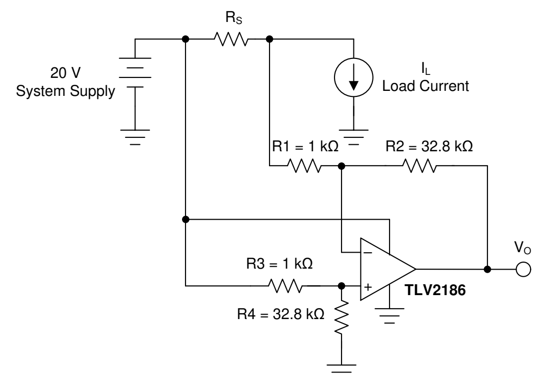

Figure 1. High-Side Current-Sense Circuit

In this design the *TLV2186* is configured as a difference amplifier for high-side current sensing. The device was selected because it has a rail-to-rail input and output, is low power and has very low offset (10 µV) and drift (0.1 µV/C) thanks to the zero-drift architecture which improves system accuracy.

Designing a high-side current sense circuit

The first step in the design is to determine the value of the shunt resistor (R_S) based on the allowable voltage drop during the maximum system current draw. The voltage drop should be small enough to maintain the desired system voltage at the load and to ensure low power dissipation in the shunt resistor. The voltage drop should also not be too small as error sources in the amplifier and feedback resistors will limit the system accuracy. In this example, the maximum load current is 2 A and the feedback resistor is selected for a maximum voltage drop of 100 mV, which equates to 200 mW of power dissipation at the maximum load current. In Figure 1, the shunt resistor is set at 50 mΩ.

$$R_S = \frac{V_S}{I_L} = \frac{0.1\ V}{2\ A} \qquad (1)$$

Next, the gain of the system must be determined based on in the voltage drop across the shunt and the input range of the ADC. Here an input range of 0 V to 3.3 V is used as it is a common input range for both discrete ADCs and those integrated into microcontrollers. Use Equation 2 to calculate the system gain, which in this example is 33 V/V.

$$\text{Gain} = \frac{V_{OMAX}}{V_S} = \frac{3.3\ \text{V}}{0.1\ \text{V}} = 33\frac{\text{V}}{\text{V}} \quad (2)$$

Finally the resistors are selected to set the system gain. The value of the resistors should be large enough so that their power consumption is not a drain on the supply or contribute to system heating, but low enough so that the input bias current of the amplifier flowing through the feedback network does not introduce systematic errors especially at low load currents. It is recommended to keep the parallel combination of the feedback resistors less than 10 kΩ (that is, R1 || R2 and R3 || R4 < 10 kΩ). In this design, 1 kΩ and 32.8 kΩ is used which are standard 0.1% resistor values.

System modeling and verification

To verify this system, TINA-TI is used to model and simulate the system output voltage as the input current sweeps from 0 A to 2 A.

Figure 2 shows in system output voltage vs load current, and although it looks linear across the full current range Figure 3 shows that for very low currents the output is limited to approximately 12 mV. This is due to the output voltage range limitation of the amplifier.

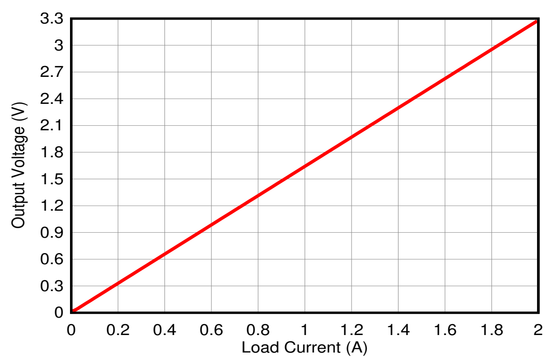

Figure 2. TLV2186 Output Voltage vs Load Current

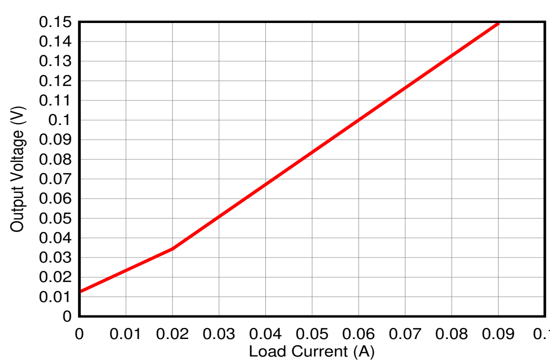

Figure 3. TLV2186 Output Voltage With Low Load Current

If the system requires a true rail-to-rail output so that accuracy can be maintained across the full input current range, a small negative charge pump such as the *LM7705* can be used to generate a small negative rail for the amplifier. This allows the output to extend all the way to 0 V when there is zero current flow and prevents the amp from 'slamming' the output into a rail which can introduce additional error sources due to the internal architecture. With this configuration, the new system output range is seen in Figure 4.

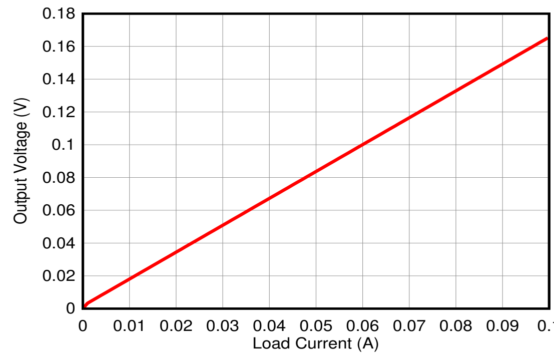

Figure 4. TLV2186 Output Voltage With Negative Supply Rail

In summary, the TLV2186 can be used for high-side current sensing in power- or space-constrained systems. The rail-to-rail input and output combined with low offset, low offset drift and low input bias currents enables the amplifier to accurately measure the load current across the full current range as well and maintain accuracy across temperature range. For additional information on high-side current sensing, including additional error sources to consider when designing such systems such as common mode rejection, see the *Analog Engineer's Circuit Cookbook*. Table 1 shows additional amplifiers recommended for high side current sensing.

Table 1. Alternative Device Recommendations

Device	Supply Voltage Range (V)	Bandwidth (MHz)	Input Offset Voltage (µV)	Input Bias Current (pA)	Quiescent Current (mA)
LPV811	1.6 to 5.5	0.008	60	0.1	0.00045
OPA333	1.8 to 5.5	0.35	2	70	0.017
OPA388	2.5 to 5.5	10	0.25	30	1.7
OPA191	4.5 to 36	2.5	5	5	0.14

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