Monolithic Buck Regulator Operates Down to 1.6V Input; Simplifies Design of 2-Cell NiCd/NiMH Supplies

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Introduction

The LTC3409 is a monolithic synchronous step-down regulator designed specifically to save space, improve battery life and simplify the design of 2-cell-alkaline, NiCd and NiMH powered applications. It operates from a wide input voltage range, 1.6 to 5.5V, without the complexity and accompanying loss of efficiency of competing devices that require boost circuitry for generating internal voltages greater than V_{IN}.

Space-saving features include an available 3mm × 3mm DFN package and a high, 1MHz to 3MHz, operating frequency, which allows the use of surface mount capacitors and inductors. To extend battery life, the LTC3409 offers two operating modes that improve light load efficiency, including Burst Mode operation, which consumes only 65µA of supply current at no load, and pulse skipping mode, which offers low ripple currents for noise-sensitive applications. Both modes consume less than 1µA quiescent current in shutdown.

The LTC3409 also features soft start, which limits inrush current at start-up.

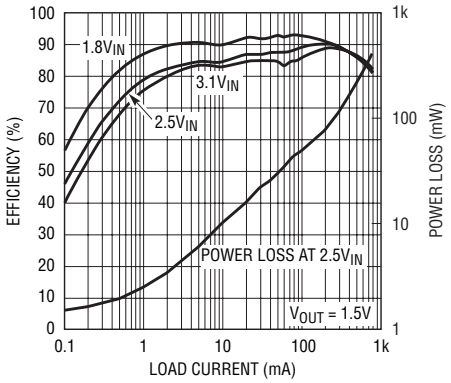

Figure 1. Efficiency vs load current for the LTC3409 in Burst Mode operation.

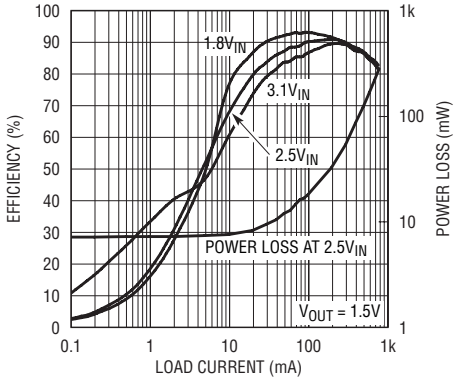

Figure 2. Efficiency vs load current for the LTC3409 in pulse skip mode.

Features

Soft Start

To reduce inrush currents at start-up, the LTC3409 offers a soft start function, which linearly ramps up the output voltage in about 1ms. For instance, the average output current required during soft start to charge a 10µF output capacitor to 1.8V in 1ms is 18mA. The total output current is the sum of the output capacitor charging current and the current delivered to the load as V_{OUT} ramps up.

Switching Frequency Synchronization

The LTC3409 offers an internally compensated phase locked loop (PLL) for switching frequency synchronization from 1MHz to 3MHz in addition to fixed frequencies of 1.7MHz and 2.6MHz. This high frequency range allows the use of surface mount capacitors and inductors.

The sync pin has three states: high, where the LTC3409 operates at a fixed 2.6MHz switching frequency; low, where the LTC3409 operates at a fixed 1.7MHz switching frequency; or as the input to the PLL, when the sync pin is toggled at a frequency of at least 1MHz for greater than 100µs. The SYNC pin threshold for PLL input is nominally 0.63V, thus allowing compatibility to low voltage logic interfaces.

Efficiency-Improving Operating Modes

The Mode pin has two states corresponding to two operating modes that improve efficiency at light loads: high for pulse skip mode, and low for Burst Mode operation. In pulse skipping mode, constant-frequency operation is maintained at lower load currents to decrease the output voltage ripple, and therefore reduce the chance of interference with audio circuitry. If the load current is low enough, cycle skipping eventually occurs to maintain regulation. Efficiency in pulse skipping mode is worse than Burst Mode op-

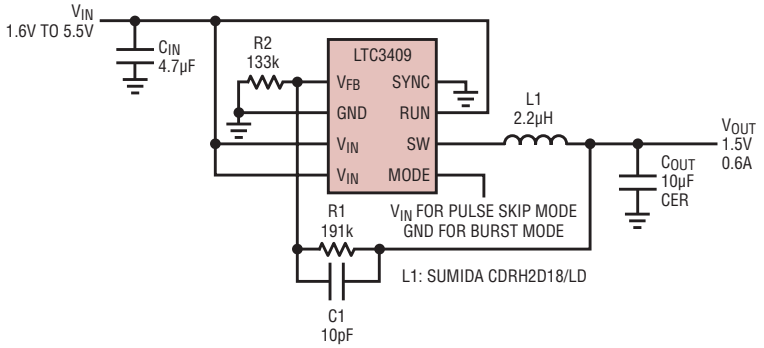

Figure 3. 1.5V/600mA step down regulator

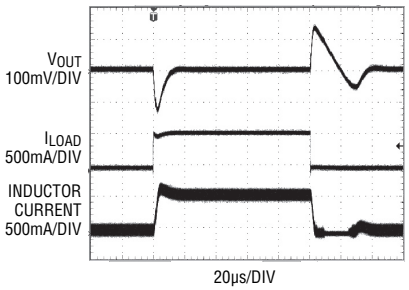

Figure 4. LTC3409 transient response to a 50mA–600mA load step, pulse skip mode

eration at light loads, but comparable when the output load exceeds 50mA (see Figure 1 & 2).

In Burst Mode operation, the internal power MOSFETs operate intermittently based on load demand. Short burst cycles of normal switching are followed by longer idle periods where the load current is supplied by the output capacitor. During the idle period, the power MOSFETs and any unneeded circuitry are turned off, reducing the quiescent current to 65µA. At no load, the output capacitor discharges slowly through the feedback resistors resulting in very low frequency burst cycles that add only a few µA to the supply current. Burst Mode operation offers higher efficiency at low output currents than pulse skip mode, but when activated, Burst Mode operation produces higher output ripple than pulse skip mode.

Output Voltage Programmability

The LTC3409 output voltage is externally programmed with two resistors to any value above the 0.613V internal reference voltage, and is capable of 100% duty cycle. In dropout, the output voltage is determined by the input voltage minus the voltage drop across the internal P-channel MOSFET and the inductor resistance.

Fault Protection

The LTC3409 protects against output over-voltage, output short-circuit and power over-dissipation conditions. When an over-voltage condition at the output (>10% above nominal) is sensed, the top MOSFET is turned off until the fault is removed. If the output is shorted to ground, reverse current in the synchronous switch is monitored to prevent inductor-current runaway. If the synchronous switch current is too high, the top MOSFET remains off until the synchronous switch current falls to a normal level.

When the junction temperature reaches approximately 160°C, the thermal protection circuit turns off the power MOSFETs allowing the part to cool. Normal operation resumes when the die temperature drops to 150°C.

1.5V/600mA Step-Down Regulator Using Ceramic Capacitors

Figure 3 shows an application of the LTC3409 using ceramic capacitors. This particular design supplies up to a 600mA load at 1.5V with an input supply between 1.8V and 3.1V. Ceramic capacitors have the advantages of small size and low equivalent series resistance (ESR), allowing very low ripple voltages at both the input and output. Because the LTC3409's control loop does not depend on the output capacitor's ESR for stable operation, ceramic capacitors can be used to achieve very low output ripple and small circuit size. Figures 4 and 5 show the transient response to a 50mA to 600mA load step for the LTC3409 in pulse skip mode, and burst mode.

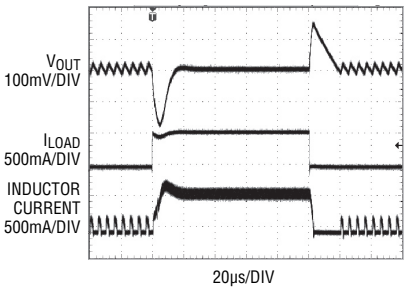

Figure 5. LTC3409 Transient response to a 50mA–600mA load step, Burst Mode operation

Efficiency Considerations

Figure 1 shows the efficiency curves for the LTC3409 (Burst Mode operation enabled) at various supply voltages. Burst Mode operation significantly lowers the quiescent current, resulting in high efficiencies even with extremely light loads. Figure 2 shows the efficiency curves for the LTC3409 (pulse skipping mode enabled) at various supply voltages. Pulse skipping mode maintains constant-frequency operation at lower load currents. This necessarily increases the gate charge losses and switching losses, which impact efficiency at light loads. Efficiency is still comparable to Burst Mode operation at higher loads.

Conclusion

The LTC3409 operates over a wide, 1.6V to 5.5V, input range, which allows it to operate from various power sources, from a 5V AC wall adapter to two series alkaline batteries. This flexible device is available in a 3mm × 3mm DFN package and includes a number of features to improve battery life and save space.

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ers and USB sources. They extend lifetime of the batteries by avoiding unnecessary charge cycles. The LTC4061 and LTC4062's versatility of charge terminations, low quiescent current, simplicity, high level of integration and small size makes them an ideal choice for many portable USB applications. LTC4061 and LTC4062 are available in a small 10-lead low profile 3mm x 3mm DFN package.