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(R)evolution of E/E Architectures

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ABSTRACT

This paper presents an overview of the evolution & revolution of automotive E/E architectures and how we at Bosch, envision the technology in the future. It provides information on the bottlenecks for current E/E architectures and drivers for their evolution.

Functionalities such as automated driving, connectivity and cyber-security have gained increasing importance over the past few years. The importance of these functionalities will continue to grow as these cutting-edge technologies mature and market acceptance increases.

Implementation of these functionalities in mainstream vehicles will demand a paradigm shift in E/E architectures with respect to in-vehicle communication networks, power networks, connectivity, safety and security. This paper expounds on these points at a system level.

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INTRODUCTION

Electronics in automobiles has come a long way since their introduction in this industry a few decades ago. Automobiles of today rely on electronics more than ever before; to not only provide better implementation of functionalities but also to provide new, paradigm changing functionalities.

EVOLUTION/ REVOLUTION OF E/E ARCHITECTURES

Automotive electronics has evolved from only providing non-critical functionalities to assisting the driver in driving the vehicles of today. From electro-mechanical components for sensing and actuation to higher performance microcontrollers that process heavy information and control the vehicle, automotive electronics has evolved a great extent.

The trend of electrifying traditional pure mechanical systems has been ongoing for decades. From the introduction of ECUs that handled single functions (one box-one function system) to ECUs handling several functionalities in one box, there has been emphasis on integrating functionalities into lesser number of ECUs. And this trend seems to continue further with cheaper and more powerful electronic devices being available for automotive systems.

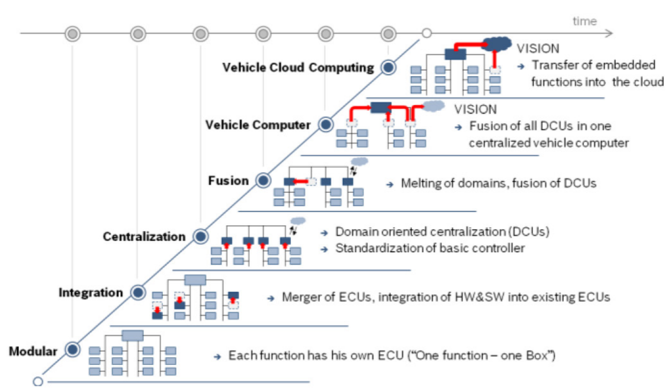

Figure 1. Evolution/ Revolution of E/E architectures

Not only are electronics getting cheaper, driven by innovations from consumer electronics, they are getting powerful every day, becoming more capable of handling several functions in a vehicle. And thus, the trend of integration of ECUs and functionalities will continue. Higher integration of ECUs will enable ECUs to controlling domains in a vehicle, thus becoming the master ECUs for each domain. Figure 1 shows the progress of E/E Architectures, from a modular approach to a more integrated approach leading to fusion of ECUs and domains ultimately leading to centralized computers handling the core functionalities of the vehicle.

Further integration would mean integration of tightly linked domains, enabling cross-domain ECUs. Our vision is that this trend will continue to eventually enable central vehicle computers which function as the masters of the vehicle. Not only this, but with better connectivity in the coming years, there will arise the possibility of using the cloud computing for processing intensive vehicle functionalities.

Technology Drivers

Developments in automotive electronics have advanced by several drivers that include market requirements and expectations, technology improvements and OEM/supplier strategies. These drivers will continue to influence the future of E/E architectures. Figure 2 provides an overview of the various trend drivers for the evolution of E/E Architectures.

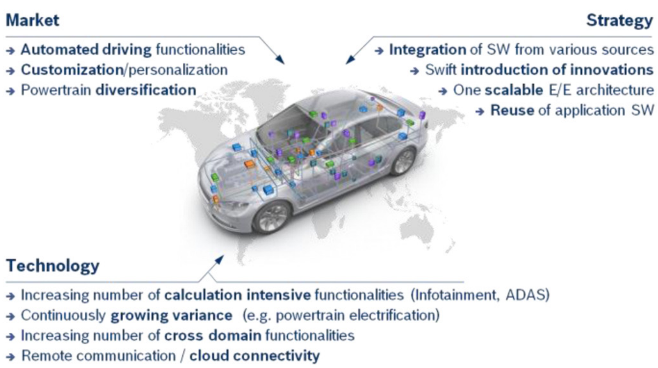

Figure 2. Drivers for evolution of E/E architectures

Market expectations from the vehicles of today and tomorrow greatly influences the E/E architectures of the future. The market today is only starting to accept alternate propulsion technologies such as electric hybrids and pure battery electric vehicles. In the future, the market demand from a powertrain perspective will be more diverse. The demand for powertrain technologies will range from the traditional pure internal combustion engine propulsion to more radical pure electric and fuel cell propulsion systems along with combinations of pure combustion and pure electric systems.

On the non-powertrain front, the market expects highly integrated functionalities such as automated driving. Enabling such technologies in the vehicles of tomorrow will require a significant change in today's E/E architecture to achieve the computational and functional effort required. Electronics that provide the computational strength needed to enable these functions not only requires great improvements in today's processing requirements for ECUs but also require improvements in sensing and actuation technologies while maintaining enough redundancies to achieve the required safety levels. Scalable E/E architectures that provide the flexibility to integrate software from various sources will effectively enable the integration of new innovations. This will ultimately provide a significant strategic advantage for manufacturers.

The market will also demand higher personalization and customization options in comfort and safety technologies. These technologies differ significantly in their attributes and component requirements, thus demanding higher flexibility in E/E architectures to accommodate such variability. The ideal future E/E architectures should readily accept these requirements with minimal effort. This will reduce the time to introduction of new innovations to the market.

Bottlenecks in Today's E/E Architecture

Today's E/E Architectures have been capable of handling the requirements of the past, but they may not be as effective for future requirements. There are several bottlenecks for implementing tomorrow's functionalities into today's E/E Architecture patterns. Figure 3 provides an overview to some of today's E/E Architecture bottlenecks: Communication bandwidth, external communication (connectivity), increasing number of variants, computational power, extensibility and feasibility.

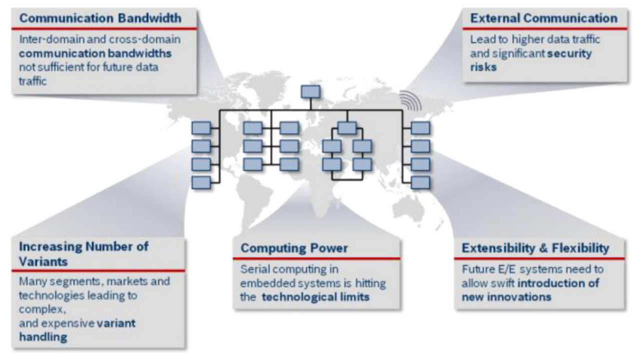

Figure 3. Bottlenecks of today's E/E architectures

The first of which is in-vehicle communication networks, which are today, primarily based on CAN with instances of FlexRay, LIN & MOST. Such in-vehicle communication networks provide bandwidth capabilities that have been capable of handling the functionalities over the past several years. The same networks, however, may not be effective in handling the intense requirements for automated driving and connectivity. These functionalities require much higher bandwidth, lower latency and higher security requirements. Consequently, newer protocols such as automotive Ethernet and CAN-FD will be required for the in-vehicle communication networks of the future.

These future functionalities will also require ECUs that are more capable than the ECUs of today. Further integration of vehicle functionalities will require future ECUs to have software mechanisms to provide safe separation of functions via mechanisms for hardware virtualization like hypervisors.

With newer, complex technologies, coupled with diverse propulsion systems, there will be a need for E/E architectures that are capable of handling several variants. This will enable manufacturers to meet a broad spectrum of market requirements and thereby reduce the costs of handling these variants with multiple architectures.

With the industry rapidly changing, there is a need to implement new technologies into existing E/E architectures as swiftly as possible. The typical development cycle of 5-7 years will not be feasible for introducing new innovations in automotive E/E systems.

Future E/E architectures will have to be designed keeping the idea of extensibility and feasibility in mind, which will provide strategic advantage in being the 'first to market' for new technologies.

Key Technologies for Tomorrow's E/E Architecture

There are a few key technologies in fulfilling the requirements and shaping the E/E architectures of tomorrow. These technologies will enable several new functionalities in the vehicles of tomorrow. Key technologies such as advance gateways, connected vehicles, domain ECUs, new in-vehicle communication networks and new software approaches are shown in Figure 4.

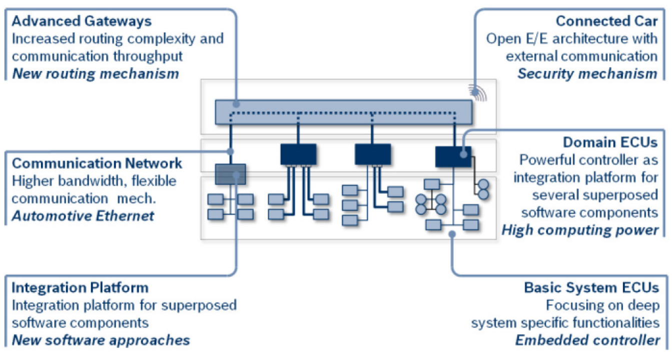

Figure 4. Key technologies for tomorrow's E/E architectures

In-vehicle communication networks with newer standards such as automotive Ethernet will fulfill the requirements for higher bandwidth while providing better security and safety measures. These characteristics help enable highly automated driving and high definition infotainment systems in vehicles.

With higher bandwidth in-vehicle communication networks, advanced gateways with new routing mechanisms will provide low latencies and high throughput through hardware based acceleration. In addition, hardware based acceleration mechanism will be required to off load CPU's loads which will be generated by the introduction of automotive Ethernet.

Higher performance multi-core ECUs will enable integration of application software into ECUs. This can be achieved through hardware virtualization methods like hypervisors. Hardware virtualization will enable further integration of ECUs.

With a growing number of use cases for connecting to the external world, such as over the air software updates, there will be an emphasis on utilizing its full benefits while keeping the vehicle secure and safe from malicious attacks.

Domains such as infotainment, chassis systems, body electronics, powertrain will be handled by additional domain controllers or integration platforms (e.g. engine control unit or ESP), that provide high computing power and work as masters of the domain by controlling and handling the higher level domain computations for the vehicle. And since domain ECUs will perform the bulk of the high level computation, current component blocks will handle only the basic component computations, thus enabling the possibility of standardized component blocks. The level of integration for domain controllers will depend on the ratio between vehicle volumes vs. development costs associated with it.

IN-VEHICLE COMMUNICATION NETWORKS

With the introduction of CAN in 1982 by Bosch, the modern vehicle E/E architecture with interconnected ECUs started gaining traction and has continued to grow in complexity. Its capabilities have been sufficient for moat applications in the past.

However, the continuing growth in the number of electrical components has lead to an increase in the data traffic that cannot be supported through these CAN networks.

With growing market interest in automated driving, infotainment and connectivity, there is a need to include these functionalities in tomorrow's vehicles. Integrating these technologies will require a significant change in the in-vehicle communication networks architecture and protocols. Next generation architectures must be designed to meet these future requirements.

New powertrain functionalities such as hybrid and electric drives will also require in-vehicle communication protocols that provide higher bandwidth than CAN. CAN-FD is a suitable upgrade since it provides the necessary increase in bandwidth required to enable alternate powertrain and higher functions. CAN-FD is also suitable for the body domain to account for the increasing number of comfort related body components along with providing extra bandwidth for future body functionalities. For chassis functionalities other than the driver assistance sub-domain, CAN-FD will also provide the much needed increase in bandwidth and enable higher functionalities.

For driver assistance, infotainment and diagnostics, higher bandwidth requirements will drive the implementation of faster protocols such as automotive Ethernet. Driver assistance functionalities consist of components requiring high data transfer rates to communicate with each other. The significantly higher bandwidth achieved through using Ethernet is advantageous in implementing driver assistance functionalities and provides a framework for highly automated driving functionalities. With the demand for high-definition infotainment systems which may include several HD displays in the vehicle, Ethernet will fulfill the bandwidth requirements for the infotainment domain. To achieve faster diagnostics and software updates, Ethernet will also be used. A higher and more widespread implementation of Ethernet in the all the domains will enable an Ethernet backbone structure, which will provide better inter-domain communication.

With the widespread utilization of Ethernet and Ethernet backbone architectures, there will be a need for central gateways to provide low latency. Such low latency requirements will be achieved through hardware based acceleration inside the central gateway.

Figure 5 shows a roadmap for communication network protocols. Different domains, depending on their network requirements, will move towards new protocols to enable newer functionalities and improve existing ones.

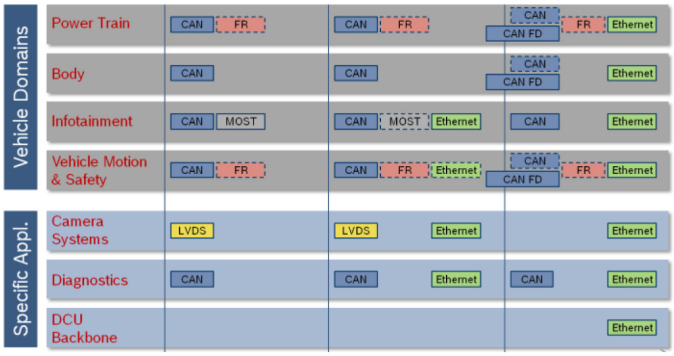

Figure 5. Bosch vision of E/E architecture in-vehicle communication networks

Domain ECUs and Integration Platforms

Domains in automotive electronics handle certain set of functionalities. For example the infotainment domain consists of ECUs, sensors and actuators handling the infotainment related functionalities of the vehicle. Domains provide proper segregation of ECUs according to their functionality and facilitate communication access to ECUs handling similar functionalities. Today's domains require greater interaction between the ECUs within the domain. For example, to enable highly automated driving functionalities, the driver assistance components such as radars, cameras and ultrasonic sensors within the chassis domain require much stronger intercommunication. As such, there is a need to have a single master ECU that controls components providing similar functionalities.

Continuing with the driver assistance domain example, consider today's system where different ADAS sensors preprocess data and communicate the object data to the ECUs. This is effective for partially automated systems such as adaptive cruise control and traffic jam assist. For higher automation, however, there is a need for more sensors and an ability to build an environment model using the data from these sensors. Some of these sensors will work together and process the data, providing object information to the other sensors. This would lead to a partially centralized domain wherein several sets of sensors provide environment to each other. For enabling highly automated driving functionalities, there is a need to have a centralized sensor fusion system that consolidates the data it receives from the sensors and performs simultaneous localization and mapping functions. Such a centralized ECU that works as the master of the driver assistance domain is a prime example of a domain ECU.

As shown in figure 6, domain ECUs as integration platforms will have several key properties. Since these kinds of ECUs will perform heavy computations, they will consist of many core or multi core processing units. They will house different application software for the different functionalities and components in the domain. Hypervisors will provide the required hardware virtualization for safe separation of these functionalities.

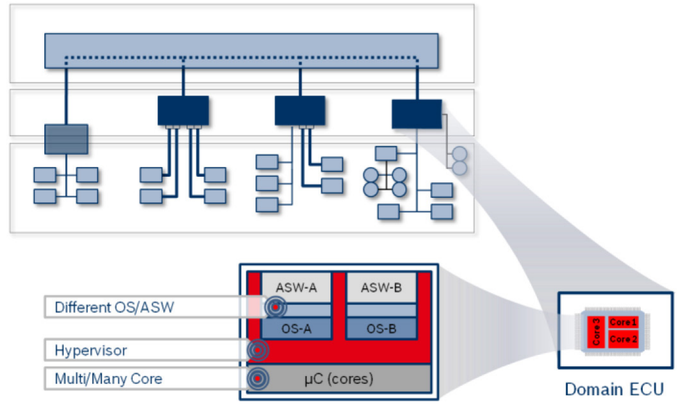

Figure 6. Domain ECUs for hardware virtualization

Integration of domain ECUs enables a much more transparent operation of cross-domain functionalities. Today, the chassis and powertrain domains are considered as separate. With highly automated driving functions, there will be a need for a tighter bond between the chassis and the powertrain domains and their respective sensing and the actuation capabilities. The ADAS sensors will provide environment information to the various functions in the vehicle. And these functions, performed by separate ECUs will provide signals to the vehicle's actuators (e.g., brakes, throttle, etc.).

In the coming years, the powertrain and driver assistance domain will work closely with each other. The driver assistance domain ECU will be the liaison between the sensors and the functionalities embedded in the chassis domain. Subsequently, the chassis and powertrain domains will be merged, being coordinated by a functional arbitration layer, to form vehicle motion control domain. This domain will work with the driver assistance domain and the energy management system to control the vehicle. Such architecture will greatly simplify the implementation of highly automated driving.

POWER NETWORKS

Today's power network is primarily based on 12V with the electrical loads powered by a 12V battery and an alternator. The market demand over the years has been for higher comfort functions along with more electrical components. These comfort based electrical components add additional load to the power network. 12V systems work well with low current/ low power requirements, but will not work as well for high power requirements. To electrify high load components such as a turbocharger or an HVAC system, a 12V power network is inefficient due to the thicker cables required to fulfill high current requirements, which also add extra weight and costs.

48V systems provide a low voltage solution to these issues. With four times the voltage that a 12V powernet provides, only one fourth of the current is required when compared to a comparably powered 12V component. The higher voltage and lower current of a 48V system yields significant efficiency improvements.

A 48V electric machine designed for boosting and recuperation provides a good cost-benefit ratio for manufacturers to reduce CO_2 emissions. And since 48V electric machines, in general, provide better efficiency and more recuperation when compared to 12V electric machines, the CO_2 benefit achieved from a 48V electric machine is higher. Hence a 48V BRS system is the primary enabler for a 48V powernet, providing the necessary framework to move high load consumers from 12V to 48V

Implementing a dual powernet consisting of 48V and 12V systems provides a smooth transition of components from 12V to 48V over the lifetime of the powernet architecture. The dual powernet architecture is coupled using a bidirectional power converter unit. High load components such as, A/C compressors, blower motors, windshield heaters can be shifted from 12V to 48V to provide better results in performance and efficiency. Furthermore, the higher power transfer capability of 48V powernet enables several vehicle components such as turbochargers, to be electrified, thus reducing the loads on the combustion engine and provides better performance. A simple dual voltage powernet coupled by a DC-DC converter is shown in figure 7.

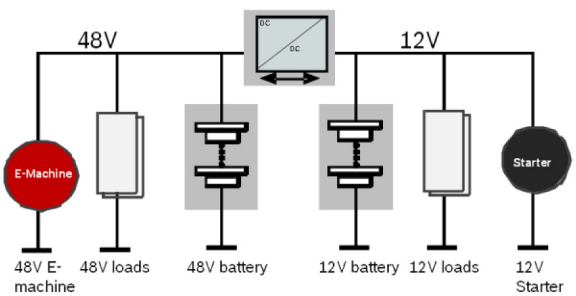

Figure 7. 48V Powernet topology with 48V and 12V loads

Solid State Devices & Powernet Backbone

The powernet of today include fuses and relays to protect and control electrical loads. These traditional fuses need to be replaced when blown which requires them to be housed in easily accessible locations. With an ever increasing number of electrical components, this requirement leads to higher routing complexity, longer cables lengths and higher cable weights and costs. Furthermore, current electro-magnetic fuses and relays consume a lot of energy. Thus, there is a need to provide solutions to not only simplify the layout of the powernet but to also make it more efficient.

Solid state relays and fuses have better efficiency and lower weights than traditional electro-magnetic relays and fuses. Unlike electro-magnetic fuses, solid state fuses require no maintenance, thus enabling the possibility to position the fuses in strategic location to reduce the complexity of the powernet layout. A new layout would provide better routing and reduce cable length, cost and weight. They feature also better lifetime and advanced diagnosis of failures. Figure 8. provides an example showcasing the reduction in complexity of powernet routing by enabling a powernet backbone through solid state fuses and relays.

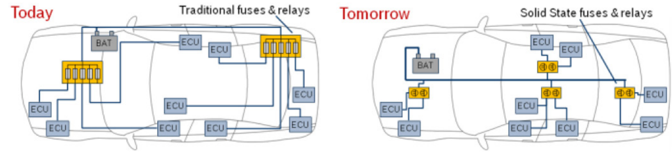

Figure 8. Solid state devices and their impact on future power network architectures

CONNECTIVITY

There is an increasing demand to connect vehicles to the external world. This connectivity enables several use cases for future vehicles and transportation systems. These use cases include using head unit displays to surf the internet and access online services; connecting vehicles with each other to achieve car to car connected driving, connecting vehicles to the infrastructure to achieve automated parking and other services; and updating vehicles through over-the-air updates etc.

Today, a connectivity control unit/ module primarily handle the connectivity to the outside of the vehicle wherein the exchanged data set is pre-defined. To enable various use cases for connected vehicles, the ability of the electrical systems in the vehicle to access the connectivity units and the outside world will be possible. Thus, there will be several points in the vehicle that may see connectivity. This is shown in figure 9.

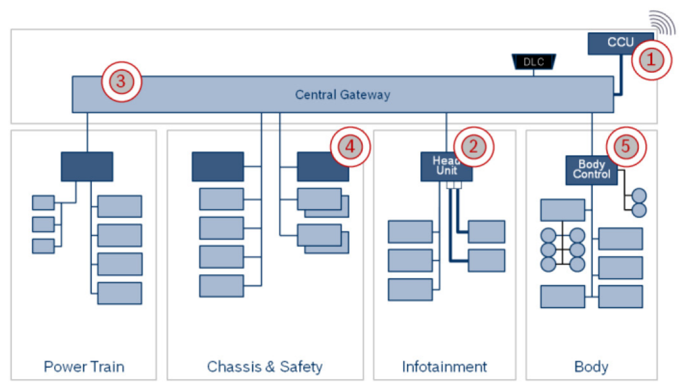

Figure 9. Possible realizations for connected E/E architecture

With connectivity becoming more widespread, new services with higher demand for data volume, data rate and real-time availability will be added. In a moving vehicle this has to be dealt with changing service conditions with possible gaps in network coverage. Therefore, management of the quality of service is needed to handle such scenarios.

In order to effectively implement such features, these use cases must be considered when designing future E/E Architectures.

SAFETY & SECURITY

With more electronic systems providing sensitive safety functionalities in tomorrow's vehicles, protecting the vehicle from malicious attacks will be important for the automotive industry.

E/E architectures today may not have necessarily been designed to provide better security from malicious attacks. But keeping in mind the impact of such attacks in the future, E/E architectures will have to be designed to provide higher security attributes. One of the most effective ways to provide this is by implementing a layered security approach. Figure 10 shows such a layered automotive security approach. Providing several layers of security in the in-vehicle communication networks will make it difficult for attackers to break through all of the layers and access the targeted component or functionality.

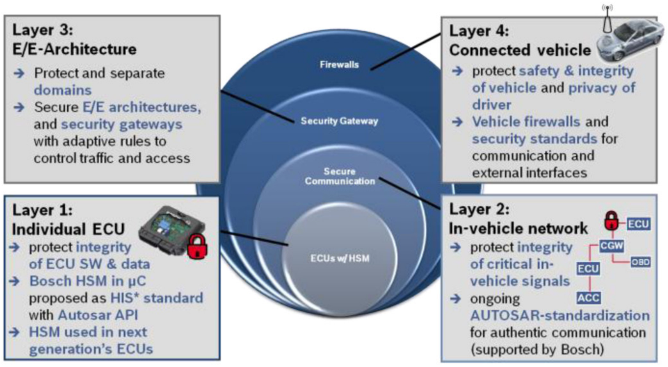

Figure 10. Layered automotive security approach

Primary attack vectors, such as connectivity units used for communicating outside the vehicle must be protected via firewalling, thus making sure only the required relevant data gets transferred/ communicated through these vectors. This outermost layer, consisting of attack vectors, must be protected and is layer 4 in the figure.

Layer 3 in the figure is based on protecting the E/E architecture. Domains have to be protected by separating domains with different security risks. The central gateway plays an important role in this layer, providing the functionality of monitoring the traffic for abnormal behavior and access.

Layer 2 is for secure communication between the different components in the given domain. Protecting the integrity of critical in-vehicle signals is the main purpose for this layer.

Layer 1 form the lowermost layer in this approach. It consists of the trust anchors for security in the vehicle. These trust anchors, such as HSM, are embedded in the individual ECUs and protect the integrity of the ECU SW and data.

With the increasing application of electronics for controlling vehicle functionalities, cyber-security is and will be essential in securing vehicles.

CONCLUSIONS

Driven by market expectations along with technological and strategic requirements, E/E architectures will need to significantly evolve to overcome current bottlenecks and fulfill future communication, power, connectivity and security requirements.

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DEFINITIONS/ABBREVIATIONS

ADAS - advanced driver assistance systems

BRS - boost recuperation system

CAN - controller area network

CAN-FD - controller area network flexible data

HD - high definition

HSM - hardware security module

HVAC - heating ventilation & air conditioning

LIN - local interconnect network

MOST - media oriented systems transport

powernet - power network

SW - software