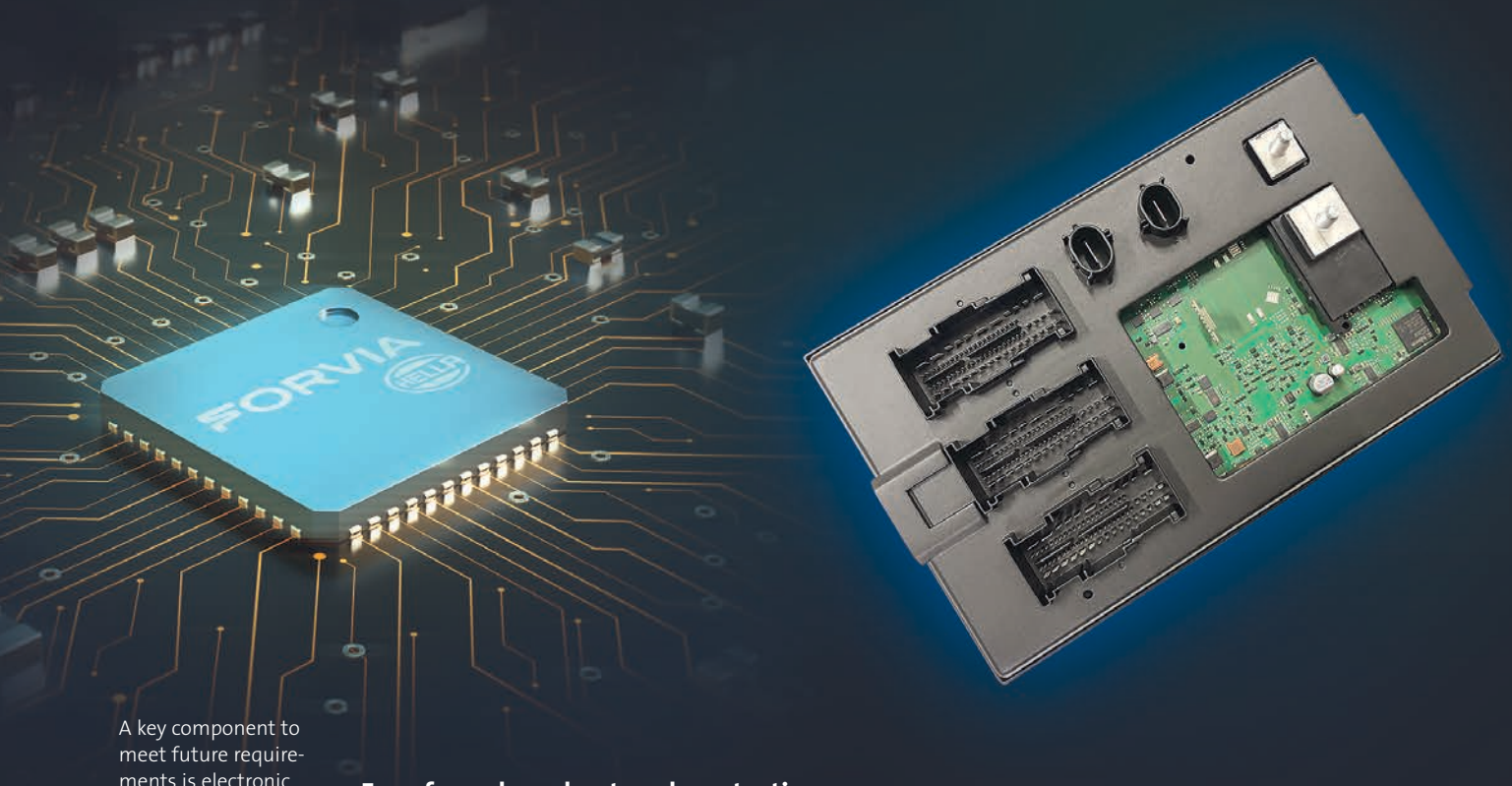


A key component to meet future requirements is electronic fuses, known as eFuses. Instead of the fuse wire, semiconductor elements take over the fuse function.

eFuse for onboard network protection

From Cable Protection to Proactive Fault Management

Vehicles equipped with advanced automated driving functions require an onboard network that ensures maximum system availability even in the event of defects in the wiring harness or connected consumers. Instead of traditional fuses, electronic fuses, known as eFuses, are used.

At a glance

- *Instead of the fuse wire eFuses use semiconductor elements for the fuse function.*
- *The next generation of FORVIA HELLA's eFuses is iConF, which is based on specifically tailored ASICs.*

FORVIA HELLA optimizes the eFuse concept both functionally and cost-effectively with a system approach based on specific ASIC development and a new topology for future E/E architectures of 'Software Defined Vehicles' (SDV). Additionally, it is developed into an intelligent energy distribution system that detects anomalies early and takes proactive measures to maintain system functionality.

Limitations of Conventional Fuses

Fuses in vehicle onboard networks serve the purpose of overcurrent protection. By the defined burning of a thin conductor, excessive current flow and thus excessive heat development in the vehicle's wiring harness are prevented. Without this protective measure, a fault in the E/E architecture could lead to damage to cables and other components, potentially resulting in a vehicle fire.

The principle of a fuse allows for fail-safe behavior, meaning that triggering the fuse cuts off power to the respective wiring harness and connected systems. For future challenges to the onboard network, this approach is no longer sufficient. An example is automated driving functions (SAE 3 and above), where the E/E architecture plays an active role in vehicle control. Instead of fail-safe, the fuse concept must be fail-operational, ensuring the desired target functionality continues even in the event of a fault.

Electronic Fuse eFuse iConF

A key component to meet future requirements is electronic fuses, known as eFuses. Instead of the fuse wire, semiconductor elements take over the fuse function. Depending on the design, eFuses use classic high-side drivers, gate drivers, and MOSFETs. Additional components are needed for logic, stabilization, availability, and energy management. To reduce this complexity, FORVIA HELLA develops an eFuse consisting only of a logic part (ASIC) and a power part (MOSFET), the iConF. FORVIA HELLA's eFuses can handle operating currents from 100 mA to 250 A and peak currents of up to 800 A – or more if needed – and offer additional functions such as overcurrent protection, overvoltage protection, undervoltage protection, voltage measurement, or current measurement, and secure energy supply. Extensive functionality supports not only the integration of current system functions into the vehicle but also facilitates the transition to automated driving for automotive manufacturers.

Due to significant development challenges, standard development methods are increasingly reaching their limits with modern eFuses. FORVIA HELLA has therefore implemented an advanced systems engineering approach for consistent and holistic development that connects all subsystems and phases. Through this concept, where hardware and software are developed in

alignment, it is possible to cover the requirements resulting from the use cases for eFuses.

Figure 1 shows the power and control paths of the first-generation eFuse from FORVIA HELLA. With the currently developed second-generation eFuse iConF, this concept is significantly simplified. FORVIA HELLA implements the self-developed eFuse in its own control units, but also offers the system as a complete, coordinated hardware and software solution for integration into third-party control units on the market. System suppliers and OEMs with their own control unit development can quickly and easily adopt a robust, coordinated modular and configurable eFuse solution for their systems. To simplify the application, predefined software elements are available that only need to be parameterized according to the respective requirements.

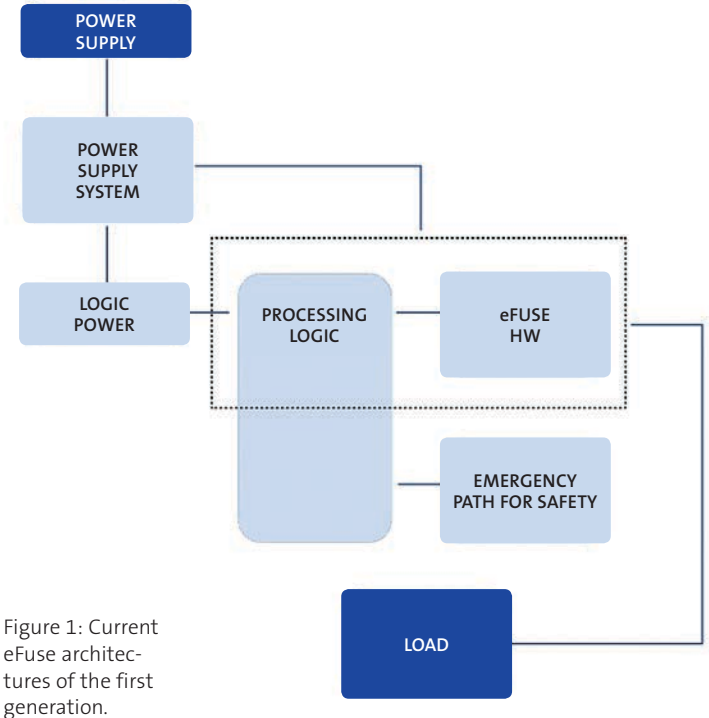


Figure 1: Current eFuse architectures of the first generation.

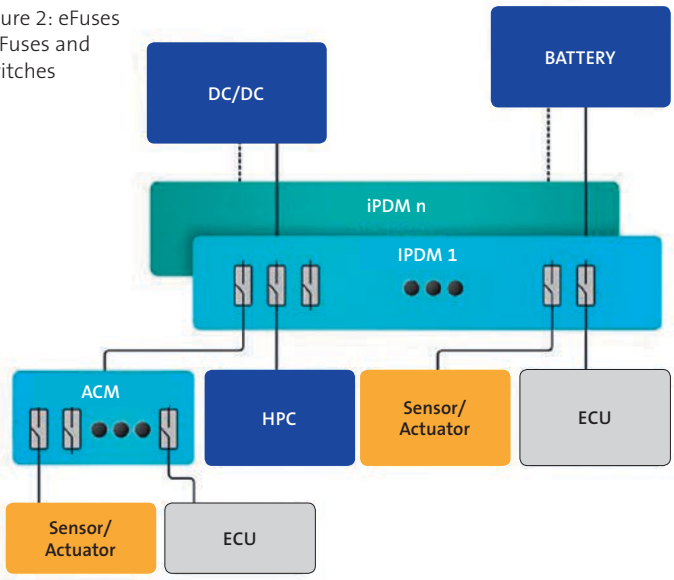
eFuse Implementation in E/E Architecture

Based on extensive experience over the past decades in developing and manufacturing complex control modules and energy distribution systems, a strategic system development was initiated, analyzing future challenges in vehicle energy supply and translating them into advanced eFuse product development. In modern vehicles, onboard networks are state-of-the-art, where one or more intelligent Power Distribution Modules (iPDMs) with integrated eFuses act as overarching power distribution and protection hubs for control units, sensors, and actuators. Additional Advanced Control Modules (ACMs), also known as zonal modules, enable secure functions. Examples include seat heating or electric window lifters.

IPDMs and ACMs offer uninterrupted power supply and maintain further eFuse functions across all control unit states, even in flash and sleep modes, ensuring the stability of critical circuits in all operating phases. The system is flexibly expandable and can be easily adapted to different onboard network requirements within a vehicle platform or model series. The decentralized arrangement of intelligent eFuses leads to improved operational efficiency and high scalability. Since eFuses can be automatically reset after triggering, they do not need to be manually accessible, resulting in shorter cable lengths with corresponding weight and cost savings, reduced space requirements, and accompanying the transformation to zonal E/E architecture.

FORVIA HELLA's eFuse system is designed for onboard network voltages between 12 and 48 V. Both in iPDMs and ACMs, identical components are used at the logic level, contributing to less variant formation on the software side. The software itself is standardized but flexibly scalable and configurable. The hardware at the power level is scalable and adapted to the respective needs. By adopting standardized hardware, this solution simplifies production processes and reduces complexity.

Figure 2: eFuses as Fuses and Switches



Design of Fuses

When designing fuses – both conventional fuses and eFuses – a multitude of requirements must be considered, which arise from the respective use case. The basic function is overcurrent protection. Figure 3 schematically shows the I^2t diagram (limit load integral) of an exemplary cable strand that is to be protected by a fuse. The blue curve represents the maximum current in the circuit, which occurs at the maximum during normal system function of the connected consumer. In the event of a defect, such as a component failure, higher currents flow, meaning the current curve shifts to the right side of the blue curve. The gray dashed line marks the desired triggering of an eFuse. The software-based application of the eFuse considers multidimensional criteria such as current, voltage, and temperature and their temporal dynamics. By adjusting the various parameters, an eFuse triggering curve can be developed that provides optimal protection tailored to specific requirements.

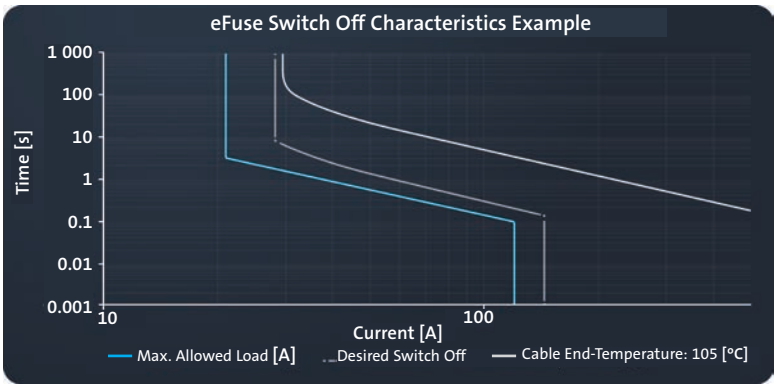


Figure 3: I²t diagram (limit load integral) of an exemplary cable strand that is to be protected by a fuse.
Images: FORVIA HELLA

Own ASIC Development

FORVIA HELLA has a long tradition of collaboration with development partners in specialized areas such as chip manufacturing and has established itself as an innovation driver in hardware and software development over the past decades. From these collaborations, FORVIA HELLA develops the next generation eFuse concept, the iConF. This is based on specifically tailored ASICs. The iConF relies on more than 15 years of eFuse development and currently offers the only scalable and flexible technology on the market that addresses all critical use cases where conventional eFuses can cause problems. For complete coverage of eFuse requirements, the iConF offers:

- Flexible characteristics and scalability
- Pre-charging of loads
- Support for „Always On“ systems with low standby current
- Self-protection while ensuring secure energy supply
- Secure supply in all control unit states, e.g., during flashing
- Independence from the microcontroller
- True ASIL-capable energy supply.

Compared to standard chips, ASICs offer cost advantages and significantly greater application possibilities, as system parameters can be freely programmed. Peak loads are recognized even more securely and mitigated through intelligent energy distribution. Instead of simple overheating protection, securing load supply in terms of maximum availability of important system functions comes to the forefront.



With eFuse to Active Fault Management

The iConF approach is expanded into a comprehensive fuse concept that translates theoretical advantages into practically applicable functionalities. This entails a shift from a reactive system to proactive protection. The system distributes and manages energies in the onboard network before a shutdown leads to unpredictable consequences and high costs. Decentralized architecture promotes system modularity, resulting in less effort for hardware and software development, application, testing, and maintenance, while further increasing robustness and functionality. Additionally, seamless integration into future E/E architectures of 'Software Defined Vehicles' (SDVs) is enabled. The new safety concept based on the iConF is already part of series development and is expected to go into series production by 2027.

Consistent hardware and software development opens the possibility of integrating additional detection and monitoring functions into the eFuse concept. Through real or virtual sensors, eFuses can detect anomalies in power consumption, current flow, and voltage early and counteract them. FORVIA HELLA is working on novel AI methods and cloud-based digital twins to further improve predictive maintenance capabilities. Algorithms are currently being developed based on long-term data from components such as actuators and sensors to recognize system anomalies and incorporate them into predictive maintenance. This supports the potential of eFuses as an intelligent diagnostic tool. The integration of predictive maintenance services into eFuses will occur in the coming years.

Summary and Outlook

To implement future requirements for eFuses, functionally secure and cost-optimized solutions are necessary. In 2025, a modular eFuse platform based on FORVIA HELLA's eFuse system development will go into series production at a German premium OEM, tailored to specific requirements. By 2027, the iConF will be launched on the market. Compared to standard chips, ASICs offer cost advantages and greater application possibilities, as system parameters can be freely programmed. Identical hardware components are used at the logic level, contributing to less variant formation on the software side. The software itself is standardized but flexibly scalable and configurable. The hardware at the power level is scalable and adapted to the respective needs. The advantages include higher functionality and lower costs. This concept is also a pioneer for new E/E architectures with centralized control unit topologies, specifically designed for SDVs.

Further into the future, concepts are being developed where the eFuse is advanced into a system that recognizes anomalies and counteracts them through energy management before a shutdown leads to unpredictable consequences and high costs. The introduction of predictive system functions, including the use of modern AI methods and cloud-based digital twins, is expected from 2029. FORVIA HELLA is thus a driver of economically attractive and technically advanced onboard network solutions for future vehicle architectures. The future oriented eFuse concept iPDM, along with the predecessor of iConF, was awarded the PACEpilot Award by Automotive News and an award by CLEPA, the European Association of Automotive Suppliers, in 2024. *(na)* ●

Authors:
Dr.-Ing. Christopher Lankeit, Lead System Engineer at FORVIA HELLA
Daniel Klimeck, Head of Hardware Foundation Body Control at FORVIA HELLA
Dr.-Ing Olaf Lüdtke, Vice President Product Segment Body Control at FORVIA HELLA