Automotive Applications Benefit from Multiphase Boosters

Multiphase operation results in lower component stresses, smaller input and output capacitance, smaller solution size, better thermal management, and lower output noise. With its programmability up to 12 phases using multiple daisy-chained controllers, the new LTC3862 serves the needs of step-up power supplies from 100 to 1000W in automotive fuel injection systems and high power audio amplifiers. The reduced ripple currents and multiphase operation reduces EMI and provides higher efficiency, faster transient response, and a wider selection of off-the-shelf components and increase power density when compared to single phase alternatives. **Bruce Haug and Tick Houk, Linear Technology, Milpitas, USA**

High power step-down DC/DC converters have long benefited from multiphase operation. But all the advantages of multiphase operation, such as reduced input and output ripple currents, lower output noise and lower component stresses, can also be realised in step-up applications. Many of the controllers used in step-down applications can also be used in step-up applications and generally have two phases, which may not provide enough output power or have the ability to keep the phase currents balanced. They also usually need extra support components, like gate drivers, extra bias voltage and an external error amplifier to complete the circuit.

Until recently, most high power step-up converters have utilised non-optimised solutions due to the lack of an available multiphase boost controller. The most common non-synchronous two-phase step-up converter solution has been to use the top-side drivers of a two-phase synchronous step-down controller configured to drive two low-side power MOSFETs 180° out-of-phase. Another solution has been to use two or more single-phase step-up controllers and an external clock circuit to achieve the required channel-to-channel phase relationship. Other non-optimised solutions have used either push-pull or dual interleaved forward controllers in a non-isolated step-up configuration. However, all of these solutions suffer from significant drawbacks which limit their utilisation in many of today's demanding applications.

In the automotive environment, the next generation of low emissions diesel fuel injection systems requires up to 2A of output current at an output voltage in the 70 to 110V range, and delivered from a 12V battery that can vary from 9 to 28V. This input-to-output voltage conversion requires a boost converter capable of greater than 92% duty cycle with constant frequency operation.

Furthermore, high power car audio amplifiers often need a main supply rail in the 25 to 35V range with the ability to supply peak power levels approaching 1000W, making multiphase operation essential. By splitting the power stage into

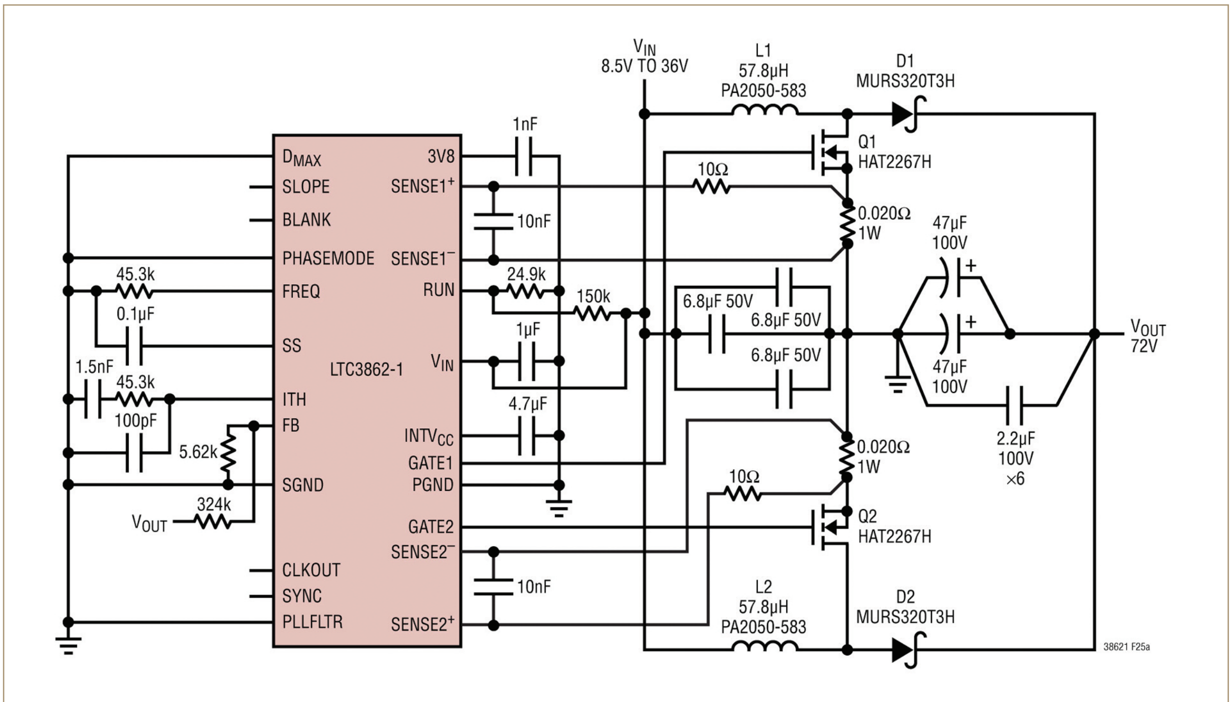

Figure 1: **A two-phase, 72V output, low emissions automotive fuel injection boost converter using the LTC3862-1**

PHASEMODE	CH-1 to CH-2 PHASE	CH-1 to CLKOUT PHASE	APPLICATION
SGND	180°	90°	2-Phase, 4-Phase
Float	180°	60°	6-Phase
3V8	120°	240°	3-Phase

Table 1: **Programming the phase relationship between channels**

multiple paralleled phases, thermal stress is reduced on the power components, thereby reducing output voltage ripple and noise, allowing the use of smaller output capacitors, and improving system efficiency.

As power densities continue to rise, multiphase boost designs become a necessary option to keep input currents manageable, increase efficiency and increase power density. With mandates on automotive energy savings more common, a multiphase converter topology may be the only way to achieve these design objectives. A two-phase or higher phase converter built around LTC3862, can demonstrate the benefits of this type of approach.

A multiphase solution

The LTC3862 is a non-synchronous multiphase controller capable of operating in boost, SEPIC and flyback topologies. This controller utilises a constant frequency, peak current mode control scheme with its two power stages operating 180° out-of-phase. Each power stage is comprised of a single inductor, MOSFET, Schottky diode and current sense resistor. The two phases are balanced closely with a tight current limit threshold and a highly accurate transfer function from the ITH pin (the output of the error amplifier) to the current comparator sense inputs, both from channel-to-channel and chip-to-chip. Because of this, the peak inductor current matching is kept accurate, forcing a balanced current in multiphase applications.

In a two-phase converter, only one IC is required, and the two output stages are driven 180° out-of-phase. In a three-phase converter, two chips are needed (two channels from the master and one channel from the slave) and the output stages are driven 120° out-of-phase. Similarly, a four-phase converter utilises two ICs with each channel running 90° out-of-phase. And so on, until a 12 phase application, where six chips would be used, with each channel operating 30° out-of-phase. By splitting the current into multiple power paths, conduction losses can be reduced and thermal stresses can be balanced between a larger number of components and over a larger area on the board, and output noise can be significantly reduced. Conversely, for a given output voltage ripple, multiphase operation will result in a smaller total output capacitance, which is especially important in high voltage applications where the voltage coefficient of the output capacitor typically reduces the effective capacitance.

The LTC3862 contains two PMOS output stage low dropout (LDO) voltage regulators, one for the powerful on-board gate drivers (which contain 2.1Ω PMOS source transistors and 0.7Ω NMOS sink transistors) and one LDO for the low voltage analog and digital control circuitry. Low dropout operation allows the input voltage to dip to a lower value before circuit operation is affected. This is especially important in automotive applications, where the cold cranking of an engine can result in a battery voltage droop to as low as 4V. The LTC3862 provides a 5V gate drive for logic level MOSFETs and the LTC3862-1 provides a 10V gate drive normally required for higher output voltage applications.

A low emissions diesel fuel injection power supply

Figure 1 illustrates a boost converter designed for low emissions diesel fuel injection systems. This converter operates over a wide input voltage range to accommodate the variation of an automotive battery, from a cold crank condition to a double battery connection for jump starts. Because of the wide input voltage range (8.5 to 36V), the converter must be able to operate at very high duty cycles and still maintain constant frequency operation. The LTC3862 has a minimum on-time of approximately 180ns and a maximum duty cycle of 96%, with both of these parameters being user programmable. The operating frequency can be programmed from 75 to 500kHz using a single resistor, and a phase lock loop can be used to synchronise the operating frequency to an external clock source. For the example, the power MOSFETs used in Figure 1 are the HAT2267H from Renesas, a 57μH inductor with a saturation current rating of 5A, and a total output capacitance of only 107μF is necessary. The output capacitance consists of two 47μF aluminum electrolytic bulk capacitors connected in parallel with six low ESR 2.2μF ceramic capacitors, in order to meet the output voltage ripple and RMS current requirements. This configuration also limits the output voltage ripple to only 500mV.

This circuit operates with a peak efficiency of 96% at an input voltage of 32V. Because a single-ended boost converter regulates the current in the source of the low-side switch, the maximum current that can be delivered to the load is a function of the input voltage. As a result, this converter is capable of delivering 0.5A to the load at an input of 8.5V, 1.5A at an input of 24V, and 2A at an input of 32 to 36V.

The LTC3862 features two pins, CLKOUT and PHASEMODE that allow multiple ICs to be daisy-chained together for higher current multiphase applications. For a three- or four-phase design, the CLKOUT signal of the master controller is connected to the SYNC input of the slave controller in order to synchronize additional power stages for a single high current output. The PHASEMODE pin is used to adjust the phase relationship between channel 1 and CLKOUT, as summarised in Table 1. The phases are calculated relative to the zero degrees, defined as the rising edge of the GATE1 output. In a six-phase application, the CLKOUT pin of the master controller connects to the SYNC input of the 2nd controller and the CLKOUT pin of the 2nd

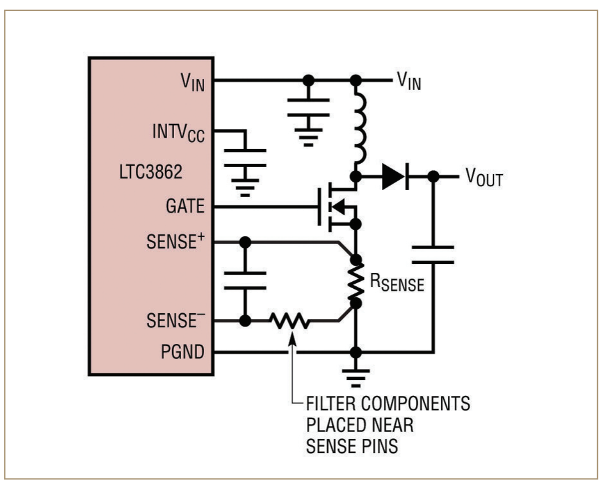

Figure 2: **LTC 3862 current sense circuit**

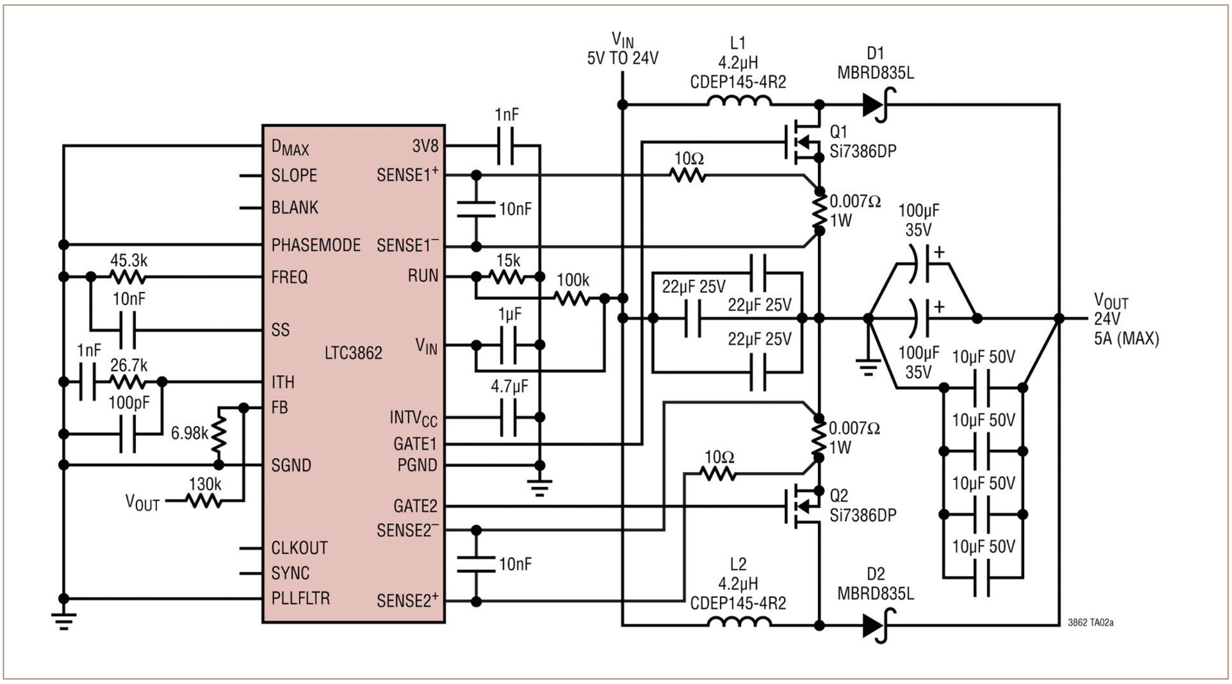

Figure 3: A 12V input, 24V/5A output two-phase car audio power supply using the LTC3862

controller connects to the SYNC input of the 3rd controller.

Additional features

The LTC3862 error amplifier is a transconductance amplifier, meaning that it has high DC gain and high output impedance. This style of error amplifier greatly eases the task of implementing a multi-phase solution, because the amplifiers from two or more controllers can be connected in parallel. In a multiphase application requiring more than one IC, all of the FB pins should be connected together and all of the ITH pins should be connected together. The composite transconductance of the error amplifier is simply the sum of the number of ICs connected together, multiplied by the 660µs of each amplifier. This parallel connection of error amplifiers is not possible with control ICs that use a true operational amplifier, since this amplifier type has a very low output impedance.

In addition to using parallelable error amplifiers, the transfer function from the ITH pin to the current sense comparators is very accurate, in order to provide the best channel-to-channel and chip-to-chip current sense threshold matching possible. This phase-to-phase current matching is especially important in high current applications, where resistive losses are proportional to the square of the current. Minimising the mismatch between channels results in a balanced thermal design, which prevents hot spots on the PCB and possible thermal runaway.

The LTC3862 has a maximum current sense threshold of each phase of 75mV, which allows for a relatively lower power sense resistor, reducing the circuit size, increasing efficiency and eliminating the need for a current sense transformer. It also includes leading edge blanking for the current sense inputs, so an external RC filter is not required. Nevertheless, some users may benefit from adding an external filter, as shown in Figure 2. If external RC filters are used on the current sense inputs, the filter components should be placed as close as possible to the SENSE pins, and the connections to the sense resistor should run parallel to each other and kelvin-connect to the resistor in order to avoid parasitic IR drops. The SENSE+ and SENSE- pins are high impedance inputs to the CMOS current comparators for each channel.

Programmable blanking

The Blank pin on the LTC3862 allows the user to program the amount of leading edge blanking at the SENSE pins. The purpose of leading edge blanking is to filter out noise on the SENSE at the leading edge of the power MOSFETs at turn-on. During the turn-on of the power MOSFET the gate drive current, the discharge of any parasitic capacitance on the SW node, the recovery of the boost diode charge, and the parasitic series inductance in the high di/dt path all contribute to overshoot and high frequency noise that could cause false-tripping of the current comparator. Providing a means to program the blank time allows users to optimise the SENSE pin filtering for several applications and can be set to a minimum on-time of 180, 260 or 340ns.

An audio amplifier boost converter supply

Figure 3 illustrates a two-phase car audio power supply that operates from a 5 to 24V input and produces a 24V/5A output. The wide input voltage range covers an automotive input voltage range, and the efficiency curves are also shown reaching up to 96.5%. This circuit can be easily extended to three-, four-, six- or 12-phase operation for higher power applications, with minimal modifications to the basic design. This multiphase boost converter protects the load from mild overload conditions by imposing a current limit on each phase (boost converters are typically not short-circuit proof due to the diode and inductor connection from input to output). Audio applications have short-duration peak power demands that are much higher than the average output power. Therefore, the current limit must be set high enough to satisfy these peak power requirements.

In order to maintain constant frequency operation and a low output ripple voltage, a single-ended boost converter is required to turn off the power MOSFET switch every cycle for some minimum amount of time. This off-time allows the transfer of energy from the inductor to the output capacitor and load. Having a high maximum duty cycle is desirable, especially in low V_{IN} to high V_{OUT} applications. The maximum duty cycle for the LTC3862 is 96% with the DMAX pin connected to ground. For other topologies, such as a non-isolated flyback converter, it is desirable to limit the maximum duty cycle in order to balance the volt-sec of the transformer. The LTC3862 has a maximum duty cycle that is user-programmable. By floating the DMAX pin, the duty cycle is limited to 84%. Connecting the DMAX pin to the 3V8 supply pin limits the duty cycle to 75%.