Application Note

Point-of-Load Designs in Data Center Applications for Intel Xeon Sapphire Rapids Scalable Processors

TEXAS INSTRUMENTS

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ABSTRACT

Data centers are crucial for business continuity and reliable communications. Texas Instruments (TI) provides performance power management solutions, enabling high availability and efficiency when powering processors for data centers and rack servers. Advanced processors such as Intel® Xeon® Sapphire Rapids scalable processors, need point-of-load solutions for low-power CPU rails, 3.3-V and 5-V rail requirements from a nominal 12-V input bus. DDR5 memory point-of-load power is now provided by the Dual In-line Memory Module (DIMM) and no longer required on the motherboard. For specific information about Intel processors and their power requirements, log on to the Intel Resource and Design Center. Contact TI for information about multiphase controllers and power stages designed specifically for addressing the VR14 V_{CCIN} and Serial Voltage Identification (SVID) specifications. This document highlights DC/DC converters and describes their features addressing performance processor power requirements.

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1 Suggested DC/DC Converters

Table 1-1 highlights the latest point-of-load DC/DC converters with integrated MOSFETs that are applicable to powering Sapphire Rapids applications; however, they are designed to accommodate the requirements for a wide range of markets. These devices are designed to achieve fast transient response, high efficiency, good thermal performance, and high output voltage accuracy. Notice that different control architectures are suggested in Table 1-1.

Fixed-frequency control architectures provide a predictable switching frequency and can be synchronized to an external clock. Current mode or voltage mode control is desirable in noise-sensitive applications that use data converters and high-speed analog circuits. On the other hand, devices implementing constant on-time control deliver a faster transient response than voltage or current mode control to quickly changing load profiles, since there is no internal clock to control the switching frequency. Several devices feature PMBus® or I^{2}C with adaptive voltage scaling and margining. Devices integrating PMBus or I^{2}C with telemetry report voltage, current, and temperature information to a host processor.

DC/DC converters with integrated MOSFETs supporting Serial Voltage Identification (SVID) are now available, and offer a solution that is smaller and easier to design than a multi-phase controller-based solution when the output current is lower. The TPS53820 provides up to two outputs to power the low current SVID rails such as VCCANA (5.5 A) and P1V8 (4 A) in VR13.HC applications, and the TPS544C26 is Intel VR13 SVID compliant for Eagle Stream (EGS) and Birch Stream (BHS) applications. The TPS544C27 and TPS544E27 support VR14 Oak Stream (OKS) applications which include telemetry and security features, and are backwards-compatible to earlier Birch Stream and Eagle Stream applications.

Table 1-1. Suggested Point-of-Load Converters

I$_{OUT}$ Rating	Constant On-Time Control	Fixed Frequency Control	SVID Converter	PMBus / I^{2}C with Telemetry
DC/DC Converters with Integrated MOSFETS				
≤ 2 A	*TPS562231*	TPS62902	*TPS53820*	N/A
2 A – 3 A	*TPS563231*	TPS543320	*TPS53820*	N/A
3 A – 6 A	*TPS54J061*	*TPS543620*	*TPS53820*	TPS546C25
7 A – 11 A	*TPS548A28*	TPS543A22	*TPS544C27*	TPS546C25
12 A – 15 A	*TPS548B23*	TPS543B22	*TPS544C27*	TPS546C25
16 A - 20 A	*TPS548B23*	TPS543B22	*TPS544C27*	TPS546C25
21 A – 25 A	*TPS548C26* TPS54KB20	TPS543B25	*TPS544C27*	TPS546C25
26 A – 35 A	*TPS548C26*	TPS543C20A	*TPS544E27*	*TPS546E25*
>35 A	*TPS548D26*	TPS543C20A	*TPS544E27*	*TPS546E25*
Serial Voltage Identification (SVID) Controllers				
Dual Channel, 8-Phase (EGS)	*TPS53689*			
Dual Channel, 12-Phase (EGS)	*TPS536C9*			
Dual Channel, 8-Phase TLVR (BHS)	*TPS53689T*			
Dual Channel, 12-Phase TLVR (BHS)	*TPS536C9T*			
OKS: *Contact TI for multi-phase controllers*				
Smart Power Stage				
90-A NexFET™ smart power stage in 5x6mm package	*CSD95410*			
50-A NexFET™ smart power stage in 4x5mm package	*CSD95420*			
BHS, OKS: Contact TI for Smart Power Stages in Development				
Low Drop Out Regulator				
1.5A	TPS748A	Linear Regulator with Adjustable Soft-Start, PG, Enable, and 0.85% Reference Accuracy		

Products in italics have a second-source from another supplier.

2 Voltage Regulation Accuracy

As the semiconductor process technology advances, processors require tighter voltage accuracy and lower operating voltages. The processor data sheet specifies the voltage tolerance as either a percentage or as a value in millivolts, which includes DC, AC and ripple variations over the entire operating temperature range. Designers also consider the tolerance of the resistor divider used by the DC/DC converter, the routing and trace losses of the circuit board, and the variations of the application, like the input voltage variations, temperature swings, and fast changes in the load.

Check the feedback voltage accuracy of the DC/DC converter in the data sheet rather than the front page. Table 2-1 shows the regulated feedback voltage, or the internal voltage reference specification of the TPS548A28, which is a 2.7V to 16V, 15A converter, and shows that the reference accuracy is ±6 mV or ±1% over the full operating temperature range. The total output voltage accuracy is improved by choosing tighter tolerance resistors for the dividing network. If more headroom is needed, designers can choose 0.1% or 0.5% resistors, even though they may cost a little bit more. The additional headroom allows a total ±3% or ±5% output voltage variation to be met with less bulk and bypass capacitance. [1]

Table 2-1. Internal Voltage Reference of the TPS548A28

| Parameter	Test Condition	Minimum	Typical	Maximum	Unit
Internal voltage reference	T_J = –40°C to 125°C, V_{CC} = 3V	594	600	606	mV
	T_J = 0°C to 85°C, V_{CC} = 3V	597	600	603	mV

A DC/DC converter with a selectable output voltage, which has internal voltage feedback, is advantageous to a DC/DC converter using an external voltage feedback divider to program the output voltage. A converter with internal voltage feedback, such as the TPS548B23, requires fewer external components and can provide higher voltage accuracy. Both converter types have an internal voltage reference, but the DC error of the external resistor divider is accounted for inside the converter with internal voltage feedback. Table 2-2 shows the actual output voltage of the TPS548B23 with internal voltage feedback.

Table 2-2. Output Voltage Regulation Accuracy of TPS548B23

Parameter	Test Condition	Minimum	Typical	Maximum
Output voltage regulation accuracy	Internal Feedback Configuration, T_J = 0°C to +85°C	-0.75%		+0.75%
	Internal Feedback Configuration, T_J = -40°C to +125°C	-1.25%		+1.25%

The TPS548B23 is configurable to use either external or internal feedback as shown in Figure 2-1. If the output voltage required is one of the 16 present selections, the TPS548B23 will reduce the external components and improve the output voltage accuracy. Often times, layout constraints, connectors, and board density requirements affect the total output voltage accuracy. A remote sense feature of a DC/DC converter compensates for voltage drops from long trace lines to accommodate processors needing high accuracy output voltage. This feature is especially useful when routing higher currents since the voltage drop can be a large portion of the overall DC error. Newer DC/DC converters are integrating a remote sense amplifier across the feedback pin (VOS) and ground sense return pin (GOS) instead of traditional VSNS+ and VSNS- pins to reduce the converter's pin-count. The remote sense function is fully differential in both cases and compensates for a voltage drop on the circuit board traces helping to maintain V_{OUT} accuracy under steady state operation and load transient events.

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[1] Power Tip #18: The output-voltage accuracy of the regulator may not be as bad as perceived.
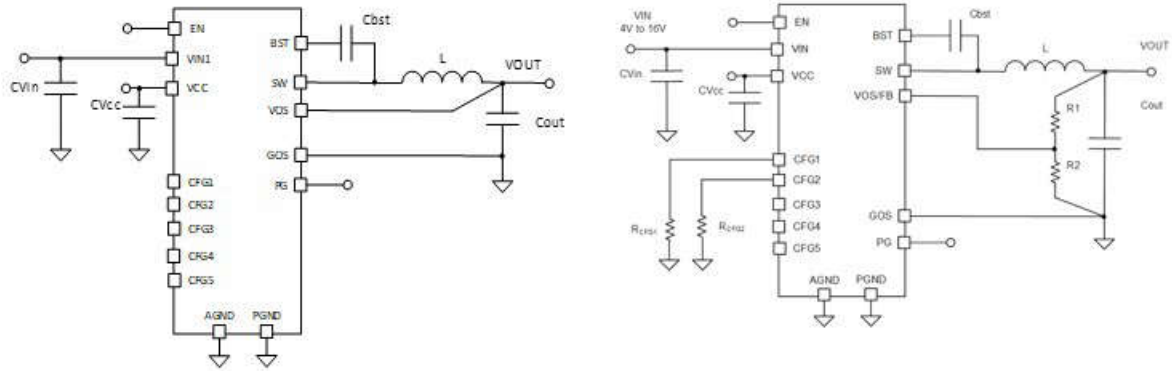
Figure 2-1. TPS548B23 Configured with Internal or External Feedback

3 Load Transient Response with D-CAP4

Since the load profile can change dramatically in an enterprise rack server, it is important to consider AC transient performance. Choosing a DC/DC converter with a fast transient response using non-linear control techniques, such as constant on-time or D-CAP4™, allows a fast transient response with minimal output capacitance. The D-CAP4 control architecture includes an internal ripple generation network enabling the use of very low ESR output capacitors such as multi-layered ceramic capacitors (MLCC) and low ESR polymer capacitors. No external current sensing network or voltage compensator are required with D-CAP4 control architecture. The role of the internal ripple generation network is to emulate the ripple component of the inductor current information and then combine with the voltage feedback signal to regulate the loop operation. D-CAP4 control architecture is different from D-CAP3™ and reduces loop gain variation across the output voltage, enabling a fast load transient response across the entire output voltage range with one ramp setting, especially at higher output voltages, like 3.3V and 5V. The R-C time-constant of the internal ramp circuit sets the zero frequency of the ramp, similar to other R-C based internal ramp generation architectures. The reduced variation in loop gain also mitigates the need for a feed-forward capacitor to optimize the transient response. The ramp amplitude varies with the input voltage to minimize variation in loop gain across input voltage, commonly referred to as input voltage feed-forward. Converters with D-CAP4, as well as D-CAP3, use internal circuitry to correct for the dc offset caused by the injected ramp, and removes the dc offset caused by the output ripple voltage, especially with light load current when skip mode operation is selected. Figure 3-1 shows D-CAP3 and Figure 3-2 shows D-CAP4 transient response comparisons under the same operating conditions with a 5-A to 15-A load step, 1-A/µs slew rate, 3.3V output and 800kHz switching frequency. D-CAP4 performed better with a 60.7mV droop and overshoot voltage response compared to D-CAP3's 117mV droop and overshoot response, with both converters using the same 470nH inductor and 570µF of total output capacitance.

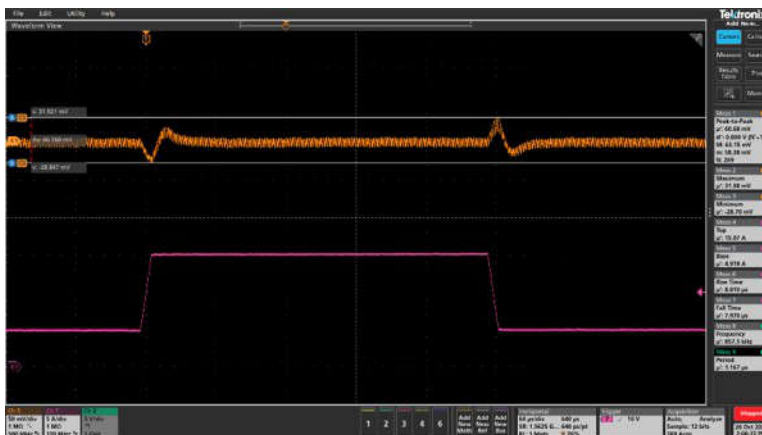**Figure 3-1. TPS54JB20 Transient Response with D-CAP3**

Figure 3-2. TPS54KB20 Transient Response with D-CAP4

4 Security Features

Traditionally, digitally controlled power designs, whether using I^{2}C, SMBus, PMBus, SVID or some other digital interface, have relied on the security of the bus controller devices to prevent malicious actors from gaining access and using the digital control to shut down the converter or even damage hardware. That was considered good enough for most applications. With the ever increasing presence of digital interfaces, and ever more sophisticated threats, that is no longer always sufficient to make sure the integrity of a system. When a device is connected to a remote interface, there is the possibility for remote actors to gain access the digital bus through one of the connected devices, and potentially send malicious commands over the bus. Table 4-1 shows the latest DC/DC converters with security features.

Table 4-1. DC/DC Converters with Security Features

Device	Digital interface	Security	Current & package
TPS544C27	SVID, PMBus	Level 2	35A, 4x5mm
TPS544E27	SVID, PMBus	Level 2	40A, 5x6mm
TPS546C25	PMBus	Passkey	35A, 4x5mm
TPS546E25	PMBus	Passkey	50A, 5x6mm

The PASSKEY feature provides the designer with a intermediate level of security between the open security, and the permanent lock created by using the write-protect command for protection. PASSKEY is a 16-bit digital key. When set, PASSKEY disabled write access to both EXT_WRITE_PROTECT and the User NVM store until the PASSKEY is written back to the device. To protect devices from brute force attacks, PASSKEY is limited to three failed PASSKEY write attempts per power-cycle.

Level 2 security uses a 32 byte pre-shared key (PSK) to perform device attestation and authenticated updates. Both of these functions use a combination of SHA2-384 and HMAC SHA2-256 hash algorithms within the device to calculate the message authentication code (MAC). In the case of device attestation, the MAC calculated by the device is compared to an expected MAC to verify the device has the correct PSK programmed and NVM configuration.

5 High Efficiency and Thermal Performance

Rack servers employ circuit boards with many PCB layers, depending on the form factor constraints. Since the rack server is designed to be used in tight spaces, consider the thermal environment and available airflow when selecting DC/DC converters. The ambient temperature inside a rack server is typically between 60°C and 70°C since forced airflow is usually available. Higher circuit board temperatures translate to lower reliability, and higher current DC/DC converters contribute to the overall thermal budget.

Figure 5-1 shows the safe operating curve and Figure 5-2 shows the power loss plot of TPS543C20A. The TPS543C20A DC/DC converter delivers 40 A and 1 V output with an ambient temperature of 75°C, without airflow. At 25 A and 1 V output, the entire solution dissipates less than 3 W, which translates to around 90% efficiency when switching at 500 kHz.

The TPS543C20A measured junction-to-ambient thermal resistance is 12°C/W based on a 6-layer, 2-oz Cu per layer and a 2.75 inch by 3 inch board size, which demonstrates low thermal resistance. However, many thermal metrics exist for semiconductor and IC packages, which range from RθJA to ψJT. Often, designers misapply these thermal metrics when trying to estimate the junction temperatures in their systems. Ultimately, thermal performance depends on the circuit-board layout and using standard JEDEC-referenced thermal numbers. [2]
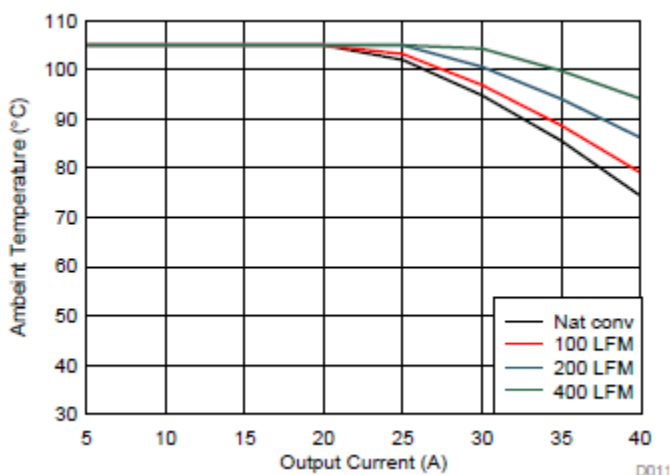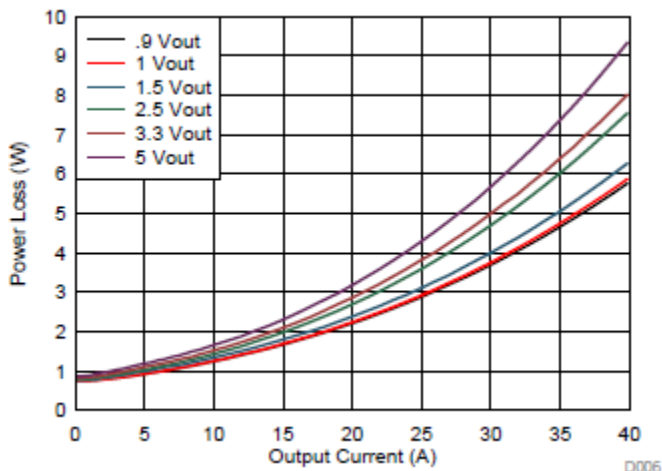

Figure 5-1. SOA Curve for TPS543C20A

Figure 5-2. Power Loss Curves for TPS543C20A

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[2] Understanding the thermal-resistance specification of DC/DC converters with integrated power MOSFETs

6 Linear Regulator with Adjustable Soft-Start and High Output Voltage Accuracy

For low current rails, a linear regulator with a user-programmable soft-start minimizes stress on the input power source by reducing the capacitive inrush current on start-up, especially from highly capacitive loads or with processors requiring many bypass capacitors. The TPS748A adjustable linear regulator provides a monotonic (non-negative slope), linear soft-start ramp that is well-suited for powering many different types of processors. The linear regulator also includes enable and power good pins to aid in sequencing schemes. Figure 6-1 illustrates the start-up waveform showing the start-up times varying over several soft start capacitor values.
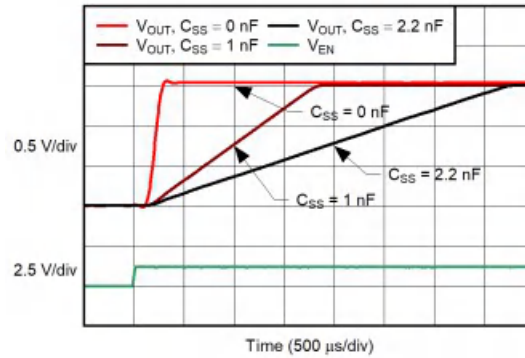
Figure 6-1. TPS748A Start-up Waveform

The linear regulator has a precision reference and error amplifier delivering 0.85% accuracy over load, line, temperature, and process variations. The reference voltage accuracy rivals many switch-mode DC/DC converters on the market, allowing a linear regulator to be used in lower current applications without sacrificing feature and sequencing requirements or output voltage accuracy performance.

SLVAF22C – JANUARY 2021 – REVISED OCTOBER 2024
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7 Conclusion

Performance processors, such as Intel's Xeon Sapphire Rapids scalable server processors, benefit from DC/DC converters that offer improved output voltage accuracy, fast transient response, reduced external component count, high efficiency and excellent thermal performance. TI offers high performance point-of-load solutions to address these design requirements.

8 Additional Resources

- Texas Instruments, *How to meet DC voltage accuracy and AC load transient specification*, TI training video.
- Texas Instruments, *Accuracy-Enhanced Ramp-Generation Design for D-CAP3 Modulation*, application note.
- Texas Instruments, *Control Mode Quick Reference Guide, Step-Down Non-Isolated DC/DC*.
- Texas Instruments, *TI Rack Server*.

9 Revision History

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