Monolithic 2A Buck Regulator Plus Linear Regulator Simplifies Wide Input Voltage Applications

by Rich Philpott

Introduction

Wide ranging voltage sources—such as automotive batteries, unregulated wall transformers, and industrial power supplies—require regulation to provide stable output voltages during harsh input transient conditions. Simple, robust and relatively inexpensive linear regulators offer one solution. They produce low output ripple and offer excellent power supply ripple rejection, but low efficiency, high power dissipation and thermal constraints are problems at high input-to-output ratios.

The typical alternative to the linear solution is a high voltage monolithic step-down switching regulator. Switching regulators offer high efficiency, excellent line and load regulation, and good dynamic response, but systems with multiple outputs require multiple switchers. This can quickly drive up the power supply cost, space requirements, design effort and noise.

A better solution combines the advantages of switchers and linear regulators in a single package. The LT3500 does just this by integrating a high frequency switcher and a linear regulator in a 3mm × 3mm 12-pin DFN package, thus eliminating the need for a second switching regulator in a dual output system.

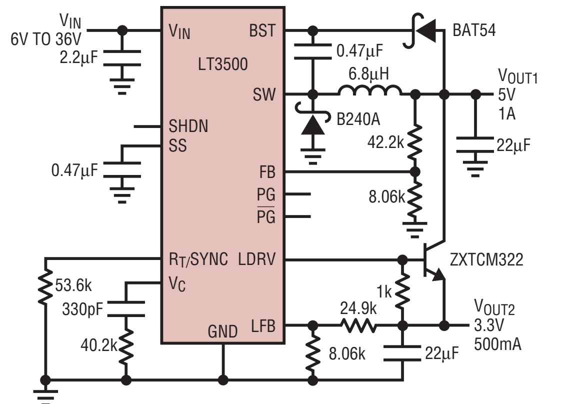

Figure 1. Dual step-down converter for 5V at 1A and 3.3V at 1A

Get Two-for-One and Change…

A common power supply problem is producing 3.3V and 2.5V power rails from a high voltage supply. To solve this problem, the LT3500's switcher efficiently converts the high voltage input to 3.3V, while the linear regulator—plus an external NPN transistor—generates 2.5V from the switcher's 3.3V output. You get two outputs for the cost of one small package.

…Or, Just Beat the Heat

In high voltage input, single-output systems where linear regulation is preferred because of low output ripple and power supply rejection, but heat dissipation is an issue, the LT3500 also offers an elegant solution. For example, if a linear regulated 3.3V output is needed, the LT3500's switcher can efficiently step-down the input voltage to 3.6V. The integrated linear regulator (plus an external NPN) can generate a clean 3.3V from 3.6V with minimal heat dissipation.

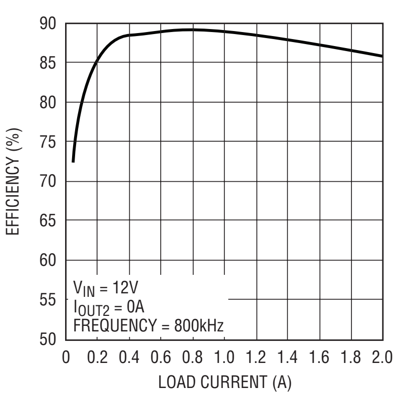

Figure 2. LT3500 switching regulator efficiency

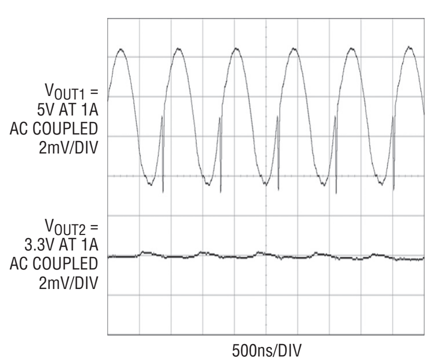

Figure 3. 5V and 3.3V output ripple waveforms

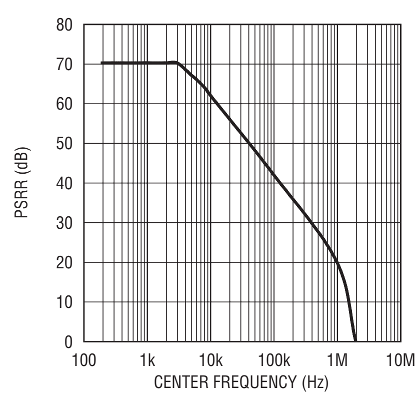

Figure 4. PSRR vs Frequency for V_{OUT2} for the application shown in Figure 1

Features of the LT3500

The LT3500's switching regulator is a constant frequency, current mode PWM step-down DC/DC converter with an internal 2.3A switch. The wide 3V–36V input range makes the LT3500 ideal for regulating power from a wide variety of sources, including automotive batteries, 24V industrial supplies and unregulated wall adapters.

The switching frequency can be set from 250kHz to 2.2MHz via a single resistor from the RT/Sync pin to ground, or synchronized over the same range by driving the pin with a square wave. Programmable frequency range and synchronization capability enable optimization between efficiency and external component size. Cycle-by-cycle current limit, frequency foldback and thermal shutdown protect the LT3500 from harmful fault conditions.

In addition to the switching regulator, the LT3500 contains an internal NPN transistor capable of delivering 13mA with feedback control, which can be configured as a linear regulator or a linear regulator controller. The LT3500's soft-start feature controls the ramp rate of the output voltages, eliminating input current surge during start-up, while providing output tracking between the switcher and linear outputs. The SHDN pin has an accurate threshold with current hysterisis, which enables the user to program an undervoltage lockout. The LT3500 provides open collector power good flags that signal when the output voltages on both outputs rise above 90% of their programmed values. The PG pin is high impedance when the outputs are in regulation and is typically used for a system reset function. The PG pin is active when the outputs are in regulation and is used as a drive signal for an output disconnect device. In shutdown mode the LT3500 draws less than 12μA of quiescent current.

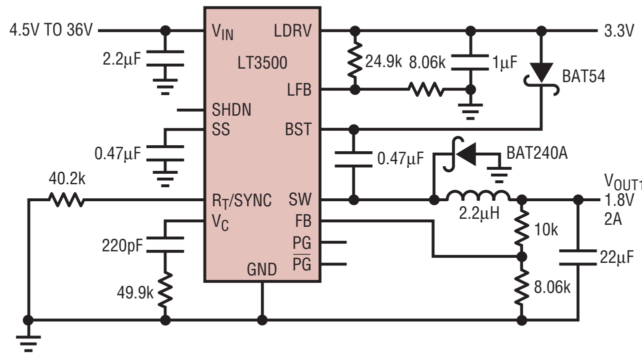

Figure 5. 1.8V/2A step-down regulator

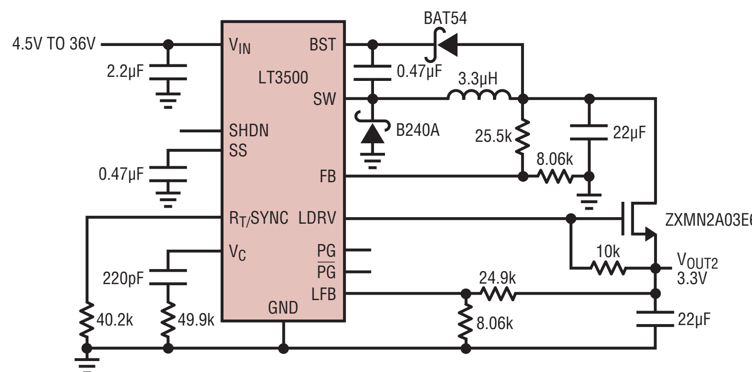

Figure 6. High efficiency linear regulator

High Voltage Step-Down Regulator Plus Low Ripple Linear Regulator

One of the most common applications for a high voltage step-down regulator is as a pre-regulator to other power supplies. The pre-regulator must be immune to harsh input transients as it produces a stable output voltage for other downstream regulators. In systems where noise and ripple are of concern, a linear regulator is often used to step down the output of the switcher to the desired voltage.

The LT3500 plus an external NPN transistor as shown in Figure 1 is a perfect fit in these types of applications. The circuit takes an input from 6V to 36V and generates an intermediate 5V output. The LT3500's linear regulator is configured as a controller for the external NPN with its output set to 3.3V. Note that although the load current rating for each individual output is 2A, here the sum of both outputs must be less than 2A. Also, care must be taken not to violate the maximum power dissipation of the external NPN.

The comparison of output ripple at 1A load current shown in Figure 3 illustrates the benefit of using linear regulation to reduce switching ripple and noise. The excellent PSRR versus frequency of the LT3500's linear regulator is shown in Figure 4.

High V_{IN}, Low V_{OUT}, and Boost Pin Problems Solved

Operating the LT3500 at high frequencies allows the use of small low cost inductors and ceramic capacitors while maintaining low output ripple. However, due to minimum on time restrictions ($T_{ON(MIN)}$ < 140ns) high V_{IN}-to-V_{OUT} ratios may cause increased output ripple. The LT3500's adjustable frequency allows the user to optimize

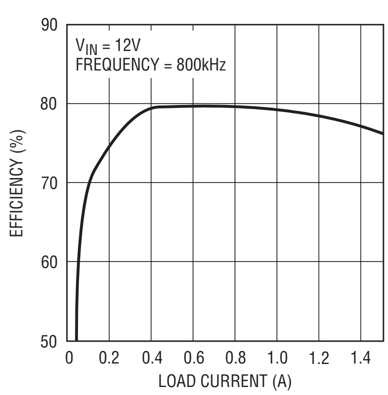

Figure 7. Efficiency vs load current for Figure 6 application

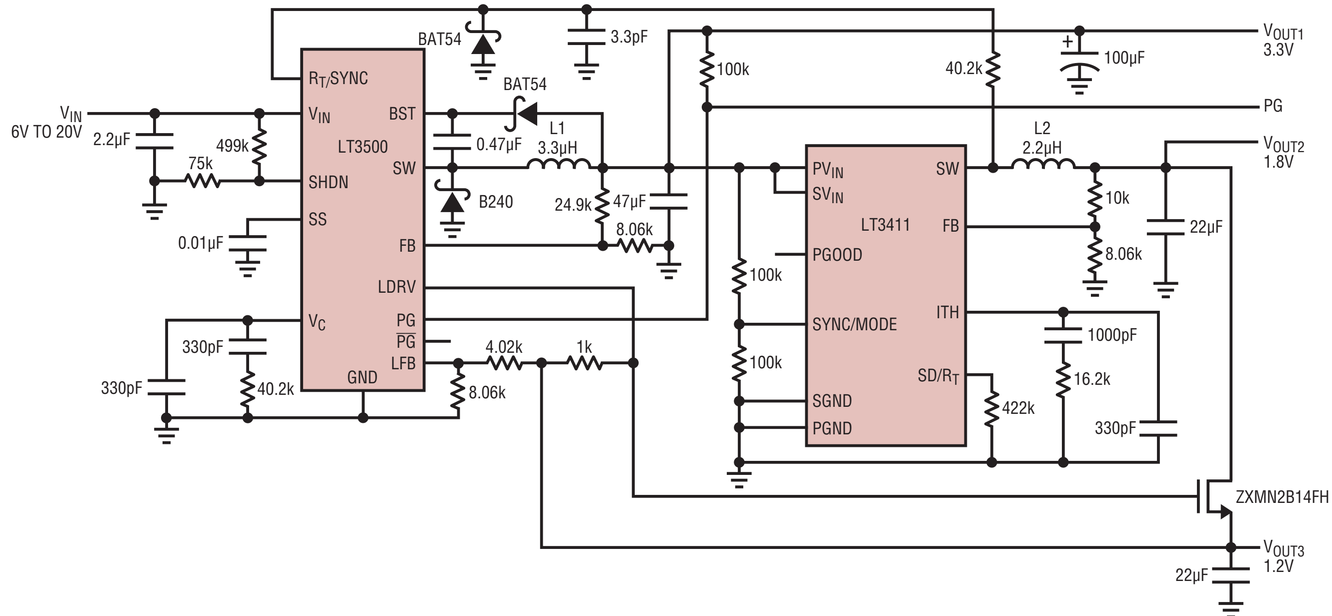

Figure 8. Triple output application

external component size regardless of V_{IN}-to-V_{OUT} ratio.

High V_{IN}-to-V_{OUT} ratios also pose a boost pin problem for most monolithic step-down regulators. When the desired output voltage is not high enough to fully turn on the output switch, the boost voltage must be derived from the input voltage or another available voltage. Taking the boost voltage from the input poses a couple of problems. First, the switcher efficiency suffers due to the large drop from the boost pin to the switch pin. Second, the boost pin is exposed to high input transients, which may violate its ratings. The LT3500 alleviates boost voltage problems by generating the boost voltage with the on chip linear regulator as shown in Figure 5. This circuit generates its own 3.3V boost rail to regulate 1.8V from 4.5V to 36V.

High Efficiency Linear Regulator

In many step-down applications linear regulators are preferred because of their excellent PSRR and output ripple, but are not used due to low efficiency or thermal constraints. Figure 6 shows another way to optimally combine the benefits of a switcher and a linear regulator, resulting in a high efficiency, low noise regulator. The switcher output is set to step down the 4.5V to 36V input voltage range to 3.5V and the linear controller is set to generate 3.3V from the 3.5V output of the switching regulator. With only 200mV across the NMOS pass device, the efficiency of the linear regulator is only 6% less than a switcher only solution with the added reduction in output ripple. The efficiency versus load current for the application is shown in Figure 7.

NPN or NMOS Pass Transistor

NPN or NMOS pass transistors both work well when configured as a linear controller, but each has its advantages and disadvantages.

During a shorted linear output fault, the current through the NPN is limited to $\beta_{NPN} \bullet I_{LDRV(MAX)}$, while the current through an NMOS is essentially unlimited. Since the maximum NPN current is typically less than the maximum switcher current, a shorted output will flag as an error but it will not affect the switcher output (assuming the switcher load plus shorted linear load is less than 2A). A shorted output on the NMOS will likely cause both outputs to crash to zero.

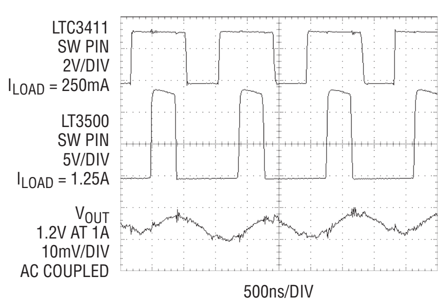

Figure 9. Synchronized switch waveforms for Figure 8 application

The minimum input voltage for the linear controller to regulate is V_{OUT2} + (V_{be} or V_{gs} at max load) + 1.2V. The V_{be} for a NPN is typically 0.7V where as the NMOS can range from 1.8V to 4.5V depending on the transistor size. For example, the minimum input voltage for a 1.8V output is typically 3.8V for a NPN pass transistor and 5V for a low threshold NMOS transistor.

The power loss of the linear regulator is simply the voltage drop across the device multiplied by the current through the device. NMOS transistors can be sized such that the device can be operated with V_{ds} less than the saturation voltage of most NPN transistors resulting in lower power loss (greater efficiency).

Multiple Output Application

The trend in many of today's systems is to provide multiple regulated voltages from a single high voltage source to optimize performance. When multiple switching regulators are used, beat frequencies along with output ripple can cause problems with some systems. The application circuit in Figure 8 tackles these issues by synchroniz-

continued on page 18

a 48V input power supply. Figure 2 shows the LT3590 driving ten white LEDs from 48V input supply. Figure 4 shows another high voltage application for the LT3590. Here, two strings of ten white LEDs are driven at 25mA. In this example we rely on the fact that the voltage drop across each LED string is a sum of ten average LEDs. Differences in individual LEDs are averaged across the string. Reasonable current matching is expected in this scheme with better than 90% efficiency for a wide range of LED currents.

In larger applications, where multiple LED strings are used, it is important to match the string currents accurately to produce uniform brightness. The LT3590's accurate current control makes this possible.

Indicator Light

Single-LED Indicator lights are popular in a wide range of applications from consumer electronics to automotive. In applications where a low voltage supply is available, it is easy to bias the LED using a simple series resistor. If the input supply voltage is much higher than the LED's forward drop, using a resistor is inefficient and could generate excessive heat. Also,

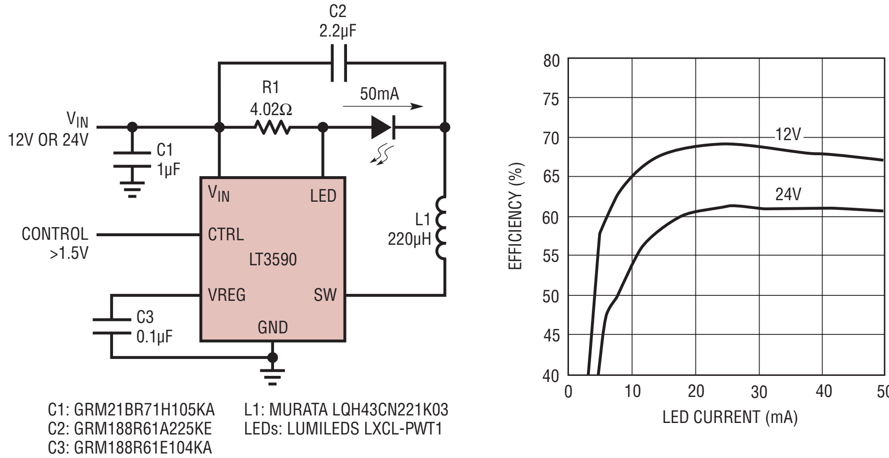

Figure 5. A 12V or 24V supply for a single LED, 50mA current

in order to handle the power, bulky power resistors are needed. Another drawback of biasing with a resistor is that the LED current, and therefore its brightness, depends on the input supply voltage.

The LT3590 is the ideal solution for driving low LED counts from high voltage supplies. Figure 5 shows the application circuit with one LED and a 12V or 24V input supply. The resulting efficiencies for both input supply voltages are also shown in Figure 5. At 50mA LED current, this solution provides 67% and 61% efficiencies for the 12V and the 24V input supplies respectively. In comparison, the resistor-biasing approach would yield dismal 25% and 12.5% efficiencies.

Conclusion

The LT3590 offers easy-to-use accurate current drive for LED strings. Overall solution size is very small due to its small package size and an architecture that requires few additional components. Its high efficiency and wide input voltage range makes it suitable for a variety of applications, including driving LED strings with up to 40V of total LED voltage.

LT3500, continued from page 15

ing the switching regulators and also providing a low ripple linear output.

The LT3500 in Figure 8 steps down voltages between 6V and 20V to 3.3V. The 3.3V output is fed to the LTC3411, which generates 1.8V and also provides the drain voltage for the NMOS pass transistor. The output of the NMOS provides a low ripple 1.2V output controlled by the

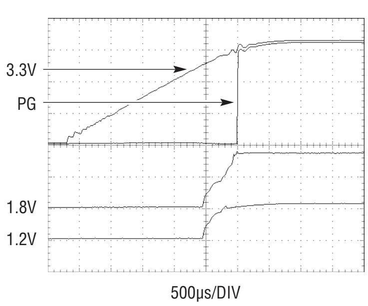

Figure 10. Start-Up waveforms for Figure 8 application

LT3500. Operating the LTC3411 in forced continuous mode generates a 3.3V square wave at its SW pin, which is used to synchronize the LT3500 to the LTC3411, thus removing any system beat frequencies. The application switching waveforms are shown in Figure 9. The LT3500 controls start-up, and provides power good information via the SHDN, SS and PG pins as shown in Figure 10.

The current capability for each output must be determined with the entire system in mind. The maximum output current for the LTC3411 is 1.25A, which must be shared between the 1.8V and 1.2V outputs. The LT3500 powers the LTC3411 so the available current to the 3.3V rail depends on whatever power is left. For example, assuming the 1.2V output maximum current is 1A, the maximum current available for the 1.8V output is 250mA. The maximum output power for the 1.8V output is 2.25W (1.8V • 1.25A). The load seen by the 3.3V rail due to the LTC3411 is defined as

$$I_{LOAD(3.3V)} = \frac{P_{OUT(1.8V)}}{\varepsilon_{LTC3411(1.8V)} \bullet V_{IN(LTC3411)}} = \frac{2.25W}{0.9 \bullet 3.3V} = 0.75A$$

The current capability of the 3.3V rail is 1.25A (2A maximum minus 0.75A).

Conclusion

The combination of a wide input range switcher and a linear regulator makes the LT3500 a perfect solution to a wide variety of automotive, industrial and distributed power problems.