Future Vehicle Networks and ECUs
Architecture and Technology considerations

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This article reviews today's Electronic Control Units (ECUs), especially from a semiconductor technology perspective. Then, based on potential future vehicle networks, future ECUs are described along with the limitations and opportunities of (future) semiconductor technologies.

Introduction

The automotive industry is in a transition phase, while the first vehicle generations were dominated by mechanics. In a subsequent era electronics were introduced, also partially replacing mechanics (known as "electrification"). Now the automotive industry is heading towards connected vehicles, both car to car and car to Infrastructure, which will eventually also support fully autonomous driving. The main driving factor behind this is the reduction of fatalities and accidents and if we realize that more than 90% of all car accidents are caused by human failures, self-driving cars will play a crucial factor in accomplishing the "zero accident" vision of the automotive industry.

Autonomous vehicles will not happen at once; a gradual introduction can be expected following from six subsequent levels defined by the Society of Automotive Engineers (SAE) [1]. These levels range from no automation via, amongst others, conditional automation to full automation (even when for the highest level of automation legal aspects need to be clarified). With increasing levels of automation the vehicle will take over more functions from the driver, like control of speed and steering up to complete control of the vehicle. In addition, when automation levels increase, there will be a need for more processing power and sensors, with associated network bandwidth. This certainly may also lead to new car networks and associated future ECUs.

Two future vehicle networks will be reviewed in this article, one based on domain computing and one based on a central computing platform, and especially also introduce the associated future ECUs, but todays ECUs and vehicle network will be discussed first.

Today's ECUs and vehicle network

Vehicle networks in modern cars contain many ECUs, while low/mid-end cars might contain around thirty ECUs, this can be around hundred for a high-end vehicle. A generic ECU is shown in Figure 1 below.

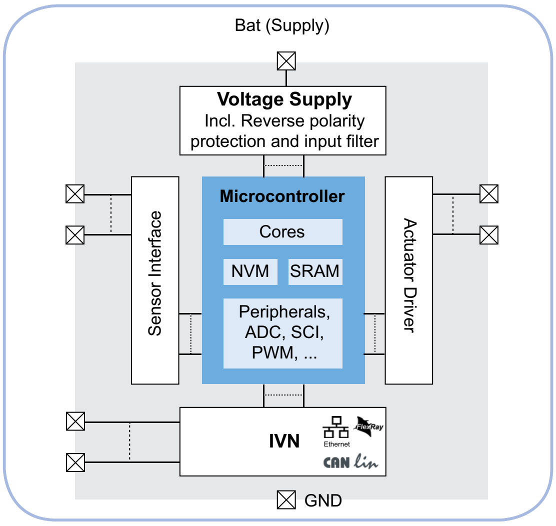

Fig. 1 Main blocks in todays ECUs.

The partitioning of ECUs is also driven by semiconductor technologies. Microcontrollers generally include non-volatile memory (NVM) so that software can be updated in the field in case of a bug fix or a feature upgrade. The technology of choice for a cost-effective solution will be (deep) submicron CMOS, which implies a voltage rating of the microcontroller of 5 V or 3.3 V for the interface signaling and even lower for the core supply (e.g. 1.5 V or 1.2 V). For this reason, a microcontroller cannot be directly connected to the car battery and voltage regulators need to be added in between. But there is another requirement on the voltage regulator, it also needs to be robust against the large voltage fluctuations and transients that are present on the battery line. Additionally, Electrostatic Discharge (ESD) and Electromagnetic Interference (EMI) events may also be present on the battery line. The other blocks shown in Figure 1 with outside connections, like the in-vehicle-networking (IVN) and sensor and actuator interfaces, also need to be able to withstand these transients. In summary, all blocks around the microcontroller form a shield that protects the microcontroller from voltage excursions and events that would have otherwise destroyed the microcontroller and this requires a high voltage technology.

Therefore at least two semiconductor technologies are present in today's ECUs, indicated by the different colors in Figure 1. It is noted that there are further technologies needed for sensors and sometimes for high power actuator drivers. Since there are just two main technologies depicted in Figure 1, we need to evaluate if all functionality can be included in one technology and device. Even when there are also high-voltage technologies- of up to 90 V- including automotive qualified NVM, these technologies lag a few nodes (feature size) compared with the deep submicron automotive technologies used for the microcontrollers. The price penalty for the digital contents and the SRMM and NVM memories, but especially the penalty from the NVM then becomes too high in such type of single-chip, or System on Chip (SoC) type of solutions compared with multiple chip implementations. Therefore, SoCs are not very widespread in today's ECUs, they are mainly seen in LIN-based Slave nodes where NVM demand is low and there is not much processing capability required. What is feasible and often realized is the combination of voltage regulators with IVN in so-called System-Basis-Chips (SBCs), or even combining the voltage regulators with IVN and sensor interfaces and/or actuator drivers defined as Application Specific Standard Products (ASSPs) [2]. The motivation for these type of products is system cost reduction and it is technically feasible since the integrated functions call for the same high voltage technology.

In today's vehicle networks ECUs typically support just one application, such as engine control, window lifter, or electronic power steering. There are only a few exceptions to this, such as the combination of a braking and an airbag ECU. It is furthermore important to realize that there is local processing of sensor data and algorithms in each dedicated ECU. Just as an example, in braking ECUs today, the algorithms that are used to maintain the stability of the vehicle as well as preventing the locking of wheels all run on the braking ECU itself. There is not much exception to this conclusion in today's car architectures, but we will discuss this topic further through the remainder of this article.

Domain based vehicle networks

In Figure 2 a vehicle network that is based on multiple domains is shown. One important enabler for this architecture is the introduction of automotive qualified Ethernet PHYs and switches [3]. Ethernet technology serves as a communication backbone, as shown in Figure 2. Furthermore, it follows that there will be several domain controllers. One example of this is the advanced driver assistance systems (ADAS) domain controller which is key for the enablement of (semi) autonomous vehicles. For this controller NXP offers the BlueBox as a development platform [4]. The BlueBox engine processes multiple streams of sensor data, which can come from cameras and RADAR or LiDAR, the support of sensor fusion is a powerful key and crucial feature for autonomous vehicles.

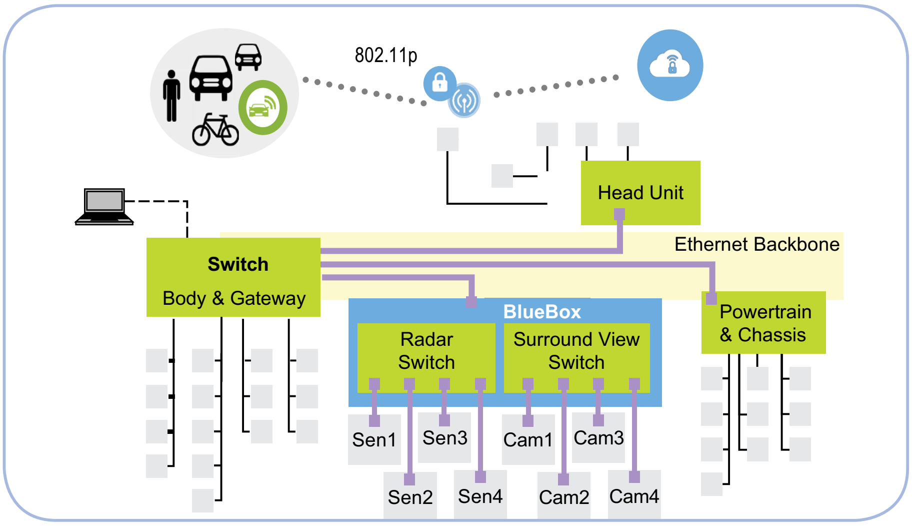

Fig. 2 Domain based network.

The BlueBox has a total computing power of 90,000 DMIPS (Dhrystone Million Instructions Per Second) while the total power consumption of the processor is less than 40 watts.

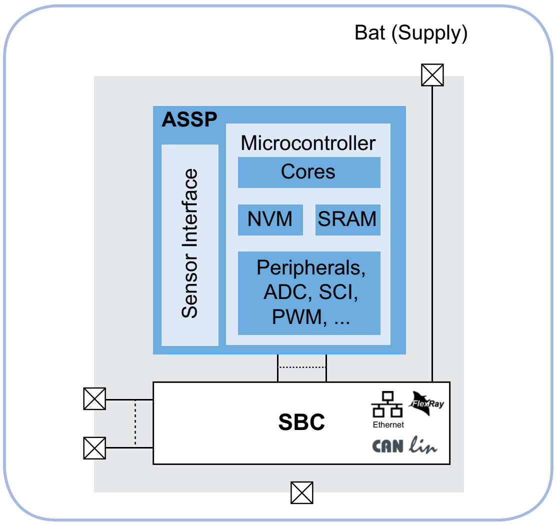

Fig. 3 Sensor based ECU.

The architecture shown in Figure 2 allows for changes in the individual ECUs (e.g. Sen1 in Figure 2). The processing of sensor data and/or the executing of algorithms may be performed on the domain controller. This means a less powerful microcontroller can be used in the corresponding ECU, especially since this requires less NVM. In this case the sensor is inside of the ECU, so that there is no external sensor connection with associated demanding requirement that would call for a high-voltage technology. In addition, in a RADAR sensor ECU, the sensor interface can be realized in a deep sub-micron CMOS technology. This can also be used to implement the microcontroller, so that a new type of ECU is defined as shown in Figure 3. Next to the ASSP, combining the sensor interface and microcontroller, there is a SBC that implements IVN and the voltage regulators to supply the ASSP.

Enabled by the Power-over-Ethernet technology, one could- in the ECU shown in Figure 3, even eliminate the need for a battery connection and associated high-voltage technology. This will enable a SoC based solution that is fully realized in a deep sub-micron technology.

Central computing platform

In an extreme case one could even consider the merger of multiple or all domain controllers to a central computing platform, as presented by multiple OEMs during the 2016 Automotive Conference in Ludwigsburg, Germany. Advantages could be the scalability over different vehicle platforms as well as for future updates via spare memory, even though these features can also be realized in other architectures. Dissipation will certainly be significant in these platforms and fan or water cooling might be required, even when the latter might already be present anyway in the electrical vehicle, it can still increase the module costs. It might look attractive to select the most advanced deep submicron CMOS technologies for microcontrollers in these modules, however these technologies are typically not automotive qualified. In addition, as the safety aspect is important, the Module will have to be compliant to ISO 26262 that needs special precautions in the development process as well as in device architectures. Finally, a "zero ppm" quality level is required. In all these respects, traditional automotive semiconductor suppliers are better positioned than new suppliers trying to enter the automotive market.

Now that we discussed the central computing platform, we can evaluate impact on individual ECUs.

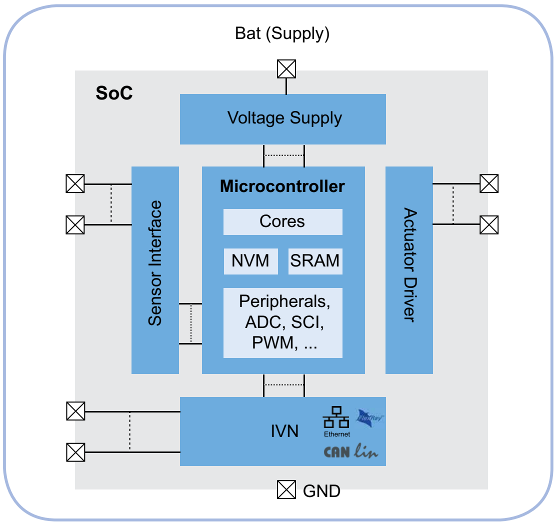

Figure 4: SoC based ECUs

Also in this case, processing will not be done locally in the ECU. This implies there is no need for large processing capability and little NVM is needed. Furthermore, the smaller microcontroller will be less power hungry, meaning that the voltage regulators for the microcontroller can be reduced in size and thus optimized in cost. Therefore, all the required functionality can now be cost effectively realized in one high-voltage semiconductor technology including automotive qualified NVM, resulting in an ECU based on a SoC as depicted in Figure 4. In fact, this becomes much more feasible now for many ECUs than in today's vehicle. The SoC will combine the microcontroller with voltage regulators and IVN as well as actuator drivers and sensor interface, which will reduce system costs. Overall module costs can further decrease because the power dissipation as well as the physical size of the module decreases. On the other hand, compared with conventional architectures, there will now be a need for more bandwidth for the communication to and from the central domain processing module. In addition, the transported data may be safety critical (like the actuation of a brake or an airbag). So, when processing is not done locally one has to take into account that additional delays will be introduced between sensors and actuators that might impact the overall control loop stability. Therefore, there might be a need for a guaranteed (maximum) latency.This will increase the costs for IVN, even when these costs might well be offset by the previously mentioned system costs reduction.

Cloud computing

We have already discussed shifting computing from ECUs to domain controllers or central computing platforms, but in future vehicle architectures it is also feasible to shift (some) computing functionality to the cloud. As an example, we mention the company HERE, co-owned by AUDI, BMW and Daimler [5]. This allows for maps and services needed for today's navigation systems but certainly also for tomorrow's autonomous driving cars. It is questionable if a generic shift of all computing power from all vehicles to the cloud is feasible. This could quickly result in problems for applications where a fast response time is required, due in part to the delay times associated with the communication to and from the cloud. In addition, this approach could generate amounts of data that are difficult to manage. It goes without saying that security is of crucial importance, this applies both to the interconnection to and from the cloud as to cloud storage.

Conclusions

Future semi-autonomous and autonomous car to X vehicles will need significantly more processing power and sensors than today's vehicles.

Today's ECUs were described and the semiconductor technologies present in those were reviewed. We also introduced new type of ECUs based on possible future vehicle architectures, being the domain based solutions and the central computing based platform. Even when both solutions have their individual pros and cons it looks more realistic that the domain based architectures will be introduced on the short- to mid-term while for the central computing platform items like safety, reliability and cost still need to be answered especially for the central Module.

References

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[5] https://company.here.com/here

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