Simple and Accurate High Side Current Sense Circuit

Introduction

There is a need in many applications to sense currents on the high side rail of a power bus and translate this into a voltage with respect to ground which is proportional to this current. Typically this voltage is fed into the analog–to-digital converter (ADC) of a microcontroller (µC) or used as an analog input to a switching power controller (See Figure 1).

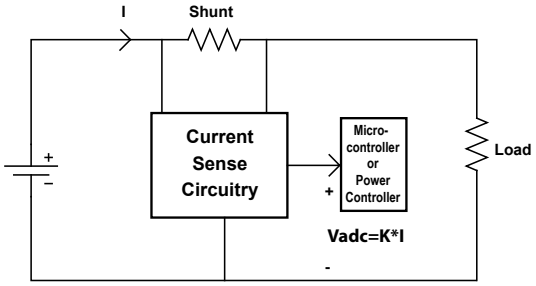

Figure 1. Simplified Block Diagram

This paper describes a simple technique which can be used to sense current on a high voltage rail. There are several advantages to this circuit:

1. This circuit allows use of conventional 5V op amps, which have very low offset (as low as a few µV). Best in class 5V amplifiers have 5~10x better offset than best in class 30~40V amplifiers and typically cost less.
2. Low voltage, low offset amps like the ISL28133 can be biased with very low current (25µA). Simple, low power consumption biasing schemes can be used to power the amplifier, even when the input rail is at very high voltages.
3. The gain-bandwidth of the overall circuit can be much higher than the gain bandwidth of the amp itself.

The circuit technique is shown in Figure 2. This example shows the shunt on a 12V rail being measured by the 5V ISL28133 chopper stabilized amplifier. By virtual null principles, the voltage across the shunt also appears across resistor R9, determining the current through R9. This same current flows through the drain and source of buffer transistor Q3 and through R7, generating a voltage V_{adc} with respect to ground that is proportional to the high side current:

$$V_{adc} = V_{shunt} \times R7/R9 \qquad \text{(Equation 1)}$$

Note that this circuit can be biased without much dissipation using a resistor R8 and zener diode D1. The resistor R8

Key Components

ISL28133 **Single 5V Micro Power, Zero Drift, RRIO, Precision Op Amp**
- Very Low Offset (V_{OS}-6µV max) and Tempco (TCV_{OS}-75nV/°C max)
- Very Low Power Consumption (I_S-25µA max)

ISL28134 **Single 5V Ultra Low Noise, Zero Drift, RRIO, Precision Op Amp**
- Best-in-class, Very Low Offset (V_{OS}-2.5µV max) and Tempco (TCV_{OS}-15nV/°C max)
- Ultra Low Noise (e_N-10nV/√Hz)

needs to only provide supply current for the ISL28133 (25µA) and ~1mA to bias the zener diode. This results in power dissipation of 12V x 1.025mA = ~12mW. Even with a 48V high side rail, the power dissipation to bias the part will only be ~50mW. There will be additional power in Q3 with the amount of loss dependant on the level shift current in the drain of Q3. Acceptable circuit bandwidth and accuracy can usually be obtained with 100µA drain current at full scale, resulting in negligible loss.

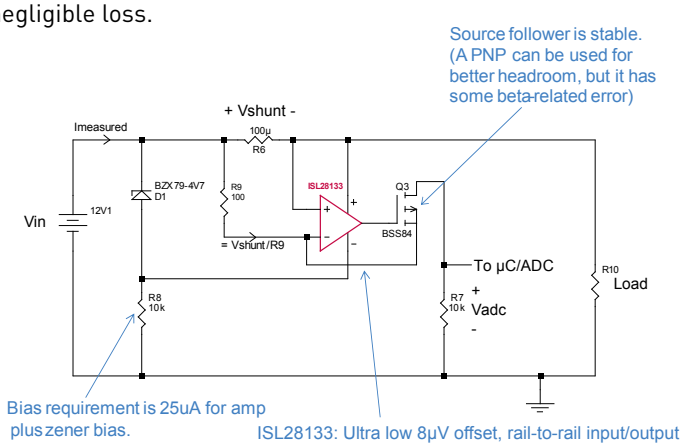

Figure 2. Simple level shift circuit using a low voltage amplifier.

Error Analysis

The total error in amplifying the shunt voltage is the error mainly due to R7, R9 and the offset voltage. A typical shunt voltage is 10mV. The total error is calculated using Equation 2:

$$\text{Error} = \text{R9 error} + \text{R7 error} + \text{offset/Vshunt} \qquad \text{(Equation 2)}$$

With 0.1% resistors and the 8µV offset of the ISL28133, the full scale error is <0.3% and better than 1% tolerance is maintained down to 1mV sensed current (See Figure 3). The error due to bias current (300pA) of the ISL28133 is insignificant with the values in this example and therefore has been ignored in Equation 2. The gate-to-source leakage of transistor Q3 is typically insignificant, but can also be a factor at low drain currents and high temperatures. The error due to the shunt itself could also be factored in.

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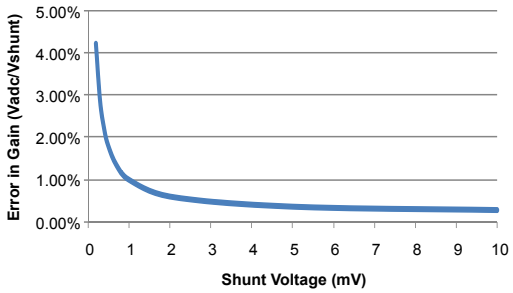

Figure 3: Error in gain (Vadc/Vshunt) assuming 0.1% resistors

Error in the current sense circuit of Figure 2, assuming 0.1% resistors and 8µV offset. Error due to the bias current of the ISL28133 (300pA) and leakage of Q3 is assumed insignificant.

Figure 3 shows the accuracy at room temperature for a typical sense voltage. This level of accuracy is acceptable in many cases. Obviously, there will be additional error over temperature. The circuit can be made much more accurate if needed. The current measurement is calibrated at room temperature in many applications, making the accuracy a function of the temperature drift only. Figure 4 shows the accuracy assuming calibration at room temperature using 10ppm/C resistors and a premium chopper amp, the ISL28134, which has an offset drift of 15nV/°C. Better than 0.2% precision is maintained down to a sensed voltage of 1mV.

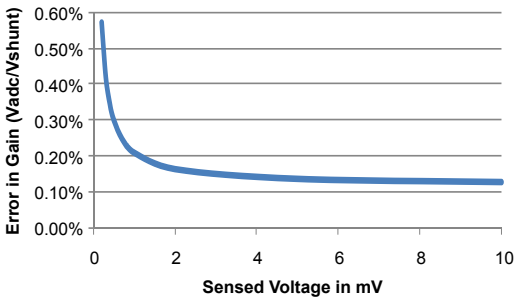

Figure 4: Error in gain (Vadc/Vshunt) over +/-60°C assuming 10ppm resistors, ISL28134 op amp and room temp calibration

Accuracy of the sense network over temperature (-40°C to + 80°C) assuming room temperature calibration and using a premium grade amplifier ISL28134.

Stability and Bandwidth

Note that the manner in which the buffer transistor is configured should not destabilize the amp if the amp is internally compensated to be unity gain stable. The source of the buffer transistor Q3 follows the output of the amp and this buffering is therefore the equivalent of taking the output back to the inverting input, as in a unity gain configuration.

Another important item to note is that the buffer transistor Q1 does relieve the gain-bandwidth restrictions of the op amp. The configuration in Figure 2 has a gain (V_{adc}/V_{shunt}) of R7/R9=100 from Vshunt to the output. Figure 5 shows the simulated frequency response of this circuit using the ISL28133. The gain-bandwidth of the amp is 400kHz, yet the overall circuit gain bandwidth is 100*200KHz or 20MHz. The buffer transistor improves the circuit bandwidth without destabilizing the op amp. The improvement in gain bandwidth is intuitive when viewed in this manner: With an input signal of 1mV and an ideal buffer transistor (i.e., one in which the gate-source threshold voltage is constant regardless of drain current), the output of the amp will only have a 1mV signal. So the op amp is functioning with an ac gain of 1. The voltage gain of 100 is achieved by the buffer transistor. With a non-ideal transistor, the output of the amp will have a somewhat higher signal (~2mV in this case), but the BW of the overall circuit is still ~half of the unity gain bandwidth of the amp and the gain-bandwidth of the circuit is ~50x the GBW of the op amp.

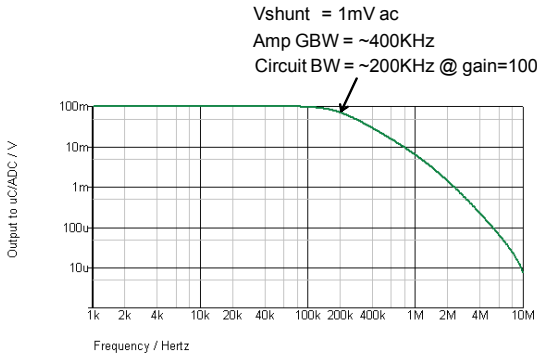

Figure 5: Frequency response of the circuit in Figure 2. 1mV input is applied at V_{shunt} and the output is measured V_{adc}. Note that the gain-Bandwidth of the overall circuit is 20MHz.

Summary

Accurate high side current sensing can be achieved using a low voltage, low offset op amp, combined with a simple, low power bias scheme and a level shift transistor. This approach can be lower cost and much more accurate than circuits requiring higher voltage amplifiers. When sensing a 10mV signal, room temperature, full scale accuracy of <0.3% is achieved with 0.1% resistors and the ISL28133 chopper stabilized amplifier. With the ISL28134 and room temperature calibration, 0.2% is maintained over temperature with 1mV sensed. The circuit topology is inherently stable, yet the gain bandwidth of the overall circuit is significantly higher than that of the op amp by itself. In the example, the gain bandwidth of the overall circuit is improved by a factor of 50.

Reference Documents

• Intersil "High-Side, Current Sensing Techniques" App Note: AN1827

INDEX

Sensor: shunt, low ohmic, hall effect, resistor, high side, low side, bi-directional, flow sensor

Applications: power monitor, voltage monitor, current monitor, industrial controls, instrumentation, medical, portable, battery monitor, data loggers, 4-to-20mA current loops, energy harvesting, wireless solution, overcurrent, undercurrent, fault detection, motor control, remote sensing, power management, energy meters, wind power, alternative energy, Servers, cloud computing, microservers, telecom, mobile radio, inductive charging, enterprise switch, BST, smart phones, LCD Display Tablet/PC, distributed power, basestations, power supplies, networking, inverters, solar, negative voltage monitor, -48V supplies, rack mount power, power strip, surge protection, PLC, smart power

Performance: high performance, low power, micro power, high voltage, low cost, precision analog, signal conditioning, 16-bit Sigma Delta, zero-drift, chopper, chopper stabilized, low offset drift, low noise