Trends in Automotive Electronics

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***Abstract*—This paper gives an overview on current trends in automotive electronics from the perspective of an automotive electronics systems and components supplier.**

I. INTRODUCTION

In recent years, modern vehicles are showing an increasing number of electronic systems and functions. The driving forces behind this development are the ever growing needs for more safety, less emissions and energy consumption, more driver information and driver assistance, and last but not least more driving fun and comfort.

The history of modern automotive electronics started in the 50's to 60's of the last century with the introduction of semiconductor transistors in car radios and power diodes in alternators. Since the 80's, the integration of electronic systems like engine management or brake control systems has come into focus. The era of today is characterized by the vehicle-wide networking of all electronic systems, thus allowing for new additional functions. As a next wave, we expect an increasing networking between the vehicle and its environment. All those trends are enabled by electronics and communication technologies supporting increasing digitalization, integration and networking of electronic devices.

II. TOWARDS THE INTELLIGENT VEHICLE – CHALLENGES AND REQUIREMENTS

In our vision, the "intelligent" vehicle of the future will consist of three mayor architectural elements:

- "intelligent" sensors,
- powerful electronic "domain" control units,
- "mechatronic" actuators.

Thus, all vehicle functions will be controlled using networked electronic sensors, control units, and "mechatronic" actuators.

As a consequence, automotive electronics is expected to continue its growth - by about 6% p.a. regarding the overall systems value, or even 10% p.a. regarding the specific semiconductor content. However, this growth will only continue if we cope with some severe challenges:

- How to handle the increasing complexity of networked automotive systems in the development phase?
- How to keep vehicles – despite their increasing electronics content – affordable for the consumer?
- How to assure extended lifetime reliability and availability of the vehicles despite the underlying, very complex electronic systems?

Naturally, there is not one single answer to those challenges, but a plurality of solutions is required to fulfill the requirements.

III. SOLUTIONS: THE IMPORTANCE OF ARCHITECTURES, INTERFACES, AND STANDARDS

In this paper, we highlight primarily the perspective of automotive electronics hardware. Obviously, other aspects of automotive electronic systems are as well of great importance for the overall performance and will also affect hardware. Some of those aspects are listed here:

A. Systems Architecture

The further development of automotive electronics will be strongly influenced by underlying decisions on the vehicle's overall systems architecture, covering the distribution of functions to subsystems, their partitioning, and their mutual networking/communications infrastructure. Our perspective on systems architecture consists of functions being well structured according to CARTRONIC [1] principles, resulting in a clearly structured domain architecture. We expect further concentration of functions within those domains using a smaller number of separate ECU's (becoming "domain controllers") and a growing number of intelligent sensors and intelligent actuators.

B. Standardized Interfaces

While today's interfaces between electronic subsystems are mostly proprietary and even application-specific, we expect increasing standardization in this area, allowing better exploitation of economics of scale, and a reduction in application specific adaptation and debugging work.

C. Bus systems for networking:

As new vehicle functions will mostly depend on the combination of several subsystems (sensors, actuators) within different vehicle domains, the amount of subsystems networking will certainly increase further. While the high-speed and low-speed CAN will remain the predominant networking bus standard for the next years, increasing bandwidth requirements and the need for a predictable, deterministic behavior will motivate high-end system applications to use FLEXRAY [2] as their main "backbone" solution, interconnecting the electronics of mission-critical domains (powertrain, chassis, occupant safety, driver assistance). For other applications (mobile communication etc.) dedicated bus solutions will continue to be used.

D. Software Architecture

In parallel to the creation of domain-oriented systems architecture with standardized interfaces and new bus systems, also the software architecture within the ECUs will be further modularized and standardized in order to allow re-use of software investments and more flexible software distribution between various ECUs.

In our view, today's mainstream for the new systems architecture, interface standardization and new software architecture is formed by the AUTOSAR initiative [3]. Similarly, we consider FLEXRAY [2] to become the future mainstream for high-end networking busses.

E. *Reliable electrical supply systems*

Regarding the overall performance of "mechatronic" systems, the efficiency, reliability and availability of the underlying electric power supply is of core importance. New power semiconductors allow developments like integrated electronic battery monitoring, electrical energy management [4] and highly efficient starter-generators.

F. *Mature product development processes*

Last but not least, both software and hardware for up-to-date automotive electronic solutions must be developed using systematic, mature, integrated product creation processes. The organization of V-shaped simultaneous-engineering processes for all product aspects (from overall system to individual components, both hardware and software) according to CMMI [5] requirements is considered to be key for the quality and efficiency of the results.

IV. REQUIREMENTS FOR AUTOMOTIVE ELECTRONICS HARDWARE

Let us now turn our focus on automotive electronics hardware. To start, Table I shows a comparison of some requirement profiles for electronics in consumer, industrial, and automotive applications:

TABLE I. REQUIREMENTS ON ELECTRONIC DEVICES.

Parameter	***Consumer***	***Industrial***	***Automotive***
temperature	0°C → 40°C	-10°C → 70°C	-40°C → 85/155°C
operation time	1-3 years	5-10 years	up to 15 years
humidity	low	environment	0% up to 100%
tolerated field failure rates	< 10%	<< 1%	target: zero failure
documentation	none	conditional	true
supply	none	up to 5 years	up to 30 years

It is easily seen that automotive electronics are subject to much higher requirements and specifications than electronics for other "mainstream" applications. In the following, some specifics are highlighted:

A. *Operating Conditions of Automotive Electronics*

The requirements regarding environmental and operating conditions of automotive electronics [6] are typically characterized by at least four elements,

- operating temperature range (minimum and maximum temperatures)
- number of temperature cycles over lifetime in the application
- vibration load – characterized the peak mechanical accelerations
- degree of exposure to humidity and corrosive substances (for example, salt, fluids, vapors…).

Figure 1 shows some typical values for environmental temperatures and peak mechanical accelerations for different applications as well as the typical limits for different control unit technologies using PCB (printed circuit board) and µHybrid (low-temperature cofired ceramics, LTCC) substrates [7].

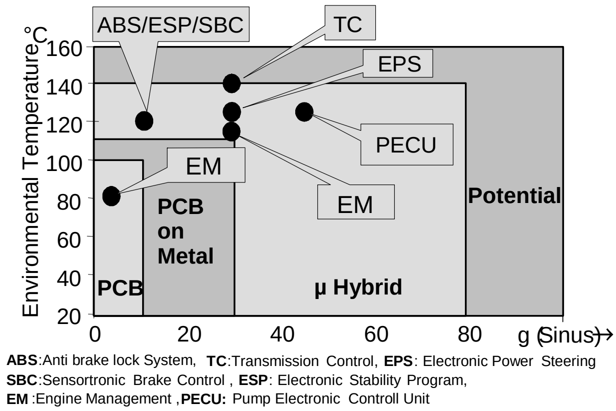


Figure 1. Environmental temperature and peak accelerations for automotive electronic control units

It is observed throughout the last years that automotive operating conditions for control units and its components have become increasingly tougher. This is related to several facts, for example

- rising underhood temperatures as a consequence of higher engine output, drag optimized hood shapes, and noise encapsulation of engines,
- rising power dissipation of microcontrollers due to increased clock frequencies,
- rising electrical power demands of control unit loads (like valves, motors etc.),
- higher integration of automotive electronics (more power in smaller packages), both on the level of semiconductors and control units
- the trend to apply electronics like sensors and "mechatronic" actuators directly in environmentally difficult locations (on-engine, in-exhaust, within transmission, on-wheel, on-axle, in-tire,..).

B. *Reliability of Automotive Electronics*

As a result of the increased use of automotive electronics in modern vehicles, car manufacturers are today asking for

ECU 0 km and field failure rates < 10 ppm/year

It is obvious, that such low failure rates – which for smaller production volumes are equivalent to a zero failure requirement - can be met only through a systematic approach starting early in the development phase and covering the whole lifecycle of the product.

The reliability of electronic control units [8] may be well characterized by the known "bath tub curve" using

Weibull distributions, see Figure 2. Over lifetime, three phases may be distinguished:

- *Early failures* happen mostly at 0 km, after that we observe typically a strongly decreasing failure rate within the first 2 years of vehicle operations (Weibull parameter ß < 1).
- *Stochastic failures*: after decay of the early failures, the probability of failures remains for a long time practically constant (ß = 1) at a low level - until the begin of the
- *Ageing failures*: the probability of failures increases again (ß > 1) until end of life, where practically all devices have failed.

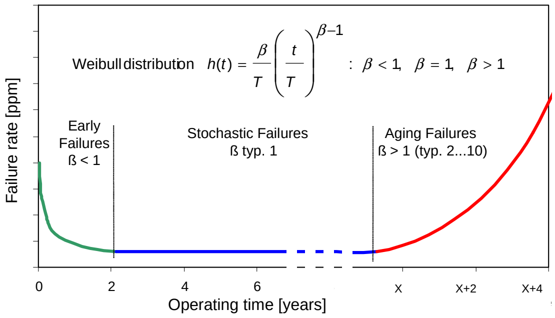


Figure 2. Typical failure probability of electronic control units

Obviously, the duration of the three phases and the parameters of their Weibull distributions will depend on many factors such as technology, design, component selection, and operating conditions in the application.

In the following, we will concentrate on the early failure phase and on the aging phase. It is an important engineering task to optimize the reliability in both phases by suitable choices of technologies, designs, components, to verify it by simulation and proper testing, and to assure adequate manufacturing processes. In order to do so, the root causes for early failures as well as aging failure mechanisms must be perfectly understood.

1) *Reliability against early failures*

If we exclude design and software failures, the majority of early failures of today's control units are, according to our experience, caused by defects of supplied components. Especially complex semiconductors like 32bit-controllers may show higher failure rates than desired as a result of semiconductor manufacturing defects in combination with insufficient testability or test depth.

In order to achieve a 10 ppm requirement for ECUs, we may derive suitable limits for all potential failures and defects. Figure 3 shows an exemplary brake-down scheme for 0-km failure limits of ECUs. As a result of a detailed analysis using real data, it was concluded that the allowable limits for automotive electronic component failures must be significantly below 1 ppm, which is in fact equivalent to a zero-defect target for typical quantities. Depending on the complexity of the component, individual maximum allowable failure rates have been assigned to all components. Those quality limits have been agreed with all suppliers and are tightly controlled.

In order to assure manufacturing and logistics quality targets, systematic in-process quality assurance measures are applied throughout the value creation chain. In addition to those, an intensive "quality mindset" training of all employees was found to be an important success factor [9].

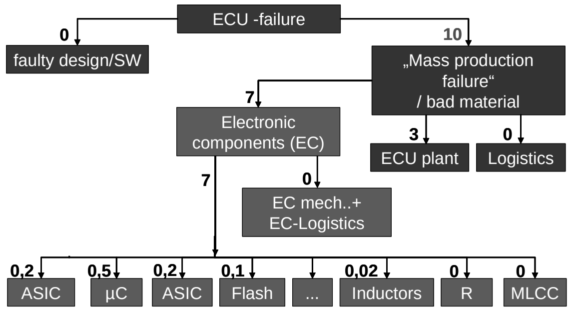


Figure 3. Early failure probability ppm limits (example)

2) *Reliability against ageing failures*

Reliability against ageing failures of automotive electronics is closely linked to understanding the electronics operating conditions in combination with the electronics ageing behavior. Mechanical fatigue from temperature cycles (thermal stress) is considered to be the most important long-term failure mechanism of automotive electronics, as in principle it can not be avoided. Other potential long-term failure mechanisms, for example related to mechanical fatigue from vibration, electrical overstress, thermal overload or corrosion, can be controlled or avoided by well known design measures and will therefore not be considered here.

In order to systematically achieve longterm-reliable designs, we have implemented the following systematic "design for reliability" process [8] in order to assure that the designs will withstand temperature cycles over lifetime:

1. Describe the known physical failure mechanisms by suitable mathematical models. Those models typically result from prior end-of-life testing of similar products using the same technologies and comparable components.
2. Determine real-life, application specific "load profiles" from experimental vehicle testing and – if available - field data.
3. Simulate field reliability using the failure model and the real-life load profiles

Using those three steps, both an adequate ECU technology as well as the detailed design may be evaluated as early as in the concept phase. In subsequent detail design steps, the models and data may be iteratively further refined.

For verification of the design and the models, the following steps are added:

4. Define shortened release test profiles on the basis of the known physical failure mechanism and its mathematical model
5. Run a sufficient number of release tests for confirmation of the life-time reliability of the design
6. Run additional end-of-life tests for further design confirmation and for additional verification and improvement of physical failure models.

V. TRENDS IN AUTOMOTIVE SEMICONDUCTORS

Automotive control units usually consist of a microcontroller with integrated or external Flash memory and of ASIC/ASSP peripheral chips for connection with the vehicle environment. As vehicle actuators consist of electro-mechanic and electro-hydraulic components, usually high control currents (> 10A) and/or high voltages (>70V) must be supplied. Therefore, automotive ASIC/ASSP are preferably implemented as mixed signal (analog/digital) circuits using combined semiconductor technologies (BCD: Bipolar, CMOS, DMOS). Today's complex ASICs may be considered as „System on Chip", like for example the Bosch ASIC for an ABS application shown in Figure 4.

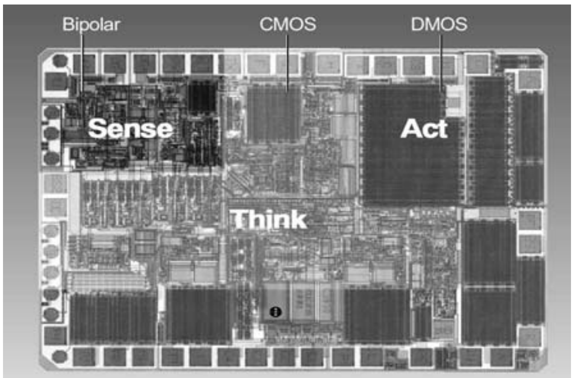


Figure 4. Bosch ASIC for ABS :
„Sense": wheel speed calculation, over-/undervoltage monitoring,
„Think": actuation logic, intelligent watchdog for µC monitoring
„Act": powerstages for valve switch and motor switch

Moore's Law is also followed in the automobile: we observe an ongoing trend towards shrinking semiconductor structures. Figure 5 shows some current semiconductor technologies used in automotive applications and their expected development. It is remarkable, that automotive electronics require a large and increasing variety of different, specialised semiconductor processes to cope with specific requirements.

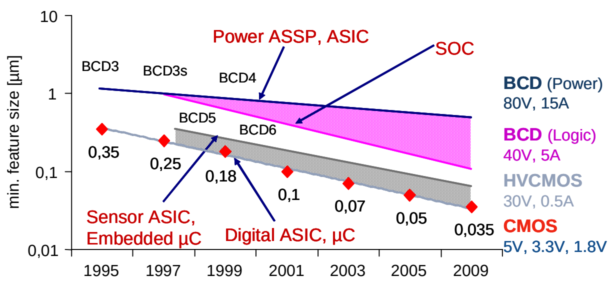


Figure 5. Semiconductor processes for automotive applications

Those new, compared with predecessor generations „shrinked" processes are supporting a higher integration of functions on a single chip, resulting in a lower number of ASIC chips per control unit. As example, Figure 6 shows the hardware architecture of a future engine management control unit: while the current generation ECU is still using up to 10 peripheral ASICs, the next generation will be using only 3 to 5 ASIC chips.

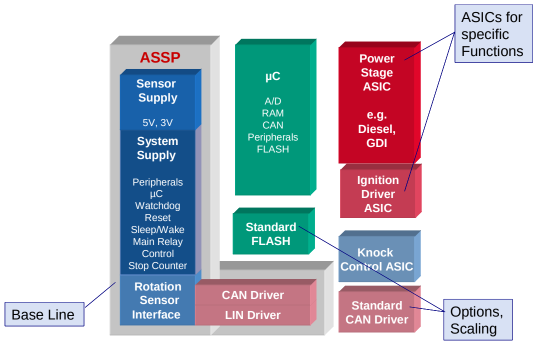
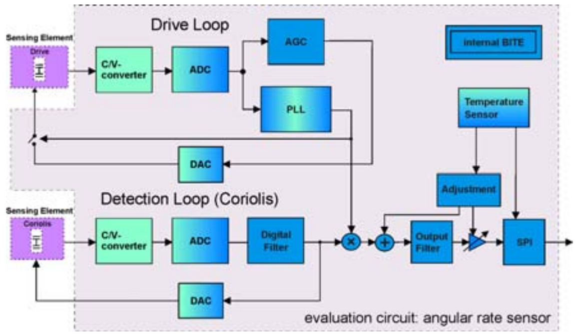


Figure 6. Architecture of a future engine management control unit

The most impressive progress is achieved regarding the packaging density of digital circuits. As a result, we observe an increasing digitalization of functions which have been so far implemented using analog circuitry. As an example, Figure 7 shows the signal processing ASIC of the Bosch MM3 yaw rate sensor, which has been implemented to a large extent using digital technology [10].



analog ←→ digital

Figure 7. Block diagram of a signal processing ASIC for a MEMS gyro sensor

With shrinking semiconductor structures, higher functional integration and growing complexity of automotive ASICs, also their development costs and mask costs are increasing. Therefore, the so far proprietary, "per-application" custom developed ASICs will become more and more replaced by ASSPs (application specific standard products), which may be shared across different applications and different ECU manufacturers.

VI. MICROMACHINED SENSORS FOR AUTOMOTIVE ELECTRONICS

Today micromachined silicon sensors (MEMS: MicroElectroMechanical Systems) have become an essential component of all electronic automotive systems. Since their introduction 10 years ago, Bosch has manufactured more than 400 millions MEMS sensors. The most important sensor types and their applications are today in the automobile:

a.) *Pressure sensors*: Low pressure sensors with ranges of 1…100 bar are used in many applications, for example in engine management for air pressure and intake mass flow sensing, in airbag systems as side crash sensors, or in tire monitoring systems as tire pressure sensors.

High pressure sensors with ranges of 200…>2000 bar are used in brake control systems, gasoline direct injection systems, and Diesel common rail systems.

b.) *Inertial sensors*: Micro machined acceleration sensors are used for collision detection in airbag systems, other applications are vehicle dynamics and suspension control systems. MEMS gyroscopes are the basis of ESP (electronic stability program) and other vehicle dynamic systems. They may be also used for rollover detection in advanced occupant safety systems. Figure 8 shows the recent Bosch MM3 sensor cluster, which combines several MEMS gyroscopes and accelerometers together with its signal processing circuitry in one housing [10].

Figure 8. Bosch MM3 inertial sensor cluster

VII. Application Examples

A. 1. Electronic Power Steering Control Unit

The 2nd generation EPS control unit, Figure 9, developed and manufactured by Bosch for ZF Lenksysteme's electrical assisted power steering system [11], is a typical example of an "intelligent actuator". The device was introduced in 2003 for large-volume production. The control unit is directly attached to the electrical steering servomotor thus forming a highly-integrated "servo-unit" which is directly mounted to the front axle. The ECU is using the latest LTCC (Low Temperature Cofired Ceramics) and DBC (Directly Bonded Copper) technologies, thus allowing for high currents, high temperatures and high shock resistance within a very small, individually to the car design adapted, package. The small package counts heavily on large-scale integration of digital and analog peripheral functions into 2 specific ASICs developed and manufactured by Bosch.

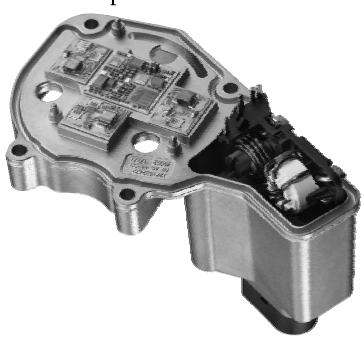


Figure 9. Control unit for Electrical Power Steering (EPS) using LTCC micro-hybrid technology

B. Long Range Radar Sensor

As an example for an "intelligent sensor" the 2nd generation Adaptive Cruise Control (ACC) unit, introduced by Bosch in 2005 in the market, may be considered. In today's industries' smallest (7,4 x 7,1 x 5,8 cm) housing for such a device, both the 77 GHz radar transceiver as well the very powerful signal processing and vehicle control hardware are integrated. The unit's small size allows for easy application in the front of the vehicle. An electrically heatable front lens allows also operation under bad weather conditions. Despite the small size, the unit has computing performance that allows further functional expansion. Additional functionality has been recently integrated into the device: the cruise control capability is expanded over the full speed range (down to zero), thus supporting also slow-speed stop and go traffic situations. The unit allows also for "predictive safety system" functionalities [12] for advance detection of potential emergency situations, allowing brake and restraint systems to optimize their response and give the driver additional warnings.

Figure 10. Intelligent 77 GHz radar sensor for Adaptive Cruise Control (ACC) and Predictive Safety Systems

C. Integrated Video System

Another recent example of an "intelligent sensor" is the Integrated Video System, which Bosch has introduced 2005 in the market. It consists of a high quality, day-and-night sensitive CMOS camera, and a separate, very powerful control unit for image signal processing. Its first application is a Night Vision system using additional near-infrared (800nm…1000 nm) lighting, which is invisible to humans, but can be well detected using the CMOS camera's extended sensitivity range, resulting in a very naturally looking enhanced image that can be displayed to the driver [13]. Further automotive applications of such integrated video systems are currently under development.

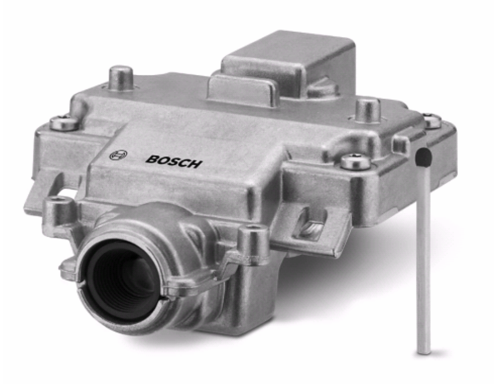


Figure 11. Day and night sensitive CMOS video camera of the Integrated Video System for automotive Night Vision applications

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