Power Solution Options for Data Center Applications

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Designing a power supply for data center server, switch and hardware accelerator applications is challenging. There are strict requirements on power density, thermal performance, efficiency and core rail tolerance, including DC accuracy and load transient response (AC tolerance), as well as many other specifications such as ripple and electromagnetic interference.

Field programmable gate arrays (FPGAs) are very popular in data center applications, with high-performance versions exceeding 100 or even 200 A.

A wide variety of power solutions exist for non isolated DC/DC rails. You can choose from power modules with integrated inductors, metal-oxide semiconductor field-effect transistors (MOSFETs) and passives, converters with integrated MOSFETs and controllers with external MOSFETs. As a designer, it can be tough to know which solution to use when so many options are available. In this white paper, I will compare the different options and their advantages and disadvantages.

Thermal performance

One major issue to consider when designing a power supply for server and switch applications is heat. Heat that is not properly controlled can slow down processing speeds or even damage the board by creating "hot spots" that essentially force components and the printed circuit board (PCB) to withstand a "thermal beating." There are many ways to cool down circuit boards externally through cooling systems such as fans, water pipes or heat sinks, but designing the power supply and PCB with thermals in mind at the beginning can dramatically improve the heat dissipation of the whole system, and increase robustness and reliability.

One way to design for better thermal performance is to consider using DC/DC power modules with an open-frame package type, built on PCB substrates with surface-mount display or through-hole interface pins (**Figure 1**). By not encapsulating the integrated circuits (ICs), air will flow more easily, thus dissipating more heat in the process. This enables open-frame modules to achieve higher currents than traditional quad flat no-lead packages.

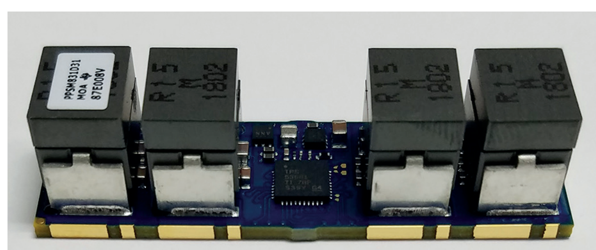


Figure 1. *TPSM831D31 120-A -plus- 40-A dual-output Power Management Bus (PMBus) open-frame module.*

The TPSM831D31 dual-output 120-A -plus- 40-A PMBus power module is an open-frame module developed for high-current application-specific ICs (ASICs) and FPGAs used in data center switches, servers and hardware accelerators. The TPSM831D31 is a PMBus-controlled, dual-output, four-phase power module that combines a high-performance D-CAP+™ control mode multiphase pulse-width modulation (PWM) buck controller with four high efficiency smart power stages (a synchronous MOSFET driver paired with a high-side/low-side MOSFET in one package) and low-loss inductors in a rugged, thermally enhanced surface-mount package. The first output is configured as a three-phase power stage that can deliver up to 120 A of continuous output current. The second output is a single-phase power stage that can deliver up to 40 A of output current. The rectangular pads on the bottom of the module (**Figure 2**) enable direct heat sinking into the PCB internal layers. **Figure 3** compares the thermal performance advantages of this open frame and PCB pad construction versus other industry modules.

The **TPSM846C23** 35-A PMBus power module is another open-frame power module designed to power high-current ASIC and FPGA core rails. Paralleling two TPSM846C23 devices increases the current to 70 A. For applications requiring only analog control, the TPSM846C24 is the analog version of the TPSM846C23.

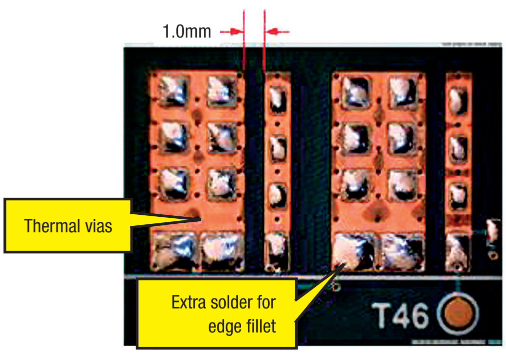


Figure 2. *TPSM831D31 PCB bottom pads – all rectangles.*

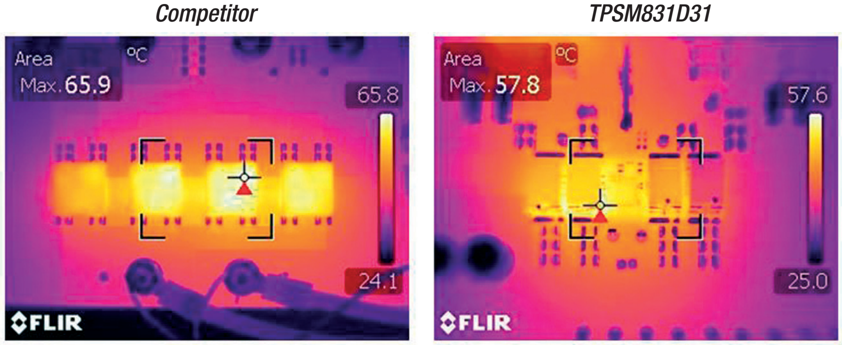


Figure 3. *Thermal performance comparison: V_{IN} = 12 V, V_{OUT} = 1.0 V, I_{OUT} = 100 A, F_{sw} = 500 kHz, 22°C ambient, 200 linear ft./min. airflow.*

Another way to design for better thermal performance is to use DC/DC controllers with external FETs. Many designers believe that the fewer components on the bill of materials, the more reliable the system. This may not be the case all the time, however. If you're thinking of using converters or power modules, you will need to take into account how the heat of the integrated MOSFETs will affect the converter's performance and reliability, since their proximity is now closer inside one integrated package. In a controller with external MOSFETs, the MOSFETs are spaced farther away from the controller, so it may have better reliability.

Figures 4 and **5** show the measured thermal performance of the **TPS53119** buck controller with external MOSFETs and the TPS548B22 buck converter with integrated MOSFETs. Conditions for the TPS53119 were a 12-V input and 0.9-V output at 25 A. Conditions for the **TPS548B22** were a 12-V input and 1.0-V output at 25 A. The TPS53119 had a maximum temperature of 58.5°C, while the TPS548B22 had a maximum temperature of 66.3°C.

By comparing the thermal performance in these figures, you can see that a controller with external MOSFETs may have better reliability than a converter with integrated MOSFETs. This distribution of heat in your design will help enable better thermal performance and reduce the risk of failures or permanent damage to the board. Ensuring that the boards are well protected from heat damage will be a huge advantage for your design.

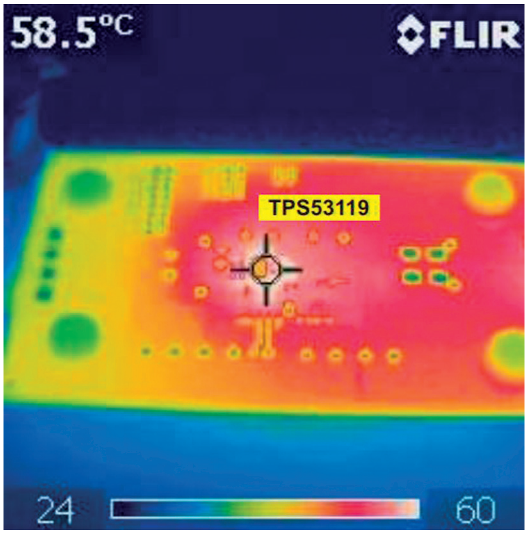


Figure 4. *TPS53119 thermal performance, T_{max} = 58.5°C.*

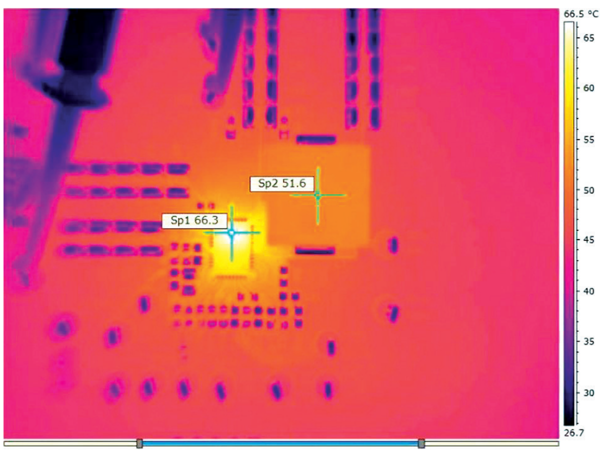


Figure 5. *TPS548B22 thermal performance, T_{max} = 66.3°C.*

MOSFET flexibility

Designing a DC/DC controller with external MOSFETs also gives you the flexibility to choose the most optimized MOSFETs for your design. Since converters and power modules have integrated MOSFETs, you are restricted to the MOSFETs that the converter manufacturers chose. But being able to choose your own MOSFETs has advantages in pricing, sourcing and current scaling.

DC/DC controllers are already a cost-effective option, since you are not paying for MOSFET integration. When you combine that cost savings with the savings from lower-cost external MOSFETs, the savings really add up. On the other hand, if you have limited time, power design knowledge or team members, using a converter or power module could help you save design and test time, which over the long run could save money.

Because many different semiconductor companies manufacture MOSFETs, there is a wide selection from which to choose. MOSFETs also typically come in industry-standard packaging, which will help meet dual sourcing requirements.

Another advantage is being able to choose different MOSFETs for different design needs. Some designs require high efficiency, while others are designed for cost-effectiveness. The flexibility to scale for higher performance or cost-effectiveness is a big plus.

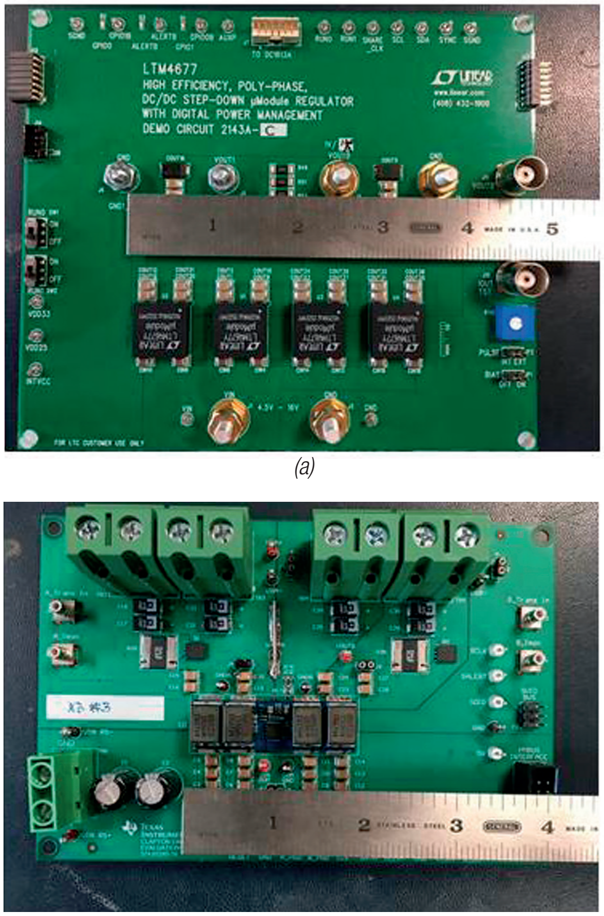
Finally, when using controllers with external MOSFETs, you have the ability to scale your solution to different current levels, all while using the same controller. This means that you do not have to design with a different converter for each power rail, but instead can use the same controller on several rails and then select the MOSFETs for the desired current levels.

In other words, controllers with external MOSFETs provide reusability across multiple projects. If a different project requires a different current level, it doesn't mean that you will need a different controller. You can use the same controller but select different MOSFETs depending on the current levels. Using the same controller across multiple projects will save you time and money.

Power density

Power density is a key design requirement for data center applications as more designs use power-hungry central processing units and FPGAs that must fit within a particular rack-unit form factor without extending the board size.

Power modules can optimize the layout of the power supply to fit a small area near the point of load. Technologies such as raised inductors and embedded components enable power modules to occupy a smaller X-Y board area compared to a similar converter or controller with an external MOSFET design. The TPSM831D31 occupies only 40% of the area required versus competitive solutions, as shown in **Figure 6**.



(a)

(b)

Figure 6. *Power-density comparison at 120 A: four competitor modules current sharing (a); one TPSM831D31 module (b).*

High efficiency

Another major concern in server applications is the need for highly efficient power conversion. Looking at the efficiency plots in **Figures 7** and **8**, you can see that a buck controller with external MOSFETs (the TPS53119) will have efficiency similar to a buck converter with integrated MOSFETs (the TPS53353). One key thing to keep in mind is cost. With an unlimited budget, you could purchase the most efficient solution on the market and call it a day. Unfortunately, not everyone has an unlimited budget to spend on their power architecture. You will need to perform a balancing act between performance and cost, depending on your individual project constraints.

Fortunately, TI's buck controllers are good options because of their performance-to-cost ratio. As I mentioned earlier, buck controllers typically cost much less than converters and power modules, especially at higher currents. Even when including the cost of the external MOSFETs, your total solution cost will most likely be lower than a converter or power module solution.

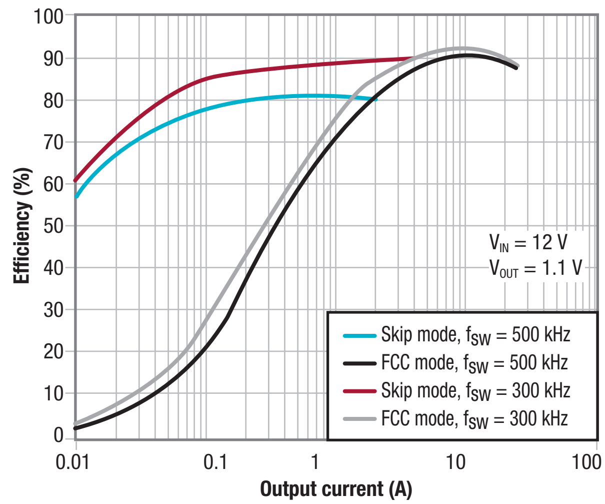


Figure 7. *TPS53119 efficiency plot; skip and forced continuous conduction (FCC) mode operation.*

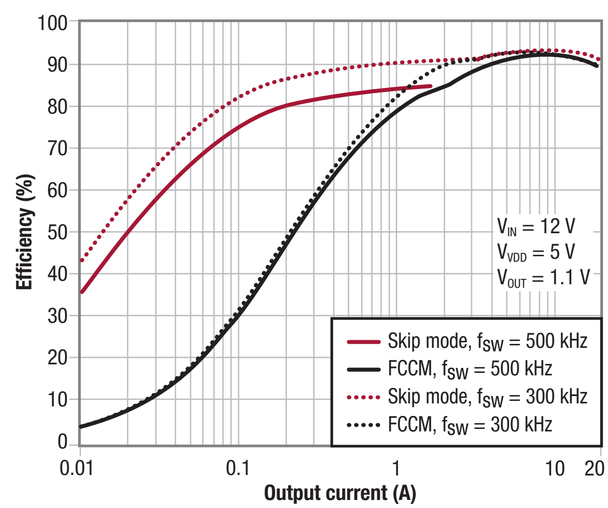


Figure 8. *TPS53353 efficiency plot; skip and FCC mode operation.*

Although modules come with pre-selected components, which enables a drop-and-forget power solution for ease of use, it's thought that module efficiency generally lags behind that of a discrete converter solution.

TI module designs use an optimized layout and thick copper to enable efficiency that approaches that of a discrete solution. For example, the TPSM831D31's dedicated layers with thicker copper traces can minimize power-path resistance and deliver efficiency comparable to a discrete voltage regulator solution, as shown in **Figure 9**.

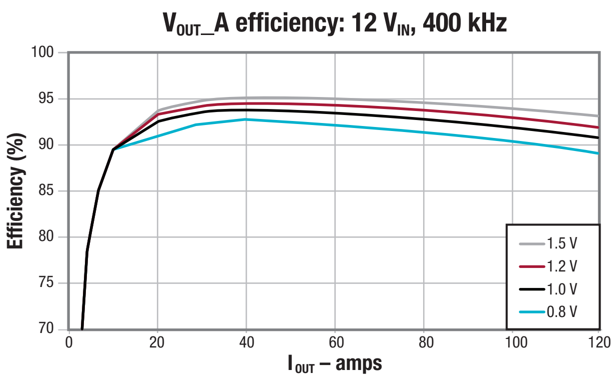


Figure 9. *TPSM831D31 module channel at 120-A efficiency.*

Control mode

TI's series of D-CAP™, D-CAP2™, D-CAP3™ and D-CAP+ control modes provide distinct advantages over traditional voltage or current control modes for a wide range of applications. For server applications, D-CAP control mode includes numerous improvements over traditional control modes: ease of use with no loop compensation; a minimal number of required external components; and a faster transient response, which reduces the output capacitance and saves board space and cost.

Figure 10 shows an example of a fast transient response supported by the TPS53119 with D-CAP control mode. D-CAP2 control mode also provides an ultra-fast load-step response and does not require an external phase compensation network. To learn more about TI's DC/DC control modes, see the "Control-Mode Quick Reference Guide: Step-Down Non-Isolated DC/DC."

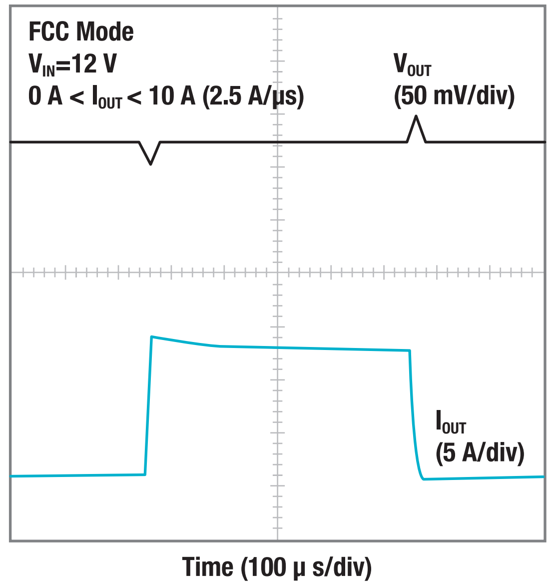


Figure 10. *TPS53119 transient response.*

Another version of the D-CAP control mode is the D-CAP+ control mode, which combines the benefits of constant on-time control with those of multiphase converters. The major differences are that the inductor currents of each phase are fed back to the system for accurate voltage droop control and tight current sharing. Also, an error amplifier improves DC accuracy over load and line. D-CAP+ control mode, as used in the TPSM831D31 module, offers outstanding DC regulation and exceptional load transient response in high-current applications, as shown in **Figures 11** and **12**.

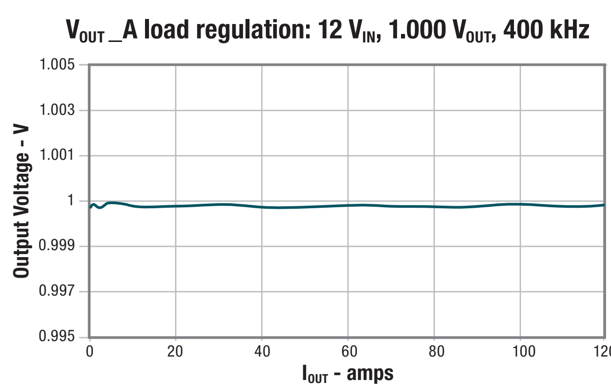


Figure 11. *TPSM831D31 DC load regulation up to 120 A.*

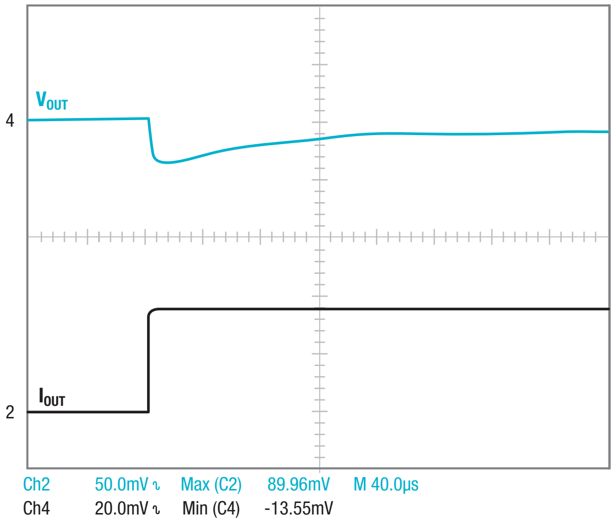


Figure 12. *TPSM831D31 load transient – 30-A step, 100 A/µs.*

PMBus capabilities

DC/DC buck controllers, converters and power modules with PMBus have many advantages over purely analog solutions. Although power modules and converters are also available with PMBus capability, PMBus buck controllers with external MOSFETs may be the best PMBus solution, since the controller does not need the extra package space for integrated MOSFETs. With this smaller controller size come fewer pins, and this is really where having PMBus comes in handy. A controller with PMBus capabilities will offer excellent functionality while also maintaining a low pin count.

One function of PMBus that is imperative in server applications is the ability to optimize the output voltage with output voltage margining. First, you can trim the output voltage to different levels without changing the resistor divider circuit. Second, you can adjust the output voltage up or down depending on system needs. For example, you could adjust the output voltage up to accommodate a higher processing power or adjust down to enable energy savings. The TPS53819A has a ±9% voltage adjustment, which gives a good amount of margin to work with.

Another benefit of using PMBus is being able to control aspects of the system. Once the pin-strapped resistors (for non-PMBus devices) are set, they cannot be changed. Having PMBus capability enables designers or end users to change aspects of the design on the fly.

Many hardware designers use PMBus for its ease of use in terms of developing a script: Unlike I^2C, where the designer has to write code, a PMBus script is generated by adding easy-to-understand PMBus commands in a top-to-bottom stacking approach by addressing the PMBus voltage regulator, enabling it, programming it, monitoring its input/output parameters and then storing these commands with their respective values in the on board non-volatile memory (NVM). PMBus monitoring of current, voltage, temperature, power and system faults is especially beneficial in data center applications, where upkeep (99.999% availability) is the most important objective.

As a PMBus module example, the TPSM831D31 offers full PMBus programming and monitoring of input/output current, voltage, temperature and faults. Real-time current and voltage information also enables the monitoring of input/output power. The current read out accuracy is ±3%, the voltage is ±1.2% and the temperature is ±2°C. All of the warning and fault thresholds are fully programmable, with very fine resolution through PMBus. **Figure 13** shows the Monitor tab of the Fusion Digital Power™ designer graphical user interface.

The [TPS546D24A](#) 40-A DC/DC buck converter with PMBus and telemetry is also available if a discrete solution with integrated MOSFETs is preferred. Up to four devices can be paralleled to deliver up to 160 A of output current at an 85°C ambient temperature, and better than 1% output voltage accuracy, as well as excellent thermal performance and high efficiency. The 5-mm-by-7-mm QFN package achieves a low thermal resistance of 8.1°C per watt and integrates both high- and low-side MOSFETs with $R_{DS(on)}$ of 4.5 mΩ and 0.9 mΩ respectively, for low power loss, especially in data center applications that have limited or no airflow.

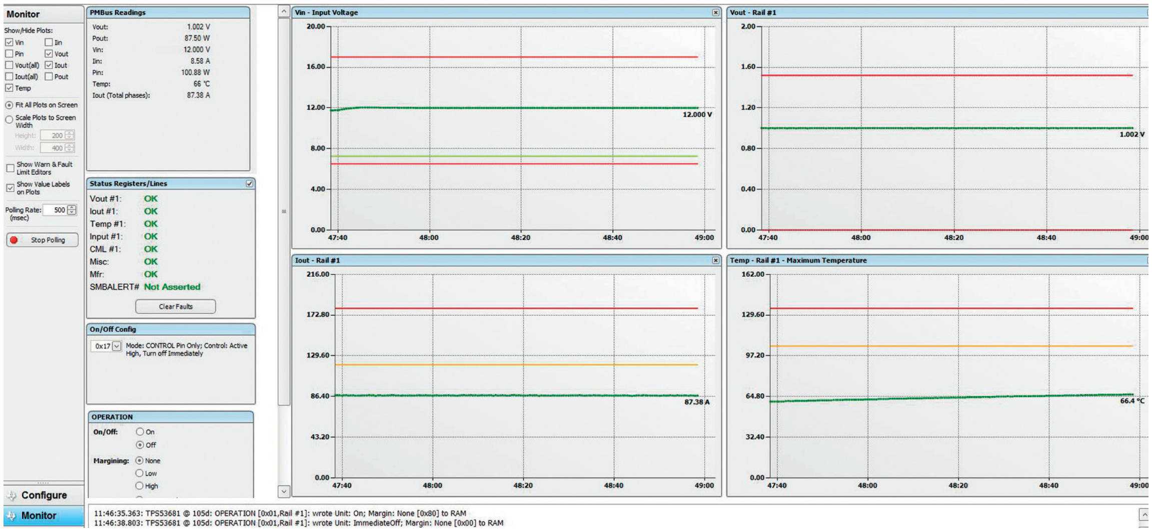


Figure 13. TPSM831D31 PMBus graphical user interface.

Ease of use

Selecting power components requires that you consider power-supply design knowledge, design resources and design time. These factors (along with others) determine the ease of use of the power design.

Power modules are considered the easiest to use given their high level of integration. In a power module, the power design has already been completed, including component selection, design testing, device qualification and the verification of allowable operating conditions. Using a power module in a design will require adding the component footprint to your PCB along with any required input and output capacitors, which are called out in the data sheet.

Converters with integrated MOSFETs aid with alleviating power-supply design complexity, eliminating the MOSFET selection process; however, you still have to design and select the inductor and any compensation components. Controllers with external MOSFETS offer the highest level of flexibility in a power design, but require the most design work and design time to select components.

Figure 14 compares the level of integration of a power module to a controller with an external FET. The TPSM831D31 power module replaces as many as 65 components when compared to a controller solution.

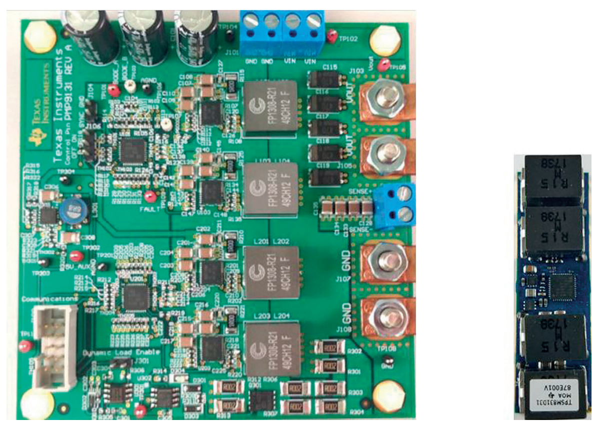


***Figure 14.** Discrete regulator vs. the TPSM831D31 (four total phases in each design).*

Reliability

Reliability in data center applications is critical (and closely coupled) to thermal performance and PMBus monitoring, as discussed earlier.

When designing with discrete solutions such as PWM controllers or DC/DC converters, you have a lot more leeway to route the power supply to achieve the best layout, performance and design robustness.

Power modules as a drop-and-forget power-supply solution have to be reliable, including manufacturing. The TPSM831D31 module uses specific manufacturability features to enable robust and reliable assembly. Edge plating ensures robust solder joints and high current delivery.

As shown in **Figure 15**, the solder fillet on the edge of each inductor (connection to the load) enables a much more reliable high-current connection.

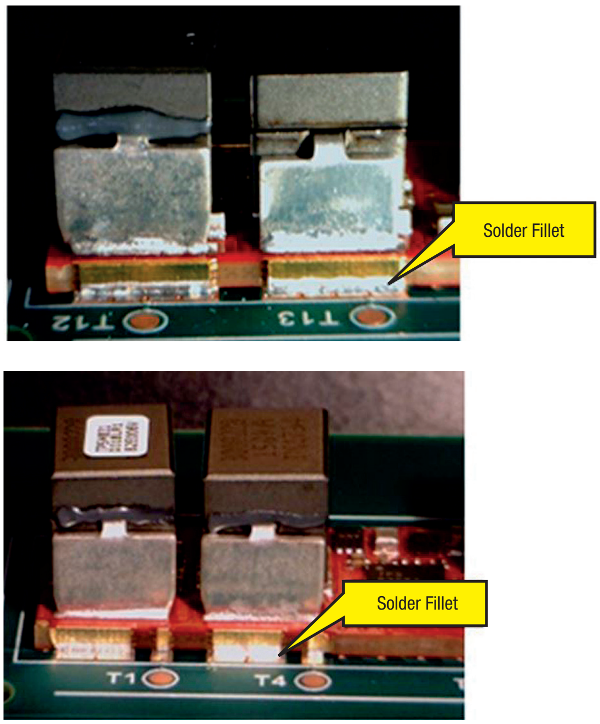


Figure 15. *TPSM831D31 module edge plating.*

Additionally, the TPSM831D31 module footprint uses TI's gaseous edge technology (GET), which uses 250-µm-wide slots as shown in **Figure 16** that are free of copper, and a solder mask that enables outgassing of solder flux volatile gases that form during reflow soldering. This technology reduces voids in solder joints and solder ball formation, and greatly mitigates solder shorts on the module pads.

An electroless nickel immersion gold (ENIG) finish is also used for superior wetting and additional assembly robustness. ENIG has several advantages over more conventional (and cheaper) surface plating such as hot-air solder leveling (solder), including excellent surface planarity (particularly helpful for PCBs with large ball grid array packages), good oxidation resistance, and usability for untreated contact surfaces such as membrane switches and contact points.

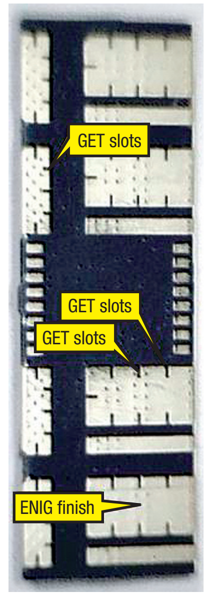


Figure 16. *TPSM831D31 GET technology slots.*

RoHS compliance

There is a fundamental limitation in multichip module (MCM) converters used in applications that require more than 20 A of current while still being in lead (Pb)-free packages. The industry has had difficulty finding a solder-alloy replacement to tin-Pb (Sn-Pb). But given the increasing restrictions on hazardous materials in landfills, recycling requirements and manufacturer responsibility, semiconductor manufacturers have stricter requirements for their Pb-free packages.

The European Union's Restriction of Hazardous Substances (RoHS) directive originally restricted the use of six hazardous materials found in electronic products. This directive has made its way to other parts of the world such that the need to be RoHS-compliant is almost ubiquitous. To be considered RoHS-compliant in 2018, 10 restricted substances must be under specific maximum levels: Pb, mercury (Hg), cadmium (Cd), hexavalent chromium (Cr VI), polybrominated biphenyls (PBBs), polybrominated diphenyl ethers (PBDEs), bis (2-ethylhexyl) phthalate (DEHP), benzyl butyl phthalate (BBP), dibutyl phthalate (DBP) and diisobutyl phthalate (DIBP).

Since MCM converters providing more than 20 A of current are not RoHs-compliant, you must look at other options (such as buck controllers) for your high-current (>20-A) RoHs-compliant designs. Monolithic converter solutions tend not to reach currents higher than 20 A, and power module options at such high currents can be a cost sink on a project. TI's DC/DC buck controllers are RoHs-compliant and can handle more than 20 A of current.

Conclusion

When choosing between using a controller, a converter or a power module solution, you have to decide between flexibility and integration and the degree of each that you want in your design. Designs using controllers with external MOSFETs offer the highest flexibility but the lowest integration. Designs using power modules offer the highest level of integration but less flexibility in design. Designs using converters can use some degree of integration, while also taking advantage of the flexibility of selecting the inductors and other passives. More integration will enable a faster time to market, while more flexibility will enable more optimization for each design's individual needs.

Due to their high level of integration, power modules offer the best ease of use, but are often too expensive for server designs. Converters also offer good ease of use and give you the flexibility to choose inductor values, but thermal issues and a lack of MOSFET flexibility may be drawbacks.

There are many key server design problems that controllers with external MOSFETs are well-equipped to solve. Compared to converters and power modules, controllers have better thermal performance, offer external MOSFET flexibility and are RoHS-compliant for all current levels. Because of these issues, controllers may be the best option over converters and power modules for enterprise server applications, depending on the requirements and resources available for each design.