Dual Battery Require Bi-Directional DC/DC Controllers

With fuel economy regulations tightening and autonomous-driving capability with connectivity proliferating, the old-fashioned 12 V automotive electrical system has reached its usable power limit. Furthermore, a vast increase in automotive electronic systems, coupled with related demands on power, has created an array of new engineering opportunities and challenges. As a result, the 12 V lead-acid battery automotive system with its 3 kW power limit has been supplemented. A newly proposed automotive standard, LV148, combines a secondary 48 V bus with the existing 12 V system. **Bruce Haug, Senior Product Marketing Engineer, Linear Technology, Milpitas, USA**

The 48 V rail includes an integrated starter generator (ISG) or belt start generator, a 48 V lithium-ion battery and a bi-directional DC/DC converter for delivery of up to 10 kW of available energy from the 48 V and 12 V batteries combined. This technology is targeted at conventional internal combustion automobiles, as well as hybrid electric and mild hybrid vehicles, as auto manufacturers strive to meet increasingly stringent carbon dioxide emissions targets.

More power required

Typically, the 12 V bus will continue to power the ignition, lighting, infotainment and audio systems. The 48 V bus will supply active chassis systems, air conditioning compressors, adjustable suspensions, electric superchargers/turbos and also support regenerative braking. The decision to use an additional 48 V bus, which is expected be available across production model ranges soon, can also support starting the engine, which would make stop-start operation smoother. Moreover, the higher voltage means smaller cable cross-sections are needed which reduces cable size and weight. Today's high-end vehicles can have more than 4 kilometers of wiring. Vehicles will become more like PCs, creating the potential for a host of plug-and-play devices. On average, commuters spend 9 % of their day in an automobile. Thus, introducing multimedia and telematics into vehicles can potentially increase productivity as well as providing additional entertainment.

The key components for autonomous driving include a computer, cameras, radar and LiDAR sensors, all of which require additional energy. This additional energy is required to improve vehicles' connectivity, not just to the Internet, but to other vehicles and buildings, traffic signals and other structures in the environment. Furthermore, drivetrain components, power steering, oil and water pumps will switch over from mechanical to electrical power.

The future for the 48 V battery system is much more near-term than the fully autonomous car, although many automotive suppliers see strong demand for the technological building blocks ultimately needed for self-driving vehicles over the next few years. According to some auto manufactures, a 48 V based electrical system results in a 10-15 % gain in fuel economy for internal combustion engine vehicles, thereby reducing CO_2 emissions. Moreover, future vehicles that use a dual 48 V/12 V system will allow engineers to integrate electrical booster technology that operates independently of the engine load, thereby helping to improve acceleration performance. Already in its advanced development phase, the compressor is placed between the induction system and intercooler and uses 48 V to spin-up the turbos.

Nevertheless, the implementation of an additional 48 V supply network into vehicles translates into major design challenges for suppliers across the value chain. In particular, providers of semiconductors and Electronic Control Units (ECUs) will be affected – they will need to adjust their operational range to the higher voltage and in part re-design their products. Correspondingly, the manufactures of DC/DC converters will need to develop and introduce specialized ICs to enable this high power transfer.

It is clear that there is a need for a bi-directional step-down and step-up DC/DC converter that goes between the 12 V and 48 V batteries. This DC/DC converter can be used to charge either battery and allows both batteries to supply current to the same load if required. Most of the early 48 V/12 V dual battery DC/DC converter designs use different power components to step-up and step-down the voltage. However, the recently released LTC3871 bi-directional DC/DC controller from Linear Technology uses the same external power components for the step-up conversion as it does for stepping down the voltage.

A single bi-directional IC solution

The LTC3871 is a 100V/30V bi-directional two phase synchronous buck or boost controller which provides bi-directional DC/DC control and battery charging between the 12 V and 48 V board nets. It operates in buck mode from the 48 V bus to the 12 V bus or in boost mode from 12 V to 48 V. Either mode is configured on demand via an applied control signal. Up to 12 phases can be paralleled and clocked out-of-phase to minimize input and output filtering requirements for high current applications (up to 250 A). Its current-mode architecture provides current matching between phases when paralleled. Up to 5 kW can be supplied in buck mode or in boost mode with a 12-phase design.

When starting the car, or when additional power is required, the device allows both batteries to supply energy simultaneously by converting energy from one board net to the other. Up to 97 % efficiency can be achieved and the on-chip current programming loop regulates the maximum current that can be delivered to the load in either direction. Four control loops, two for current and two for voltage, enable control of voltage and current on either the 48 V or 12 V board nets.

The LTC3871 operates at a user selectable fixed frequency between 60 kHz and 475 kHz, and can be synchronized to an external clock over the same range. The user can select from continuous operation or pulse skipping during light loads. Additional features include overload and short-circuit protection, independent loop

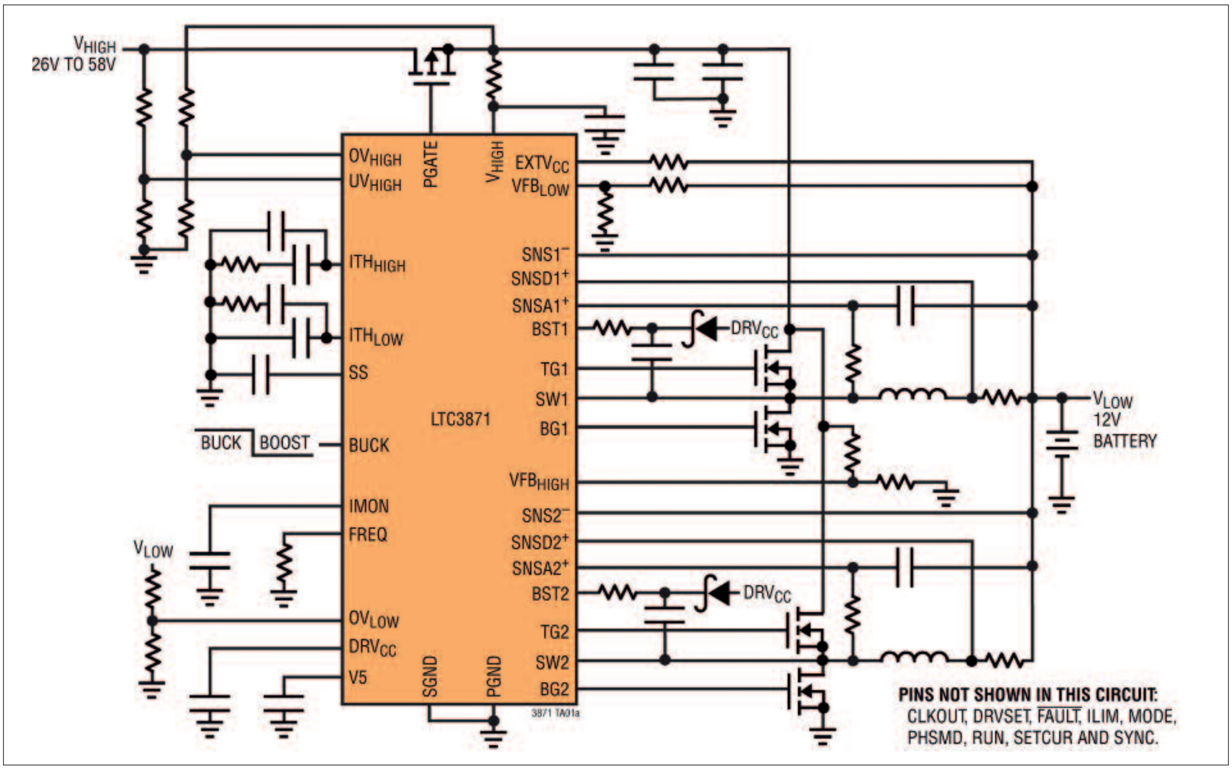

Figure 1: LTC3871 bi-directional schematic 12 V output from a 26 V to 58 V input delivering 30 A of current

compensation for buck and boost modes, EXTVcc for increased efficiency, ±1% output voltage regulation accuracy over temperature, along with under-voltage and over-voltage lockout. The LTC3871 has been qualified to meet AEC-Q100 specifications and was designed for diagnostic coverage in ISO26262 systems.

The LTC3871 is available in a thermally enhanced 48-lead LQFP package. Three temperature grades are available, with operation from –40°C to 125°C for the extended and industrial grades and a high temp automotive range of –40°C to 150°C. Figure 1 shows its typical applications schematic. The P-Channel MOSFET shown at the top of the schematic is for over-current and short-circuit protection.

Integrated starter-generator operation modes

The electronically controlled ISG replaces both the conventional starter and alternator with a single electric device for the following reasons: 1 - eliminate the starter which is only a passive component during engine operation; 2 - replaces the present belt and pulley coupling between the alternator and the crankshaft; 3 - provide fast control of the generator voltage during load dumps; and 4 - eliminate the slip rings and the brushes in some present wound rotor alternators.

The ISG has three important features which are the start-stop function, electricity generation and power assistance. The ISG allows the internal combustion engine to turn off its motor to save fuel at stops and instantly re-starts upon pressing of the gas pedal. Normally referred to as a start-stop system, an ISG makes for a smoother transition when starting the engine. Like a conventional alternator, the ISG produces electric power when the vehicle is running. In addition, the ISG can help to decelerate

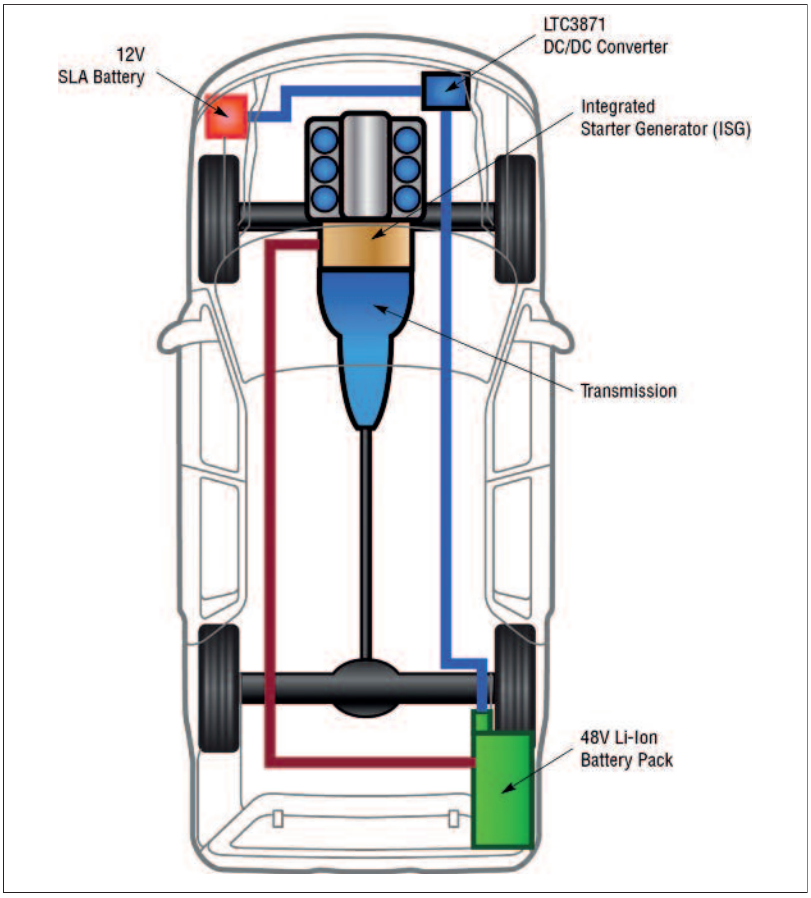

Figure 2: Block diagram of the ISG, LTC3871 along with the 12 V and 48 V batteries are incorporated

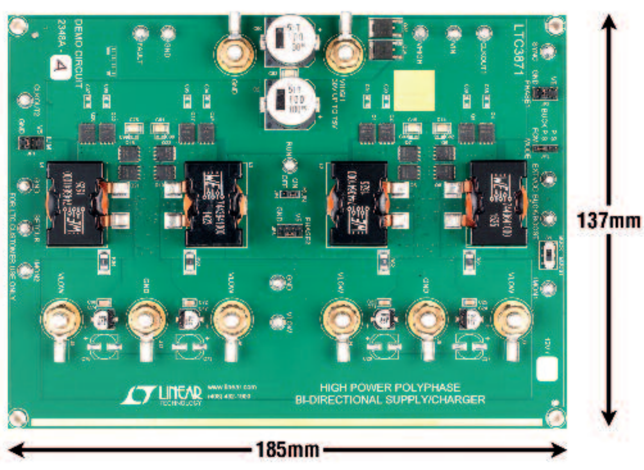

Figure 3: LTC3871 four-phase demo board

the vehicle by generating electric power (regenerative braking). The electric power generated during regenerative braking charges the 48 V battery, which in turn reduces fuel consumption and its resultant emissions. Figure 2 shows a block diagram how the ISG, LTC3871 along with the 12 volt and 48 volt batteries are incorporated into an internal combustion engine vehicle.

The LTC3871 can be dynamically and seamlessly switched from buck mode to boost mode and vice versa via a simple control signal. There are two separate error amplifiers for V_{HIGH} or V_{LOW} regulation. Having two error amplifiers allows fine tuning of the loop compensation for the buck and boost modes independently to optimize transient response. When the buck mode is selected, the corresponding error amplifier is enabled, and I_{THLOW} voltage controls the peak inductor current. The other error amplifier being disabled. In boost mode, ITHHIGH is enabled while ITHLOW is disabled. During a buck to boost or a boost to buck transition, the internal soft-start is reset. Resetting soft-start and parking the ITH pin at the zero current level ensures a smooth transition to the newly selected mode.

Multiple LTC3871s can be daisy chained to run out of phase to provide more output current without increasing input and output voltage ripple. The SYNC pin allows to synchronize to the CLKOUT signal of another LTC3871. The CLKOUT signal can be connected to the SYNC pin of the following device stage to line up both the frequency as well as the phase of the entire system. A total of 12 phases can be daisy chained to run simultaneously out-of-phase with respect to each other.

The demonstration circuit DC2348A shown in Figure 3 can be configured with two or four phases utilizing one or two LTC3871 devices. The four phase version operating in buck mode has an input voltage range of 30 V to 75 V and produces a 12 V output at up to 60 A. When operating in boost mode, the input voltage is from 10 V to 13 V and produces a 48 V at up to 10 A.

The LTC3871 efficiency curves in Figure 4 are representative of a four-phase demo board design using two LTC3871 devices. The buck mode curve steps the 48 V down to 12 V at up to 60 A, while the boost curve steps up the 12 V to 48 V at up to 10 A. Both operate with 97 % peak efficiencies.

In buck mode, the LTC3871 includes current fold-back protection to limit power dissipation in an over current condition or when the V_{LOW} is shorted to ground. If the V_{LOW} falls below 85 % of its nominal output level, then the maximum sense voltage is progressively lowered from its maximum programmed value to one-third of the maximum value. Foldback current limiting is enabled during soft-start. Under short-circuit conditions with very low duty cycles, the LTC3871 will begin cycle skipping in order to limit the short-circuit current.

In a typical boost controller, the synchronous diode or the body diode of the synchronous MOSFET conducts current from the input to the output. As a result, an output (V_{HIGH}) short will drag the input (V_{LOW}) down without a blocking diode or MOSFET to block the current. The LTC3871 uses an external low $R_{DS(ON)}$ P-channel MOSFET for input short-circuit protection when V_{HIGH} is shorted to ground. In normal operation, the P-channel MOSFET is always on, with its gate-source voltage clamped to 15 V maximum. When the UVHIGH pin voltage goes below its 1.2 V threshold, the FAULT pin goes low 125 µs later. At this point, the PGATE pin turns off the external P-channel MOSFET.

Conclusion

The LTC3871 brings a new level of performance, control and simplification to 48 V/12 V dual battery DC/DC automotive systems by allowing the same external power components to be used for step-down and step-up purposes. It operates on demand in buck mode from the 48 V bus to the 12 V bus or in boost mode from 12 V to 48 V. Up to 12 phases can be paralleled for high power applications and when starting the car or when additional power is required, the LTC3871 allows both batteries to supply energy simultaneously to the same load. The additional 48 V battery running a portion of a vehicle's electrical system will play a central role in increasing available energy, while reducing wiring harness weight and losses. This additional energy capacity paves the way for new technologies, enabling cars to be safer and more efficient, all while lowering its CO_2 emissions.

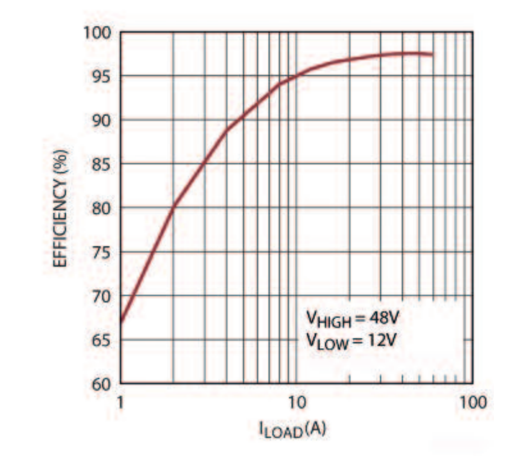

Figure 4: Buck (left) and boost (right) efficiency curves with a four-phase design