Application Brief

High Speed Current Sensing for Data Center mCRPS Standards

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Introduction

As data centers transition to high-density artificial intelligence (AI) workloads, the requirements on functionality, power levels, efficiency, and complex sensing continues to be driven to greater heights. This continues to be advanced through the latest server power supply requirement specifications including Modular Hardware System-Common Redundant Power Supply (M-CRPS) and Open Compute Project Open Rack v3 (OCP ORv3).

As a means of expanding server power supply unit (PSU) capability, new Silicon Carbide (SiC) or Gallum Nitride (GaN) switches are found in multiple places within a server PSU, both on the primary and secondary side of the isolation transformer within the DC/DC power stage. Figure 1 demonstrates a simplified signal chain block diagram for the main system function, including the voltage translations that are made within a typical 12V output PSU.

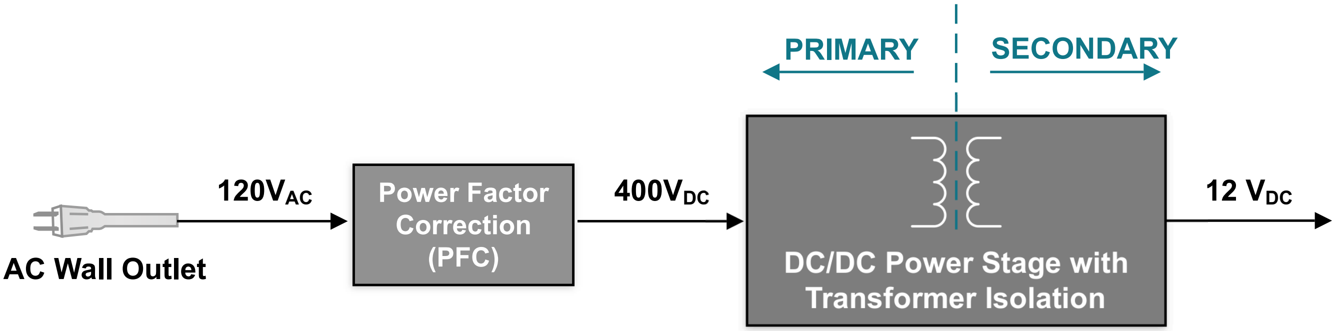

Figure 1. Server PSU Block Diagram

SiC or GaN switches are easily susceptible and sensitive to an overcurrent event. If a short-circuit occurrence is not identified in an ultra-fast response time and subsequently resolved by lowering the current flowing through the power switches, there is a risk of permanently damaging the switches and surrounding circuitry. Typical PSUs have a switching frequency in the hundreds of thousands of hertz (100-500kHz) which yields a total period of 10 - 2µs. Thus, an over current event must be detected and signaled downstream within a fraction of that period to have enough time for action to be taken on, yielding a 1 to 2µs response time. This safety function is referred to as Over Current Protection (OCP) and occurs wherever sensitive SiC or GaN switches are found, most commonly in the power factor correction (PFC) stage and system output rail.

What does the *Open Compute Project* standard specify for Over Current Protection?

According to the *Open Compute Project* standard for m-CPRS (version 1.05, section 9.5), *the power supply shall incorporate an output current monitoring pin (I_{MON}) which acts as a current mirror of the main 12V output, I_{MON} signals from other power supplies in the system can be tied together to provide a mechanism for the system to measure the total output current of all the power supplies combined* (9). Table 1 lists the subsequent I_{MON} signal characteristics as required by the standard.

Table 1. I_{MON} Signal Characteristics from Open Compute Standard[9]

Signal Type	Current Source
Sensitivity	0 to 2mA (representing 0 to 200% of rated current)
Minimum bandwidth	40kHz
Signal delay	≤ 20µs (tested using a load step from 5% to 105% and di/dt of 8A/µs without external capacitance connected to the power supply's main output)

A direct current value is sensed from the main system commonly through a direct shunt resistor circuit and is then split for various functions and mirrored for the final I_{MON}output, as shown in the system block diagram in Figure 2 .

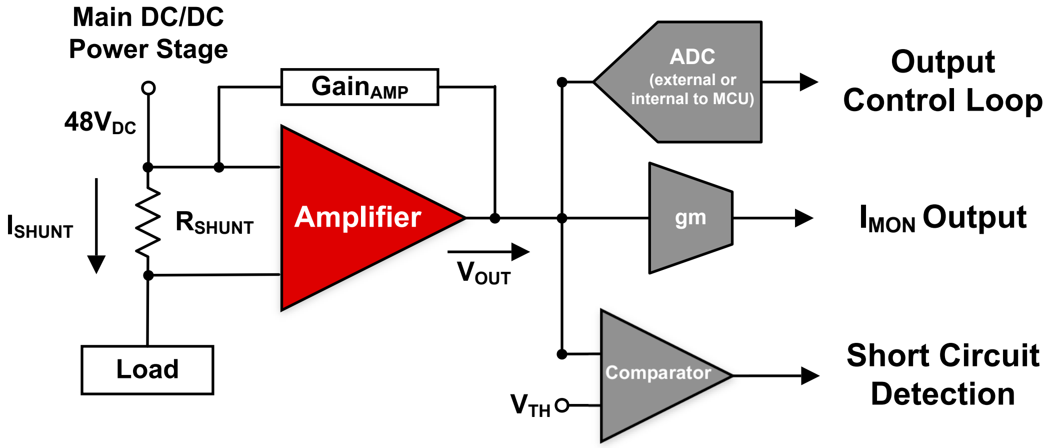

Figure 2. I_{MON} Sensing Block Diagram

To translate this standard into component selection for the current sensing circuitry, there are multiple calculations that need to be made. Using an example of a 3.5kW AI server with a 48V rail, the typical output current at 100% load is approximately 73A (Equation 1). Therefore at 200% load, the output is approximately 146A, as shown in Equation 2 .

$$I_{OUT@100\%load} = \frac{P}{V} = \frac{3500W}{48V} = 73A \tag{1}$$

$$I_{OUT@200\%load} = 2 \times 73A = 146A \tag{2}$$

Assuming a shunt resistor of 0.5mΩ, the voltage drop across the shunt resistor is calculated using Ohm's Law as a function of the current flow.

$$V_{SENSE@100\%} = I_{OUT@100\%} \times R_{SHUNT} = 73A \times 0.0005\Omega = 36.5mV \tag{3}$$

$$V_{SENSE@200\%} = I_{OUT@200\%} \times R_{SHUNT} = 146A \times 0.0005\Omega = 73mV \tag{4}$$

Once the voltage drop across the shunt resistor is determined, the required gain to amplify the sensed voltage change (which is proportional to the current) can be determined by approximating the required peak-to-peak output voltage. This voltage can then be used for subsequent analysis such as a comparator in the case of over current detection or an analog-to-digital converter (ADC) for an output control loop. An example usable voltage range is between 0.5V – 2V. At a gain of 25V/V, the corresponding output voltages for both the minimum and maximum are within target, shown below.

$$V_{out@100\%} = Gain_{amplifier} \times V_{sense@100\%} = 25 {}^{V}\!/_{V} \times 36.5mV = 0.913V \quad (5)$$

$$V_{out@200\%} = Gain_{amplifier} \times V_{sense@200\%} = 25 {}^{V}\!/_{V} \times 73mV = 1.83V \quad (6)$$

Signal Chain Calculations

Using the same amplifier and shunt resistor, the sensed current can be used for over-current protection signaling (OCP). Figure 2 demonstrates an example signal chain of how to use high-side current sensing on a 12V or 48V rail for over-current protection using a high-speed comparator, as described. Using the calculated system parameters, the required amplifier bandwidth can be calculated accordingly.

$$T_{OCP} = T_{Amplifier} + T_{Comparator} \le 1\mu s \quad (7)$$

$T_{Amplifier} \le 0.3\mu s$, to leave sufficient time delay for other analysis components (8)

$$Bandwidth = \frac{0.35}{T_{Amplifier}} = \frac{0.35}{0.3\mu s} \cong 1MHz \quad (9)$$

$$Gain\ \ Bandwidth\ \ Product(GBW) = Gain \times BW = 25 {}^{V}\!/_{V} \times 1MHz = 25MHz \quad (10)$$

In this system calculation, a 25MHz GBW amplifier is the minimum speed device that has enough tolerances for overall system performance. A similar calculation can be completed using the maximum signal delay of 20µs for implementing using I_{MON}.

$$T_{I_{MON}} = T_{Amplifier} + T_{gm} + T_{other} \le 20\mu s \quad (11)$$

$T_{Amplifier} \le 0.3\mu s$, assuming using the same device from the OCP calculation (12)

$$Bandwidth = \frac{0.35}{T_{Amplifier}} = \frac{0.35}{0.3\mu s} \cong 1MHz \quad (13)$$

$$Gain\ \ Bandwidth\ \ Product(GBW) = Gain \times BW = 25 {}^{V}\!/_{V} \times 1MHz = 25MHz \quad (14)$$

Table 2. Example Design Summary

Parameter	Value
Server Power Rating	3.5kW
Output Voltage	48V
Shunt Resistor	0.5mΩ
Amplifier Gain	25V/V
Required Minimum Amplifier Gain Bandwidth Product	25MHz

Amplifier Selection

As shown in Equation 10 and Equation 14, selecting an amplifier with wide gain bandwidth product is important to enable the overall system response time required to verify over current protection shut off, and further system level monitoring and feedback.

In addition to the bandwidth requirements, the precision performance of an amplifier is important for the overall current sensing performance. The lower the offset voltage and input bias current, the lower the error in the sensing measurement. A popular architecture for achieving this performance is a Zero-Drift[1] amplifier, such as OPA488. Zero-Drift[1] amplifiers utilize an internal switching architecture that dramatically reduces the offset voltage and offset voltage drift performance without the need for any additional trimming or post-process calibration.

Alternatively, a balance of high speed and high precision performance can also be achieved with devices such as OPA863A or OPA620 which feature TI's e-Trim™ technology for post-packaging stress trimming.

Summary

Texas Instrument's portfolio of high-speed, high precision amplifiers enables future server PSU current sensing designs to support the ever growing demands of AI data centers.

Table 3. Recommended Amplifiers

Part Number	Architecture	GBW (MHz)	Max Supply Voltage (V)	Input Bias Current (pA, max)	Offset Voltage (V_{OS}) (mA, max)	CMRR (typ, dB)
OPA488	Zero-Drift[1]	14	48	0.35	0.0075	150
OPA620	CMOS	50	5.5	50	0.3	96
OPA863A	e-Trim™ [2]	50	12.6	730	0.095	120
OPA810	FET-input[8]	70	27	0.02	0.5	100

Table 4. Recommended Comparators

Part Number	Output Type	Propagation Delay (ns)	Max Supply Voltage (V)	Input Common Mode (V_{CM})	Offset Voltage (V_{OS}) (mA, max)	Power Consumption (I_Q) (µA)
TLV3201	Push-Pull	40	5.5	Rail-to-Rail	1	40
TLV7021	Open-Drain	260	5.5	Rail-to-Rail	0.5	5
TLV1805	Push-Pull	250	40	Rail-to-Rail	4.5	150

Table 5. Recommended Analog-to-Digital Converters

Part Number	Architecture	Resolution (Bits)	Max Samping Rate (kSPS)	Interface Type	SNR (dB)
ADS7042	SAR	12	1000	SPI	70
ADS127L11	ΔΣ	24	1000	SPI	110
ADS7138	SAR	12	140	I2C	73

References

1. Texas Instruments, *Zero-Drift Amplifiers: Features and Benefits*, application brief.
2. Texas Instruments, *Offset Correction Methods: Laser Trim, e-Trim™, and Chopper*, application brief.
3. Texas Instruments, *Reference Design: High-Speed Current Shunt Monitor*, product page.
4. Texas Instruments, *1-kW, 12-V HHC LLC reference design using C2000™ real-time microcontroller*, product page.
5. Texas Instruments, *Reference Design: Current Sensing with <1-us Settling for 1-, 2- & 3-Shunt FOC in 3-Phase Inverter*, product page.
6. Texas Instruments, *Quickly Detecting Overcurrent Faults with Low-Side Current Shunt Measurement Required for SiC or GaN Switches*, application brief.
7. Texas Instruments, *Simplifying Power Conversion in High-Voltage Systems*, marketing white paper.
8. Texas Instruments, *What Are the Advantages of Using JFET-input Amplifiers in High-speed Applications?*, technical article.
9. Open Compute Project, *Server/MHS*, webpage.

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