Switch Mode Power Supply Current Sensing—Part 2: Where to Place the Sense Resistor

Henry Zhang and Kevin B. Scott
Analog Devices, Inc.

The placement of the current sense resistor, in conjunction with the switching regulator architecture, determines what current is being sensed. Currents that are sensed include the peak inductor current, the valley inductor current (the minimum value of the inductor current when in continuous conduction mode), and the average output current. The location of the sense resistor affects power loss, noise calculations, and the common-mode voltage seen by the sense resistor monitoring circuitry.

Buck Regulator High-Side Placement
For a step-down (buck) regulator, the current sense resistor can be placed in several locations. When placed on the high side of the top MOSFET (as shown in Figure 1), it detects the peak inductor current when the top MOSFET is on and, thus, can be used for peak current mode controlled supplies. However, it does not measure inductor current when the top MOSFET is off and the bottom MOSFET is on.

Buck Regulator Low-Side Placement
In Figure 2, the sense resistor is placed below the bottom MOSFET. In this configuration it detects the valley mode current. To further reduce power loss and save component cost, the bottom FET RDS(ON) can be used to sense current without using an external current sensing resistor RSENSE.

Buck Regulator Placement in Series with the Inductor
In Figure 3, the current sensing resistor RSENSE is placed in series with the inductor so it can detect the continuous inductor current, which can be used for average current monitoring and peak or valley current monitoring. Accordingly, this configuration allows peak, valley, or average current-mode controls.

Figure 1. Buck converter with high-side RSENSE.

Figure 2. Buck converter with low-side RSENSE.

Figure 3. RSENSE in series with the inductor.

This sensing method provides the best signal-to-noise ratio performance. An external RSENSE usually can provide a very accurate current sensing signal for accurate current limit and sharing. However, the RSENSE also causes additional power loss and component cost. To reduce the power loss and cost, the inductor winding dc resistance (DCR) can be used to sense current without an external RSENSE.

Visit analog.com | Share on Twitter | Share on LinkedIn | Email
Boost and Inverting Regulators’ High-Side Placement
For a step-up (boost) regulator, the sense resistor can be placed in series with the inductor providing high-side sensing (Figure 4).

![Figure 4. Boost converter with high-side RSENSE.](image)

Since the boost has continuous input current, a triangular waveform results and current is continuously monitored.

Boost and Inverting Regulators’ Low-Side Placement
The sense resistor can also be placed on the low side of the bottom MOSFET, as shown in Figure 5. Here, the peak switch current (which is also the peak inductor current) is monitored, resulting in a current waveform every half cycle. Due to the MOSFET switching, the current signal has strong switching noises.

![Figure 5. Boost converter with low-side RSENSE.](image)

Buck-Boost Low-Side SENSE Resistor Placement or in Series with the Inductor
A 4-switch buck-boost converter is shown below in Figure 6 with the sense resistor on the low side. The converter operates in buck mode when the input voltage is much higher than the output voltage, and in boost mode when the input voltage is much lower than the output voltage. In this circuit, the sense resistor is located at the bottom of the 4-switch H-bridge configuration. The mode of the device (buck mode or boost mode) determines what current is being monitored.

![Figure 6. Buck-boost with RSENSE on the low side.](image)

In buck mode (Switch D always on, Switch C always off) the sense resistor monitors the bottom side Switch B current and the supply operates as a valley current mode buck converter.

In boost mode (Switch A always on, Switch B always off) the sense resistor is in series with the bottom MOSFET (C) and measures peak current as the inductor current rises. In this mode, since the valley inductor current is not monitored, it is difficult to detect the negative inductor current when the supply is in light load condition. Negative inductor current means energy is simply being transferred from the output back to the input—but due to losses associated with the transfer, efficiency suffers. For applications such as battery-powered systems for which light load efficiency is important, this current sensing method is undesirable.

The circuit of Figure 7 resolves this issue by placing the sense resistor in series with the inductor so that the inductor current signal is continually measured in both buck and boost modes. Since current sensing RSENSE is connected to the SW1 node that has high switching noises, the controller IC needs to be carefully designed to allow sufficient blanking time for the internal current comparator.

![Figure 7. LT8390 buck-boost with RSENSE in series with the inductor.](image)

An additional sense resistor can also be added at the input for input current limiting or at the output (as shown below) for constant output current applications such as battery charging or driving LEDs. In this case, since the average input or output current signal is needed, a strong RC filter can be added to the current sensing path to reduce current sensing noise.

In most of the above examples the current sensing element is assumed to be a sense resistor. However, this does not have to be and often is not the case. Other sensing techniques include using the voltage drop across a MOSFET or the dc resistance (DCR) of the inductor. These current sensing methods are addressed in Part 3 “Current Sensing Methods.”

Software
- **LTspice**
  LTspice® software is a powerful, fast, and free simulation tool, schematic capture, and waveform viewer with enhancements and models for improving the simulation of switching regulators.

- **LTpowerCAD**
  The LTpowerCAD design tool is a complete power supply design tool program that can significantly ease the tasks of power supply design. It guides users to a solution, selects power stage components, provides detailed power efficiency, shows quick loop bode plot stability and load transient analysis, and can export a final design to LTspice for simulation.
About the Authors

Henry Zhang is an applications engineering director for power products at Analog Devices. He started his career with Linear Technology, now part of Analog Devices, as a power applications engineer in 2001. He became an applications section leader in 2004 and an applications engineering manager in 2008. His group supports a wide range of products and applications, from small size integrated power modules, to large kW level high power, high voltage converters. In addition to supporting power applications and new product developments, his group also develops the LTpowerCAD supply design tool program. Henry has broad interests in power management solutions and analog circuits. He has over 20 technical articles, seminars, and videos published and over 10 power supply patents granted or pending.

Henry graduated from Virginia Polytechnic Institute and State University in Blacksburg, Virginia, with his master’s and Ph.D. degrees in electrical engineering. He can be reached at henry.zhang@analog.com.

Kevin Scott works as a product marketing manager for the Power Products Group at Analog Devices, where he manages boost, buck-boost, and isolated converters, LED drivers, and linear regulators. He previously worked as a senior strategic marketing engineer, creating technical training content, training sales engineers, and writing numerous website articles about the technical advantages of the company’s broad product offering. He has been in the semiconductor industry for 26 years in applications, business management, and marketing roles.

Kevin graduated from Stanford University in 1987 with a B.S. in electrical engineering. He can be reached at kevin.scott@analog.com.