Application Report

DC/DC Converter Solutions for Hardware Accelerators in Data Center Applications

ABSTRACT

Hardware accelerators are custom-made hardware designs on a circuit board that perform specific functions better than software. Hardware accelerators use advanced processors, such as:

- FPGAs
- ASICs
- SoC
- GPUs

These processors are very suitable for performing specific, computation-intensive algorithms. Hardware acceleration helps enable artificial intelligence, including special functionalities such as machine learning, brain simulation, and neural engines. These functions use statistical techniques that allow computer systems to learn from data without being programmed, similar to our understanding of how the brain operates. Examples include 360° camera-view image recognition and speech recognition. The advanced processors used in hardware accelerator applications need special attention from point-of-load power management solutions, with features such as:

- Margining
- Adaptive Voltage Scaling (AVS)
- High temperature
- Safe Operating Area (SOA)
- High-current capability

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Trademarks

PMBus™ is a trademark of SMIF Inc.

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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 for hardware accelerator applications from either a 5-V or 12-V input bus. These devices are designed to achieve high-output voltage accuracy, high efficiency, and good thermal performance. Several devices feature a Power Management Bus (PMBus™) with adaptive voltage scaling and margining. PMBus devices integrate telemetry report voltage, current, and temperature information to a host.

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

Output Current	Converter	Converter with PMBus or I^2C	Converter with PMBus and Telemetry
≤ 3 A	TPS62903	-	-
3 A – 6 A	TPS54J061	TPS542A50	TPS546A24A
6 A – 8 A	TPS543820	TPS542A50	TPS546A24A
8 A – 12 A	TPS548A29	TPS542A50	TPS546B24A
12 A – 15 A	TPS548A29	TPS542A50	TPS546B24A
15 A – 20 A	TPS548B28	TPS549B22	TPS546B24A
20 A – 25 A	TPS543B20	TPS549B22	TPS546D24A
25 A – 40 A	TPS543C20A	TPS549D22	TPS546D24A
>40A	TPS543C20A	TPS546D24A	TPS546D24A

2 Adaptive Voltage Scaling

Adaptive voltage scaling (AVS) is the adaptation or modification of the supply voltage for a processor (given the processing strength). The supply voltage of the DC/DC converter can be adjusted to minimize power while still achieving desired performance. In hardware accelerator applications, the processor can allow the DC/DC converter to increase or decrease supply voltage based on the required performance. When the supply voltage is reduced, the power consumption of the processor is reduced. This is displayed in Equation 1, where C is the transistor capacitance of the processor. Since power consumption and heat generation are key concerns, especially in high ambient temperature environments, using AVS results in substantially improved processor thermal performance, energy savings, and long-term reliability. Advanced processors typically use a serial communication protocol to set the DC/DC converter's output voltage, but there are other alternative approaches. These include using external MOSFETs to adjust the voltage divider resistors of the feedback loop, or, as shown in Figure 2-1, implementing a parallel identification scheme by placing the LM10011 VID voltage programmer in the feedback loop of any DC/DC converter.

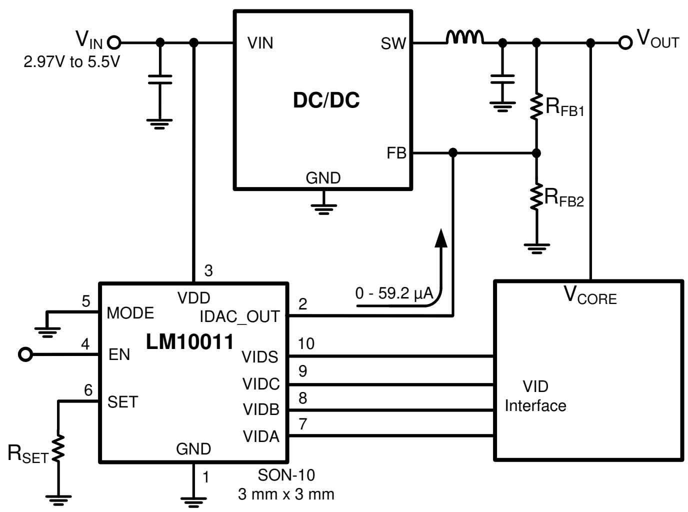

Figure 2-1. Using LM10011 for AVS

$$P = \frac{1}{2} \times C \times V^2 \quad (1)$$

DC/DC converters with an integrated serial bus supporting AVS are the easiest to implement. The PMBus protocol is a simple and powerful open-industry specification that unifies the communication standards for digital power-management systems and power conversion devices. It is the widely accepted Inter-Integrated Circuit (I^2C) communication protocol for defining the physical layer. Many DC/DC converters from Texas Instruments with PMBus feature the VOUT_COMMAND to adjust the output voltage on-the-fly. The output voltage can also be adjusted on-the-fly by the VOUT_MARGIN_HIGH and VOUT_MARGIN_LOW commands. The support range for the VOUT_COMMAND of the 25-A TPS549D22, for example, is 0.5996 V to 1.1992 V. Please note that supported PMBus commands differ from one DC/DC converter to another, and it is wise to check the data sheet for the list of supported commands. Any power management device only needs one command to be PMBus-compliant. More DC/DC converters feature telemetry to read voltage, current, and temperature for improved thermal management capability and fault reporting, in addition to supporting AVS. Figure 2-2 shows the TPS549B22 with PMB_DATA and PMB_CLK pins for serial communication, which support AVS and other programmable features.

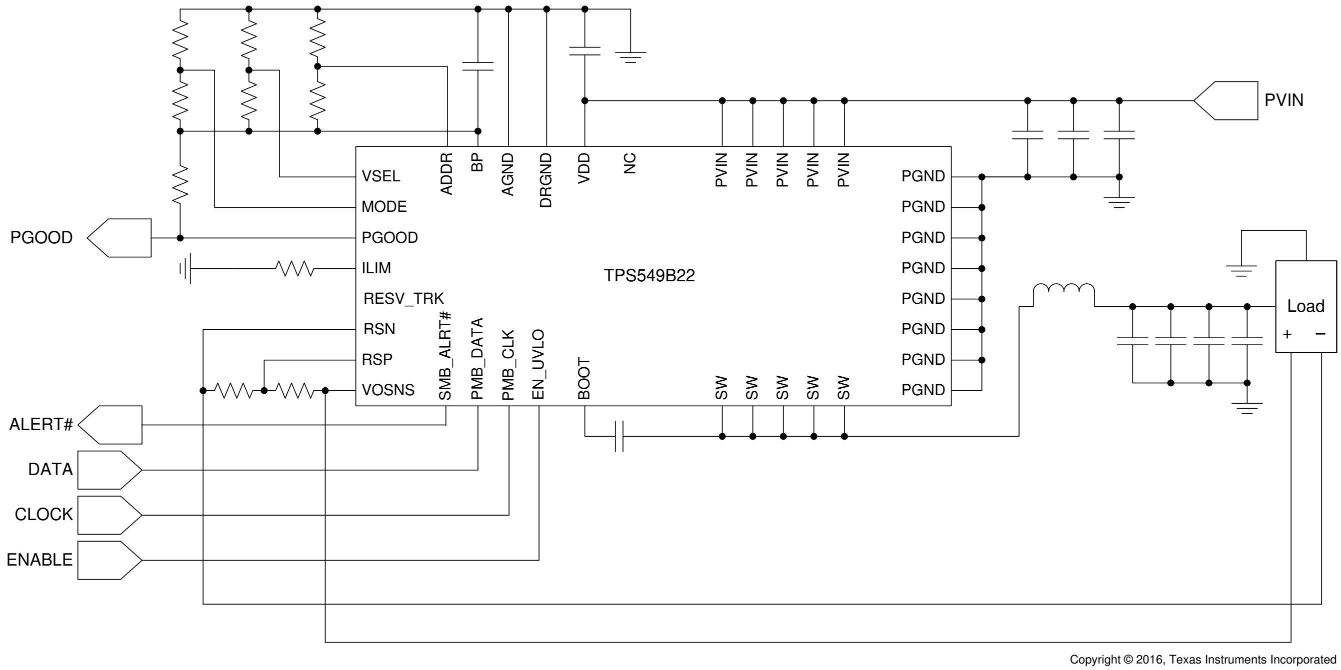

Figure 2-2. TPS549B22 with Integrated PMBus Interface

3 High Efficiency and Thermal Performance

Depending on form factor constraints, hardware accelerators are built on circuit boards with many PCB layers. Since the hardware accelerator is typically designed for use in tight spaces, special attention must be taken in selecting DC/DC converters to ensure the application operates in thermally challenging environments with the available airflow. This is displayed in the SOA curve of Figure 3-1, and the power-loss plot in Figure 3-2, the TPS543C20A DC/DC converter delivers 40-A and 1-V output with an ambient temperature of 75°C without airflow. At 25-A, 12-V input 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 six-layer, 2-ounce Cu per layer, and 2.75 inch by 3-inch board size, which demonstrates low thermal resistance. However, many thermal metrics exist for semiconductor and integrated circuit packages, which range from $R_{\theta JA}$ to ψ_{JT}. Often, designers misapply these thermal metrics when trying to estimate the junction temperatures in a system. Ultimately, thermal performance depends on the circuit board layout and using standard, JEDEC-referenced thermal numbers [1].

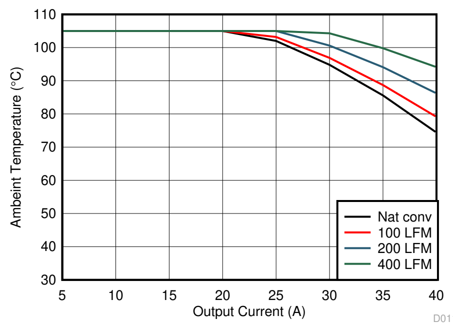

Figure 3-1. TPS543C20A SOA Curve

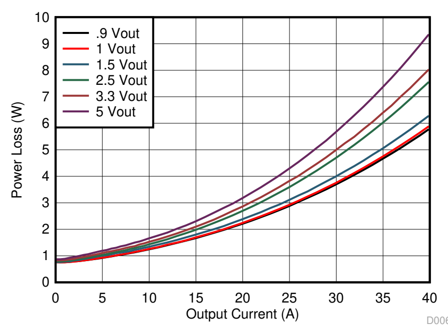

Figure 3-2. TPS543C20A Power Loss Curve

[1] *Analog Design Journal: "Understanding the thermal-resistance specification of DC/DC converters with integrated power MOSFETs"*

4 Current Sharing

When two devices operate in a dual-phase, stackable application, a current-sharing loop maintains the current balance between devices. Both devices share the same internal control voltage through VSHARE pin. The sensed current in each phase is first compared in a current-share block by connecting the ISHARE pin of each device, and then the error current is added into the internal loop. Connect the SYNC pin of the master and slave converters to share switching frequency information. The resulting voltage is compared with the PWM ramp to generate the PWM pulse for DC/DC conversion. Figure 4-1 shows the TPS543C20A in a stackable configuration to current-share up to 80-A while operating 180 degrees out of phase. Not only does a stackable configuration support higher currents, but it also reduces input ripple with out-of-phase operation, and improves overall system thermal performance, since the generated heat is spread over more circuit board area. If higher current is desired from an integrated MOSFET DC/DC converter, the TPS546D24A can be stacked up to four devices to support up to 160 A. For more information, see the reference design PMP21814.

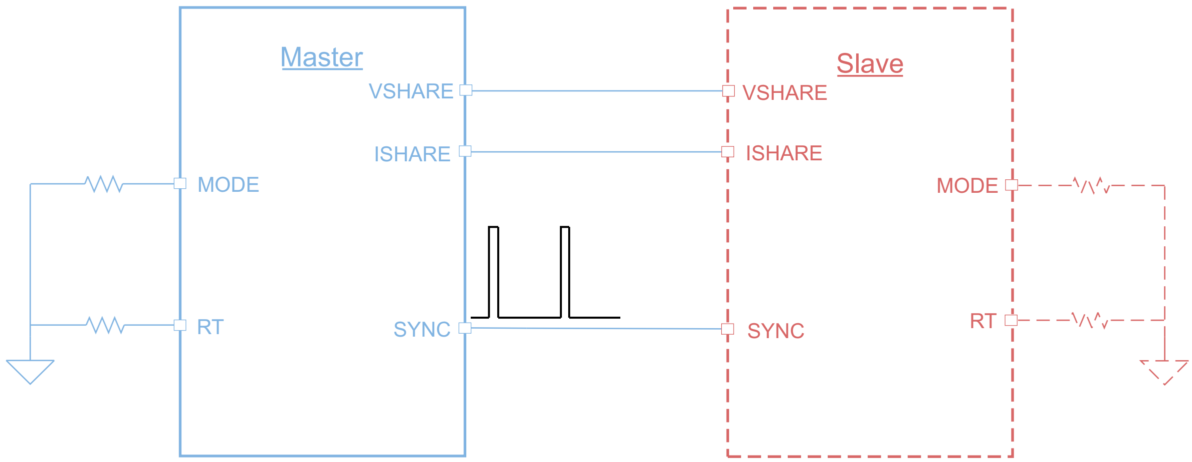

Figure 4-1. TPS543C20A in Stackable Configuration Supports up to 80 A

5 Voltage Regulation Accuracy

As 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 value in mV, which includes DC, AC and ripple variations over the entire operating temperature range. Designers must also consider the tolerance of the resistor divider used by the DC/DC converter, the routing and trace losses of the circuit board, and variations in the application. These include input voltage variations, temperature swings, and fast changes in the load.

It is important to check the feedback voltage accuracy of the DC/DC converter in the data sheet rather than the front page. Table 5-1 shows the regulated feedback voltage specification of the TPS543820, which is a 4 to 18-V, 8-A converter, and shows that the reference accuracy is ±2.5mV, or ±0.5%, over input voltage and temperature variations. The total output voltage accuracy is improved by choosing tighter tolerance resistors. If more headroom is needed, designers can choose 0.1% or 0.5% resistors [2], even though they may cost a little bit more. The additional headroom will allow the total ±3% or ±5% output voltage variation during load transients to be met with less bulk and bypass capacitance.

Table 5-1. TPS543820 Feedback Voltage Regulation

Parameter	Test Condition	Min.	Typ.	Max.	Unit
Feedback Voltage V_{FB}	T_J = -40°C to 150°C, V_{IN} = 4 V to 18 V	497.5	500	502.5	mV

Often, 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 that need high-accuracy output voltage. This feature is especially useful when routing higher currents, as the voltage drop can be a large portion of the overall DC error. Figure 5-1 shows the TPS543B20 using the remote-sense feature with voltage feedback resistors used to program the output voltage. Figure 5-2 shows the TPS543B20 using the remote-sense feature, without voltage feedback resistors, when the VSEL pin selects the reference voltage. The RSP and RSN pins are extremely high-impedance input terminals of a true-differential, remote-sense amplifier.

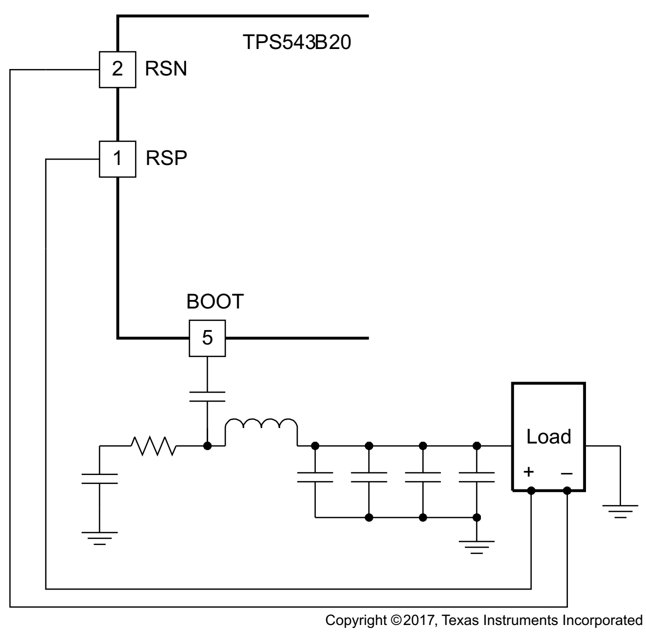

Figure 5-1. Remote Sense Without Feedback Resistors

[2] *Power Tip #18: Your regulator's output-voltage accuracy may not be as bad as you think*

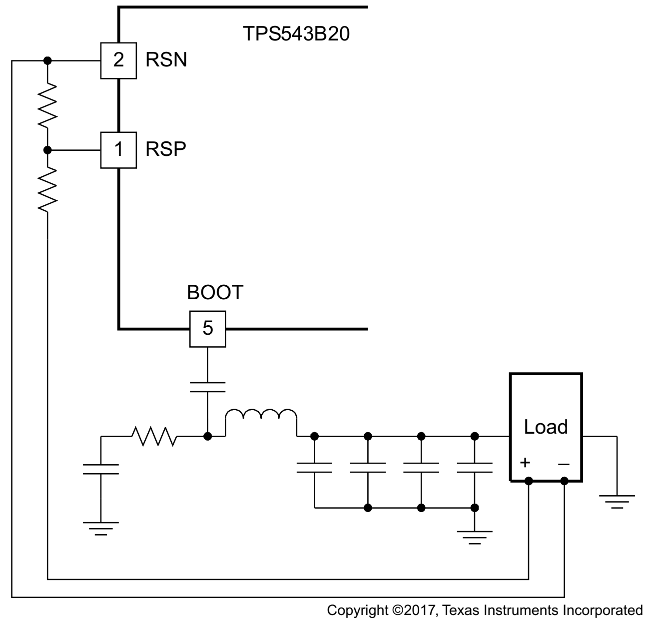

Figure 5-2. Remote Sense With Feedback Resistors

6 Conclusion

Hardware accelerators need DC/DC converters that offer:

- Improved output voltage accuracy
- Fast transient response
- Adaptive voltage scaling
- High efficiency
- Excellent thermal performance

Texas Instruments offers high-performance point-of-load solutions to address these requirements. Visit TI's End Equipment page to learn more about power management solutions for hardware accelerator applications.

7 Resources

- Texas Instruments Training Video, *How to Meet DC Voltage Accuracy and AC Load Transient Specifications*.
- Texas Instruments, *PMP21814: 4-Phase, 160-A Synchronous Buck Converter Reference Design Using TPS546D24A*.
- Texas Instruments, Hardware Accelerator Card End Equipment page.

8 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (August 2019) to Revision A (May 2021)	Page
• Added sample history element as an example	1