Improving the automotive power distribution architecture

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In automobiles, a revolution has occurred in essentially all design aspects, from engine management to body control functions, to wheels, braking, safety and more. Only one aspect remains the same as a century ago: the power distribution architecture. This remaining vestige is about to undergo the same transition as the others - and join the revolution.

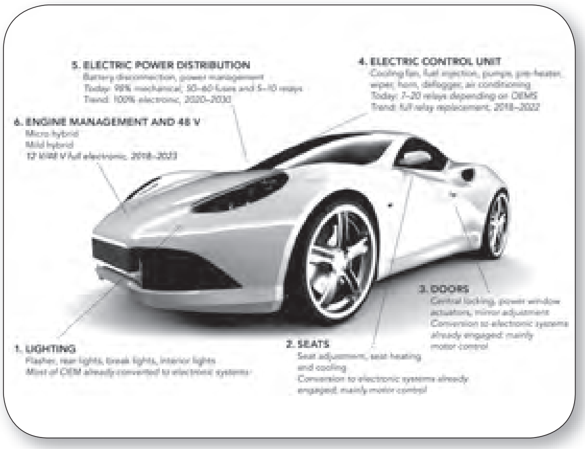

Figure 1. Relay replacement has occurred at different rates in various areas of the car.

■ The ongoing electrification of vehicles impacts all vehicle systems and provides an excellent reason for overhauling automotive power distribution architecture. Three major forces drive this push for electrification: the connected car model, new powertrains and regulations, and the globalization and consolidation of platforms. There are two aspects that will be considered in this analysis: relay replacement and fuse alternatives. Figure 1 shows the current status for automakers in six specific areas.

For lighting 1), relay replacement has already started to occur. The same is true for seating 2) and doors 3). However, for the electronic control unit 4), relays are still commonly used for cooling fans, fuel injectors, pumps and more, ranging from 7 to 20 units depending on the original equipment manufacturer (OEM). The trend in this area is full replacement with a solid-state alternative between 2018 and 2022. The big future for electrification will come from the junction box in electric power distribution 5) with revised power distribution architecture. From 50 to 60 (or even 100) fuses and from five to ten relays are required to distribute power from the battery to a module or group of loads. For example, a fuse + wire that goes to the body controller could control several different functions. Today, almost all manufacturers use relays and fuses in the junction box. The trend from 2020 to 2025 or even to 2030 will be to replace all the mechanical pieces in the car distribution box. The last box 6) is engine management. With 48V power increasing for stop-start systems and other mild hybrid applications, the relay can no longer satisfy the load switching requirements due to arcing on the 48V bus. This arcing subsequently creates other system issues. As a result, 48V applications dictate solid-state solutions.

For the connected car trend, the vehicle power network must connect to the external power source of a fixed structure. In addition to the power, connecting a 48V mild hybrid car to a fixed structure requires communication between the 48V port in the garage or external 48V source and the vehicle. Many new features will come with 48V capabilities, such as X-by-wire, that require high quality and a high level of safety. The trend being discussed is classifying the wiring harness as an ISO 26262 element for critical areas such as steer-by-wire and brake-by-wire. As a result, the wiring needs to be considered as a safety-critical aspect compliant with ISO 26262. While the ISO specification has been required for many automotive safety aspects for several years, its addition to the wiring harness is rather new. The added complexity from having both 12V and 48V power sources in vehicles creates design challenges as well as challenges in assembly, servicing and aftermarket to ensure compatibility and isolation between systems. While automotive technology will be even more advanced and ready for these applications than it has been in the past, the real driving force for power distribution architecture replacement will come from new functions of the connected car for which relays are not adequate. For example, the stop and start function being embraced by many manufacturers has an impact on some applications, such as windshield wipers. With the stop and start function, the mission profile for a wiper system dramatically increased in terms of the number of switching cycles, far beyond the capability of any common relay. As a result, the relay is no longer adequate to perform as expected over the lifetime of the vehicle. This same situation occurs for relays in other applications such as pumps and the HVAC system.

The cost savings behind wiring harness optimization and vehicle weight reduction drive the second argument for overhauling automotive power distribution architecture via electrification. For example, in the European Union (EU) communities, the cost per gram of over-limit CO_2 emissions will increase in 2019 to 95 Euros for the first gram that exceeds the EU limit. Avoiding these costly penalties

	Dry contact relays EMR (electromagnetic relays)	Smart power SSR (solid state relays)
Power consumption	~ 2 W (Coil)	~ 50 mW (5 mA)
PCB space	~ 20 x 20 x 20 mm	~ 9 x 9 x 2 mm
Blocks reverse current	YES	YES
ON/OFF cycles	< 300 K	> 1M
Bounce-free switching	NO	YES
Magnetic Interference	YES	NO
Contact aging	YES	NO
Wetting current	YES	NO
Power dissipation	~ 1 W (Contact)	~ 1 W (Ron)
Leakage current	Small	Few µA
Prevent arcing	NO	YES
Direct drive from UC	NO	YES
PWM control	NO	Up to 1 kHz
Silent switching	NO	YES
Response time	< 10 ms	20 µs range
Protection & energy discharge	NA	YES
Normally closed contact	Possible	Two smart power SSRs needed

Table 1. Comparison between a mechanical relay and a solid-state relay

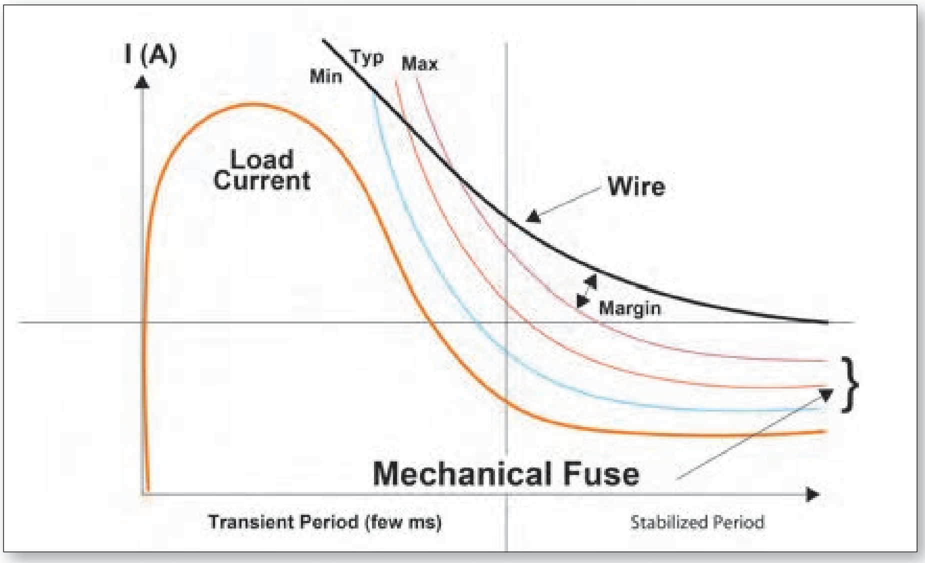

Figure 2. Inaccuracy is a major problem associated with mechanical fuses and a cause of over-specifying wire size.

should motivate OEMs to optimize and trim wiring harness weight, especially since the harness for a mid-line vehicle has an average weight of 30kg. The last trend is globalization. With mega-platform approaches, OEMs can minimize engineering time and the associated cost as well as reduce the overall time-to-market for new vehicles. A single platform provides commonality for a range of vehicles at a minimum of engineering effort and expense. For semiconductor suppliers, the wiring harness including power distribution must be as flexible as possible to be compatible with low- to high-end cars. The replacement of mechanical relays with semiconductor technology has been proposed for over 30 years and the capability to replace fuses has been possible for almost 20 years. However, significant reductions from existing alternatives are required to make the transition compelling enough to reject the status quo. Today, some OEMs still need to initiate the design activity required to make this transition. Solid-state relays have several differentiating features and benefits compared to mechanical versions. Table 1 shows a comparison of well-known characteristics. One of the more well-known problems of mechanical relays is contact bounce. Contact bounce or rebound can create dV/dt values up to 300 V/µs. Eliminating all the mechanical relays will allow the reduction of electromechanical interference (EMI) noise in the harness. One example of an incentive for replacing mechanical relays is a safety regulation that requires anti-pinch diagnostics/protection. For a mechanical relay, meeting this regulation requires many additional components that make the mechanical design much more expensive. These expensive elements add even more justification to increased system requirements. With 48V, mechanical relays will have severe challenges to be compliant. A modern high-end vehicle can easily have 100 fuses and four fuse boxes that need to be accessible for servicing and fuse replacement. The cost of this space and access in the passenger compartment is very expensive because it detracts from passenger comfort. Since a solid-state protected device (an electronic or eFuse) does not have to be replaced after a short circuit occurs, it can be placed in an area that is not easily accessible. This configuration simplifies vehicle design and provides additional passenger compartment space. In contrast to the mechanical fuse that is designed for a single value and is not programmable, an eFuse can be programmed for 10, 15, 20 or however many amps are required. This flexibility makes the electronic fuse fully compliant with mega-platform vehicle designs.

Mechanical fuses, especially the ones being manufactured today, have inaccurate minimum and maximum values that require the wiring to be oversized to have sufficient safety margin under all extremes. Common aftermarket replacement fuses play a significant role in meeting the oversizing requirement to avoid unsafe operating conditions and ensure that the fuse protects the wiring under all operating conditions. Figure 2 shows how the wire size must have greater safety margin because of the inaccuracy of mechanical fuses nowadays. Today, the main driving force for electronic replacement comes from carmakers and not the semiconductor industry. The OEMs know the value of the transition and are requesting the electrification of the car. While the silicon solution is more expensive, the carmakers calculations have led them to conclude that there will be cost savings at the system and vehicle levels.

Changes to the vehicle power distribution architecture depend upon the affordability of the solution to replace mechanical relays and fuses. As a result, this electrification is expected to go through several steps or phases. The first step could occur between 2018 and 2022. This phase will involve an electrification of the mechanical components but the architecture will remain the same. Electronic relays and electronic fuses will simply replace mechanical relays and fuses. Later, between 2020 and 2030, a transition to connected smart junction boxes and smart fuse boxes will occur and take full advantage of all the benefits that electrification can bring by revisiting the architecture to optimize the wire harness size, align it with the source capabilities and be ready for an autonomous car with a full safe and fault tolerant architecture. Some emerging concepts are under analysis at NXP to prepare for this future revolution. However, the electrification revolution cannot be solved by one company alone, and it needs cross-industry alignment. ■