48V Automotive Systems: Why Now?

Madison Eaker
Systems Manager
Body Electronics and Lighting

In this paper, we discuss the growing interest in 48V low-voltage rail systems for electric and hybrid vehicles and how engineers can use them to reduce wire harness size and cost while enabling new features.

At a glance

1 **48V in MHEVs vs. BEVs**
Learn about the evolution of 48V systems in MHEV and BEVs.

2 **Reducing the wire harness**
Read how 48V systems with zone architecture can reduce wire harness complexity and costs.

3 **48V architectures**
Discover the different 48V system design approaches for optimizing wire harness design and costs.

4 **48V design challenges**
Explore key design challenges when adopting 48V systems, including transient voltages, creepage/clearance requirements, EMC standards, and IC costs.

Introduction

*Originally published on **Electronic Products***

In recent conversations with auto manufacturers, 48V low-voltage rail has come up frequently. But why now? 48V systems aren't new. They've helped improve efficiency and performance in mild hybrid electric vehicles (MHEVs) for years.

The renewed interest in 48V systems might have to do with the growing popularity of both battery electric vehicles (BEVs) and hybrid vehicles (HEVs). Electric or hybrid vehicles generating 48V off a high-voltage battery can realize an important benefit of 48V systems: adding a 48V low-voltage rail reduces the gauge of the wire harness that supplies power throughout the vehicle, and reduces the load current requirements of downstream semiconductor components such as power switches and motor drivers. Thus, 48V systems can deliver more power than 12V systems, opening up the opportunity to add features such as artificial intelligence or mini fridges.

BEV original equipment manufacturers (OEMs) are looking to optimize cost, weight and driving range for BEVs. From an electrical perspective, it's possible to address all three by reducing wire harnesses through a **zone architecture**, as discussed in the Texas Instruments white paper, "**How a Zone Architecture Paves the Way to a Fully Software-Defined Vehicle**" or using a 48V low-voltage rail for power distribution. In the early 1900s, the automotive industry used a 6V rail to provide power, until the power demands of the electrical/electronic (E/E) systems forced the market to move to 12V. Now, today's feature-rich vehicles are pushing the limits of 12V rail. There are challenges of moving from 12V to 48V, but also opportunities if OEMs move to adopt a 48V low-voltage rail.

48V in MHEVs vs. BEVs

In the late 1990s, there was a push for 42V E/E systems. But OEMs abandoned this approach given the lack of high-efficiency motors, and there was a market shift toward MHEVs that used a high-voltage starter generator. Thus, while MHEVs were the "first" 48V systems, they used only a 48V battery and small electric motor to assist the ICE, which reduces fuel consumption and improves efficiency.

The main low-voltage rail powering E/E systems within MHEVs remains at 12V and requires a large bidirectional converter between the 48V and 12V rail, adding a large cost burden. In contrast, full hybrids (HEVs), plug-in hybrids (PHEVs) and BEVs can use the high-voltage battery to create a 48V low-voltage rail to power the entire E/E system.

Because of limited trim lines and platforms, future BEV platforms were the primary target for OEMs to implement 48V automotive systems. The transition to electric-drive vehicles has also increased investments in HEVs and PHEVs. Figure 1 provides an overview of the differences between vehicle types.

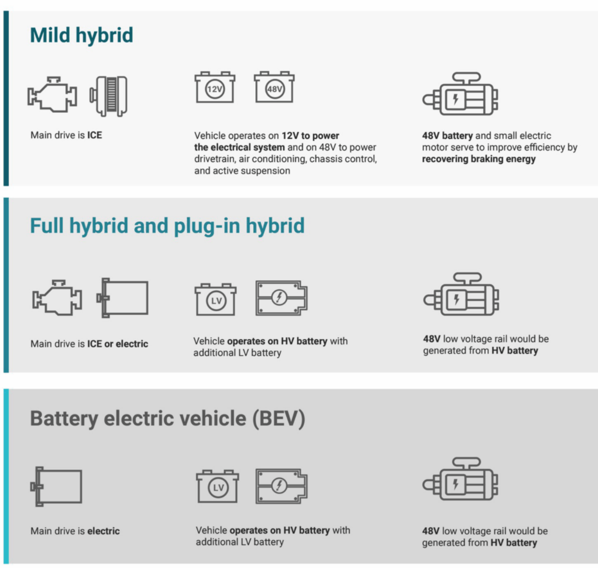

***Figure 1.** Overview of vehicle powertrain types.*

Reducing the wire harness

The first major attempt to reduce the wire harness was the introduction of the zone architecture, which optimizes wiring in the vehicle by grouping power distribution, communication and load actuation based on location rather than by function, as shown in Figure 2. A zone architecture reduces vehicle wiring by using smart semiconductor fuses to replace the traditional melting fuses for power distribution, and by acting as a communication gateway from the central computer to sensors, actuators and electronic control units (ECUs).

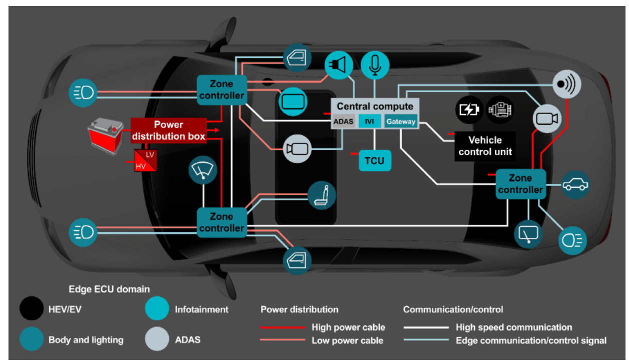

***Figure 2.** First-generation zone architecture.*

Including a 48V low-voltage rail in next-generation zone architectures could further reduce wire harness weight and costs. A 48V rail enables reduced wire gauges, reduces power losses in the wire harness, and possibly reduces printed circuit board (PCB) size given the reduction in current to deliver the same amount of power (25% compared to 100% at 12V, for example). Figure 3 illustrates the benefits of moving from 12V to 48V.

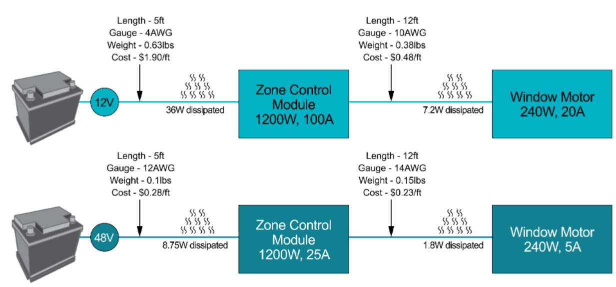

***Figure 3.** 12V-to-48V wire harness reduction.*

In **Figure 3**, a zone control module needs 100A to deliver 1,200W at 12V. In contrast, a 48V rail requires only 25A to deliver 1,200W. Quadrupling the voltage and lowering the current by one-fourth reduces wire harness cost and weight by 85%. For a window motor, 20A at 12V becomes 5A at 48V, resulting in a 60% cost savings and a 52% wire weight savings. As the load current requirements decrease, the wire harness benefits of moving to 48V also decrease.

While the main benefit of moving to 48V is to reduce the wire gauge, wire cost is not the only factor. Today, installing thick wire gauges such as 4 American Wire Gauge (AWG) into vehicles is labor intensive. Reducing the wire gauge in a 48V system enables the use of automated manufacturing processes for wire harness installation, significantly reducing costs.

48V architectures

When optimizing wiring harnesses for 48V architectures, OEMs will need to evaluate different architectures. **Figure 4** through **Figure 6** show three options when implementing a 48V low-voltage rail: 48V primary distribution and 12V local, 48V distribution and 12V distribution, or 12V distribution and 48V high current loads only.

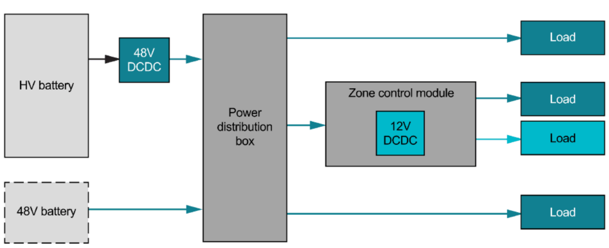

Figure 4. *48V architectures (48V primary distribution, 12V local).*

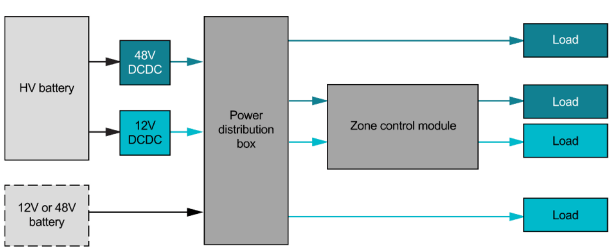

Figure 5. *48V and 12V distribution – ZCM 48V & 12V.*

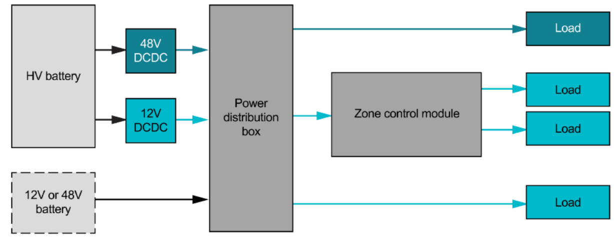

Figure 6. *12V primary distribution, 48V high current loads.*

The least disruptive approach to 48V design is to use the 48V rail to power high-current loads and keep everything else at 12V. 48V and 12V can be distributed to zone control modules or other ECUs; however, this approach poses some challenges. The distribution of two different voltages makes the routing of the wire harness a factor, because routing both 12V and 48V in the same wire harness could result in a potential short from 12V to 48V. Functional safety considerations will also add costs, as there may be a need for redundant 12V and 48V supplies.

A more drastic design change is to move directly to a 48V power distribution architecture and create a 12V rail locally as needed. 48V distribution with local 12V is the best architecture to achieve the full benefit of moving to 48V because it provides the greatest reduction in wire harness size and cost.

In a 48V distribution with 12V local, there are many different options for creating a local 12V rail at the ECU, or selecting a different voltage entirely (25V, 16V, 5V, 3.3V). **Figure 7** provides two possible power architectures, distributed and central 12V, for 48V systems.

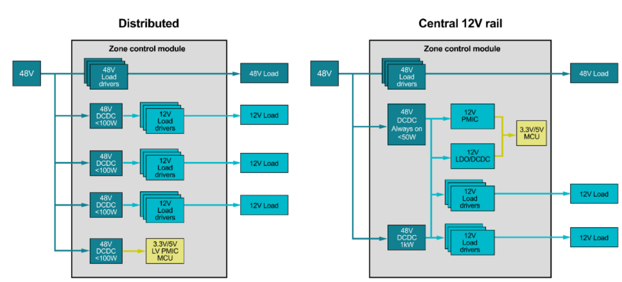

Figure 7. *Voltage conversion from 48V at the ECU.*

In a distributed architecture, multiple DC/DC converters with lower power requirements can create a 12V rail for different load groupings. This approach enables the use of DC/DC converters with integrated metal-oxide semiconductor field-effect transistors, along with the freedom to choose the voltage (such as 48V to 3.3V) and better thermal spreading across the PCB. If OEMs want to reuse existing 12V designs, a central 12V rail is the easier approach. In this architecture, an always-on DC/DC converter provides power to functional safety-critical loads, while a DC/DC converter with high power requirements supplies the rest of the 12V system. Another option is to use bidirectional 48V-to-12V DC/DC converters to allow back-electromotive force from the motors, or positive transient voltage energy from the 12V rail to flow back into the 48V rail.

48V design challenges

The design challenges when adopting a 48V low-voltage rail include transient voltages, creepage and clearance requirements, electromagnetic compatibility (EMC) standards, and integrated circuit (IC) costs.

Transient voltages are the main topic of conversation in 48V systems. Today, 12V systems are well known, with standards such as International Organization for Standardization (ISO) 16750-2 specifying voltage transient curves for worst-case events such as load dumps. For 48V systems, the standards available today (ISO 21780 and Liefervorschriften [LV] 148) were written for MHEVs requiring overvoltage points up to 70V. But when factoring for switching transients or component margin, it results in component ratings much greater than 70V.

The standards for MHEVs, while useful as a starting point, are not necessarily valid for an electric or hybrid system generating 48V off the high-voltage battery without a high-power starter-generator system. The exact standards around a BEV 48V low-voltage net are still being defined, but OEMs may begin defining their own standards to contain line transients below 70V.

Figure 8 compares a potential BEV standard to the existing ISO 21780 standard.

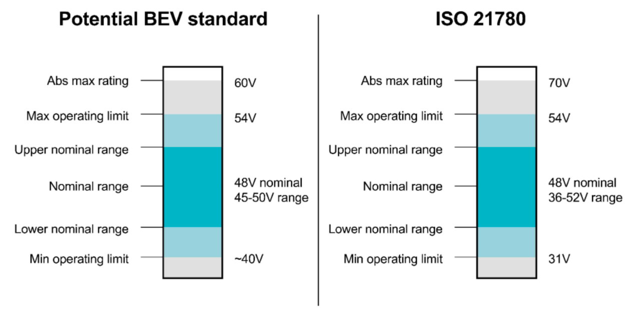

Figure 8. *Potential BEV standard and ISO 21780 transient voltage comparison.*

While the difference between 60V and 70V may seem small, the cost of ICs to accommodate higher voltages doesn't necessarily scale linearly. Also, even if it were possible to contain the supply ranges, it's important to consider the potential for harness failure-mode events, which current standards such as ISO 7637-2 do address.

Creepage and clearance requirements are industry-standard measurements of the shortest distance between all conductive parts on the PCB. They are critical design parameters for preventing arcing, which occurs when the voltage between two points exceeds the breakdown voltage. There are many different standards for creepage and clearance (International Electrotechnical Commission 60664-1 and Institute of Printed Circuits 2221A) and OEMs may even have their own internal guidance. Moving from 12V to 48V increases creepage and clearance requirements, directly impacting IC packages, PCB layout, wire harness connectors and more.

A subtler impact of 48V systems is that while they help reduce conduction losses, switching losses increase. This becomes relevant in EMC testing for switching power converters such as DC/DC converters and motor drives. Increasing the voltage (V_{DS}) from 12V to 48V allows the current (I_{DS}) to reduce. However, if the slew rate ($t_R + t_F$) in 48V systems remains the same as

12V systems, then the power switching losses (P_{SW}) quadruple.

While there are more factors that impact switching losses, **Figure 9** illustrates how slew rate impacts switching losses in 48V systems. For more information on reducing conducted emissions in DC/DCs, see the application note, "**Reducing Conducted EMI in a Buck Converter for 48V Automotive Applications**."

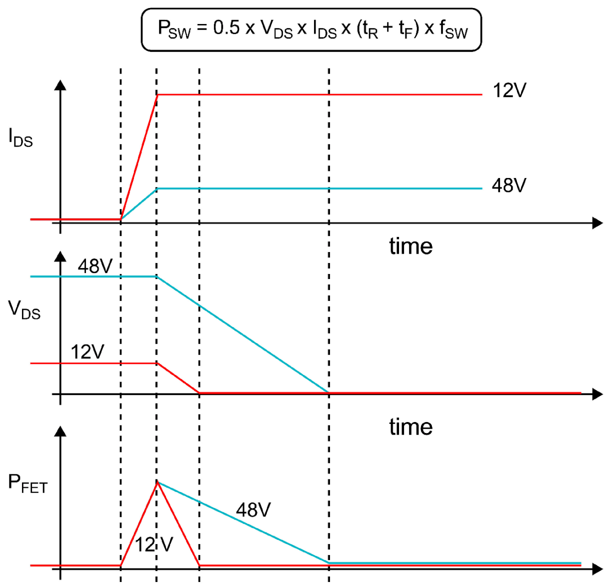

Figure 9. *Switching-loss impact on EMC.*

Conclusion

While 48V systems can reduce weight and gauge of the wire harness, saving cost in the actual copper of the wire and in manufacturing, the conversation comes back to cost. The adoption of 48V has many benefits and challenges that will affect cost in some way, whether at the IC level or system level. OEMs will decide when and how to incorporate 48V systems to maximize benefits and reduce cost. The market and semiconductor suppliers are ready for 48V systems, as evidenced by recent vehicle innovations.