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

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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.

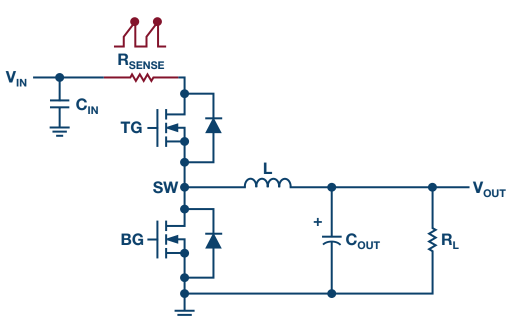

Figure 1. Buck converter with high-side R_{SENSE}.

In this configuration, current sensing can be noisy because the turn-on edge of the top MOSFET has strong switching voltage ringing. To minimize this effect, a long current comparator blanking time (the time during which the comparator ignores the input) is needed. This limits the minimum switch ON time and can limit the minimum duty cycle (duty cycle = V_{OUT}/V_{IN}) and maximum converter step-down ratio. Note in the high-side configuration, the current signal can be riding on top of a very large common-mode voltage (V_{IN}).

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 R_{SENSE}.

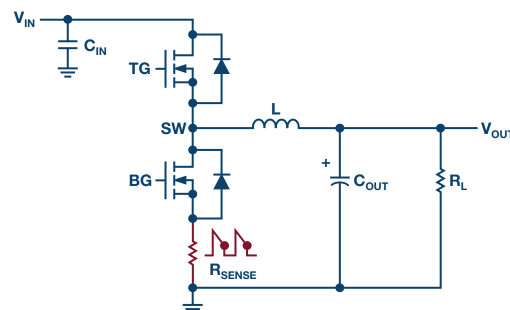

Figure 2. Buck converter with low-side R_{SENSE}.

This configuration is usually used for a valley mode controlled power supply. It can also be sensitive to noise, but in this case it is sensitive when the duty cycle is large. A valley mode controlled buck converter allows high step-down ratios; however, its maximum duty cycle is limited due to its fixed/controlled switch ON time.

Buck Regulator Placement in Series with the Inductor

In Figure 3, the current sensing resistor R_{SENSE} 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.

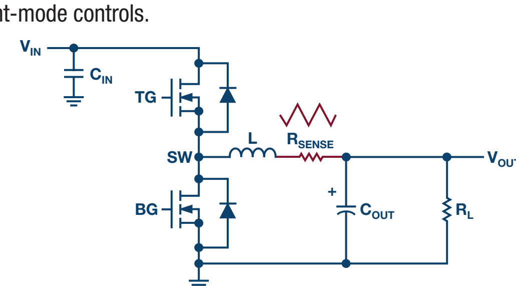

Figure 3. R_{SENSE} in series with the inductor.

This sensing method provides the best signal-to-noise ratio performance. An external R_{SENSE} usually can provide a very accurate current sensing signal for accurate current limit and sharing. However, the R_{SENSE} 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 R_{SENSE}.

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).

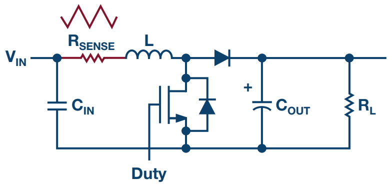

Figure 4. Boost converter with high-side R_{SENSE}.

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.

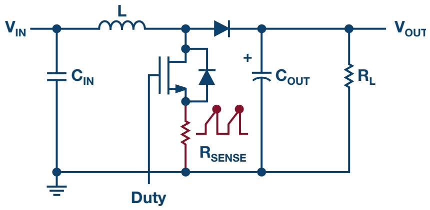

Figure 5. Boost converter with low-side R_{SENSE}.

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.

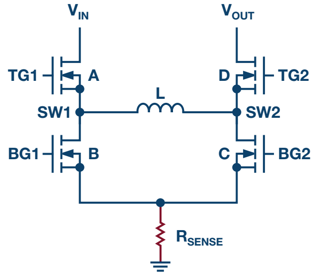

Figure 6. Buck-boost with R_{SENSE} on the low side.

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 R_{SENSE} 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.

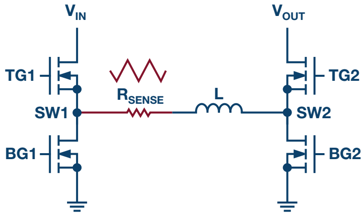

Figure 7. LT8390 buck-boost with R_{SENSE} in series with the inductor.

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."

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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.

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