Cross-domain vehicle control units in modern E/E architectures

Waldemar Haas, Dr. Petra Langjahr, Bosch Engineering GmbH

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1 Introduction

The complexity of E/E systems increases because of many new functionalities interacting across domain boundaries as for example in the area of automated driving and parking and powertrain electrification.

Today's challenge is to manage a growing number of functional requests within and across domain boundaries. Therefore E/E architecture concepts have to be developed. Important elements of the architecture are electronic control units (ECU) / vehicle computers and their hardware and software concepts.

As described by Navale et al. [1], E/E architectures are undergoing an evolution / a revolution from pure mechanical systems to highly centralized E/E vehicle architectures. The evolution of E/E architectures could happen as shown in Figure 1:

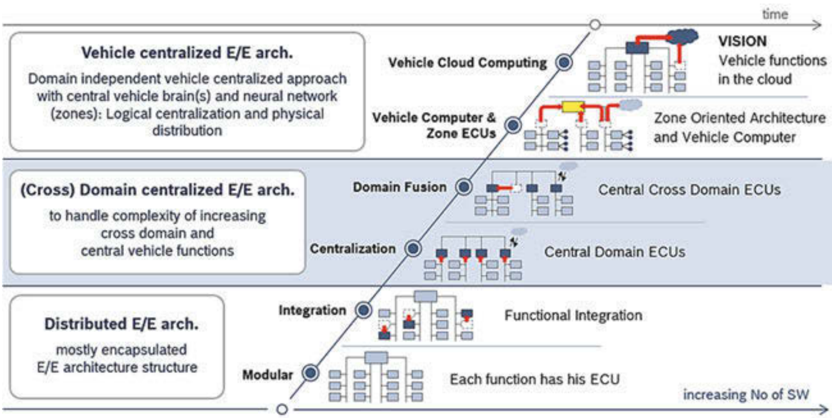

Figure 1: Evolution / revolution of E/E architectures from distributed mostly encapsulated E/E architectures via cross domain centralized E/E architectures to vehicle centralized architectures including vehicle computers and cloud computing

First ECUs were modular and handled single functions (one box-one function systems). By integration of several functions into existing ECUs the focus was on the reduction into a smaller number of ECUs.

The next architecture step with a higher integration level introduces central domain control units that control domains in a vehicle thus becoming the master ECU for each domain and also by fusion of ECUs and domains as central cross domain ECUs. It may be a separate additional control unit providing extra computation resources, but it is also possible to implement cross domain functions in an already existing ECU [2].

Centralization and exchangeability is also supported by the AUTOSAR (AUTomotive Open System Architecture) standard for automotive basic software in line with an architecture that eases exchange and transfer of application software components between domains or platforms, see Cordes et al. [3].

Central domain and cross domain ECUs are solving the first challenges for modern E/E architectures. The paper is handling the possibilities to provide solutions for the next generation of cross domain control units based on available technology.

The next step ahead is going to zone oriented architectures and vehicle cloud computing as a vision. For this step still further issues have to be solved.

2 Drivers and trends in modern E/E architectures

New E/E architectures are influenced by market expectations and related technical and strategic drivers and trends.

Market expectations strongly influence the feature scope of the vehicles and therefore their architecture. The demand for powertrain technologies includes not only internal combustion engines, but also electric or hybrid vehicles or fuel cell systems. Topics like automated driving also have a strong influence on the E/E architecture and are very challenging regarding computational processing requirements and safety requirements.

Technical drivers are e.g.:

- Introduction of complex cross-domain functions and calculation-intensive functions (advanced driver assistance systems – ADAS, infotainment, …)
- Variant management for growing variance
- Remote communication and cloud connectivity

The strategic drivers are more related to cost and optimization, like:

- Fast innovation cycles
- Scalable modular platform concepts (HW/SW) prepared for safety requirements according to ISO26262
- Integration of software from different sources

Due to that drivers, the boundaries between systems begin to flow or even disappear because the single systems like powertrain or chassis systems act much less as stand-alone systems as before.

As a challenge the computing power in embedded systems is hitting the technological limits for single controllers. The inter-domain and cross-domain communication bandwidths are often not sufficient for future data traffic. Also for external communication there is a need for higher data traffic and speed. Due to this increased external communication, also security risks are arising and require multi-level security concepts.

New functionalities often can't be implemented in consisting control units due to lack of resources. Therefore cross-domain vehicle control units are needed in many cases to increase computing resources and provide data logger functionalities.

3 Use cases for modern Cross-Domain Vehicle Control Units in connected applications

In the following figure several use cases and positions in modern E/E architectures are shown, see. Figure 2. Such a flexible control unit can handle different domains and therefore can be exchanged between the use cases with synergies. Therefore the trend that the development in different domains moves closer together is supported.

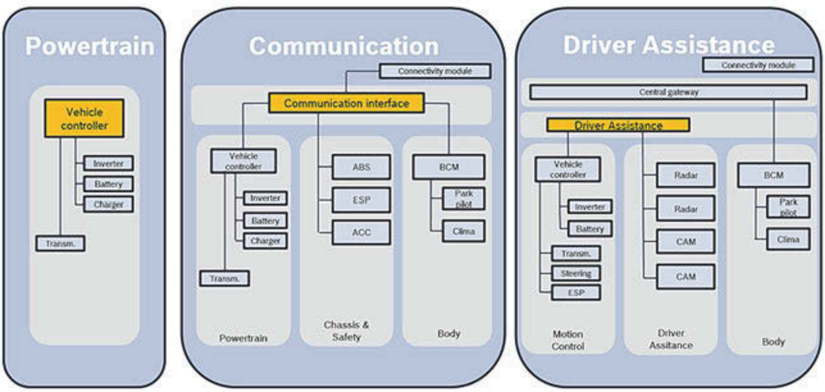

Figure 2: Examples for the use of a cross-domain vehicle control unit on several positions of modern E/E-architectures in powertrain as vehicle control unit, as communication interface box or in driver assistance applications.

3.1 Powertrain

A vehicle control unit (VCU) can act as master electronic control unit in the powertrain path, for example in electric or hybrid vehicles where the torque demand is recorded, split and distributed to the different types of powertrain. It is interfaced with driver inputs and other control units to achieve an optimal control mode of the vehicle. It is responsible for the propulsion of the electric vehicle and therefore controls and monitors functions that affect multiple powertrain controls like inverter, battery management, charger, thermal management and transmission control. It also includes communication with other domains like chassis domain (anti blocking system ABS, electronic stability control ESP and adaptive cruise control ACC) as described in section 3.2.

3.2 Communication

A cross-domain control unit can serve as communication interface box (CIB) between various domains like powertrain, chassis and safety, body control management (BCM) and infotainment.

The growing number of electrical components and growing market interest in automated driving, infotainment and connectivity require an in-vehicle communication network that supports several bus systems like CAN, FlexRay, LIN, SENT and also Automotive Ethernet. The demands for higher bandwidths and faster protocols are increasing. Signals are received by bus systems or by sensors, processed and sent out by bus systems to other domains as connectivity module.

3.3 Driver Assistance

In driver assistance applications often an additional control unit is needed as interface between different domains and as a calculator domain. Data are provided e.g. by radar or video cameras in the chassis domain, by environmental sensor data or by an electronic horizon. Data are logged, processed and sent out to be received by other domains like the powertrain. With data like navigation / GPS-information, the most efficient driving profile can be calculated that optimizes the energy consumption of the vehicle.

4 HW and SW Concepts

To provide a domain controller that meets the mentioned requirements and can be used in different use cases, modular concepts in hardware and software are needed. For efficiency reasons it ideally should base on existing concepts and modules.

4.1 HW Concepts

The hardware has to be as flexible as possible on the one side to fit all the requirements already described. On the other side as the cross domain functions and the according control units are still in a niche and growing, the development costs have to be as small as possible. For the HW concept it is also helpful, if existing HW parts and configurations can be used. So as first step into the market the HW is based on existing microcontrollers and therefore existing tooling and compilers. Also the other parts like the communication interfaces and inputs are already used in existing control units like for combustion engines. The new point is the amount of communication interfaces in combination with the most powerful controller in a compact housing. From mechanical side the re-use of existing housing concepts also brings advantages in development costs as well as piece price, since the parts ideally are already in mass production with very high volume.

Re-using an existing computation core, the corresponding voltage supply should also be available. Like shown in block diagram in Figure 3, all the other parts are also already in scope of control units in distributed E/E architecture like control unit for combustion engines, chassis and body functions. A small amount of power stages and usual digital and analogue inputs and a higher number of communication interfaces compared to the known control units are added. The range of the communication interfaces goes from LIN, via well-known CAN to the latest E/E-architecture backbone automotive BroadR-Reach Ethernet. The inputs and outputs enable the HW to also have some local components connected, that do not have a dedicated controller within the E/E-architecture.

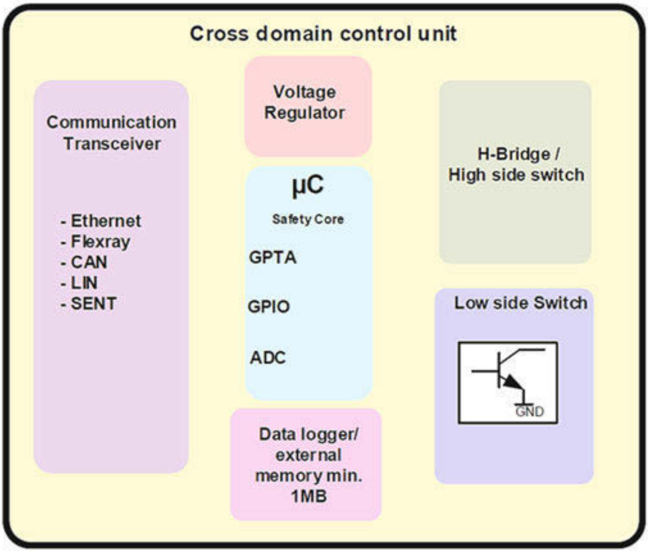

Figure 3: Block diagram of a cross domain control unit, combined out of already available HW modules from controllers of today's domains. Powerful micro controller with corresponding power supply and a high amount of communication interfaces and some inputs and outputs.

All this steps help to bring a control unit to the market with the minimum of effort and short time to market. In some parts it may not reach the requirements that will come up in some of the described domains. Future driver assistance functions for instance will need much more calculation power for functions like autonomous driving, which are not yet available in automotive controllers. But for the first step into the various domain it is the right base.

4.2 SW Concepts

The software concept has to be modular and sort of a kit depending on the use case as vehicle control unit, communication interface box, for driver assistance applications or else, see Figure 4.

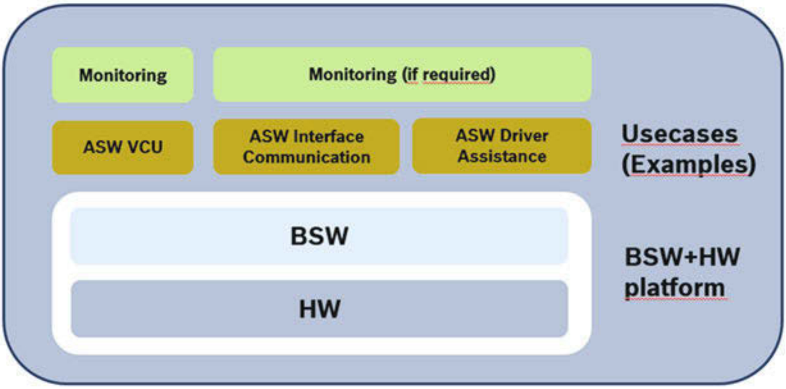

Figure 4: Software structure for different use cases. A modular software structure is required consisting of a base software (BSW) and application software (ASW) for different use cases and optional (if required) monitoring software.

Standardization of components and their exchangeability in between control units is addressed by AUTOSAR (AUTomotive Open System ARchitecture). A SW concept has to support AUTOSAR and non-AUTOSAR components as well as SW sharing concepts and can look as follows, see Figure 5:

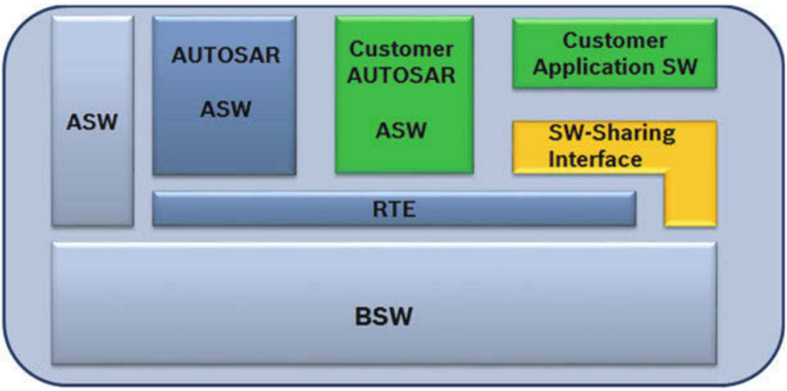

Fig. 5: AUTOSAR and Software Sharing Concept for a Cross-Domain Control Unit. AUTOSAR application software is linked by the run-time environment (RTE) interface as middleware to the AUTOSAR base software. In addition software sharing concepts have to be supported to have the flexibility to include code of third-parties. Alternatively non-AUTOSAR components can be linked by software sharing via a software-sharing interface.

5 Summary

The introduction at the beginning of this document shows, that there are some challenges to be solved for future E/E architectures. Zonal architectures require high computing power and a flexible SW base, to run the different applications from the various domains and even with different ASIL requirements in parallel and without mutual influence.

With the described HW and SW concepts it is possible to step into the future. Combining available HW modules from available, domain specific control units and updating the available SW for the modular concepts allows to develop the first functions and use cases.

It is possible and some projects already have realized successfully cross domain functions running on such a cross domain control unit, embedded in today's E/E architecture. These are driver assistance functions, which represent the start into autonomous driving.

Nevertheless there are also some challenges to solve for future automotive trends. From HW side more powerful microcontrollers have to be introduced and complemented by microprocessors. Those microprocessors are needed to have sufficient computing power for future functions in autonomous driving. Up to 3 or 4 of them need to be combined to have the required volume. This on the other hand leads to challenges in SW structure and architecture, to be able to use this power completely.

From SW side, there are points to be harmonized during development. For historical reasons, several domains like powertrain, driver assistance and others have their own tools and methods in SW development and integration. This leads to challenges during integration of cross domain functionality in a control unit as described in this document. But with tools and architecture like AUTOSAR and sharing models as described in chapter 4.2 this can also be solved with appropriate effort.

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