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Benefits of eFuses

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June 2026 mobilityengineeringtech.com

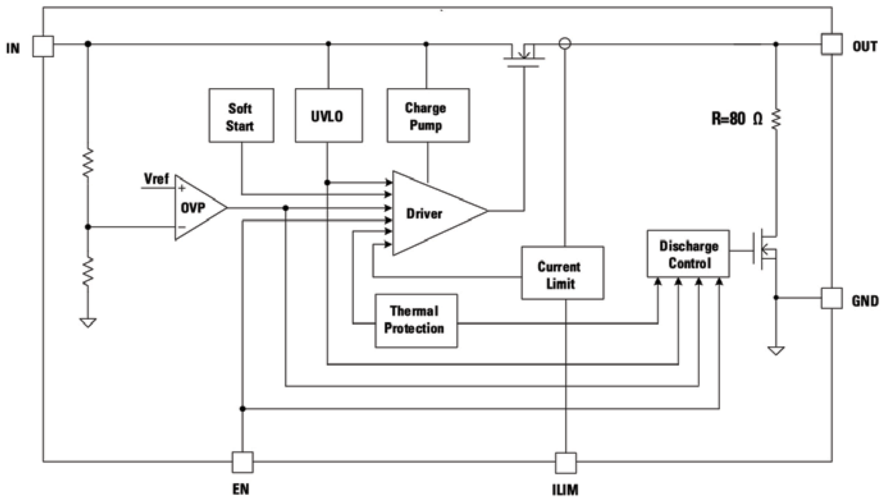

Figure 1. Example eFuse IC with overcurrent, overvoltage, overtemperature, inrush current, and undervoltage lockout control.

INTELLIGENT POWER DISTRIBUTION will change the way vehicles are designed

Electronic fuse (eFuse) technology can create electronic power distribution modules (ePDMs) for architectural flexibility, higher reliability, greater safety, and proactive maintenance.

Automotive engineers who design vehicles and vehicle assemblies, especially for electric vehicles, strive to maximize efficiency in every subsystem. Electrification and intelligence are deployed across numerous vehicle subsystems, including drive trains, braking, and collision avoidance. Nevertheless, one area that has been overlooked, until now, is power distribution.

Electronic fuse (eFuse) technology has emerged that can provide overcurrent protection similar to that of traditional fuses along with new programmable features. Integrating eFuse technology into an intelligent electronic power distribution module (ePDM) significantly impacts how vehicles are designed and serviced.

An ePDM module combines superior circuit safety with efficient load power management, enables reduced harness weight, and permits flexibility in the vehicle's electrical architecture. In addition, ePDMs will be able to monitor, diagnose, and remotely reset circuits, transforming how fleet operators manage maintenance and limit downtime.

This article explains how eFuses and ePDMs work, the limitations of traditional fuse technology for modern vehicle requirements, and how an ePDM enables previously unavailable benefits across the vehicle lifecycle.

Applications for intelligent power distribution

Intelligent power distribution systems open a wide range of capabilities that traditional fuse boxes and relays simply cannot provide. Design engineers can apply ePDM technology to address several vehicle-level challenges simultaneously:

- Improving safety while allowing circuit reset after a fault rather than a complete sub-system shutdown
- Monitoring and managing power consumption by fine-tuning power distribution based on the vehicle state, including inrush current management and deactivating unused loads
- Reducing system complexity and wiring harness weight
- Adapting to various vehicle electrical architectures, including domain and zonal architectures
- Interfacing with ECUs and main controllers through standard protocols such as LIN, CAN, and Ethernet
- Protecting power distribution control and monitoring with cybersecurity technology
- Enabling predictive maintenance and firmware upgrades through a standardized bootloader

Together, these capabilities represent a fundamental rethinking of how engineers protect, monitor, and manage vehicle electrical systems.

Fuse boxes and electro-mechanical components

Traditional fuses and relay-based power distribution systems have served the automotive industry for a century. However, the increasing electrical complexity within modern vehicles is exposing the limitations of these legacy components. Engineers face several structural challenges that conventional fuse boxes cannot solve:

- Traditional fuses are one-time-use devices that require physical replacement after every fault event
- Fuse boxes must be physically accessible, which constrains vehicle packaging and limits freedom in electrical architectural design
- Electro-mechanical relays have moving parts that wear over time, creating reliability problems and added maintenance costs
- Fixed fuse ratings cannot adapt to different operating conditions, inrush currents, or load variability
- Higher OEM development costs for documenting fuse ratings in service manuals and higher manufacturing costs for creating and installing physical labels
- Lack of real-time data collection, fault trending, or predictive maintenance capability

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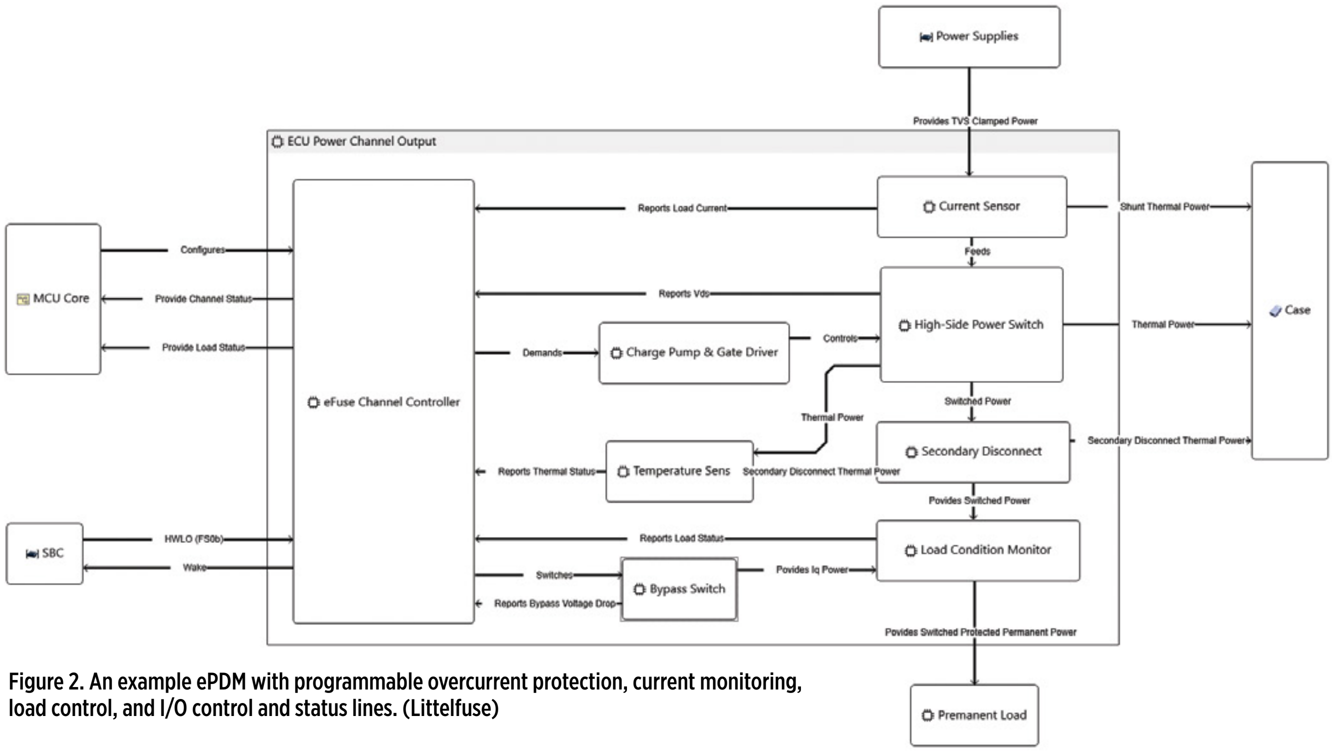

Figure 2. An example ePDM with programmable overcurrent protection, current monitoring, load control, and I/O control and status lines. (Littelfuse)

Additionally, the traditional design approach requires engineers to derate fuse ratings to account for temperature and trigger characteristics. The permanent current through a circuit should not exceed 75% of the fuse rating to prevent nuisance openings at room temperature. Engineers must also adjust for the trigger characteristic of the fuse, where switch-off current can be orders of magnitude higher than the nominal operating current. These constraints add complexity and limit design optimization.

The pathway to intelligent protection and power distribution

Automotive designers can overcome traditional limitations by replacing the fuse box, relays, and circuit breakers with a system based on eFuse technology. An eFuse is an integrated circuit (IC) that provides overcurrent protection using a resettable methodology. Unlike a traditional fuse, an eFuse does not open and does not require replacement. Instead, it detects an overcurrent condition, shuts off the current load, and can be configured to reset after the fault clears.

In addition to overcurrent protection, the eFuse also provides overvoltage transient protection, inrush current protection, and overtemperature protection. This multi-function protection capability consolidates what previously required several discrete components into a single device. Figure 1 shows an example eFuse using a MOSFET for power control.

Augmenting an eFuse with processing power, memory, input/output (I/O), and communication interfaces creates a complete power distribution module. An ePDM integrates power switching, load protection, load monitoring, and power management into a single solid-state module. The module can also include compliance with ISO 26262 for functional safety and ISO 21434 for cybersecurity, to address the stringent requirements of modern automotive development programs.

The value of an ePDM: benefits across the vehicle lifecycle

An ePDM concept, illustrated in Figure 2, can deliver value across multiple dimensions of vehicle design and operation. Engineers should consider these benefits for both the development cycle and the vehicle's operational life.

Superior safety

An ePDM can respond to fault conditions far faster than traditional fuses. Fast overcurrent trip times reduce the energy delivered to a fault, protecting wiring and downstream components. Moreover, because protection is resettable, a temporary fault would not result in a complete sub-system shutdown. Engineers can configure the module to reconnect a circuit remotely once the fault condition resolves, without requiring a technician to physically access the fuse box. Disconnection of a load upon detection of an electrical fault is automatic, and the integrated functional safety design can meet ISO 26262 requirements.

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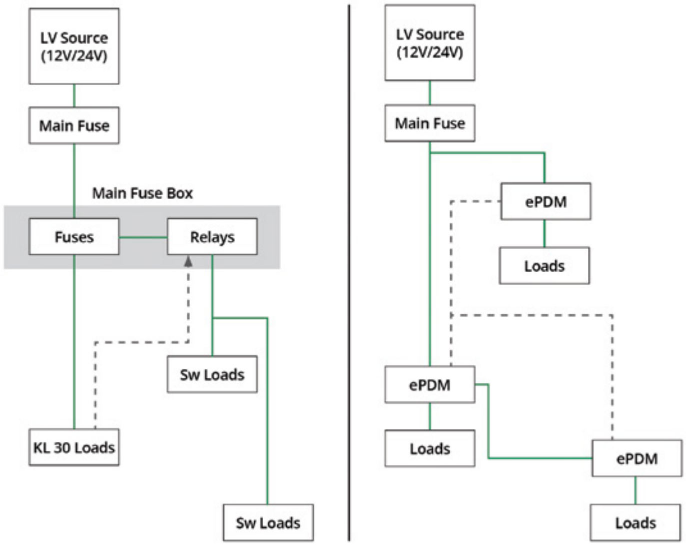

Figure 3. Contrast of one-time fuse and inflexible current architecture (left side) with resettable, programmable overcurrent protection and load control with an ePDM architecture (right side).

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Intelligent power management and load optimization

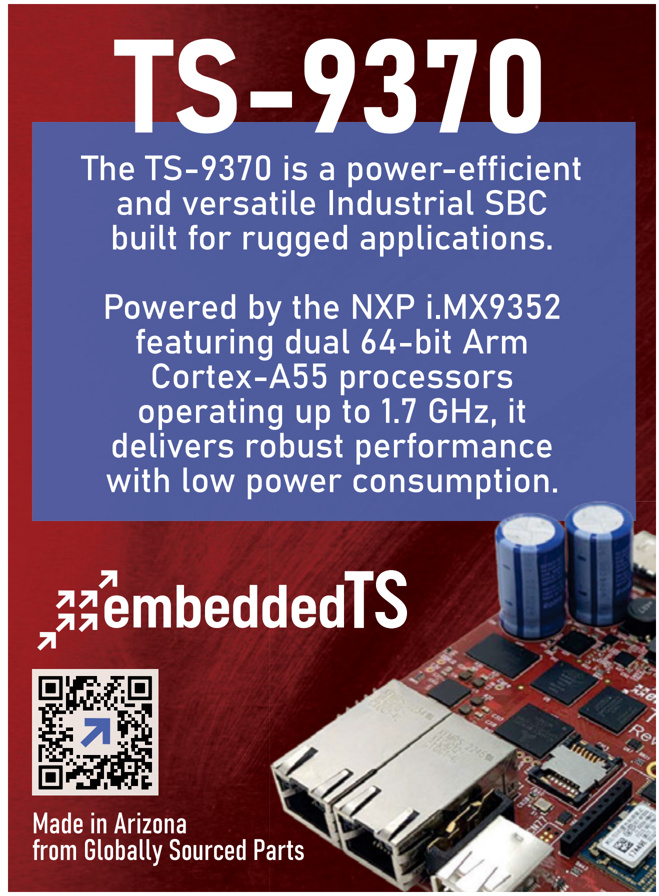
An ePDM can continuously monitor current and voltage across all channels, providing real-time system-state awareness. Engineers can use this data to implement load shedding – intelligently turning off unused loads based on the vehicle operating state, whether driving, charging, preheating, or idling. In addition, an ePDM can manage inrush currents during start-up, protecting circuits and downstream components from the high transient currents that occur when large loads switch on.

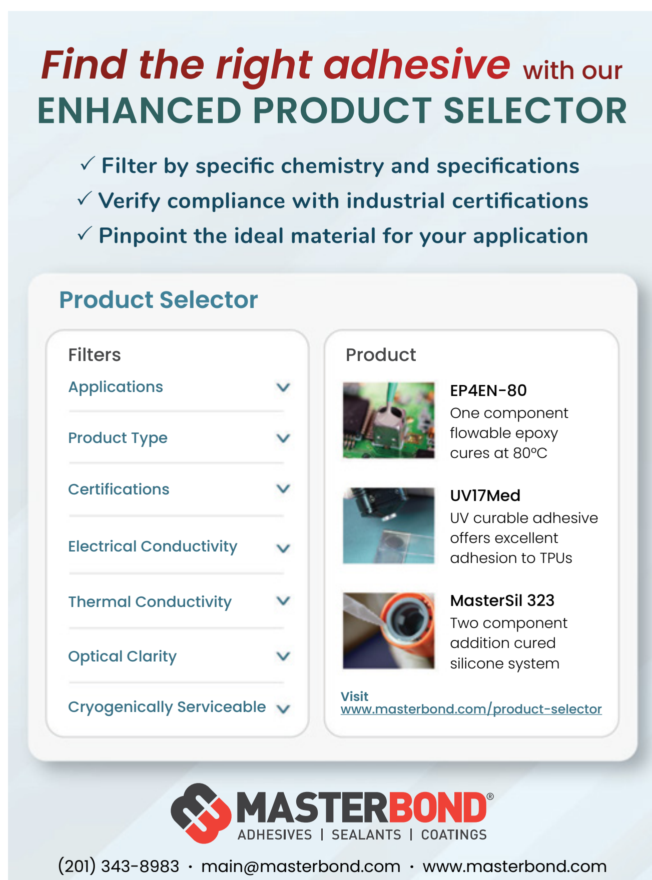
With battery-powered vehicles, this capability is highly valuable. An ePDM optimizes energy delivery to the drivetrain rather than to auxiliary loads, extending the available drive range. Also, by fine-tuning power distribution based on varying vehicle requirements, fleet operators and OEMs can increase overall system efficiency. Figure 3 illustrates how ePDMs provide programmable overcurrent protection and load control for any type of load compared with the one-time discrete fuses and fixed configuration of existing automotive power distribution.

Predictive maintenance and fleet uptime

One of the most valuable benefits of an ePDM is its ability to transform maintenance from reactive to predictive. The module continuously logs fault events, and repeated trips on the same channel signal an emerging problem before a failure occurs. Furthermore, integration with vehicle telematics allows real-time transmission of fault data to fleet managers or OEM service systems.

An ePDM can also identify sub-systems drawing too much or too little power. Both deviations are diagnostically valuable.





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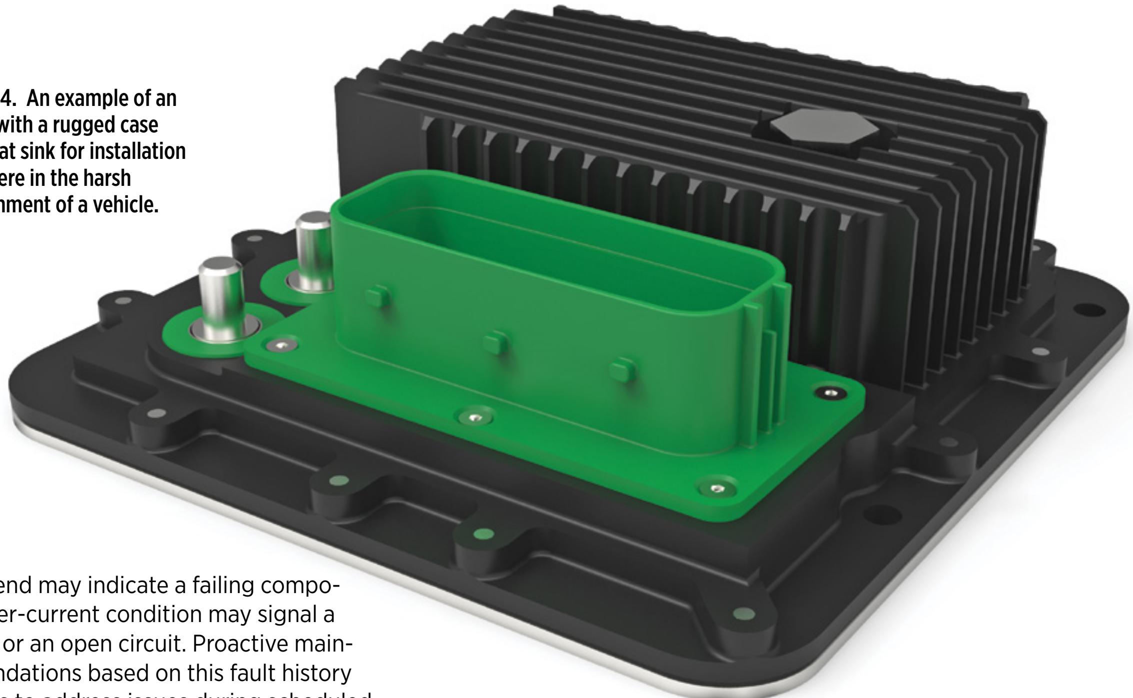

Figure 4. An example of an ePDM with a rugged case and heat sink for installation anywhere in the harsh environment of a vehicle.

An over-current trend may indicate a failing component, while an under-current condition may signal a disconnected load or an open circuit. Proactive maintenance recommendations based on this fault history allow service teams to address issues during scheduled maintenance intervals rather than responding to unanticipated breakdowns.

Furthermore, the ePDM has a remote reset capability. This feature improves the serviceability of the device in hard-to-reach locations and reduces maintenance costs.

Software-defined flexibility

An ePDM brings the software-defined paradigm to power distribution. Protection parameters – including trip levels, let-through energy (I^2t) profiles, and retry counts – are configurable via unified diagnostic services (UDS). Engineers can tune the system during development without requiring hardware changes. This greatly accelerates the development cycle and reduces prototype iteration costs.

Production units ship with a validated, locked configuration that meets functional safety requirements. After production, firmware updates enable post-production feature additions and calibration refinements. Also, if the vehicle's use case or accessory configuration changes, engineers can re-tune load profiles to match the new requirements without a hardware redesign.

Cybersecurity: protecting the power distribution network

As vehicles get more connected, the power distribution network becomes a potential attack surface. An ePDM can overcome this risk through a cybersecurity design developed in accordance with ISO 21434. Authenticated CAN communications prevent unauthorized access to protection and control functions. In addition, a secure bootloader can enable authorized firmware updates while blocking malicious access. This approach ensures that the intelligence added to the power distribution network does not create new vulnerabilities.

Harness weight and packaging benefits

An ePDM delivers meaningful benefits to vehicle packaging and wiring architecture. Faster, tighter fault response allows engineers to specify smaller-gauge wire, directly reducing harness weight and copper costs. Furthermore, because the ePDM eliminates the requirement for a physically accessible fuse box, engineers gain greater freedom in designing system wiring architectures.

The module also supports point-of-load switching strategies that further reduce harness length and cross-sectional area. By replacing multiple electro-mechanical components, fuses, relays, and ECU control circuits with a single integrated module, engineers reduce connector count and associated failure points. Additionally, an ePDM eliminates the service manual and physical label requirements for fuse identification, delivering meaningful per-vehicle cost savings for OEMs. Figure 4 illustrates an ePDM assembly.

Architectural flexibility

An ePDM can support both domain and zonal electrical architectures. In a domain architecture, the ePDM functions as a centralized power distribution hub connected to a domain backbone gateway, with CAN communication integrated directly into existing domain ECU networks. An Ethernet support path is also available for high-bandwidth domain architectures.

In a zonal architecture, smaller ePDM variants can be distributed as zonal nodes throughout the vehicle, while larger variants serve high-current zones such as cab, infotainment, and climate control systems. This flexibility allows engineers to match the ePDM configuration to the vehicle's electrical topology without compromising protection or monitoring capability.

Shaping solutions for the next generation of vehicles

An ePDM represents a significant advance in the design, protection, and maintenance of vehicle electrical systems. Engineers and OEMs who engage with this technology early in the development cycle will find that it changes not just component selection but also the entire approach to electrical architecture design. The technology requires engineers to think differently about power distribution from the very beginning of a program.

The benefits span safety, harness weight, packaging, uptime, maintenance cost, and software flexibility. Furthermore, the technology is architecture-agnostic and applicable to any vehicle regardless of powertrain type, from battery electric to hybrid to conventional ICE.

Automotive engineers should partner with an ePDM supplier early in the design process to receive guidance on applying intelligent power distribution, designing their system architecture, and optimizing vehicle power management. Littelfuse is working with forward-thinking OEMs and Tier 1 suppliers today to define the future of solid-state power distribution and bring these capabilities to vehicles at scale. ■

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Matthew Drew is engineering director at Embed, a Littelfuse brand, and wrote this article for SAE Media Group.

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