How a Zone Architecture Paves the Way to a Fully Software-Defined Vehicle

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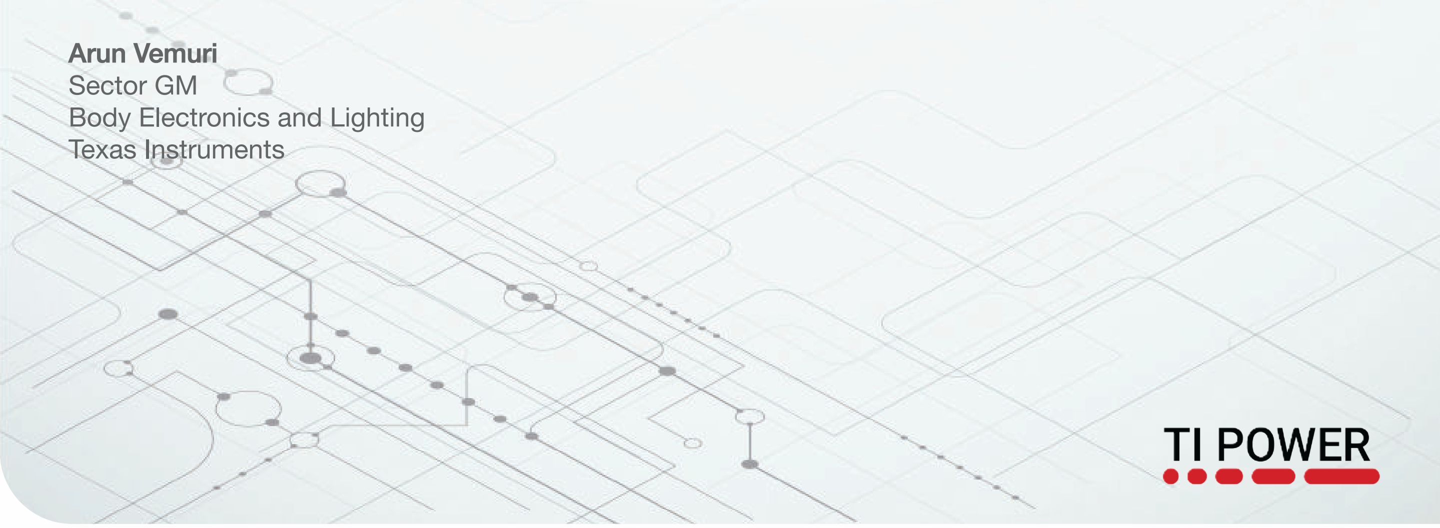

At a glance

This paper looks at the transition to software-defined vehicles and how moving to a zone electric/electronic (E/E) architecture addresses power distribution, sensor and actuator, and data communication challenges.

1 Power distribution challenges and solutions

Explore implications of new zone architectures on automotive power distribution.

2 Smart sensor and actuator challenges and solutions

Understand separation of physical and logical IO functions and the impact on sensors and actuators.

3 Data challenges and solutions

Learn about the mix of data types required and their coexistence while maintaining communication security.

Introduction

Electronics have played a key role in automotive system innovations in the past several decades. The incorporation of new semiconductor devices with novel features has enhanced the functionality offered by the vehicle's mechanical systems.

While semiconductor solutions and electronics continue to play a key role in vehicle electronics, looking ahead, innovation in vehicles will be much more characterized by innovations in and consolidation of software. This change in software architectures is enabled through the development of relevant hardware and semiconductor solutions.

Overcoming E/E architecture challenges

Today's E/E architectures primarily employ a domain architecture, organizing electronic control units (ECUs) and cabling together into specific domains such as the powertrain domain. In contrast, zone architectures group many – if not all – domain functions based on their geographical location, or zone, inside the car.

Figure 1 illustrates the domain and zone methods of grouping the vehicle functions, while **Figure 2** shows a more detailed view of the zone architecture that includes a central computing node called Vehicle compute.

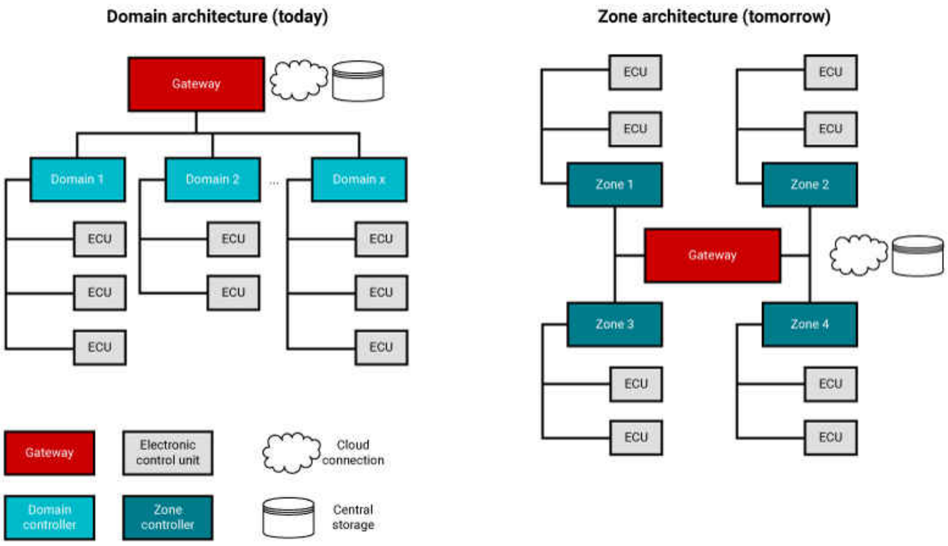

Figure 1. *Domain vs. zone architectures.*

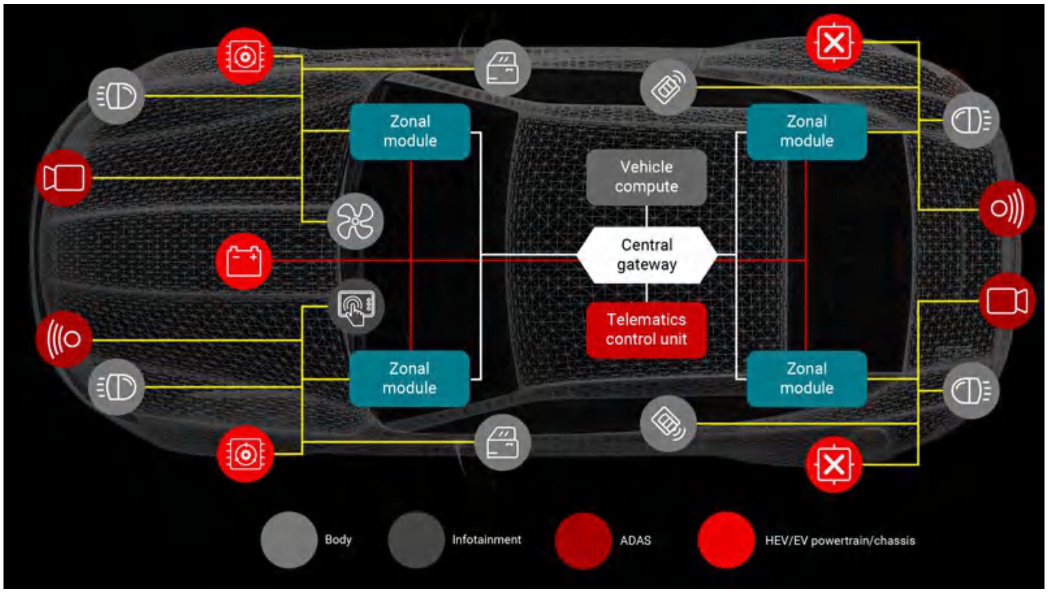

Figure 2. *A typical zone architecture in a car showing sensors, actuators, zonal modules and a central computing node.*

This transformation from a domain to a zone architecture will facilitate independence of sensors and actuators from the central vehicle compute node. In other words, hardware and software update cycles can differ, and sensor and actuator designs can last a more vehicle design cycles. Moreover, zone architectures will reduce the number of ECUs and cable lengths, simplifying the vehicle architecture and the associated system validation effort.

The zone architecture gives OEMs much more control, from high-level software maintenance with over-the-air updates; firmware-over-the-air (FOTA) updates and always-on cloud connection to enable new functions and to improve features such as autonomous driving. This will also allow OEMs to move to a service-based software structure, such as shifting real-time control loops to the zone modules. Additionally, zone modules enable more optimized power distribution topologies and including powering down of unused modules, which is especially advantageous in battery electric vehicles and hybrid electric vehicles.

Despite the potential for tremendous improvements through zone architectures, there are challenges in the areas of power distribution, sensors and actuators, and data-plane topologies. Power distribution will transition from a centralized to a decentralized implementation using smart fuses located in the zonal modules. Sensors and actuators will become smart. Some functionality – including control loops – will move to zonal modules in order to permit the increase of service- vs. signal-based communication. And finally, data communication will occur over higher-speed networks, with new physical layers (PHYs) transmitting a variety of data types.

Power distribution challenges and solutions

The battery must supply power to most ECUs, which are distributed across the vehicle. In domain architectures, power distribution boxes comprising melting fuses and relays distribute this power, as shown in **Figure 3**.

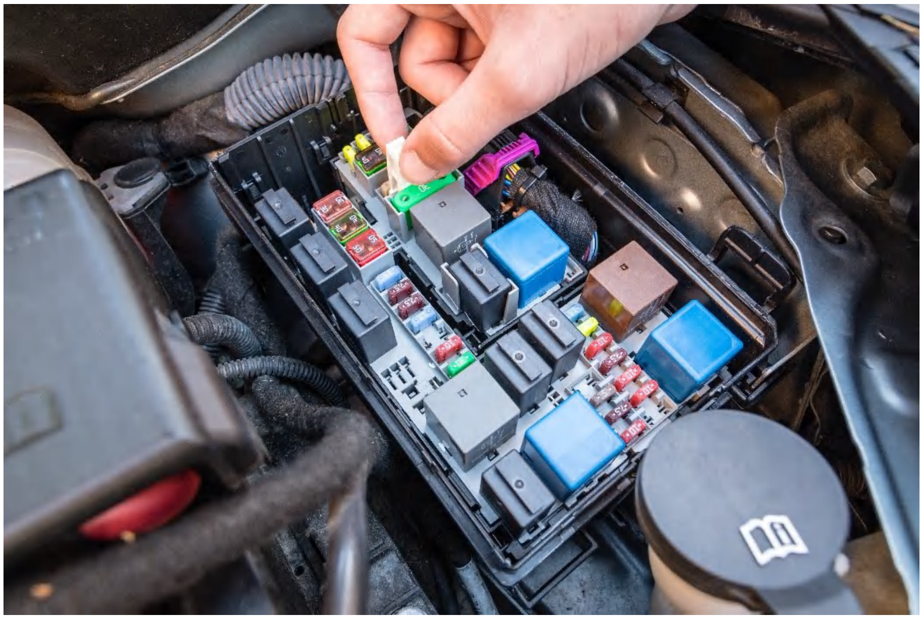

Figure 3. *A typical power distribution box with melting fuses and mechanical relays.*

The melting fuses in the power distribution box have different time-current characteristics (TCC) in order to support different types of wire harnesses and loads in the car. The box is located in an accessible spot in the vehicle in order to replace the fuses easily.

While **Figure 3** shows no semiconductor content in the power distribution box, OEMs are upgrading these distribution boxes with semiconductor content; relays are being replaced by semiconductor high-side switches and input/output control lines are being replaced by communication interfaces such as Controller Area Network (CAN) and Local Interconnect Network (LIN) transceivers.

The motivation for using a semiconductor-based power distribution box is manifold – enhanced diagnostics, fault protection, resettable fuses, small-form-factor designs and harness wire weight reduction.

As OEMs implement zone architectures, system designers are rethinking power distribution with two additional considerations: decentralization of power distribution and replacing melting fuses with semiconductor fuses.

Decentralization of power distribution

The zone architecture uses zone gateways to distribute data to the smart sensors, actuators and ECUs in the zone and to consolidate data for communication to the central computing modules. These zone data gateways can also distribute power to modules in that zone. For example, if routing a single power harness from the battery to the zone, the zone module in that zone then distributes power to the modules in that zone. Figure 2 also illustrates this concept, in which the zone modules distributes power to module in that zone. That is, the zonal module includes relevant fuses and relays required for distributing power.

The advantage of this power distribution method is reduction in the length of power harnesses routed from the battery to each zone when compared to the length of harness wires required for centralized power distribution. This reduction directly translates to lower weight and cost.

In decentralized power distribution, one of the challenges is to design power distribution boxes that work in any zone, regardless of the loads in that zone, not only to help lower design costs but also to alleviate inventory management. Using smart power distribution boxes that include semiconductor microcontrollers (MCUs), high-side switches and transceivers makes it possible to configure the hardware using software to match the loads in that zone.

Replacing melting fuses with semiconductor fuses

A standard melting fuse interrupts the flow of current by melting for large currents. The TCC curves shown in **Figure 4** characterize this melting behavior.

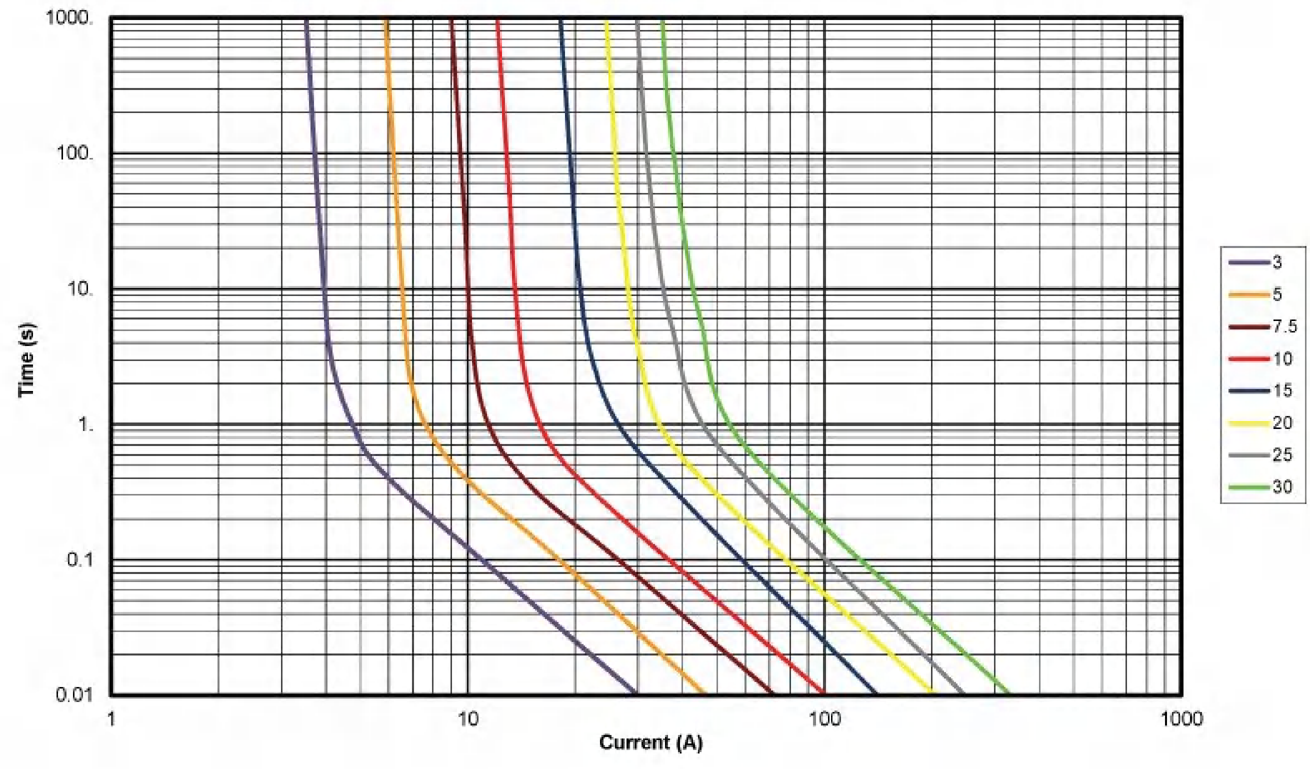

Figure 4. *TCC curves of Littlefuse microfuses.*

Many factors influence fuse characteristics, such as contact resistance, air temperature and current transients. Because of these factors, system designers derate a fuse's nominal melting point I^2t (Ampere squared seconds) rating based on the nominal operating current, operating temperature range, inrush currents and current transient shapes. For example, derating the nominal current rating of the fuse by 25% may prevent the fuse from experiencing nuisance blowing.

The selection of fuse-based derated currents implies that the currents in the harness varies depending on the temperature conditions at the fuse. Harness designers may have to select less-optimal harness gauges in order to pass higher currents allowed by the fuse under certain temperature conditions.

One idea to further optimize harness wires is to use semiconductor high-side switch integrated circuits (ICs) with I^2t characteristics. A typical high-side switch includes overcurrent protection; that is, when the current exceeds a certain threshold, the high-side switch either clamps the current or opens itself, thus protecting the downstream wire harness and load. By adding an I^2t feature to the high-side switch, the switch opens at varying times depending on the current (or more specifically, the current squared) flowing through. Using I^2t-based semiconductor high-side switches leads to less variation in fuse characteristics, which leads to more optimized wire harness gauges, which helps further lighten the weight of the harness.

Smart sensor and actuator challenges and solutions

The zone E/E architecture significantly affects sensing and actuation functions at the boundary of a vehicle – the so-called edge. In domain architectures, dedicated ECUs that are typically in proximity to the sensors or actuators perform these functions. New features and functions usually result in new ECUs, each with dedicated battery power and networking wires, further increasing harness complexity. The introduction of zonal modules can greatly reduce harness complexity by merging the logical input/output (I/O) functions of multiple ECUs into the zonal module, and by maintaining sensor and actuator locations. This results in separation of physical and logical I/O functionality as shown in **Figure 5**, which brings new challenges and demands new solutions.

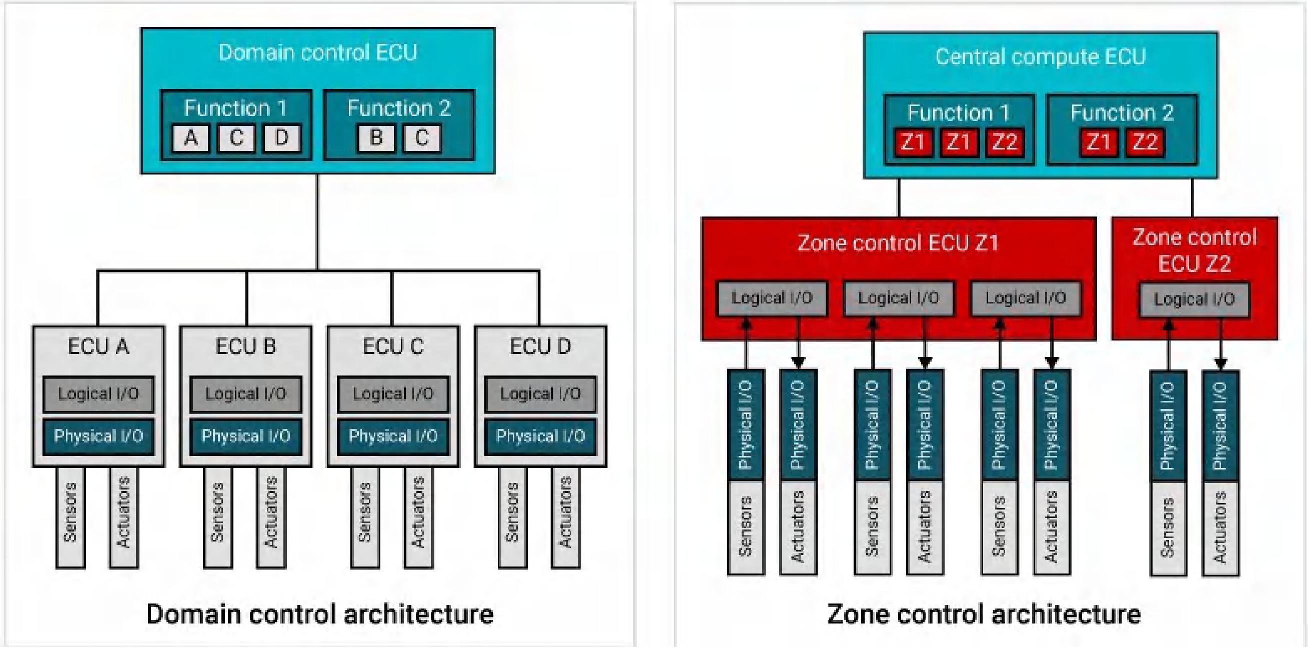

Figure 5. *Separation of logical and physical I/O functionality from a domain architecture to a zone architecture.*

Zonal modules –new microcontroller requirements

The integration of different logical I/O functions – including control loops – in a single zonal module means that the module inherits the sum of the individual requirements per I/O function, resulting in these specific requirements for microcontrollers (MCUs):

- High real-time performance
- A large amount of program and data memory
- Mixed-criticality support for functions with different Automotive Safety Integrity Levels through virtualization
- High-speed communication interfaces toward the backbone
- Multiple instances of low-end communication peripherals (such as CAN FD or LIN) to interface with smart sensors and actuators

Addressing this diverse list of requirements necessitates MCUs to support zonal module driven requirements. In the meantime, heterogenous system-on-chips (SoCs) with sufficient real-time capabilities such as the Jacinto 7 (for example, DRA821) or Sitara (for example, AM2xxx) devices from Texas Instruments (TI) can bridge the gap until optimized zone MCUs are available.

Smart sensors and actuators

The separation of logical and physical I/O functions affects the sensors and actuators. ICs targeted for conditioning sensor signals and driving actuators require enhancement with local intelligence and communication capabilities. Local intelligence maintains the state of the circuit and may run background diagnostics to detect sensor or actuator faults. The integrated communication interface includes at least a protocol handler such as a LIN responder implementation or even a simpler version of the CAN FD data link layer. Such integration would enable the smart IC to autonomously control a sensor or actuator and create a cost- and size-optimized solution that could be integrated into the sensor or actuator housing, as shown in Figure 6 (a).

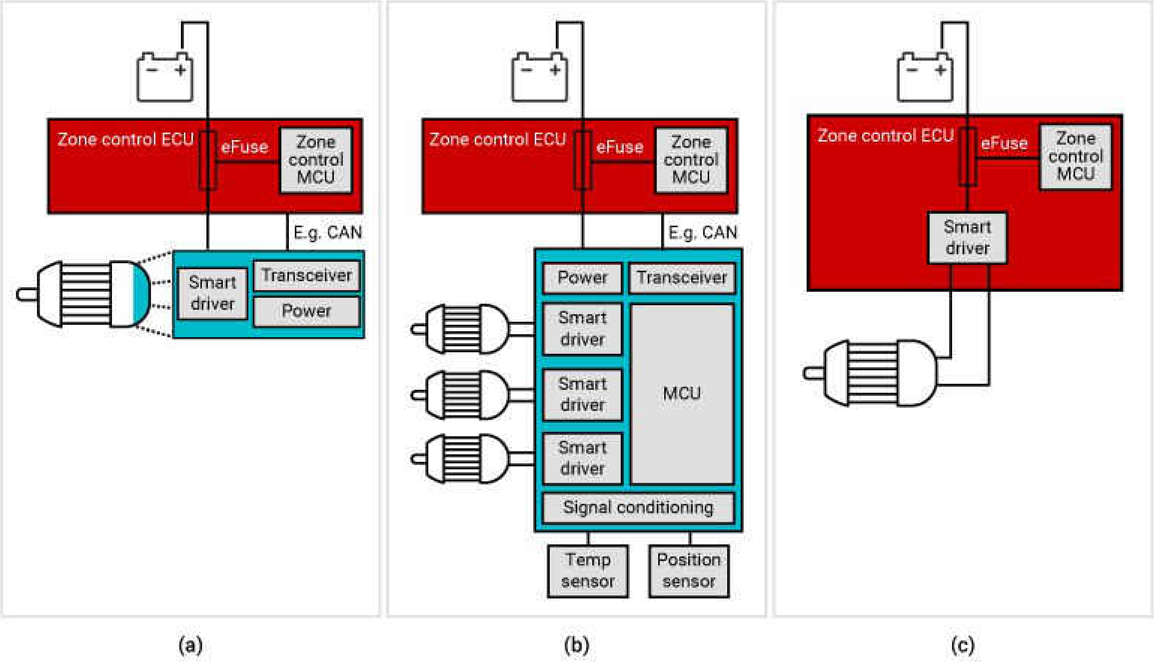

Figure 6. *Driver implementation examples: smart driver integrated in confined housing (a); small ECU for composite actuator solutions (b); simple actuator controlled from a zonal module (c).*

For more complex sensors (such as a radar satellite) or composite actuators (such as a seat control unit with various motors), a classic approach based on a small ECU might remain the most efficient solution (see Figure 6 (b)). Additionally, dedicated signal lines from a zonal module (see Figure 6 (c)) can directly control very simple sensors or actuators.

Depending on aspects such as the number of control and sense signals, sensor and actuator complexity, and mounting constraints, designers may selectively choose any one of these solutions.

Data challenges and solutions

The zone topology needs a new and bigger focus on networking; thus, high-bandwidth interfaces such as Peripheral Component Interconnect Express [PCIe] and gigabit Ethernet are gaining momentum. The right physical layer (PHY) can address the bandwidth requirements.

Figure 7 is a block diagram of a typical zonal module that includes high-speed communication links. For the different throughput needs, and to provide bandwidth for a combination of traffic between the zonal module and central computing, gigabit Ethernet, and potentially PCIe could be vital. In several cases, deploying PCIe retimer or redriver devices for long-distance cable connections can be advantageous. For zonal module connections to and from sensors and actuators, there might be a contrasting need for even lower-bandwidth – and thus cheaper – bus systems such as LIN. Common to all is the provision of a standardized bus with standardized software control to employ a complete service- and software-based approach.

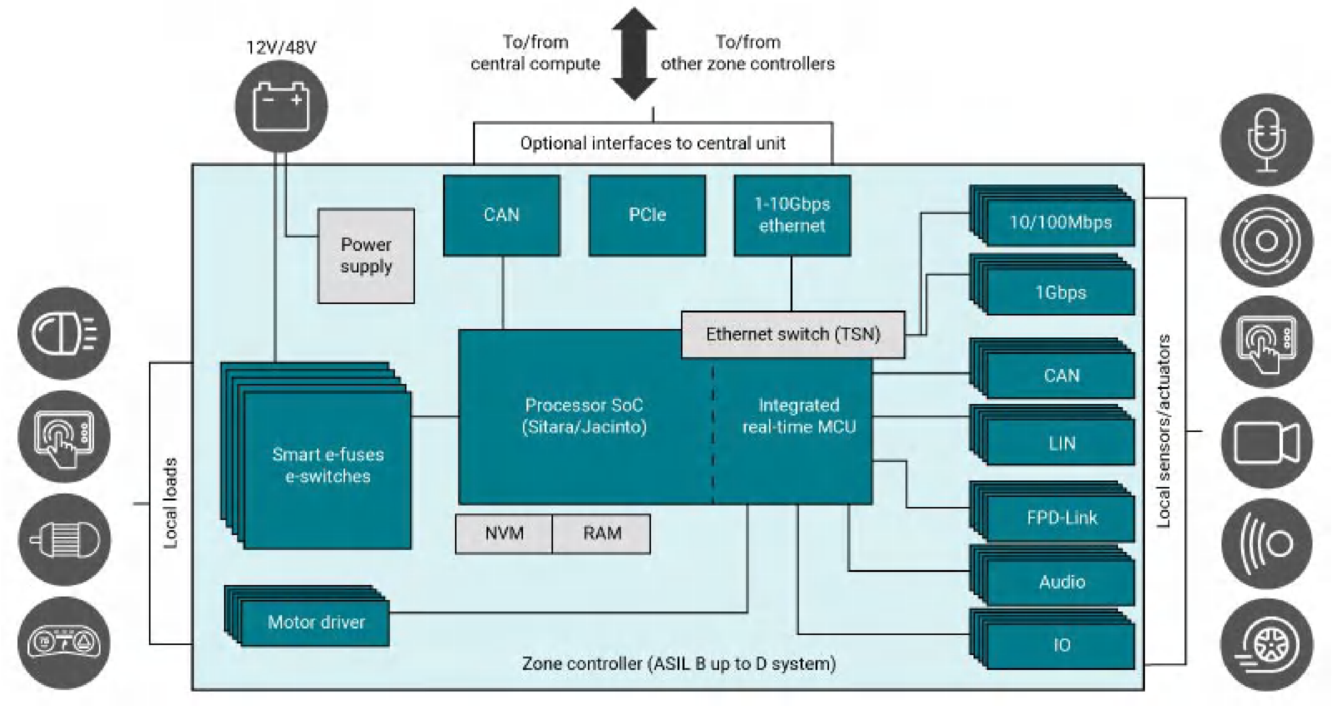

Figure 7. *Zonal module block diagram with communication interfaces.*

For all links to be future-proof, the network topology secures spare bandwidth, especially between the zonal module and central computing, to enable software upgrades while maintaining existing and already validated hardware.

Types of data

Future-proof also means a path toward fully autonomous driving (up to Level 5); thus, the architecture includes availability, resiliency and safety standards. One way to reach data communication resiliency and structural redundancy is through a ring topology, enabling multicast protocols and data validity checking.

On the software side, it is essential for a distributed zone topology to handle a mix of very different packet types to accommodate data ranging from a short control message to high-throughput sensor and infotainment data. All of these traffic types additionally vary in latency, jitter, synchronization and error-rate requirements. In short, they vary in terms of quality-of-service (QoS) needs.

Time sensitivity of data

To accommodate different latency or QoS requirements, Ethernet-based time-sensitive networks (TSN) are a good option, but this deployment needs a lot of fine-tuning; older MCUs and processors might not even support this fully in hardware. PHY IC-level or switch support can help, especially considering time synchronization.

In many cases, the integration of multiple Ethernet ports in a single SoC can be a big advantage to save on board space and cost.

For audio, many infotainment architectures already use audio video bridging (AVB), for which time synchronization is important (see the TI E2E™ technical article, "**Optimizing eAVB for Automotive Applications Using Clock Generators**"). AVB networks are well proven, but they are agnostic to many concurrency problems when deployed in a domain architecture. With the move to a zone architecture, which combines all kind of data traffic, the newer TSN features gain importance.

Table 1 lists some Institute of Electrical and Electronics Engineers (IEEE) TSN standards that could be relevant for zone architecture implementations. For more information, see the white paper, "**Time-Sensitive Networking for Industrial Automation**."

Standard	Alias	Description
IEEE 802.1AS	Timing and synchronization	Provides Layer 2 time synchronization
IEEE 802.1Qbv	Time aware shaper (now: enhancements for scheduled traffic)	Runs the 8-port output queues of a bridge on a rotating schedule. Blocks all ports except one based on a time schedule in order to prevent delays during scheduled transmission.
IEEE 802.3br	Interspersed express traffic	Interrupts transmission of an ordinary frame to transmit an "express" frame, then resumes the ordinary.
IEEE 802.1Qbu	Frame pre-emption	Improves the interruption of non-time-critical frames to enable time-critical frame throughput.
IEEE 802.1CB	Redundancy	Messages are copied and communicated in parallel over disjoint paths; redundant duplicates are removed at the receiver end.
IEEE 802.1Qch	Cyclic queuing and forwarding	Collects packets according to their traffic class and forwards them in one cycle. Provides a simple way to use TSN if controlled timing is a priority but reducing latency isn't important (can be covered by IEEE 802.1AS and IEEE 802.1Qbv).
IEEE 802.1Qci	Per-stream filtering and policing	Filters frames on ingress ports based on arrival times, rates and bandwidth to protect against excess bandwidth usage and burst sizes, as well as against faulty or malicious endpoints.
IEEE 802.1Qav	Traffic-based credit shaper	Avoids bursts of frame (same class or stream); change priorities between traffic classes or streams.

Table 1. *Some relevant TSN standards for automotive real-time applications.*

For audio use cases, latency targets are less strict than for powertrain or chassis control use cases (milliseconds versus microseconds). But even when routing a lot of meta or configuration data traffic or a massive amount of ADAS sensor data through the same network, the audio latency requirement cannot be violated – packets cannot be dropped. That's why arbitration and fine-tuning of the existing TSN knobs is important. One well-known knob is time aware shaping (TAS), available in TI's processor SDK referenced as enhancements for scheduled traffic (EST) offload. TAS guarantees the transfer of lower-bandwidth traffic after a pre-defined time window, no matter how much other data (such as ADAS sensor data) is transported in parallel. In the best case, integrating the TSN hardware switch as in TI's processors, such as DRA821, offers full software flexibility, while being supported by hardware accelerators for data packet handling and forwarding or willingly dropping.

Communication security

Besides physical network properties like latency and jitter, the zone architecture requires a secure communication path. Ethernet-based attack methods and tools common on the internet will be largely applicable to road vehicles. When security is compromised in a car network, no trustful communication is feasible, and the whole concept of separating I/Os from computing collapses.

For these reasons, it is important to approach the cyber security topic holistically. Beyond the core functionality of data integrity, authenticity and confidentiality, a security mindset and culture accompanies the whole product development and life cycle. Similar to the International Organization for Standardization (ISO) 26262 functional safety standard, ISO/Society of Automotive Engineers ISO/SAE 21434 is a new standard for automotive cybersecurity engineering. In addition, the United Nations Economic Commission for Europe has released two new regulations that specify how to manage vehicle cybersecurity risks, and how to detect and respond to security incidents across a fleet of cars.

It is not possible to simply add security for such a diversity of data types; communication efficiency is also paramount. The classic approach of securing internet protocol packets with IPsec is suited for control and sensor data consuming low network bandwidth. To stream audio data or vision or radar sensor data requires a continuous stream of Internet Protocol packets, secured at least through authentication. Doing so in software, however, would result in large overhead, consuming vital processor resources.

Overcoming the bottleneck demands new lower-level encryption and authentication. An example is MACsec, which can be applied to Level 1 or 2 of an Ethernet protocol and integrated either into the ethernet media access control IP or into the Ethernet PHY for line-rate authentication, payload encryption, or both.

Conclusion

Zone architecture requirements necessitate new solutions to overcome power distribution, sensor and actuator, and data communication challenges.

The transition to decentralized smart fuses, more use of smart actuators and sensors, and higher-bandwidth interfaces with the right support on very diffuse data-type combinations may address the most apparent design problems in zone architecture implementations.

These solutions will not occur all at once, but rather in a sequential evolution that introduces changes over time as and when they make sense commercially, while minimizing risk of delays for being too early. The body domain, with its many distributed actuator and sensor ECUs, will be one of the first domains that moves to the zone architecture. Transitioning of ADAS or power train and chassis control into the zone architecture may need more time.

The ultimate goal of the zone architecture is a fully software-defined vehicle that combines ideally standardized components for sensors, actuators, zonal modules and data links. With that goal in mind, very diverse ideas in many different fields are combining in a holistic fashion, enabling software-based innovation for decades to come.

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