Technical Article

4 critical design challenges for 48V systems

By Donovan Porter, general manager of body and lighting, automotive systems, Texas Instruments

48V is replacing the traditional 12V power net to reduce wire harness weight and cost. The vehicle power supply demands are increasing to enable Level 3 autonomous driving and software defined vehicles that implement advanced processing, edge AI, steer-by-wire, and brake-by-wire systems. Although 48V addresses the 12V wire harness issues, four key electronic system and circuit design challenges must be addressed. For an introduction to 48V systems, read the white paper, "48V Automotive Systems: Why Now?"

This article covers four design challenges introduced by the shift to 48V automotive systems:

- Safe and reliable 48V power distribution
- Efficient load actuation and 48V-to-12V/5V/3.3V conversion
- Protecting 12V and 5V I/O circuits from 48V short faults
- Maintaining CAN and LIN integrity through 48V fault conditions

Challenge No. 1: Safe and reliable 48V power distribution

Automakers require cost-effective electronic architectures that can support fail-operational power supply and delivery for safety-critical ECUs including high-performance compute for autonomous driving and brake-by-wire control systems.

Replacing traditional melting fuses with TI's smart eFuse high-side switches provides the protection and diagnostics necessary to safely and reliably distribute 48V throughout the vehicle. Smart eFuses integrate advanced diagnostics including short-to-ground protection and programmable fuse time-current characteristic for adjustable wire-harness protection. Additional eFuse features include integrated ADC, current, voltage, and temperature sensing circuits that equip the power distribution system to detect system-level faults and implement measures to guarantee critical electronics always remain powered. Additionally, TI eFuses meet ISO 26262 Automotive Safety Integrity Level (ASIL) B so that designers can simplify safe power distribution design. For details on smart eFuse high-side switches read "Fully Software Configurable High Side Switch for Power Distribution Applications in Zone Controllers."

Safety-critical ECUs must manage redundant supply inputs often requiring ORing or power muxing of the supplies. Additionally, multiple 48V-to-12V DC/DC converter outputs are often ORed together within a single zone control module to support both low-power and normal operating modes. In both cases, ideal diode controllers can provide efficient ORing solutions with reverse-current blocking and optional overvoltage and overcurrent protection. For more information read "Six System Architectures With Robust Reverse Battery Protection Using an Ideal Diode Controller."

Safe power distribution architectures can be further optimized with 48V due to the approximately 75% reduction in load current compared to 12V (for the same amount of power). The reduction in load current directly reduces the thermal stress on power distribution electronics including eFuses and discrete MOSFETs. Therefore, designers can eliminate traditional power distribution boxes to further reduce electronic control unit (ECU) quantity and cost. Zone control modules can perform both primary and secondary power distribution functions. Figure 1 shows a traditional 12V power distribution architecture vs a 48V backbone architecture.

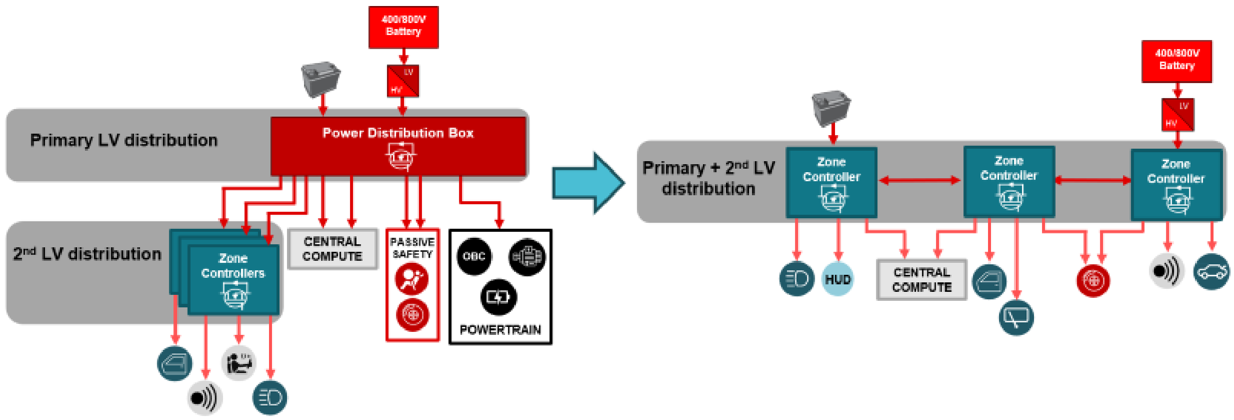

Figure 1. Traditional 12V vs 48V backbone power distribution

Challenge No. 2: Efficient load actuation and 48V to 12V, 5V and 3.3V conversion

Although 48V reduces load currents compared to 12V, switching losses (P_{SW}) increase approximately four times due to the longer rise and fall times (t_R, t_F) for the MOSFET turn-on and off. Equation 1 can be used to estimate the switching loss increases of a MOSFET when shifting from 12V to 48V. Figure 2 shows that a constant slew rate across 48V and 12V MOSFETs leads to 4 times longer t_R and t_F for 48V V_{DS}. While the drain-to-source voltage (V_{DS}) increase and drain-to-source current reduction cancel out, the remaining 4 times increase in t_R and t_F increase the overall P_{SW} by 4 for 48V vs 12V V_{DS}.

$$P_{SW} = 0.5 \times (\mathbf{4} \times V_{DS}) \times \left(\frac{\mathbf{1}}{\mathbf{4}} \times I_{DS}\right) \times [\mathbf{4} \times (t_R + t_F)] \times f_{SW} \quad (1)$$

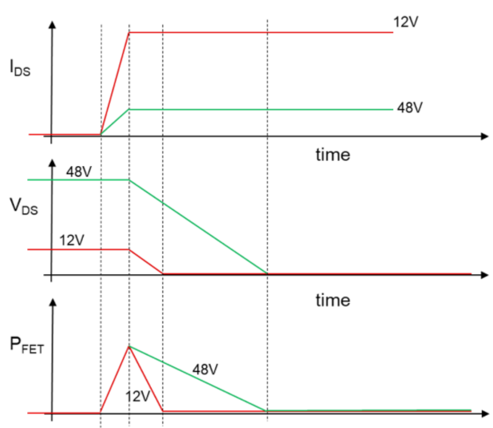

Figure 2. Same voltage slew rate at 48V vs 12V MOSFET Turn-on

Designers must mitigate or reduce the additional P_{SW} across 48V devices that constantly switch MOSFETs on and off including DC/DC converters, motor drivers, high-side switches, LED drivers and audio amplifiers while limiting electromagnetic interference (EMI). Traditional design knobs to reduce EMI such as slew rate adjustment are limited. Therefore, alternative approaches must be taken including spread spectrum or dithering of the pulse-width modulation clock frequency with faster slew rate, improved packaging for thermal dissipation, and replacing MOSFET technology with gallium nitride (GaN) to reduce thermal losses and mitigate EMI. For more information on 48V thermal and EMC performance trade-offs refer to "Design Trade-offs for 48V Automotive Body Motor Applications" and "Motor Driver Slew Rate Considerations for 48V Automotive Systems."

High-power applications for converting 48V to 12V, 5V or 3.3V require different DC/DC topologies. Every topology choice (buck, buck-boost, switched capacitor converter [SCC], switched tank converter [STC] or inductor-inductor-capacitor [LLC]) has trade-offs between thermal performance, complexity, size and cost. Furthermore, as 12V loads remain in first-generation 48V vehicles, new 48V-to-12V converters are added to supply external loads. Finally, 48V vehicles must implement a 12V-to-48V step-up or a bidirectional 48V-to-12V converter to support jump-start from 12V vehicles.

Zone control modules, typically requiring >250W nominal on the 48V-to-12V converter output, require additional topologies to improve efficiency and reduce thermal losses. Buck-boost converters handle a wide input voltage range, but may require multiple phases. STC and SCC topologies offer a path for high-density, high-efficiency conversion with minimal to no magnetics, but require large ceramic capacitor banks and many MOSFETs. LLC converters push efficiency around 98%, but require large and expensive magnetics.

GaN solutions can further enhance topologies, such as TI's LMG708B-Q1 buck converter that provides a simple and compact solution to reduce printed circuit board size. Figure 3 shows a 2-phase LMG708B-Q1 48V-to-12V buck converter supplying TAS6754-Q1 Class-D audio amplifiers in a compact form factor.

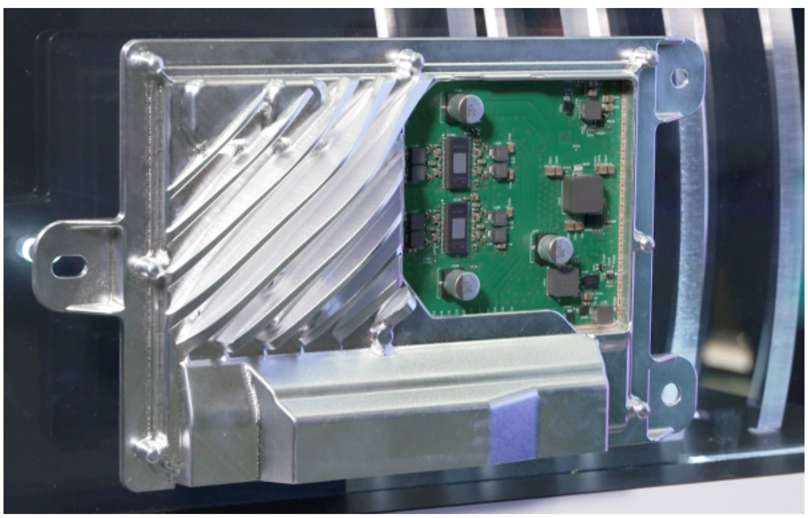

Figure 3. Panasonic 48V-to-12V design using TI's LMG708B-Q1 converter to supply Class-D audio amplifiers in a compact form factor

Challenge No. 3: Protecting external 12V and 5V I/Os circuits from 48V short faults

48V, 12V, and 5V loads will coexist in first-generation 48V architectures. The 48V supply will distribute power throughout the vehicle and directly drive high-power loads. Local converters in the zone control module will generate 12V from the 48V supply to drive multiple low-power (<60W) motors, solenoids, LEDs and resistive loads. 5V will continue to power small off-board components such as negative temperature coefficient resistors and hall-effect sensors. In addition to outputs, many ECUs have off-board inputs such as digital switches (buttons) and analog sensors (NTC resistors, potentiometers, etc.) that also require protection from 48V short conditions. A short circuit across connectors or wires between 48V and 12V or 5V inputs or outputs can damage legacy components, cause system-critical failures, and lead to expensive ECU replacement.

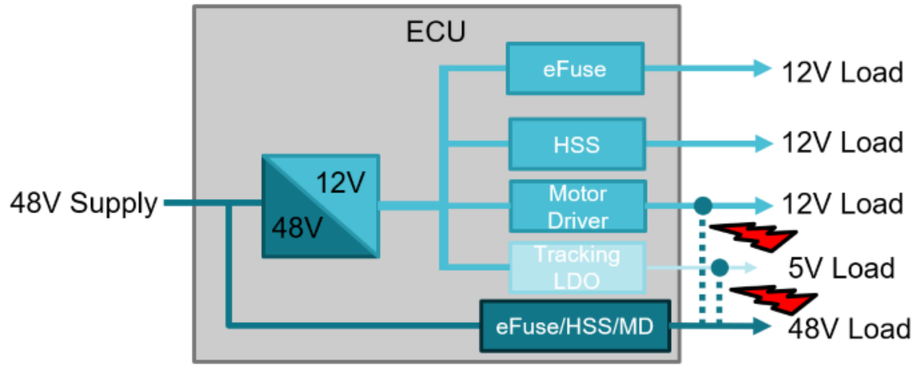

Figure 4. A short circuit may occur at any voltage level when stepping down from 48V

48V-supplied ECU designs must also support power-supply transient standards such as the upcoming ISO 25769 to ensure safe and reliable operation across the entire vehicle life cycle. Additional protection circuits or expanded device capabilities are required to support worst-case conditions. TI offers a broad portfolio of 48V-capable load drivers including brushed DC motor drivers, brush-less DC motor drivers, high-side switches and eFuses, in addition to built-in 48V short protection muxes.

Challenge No. 4: Maintaining CAN and LIN integrity through 48V fault conditions

Controller Area Network (CAN), CAN Flexible Data Rate (FD), and Local Interconnect Network (LIN) protocols are vital for ECU communication. All transceivers must avoid damage if a short between the 48V supply and communication bus occurs. Additionally, CAN and CAN FD networks often carry safety-critical data that require communication even when a single node fails after a loss of ground.

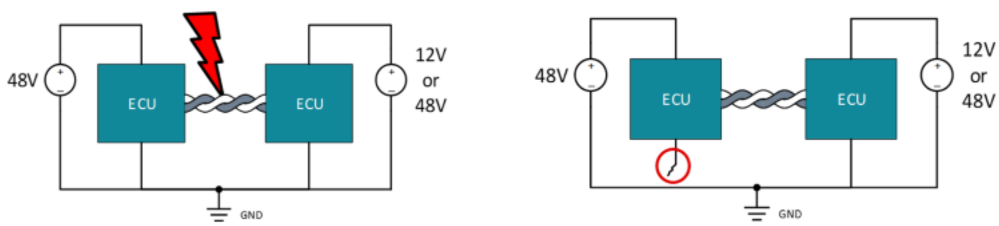

Figure 5. CAN bus short-circuit conditions impacting ECU communication bus

Although these fault conditions are not new, 48V changes their requirements. Bus voltages will exceed legacy transceiver capabilities and a loss of ground can disable the entire bus due to increased common mode voltage from 48V floating CAN nodes. TI's CAN and LIN transceivers can survive both conditions supporting ±70V bus fault conditions to meet the latest ISO 25769 standard.

Designing for the next decade of 48V

The transition to 48V continues to gain momentum in the automotive industry. While the 48V power net can support future L3+ autonomous and AI-defined vehicles new challenges for power distribution, power conversion, ECU I/O protection, and communication are introduced. Innovation at the semiconductor level directly addresses these challenges enabling automakers to streamline system design and release vehicles to market faster.

Additional resources

- Read the white paper, "Smarter Power Distribution: Shaping the Future of Automotive Technology."
- Download the 48V Zone Reference Design and Automotive 48V, 300W HVAC Pump, Blower and Fan Reference Design.

About the author

Donovan Porter is general manager of body electronics and lighting for automotive systems at TI, where he leads a worldwide team of system engineers to address next-generation design challenges and drive strategy across TI. He previously worked with the automotive systems team as a systems engineer and manager. Donovan has a bachelor's degree in electrical engineering from Texas Tech University.

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