Low Voltage Hot Swap Controller with Inrush Current Control

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Introduction

The LTC4216 is a low voltage Hot Swap controller that allows a board to be safely inserted and removed from a live backplane. The LTC4216 is designed to meet the latest low voltage board supply requirements with its unique feature of controlling load voltages from 0V to 6V. It also features an adjustable soft-start that provides both inrush current limiting and current slew rate control at start-up, important for the large load capacitors typical in low-voltage applications.

When a board is plugged into a backplane, the inrush currents can be large enough to create a glitch on the load supply causing other boards on the bus to malfunction. The LTC4216 provides a low circuit breaker trip threshold (25mV) with adjustable response time and analog current limiting for dual level overcurrent protection. It also includes a high side gate drive for an external N-channel MOSFET. Figure 1 shows a circuit using the LTC4216 as a Hot Swap controller for a 1.8V load supply.

Controlling Load Voltages Down to Zero Volts

The LTC4216 can control load voltages as low as 0V as it provides two separate pins: SENSEP pin for controlling the load voltages from 0V to 6V and V_{CC} pin for powering the device's internal circuitry with a minimum of 2.3V. An RC network shown in Figure 1 can be connected at the V_{CC} pin to ride out supply glitches during output-shorts or adjacent board transients. These supply glitches can potentially trigger the device into an undervoltage lockout condition, causing its internal latches to reset.

Output Voltage Monitoring

The output voltage is monitored through a resistive divider connected at the feedback (FB) pin, and an FB comparator with a 0.6V reference. The FB comparator has a built-in glitch filter to ride out any unwanted transients appearing on the FB pin. When the FB pin voltage exceeds 0.6V, it signals the $\overline{\text{RESET}}$ high after a power-good delay set by an external capacitor at the TIMER pin. The delay is given by:

$$\frac{1.253V \bullet C_{TIMER}}{2\mu A} = 0.6265 \bullet C_{TIMER}\left(\frac{ms}{nF}\right)$$

Soft-Start Controls Inrush Current Slew Rate

The LTC4216 features a soft-start function that controls the slew rate of the inrush current during power-up (Figure 2). The rate is controlled by an external capacitor connected from the soft-start (SS) pin to ground. A built-in Analog Current Limit (ACL) amplifier servos the GATE pin to track the rate of SS ramp-up during power-up. There are two slopes in the SS ramp-up profile: a 10µA pull-up for a normal ramp-rate, and a 1µA pull-up for a slow ramp rate. The slow SS ramp rate allows the gate of the external MOSFET to be turned on with a small inrush current step. When the load current starts flowing through the external sense resistor, SS reverts back to a normal ramp rate. At the end of the SS ramp-up, the GATE is servoed to limit the load current to 40mV across the sense resistor during startup. If the voltage across the sense resistor drops below 40mV due to reduced load current, the ACL amplifier shuts off and GATE ramps further with a 20µA pull-up.

Inrush Control with a GATE Capacitor

Figure 3 shows an alternative approach from the soft-start method to limit the inrush current during power up for a large load capacitor. An external capacitor, C4, is connected from the GATE pin to ground to limit the inrush current by slewing the GATE pin voltage. With a GATE pull-up

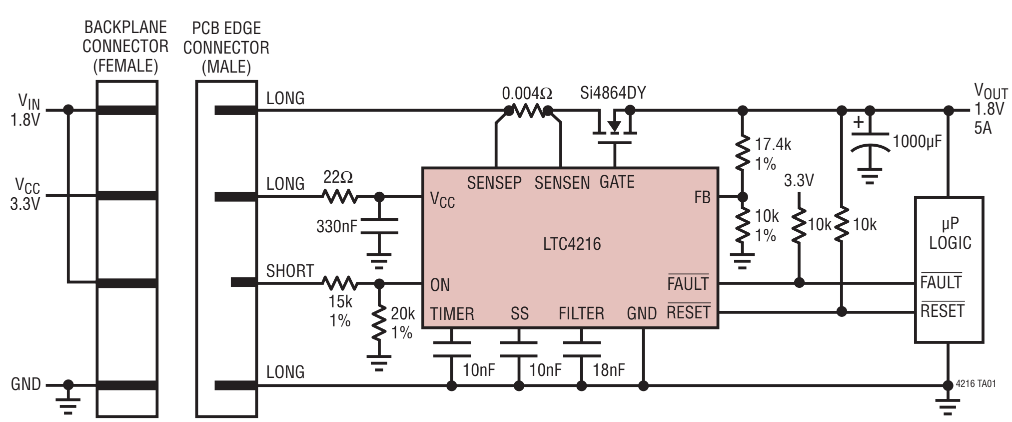

Figure 1. A 1.8V Hot Swap application

current of 20µA, the GATE slew rate is given by:

$$\frac{dV_{GATE}}{dt} = \frac{20\mu A}{C4 + C_{ISS}}$$

where C_{ISS} is the external MOSFET's gate input capacitance. The inrush current flowing into the load capacitor, C_{LOAD}, is limited to:

$$I_{INRUSH} = C_{LOAD} \bullet \frac{dV_{GATE}}{dt} = \frac{C_{LOAD}}{C4 + C_{ISS}} \bullet 20\mu A$$

For the application shown, C_{LOAD} = 470µF, C4 = 22nF and C_{ISS} = 3nF, I_{INRUSH} = 376mA. If C_{LOAD} is very large and I_{INRUSH} exceeds the analog current limit, the GATE servos to control the inrush current to $40mV/R_{SENSE}$.

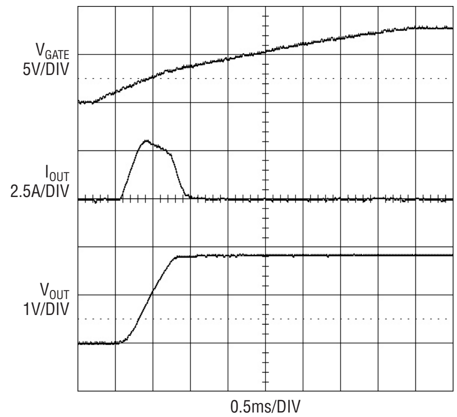

Figure 2. Power-up with soft-start for inrush control

Electronic Circuit Breaker

The load current is sensed by monitoring the voltage across an external sense resistor, R_{SENSE}, connected between SENSEP and SENSEN pins in Figure 1. The Electronic Circuit Breaker (ECB) trips at 25mV across the sense resistor during an overload condition. The response time is adjustable through an external capacitor connected from the FILTER pin to ground. Whenever the ECB trip threshold is exceeded, the FILTER pin charges up the external capacitor with a 60µA pull-up. Otherwise, it is pulled down by a 2.4µA current. When the FILTER pin voltage exceeds 1.253V, the ECB trips and the GATE pin is pulled down to ground immediately to disconnect the board from the backplane supply. The $\overline{FAULT}$ pin is also pulled low whenever the ECB trips. In order to reconnect the board, the ON pin must be pulled below 0.4V for at least 100µs to reset the ECB, or the V_{CC} pin voltage must be below 2V for more than 200µs.

Analog Current Limiting Protects Against Severe Overcurrent Fault

In addition to an Electronic Circuit Breaker (ECB), the LTC4216 includes an Analog Current Limit (ACL) amplifier that does not require an external compensation capacitor at the GATE pin. The amplifier's stability is compensated by the large gate input capacitance ($C_{ISS} \geq$ 1nF) of the external MOSFET used. The GATE pin is servoed to limit the load current to $40mV/R_{SENSE}$. The ACL threshold (40mV) is 1.6 times higher than the ECB trip threshold (25mV) to provide dual level current sensing. When the output is in current limit, it exceeds the ECB trip threshold causing the FILTER pin to charge up the external capacitor with a 60µA pull-up. If the condition persists long enough for the FILTER pin voltage to reach its threshold, the GATE is pulled low and $\overline{FAULT}$ is latched low. If the voltage across the sense resistor exceeds 40mV during an overload condition, the ACL amplifier pulls the GATE down in an attempt to control the load current. For a mild short terrm overload, the ACL amplifier can immediately control the load current. However, in the event of a severe overload, the load current may overshoot as the MOSFET has large gate overdrive initially. The GATE is quickly discharged to ground followed by the ACL amplifier taking control.

Normal Power-Up Sequence

Figure 4 shows a normal power-up sequence with a large capacitor load in Figure 1. When the V_{CC} pin voltage rises above 2.1V and the ON pin is greater than 0.8V, the LTC4216 starts the first timing cycle. A 2µA current source charges an external capacitor (C1) connected from the TIMER pin to ground. When TIMER pin voltage rises above 1.253V, the TIMER pin is pulled

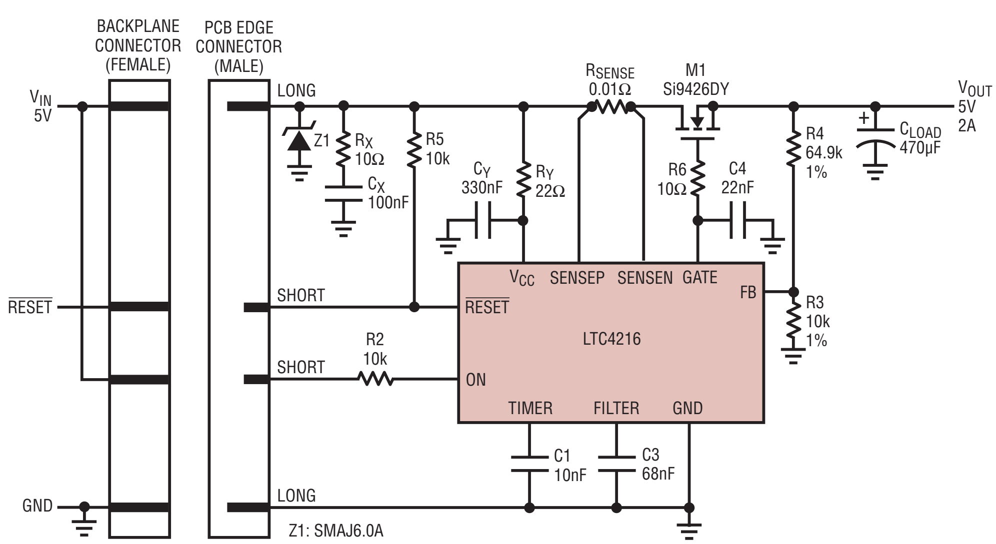

Figure 3. Application with an external GATE capacitor to enhance inrush control

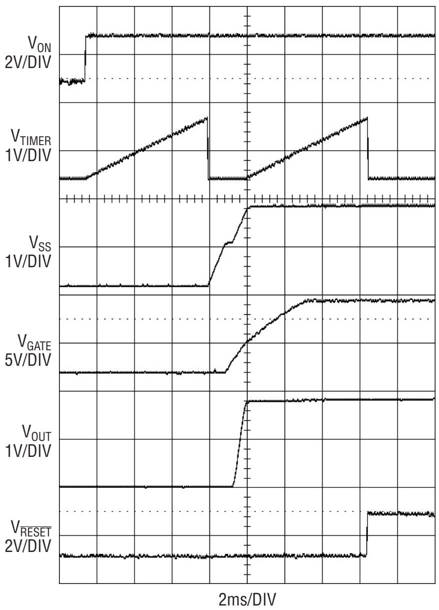

Figure 4. Power-up sequence with load

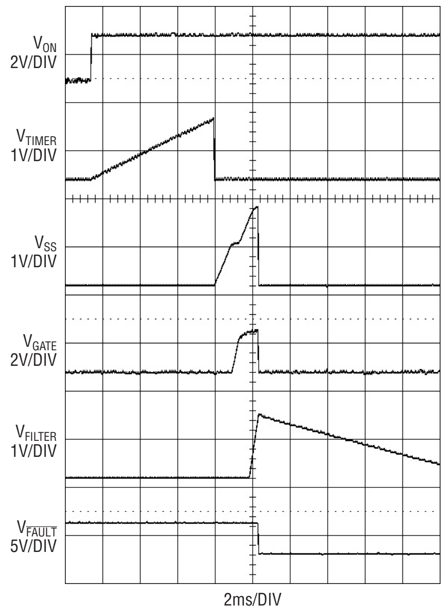

Figure 5. Power-up with short at 1.8V output

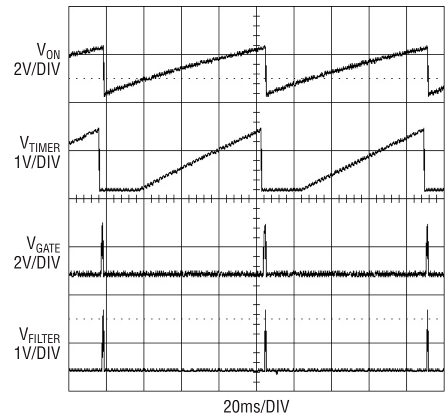

Figure 7. Auto-retry with short at 5V output

low and C1 is discharged. After this, the Electronic Circuit Breaker (ECB) is enabled and a GATE ramp-up cycle begins. GATE is held low initially by the ACL amplifier until SS switches from the 10µA pull-up to the 1µA pull-up for a slower ramp rate. The slew rate of the inrush current is in control as GATE ramps up gradually, tracking the SS ramp rate. SS reverts back to a normal ramp rate when the load current starts flowing through the sense resistor. At the end of the SS ramp, GATE continues to ramp up with a 20µA pull-up if the output is not in current limit. The second timing cycle starts when the FB pin voltage exceeds 0.6V. $\overline{\text{RESET}}$ goes high after a complete timing cycle, indicating that power is good.

Power-Up into an Output-Short Sequence

Figure 5 shows power-up with a short at the output in Figure 1. After the initial timing cycle, GATE ramps up and the external MOSFET is turned on. The load current rises due to the output short, causing the voltage across the sense resistor to rise above 25mV. The FILTER pin charges up the external capacitor with a 60µA pull-up while the output is in current limit. The output current is limited to $40mV/R_{SENSE}$ as the GATE regulates. When the FILTER pin voltage rises above 1.253V, the Electronic Circuit Breaker trips and both GATE and SS are pulled low. The device latches-off and $\overline{\text{FAULT}}$ is pulled low, indicating a fault condition. The FILTER capacitor discharges through a 2.4µA pull-down until the device resets.

Auto-Retry Application

Figure 6 shows an application that automatically tries to power up the board after the Electronic Circuit Breaker (ECB) has been tripped due to a shorted load supply output. The ON pin is shorted to the $\overline{\text{FAULT}}$ pin and is pulled up by a 200kΩ resistor (R_{AUTO}) to the load supply. A 1µF capacitor (C_{AUTO}) connected from the lower end of R_{AUTO} to ground sets the auto-retry duty cycle. The LTC4216 will retry as long as the short persists. R_{AUTO} and C_{AUTO} must be selected to keep the duty cycle low in order to prevent overheating in the external N-channel MOSFET.

Figure 7 shows the auto-retry cycle when the 5V output is shorted to ground. The ECB is tripped when the FILTER pin voltage rises above 1.253V after the first timing cycle. This causes the $\overline{\text{FAULT}}$ pin to be pulled

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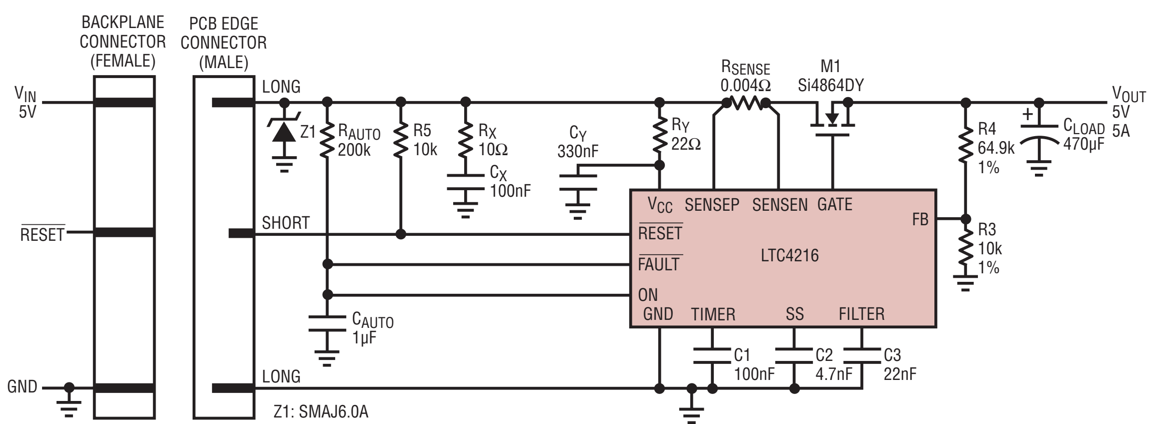

Figure 6. Auto-retry application

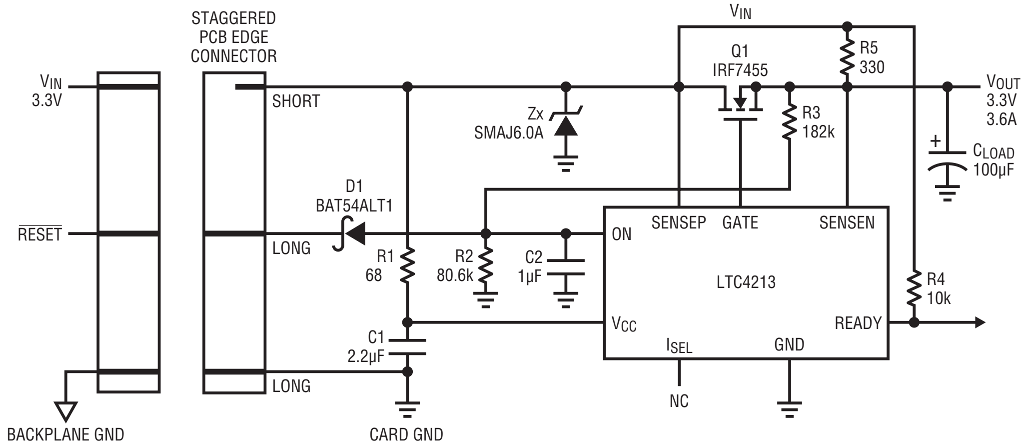

Figure 3. The LTC4213 in a Hot Swap application

Then, 50µs after the circuit breaker is armed and the READY pin goes high (see trace 3), the V_{IN} supply starts to power-up. To prevent power-up failures, the V_{IN} supply should rise with a ramp-rate that keeps the inrush current below the ECB trip level. Trace 4 shows the V_{OUT} waveform during the V_{IN} supply power-up. The gate voltage finally peaks at $\Delta V_{GSMAX} + V_{SENSEN}$. The MOSFET gate overdrive voltage is ΔV_{GSMAX} which is higher than the ΔV_{GSARM}. This ensures that the external MOSFET is fully enhanced and the R_{DSON} is further reduced. Choose the MOSFET with the required R_{DSON} at V_{GS} approximately equal to ΔV_{GSMAX}. The LTC4213 monitors the load current when the gate overdrive voltage exceeds ΔV_{GSARM}.

Typical Hot Swap Application

Figure 3 shows the LTC4213 in a single supply Hot Swap application where the load can be kept in shutdown mode until the Hot Swap action is completed. Large input bypass capacitors should be avoided in Hot Swap applications as they cause large inrush currents. Instead, a transient voltage suppressor should be employed to clip and protect against fast transient spikes.

In this application, the backplane starts with the $\overline{\text{RESET}}$ signal held low. When the PCB long trace makes contact the ON pin is held below 0.4V by the D1 schottky diode. This keeps the LTC4213 in reset mode. The V_{IN} supply is connected to the card when the short trace makes contact. The V_{CC} pin is biased via the R1-C1 filter and V_{OUT} is pre-charged by resistor R5. To power-up successfully, the R5 resistor should provide sufficient initial start up current for the shutdown load circuit and the 280µA sinking current source at SENSEN pin. On the other hand, the R5 resistor value should limit the load surge current during board insertions and fault conditions. When $\overline{\text{RESET}}$ signals a high at the backplane, capacitor C2 at the ON pin charges up via the R3/R2 resistive divider. When ON pin voltage exceeds 0.8V, the GATE pin ramps up. The GATE voltage finally peaks and the external MOSFET is fully turned on to reduce the voltage drop between V_{IN} and V_{OUT}. The LTC4213 monitors the load current when the gate overdrive voltage exceeds ΔV_{GSARM}.

Conclusion

The LTC4213 is a small package, No R_{SENSE} Electronic Circuit Breaker that is ideally suited for low voltage applications with low MOSFET insertion loss. It includes selectable dual current level and dual response time circuit breaker functions. The circuit breaker has wide operating input common-mode-range from ground to V_{CC}.

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low by an internal N-channel device and C_{AUTO} is discharged to ground. The GATE pin is pulled immediately to ground to disconnect the board. When the ON pin goes below 0.4V for more than 100µs, the ECB is reset. The internal N-channel device at the $\overline{\text{FAULT}}$ pin is switched off and R_{AUTO} starts to charge C_{AUTO} slowly towards the load supply.

When the ON pin rises above 0.8V, the LTC4216 attempts to reconnect the board and start the first timing cycle. With a dead short at the 5V output in Figure 6, the ECB trips when the FILTER pin voltage exceeds 1.253V after the first timing cycle. The entire cycle is repeated until the short is removed. The duration of each cycle is given by the time needed to charge C_{AUTO} to within 0.8V of the ON pin voltage, after the $\overline{\text{FAULT}}$ pin is pulled low and the first timing cycle delay. With $R_{AUTO} = 200k\Omega$, $C_{AUTO} = 1\mu F$ and C1 = 100nF, the cycle time is 85ms. The external MOSFET is on for about 2ms giving a duty cycle of 2.3%.

Conclusion

The LTC4216 Hot Swap controller is designed to handle very low supply voltages, down to 0V. Its adjustable soft-start function controls the inrush current slew rate at start-up, important with the large load capacitors used in low voltage systems. The analog current limit amplifier, the electronic circuit breaker with low trip threshold of 25mV and adjustable response time provides dual level overcurrent protection.