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2-Phase, Non-Synchronous Boost Controller Simplifies Design of High Voltage, High Current Supplies

by Muthu Subramanian and Tick Houk

Introduction

Due to an increasing need for high power step-up power supplies in automotive and industrial applications, Linear Technology has recently introduced the LTC3862 family of 2-phase, single output non-synchronous boost DC/DC controllers. The LTC3862 provides a flexible, high performance step-up controller in three convenient package options: GN24, 5mm × 5mm 24-pin exposed pad QFN and 24-pin exposed pad TSSOP. The LTC3862 is optimized for power MOSFETs that require 5V gate drive, whereas the LTC3862-1 is designed for 10V gate drive MOSFETs.

The LTC3862 utilizes a fixed frequency, peak current mode control topology to drive ground-referenced power MOSFETs, each with a current sense resistor in its source. The use of a precision transconductance (g_m) error amplifier allows for easy loop compensation and facilitates the parallel connection of several ICs in multiphase applications. The operating frequency can be programmed from 75kHz to 500kHz using a single resistor, and a phase lock loop allows the switching frequency to be synchronized to an external clock over a 50kHz to 650kHz range.

The LTC3862 is a versatile control IC optimized for a wide variety of step-up DC/DC converter applications. This makes it easy to optimize efficiency, size and weight of the power supply, while keeping component and manufacturing costs low.

A 24V, 5A Car Audio Power Supply

Today's high end car audio systems require significant power to drive upwards of seven speakers inside the passenger compartment. High frequency speakers such as tweeters are generally very efficient, but low frequency drivers such as subwoofers require substantial power to achieve high volume. In addition to the need for high power, the car audio system should be immune to changes in the battery voltage. These requirements can be met through the use of a step-up converter for the power

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LTC3862, continued from page 1

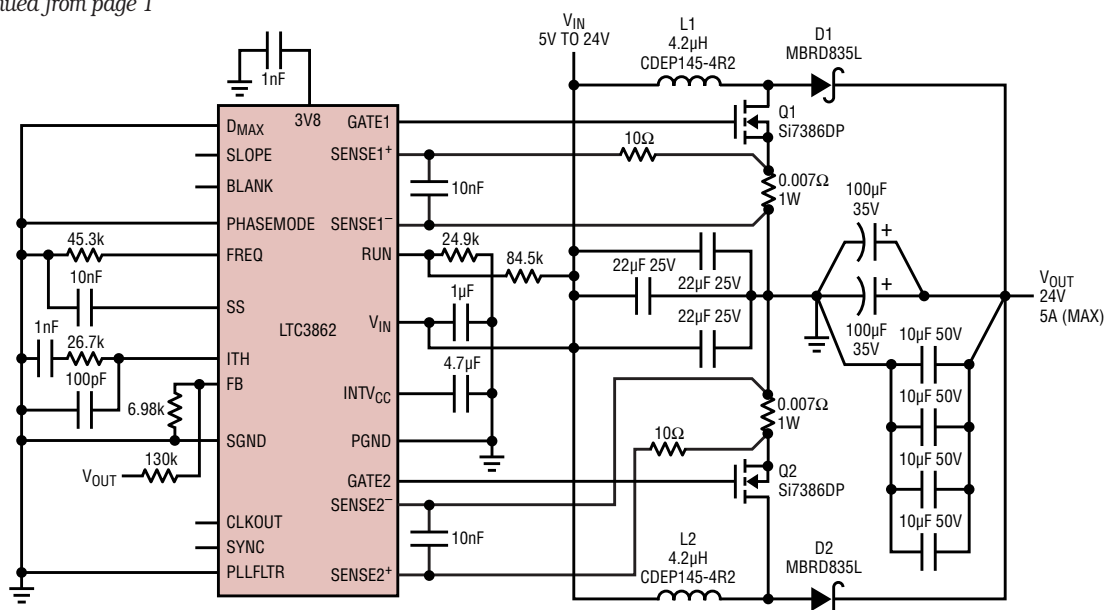


Figure 1. A 120W 2-phase, 24V/5A output car audio power supply

amplifiers. Figure 1 shows a 2-phase, 24V/5A output audio power supply that operates from a car battery, and Figure 2 shows the efficiency curve for this converter.

A 2-phase design with an operating frequency of 300kHz allows the use of significantly smaller output capacitors and inductors than a single-phase design. To keep the output ripple voltage below 60mV peak-to-peak and satisfy the RMS ripple current demand, a combination of two 100µF, 35V aluminum electrolytic capacitors are connected in parallel with four 10µF, 50V ceramic capacitors. The 4.2µH, 10.6A inductor (CDEP145-4R2) from Sumida Inductors is chosen for its high

A 2-phase design with an operating frequency of 300kHz allows the use of significantly smaller output capacitors and inductors than a single-phase design.

Also, the output current of this converter can easily be scaled by adding additional power stages and controllers, without modifying the basic design.

saturation current rating and surface mount package design.

The MOSFET is a Vishay Si7386DP, which has a maximum $R_{DS(ON)}$ of 7mΩ at $V_{GS} = 10V$ and 9.5mΩ at $V_{GS} = 4.5V$. The 35V, 8A Schottky from On Semiconductor (MBRD835L) offers surface mount capability and small size. It should be noted that the output current of a converter such as this can easily be scaled by adding additional power stages and controllers, without modifying the basic design.

Excellent Channel-to-Channel Current Matching Ensures a Balanced Thermal Design

In order to provide the best channel-to-channel inductor current matching, the LTC3862 is designed to make the transfer function from the output of the error amplifier (the ITH pin) to the current comparator inputs (SENSE+ and SENSE- pins) as accurate as possible. The specification for the maximum current sense threshold is 75mV, and the channel-to-channel ($V_{SENSE1} - V_{SENSE2}$) mismatch specification is $\pm 10mV$, over the $-40^{\circ}C$ to $150^{\circ}C$ temperature range. This excellent matching ensures balanced inductor currents and a thermally stable design, even with multiple regulators daisy-chained together. Figure 3 shows how

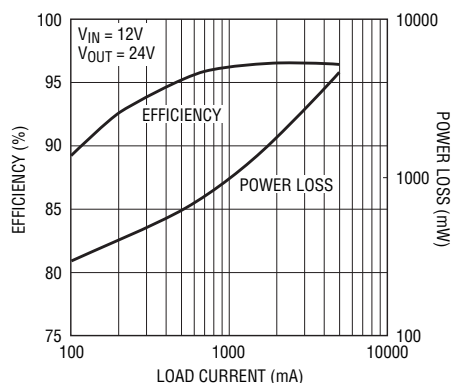


Figure 2. Efficiency and power loss vs load current for the 120W car audio power supply

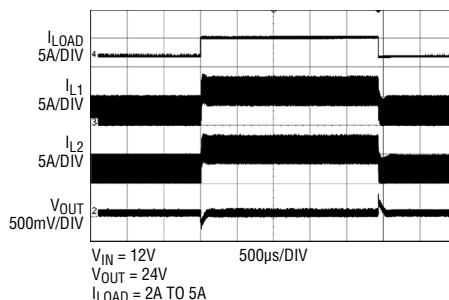


Figure 3. Inductor current waveforms in load step show accurate current matching between load sharing channels

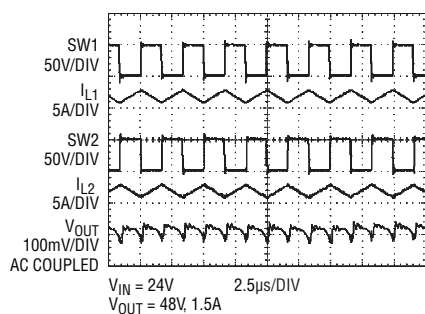


Figure 4. Inductor current and switch node voltage waveforms at heavy load, continuous conduction mode (CCM)

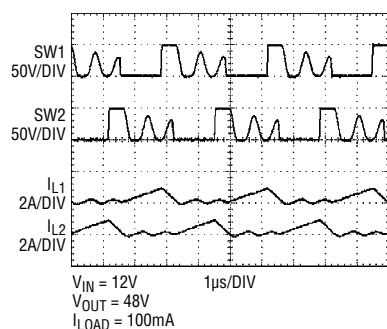


Figure 5. Inductor and switch node voltage waveforms at light load, discontinuous conduction mode (DCM)

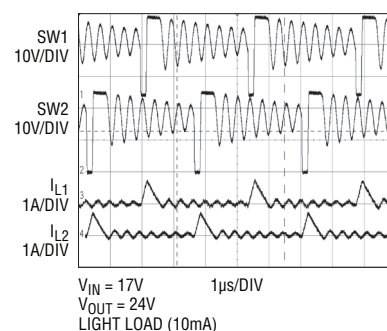


Figure 6. Inductor and switch node voltage waveforms at light load (pulse-skipping)

well matched the inductor currents are for the car audio power supply during a load step.

Constant Frequency Operation over a Wide Load Current Range

Constant frequency operation eases the task of input and output filter design, and prevents a power supply from becoming audible at light load. At heavy load, the inductor currents are generally continuous (CCM), as shown in Figure 4. At light load, the inductor current will go discontinuous (DCM), as shown in Figure 5. When the load current drops below what can be supported by the minimum on-time of the converter (approximately 180ns), the controller will begin to skip cycles in order to maintain output regulation,

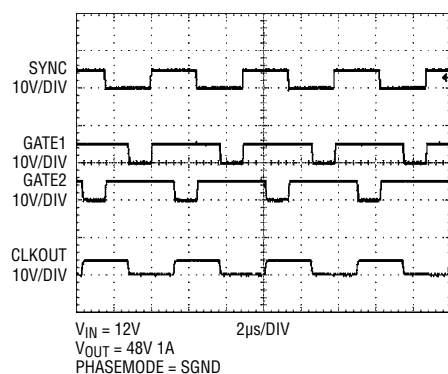


Figure 7. Synchronizing the LTC3862 to an external clock using the phase lock loop

as shown in Figure 6. This is a normal operating condition that doesn't cause any problems in the system, as long as the peak inductor current is low.

In general, the lower the load current at the onset of pulse-skipping,

the better, since constant frequency operation is maintained down to this threshold. In Figure 6 the onset of pulse-skipping occurs at a relatively low 0.2% of the maximum load current.

For systems where synchronization to an external clock is required, the LTC3862 contains a phase lock loop (PLL). Figure 7 illustrates the switching waveforms with an external sync signal applied to the SYNC pin.

Strong Gate Drivers and a High Current Internal LDO Complete the Package

In high output voltage systems, switching losses in the power MOSFETs can sometimes exceed the conduction losses. In order to reduce switching losses as much as possible, the LTC3862 incorporates strong gate drivers. The PMOS pull-up transistor has a typical $R_{DS(ON)}$ of 2.1Ω, and the NMOS pull-down transistor has a typical $R_{DS(ON)}$ of 0.7Ω. In addition to reducing switching losses, these strong gate drivers allow two power MOSFETs to be connected in paral-

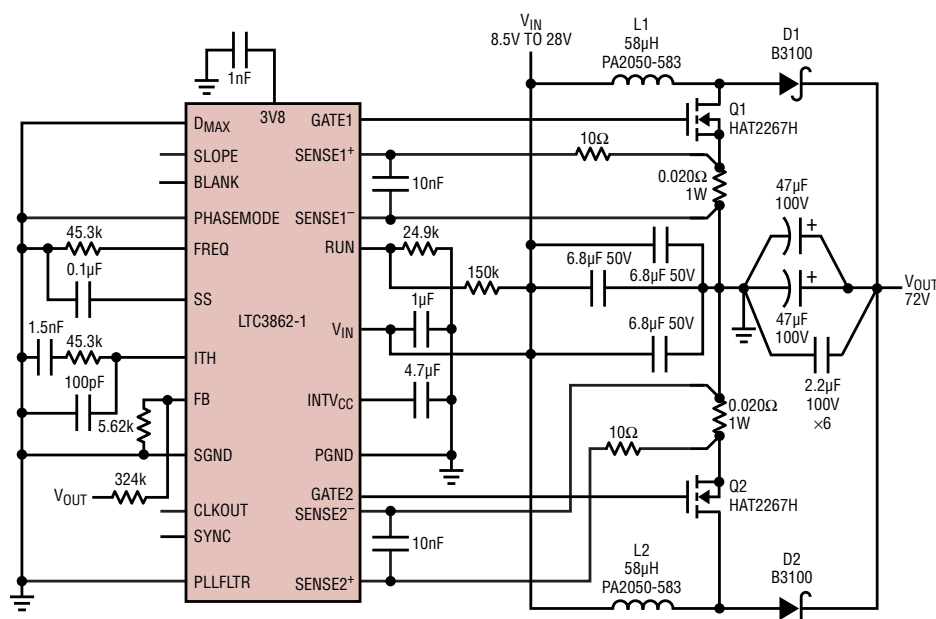


Figure 8. An 8.5V-28V input, 72V/1.5A output low emissions diesel fuel injector actuator supply

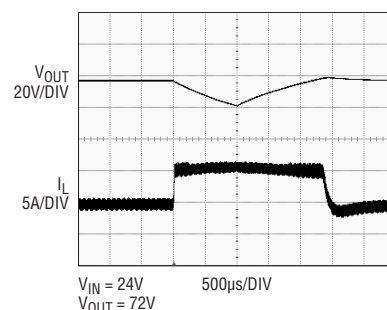


Figure 9. Load step waveforms for diesel fuel injector actuator supply

lel for each channel in high current applications.

In order to simplify operation in single-supply systems, the LTC3862 includes a 5V low dropout regulator (LDO) that can support output currents up to 50mA. The use of a PMOS output transistor ensures that the full supply voltage is available for driving the power MOSFETs under low supply conditions, such as during automotive cold cranking. An undervoltage lockout circuit detects when the LDO output voltage falls below 3.3V and shuts off the gate drivers, thereby

protecting the power MOSFETs from switching at low V_{GS} .

The LTC3862 is capable of operation over a 4V to 36V input voltage range, making it suitable for a wide variety of boost applications.

Lower Emissions Diesel Fuel Injection: A 8.5V–28V Input, 72V, 1.5A Output Boost

Tomorrow's low emissions diesel fuel injection systems require more precise and faster actuation of the fuel injectors than do their gasoline counterparts. Stepping up the voltage

of the system is an easy way to achieve fast actuation by increasing di/dt in the actuator, since the energy stored on a capacitor is $CV^2/2$. Boosting the car battery voltage from 13V to 72V significantly increases the di/dt , enabling faster actuation. The actuation of the injector typically discharges the supply capacitor by 10V–20V, after which the boost converter recharges the output cap to 72V. Figure 8 illustrates this 8.5V to 28V input, 72V/1.5A output 2-phase boost converter. Figure 9 illustrates the load step for a simulated injector.

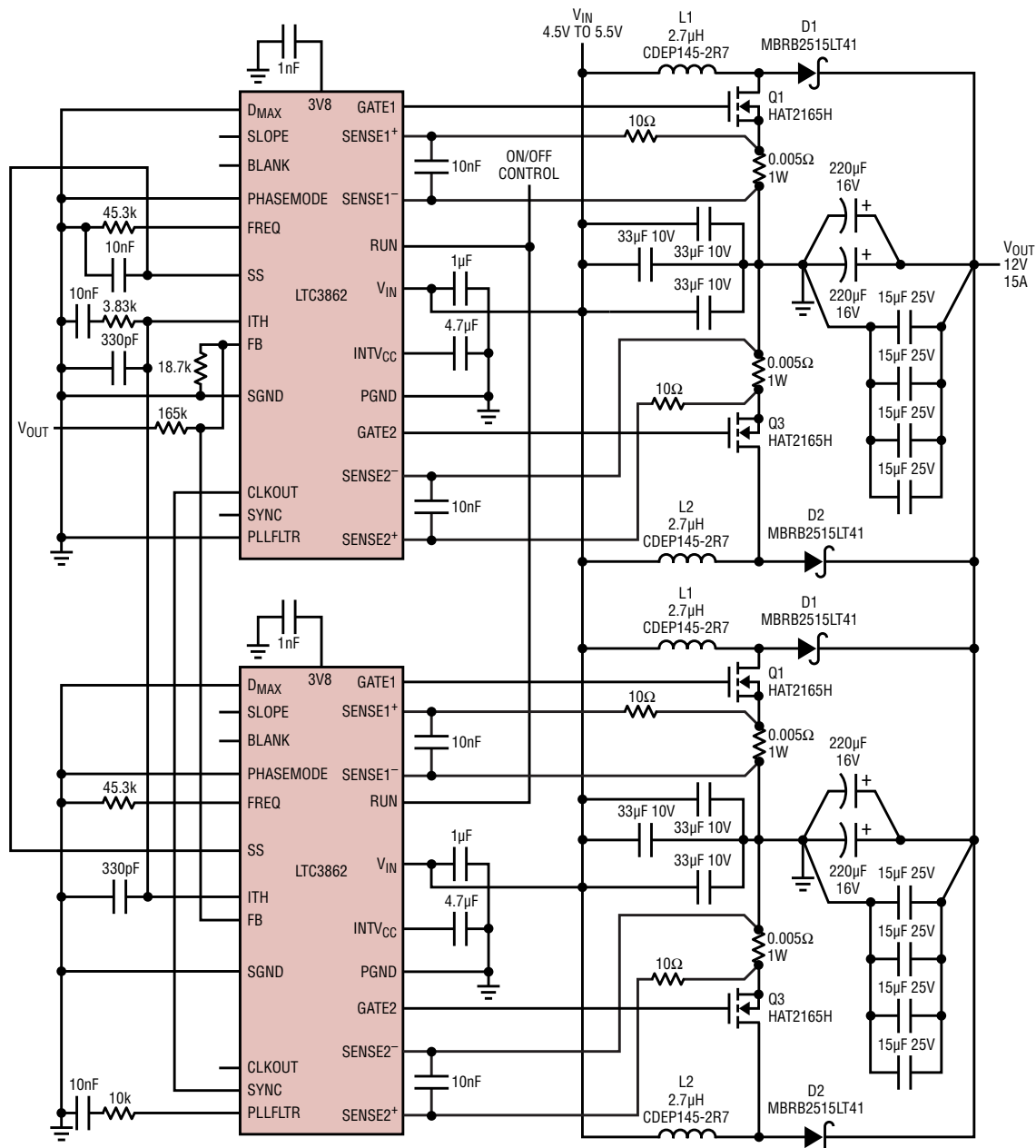


Figure 10. A 4-phase, 12V/15A industrial power supply that operates from a 5V input

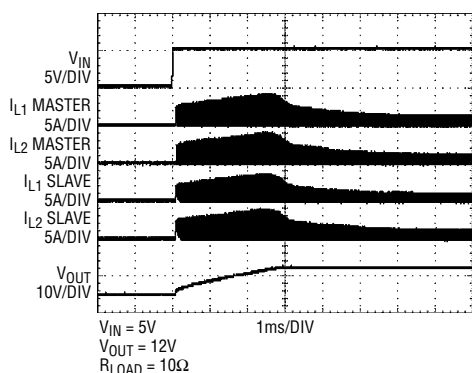


Figure 11. Power supply start-up waveforms for 4-phase, 12V/15A industrial power supply

This power supply operates at a switching frequency of 300kHz in order to reduce switching losses and uses a 57.8μH, 5A inductor (PA2050-583). An 80V Renesas HAT2267H MOSFET was chosen for this application, in order to provide sufficient guardband above the 72V output. The MOSFET has a maximum $R_{DS(ON)}$ of 13mΩ at $V_{GS} = 10V$. The Diodes Inc surface mount diode (B3100) was chosen for the 3A output current level. A combination of a two 47μF, 100V electrolytic and six 2.2μF, 100V low ESR ceramic capacitors are used to reduce the output ripple to below 100mV peak-to-peak and satisfy the RMS ripple current requirement.

A 4-Phase, 5V Input, 12V/15A Output, Industrial Power Supply

Figure 10 illustrates an industrial power supply that converts a 5V input to a 12V output at up to 15A of load current. The use of four phases greatly eases the task of choosing the power components, and reduces output ripple significantly. Figure 11

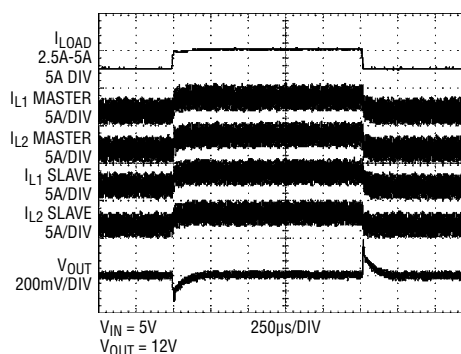


Figure 12. Load step waveforms for 4-phase, 12V/15A industrial power supply

In high output voltage systems, switching losses in the power MOSFETs can sometimes exceed the conduction losses. In order to reduce switching losses as much as possible, the LTC3862 incorporates strong gate drivers. The PMOS pull-up transistor has a typical $R_{DS(ON)}$ of 2.1Ω, and the NMOS pull-down transistor has a typical $R_{DS(ON)}$ of 0.7Ω. In addition to reducing switching losses, these strong gate drivers allow two power MOSFETs to be connected in parallel for high current applications.

shows the start-up waveforms for this converter. Figure 12 shows the load step waveforms.

Multiphase operation is made possible using the PHASEMODE, SYNC and CLKOUT pins. The PHASEMODE pin controls the phase relationship between GATE 1 and GATE 2, as well as between GATE 1 and CLKOUT. The CLKOUT pin of a master controller is connected to the SYNC pin of a slave, where the phase lock loop ensures proper synchronization. The PHASEMODE pin can be used to program 2-, 3-, 4-, 6- and 12-phase operation.

48V/5A Demo Circuit

The DC1286A demonstration circuit board is designed for high power applications, providing a 48V/5A output using the GN24 package option of the LTC3862 or LTC3862-1. The 6-layer PCB design ensures proper routing of the SENSE lines, and exhibits minimal jitter even at 50% duty cycle. Jumpers are provided to easily change the BLANK time, PHASE, maximum duty, and SLOPE compensation. There is an optional onboard 12V V_{IN} supply to power the IC, and the component footprint provides flexibility to use various inductors, MOSFETs and diodes.

Conclusion

The LTC3862 is a versatile control IC optimized for a wide variety of step-up DC/DC converter applications. Its flexible, high performance operation and three convenient package options make it possible to optimize efficiency, size and weight of the power supply, while keeping the total component and manufacturing costs low.

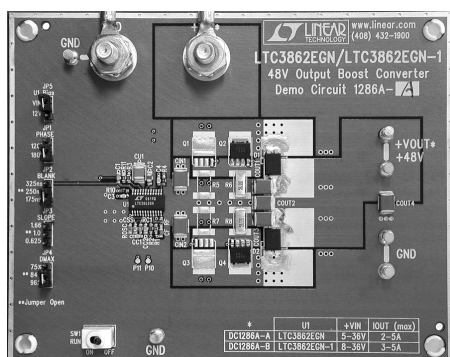


Figure 13. 48V/5A output, high power demonstration circuit

