Automotive Environments Demand Robust Power Conversion

Automotive and heavy equipment vehicle environments are very demanding for any type of power conversion devices. Wide operating voltage ranges coupled with large transients and wide temperature excursions combine to make reliable electronic system design difficult. To further complicate design considerations, the number of rails within an electronic system is also increasing. The new LTC3890 provides features that make it an good choice for a high input voltage power supply. It brings a new level of performance in terms of needing to operate safely and efficiently in a demanding high voltage transient environment. **Bruce Haug, Senior Product Marketing Engineer, Linear Technology Corp., USA**

For example, a typical navigation system can have six or more rails including 8.5 V, 5 V, 3.3 V, 2.5 V, 1.8 V and even 1.5 V. At the same time, as the number of components increases, space requirements continue to shrink, making high efficiency conversion critical due to the space limitations and high temperature conditions.

As a result, a good automotive and truck switching DC/DC regulator needs to be specified to work over a wide input voltage range. A 60 V rating gives good margin for a 12 V system, which is usually clamped in the 36 V to 40 V range. In addition, double battery applications found in trucks and heavy equipment require an even higher operating voltage due to their 24 V nominal battery voltage. Most are clamped to 58 V, so a 60 V rating is usually sufficient. The on-board automotive and truck over-voltage clamp is required to maintain a maximum transient voltage caused by the inductive kick back voltage from the starter motor, which can cause a much higher transient voltage when left unclamped.

Low quiescent current required

There are many automotive and truck systems that require continuous power even when the vehicle's motor is not running, such as remote keyless entry and alarm systems. It is essential for these types of "always-on" systems to have a DC/DC converter with low quiescent current in order to maximize the battery run time when in sleep mode. In such circumstances, the regulator runs in normal continuous switching mode until the output current drops below a predetermined threshold of around 30-50 mA. Below this level, the switching regulator must go into Burst Mode® operation to lower the quiescent current into tens of microamps, thereby lowering the power drawn from the battery in order to extend the battery run time.

With 60 V input DC/DC converters in short supply, designers have resorted to a transformer-based topology or external high side drivers to operate from up to 60 V. Others have used an intermediate bus converter, requiring an additional power stage. Both of these alternatives increase the design complexity and, in most cases, reduce the overall efficiency. However, the LTC3890 is the latest part in a growing family of 60 V input capable step-down switching regulator controllers that addresses many of the key issues required in automotive and truck applications as outlined above. Figure 1 shows a schematic of the LTC3890 operating in an application that converts a 9 V to 60 V input into 3.5 V/5 A and 8.5 V/3 A outputs.

The LTC3890/-1 is a high voltage dual

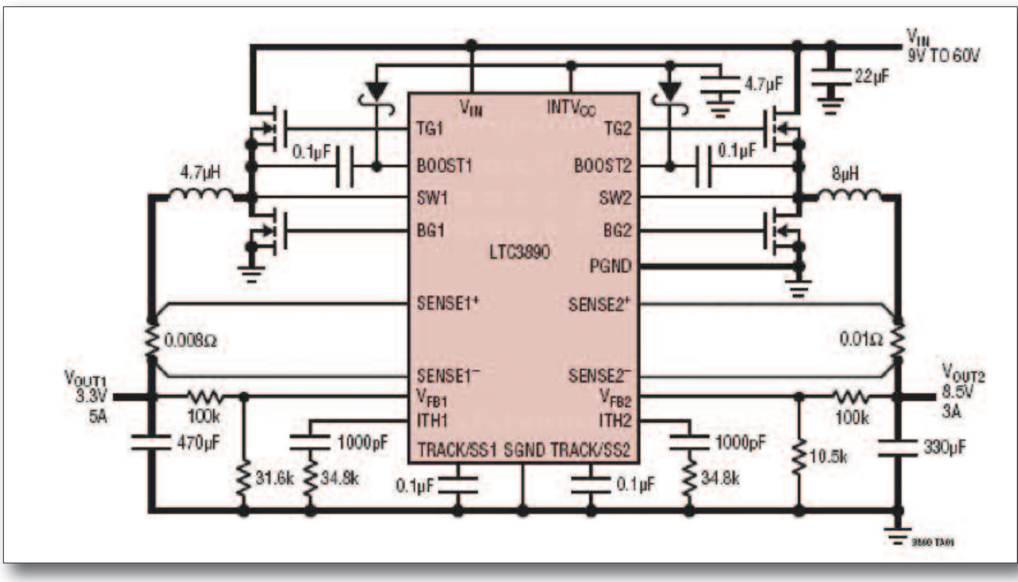

Figure 1: LTC3890 schematic with 9 V to 60 V input to 8.5 V/3 A and 3.3 V/5 A outputs

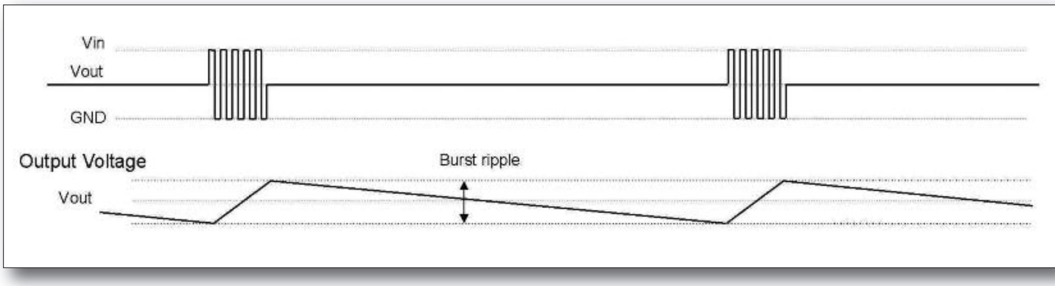

Figure 2: Burst Mode operation voltage diagram for the LTC3890

output synchronous step-down DC/DC controller that draws only 50 µA when one output is active and 60 µA when both outputs are enabled. With both outputs shut down, the device draws only 14 µA. The 4 V to 60 V input supply range is designed to protect against high voltage transients, continue operation during automotive heavy equipment and truck cold cranking along with covering a broad range of input sources and battery chemistries. Each output can be set from 0.8 V to 24 V at output currents up to 20 A, with efficiencies as high as 98 %, making it well suited for 12 V or 24 V automotive, truck, heavy equipment and industrial control applications.

The LTC3890/-1 operates with a selectable fixed frequency between 50 kHz and 900 kHz, and can be synchronized to an external clock from 75 kHz to 850 kHz with its phase-locked loop (PLL). The user can select from continuous operation, pulse skipping and low ripple Burst Mode operation during light loads. The LTC3890's 2-phase operation reduces input filtering and capacitance requirements. Its current mode architecture provides easy loop compensation, fast transient response and excellent line regulation. Output current sensing is accomplished by measuring the voltage drop across the output inductor (DCR) for the highest efficiency or by using an optional sense resistor. Current foldback limits MOSFET heat dissipation during overload conditions. These features, combined with a minimum on-time of just 95 ns, make this controller suitable for high step-down ratio applications.

The device is available in two versions; the LTC3890 is the fully featured part with functions including a clock out, clock phase modulation, two separate power good outputs and adjustable current limit. The LTC3890-1 does not have those extra features and is available in a 28-pin SSOP package. The LTC3890 is available is a 32-lead 5 mm x 5 mm QFN package.

Choice of operation modes

The LTC3890/-1 can be enabled to enter high efficiency Burst Mode operation, constant frequency pulse skipping, or forced continuous conduction mode at low load currents. When configured for Burst Mode operation and during a light load condition, the converter will burst out a few pulses to maintain the charge voltage on the output capacitor. It then turns off the converter and goes into sleep mode with most of its internal circuits shut down. The output capacitor supplies the load current and when the voltage across the output capacitor drops to a programmed level, the converter starts back up delivering more current to replenish the charge voltage. The action of shutting down and turning off most of its internal circuits significantly reduces quiescent current, thereby helping to extend the battery run-time in an "always-on" system when the system is not running. Figure 2 shows the conceptual timing diagram of how this works.

The Burst Mode output ripple is load independent so only the length of the sleep intervals will change. In sleep mode, much of the internal circuitry is turned off except for the critical circuitry needed to respond quickly, further reducing its quiescent current. When the output voltage drops low enough, the sleep signal goes low and the controller resumes normal Burst Mode operation by turning on the top external MOSFET. Alternatively, there are instances when the user will want to operate in forced continuous or constant frequency pulse skipping mode at light load currents. Both of these modes are easily configurable but will have a higher quiescent current and a lower peak to peak output ripple.

In addition, when the controller is enabled for Burst Mode operation, the inductor current is not allowed to reverse. The reverse current comparator, IR, turns off the bottom external MOSFET just before the inductor current reaches zero, preventing it from going negative. Thus, the controller also operates in discontinuous mode when configured for Burst Mode operation.

Furthermore, in forced continuous operation or when clocked by an external clock source, the inductor current is allowed to reverse at light loads or under large transient conditions. Continuous operation has the advantage of lower output voltage ripple and results a higher quiescent current.

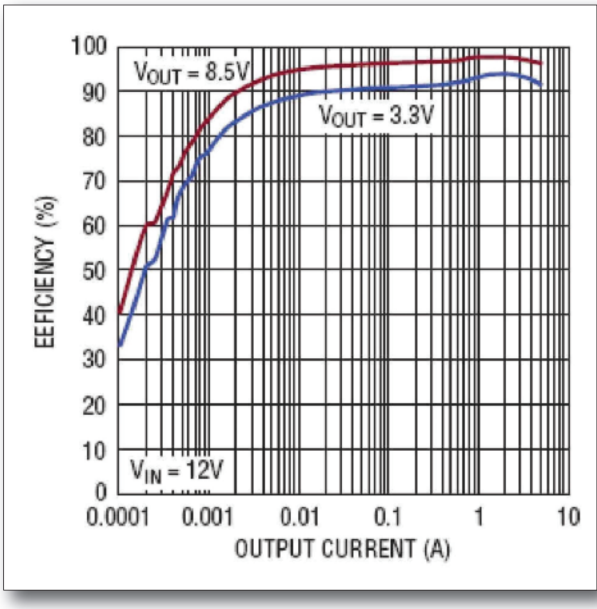

Figure 3: LTC3890 efficiency curves for 8.5 V and 3.3 V outputs from a 12 V input

Protection and efficiency

Fast accurate over-current limit protection is essential in a high voltage power supply. Because of the high voltage across the inductor when the output is shorted, the inductor of either using a sense resistor in series with the output or using the voltage drop across the output inductor to sense the output current. Either way, the output current is monitored continuously and provides the highest level of protection. Alternative designs might use the onresistance of the top or bottom MOSFET to sense the output current. However, this creates a time frame within the switching cycle where the controller is blind with regards to what the output current is and can cause a failure of the converter.

Switching losses are proportional to the square of the input voltage and these losses can dominate in high input voltage applications with an inadequate gate driver. The LTC3890/-1 has powerful 1.1 Ω on-board N-channel MOSFET gate drivers that minimize transition times and switching losses thereby maximizing the efficiency. In addition, it is capable of driving multiple MOSFET's in parallel for higher current applications.

The LTC3890 efficiency curves in Figure 3 are representative of the Figure 1 schematic with a 12 V input voltage. As shown, the 8.5 V output produces a very high efficiency at up to 98%. The 3.3 V is also over 90 % efficient. In addition, this design is still over 75 % efficient for each output with a 1 mA load, this due to its Burst Mode operation.

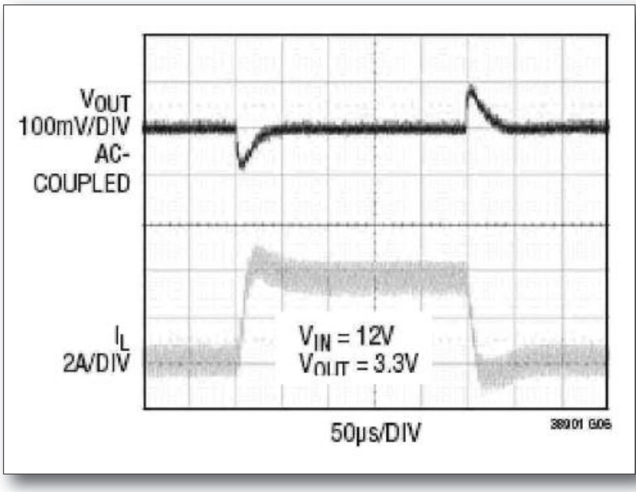

Figure 4: Transient response curve for a 4 A load step

Fast transient response

The LTC3890 uses a fast 25 MHz bandwidth operation amplifier for voltage feedback. The high bandwidth of the amplifier, along with high switching frequencies and low value inductors, allow for a very high gain crossover frequency. This allows the compensation network to be optimized for a very fast load transient response. Figure 4 illustrates the transient response of a 4 A step load on a 3.3 V output with a less than 100 mV deviation from nominal.

Conclusion

A 60V input capability make the described DC/DC converter well suited for automotive double battery, truck and heavy equipment applications. Its low quiescent current preserves battery energy during sleep mode allowing for increased battery run-time, a very useful feature in "always-on" bus systems. Furthermore, the device is easily applied to a wide variety of output voltages with up to a 24 V output voltage. Alternatively, its low minimum on-time enables the LTC3890 to be used in high step-down ratio applications. The ability to directly step-down input voltages from 60 V without requiring a bulky transformer, or external protection, makes for a cost effective, compact and reliable solution.