Synchronous Switching Regulator Controller Allows Inputs up to 100V

by Greg Dittmer

Introduction

Industrial, automotive, and telecom systems create harsh, unforgiving environments that demand robust electronic systems. In telecom systems the input rails can vary from 36V to 72V, with transients as high as 100V. In automotive systems the DC battery voltage may be 12V, 24V, or 42V with load dump conditions causing transients up to 60V.

Until now, no synchronous buck (or boost) control IC has been capable of operating at 100V, so solutions have been limited to low-side drive topologies that utilize expensive and bulky transformers. The LTC3703 is a 100V synchronous switching regulator controller that can directly step-down high input voltages using a single inductor, thus providing a compact high performance power supply for harsh environments.

Key Features for High Voltage Applications

The LTC3703 drives external N-channel MOSFETs using a constant frequency, voltage mode architecture. A high bandwidth error amplifier and patented line feed forward compensation provide very fast line and load transient response. Strong 1Ω gate drivers allow the LTC3703 to drive multiple MOSFETs for higher current applications. A precise internal 0.8V reference provides 1% DC accuracy. The operating frequency is user programmable from 100kHz to 600kHz and can also be synchronized to an external clock for noise-sensitive applications. Selectable Pulse Skip Mode operation improves light load efficiency. Current limit is user programmable and utilizes the voltage drop across the synchronous MOSFET to eliminate the need for a current sense resistor. A low minimum on-time allows high input-to-output step-down ratios such as 72V-to-3.3V at 200kHz. Shutdown mode reduces supply current to 50µA. An internal UVLO circuit guarantees that the driver supply voltage is high enough to sufficiently enhance the MOSFETs before enabling the controller (UV^+ = 8.7V, UV^- = 6.2V). The LTC3703 is available in a 16-pin narrow SSOP package or, if high voltage pin spacing is required, in a 28-pin SSOP package.

Strong Gate Drivers and Synchronous Drive for High Efficiency

Because switching losses are proportional to the square of input voltage, these losses can dominate in high voltage applications with inadequate gate drive. The LTC3703 has strong 1Ω gate drivers that minimize transition times and thus minimize switching losses, even when multiple MOSFETs are used for high current applications. Dual N-channel synchronous drives combined with the strong drivers results in power conversion efficiencies as high as 96%.

The LTC3703 provides a separate return pin for the bottom MOSFET driver (see Figure 1), allowing the use of a negative gate drive voltage in the off state. In high voltage switching converters, the switch node dv/dt can be many volts/ns, which pulls up on the gate of the bottom MOSFET through its Miller capacitance, especially in applications with multiple MOSFETs. If this Miller current, times the combined internal gate resistance of the MOSFET plus the driver resistance, exceeds the threshold of the MOSFET, shoot-through will occur, degrading efficiency. By using a negative supply on this pin, the gate can be pulled below ground when turning the bottom MOSFET off. This provides a few extra volts of margin before the gate reaches the turn-on threshold of the MOSFET.

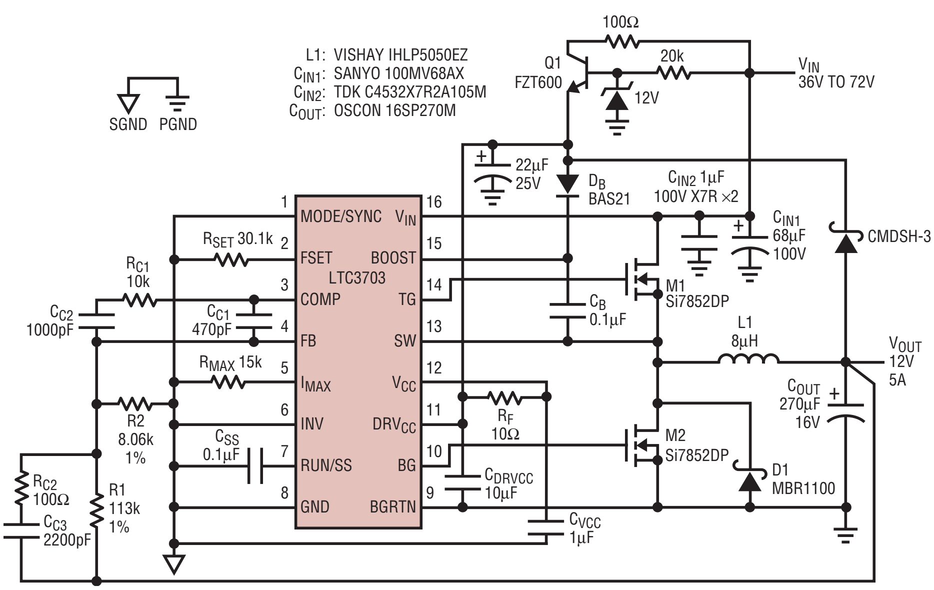

Figure 1. 36V–72V to 12V/5A synchronous step-down converter

Fast Load Transient Response

The LTC3703 uses a fast 25MHz op amp as an error amplifier. This allows the compensation network to be optimized for better load transient response. The high bandwidth of the amplifier, along with high switching frequencies and low value inductors,

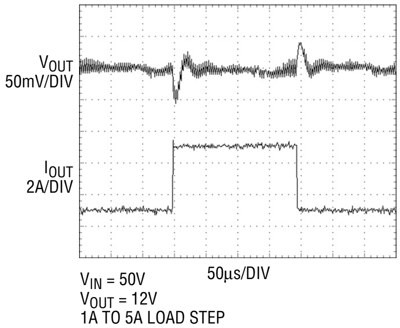

Figure 2. Load transient performance

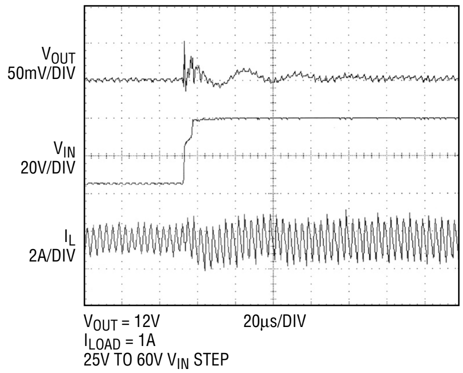

Figure 3. Line transient performance

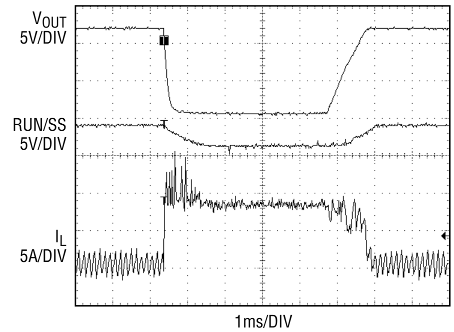

Figure 4. Short circuit performance

allow very high loop crossover frequencies. Figure 2 illustrates the transient response of a 50V input, 12V output power supply (1A to 5A load step).

Outstanding Line Transient Rejection

The LTC3703 achieves outstanding line transient response using a patented feedforward correction scheme. With this circuit the duty cycle is adjusted instantaneously to changes in input voltage without having to slew the COMP pin, thereby avoiding unacceptable overshoot or undershoot. It has the added advantage of making the DC loop gain independent of input voltage. Figure 3 shows how large transient steps at the input have little effect on the output voltage.

Overcurrent Protection

Current limiting is very important in a high voltage supply. Because of the high voltage across the inductor when the output is shorted, the inductor can saturate quickly causing excessive currents to flow. The LTC3703 has current limit protection that uses V_{DS}-sensing of the bottom-side MOSFET to eliminate the need for a current sense resistor. The current limit is user programmable with an external resistor on the I_{MAX} pin to set the maximum V_{DS} at which the current limit kicks in.

Current limit works by discharging the RUN/SS capacitor when the V_{DS} exceeds the programmed maximum. The voltage on RUN/SS controls the LTC3703's maximum duty cycle, so discharging this capacitor reduces the duty ratio until the output current equals the current limit. During the transient period while the capacitor is being discharged to the proper duty ratio, a cycle-by-cycle comparator guarantees that the peak inductor current remains in control by keeping the top MOSFET off when the V_{DS} of the bottom MOSFET exceeds the programmed limit by more than 50mV. The top MOSFET stays off until the inductor current decays below the limit ($V_{DS} < V_{IMAX}$). Figure 4 shows the inductor current waveforms during a short-circuit condition.

Application Examples

36V–72V to 12V/5A Synchronous Step-Down Regulator

The circuit shown in Figure 1 provides direct step-down conversion of a typical 36V-to-72V telecom input rail to 12V at 5A. With the 100V maximum rating of the LTC3703 and the MOSFETs, the circuit can handle input transients of up to 100V without requiring protection devices. The frequency is set to 250kHz to optimize efficiency and output ripple.

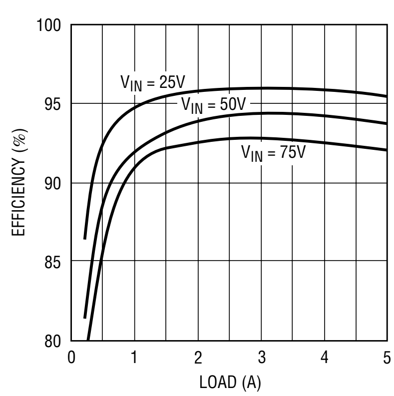

Figure 5. Efficiency of the circuit in Figure 1

Figure 5 shows a peak efficiency of almost 95% at 50V input and 93% at 75V input. The loop is compensated for a 50kHz crossover frequency which provides ~10µs response time to load transients. The IC and driver bias supply is derived from the 12V output when the output is in regulation, improving the efficiency. During startup or in a short circuit condition when the 12V output is not available, Q1 provides this IC bias voltage from the input supply.

For input voltages >30V, the practical choices for input capacitors are limited to ceramics and aluminum electrolytics. Ceramics have very low ESR but bulk capacitance is limited, while aluminum electrolytics have higher bulk capacitance but with much higher ESR. To meet RMS ripple and bulk capacitance requirements, using a combination of the two types is usually the best approach and also prevents excessive LC ringing at the input (by lowering the high Q of the ceramics) when the supply is connected.

Another consideration in high voltage converters such as this one is the boost diode. Low leakage and fast reverse recovery is essential. In order to limit power dissipation when this diode is reverse biased at high voltage, ultra-fast reverse recovery silicon diodes such as the BAS21 are recommended.

48V-to-12V 360W Isolated Power Supply

The circuit shown in Figure 6 can be used to generate a loosely regulated 12V, 30A isolated power supply for a

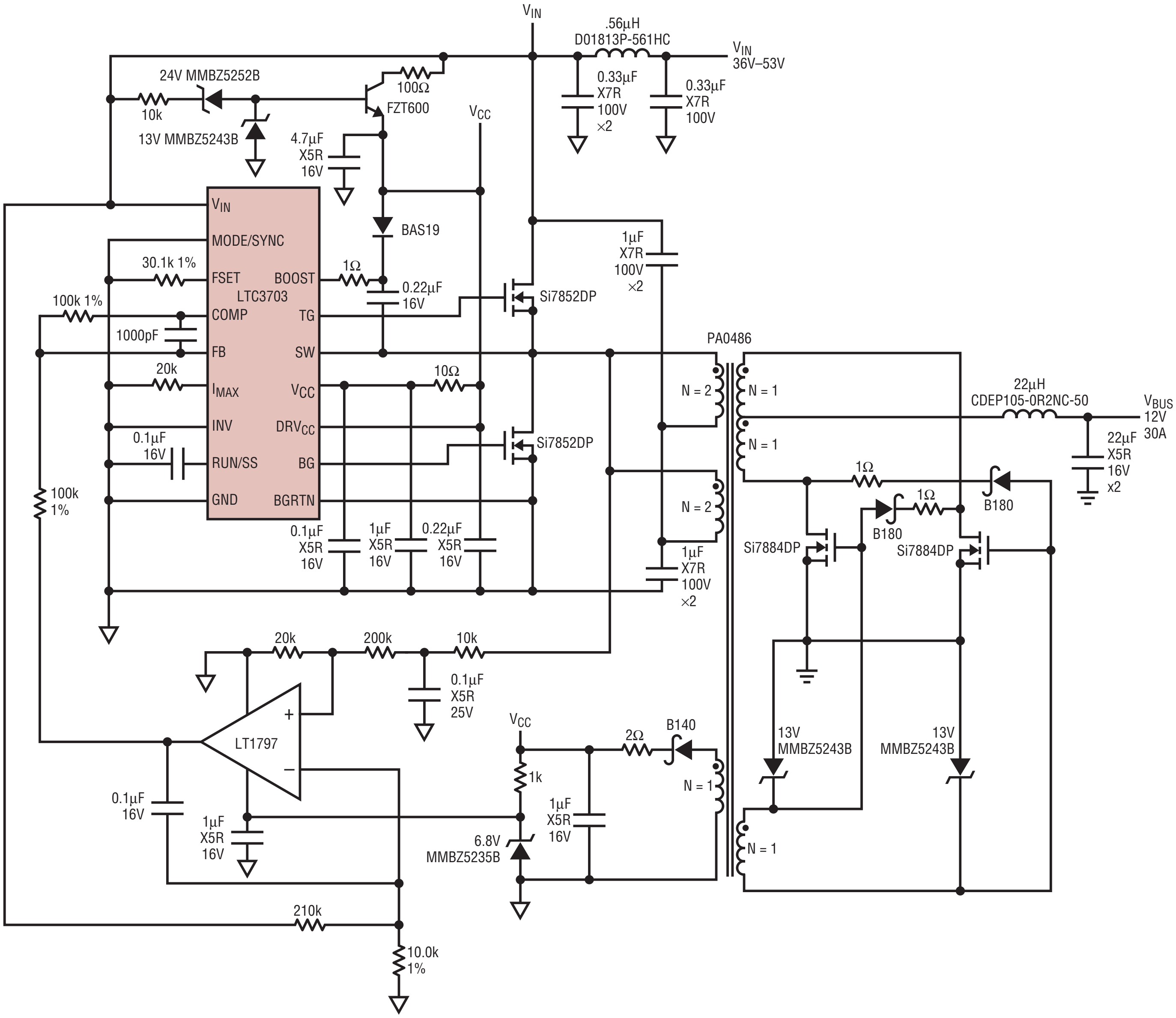

Figure 6. 48-to-12V 360W isolated power supply

360W intermediate bus that can then be stepped down with additional buck regulators to generate multiple low voltage high current outputs. Using this LTC3703-based DC/DC push-pull converter allows one to replace a conventional power module at a lower cost, smaller size and with superior efficiency. The push-pull topology has the advantage over forward/flyback topology of less voltage stress on the MOSFETs, allowing the use of a lower voltage, lower $R_{DS(ON)}$ device to improve efficiency.

The LTC3703 runs open loop using the LT1797 amplifier to force 50% duty cycle by driving the FB input of the LTC3703. The 2-to-1 transformer step-down ratio thus generates an output voltage equal to $0.25 \bullet V_{IN}$. Running open loop in this fashion eliminates the need for complex feedback circuitry

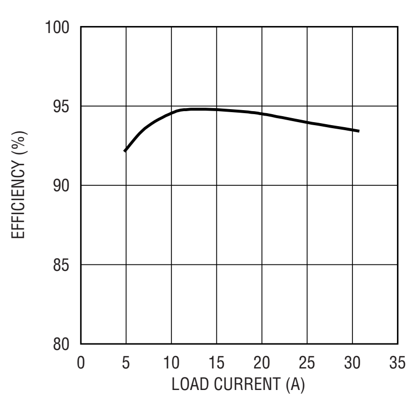

Figure 7. Efficiency of Figure 6

over the isolation barrier. The second stage step-down regulators can then convert this intermediate bus voltage to more tightly regulated outputs. Figure 7 shows that an efficiency of almost 94% can be achieved at 30A.

High Efficiency 12V-to-24V 5A Synchronous Step-Up Regulator

Synchronous boost converters have a significant advantage over non-synchronous boost converters in higher current applications due to the low power dissipation of the synchronous MOSFET compared to that of the diode in a non-synchronous converter. The high power dissipation in the diode requires a much larger package,

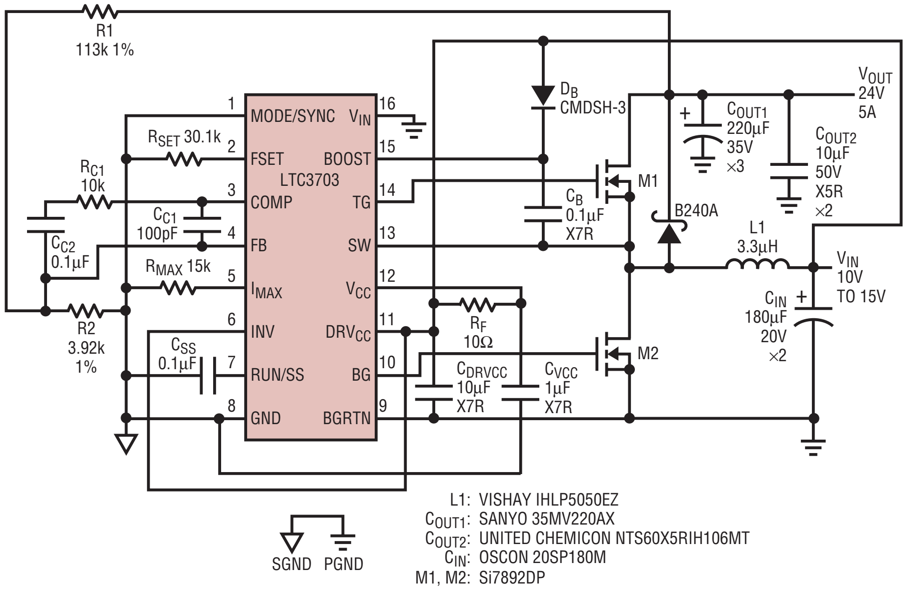

Figure 8. 12-to-24V, 5A synchronous boost converter

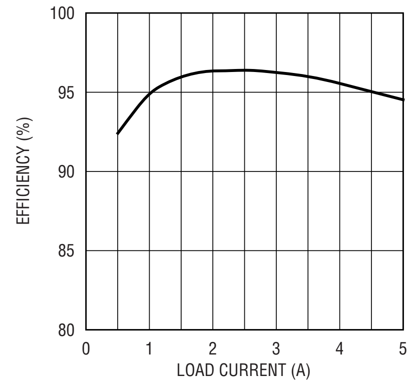

Figure 9. Efficiency of Figure 8's circuit

e.g. D^2PAK, than the small SO8-size package required for the synchronous MOSFET to carry the same current.

Figure 8 shows the LTC3703 implemented as a synchronous 12V-to-24V/5A step-up converter that achieves a peak efficiency over 96%. The LTC3703 is set to operate as a synchronous boost converter by simply connecting the INV pin to greater than 2V. In boost mode, the BG pin becomes the main switch and TG, the synchronous switch; and aside from this phase inversion, its operation is similar to the buck mode operation. In boost mode, the LTC3703 can produce output voltages as high as 80V.

Conclusion

The LTC3703 provides a set of features that make it an ideal foundation for a high input voltage, high performance, high efficiency power supplies. Those features include: 100V capability, synchronous N-channel drive, strong gate drivers, outstanding line and load regulation, overcurrent protection, and 50µA shutdown current. It is particularly well suited to the harsh environments presented by automotive, telecom, avionics and industrial applications.

Its ability to directly step-down input voltages from up to 100V without requiring bulky transformers, or external protection, makes for low cost and compact solutions.

The LTC3703 is also versatile—easily applied to a wide variety of output voltages and power levels—mainly due its low minimum on-time (which allows low duty ratios), programmable frequency, programmable current limit, step-up or step-down capability, and package options.

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useful because a switching regulator without soft-start can trip a current limited input supply during startup.

SLIC Power Supply with Soft-Start

SLICs (Subscriber Line Interface Circuits) require many voltages to operate. The LT1941 can supply all of them. Figure 9 shows a typical SLIC. The two step-down switching regulators provide the 3.3V and 1.8V logic supplies. The inverting switching regulator generates both the –21.6V and –65V outputs using a charge pump configuration. The PGOOD3 pin indicates if the –21.6V output is in regulation. Figure 10 shows the output voltages and input current during startup. Soft-start helps limit the peak input current.

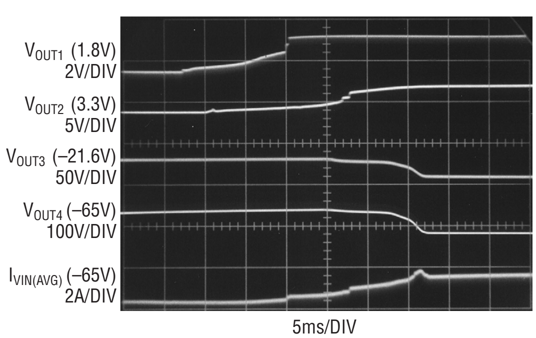

Figure 10. SLIC start-up waveforms with soft-start

Conclusion

The LT1941 is a monolithic triple output switching regulator that has the features and size to fit in a wide variety of applications. The high switching frequency allows the use of small external components, minimizing the total solution size. An internal op amp allows the part to directly regulate negative voltages. The wide input range of 3.5V to 25V and soft-start feature allow the LT1941 to regulate a broad array of power sources. Power good indicators and 2-phase switching help the LT1941 to work with almost any system.