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AUTOSAR: Achievements, roll-out, perspectives

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Abstract:

AUTOSAR (AUTomotive Open System ARchitecture) was founded as a development partnership in 2003. AUTOSAR has been working to develop and establish an open and standardized automotive software architecture. The standard includes a set of specifications describing software architecture, application interfaces, model exchange formats, and methodology. By now, several versions of the standard have been released. The latest release 4.0 was published beginning of 2010.

As AUTOSAR is currently carrying on its third development phase (2010-2012), this document gives an overview of the most important results obtained so far with a specific focus on some technologies and features introduced in the latest releases such as the support for functional safety, multi-core architectures, efficient energy management and conformance testing. The development strategy and plans developed to ensure the stability of the standard will be highlighted.

Surveys show that AUTOSAR is today the global automotive software standard. A summary of the roll-out plans of the 9 Core Partners, disclosed recently will be given showing the way AUTOSAR has been introduced in series production and what is planned for the near future. In conclusion a view will be given on the perspectives after the current phase of development.

Introduction

AUTOSAR aims to establish worldwide an open industry standard for the automotive software architecture shared between suppliers and manufacturers. After 8 years, AUTOSAR has become the global automotive software standard in the automotive industry considering the overall acceptance, the worldwide involvement of major players [Fig. 1] and the technology leadership. Analysis of sales data shows that more than 80% of the global automotive production volume is made by OEMs that are AUTOSAR members.



Figure 1: AUTOSAR members (Dec. 2011)

In the context of the growing complexity of automotive electronic architectures, the need to build a common architecture became stringent for a variety of reasons, among which:

- The high number of proprietary solutions regarding ECU software infrastructure was a barrier to flexibility and optimization of embedded electronic architectures,
- On the contrary, an open architecture can enable software reuse, reallocation and smooth evolutions limiting therefore re-development and validation costs,
- The effort to develop a standard software architecture can easily be communalized in the automotive industry as it belongs to a non-competitive area,
- A common model based methodology improves the efficiency in designing complex systems with multiple partners.

The standard comprises a set of specifications describing the basic software infrastructure, application software interfaces, methods and templates. Let's focus on the AUTOSAR layered software architecture which consists of Basic Software Modules and a middleware (Run Time Environment: RTE). It provides to the application software an abstraction of the micro-controller and of the Electronic Control Unit (ECU). The AUTOSAR basic software (BSW) [Fig. 2] plays a key role in the architecture providing to the application software a standardized set of infrastructure functions (e.g. memory services, communication, or diagnostics). On top of this architecture, the RTE achieves the independency between hardware and application software components (SW-Cs).

Today the BSW can be regarded as a Commercial-Off-The-Shelf product. Several AUTOSAR members offer BSW implementations, covering the different AUTOSAR releases and a broad variety of typical automotive embedded hardware. During the evolution of the standard several features have been introduced, which enable less resource consuming BSW implementations. In parallel the BSW vendors have been optimizing their implementations in general. Consequently, the suitability of AUTOSAR for low resource systems has improved significantly.

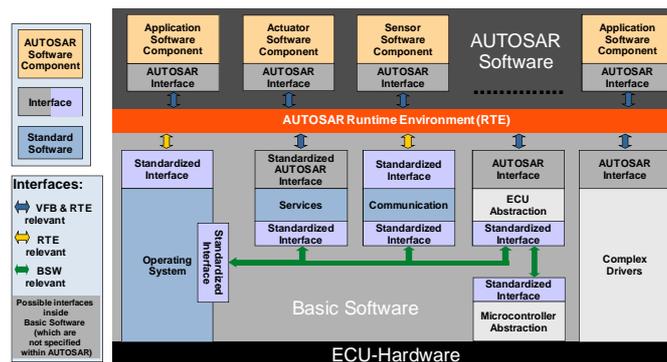


Figure 2: AUTOSAR Software Architecture

SW-Cs are integrated on top of the RTE, due to this hardware independency they can be re-used in different ways:

- A supplier can integrate them on vehicles of different car manufacturers,
- A car manufacturer can reuse them in electronic components of different suppliers,
- An ECU can integrate SW-C from multiple suppliers,
- Finally SW-Cs can be part of several product generations.

The on-going development of AUTOSAR products by the member companies provides a unique feedback loop into the development of the standard itself. This allows fast and pragmatic improvements. The reusability of software has already been experienced in major developments and it has resulted in substantial savings in the overall development costs.

AUTOSAR Timeline

AUTOSAR is experiencing its third phase in standardizing the software architecture for electronic control units in vehicles. First major sets of specifications (R2.x) were produced at the end of its Phase I [Fig. 3]. During the Phase II the main releases 3.x and 4.0 were made available.

Currently, AUTOSAR Phase III concentrates on maintenance and selective enhancements of the standard in order to ease further exploitation. For the ongoing further developments of the release 4.0, the focus is set on maintenance and on the introduction of concepts fulfilling market needs. Meanwhile

a new minor release 3.2 has been developed to fulfill short-term market needs. While being backwards compatible with the release 3.1, the release 3.2 contains a well-defined set of extensions. Currently, the maintenance of releases 2.1, 3.0 and 3.1, where very few requests for changes are identified, is performed by the mean of a LOKI (List of Known Issues).

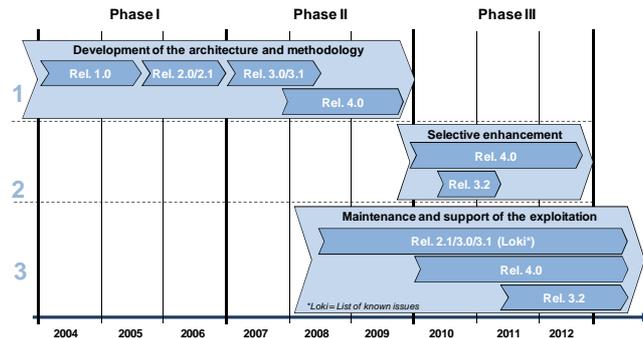


Figure 3: AUTOSAR Timeline

Achievements of Phase I and Phase II

AUTOSAR PHASE 1 (2003-2006) - The main purpose of the Phase I was to achieve a complete set of the specifications of architecture, methodology and templates.

Release 1.0 of the AUTOSAR specifications is related to parts of the basic software below runtime environment (RTE) level. This was followed by a “proof of concept” period. The findings from this period then have resulted in further refinements being made to the specifications.

Release 2.x focused on the completion of Basic Software (BSW) components and the RTE:

- Release 2.0 is a complete set of specifications including the configuration concept.
- Release 2.1 is an update of Release 2.0 with the outcome from implementation and validation of BSW modules on hardware platforms.

Both, releases 2.0 and 2.1, are in use by several AUTOSAR members for series productions.

AUTOSAR PHASE 2 (2007-2009) - Three releases were planned for AUTOSAR Phase II, providing a continuous improvement of the specifications and introducing new concepts. Additionally, the outcome from the validation at the end of Phase I and the feedback from all AUTOSAR stakeholders were incorporated.

Release 3.0 was published early 2008 on the AUTOSAR web site. It includes a large number of improvements, for example the harmonization of the ECU wake-up and the network start-up, and corrections with respect to the previous releases.

Release 3.1 was dedicated to the incorporation of On-Board-Diagnostics (OBD) regulations support mechanisms.

At the end of Phase II, the release 4.0 integrated many new features – e.g. related to functional safety or communication. The release 4.0 was delivered by the end of 2009 after its validation. Conformance test specifications followed in an update of release 4.0 by beginning of 2011.

In order to cover all vehicle functionalities, AUTOSAR has started working on two new car domains in the area of Application Interfaces during Phase II: Telematics/Multimedia/HMI and Occupants and Pedestrian Safety Systems. Moreover, Powertrain, Chassis, and Body and Comfort interfaces have performed their first steps of integration. All in all AUTOSAR interfaces of many application software functions (e.g. central locking, power train control, adaptive cruise control, etc.) were standardized in Phase II.

AUTOSAR Phase III status

PLANNING STRATEGY - After having developed the standard, specifying mature software architecture, AUTOSAR is selectively enhancing the standard by adding new features. Nevertheless, it was crucial to find a pragmatic approach, defining the right balance between innovation and stability. For this reason, the development partnership decided to enhance release 4.0 in a continuous way, preserving backwards compatibility towards deployed releases instead of publishing a new major release end of 2012.

All Members were invited to propose concepts, which could form the set of specific additions. The proposed concepts have been elaborated further on in order to get the maturity for implementation. The approval for implementation is currently being given either for the next revision 4.0.4 planned end of 2012 or on a later stage depending on the market needs, the strategic value, the impact and expected workload.

Additionally, maintenance of the different releases used for series production is ongoing in order to support the distribution of AUTOSAR into the market. Consequently, AUTOSAR developed release 3.2 based on market needs during the first half of Phase III.

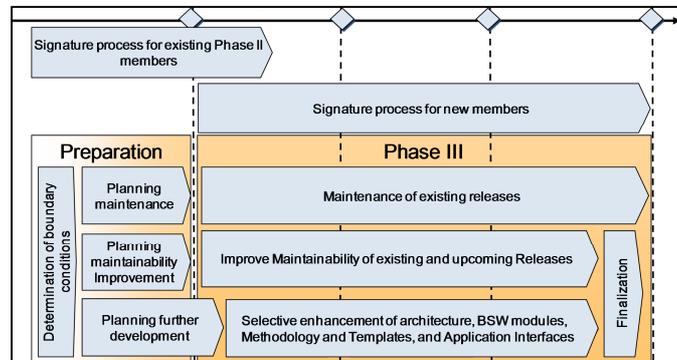


Figure 4: Project Roadmap AUTOSAR Phase III

NEW MINOR RELEASE 3.2 - During the implementation of AUTOSAR in series products, the market proposed to add certain improvements to the existing release 3.1, in order to ease migration to AUTOSAR. In order to fulfill these market needs regarding content and timing, AUTOSAR provided the new minor Release 3.2.

The release 3.2 is kept backward compatible to the release 3.1. It contains a well-defined set of extensions focusing on the communication stack and additional corrections. As major new functionality “partial networking” is supported. The first revision of release 3.2 was published end of April 2011.

RELEASE 4.0.4 –This revision supports new technologies and extends existing functions. Enhancements include concepts such as:

- **Basic Software:** extended hardware support, further capabilities to the release 4.0 Ethernet functions, means for efficient energy management, enhanced use multi-core microcontrollers, interoperability between AUTOSAR and automotive multimedia applications, partial networking, etc.
- **Methodology & Templates:** support of iterative development, distributed development, configuration profiles, AUTOSAR textual language, etc.
- **Application Interfaces:** improvements and extensions to support further applications with a priority set on well-established and often used application interfaces.

The release 4.0.4 will be delivered end of 2012.

Some concepts introduced in AUTOSAR latest releases

The introduction of new features in the Release 4.0 is motivated by the requests of the market either regarding new regulations or technology evolutions.

FUNCTIONAL SAFETY – In order to support automotive safety-related applications AUTOSAR has introduced substantial safety features in the basic software and runtime environment since its release 4.0. These features have been designed considering the standard ISO 26262 related to functional safety in automotive electronics and recently published. Some of them are summarized in this section.

- **Program flow monitoring** is checking the correct execution of embedded system software. It is focusing on control flow errors, which cause a divergence from the valid program sequence during the execution of the application. An incorrect program flow occurs if one or more program instructions are processed either in the incorrect sequence or are not even processed at all. Control flow errors can lead to data corruption, process crashes, or fault propagation.

- Memory partitioning and user/supervisor-mode features enable groups of SW-Cs to run in separate memory partitions. Moreover, user-mode partitions are executed in CPU user mode; they have therefore limited access to CPU's special function registers and supervisor mode instructions. Illegal memory access will be detected and prevented by the memory protection unit (MPU) hardware. The faulty partition will then shut down. All software components in the partition can also be restarted. Creating protection boundaries around groups of software components (SW-C) this mechanism enables the freedom of interference between SW-Cs with different safety integrity levels (ASIL) on the same ECU.
- AUTOSAR provides also end-to-end (E2E) communication protection for safety-related data exchange between software components running even on different microcontrollers. This mechanism detects faults in communication, regardless whether the source is the hardware or software. The protection mechanisms are implemented in the end-to-end library, they keep the software component implementation independent from the dedicated communication link
- Finally, AUTOSAR provides measures for mitigating hardware faults. This includes various modules for testing hardware, e.g. RAM test and/or core test, and checking stored data via CRCs.

MULTI-CORE - Latest embedded multi-core micro controllers provide a better computing power with reduced energy consumption. This increase in computing power is necessary in order to meet the needs of future control software and further integration of functionality. However multiple cores' computing power can only be taken advantage of, if the software is designed accordingly.

AUTOSAR specifications of the runtime environment (RTE) and operating system (OS) has been extended by multi-core specific features. The RTE hides the multi-core details from the application, so the application software can be developed independent of multi-core issues in a reusable fashion.

The distribution of application software among cores is supported by the AUTOSAR methodology and hence by the tool chain. Adding further flexibility w.r.t. load balancing and basic software distribution is planned for the future.

PARTIAL NETWORKING - AUTOSAR has worked on concepts addressing the reduction of electrical power consumption in vehicles, based on the fact that not all ECUs need to be active in the same time (e.g. seat control or park assistant functions). The first concept – partial networking – is incorporated in the release 3.2 and in the release 4.0.

Partial networking [Fig. 5] enables the suspension and resumption of communication activity of individual ECUs within an active communication bus. This allows the implementation of strategies that can put ECUs related to inactive vehicle functions into a low power mode or off, even as other ECUs continue to communicate on the same bus channel. Setting unneeded ECUs to low power modes reduces the overall electrical consumption, thus increasing the fuel economy and reducing CO2 emissions.

The development of partial networking deals with challenges like synchronized and selective ECU wake-up, new transceiver hardware capabilities and new network message filtering concepts. With partial networking, AUTOSAR partners and members will benefit from standardized, high quality and interoperable solutions enabling the development of new technologies for energy efficient electronic architectures.

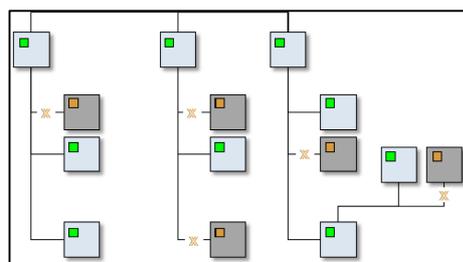


Figure 5: Basic principle of partial networking

Further concepts are considered for next revisions regarding the local management of energy consumption reduction in single ECUs that can enter in a low consumption while communication on networks remains enabled or reduce the number of their own active components.

CONFORMANCE TESTING - In order to ensure a smooth integration of basic software into a vehicle architecture, an AUTOSAR conformance test system has been defined. Conformance tests specifications has been released in the Release 4.0 addressing most basic software modules. The conformance test process is kept optional and can be conducted either by third or first party conformance test agencies. Alternatively a product supplier can declare by itself the conformance of its products to the AUTOSAR specifications.

The feed-back from conformance test development process has been very important improving the testability of the specifications of basic software modules, but the granularity of tests at module level has been questioned. Actually, optimizations of implementations of the basic software stack can require the bundling of individual modules, bundles remaining AUTOSAR compliant. A black box approach at ECU level is therefore more valuable.

For that reason, further revisions of AUTOSAR will include acceptance tests focusing on application and bus level. The Basic Software will be regarded as black box. By that, an OEM will be able to decide on the acceptance of a supplier's platform. The acceptance test is a further evolution of AUTOSAR's conformance test system and will replace the conformance tests on single Basic Software modules.

AUTOSAR roll-out in series production

During the 3^o AUTOSAR Open Conference (May 2011), the Core partners disclosed their roll-out plans, presenting how AUTOSAR will be used in the near future in series projects.

As the development time is usually about four years, all current developments will be brought into series by 2016. Many OEMs and suppliers rely on the standard and are introducing AUTOSAR in a wide range of applications. 25 million ECUs, produced by the AUTOSAR Core Partners in 2011 will be based on the AUTOSAR architecture, while 300 million are currently planned for 2016 [Fig. 6].

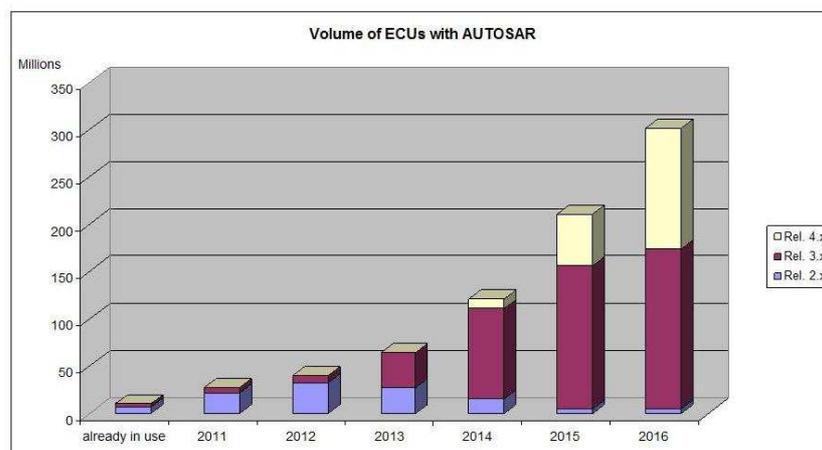


Figure 6: AUTOSAR ECUs planned production by Core Partners

ROLL-OUT STRATEGIES: The AUTOSAR implementation of the Core Partners is always time-graded. While almost all Core Partners are already using AUTOSAR basic software and parts of the methodology in series production, the usage of the complete methodology and application interfaces will follow at a later point in time. The utilization of the basic software is thus always the first step of AUTOSAR implementation. Before the AUTOSAR standard was introduced, some companies were using their own proprietary basic software solution. Switching from proprietary software to standardized software architecture offers cost and capacity benefits for all involved in automotive electronics development.

In a second step, the whole AUTOSAR methodology will be applied. While some of the Core Partners are already using several templates in series, most of the Core Partners plan to use all other templates at a later stage.

As a third step, the AUTOSAR application interfaces will be introduced. AUTOSAR is making great progress in standardizing the most commonly used application interfaces, the aim being to ensure the

reusability of applications based on them and to allow data exchange between them. These standardized application interfaces will enter then series production.

The Core Partners showed different ways in introducing AUTOSAR in series production [Fig.7]. Some of the car makers prefer the complete conversion of electronic architecture while others focus on dedicated domains or ECUs. Tiers 1 and also some car makers are following the strategy of their development partners.

	already in use	planned SOP in 2011	planned SOP in 2012	planned SOP in 2013	planned SOP in 2014	planned SOP in 2015	planned SOP in 2016	planned SOP later than 2016
conversion of complete car architecture/product lines *)		BMW Group		DAIMLER	VOLKSWAGEN		GM	
focus on dedicated domains	BMW Group PSA PEUGEOT CITROEN				Ford	GM		
starting with big / complex ECUs	PSA PEUGEOT CITROEN							
only when cost effectiveness is secured	TOYOTA		VOLKSWAGEN	Ford				
depends on strategy of development partner	BOSCH Continental PSA PEUGEOT CITROEN TOYOTA			Ford				
Others: selected ECUs in different domains Suppliers bring on their own for legacy platforms	VOLKSWAGEN			GM				

Figure 7: Core Partners preferred roll-out strategy

RELEASES IN USE: As the roll-out by the Core partners started from 2008, many releases are currently in use for series projects including the release 2.x which were the very first ones. At the moment Releases 2.1 and 3.x are the main ones being launched by the Core Partners [Fig. 8]. Starting in 2013, Release 4.0 will be brought into series together with Release 3.2 and will become the main streams. By offering and maintaining two releases at the same time for series development and production, AUTOSAR ensures continuity and a smooth change between releases.

	already in use	planned SOP in 2011	planned SOP in 2012	planned SOP in 2013	planned SOP in 2014	planned SOP in 2015	planned SOP in 2016	planned SOP later than 2016
Release 2.1	BMW Group BOSCH PSA PEUGEOT CITROEN Continental VOLKSWAGEN	DAIMLER						
Release 3.0	Continental TOYOTA			BMW Group				
Release 3.1	Continental Ford	BOSCH	VOLKSWAGEN	BMW Group DAIMLER PSA PEUGEOT CITROEN				
Release 3.2				BOSCH Continental DAIMLER VOLKSWAGEN		Ford		
Release 4.0				Continental TOYOTA	BOSCH TOYOTA	BMW Group Ford GM	PSA PEUGEOT CITROEN	
Release 4.0.4						BOSCH Continental	BMW Group	

Figure 8: Releases launch by Core Partners (1st use)

LICENSE MODE: Another topic was the preferred license model for basic software, Core Partners Tiers 1 and some OEMs are making their own development while others OEM either buy their own license to software vendors or let it to Tiers1.

	already in use	planned SOP in 2011	planned SOP in 2012	planned SOP in 2013	planned SOP in 2014	planned SOP in 2015	planned SOP in 2016	planned SOP later than 2016
buyout of AUTOSAR BSW / Stack / modules	VOLKSWAGEN 1)			DAIMLER	PSA PEUGEOT CITROEN VOLKSWAGEN			
Own development	BOSCH Continental PSA PEUGEOT CITROEN TOYOTA					GM		
qualification of preferred contractors & to be licensed by Tier 1	Ford TOYOTA		VOLKSWAGEN			GM	DAIMLER	
to be decided by Tier 1	BMW Group PSA PEUGEOT CITROEN TOYOTA		GM					

Figure 9: Core Partners Preferred License model

Conclusion

The current development phase sees AUTOSAR working on the selective enhancement of Release 3.x and Release 4.0 in order to ensure a reliable and future-oriented architecture and methodology. During this process, the development partnership focuses on backwards compatibility at all times. Furthermore, the maintenance of current releases used for series development and production plays an important role in supporting the implementation of the standard for all members.

Since the current AUTOSAR development contract ends by the end of 2012, the AUTOSAR Core Partners will set up a new contract starting beginning of 2013. The standard will be maintained, new hardware mechanisms will be supported and further market driven concepts will be specified.

AUTOSAR follows the principle 'Cooperate on standards, compete on implementation', so each company has to follow its own strategy on the basis of the roadmap for its product lines. The AUTOSAR standard is already being used in series production, and this has been a major success for AUTOSAR. Also, many AUTOSAR members are currently working on volume platforms in which the majority of ECUs are based on AUTOSAR. As the advantages of AUTOSAR are very convincing, the coming years will see a lot more launches of car models with AUTOSAR ECUs on board

By now AUTOSAR has become 'the' global standard for electronic infrastructure software and methodology. It is an enabling technology to manage the growing complexity of automotive electronics and to improve cost-efficiency without making any compromise with respect to quality.

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