Technical Article

Interconnecting Automotive 48V and 12V Rails in Dual-battery Systems

TEXAS INSTRUMENTS

Garrett Roecker

Electrification of the automotive industry is happening at an ever-increasing rate, driven largely by government standards on carbon dioxide (CO_2) emissions reduction. The European Union set a goal for new vehicles to emit only 95g/km of CO_2 by 2020. Other countries like China are setting similar regulations. To meet these standards, automotive manufacturers are moving toward mild hybrid electric vehicles, which use a secondary high-voltage battery in addition to the standard 12V automotive battery.

German automakers have already begun defining and building systems based around a 48V battery. A 48V battery can deliver more power at lower currents than a traditional 12V battery, while saving weight in the wiring harness and not sacrificing performance. Out of this development, the LV 148 standard has become the prevailing starting point for dual-battery automotive systems. A top level block diagram of a dual-battery system is shown in Figure 1.

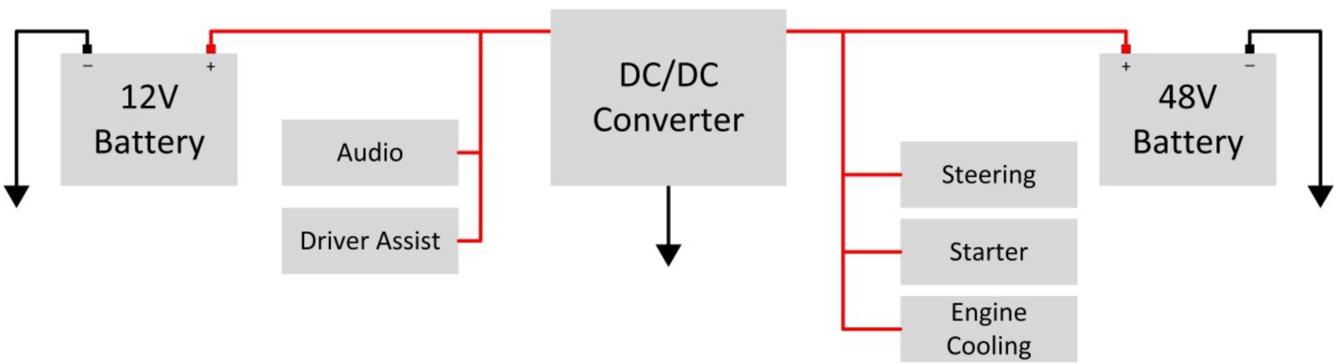

Figure 1. Block Diagram of a Dual-battery Automotive System

What are some of the challenges to the proposed system? How can you overcome the obstacles? Many OEM system requirements state that energy must be transferrable from the 48V rail to the 12V rail, and vice versa. Bidirectional power transfer is required to charge either battery if it's discharged, and to provide extra power for the opposite voltage rail in an overload condition. To charge a battery without damage, the controller must be able to control the charge current very accurately. In most automotive applications, the maximum power transfer is not small, usually falling in the range of 2kW to 3kW. Voltages on both rails can vary greatly. According to the LV 148 specifications, the 48V rail is normally between 36V and 52V, while the 12V rail can range from 6V to 16V. Protection circuitry must also be present for any fault conditions that could damage the system. With these requirements, it becomes obvious that the DC/DC converter needed to bridge the 48V and 12V rails will not be a trivial design project.

Realizing that the voltage range of the 48V rail and 12V rail never overlap greatly reduces design complexity. For power transfer from the 48V rail to the 12V rail, you can use a buck converter, while power transfer in the 12V-to-48V rail direction is achievable with a boost converter. Due to the kilowatt range power requirements, each converter should use a synchronous MOSFET instead of a freewheeling diode to increase system efficiency.

The buck and boost topologies are well known in power electronics, but designing two separate converters will take up valuable board space and increase system complexity and cost. Looking closely at both topologies, you can be seen that the power train of a buck and boost converter is very similar. Both topologies consist of at least two power MOSFETs, one inductor and some amount of output capacitance. The controller is the difference between the topologies. In a buck topology, the controlled switch is the high-side MOSFET, while in the boost topology it is the low-side MOSFET. By simply changing the controlled switch, it is possible to change the direction of current flow in the inductor while using the same power-train components, assuming that you selected the correct controller. Figure 2 illustrates the evolution from a two converter solution to a single converter solution.

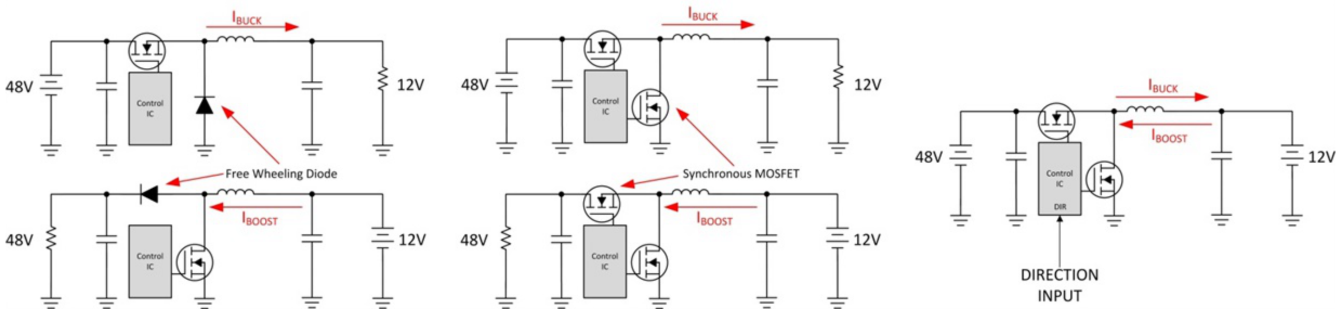

Figure 2. Evolution of a Single Controller Bidirectional Converter

While synchronous switching is necessary for high-current designs, it is not a cure-all for all obstacles. At 2kW of power, the 12V rail will conduct approximately 166A. A quick look at this tells you that you'll need multiphase operation to practically realize this design. By using a multiphase architecture, you can reduce the physical size of components and make thermal management easier. To easily parallel each power phase, the control scheme in either buck- or boost-mode operation should be current-mode control. Multiphase operation also enables interleaved switching of each phase. Not switching each phase at each time reduces output ripple, which in turn aids in reducing electromagnetic interference (EMI).

In all systems, you must design protection circuitry for operator safety. Common protection features like undervoltage lockout (UVLO) and overvoltage protection (OVP) ensure that the battery does not discharge too deeply or overcharge. Peak inductor-current limiting helps protect each power phase from being overstressed and saturating the inductor. In a dual-battery automotive setup, circuit breakers are also required to break any electrical connection between the 48V and 12V rails. Monitoring circuits can also help extend safety features. For example, during energy transfer, monitoring the current flow in each channel can indicate if or when a fault condition occurs.

A digitally controlled DC/DC converter is one possible solution, but there are a few major drawbacks to this approach. First, a substantial number of discrete components are necessary: a current-sense amplifier for each phase, power MOSFET gate drivers, protection circuitry and monitoring circuity Each component will take up valuable real estate on the printed circuit board (PCB). Second, a high-end microcontroller is necessary to implement the converter's current and voltage control loops. Third, microcontrollers also introduce delays in protection circuitry, which can cause catastrophic damage at high power levels. And fourth, the design cycle of a digital control can be on the order of years. You must have an in-depth knowledge of both switching power supplies and digital control. That being said, there are some added benefits. From a system level, digital control can be more flexible, allowing for dynamic changes in control-scheme parameters and regulation voltages. And sharing information with other subsystems improves total system performance.

TI's LM5170-Q1 synchronous dual-phase bidirectional buck/boost controller resolves many of these challenges. Integrated current-sense amplifiers, high-current gate drivers and system protection features – including an integrated circuit breaker and channel current monitoring – eliminate many of the discrete components needed in a digital solution. Stacking multiple controllers in parallel enables the delivery of kilowatts of power while elegant control of current-charging batteries occurs through the LM5170-Q1's proprietary average current-mode control scheme. Read the blog post, "Selecting a bidirectional converter control scheme," to find out how TI's average current-mode control method compares to conventional control schemes. Bridging the 48V battery and 12V battery is complex but possible, if you think each step through.

IMPORTANT NOTICE AND DISCLAIMER