# 600mA Switching Converter Reduces Noise by Automatically Shifting to a Linear Regulator at Light Loads

by Kevin Soch

## Introduction

High efficiency, low ripple current, and a small footprint are critical power supply design requirements for cell phones, MP3 players and other portable devices. The LTC3448 delivers excellent performance in each of these areas. It is a high efficiency, monolithic, synchronous buck regulator using a constant frequency, current mode architecture. It achieves very low ripple by automatically shifting to linear regulator operation at load currents below 3mA, and pulse skipping operation at moderate load currents. This is a critical feature in applications such as cell phones, where low power supply noise is required while in standby. Its built-in 0.35Ω switches provide for up to 96% efficiency. Finally, it fits into 0.1in$^2$ (see Figure 1) due to its 8-lead 3mm × 3mm DFN or MSOP package, 1.5MHz or 2.25MHz switching frequency, internal compensation, and minimum number of small external components.

## Features

The LTC3448 automatically shifts gears to maintain high efficiency and low noise over a wide range of load currents. For normal loads, it operates as a current mode constant frequency converter, which yields well-defined ripple frequencies. At moderate load currents, it transitions into pulse skipping mode for decreased output ripple. At load currents below 3mA, it automatically shifts to linear regulator operation to maintain <5mV$_{P-P}$ noise and reduce the quiescent supply current to 32µA.

No external sense resistor is required to detect the load current. Simply tie the MODE pin to $V_{OUT}$. The LTC3448 uses a patent pending process where it monitors the behavior of the switcher to determine the load current, and enters linear regulator operation when appropriate. The crossover between switcher mode and linear regulator mode can also be controlled externally by driving the MODE pin high or low.

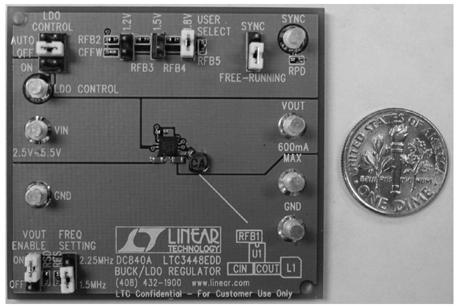


**Figure 1. The LTC3448 regulator occupies less than 0.1in$^2$ of board space.**

The LTC3448 has a 2.5V to 5.5V input voltage range, perfect for single Li-Ion battery-powered applications, and is available with an adjustable output voltage. Its 100% duty cycle provides low dropout operation, extending battery life in portable systems. Low output voltages are easily supported with the 0.6V feedback reference voltage.

Switching frequency is selectable at either 1.5MHz or 2.25MHz, or can be synchronized to an external clock applied to the SYNC pin. The high switching frequency allows the use of small surface mount inductors and capacitors. The LTC3448 also saves space with an internal synchronous switch, which eliminates the need for an external Schottky diode and increases efficiency.

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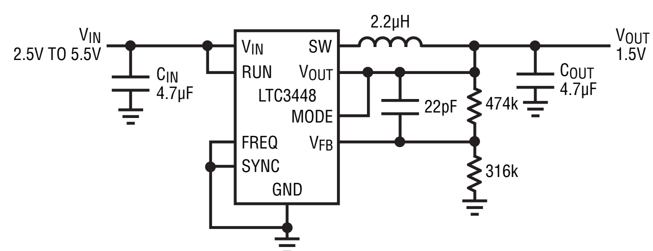


**Figure 2. LTC3448 minimum component implementation.**

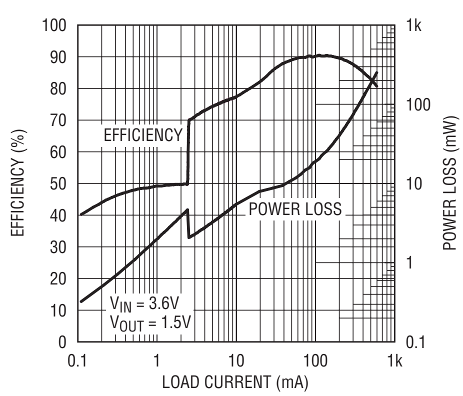


**Figure 3. Overall efficiency and power loss as a function of load current. Part is operating in automatic linear regulator mode with $V_{IN}$ = 3.6V and $V_{OUT}$ = 1.5V.**

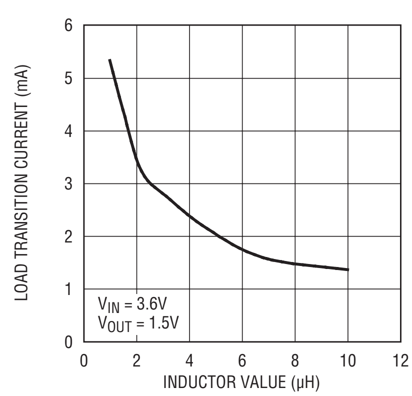


**Figure 4. Switching-to-linear-regulator crossover load current depends on inductor value. $V_{IN}$ = 3.6V, $V_{OUT}$ = 1.5V.**

Increasing the maximum power dissipation to 2W, allows well over 3A of output current. The efficiency of a switching regulator operating under these conditions is typically 75%. The added complexity and cost of a switching regulator makes a linear regulator look even better.

## Comparison of a Switcher and Linear Regulator in the Same Application

Compare the two different topologies in a 1.8-to-1.5 volt application. In this design, the power dissipation is low enough that even three amps of output current do not exceed our 1W power limitation. Figure 2a shows a 1.5A application using the LTC3026 CMOS linear regulator. A comparable step-down switching regulator circuit is shown in Figure 2b. Figure 3 compares the efficiencies and power losses of both circuits. As shown, the switching converter is more efficient at low load currents, but the linear regulator efficiency matches, then surpasses, the switcher efficiency as the load current increases. The same is true for the power losses. The linear regulator fares better as load current increases.

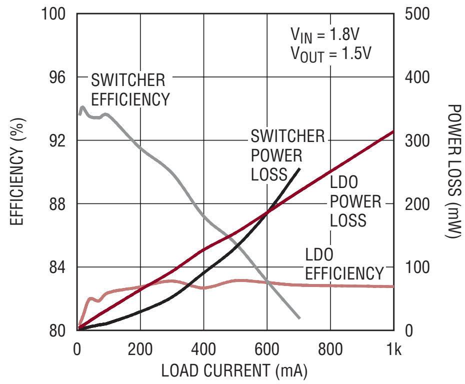


**Figure 3. Efficiency and power loss of the LTC3026 linear regulator compare favorably to that of a switching regulator. The LDO maintains good efficiency to 1.5A.**

As the input-to-output differential voltages decrease, such as occurs in battery-powered applications, the linear regulator efficiency compares even more favorably to the switcher (see Figure 4). For instance, at 500mA of load current, where the dropout voltage of the LTC3026 is only 60mV, the linear regulator is over 97% efficient, whereas the switcher efficiency is around 85%. In this case, the linear regulator beats the switcher in all aspects—efficiency, power loss, size, simplicity and cost.

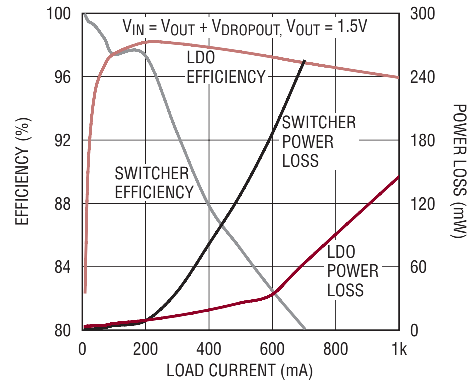


**Figure 4. At the lowest input-to-output differential voltage, $V_{IN} = V_{OUT} + V_{DROPOUT}$ and $V_{OUT}$ = 1.5V, the efficiency and power losses of the linear regulator fare even better compared to those of the switching regulator.**

## Conclusion

At low input and output voltages, linear regulators offer excellent regulation, and in many cases, deliver efficiency rivaling that of switching regulators. In all cases a linear regulator circuit is simpler and less costly. In applications where the board can adequately dissipate the power, linear regulators can handle a reasonable range of inputs and output voltages.

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## Minimum Component 1.5V Step-Down Implementation

Figure 2 shows a typical application using a minimum number of external components. The loop compensation is integrated into the device, and the optional 22pF feed-forward capacitor improves the transient response. The switching frequency is 1.5MHz as shown (FREQ pin to ground) but it can be set to 2.25MHz by connecting the FREQ pin to $V_{IN}$. Figure 3 shows the efficiency and power loss as a function of load current.

By connecting the MODE pin to $V_{OUT}$, the part automatically transitions from a switching regulator to a linear regulator at low load currents. In the circuit of Figure 2, the transition occurs when the load current drops below approximately 3mA. The transition load value has an inverse relationship to the inductor value, as shown in Figure 4, but is independent of other external component values, and largely independent of the values of $V_{IN}$ and $V_{OUT}$. The device transitions back into switching regulator mode when the load current exceeds 10mA, regardless of inductor value.

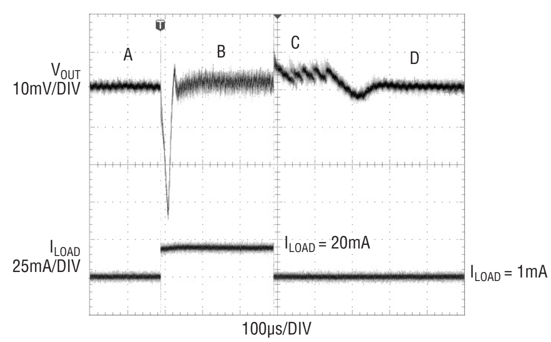


**Figure 5. The load transient response of the circuit in Figure 2. The transitions from linear regulator behavior to switching behavior and back are shown. In the region labeled A, load current is 1mA and the part is operating as a linear regulator. In the region labeled B, the load current has increased to 20mA and the switcher has turned on in pulse skipping mode. In the region labeled C, the load has decreased to 1mA, but the part has not yet transitioned back into linear regulator operation, thus the lower frequency pulse skipping behavior. In region D, the part is again operating as a linear regulator, with greatly reduced output noise.**

Figure 5 shows the load transient response when the load is increased from 1mA to 20mA and then back to 1mA. The difference in ripple between the pulse skipping operation and linear regulator operation can be clearly seen.