3A Monolithic Buck Regulator in 4mm × 4mm QFN

by Theo Phillips

Introduction

The LTC3412A is much more than a drop-in replacement for the popular LTC3412 monolithic buck switching regulator. Though still offered in a thermally enhanced 16-lead TSSOP, the LTC3412A is also squeezed into a smaller footprint 4mm × 4mm QFN, reducing the package height to 0.75mm from 1.1mm. At the same time, the maximum load current has risen to 3A from the LTC3412's 2.5A, and the minimum input voltage has been pared down to 2.25V from the earlier 2.625V. The LTC3412A can still deliver efficiency as high as 95%, accept input voltages up to 5.5V, and switch at frequencies up to 4MHz, making it a compact and efficient solution for portable electronics that require low supply voltages (down to 0.8V) converted from typical battery voltages.

Like its predecessor, the LTC3412A employs a constant frequency, current-mode architecture. The switching frequency can be set between 300kHz and 4MHz by an external resistor, or each switching cycle can commence with the falling edge of an external clock signal fed into the Sync/Mode pin. The LTC3412A's high switching frequency permits the designer to use tiny, low value inductors while holding output voltage ripple to a minimum.

Choice of Operating Modes

The LTC3412A can be configured for Burst Mode operation, forced continuous operation, or pulse skipping. In mobile applications where battery life is of paramount importance, Burst Mode operation boosts efficiency by reducing gate charge losses at light loads, and so reducing supply current to just 64µA at no load. Forced continuous operation switches at constant frequency regardless of load current; this simplifies filtering of the switch noise. Pulse skip mode provides a good compromise between light load efficiency and output voltage ripple.

During Burst Mode operation, switching cycles are skipped during light loads to reduce switching losses. The LTC3412A provides for external control of these cycles' peak current (the burst clamp level) by varying the DC voltage at the Sync/Mode pin within a 0V–1V range. Figure 1 shows the relationship between this DC voltage (which is generally tapped off of the feedback resistor network) and the burst clamp level. Higher peak currents deliver more energy, so fewer bursts are required to maintain the output voltage. If the minimum peak inductor current delivers more energy than the load current demands, the control loop causes the internal power switches to skip more cycles. Lower burst frequencies can improve efficiency at light load, at the expense

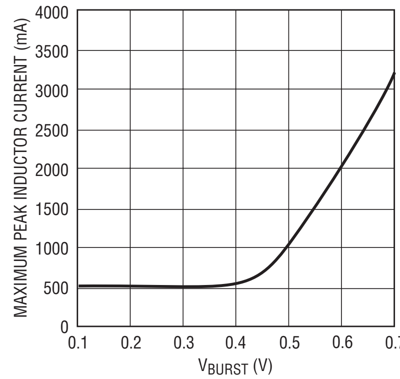
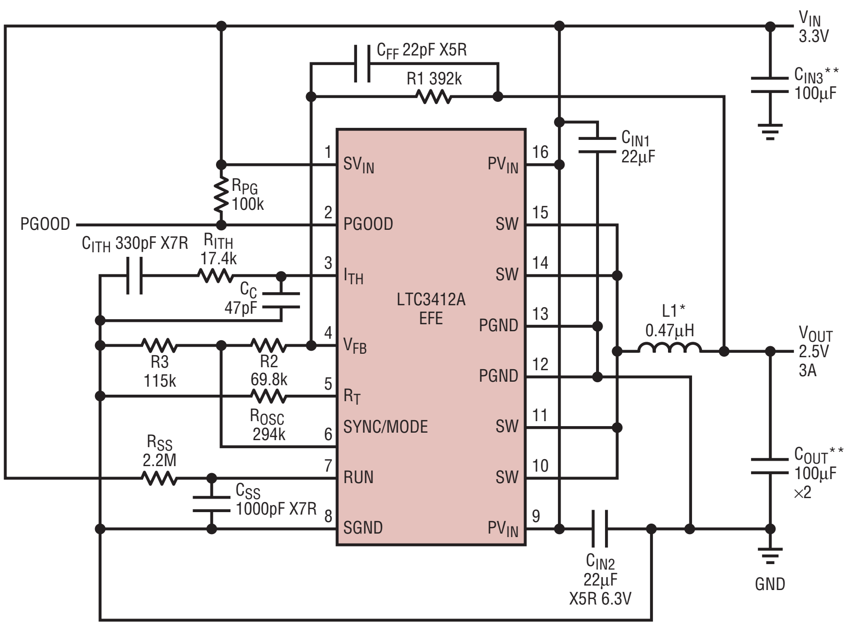


Figure 1. By tying the Sync/Mode pin to a point on the feedback voltage divider, as in Figure 2, the designer can freely adjust the peak current of the bursts (See Figure 4).



*VISHAY IHLP-2525CZ-01
**TDK 4532X5R0J107M

Figure 2. A 2.5V, 4A step-down regulator in Burst Mode operation

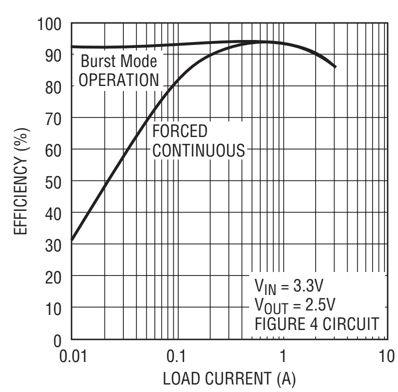


Figure 3. Efficiency vs load current for the circuit of Figure 2, V_{IN} = 3.3V, V_{OUT} = 2.5V (Burst Mode operation). If Sync/Mode were tied to ground, the efficiency would be lower (pulse skip mode), but output voltage ripple would be greatly reduced.

of a slight increase in output voltage ripple. Conversely, lowering the minimum peak inductor current increases the burst frequency and reduces the output voltage ripple.

Burst Mode operation dissipates minimal power in light load applications, but sometimes noise suppression takes priority over efficiency. To reduce noise and RF interference, the LTC3412A can be set up for forced continuous operation by connecting the Sync/Mode pin to the Signal Input Voltage pin. This mode maintains a constant switching frequency regardless of output load, dovetailing with noise sensitive applications in which it is necessary to avoid switching harmonics in a particular signal band.

In pulse skip mode, the burst clamp is set to zero current, which limits the minimum peak inductor current to a level set by the minimum on-time of the control loop. Pulse skip mode is implemented by connecting the Sync/Mode pin to GND. Pulse skipping has lower ripple than Burst Mode operation and has better light-load efficiency than forced continuous mode.

As the battery voltage decreases toward the output voltage, the duty cycle and the on-time increase. Further reduction in the battery voltage forces the internal P-channel MOSFET to remain on for more than one cycle, and ultimately to remain on 100% of the time. This dropout state extends the useful operating input voltage over the run-time of the battery. Output voltage simply follows the input voltage as the battery continues to discharge, reduced by drops across the inductor and P-channel MOSFET.

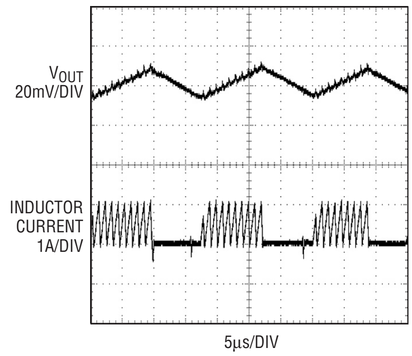


Figure 4. Burst Mode operation, showing output voltage ripple associated with bursts of inductor current. The peak currents are held to 1.1A because the Sync/Mode voltage is set to 0.49V.

The LTC3412A can deliver efficiency as high as 95%, accept input voltages up to 5.5V, and switch at frequencies up to 4MHz, making it a compact and efficient solution for portable electronics that require low supply voltages (down to 0.8V) converted from typical battery voltages.

A High Efficiency 2.5V, 3A Step-Down Regulator with All Ceramic Capacitors

Figure 2 shows a 2.5V step-down DC/DC converter that is configured for Burst Mode operation. This circuit provides a regulated 2.5V output at up to 3A from a 3.3V input. Figure 3 shows that efficiency peaks at 94%, and remains high across the load spectrum. The measured output voltage ripple is around $25mV_{P-P}$ at loads from 10mA to 200mA, and drops to around 5mV at heavier loads. Lower ripple (5mV–10mV) can be maintained at the lightest loads with pulse skip mode, with some sacrifice in light load efficiency. The switching frequency for this circuit is set at 1MHz by a single external resistor, R_{OSC}. Operating at frequencies this high allows the use of a low value (and physically small) inductor.

In this application, Burst Mode operation maintains the high efficiency at light loads. This powers down the majority of the internal circuitry during the intervals between switching cycles. The peak inductor current is set by the R2-R3 voltage divider, which generates

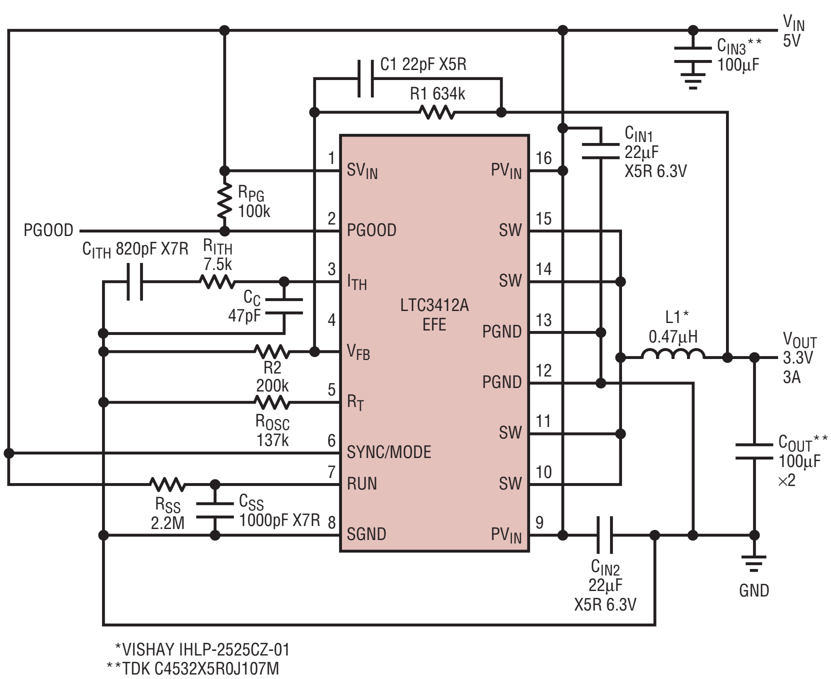


Figure 5. A 2MHz regulator, 5V to 3.3V at 3A, operating in forced continuous mode

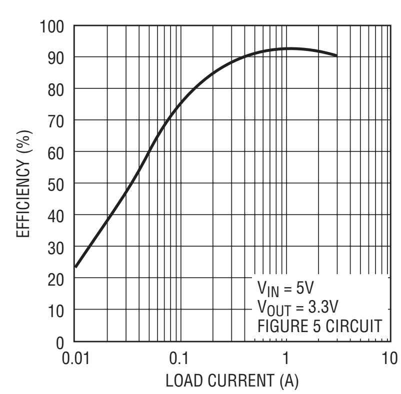


Figure 6. Efficiency of the circuit in Figure 5 reaches well into the 90s at moderate loads.

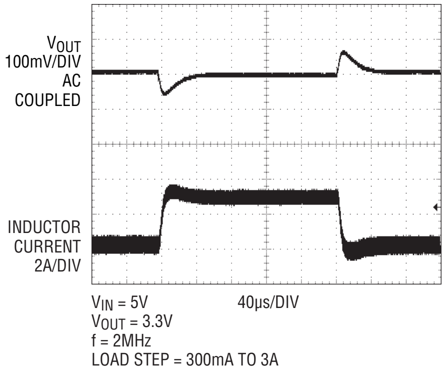


Figure 7. The circuit of Figure 5 delivers a clean transient response when the load is stepped from 300mA to 3A.

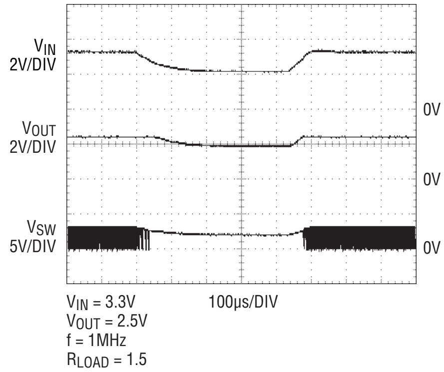


Figure 8. If the circuit of Figure 2 experiences a dip in V_{IN}, a regulated output is maintained until the LTC3412A goes smoothly into dropout. Below that level, V_{OUT} follows V_{IN} anywhere above the undervoltage lockout. For output voltages programmed below the UVLO, the LTC3412A can maintain its output voltage even when the input sinks to 2.25V.

a 0.49V reference at the Sync/Mode pin. This corresponds to approximately 1.1A minimum peak inductor current, as shown in Figure 1.

Figure 4 illustrates how Burst Mode operation produces a burst of inductor current pulses that are repeated periodically. Each inductor current pulse increases to approximately 1.1A during each switching period before the main power MOSFET is shut off. The process repeats for multiple switching cycles until the charge on the output capacitor is refreshed. Once this is accomplished, both the main and synchronous power MOSFETs are held off while the load current is supplied solely by the charge on the output capacitor. This sleep state continues until the output voltage drops low enough to initiate another burst cycle. Varying the voltage on the Sync/Mode pin affects the amplitude of the group of current bursts as well as the frequency at which they are repeated.

2MHz, High Efficiency 3.3V, 3A Step-Down Regulator with All Ceramic Capacitors

Figure 5 shows a 3.3V step-down DC/DC converter using all ceramic capacitors. Switching at 2MHz, this circuit provides a regulated 3.3V output at up to 3A from a 5V input voltage. This converter is an ideal choice for operation near an AM radio receiver, since it operates above the broadcast band and the switch noise can be filtered in a predictable manner. Efficiency for this circuit, shown in Figure 6, is as high as 95% at moderate loads.

Ceramic capacitors offer low cost and low ESR, but many switching regulators have difficulty operating with them because the extremely low ESR can lead to loop instability. The phase margin of the control loop can drop to inadequate levels without the aid of the zero that is normally generated from the higher ESR of tantalum, niobium, or special polymer capacitors. The LTC3412A, however, includes OPTI-LOOP compensation, which allows it to operate properly with ceramic input and output capacitors. The LTC3412A allows loop stability to be achieved through a wide range of loads and output capacitors with proper selection of compensation components on the I_{TH} pin. Figure 7 shows the stable transient response associated with the circuit of Figure 5.

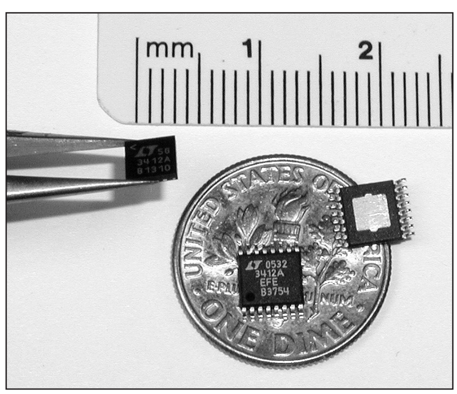


Figure 9. The LTC3412A is offered in two thermally enhanced packages: the 16-lead TSSOP (both sides shown) and the ultra-thin 4mm × 4mm QFN (shown in tweezers).

Lower Minimum Input Voltage

Sagging input voltages are handled well by the LTC3412A. Figure 8 shows the response of V_{OUT} to a substantial hit to V_{IN}. Until V_{IN} drops to V_{OUT}, the effect on V_{OUT} is negligible; below that point the P-channel FET turns on 100% of the time (dropout), and V_{OUT} follows V_{IN} right down to the guaranteed 2.25V undervoltage lockout. Output voltages set below the UVLO can be maintained while maximizing battery life, or where input rails are just loosely regulated.

Conclusion

The LTC3412A is a monolithic, synchronous step-down DC/DC converter that is well suited for applications requiring up to 3A of output current. OPTI-LOOP compensation allows diverse transient responses to be optimized with ceramic capacitors. For excellent thermal handling, the LTC3412A is offered in two tiny packages, each with an exposed pad to facilitate heat sinking (Figure 9). Its high switching frequency, low undervoltage lockout and internal low $R_{DS(ON)}$ power switches make the LTC3412A an excellent choice for compact, high efficiency power supplies.