

# High Voltage Step-Down Synchronous Controller Offers Single-Supply Operation, Current Mode Control, and 100 $\mu$ A Burst Mode Operation

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## Introduction

As more features and functions are packed into electronics packages, efficient step-down DC/DC conversion circuits that can handle high input voltages at substantial load currents are increasingly necessary. This is especially true for distributed power systems that have high power point of load requirements. The LT3800 is a feature-packed high voltage synchronous step-down controller that simplifies meeting these high power requirements.

The LT3800 is the core of single-supply DC/DC converter solutions that require few external components and maintain high-efficiencies over wide load ranges. Burst Mode operation and a reverse inductor current inhibit feature maximize efficiencies during light-load and no-load conditions, making the LT3800 ideal for use in applications with supply maintenance requirements. Maintenance requirements are common in automotive applications where a low current standby mode is required in addition to high power operating conditions. Both Burst Mode operation and reverse inductor current inhibit can be disabled if desired.

The LT3800 contains an integrated start-up regulator that powers the IC directly from the input supply for true single-supply operation. The IC uses a 200kHz fixed-frequency current mode architecture and operates with input voltages from 4V to 60V. A precision shutdown pin threshold allows for easy integration of input supply under-voltage lockout (UVLO) using a simple resistor divider, and quiescent currents are reduced to less than 10 $\mu$ A while the IC is in shutdown. Converter output voltage is programmed using

a resistor divider, and the IC includes a 1% accurate internal reference. The LT3800 also incorporates a programmable  $\Delta V/\Delta t$  soft-start that directly controls the rising rate of the converter output voltage at start-up.

The LT3800 employs continuous high-side inductor current sensing using an external sense resistor. Inductor

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***"The LT3800 is a versatile platform on which to build high-voltage DC/DC converter solutions that use few external components and maintain high-efficiencies over wide load ranges."***

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current is limited to the same value in both positive and negative directions, protecting the converter from both source and sink over-current events, and current limit is unaffected by duty-cycle.

A LT3800 DC/DC converter uses standard-level N-channel MOSFETs for main and synchronous switches, employing a bootstrapped supply rail for the main switch MOSFET driver. High current switch-drivers allow the use of low  $R_{DS(ON)}$  MOSFETs without the need for gate drive buffers.

The LT3800 is available in a small-footprint thermally-enhanced 16-lead TSSOP package.

## Onboard Start-Up Regulator

The LT3800 eliminates the need for an external regulator or a slow-charge hysteretic start scheme through integration of an 8V linear regulator. This regulator generates  $V_{CC}$ , the lo-

cal supply that runs the IC, from the converter input supply,  $V_{IN}$ .

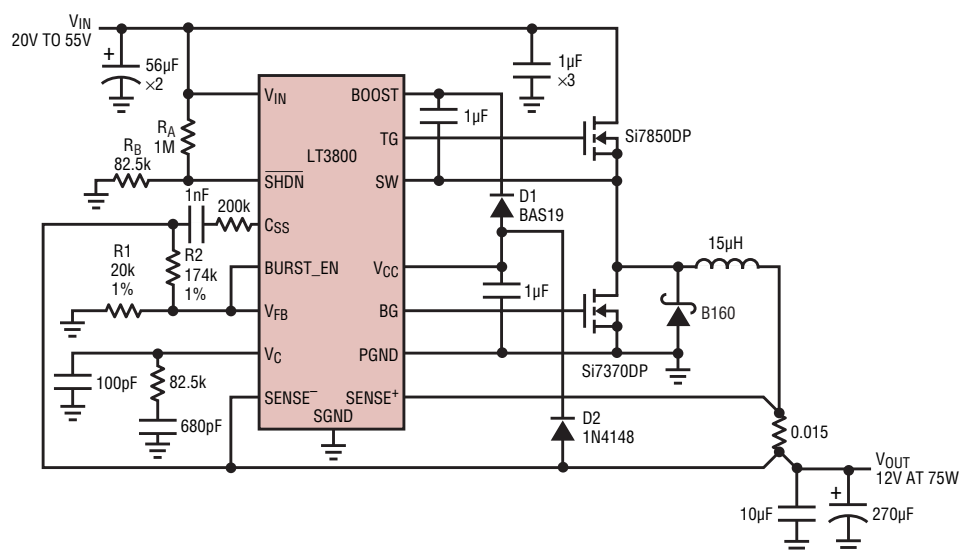
The onboard regulator can operate the IC continuously, provided the input voltage and/or FET gate charge currents are low enough to avoid excessive power dissipation in the part. Forcing the  $V_{CC}$  pin above its 8V regulated voltage allows use of externally derived power to minimize power dissipation in the IC, reducing thermal considerations. Using the onboard regulator for start-up then deriving power for  $V_{CC}$  from the converter output maximizes conversion efficiencies and is common practice.

The LT3800 has a start-up requirement of  $V_{IN} \geq 7.5V$ . This assures that the onboard regulator has ample headroom to bring the  $V_{CC}$  pin above its UVLO threshold of 6.25V. If  $V_{CC}$  is maintained using an external source, such as the converter output, the LT3800 can continue to operate with  $V_{IN}$  as low as 4V.

## Burst Mode Operation

The LT3800 supports low current Burst Mode operation to maximize efficiency during low-load and no-load conditions. Burst Mode operation is enabled by shorting the BURST\_EN pin to SGND, and can be disabled by shorting BURST\_EN to either  $V_{FB}$  or  $V_{CC}$ .

When the peak switch current is below 15% of the programmed current limit, Burst Mode function is engaged. During the Burst interval, switching ceases and all internal IC functions are disabled, which reduces  $V_{IN}$  pin current to 20 $\mu$ A and reduces  $V_{CC}$  current to 80 $\mu$ A. If no external drive is provided for  $V_{CC}$ , all  $V_{CC}$  bias currents originate from the  $V_{IN}$  pin, giving a

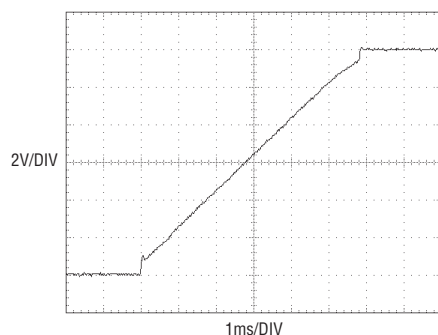


**Figure 1.** This 20V-55V to 12V 75W DC/DC converter features reverse current inhibit and input under-voltage lockout.

total  $V_{IN}$  current of 100µA. An internal negative-excursion clamp on the  $V_C$  pin is set 100mV below the switch disable threshold, which limits the negative excursion of the pin voltage during the Burst interval. This clamp minimizes converter output ripple during Burst Mode operation.

## Reverse Current Inhibit

The LT3800 contains a reverse-current inhibit feature, which maximizes efficiency during light load conditions. This mode of operation prevents negative inductor current, and is sometimes called “pulse-skipping” mode. This feature is always enabled with Burst Mode operation when the BURST\_EN pin is connected to ground. The reverse-current inhibit feature can also be enabled without Burst Mode by connecting the BURST\_EN pin to the  $V_{FB}$  pin, which is the configuration used for the DC/DC converter shown in Figure 1.



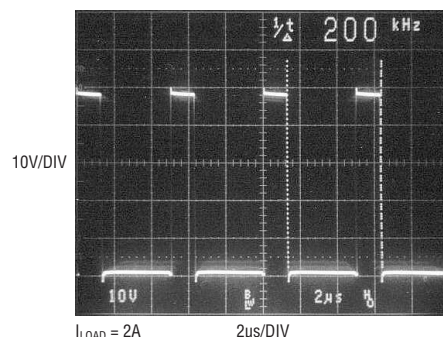
**Figure 3.** Output soft-start waveform for the DC/DC converter in Figure 1

When reverse-current inhibit is enabled, the LT3800 sense amplifier detects inductor currents approaching zero and disables the synchronous switch for the remainder of that switch cycle, simulating the light-load switching characteristics of a non-synchronous converter. Reverse-current inhibit reduces losses associated with inductor ripple currents, improving conversion efficiencies with loads that are less than half of the peak inductor ripple current.

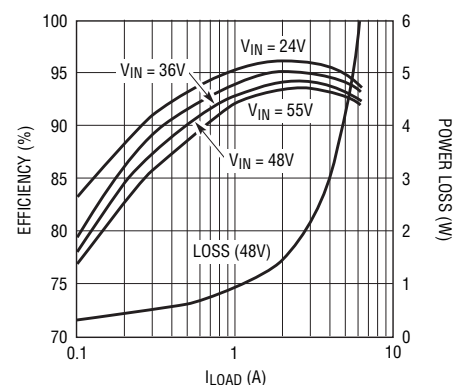
## Precision Shutdown Threshold

The LT3800 has a precision-threshold shutdown feature, which allows use of the  $\overline{\text{SHDN}}$  pin for analog monitoring applications, as well as logic-level controlled applications.

Input supply UVLO for sequencing or start-up over-current protection is easily achieved by driving the  $\overline{\text{SHDN}}$  pin with a resistor divider from the



**Figure 4.** Switching waveform for the DC/DC converter in Figure 1

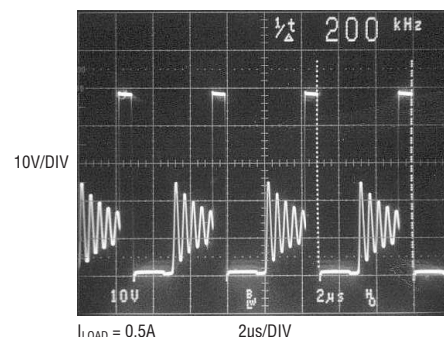


**Figure 2.** Converter efficiency and power loss for the DC/DC converter in Figure 1

$V_{IN}$  supply. The resistor divider is set such that the divider output puts 1.35V onto the  $\overline{\text{SHDN}}$  pin when  $V_{IN}$  is at the desired UVLO rising threshold voltage. The  $\overline{\text{SHDN}}$  pin has 120mV of input hysteresis, which allows the IC to resist almost 10% of input supply droop before disabling the converter. The  $\overline{\text{SHDN}}$  pin has a secondary threshold of 0.5V, below which the IC operates in an ultralow-current shutdown mode with  $I_{VIN} < 10\mu\text{A}$ . The shutdown function can be disabled by connecting the  $\overline{\text{SHDN}}$  pin to  $V_{IN}$  through a large value pull-up resistor.

## Continuous High-Side Inductor Current Sensing

The LT3800 uses a wide common-mode input range current sense amplifier that operates from 0V to 36V. This current sense amplifier provides continuous inductor current sensing via an external sense resistor. A continuous inductor current sensing scheme does not require blanking intervals or a minimum on-time to monitor current, common to schemes



**Figure 5.** Light load switching waveform for the converter in Figure 1

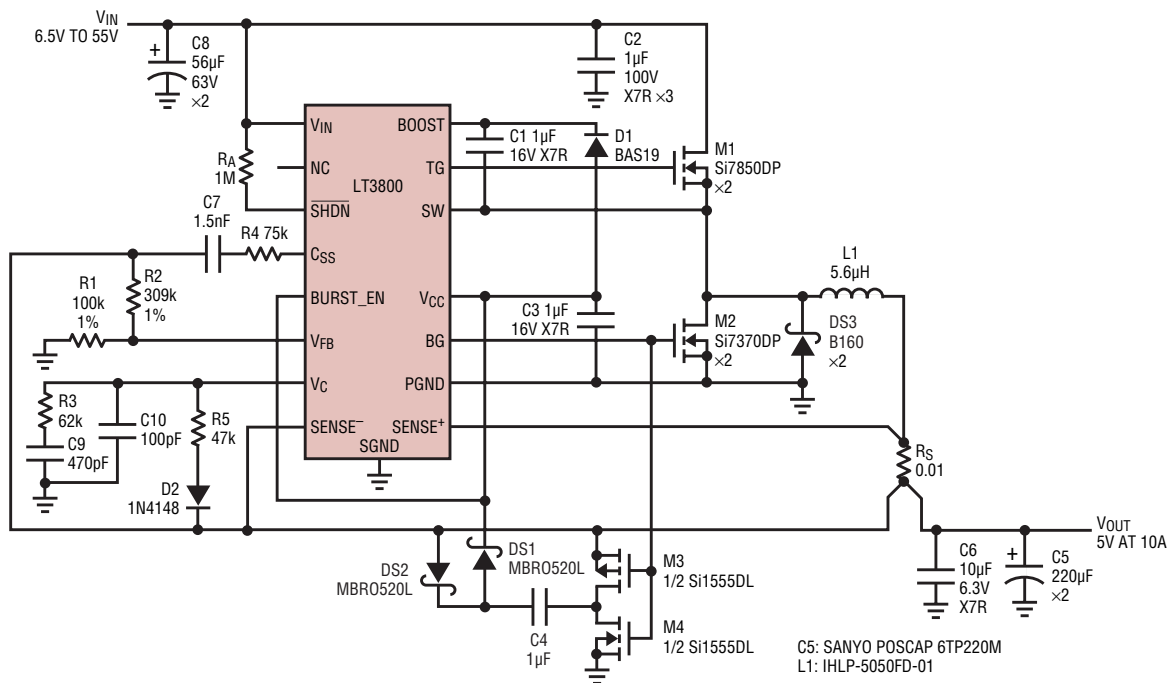


Figure 6. This 6.5V-55V to 5V 10A DC/DC converter features charge pump doubler  $V_{CC}$  refresh and current limit foldback.

that sense switch current. The sense amplifier monitors inductor current independent of switch state, so the main switch is not enabled unless the inductor current is below what corresponds to the  $V_C$  pin voltage. This turn-on decision is performed at the start of each cycle, and individual switch cycles will be skipped should an over-current condition occur. This eliminates many of the potential over-current dangers caused by minimum on-time requirements, such as those that can occur during startup, short-circuit, or abrupt input transients.

## Soft Start

The LT3800 employs an adaptive soft-start scheme that directly controls

the DC/DC converter output voltage during start-up. The rising rate of this voltage is programmed with a capacitor connected to the converter output. The capacitor value is chosen such that the desired  $\Delta V/\Delta t$  of the output results in a  $2\mu A$  charge current through the capacitor. The soft start function maintains this desired output rising rate up to 95% of the regulated output voltage, when the soft-start circuitry is disabled. The soft-start function is automatically re-enabled if the converter output droops below 70% regulation, so converter recovery is graceful from a short duration shutdown or an output short-circuit condition.

## 20V-55V to 12V, 75W DC/DC Converter

Figure 1 shows a 20V-55V to 12V 75W converter, configured for reverse current inhibit operation and input UVLO. Power for the IC is obtained directly from  $V_{IN}$  through the LT3800's internal  $V_{CC}$  regulator at start-up. The main switch bootstrapped supply is refreshed via D1 from the 8V generated on the  $V_{CC}$  pin. When the converter output comes up, D2 pulls  $V_{CC}$  above regulation, disabling the internal regulator and providing a current path from the converter output to

the  $V_{CC}$  pin. With the  $V_{CC}$  pin driven from the converter output,  $V_{IN}$  current is reduced to  $20\mu A$ . Using output-generated power in high input voltage converters results in significant reduction of IC power dissipation, which increases overall conversion efficiency, but is critical to reduce IC thermal considerations. Figure 2 shows the conversion efficiency and power loss for this DC/DC converter.

Output voltage is programmed using R1 and R2, and the output is in regulation when the voltage at the  $V_{FB}$  pin is 1.231V.  $V_{IN}$  UVLO is programmed via  $R_A$  and  $R_B$ , enabling the LT3800 at 90% of the specified low end of the  $V_{IN}$  range, or 18V, which corresponds to 1.35V on the  $\overline{SHDN}$  pin. The  $\overline{SHDN}$  input has 120mV of hysteresis, so the converter will be disabled if  $V_{IN}$  drops below 16V.

The LT3800 soft-start function controls the rising slope of the output at startup such that the  $\Delta V/\Delta t$  current through C8 is  $2\mu A$ , so the converter output will rise at a controlled rate of  $2\mu A/1nF$ , or 2V/mS. Figure 3 shows the soft-start ramp.

The BURST\_EN pin is tied to the  $V_{FB}$  pin to disable Burst Mode operation while keeping reverse current inhibit operation enabled. Figure 4 shows continuous current operation when

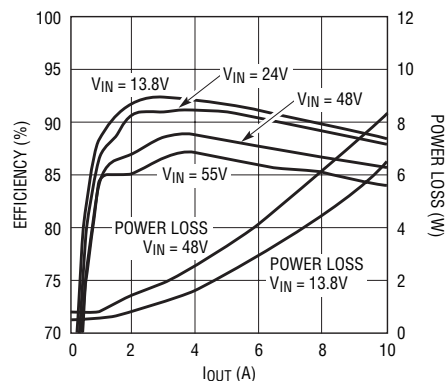
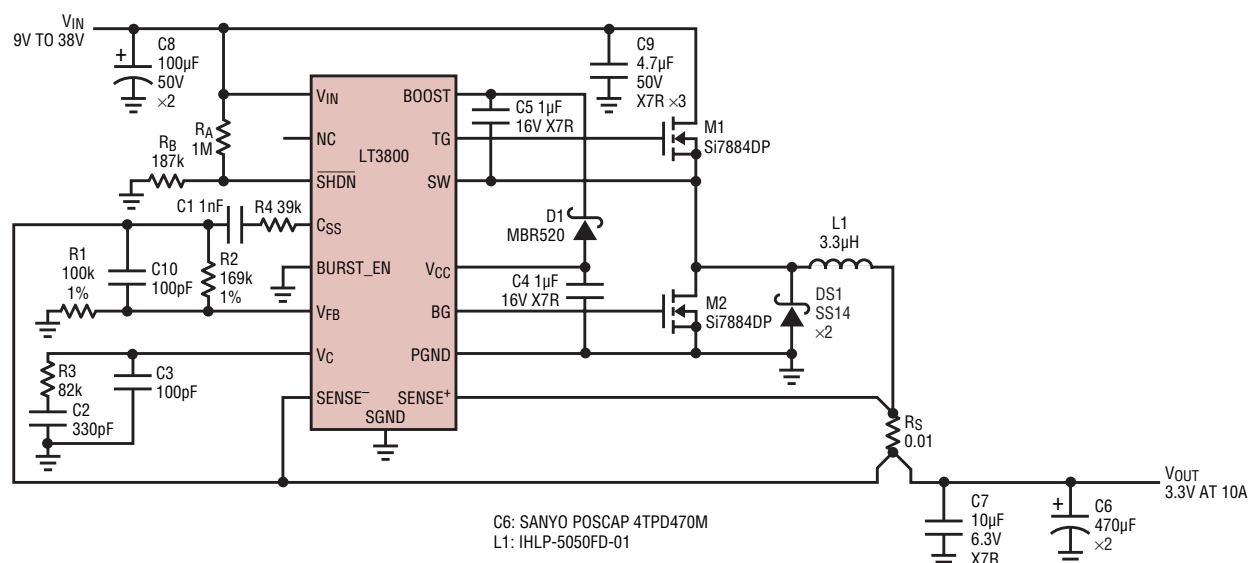


Figure 7. Efficiency and power loss for the DC/DC converter in Figure 6



**Figure 8. A 9V-38V to 3.3V 10A DC/DC converter with  $V_{IN}$  UVLO**

the load is greater than half of the peak ripple current. With lighter loads, during the switch off interval, as the inductor current approaches zero, the synchronous switch is disabled. The resulting discontinuous switching waveform is shown in Figure 5.

## 6.5V-55V to 5V, 10A DC/DC Converter

In LT3800 converter applications with output voltages in the 9V to 20V range, back-feeding  $V_{CC}$  from the converter output is trivial, accomplished by connecting a diode from the output to the  $V_{CC}$  pins. Outputs lower than 9V require step-up techniques to generate back-feed voltages greater than the

$V_{CC}$  regulated output. The 6.5V-55V to 5V 10A DC/DC converter shown in Figure 6 uses an external Si1555DL MOSFET pair (M3, M4) to create a charge pump doubler that steps up the output voltage. This simple doubler uses the synchronous gate drive (BG pin) as a control signal.

This converter also uses an external current limit foldback scheme. The foldback circuit consists of a single 1N4148 diode (D2) and a 47k resistor (R5). The current limit foldback circuit provides additional control during the first few switch cycles of start-up, and provides reduced short-circuit output current. When the output is at ground, the diode and resistor clamp the VC pin to a value that corresponds to 25% of the programmed maximum current. This circuit is only active with  $V_{OUT}$  close to ground, and becomes completely disabled once the output voltage rises above 10% regulation. Figure 7 shows the conversion efficiency and power loss for this converter.

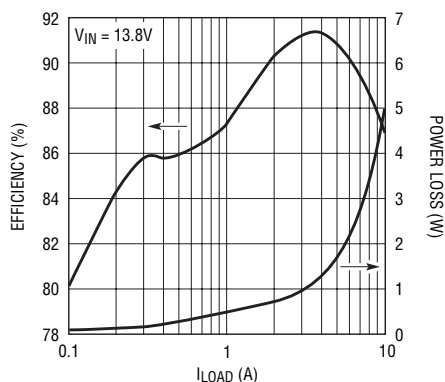
## 9V-38V to 3.3V, 10A DC/DC Converter

In some DC/DC converter applications, the typical input voltage is moderate, but the converter must

withstand or operate through intermittent high-voltage excursions. This is typical of automotive battery-voltage applications, where high voltage line transients, such as during a load-dump condition, must be accommodated. The 9V-38V to 3.3V 10A DC/DC converter with  $V_{IN}$  UVLO shown in Figure 8 is an automotive application that typically operates with  $V_{IN} = 13.8V$ , but can operate through  $V_{IN}$  excursions from 9V up to 38V. Because the typical line voltage is moderate, the LT3800 can operate directly from the internal  $V_{CC}$  regulator without excessive power dissipation, eliminating the need for a step-up scheme to regenerate  $V_{CC}$  from the converter output. Figure 9 shows the conversion efficiency and power loss for this circuit.

## Conclusion

The LT3800 is a versatile platform on which to build high voltage DC/DC converter solutions that use few external components and maintain high efficiencies over wide load ranges. The integrated start-up regulator facilitates true single-supply operation and Burst Mode function enables efficient solutions to power-supply maintenance requirements.



**Figure 9. Efficiency and power loss for the DC/DC converter in Figure 8**

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