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Switch Mode Power Supply Current Sensing—Part 3: Current Sensing Methods

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The three commonly employed current sensing methods for switch mode power supplies are: using a sense resistor, using the MOSFET $R_{DS(0N)}$, and using the dc resistance (DCR) of the inductor. Each method offers advantages and disadvantages that should be considered when selecting one method over another.

Sense Resistor Current Sensing

A sense resistor as the current sensing element results in the lowest sensing error (typically between 1% and 5%) and a very low temperature coefficient, on the order of 100 ppm/°C (0.01%). It provides the most accurate power supply in terms of performance, aids in providing a very accurate power supply current limit, and also facilitates accurate current sharing when multiple power supplies are paralleled.



Figure 1. R_{SENSE} current sensing.

On the other hand, because a current sensing resistor is added to the power supply design, the resistor also generates additional power dissipation. Thus, the sense resistor current monitoring technique may have higher power dissipation compared with other sensing techniques, resulting in a slight reduction in the solution's overall efficiency. The dedicated current sensing resistor may also increase solution cost, as a sense resistor typically costs between \$0.05 and \$0.20.

Another parameter that should not be ignored when selecting a sense resistor is its parasitic inductance (also referred to as effective series inductance or ESL). The sense resistor is correctly modeled as a resistor in series with a finite inductance.





This inductance depends on the specific sense resistor chosen. Some types of current sensing resistors, such as metal plate resistors, have low ESL and are preferred. In comparison, wire wound sense resistors have higher ESL due to their package structure and should be avoided. In general, the ESL effect becomes more pronounced with increasing current levels, reduced sensing signal magnitudes, and improper layout. The circuit's total inductance also includes the parasitics inductance due to component leads and other circuit components. The circuit's total inductance is also affected by layout, so component placement must be given proper consideration; improper placement can affect stability and exacerbate existing circuit design issues.

The effects of sense resistor ESL can be mild or severe. The ESL can result in significant ringing on the switch gate driver, adversely affecting switch turn on. It also adds ripple to the current sense signal, resulting in a voltage step in the waveform, instead of the expected saw tooth waveform as shown in Figure 3. This degrades the current sensing accuracy.



Figure 3. R_{SENSE} ESL can adversely affect current sensing.

To minimize resistor ESL, avoid using sense resistors that have long loops (such as wire wound resistors) or long leads (such as high profile resistors). Low profile surface-mount devices are preferred; examples include the plate structure SMD sizes 0805, 1206, 2010, and 2512; even better choices include reverse geometry SMD sizes 0612 and 1225.

Power MOSFET-Based Current Sensing

Simple and cost-effective current sensing is accomplished by using the MOSFET $R_{\text{DS(ON)}}$ for current sensing. The LTC3878 is a device that uses this approach. It uses a constant on-time, valley mode current sensing architecture. Here, the top switch is on for a fixed amount of time, after which the bottom switch turns on and its R_{DS} voltage drop is used to detect the current valley or the lower current limit.



Figure 4. MOSFET R_{DS(ON)} current sensing.

Though inexpensive, there are some drawbacks to this approach. First, it is not very accurate; there can be a wide variation (on the order of 33% or more) in the range of $R_{\text{DS(ON)}}$ values. It also can have a very large temperature coefficient; values greater than 80% over 100°C are not out of the question. In addition, if an external MOSFET is used, the MOSFET parasitic packaging inductance must be considered. This type of sensing is not recommended for very high current levels, and especially not for polyphase circuits, which require good phase current sharing.

Inductor DCR Current Sensing

Inductor dc resistance current sensing uses the parasitic resistance of the inductor winding to measure current, thereby eliminating the sense resistor. This reduces component costs and increases power supply efficiency. Compared to the MOSFET $R_{DS(0N)}$, inductor DCR of the copper wire winding usually has less part-to-part variation, though it still varies with temperature. It is favored in low output voltage applications because any drop across a sense resistor represents a significant portion of the output voltage. An RC network is placed in parallel with the series inductor and parasitic resistance combination, and the sense voltage is measured across the capacitor C1 (Figure 5).



Figure 5. Inductor DCR current sensing.

With proper component selection ($R1 \times C1 = L/DCR$), the voltage across the capacitor C1 will be proportional to the inductor current. To minimize measurement error and noise, a low R1 value is preferred.

Because the circuit does not directly measure inductor current, it cannot detect inductor saturation. Therefore inductors that have a soft saturation, like iron power core inductors, are recommended. These inductors typically have higher core loss than a comparable ferrite core inductor. Compared to the R_{SENSE} method, inductor DCR sensing eliminates the sensing resistor power loss but may increase the inductor core losses.

With both R_{SENSE} and DCR sensing methods, Kelvin sensing is required due to the small sense signal. It is important to keep the Kelvin sense traces (SENSE+ and SENSE– in Figure 5) away from noisy copper areas and other signal traces to minimize noise pick-up. Some devices (such as the LTC3855) have temperature compensated DCR sensing, which improves accuracy over temperature.

| | - | - | | - | | | |
|-----------------------------|---------------------------|---------------------------------|--------------------------------|----------------------------|--------------------------------|--|----------------------|
| Sensing Method | Sense Error @ 25°C (%) | Temperature Variation (%/°C) | Detects Inductor Saturation | Reliability/ Protection | Current and Thermal Balance | Component Cost | Supply Efficiency |
| R _{sense} | 1 or 5 | ~0.01 | Yes | Highest | Best | R _{SENSE} (\$0.05 to \$0.20) | Baseline value |
| Inductor DCR | ≥10 | ~0.39 | | Medium | Medium | n/a | Higher |
| MOSFET R _{DS} (ON) | ≥30 | ~0.8 | | Lower | Worst | n/a | Higher |

Table 1. The Advantages and Disadvantages of Current Sensing Methods

Table 1 summarizes the different types of current sensing methods and the advantages and disadvantages of each.

Each of the methods mentioned in Table 1 provides added protection for switch mode power supplies. Trade-offs in accuracy, efficiency, thermal stress, protection, and transient performance all can factor into the selection process, depending on the design requirements. A power supply designer needs to carefully select the current sensing method and power inductor, and design the current sensing network properly. Computer software programs such as Analog Devices' LTpowerCAD design tool and LTspice[®] circuit simulation tool can be very helpful in simplifying the design effort with optimum results.

Other Current Sensing Methods

There are other current sensing methods available. For example, a current sensing transformer is often used with isolated power supplies to provide current signal information across the isolation barrier. This approach is usually more expensive than the three techniques discussed above. In addition, new power MOSFETs with integrated gate drivers (DrMOS) that also integrate current sensing have become available in recent years, but to date not enough data exists to conclude how well DrMOS sensing works in terms of accuracy and quality of the sensed signal.

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. Click here to download LTspice.

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. Click here to download LTpowerCAD.

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*.

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