BY SHYAM CHANDRA • LATTICE SEMICONDUCTOR

A –48V hot-swap-controller design targets high-power blades

DESIGNING CIRCUITS THAT ALLOW SAFE REMOVAL AND REPLACEMENT OF HIGH-POWER PLUG-IN BLADES IN MODERN COMPUTING AND COMMUNICATION SYSTEMS IS NOT A TRIVIAL EXERCISE–ESPECIALLY WHEN THE SYSTEM SPECS DICTATE THAT THE OTHER BOARDS IN THE ENCLOSURE MUST CONTINUE TO PERFORM FLAWLESSLY DURING A BOARD SWAP. LOW-COST, PROGRAMMABLE-HOT-SWAP-CONTROLLER ICs GREATLY FACILITATE SUCH DESIGNS, HOWEVER.

Many large telecom and datacom systems use multiple PCBs (printed-circuit boards) or blades that plug into a common backplane within a subrack enclosure. The backplane supplies the power—for example, –48 or 12V—to these blades and to the communication path between them. Because the backplane power is always on, the system is called hot, or live.

A newly inserted blade begins its operation using the power it receives from the backplane. If the system detects a blade fault, you must be able to restore service by removing the blade from its slot and inserting a new blade into the same slot without affecting the operation of the other blades. Hot-swappable blades support hot swapping—the removal of a blade from the live backplane and insertion of a replacement. When you insert a blade into a live backplane, all the capacitors that connect to the backplane on that blade begin to charge, drawing a large amount of current from the backplane. This inrush current can result in a brownout—a momentary dip in backplane voltage—and arcing at the connector. Excessive inrush current can overload the backplane power supply, turning off the supply and affecting the operation of the remaining blades. The blades must therefore limit the inrush current during hot swapping. The hot-swap-controller IC is responsible for inrush-current limiting (**Figure 1**).

When you plug a card into the backplane, MOSFET parasitic capacitance causes current-inrush pulse to flow—typically, for a few microseconds. In addition, connector-contact bounce applies power to the blade in pulses. The hot-swap controller keeps the MOSFET and the dc/dc converter off until the contact bounce stops. The controller then gradually turns on the MOSFET, using the voltage across the current-sense resistor as feedback to limit the inrush current to a value less than the maximum-specified blade-supply current. This current charges the hold-off capacitor until the voltage at the V_{MOSFET} pin is close to –48V. At this point, the dc/dc con-

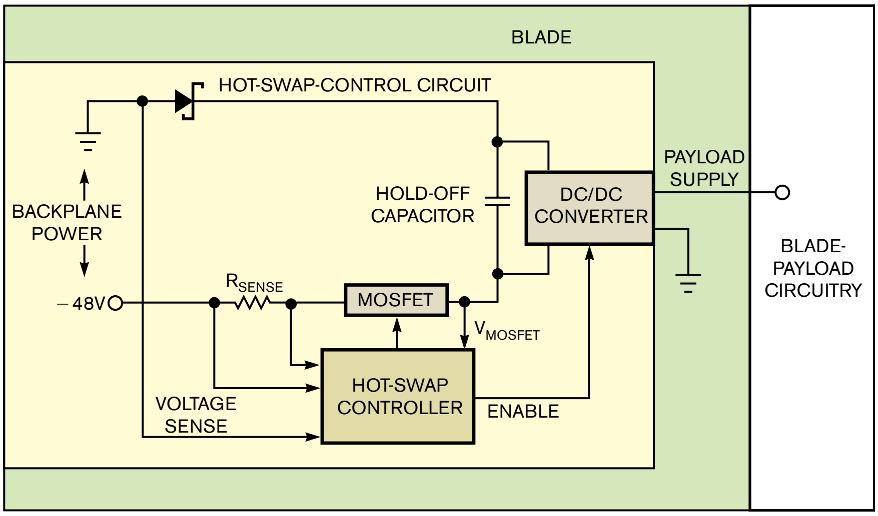

Figure 1 In this hot-swap controller, the ground terminal sends power to the dc/dc converter through a Schottky diode. The dc/dc block is an isolated supply that generates the payload power-supply voltage. The dc/dc converter's negative terminal connects to the –48V supply branch through a MOSFET switch and a current-sense resistor. The hold-off capacitor across the dc/dc converter stores enough charge to keep the board operational during backplane brownouts. The controller uses a current-sense resistor and the V_{MOSFET} signal to monitor the MOSFET's current and voltage, enabling control of the MOSFET power dissipation during inrush.

verter turns on to supply the power to the payload section of the blade.

The hold-off capacitor keeps the board operating when the backplane voltage drops because of insertion of another card. The required hold-off capacitor's value is directly proportional to the blade's total power dissipation and how long the blade can operate under brownout conditions. When a brownout lasts longer than a predetermined limit, the condition is a power-supply undervoltage, and an undervoltage-lockout process begins. Undervoltage lockout shuts off the MOSFET until the backplane voltage returns to normal. A Schottky diode in series with the supply's ground branch prevents reverse-current flow from the hold-off capacitor into the backplane during the brownout.

The hot-swap controller should also be able to detect power-supply faults, such as undervoltage and overcurrent. In both cases, the hot-swap controller should try to reapply power to the blade after the fault clears.

DESIGN CONSIDERATIONS

Not surprisingly, for designs using less than approximately 50W of power, the hot-swap-controller circuit is simple because of the small backplane current. However, modern blades must increasingly dissipate more power because of their higher performance. For example, many ATCA (Advanced Telecom Computing Architecture) blades dissipate approximately 200W. Accommodating today's blades' higher power dissipation requires the use of higher value hold-off capacitors and higher power MOSFETs.

Because the inrush-current magnitude is proportional to the capacitor size, increasing the hold-off-capacitor values can increase the brownout period for the other blades in the enclosure. To enable quick recharging of the hold-off capacitors, the hot-swap controller should keep the MOSFET fully turned on during the time just after the brownout period when the capacitor-charging current can exceed the overcurrent limit. During this interval, the hot-swap controller should temporarily disable its current limit.

When the hold-off capacitor begins to charge, the voltage across it is close to 0V, and the entire backplane voltage appears across the MOSFET. Consequently, the MOSFET's instantaneous power dissipation is large. For example, a 200W blade draws approximately 4A of current from the −48V backplane during normal operation. Such a blade has an overcurrent threshold of 5A, and the hot-swap controller limits the inrush current to this value during power-up. When the hold-off capacitor begins to charge, the MOSFET dissipates 48V×5A, or almost 250W! That much power is typically beyond the SOA (safe-operating area) of the MOSFETs that control 200W blades. To avoid compromising the circuit's reliability, designers must ensure that the MOSFET never operates outside its SOA.

A log-to-log scale graph shows the drain-to-source voltage across the MOSFET on the X axis and the MOSFET current on the Y axis (**Figure 2**). Multiple curves show safe current-pulse amplitudes for various pulse durations. The area below the curve is the MOSFET's SOA. Designers should ensure that the MOSFET does not operate outside the SOA, even during the brief start-up period. Moreover, to avoid damage to the MOSFET, designers should consider the device's average power dissipation during normal operation.

Any number of possible circuit faults can cause a blade to draw large amounts of current. The fault can be on the high-voltage side before the dc/dc converter, on the secondary side after the converter, or within the converter itself. If you insert a blade with an overcurrent fault into the backplane, the hot-swap controller should act quickly to limit the current while operating the MOSFET within its SOA to minimize interference with the other blades in the enclosure. During blade operation, faults can develop either on the backplane supply or in the payload section. A backplane fault can last for a short period, as in a brownout condition, which hold-off timing determines, or for a longer duration, in which the hot-swap controller should wait until the fault clears before trying to reconnect. If the payload section of the blade draws more power than specified, the hot-swap controller should shut down the

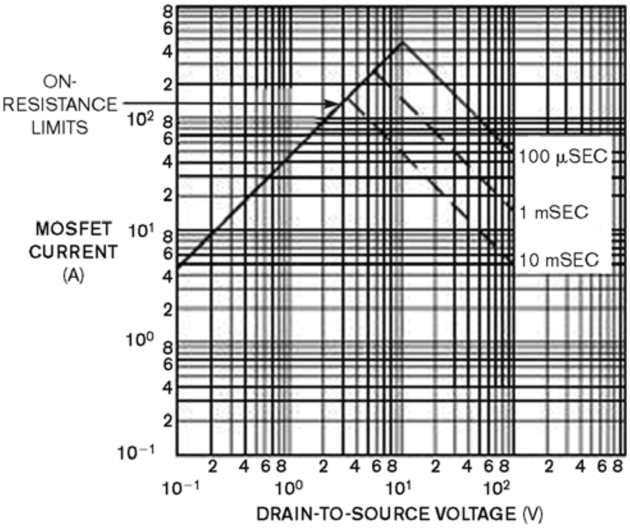

Figure 2 Multiple curves show safe current-pulse amplitudes for various pulse durations. The area below the curve is the MOSFET's safe operating area.

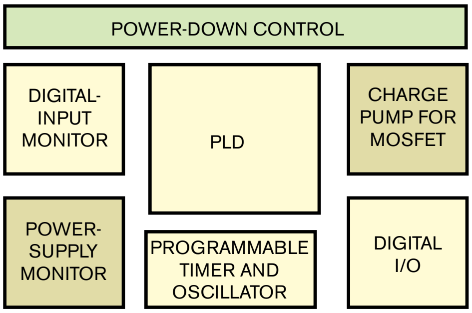

Figure 3 A programmable power-management device, such as the Lattice POWR607, has six functional blocks surrounding the PLD core.

board. The following hot-swap-circuit example addresses all of these design issues.

DESIGN EXAMPLE

The hot-swap-controller circuit in this section uses a low-cost programmable power-management device, such as Lattice Semiconductor's (www.latticesemi.com) POWR-607 (**Figure 3**). This hot-swap circuit addresses all of the previously noted design considerations. The device uses a set of six programmable-threshold comparators to monitor as many as six PCB power supplies. Additionally, the device provides seven open-drain digital outputs. You can configure two of these outputs as high-voltage MOSFET drivers. Two general-purpose digital inputs can perform miscellaneous control functions. The on-chip, 16-macrocell PLD and four programmable timers provide flexible control over the hot-swap-controller algorithm. This article refers to this power-management device as a PHSC (programmable hot-swap controller).

THE ON-CHIP, 16-MACROCELL PLD AND FOUR PROGRAMMABLE TIMERS PROVIDE FLEXIBLE CONTROL OVER THE HOT-SWAP-CONTROLLER ALGORITHM.

In the −48V hot-swap circuit, the PHSC controls the STB-120NF MOSFET for inrush-current control while operating the MOSFET within its SOA (**Figure 4**). The controller monitors the circuit current using the current-sense resistor. Two 43/3.3-kΩ voltage dividers enable the PHSC to monitor the backplane voltage and the voltage across the MOSFET. The 6V zener diode protects the PHSC's input section. When you plug the blade into the backplane, the PHSC waits for the contact bounce to settle and then begins to charge the hold-off capacitor using current pulses instead of a continuous-current feed. You can program the current-pulse rate to meet the MOSFET's power-dissipation characteristics. When the voltage reaches a preset value, the current-pulse rate increases, hastening charging of the hold-off capacitor.

After the hold-off capacitor completely charges, the MOSFET fully turns on and the power-good signal activates, enabling the dc/dc converter. The PHSC's two voltage-monitoring inputs monitor the voltage across the MOSFET. The fast-charge duty-cycle threshold programmed into the first voltage-monitoring input determines the changeover from slow to faster hold-off-capacitor charging. The end-of-soft-start threshold programmed into the second voltage-monitoring input signals completion of hold-off-capacitor charging and fully turns on the MOSFET.

The PHSC waits for a preset period, which the short-circuit watchdog timer determines, for the voltage across the MOSFET to drop below the fast-charge threshold. If the voltage across the MOSFET stays above the fast-charge level, the MOSFET turns off, indicating a fault, such as a short circuit. With this implementation, the MOSFET continues to operate within its SOA, even if a short circuit is present.

During normal operation, when the backplane voltage drops below a preset threshold, the PHSC senses the beginning of a brownout period and starts an internal programmable 5-msec time-out. If the power supply recovers within 5

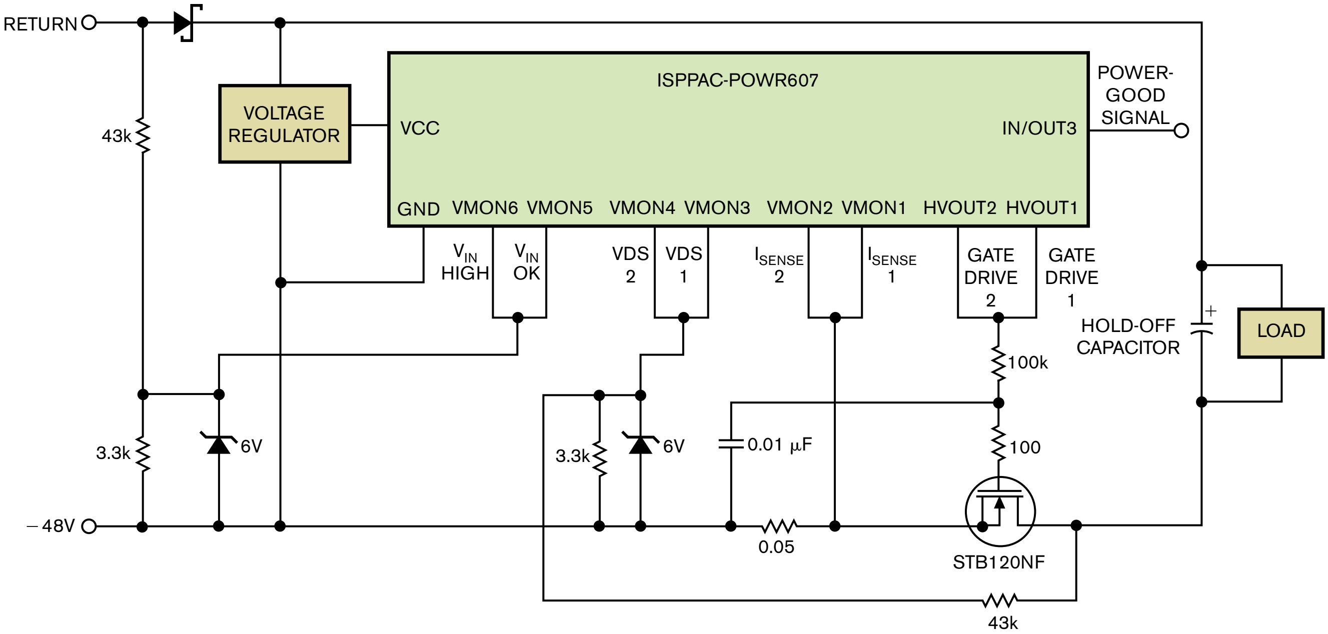

Figure 4 In this −48V hot-swap circuit, the PHSC controls the STB120NF MOSFET (bottom right) for inrush-current control and operates the MOSFET within its safe operating area. The controller monitors the circuit current using the current-sense resistor (to the left of the MOSFET). Two 43/3.3-kΩ voltage dividers enable the PHSC to monitor the backplane voltage and the voltage across the MOSFET. The 6V zener diode protects the PHSC's input section.

msec, the circuit continues to function normally. If the time-out expires, the hot-swap controller classifies the event as an undervoltage condition and jumps to the power-recycle routine, in which it waits for the supply to stabilize before initiating a hold-off-capacitor recharge. During normal operation, the PHSC also continuously monitors current; should the current exceed a preset limit, the PHSC protects the circuit by immediately turning off the MOSFET.

Figure 5's top trace shows 5-msec-long, 1.5A current pulses charging the hold-off capacitor. The bottom trace is the voltage across the MOSFET during charging of a 4700-µF hold-off capacitor. Two of the PHSC's MOSFET drivers drive the MOSFET gate. One maintains the current amplitude at 1.5A; the second controls the modulation rate. This circuit deliberately limits the modulation rate to one 5-msec pulse every 260 msec. During a short circuit, the MOSFET's worst-case average power dissipation could thus not exceed 1.5A×48V×5 msec/260 msec=1.4W.

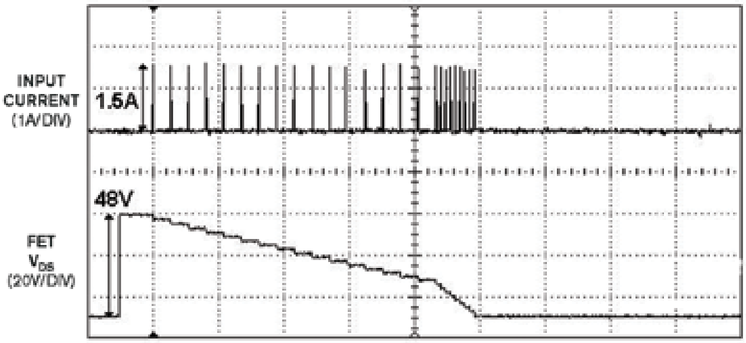

Figure 5 The top trace shows 5-msec-duration, 1.5A current pulses charging the hold-off capacitor. The bottom trace is the voltage across the MOSFET during charging of a 4700-µF hold-off capacitor. Two of the controller's MOSFET drivers drive the MOSFET gate. One maintains the current amplitude at 1.5A; the second controls the modulation rate.

CUSTOMIZING THE PHSC

You can implement the entire hot-swap algorithm within the PHSC's 16-macrocell PLD. You can customize this algorithm to suit your blade requirements by setting the following parameters:

- Short-circuit watchdog duration: If the hold-off capacitor does not charge in the specified period, the MOSFET shuts off.
- Charging-current-pulse duration: The selected pulse width guarantees that the MOSFET operates within its SOA.

- Charging-current-pulse frequency: This parameter, along with the charging-current-pulse duration, determines the power dissipation for a MOSFET.
- Minimum hold-off time before recycling: This parameter determines the blade's immunity to brownouts.
- Current-sense scaling: This parameter should match the selected R_{SENSE} resistor.
- Charging-current-pulse amplitude: The R_{SENSE} resistor value determines this parameter.
- Circuit-breaker current: This parameter is the maximum current value to initiate shutoff and restart.
- End of soft-start operation: This parameter sets the voltage at which the MOSFET fully turns on and the power-good signal activates.
- Transition to fast-charge duty cycle: This parameter determines the voltage at which the charge-pulse frequency increases to safely reduce the hold-off-capacitor charging time.
- Minimum operating voltage: This parameter determines the backplane voltage below which the brownout process begins.
- Overvoltage lock down: This parameter shuts off the MOSFET to protect the blade.

Increased blade capability is increasing blades' power consumption, imposing stringent requirements on hot-swap-controller circuits. Without significant trade-offs, traditional hot-swap-control approaches with limited features no longer meet the requirements of high-power blades.

Using a Lattice POWR607 PHSC IC increases the blade's reliability and provides many programmable features that enable designers to meet the challenges of increased blade-power dissipation. This design ensures that the MOSFET operates within its SOA even in the presence of a short circuit in the blade. Improved immunity to brownouts, overcurrent and overvoltage protection, and automatic retry in case of faults further enhance the blade's reliability. In addition, minimizing interference with other blades in the subrack enclosure makes the blade more amenable to hot swapping. By using a device such as the POWR607 and customizing its algorithm to satisfy individual PCB-power requirements, designers can standardize hot-swap-controller architecture across many blade types.EDN

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