Low EMI, Output Tracking, High Efficiency, and Too Many Other Features to List in a 3mm x 4mm Synchronous Buck Controller

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Introduction

The LTC3808 synchronous DC/DC controller packs many features required by the latest electronic devices into a low profile (0.8mm tall), 3mm × 4mm leadless DFN package, or a leaded SSOP-16 package. The LTC3808 can provide output voltages as low as 0.6V and output currents as high as 7A from a wide, 2.75V to 9.8V, input range, making it an ideal device for battery powered and distributed DC power systems. It also includes important features for noise-sensitive applications, including a phase-locked loop (PLL) for frequency synchronization and spread spectrum frequency modulation to minimize electromagnetic interference (EMI).

The LTC3808 improves battery life and saves space by delivering high efficiency with a low operating quiescent current. The LTC3808 also takes advantage of No R_{SENSE}™ current mode technology by sensing the voltage across the main (top) power MOSFET to improve efficiency and reduce the size and cost of the solution. Its adjustable high operating frequency (300kHz–750kHz) allows the use of small surface mount inductors and ceramic capacitors for a compact power supply solution.

The LTC3808 offers flexibility of start-up control with a fixed internal start-up time, an adjustable external soft-start, or the ability to track another voltage source. It also includes other popular features, such as a Power Good voltage monitor, current mode control for excellent AC and DC line and load regulation, low dropout (100% duty cycle) for maximum energy extraction from a battery, output overvoltage protection and short circuit current limit protection.

How It Works

Figure 1 shows a step-down converter with an input of 5V and an output of 2.5V at 5A. Figure 2 shows its efficiency versus load current. The LTC3808 uses a constant frequency, current mode architecture to drive an external pair of complementary power MOSFETs. During normal operation, the top P-channel MOSFET is turned on every oscillator cycle, and is turned off when the current comparator trips. The peak inductor current at which the current comparator trips is determined by the voltage on the I_{TH} pin, which is driven by the output of the error amplifier. The V_{FB} pin receives the output voltage feedback signal from an external resistor divider. This feedback signal is compared to the internal 0.6V reference voltage by the error amplifier. While the top P-channel MOSFET is off, the bottom N-channel MOSFET is turned on until either the inductor current starts to reverse, as indicated by a current reversal comparator, or the beginning of the next cycle.

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Selectable Operation Modes in Light Load Operation

The LTC3808 can be programmed for three modes of operation via the SYNC/MODE pin: high efficiency Burst Mode operation, forced continuous conduction mode or pulse skipping mode at low load currents. Burst Mode operation is enabled by connecting the SYNC/MODE pin to V_{IN}. In this mode, the peak inductor current is clamped to about one-fourth of the maximum value and the I_{TH} pin is monitored to determine whether the device will

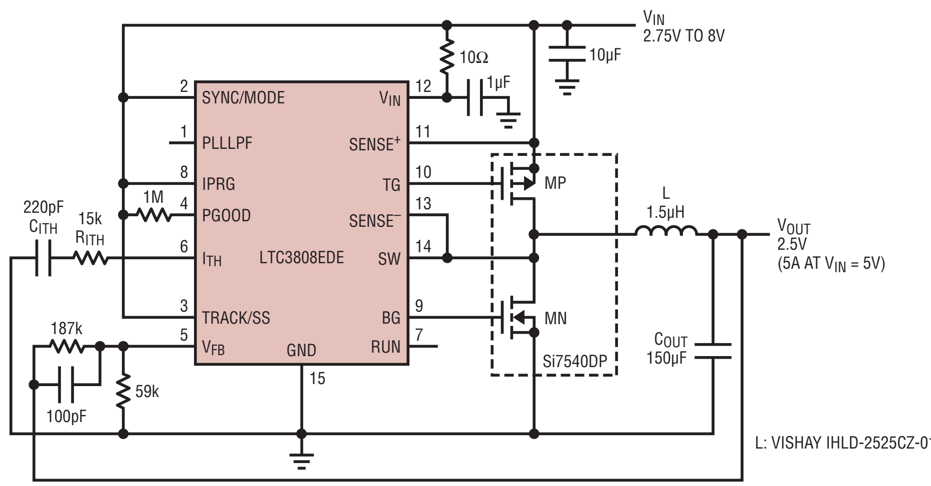


Figure 1. A 550kHz, synchronous DC/DC converter with 5V input and 2.5V output at 5A

go into a power-saving SLEEP mode. When the inductor's average current is higher than the load requirement, the voltage at the I_{TH} pin drops as the output voltage rises slightly. When the I_{TH} voltage goes below 0.85V, the device goes into SLEEP mode, turning off the external MOSFETs and much of the internal circuitry. The load current is then supported by the output capacitors, and the LTC3808 draws only 105µA of quiescent current. As the output voltage decreases, I_{TH} is driven higher. When I_{TH} rises above 0.925V, the device resumes normal operation.

Tying the SYNC/MODE pin to a DC voltage below 0.4V (e.g., GND) enables forced continuous mode which allows the inductor current to reverse at light loads or under large transient conditions. In this mode, the P-channel MOSFET is turned on every cycle (constant frequency) regardless of the I_{TH} pin voltage so that the efficiency at light loads is less than in Burst Mode operation. However it has the advantages of lower output ripple and no noise at audible frequencies.

When the SYNC/MODE pin is clocked by an external clock source to use the phase-locked loop or is set to a DC voltage between 0.4V and several hundred millivolts below V_{IN} (e.g., V_{FB}), the LTC3808 operates in PWM pulse skipping mode at light loads. In this mode, cycle skipping occurs under light load conditions because the inductor current is not allowed to reverse. This mode, like forced continuous operation, exhibits low output ripple as well as low audible noise as compared to Burst Mode operation. Its low-current efficiency is better than forced continuous mode, but not nearly as high as Burst Mode operation. Figure 3 shows the efficiency versus load current for these three operation modes.

Shutdown and Start-Up Control

The LTC3808 is shut down by pulling the RUN pin below 1.1V. In shutdown, all controller functions are disabled while the external MOSFETs are held off, and the chip draws less than 9µA.

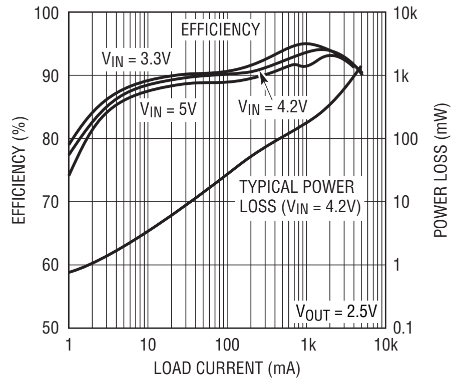


Figure 2. Efficiency and power loss vs load current of the circuit in Figure 1

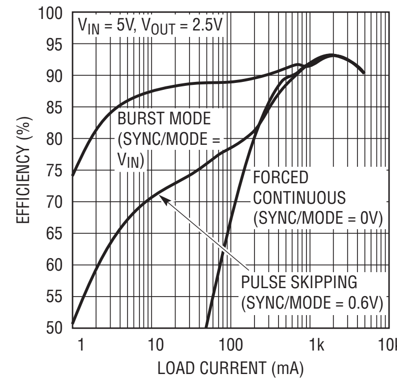


Figure 3. Efficiency vs load current in three operation modes for the circuit in Figure 1

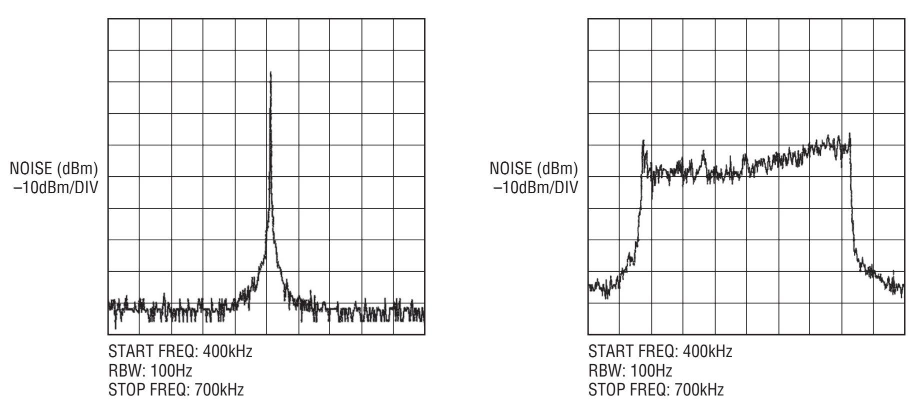
Releasing the RUN pin allows an internal 0.7µA current source to pull up the RUN pin to V_{IN}. The controller is enabled when the RUN pin reaches 1.1V. Alternatively, the RUN pin can be driven directly from a logic output.

The start-up of V_{OUT} is based on the three different connections on the TRACK/SS pin. When TRACK/SS is connected to V_{IN}, the start-up of V_{OUT} is controlled by the internal soft-start, which rises smoothly from 0V to its final value in about 1ms. A second start up mode allows the 1ms soft-start time to increase or decrease by connecting an external capacitor between the TRACK/SS pin and the ground. When the controller is enabled by releasing the RUN pin, TRACK/SS pin is charged up by an internal 1µA current source and rises linearly from 0V to above 0.6V. The error amplifier compares the feedback signal V_{FB} to this ramp instead of the internal soft-start ramp, and regulates V_{FB} linearly from 0V to 0.6V.

In this case, the LTC3808 regulates the V_{FB} to the voltage at the TRACK/SS pin. Therefore, in the third mode, V_{OUT} of LTC3808 can track an external voltage V_X during start-up if a resistor divider from V_X is connected to the TRACK/SS pin. For coincident tracking during startup, the regulated final value of V_X should be larger than that of V_{OUT}, and the resistor divider on V_X would have the same values as the divider on V_{OUT} that is connected to V_{FB}.

Selecting an Operating Frequency

The choice of operating frequency f_{OSC} is generally a trade-off between efficiency and component size. Low frequency operation improves efficiency by reducing MOSFET switching losses (both gate charge and transition losses). Nevertheless, lower frequency operation requires more inductance for a given amount of ripple current.



a. Without SSFM **b. With SSFM**

Figure 4. Spread spectrum modulation of the controller operating frequency lowers peak EMI as seen in this comparison of the V_{OUT} spectrum without spread spectrum modulation (a) and with spread spectrum modulation (b).

The internal oscillator for the LTC3808's controller runs at a nominal 550kHz frequency when the PLLLPF pin is left floating and the SYNC/MODE pin is a DC voltage and not configured for spread spectrum operation. Pulling the PLLLPF to V_{IN} selects 750kHz operation; pulling the PLLLPF to GND selects 300kHz operation.

Alternatively, the LTC3808 can phase-lock to a clock signal applied to the SYNC/MODE pin with a frequency between 250kHz and 750kHz, and a series RC filter must be connected between the PLLLPF pin and ground as the loop filter. In this case, pulse-skipping mode is enabled under light load conditions to reduce noise.

Spread spectrum frequency modulation reduces the amplitude of EMI by spreading the nominal 550kHz operating frequency over a range of frequencies between 460kHz and 635kHz with pseudo random pattern (repeat frequency of the pattern is about 4kHz). Spread spectrum frequency modulation is enabled by biasing the SYNC/MODE pin to a DC voltage above 1.35V and V_{IN} – 0.5V. An internal 2.6µA pull-down current source at SYNC/MODE can be used to set the DC voltage at this pin by tying a resistor with an appropriate value between SYNC/MODE and V_{IN}. A 2.2nF filter cap between PLLLPF and ground and a 1000pF cap between SYNC/MODE and PLLLPF are needed in this mode. Figure 4 shows the frequency spectral plots of the output (V_{OUT}) with and without spread spectrum modulation. Note the significant reduction in peak output noise (>20dBm).

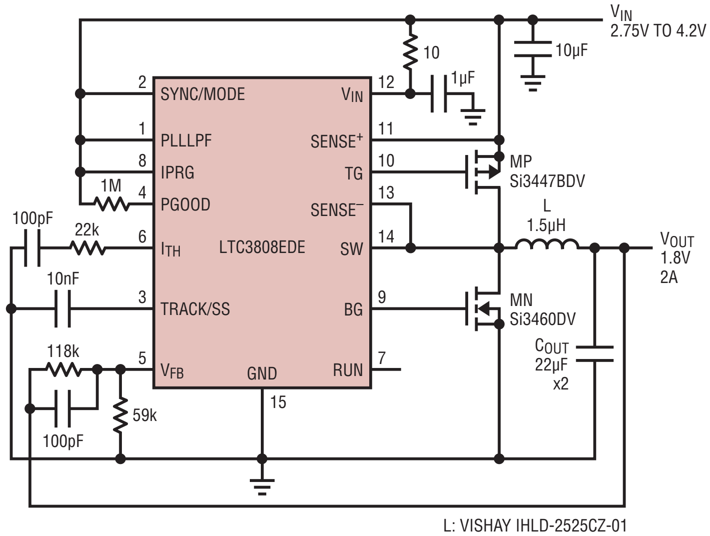


Figure 5. A 750kHz, synchronous single cell Li-Ion to 1.8V/2A converter with external soft-start and a ceramic output capacitor

Power Good Monitor and Fault Protection

A window comparator monitors the feedback voltage and the open-drain PGOOD output is pulled low when the feedback voltage is not within 10% of the reference voltage of 0.6V.

The LTC3808 incorporates protection features such as programmable current limit, input undervoltage lockout, output overvoltage protection and programmable short circuit current limit.

Current limit is programmed by the IPRG pin. The maximum sense voltage across the external top P-channel MOSFET or a sense resistor is 125mV when the IPRG pin is floating, 85mV when IPRG is tied low and 204mV when IPRG is tied high.

To protect a battery power source from deep discharge, an internal undervoltage lockout circuit shuts down the device when V_{IN} drops below 2.25V to reduce the current consumption to about 3µA. A built-in 200mV hysteresis ensures reliable operation with noisy supplies.

During transient overshoots and other more serious conditions that may cause the output to rise out of regulation (>13.33%), an internal overvoltage comparator will turn off the top P-channel MOSFET and turn on the synchronous N-channel MOSFET until the overvoltage condition is cleared.

In addition, the LTC3808 has a programmable short circuit current limit protection comparator to limit the inductor current and prevent excessive MOSFET and inductor heating. This comparator senses the voltage across the bottom N-channel MOSFET and keeps the P-channel MOSFET off until the inductor current drops below the short circuit current limit. The maximum short-circuit sense voltage is about 90mV when the IPRG pin is floating, 60mV when IPRG is tied low and 150mV when IPRG is tied high.

Single Cell Li-Ion to 1.8V/2A Application

Figure 5 shows a step-down application from 3.3V to 1.8V at 2A. The circuit operates at a frequency of 750kHz, so a small inductor (1.5µH) and ceramic output capacitor (two 22µF caps) can be used. A 10nF capacitor at TRACK/SS sets the soft-start time of about 6ms. The $R_{DS(ON)}$ of the P-channel MOSFET determines the maximum average load current that the controller can drive. The Si3447BDV in this case ensures that the output is capable of supplying 2A with a low input voltage.

Conclusion

The LTC3808 offers flexibility, high efficiency, low EMI and many other popular features in a tiny 3mm × 4mm DFN package or a small 16-lead narrow SSOP package. For low voltage portable or distributed power systems that require small footprint, high efficiency and low noise, the LTC3808 is an excellent fit.

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