Application Brief

Maximize System Efficiency With Integrated Current Sensing From TI GaN

TEXAS INSTRUMENTS

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Introduction

Switching converters generally requires some form of system-level current sensing for control, protection, or both. Many methods and devices exist to accurately measure and translate current to some voltage processed by a digital or analog controller. Most designers opt for shunt resistors in low-to-mid power converters placed in series with switching devices due to cost savings and design simplicity.

With advancing technology, the LMG362x family of GaN devices offers a more integrated approach to this necessary function. The device includes built-in current sensing that continuously outputs a real-time replica of the positive-going drain to the source device current. This new feature replaces traditional shunt resistors without trade-offs or inaccuracies and improves system efficiency and thermal performance.

Common Topologies

The majority of designers select some version of a flyback converter in low-power applications, such as consumer AC/DC converters or bias supplies. These topologies are an excellent choice for universal AC input voltages and wide output voltages used in USB-C adapters, which range from 5 V up to 20 V, or even 48 V with extended power range (EPR). A flyback converter operates with an analog controller using a form of current-mode control to set the correct on-time of the switching device.

This sensing is required to accurately adjust the on-time for varying input and output voltages and load changes. To measure this current, a shunt resistor is placed between the source of the switching FET and the power ground (PGND) of the circuit. This shunt resistor has a small resistance value and generates a proportional voltage drop that connects to an analog controller and is processed by an internal comparator. In common 65-W flyback converters, the power loss associated with the shunt resistor $R_{CS(trad)}$ is calculated using the primary side RMS current. Power loss above 350mW can cause significant buildup of heat and lower system efficiency.

At higher power levels, government regulations require some stage of power factor correction (PFC) to reduce distortions on the power grid and minimize the total apparent power consumed by the application. Adhering to these requirements creates new challenges to converter designs which are difficult to accomplish in one stage. As a result, many designs now implement an AC/DC PFC stage with a high DC output voltage, combined with a DC/DC stage, which lowers the final load voltage to an acceptable value.

A majority of mid-power converters use boost PFC topologies which are appropriate for universal AC input and output and DC voltage around 400 V. In contrast to flybacks, most transition-mode boost PFC analog controllers use voltage-mode control to adjust the switching time of the main FET to account for variations in the line voltage or output load current.

Sensing the drain-to-source voltage of the FET provides the controller with enough information to switch properly, however, current sensing is still required to use most controllers. The converter must be able to effectively shut down and avoid thermal runaway or permanent damage in the event of a surge condition or electrical failure is possible. Excess current in the switching FET causes both of these issues, which can be mitigated by sensing the drain-to-source current and sending a translated voltage to the analog controller.

Current sensing is still largely required and traditionally uses shunt resistors, regardless of current or voltage mode-controlled topologies. Switching FETs with built-in current sensing can bring added benefits while still being compatible with all existing controllers.

Benefits of Integrated Current Sensing

Texas Instruments' LMG362x device family integrates current sensing within the device and outputs a dedicated signal through one of the external pins.

Fundamentally, the device senses the positive-going drain-to-source current in the main GaN FET, scales the current down, and outputs a proportional current on the dedicated *CS pin*.

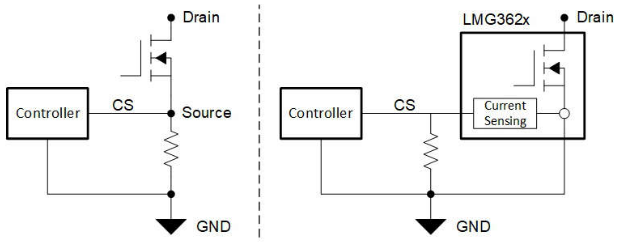

Figure 1. Diagram of Shunt and Lossless Current Sense Resistors

As previously mentioned, traditional FETs require a shunt resistor placed between the source of the FET and system ground. The placement of this shunt resistor causes the source to be electrically separated from the rest of the converter and cannot connect directly to a PGND PCB plane for thermal dissipation. Integrated current sensing mitigates this first issue by removing the resistor placed between source and PGND and replacing the resistor with one on a separate path.

Figure 1 illustrates how the current sense resistor no longer acts as a shunt and provides an adequate input to the controller while enabling the source of the FET to connect directly to the system ground. Both sensing methods require a resistor but the type and size of resistor vary greatly. A typical shunt resistor must conduct all the switch node current passing through the FET and dissipate the current as heat, as shown in Figure 2. The distinguishable hot operating temperature of the shunt resistor is noticeably warmer than an integrated design and contributes to the overall PCB heat, which must be spread.

Using a small resistance value makes thermal design manageable but not without a large package size. For a common 65-W quasi-resonant (QR) adapter, the shunt resistor value is approximately 100 mΩ with a 500 mW power rating in a 1206 package. If the main FET also has an on resistance of 100 mΩ, the conduction losses are twice as high due to the added shunt resistor. An integrated current sensing resistor only conducts a fraction of the scaled FET current and subsequently is higher in resistance value and smaller in package size. A resistor of approximately 100 Ω, rated for only 60 mW, is appropriate for this QR application and available in a 0402 package (9 times smaller than a 1206 package). This size reduction saves precious space on a circuit board where small form factors are becoming increasingly popular.

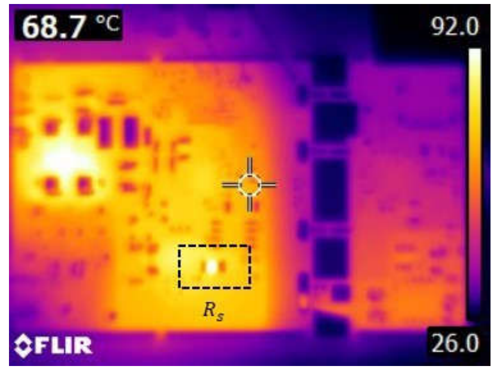

Figure 2. Thermal Capture of Traditional Current Shunt Resistor

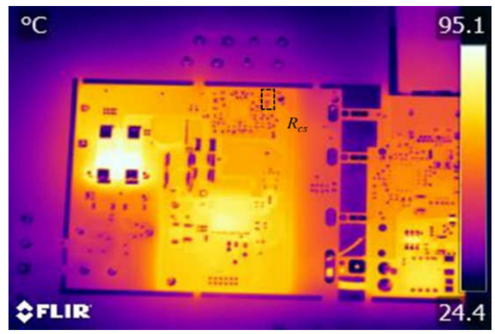

Figure 3. Thermal Capture of Lossless Current Sense Resistor

A natural reward for achieving lower power losses and better thermal heating is higher efficiency. Using the same 65 W QR example, shunt resistor losses are approximately a magnitude of hundreds of milliwatts, while integrated current sensing resistor losses fall to tens of milliwatts.

Part of this efficiency is realized in Figure 3 where the resistor temperature drops significantly. No thermal hotspot is detected compared to the shunt resistor for the same input and load conditions. Illustrated in Figure 4, measured power losses show the reduction in resistor loss exceeds 90% depending on the output power and input voltage.

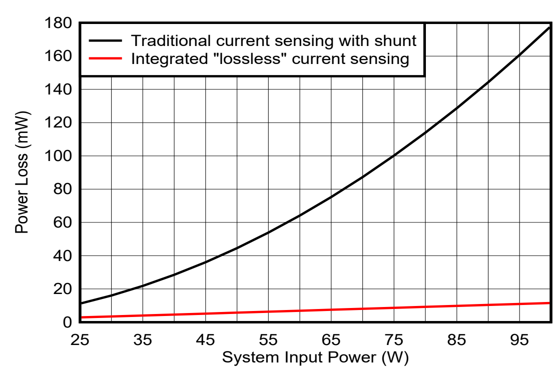

Figure 4. Integrated Lossless Current Sensing vs Traditional Current Sensing Power Loss

A converter must be designed to withstand the worst-case conditions even though the loss reduction is not constant across load. The worst-case condition is usually at the lowest input voltage and highest output power, which produce higher currents for the main power devices.

Proper Resistor Calculations and Design Example With LMG362x

Each device in the LMG362x family outputs a scaled replica of the drain-to-source current, however, the ratio between the actual drain-to-source current (gain G_{CSE}) and outputted sense current varies for each device. Using the integrated current sensing feature and selecting the right resistor value is key to compatible operations with any existing analog controller. Table 1 lists all devices in the LMG362x family with corresponding current sense ratios to help users chose a new resistor value or replace an equivalent shunt resistor with the same behavior.

Table 1. LMG362x Family Device Table

Device	Rdson (typical)	Current Sense Gain G_{CSE} (typical)
LMG3622	120 mΩ	0.691 mA/A
LMG3624	170 mΩ	0.965 mA/A
LMG3626	270 mΩ	1.633 mA/A

The integrated current sense resistor R_{CS} can be determined multiple ways: using the FET drain current and desired CS pin voltage or converting from a traditional shunt resistor $R_{CS(trad)}$ using the integrated current sense gain G_{CSE} (Equation 1). With this method, an exact voltage range is set for an analog controller to sense drain current or a traditional shunt resistor design is easily replaced and swapped with integrated current sensing.

$$R_{CS} = \frac{V_{CS}}{I_D \times G_{CSE}} = \frac{R_{CS(trad)}}{G_{CSE}} \quad (1)$$

An example of TI's integrated current sense feature is demonstrated using the LMG3624EVM-081 evaluation module for 65-W quasi-resonant flyback converter and the LMG36XX-CALC QR power stage design calculator. In this application, the worst-case input and output conditions calculate the maximum RMS current seen in the main switching FET. This current defines the proper translated voltage sent to the analog controller for current-mode control during each switching cycle. Table 2 shows some important input design specifications for this converter.

Table 2. LMG3624EVM-081 Input Design Specifications

Specification	Value
Minimum input AC voltage	90 VAC
Maximum output voltage	20 V
Transformer turns ratio	6:1
Bulk capacitance	120 µF
Magnetizing inductance	200 µH

Entering inputs from Table 2 into the QR design calculator returns a primary peak current I_{PK} of 2.8 A. Solving for an integrated current sensing resistor requires finding the appropriate traditional shunt resistor and then converting using the inverse current sense gain. To solve for the traditional shunt resistor $R_{CS(trad)}$, two other values are needed.

The first value is the controller feedback voltage V_{FB} which corresponds to the voltage range processed by the analog controller for current-mode operation. This value varies for different controllers.

The second value is the feedback loop gain K_{FB} which is a generic multiplier to account for additional gains in the controller feedback loop. Using Equation 2 and the previous values described, users can solve for a traditional shunt resistor. Converting to an integrated current sense resistor is easily calculated with Equation 3 by multiplying by the inverse current sense gain G_{CSE} for the LMG3624 device.

$$V_{FB} = K_{FB} \times I_{PK} \times R_{CS(trad)} \quad (2)$$

$$R_{CS} = 1{,}036 \times R_{CS(trad)} \quad (3)$$

The resistor placed on the output of the LMG3624 device CS pin connects to the analog controller, further documentation is found in *Using the LMG3624EVM-081 65-W USB-C PD High-Density Quasi-Resonant Flyback Converter*. The use of a design calculator provides easy input to adjust the current sense resistor due to fluctuations in design parameters or part selection. If a different LMG362x device is selected, simply use the corresponding current sense gain and recalculate. Substituting an integrated design for a shunt is calculated by simply dividing by the current sense gain. To set the voltage-to-drain current ratio, simply divide and solve.

Implementing this feature is intended to be easy for any topology regardless of controller or current sense input method. Integrated sensing is an excellent choice for bolstering efficient designs and thermal performance and pushing the limits of what is possible using TI GaN.