You will find the figures mentioned in this article in the German issue of ATZ 9/2003 beginning on page 818.

Erfolgsfaktoren für ein zuverlässiges und stabiles Fahrzeug-Bus-System

Success Factors for a Reliable and Stable

Vehicle Bus System

A glance at the last decade shows that nearly all important innovations in vehicle technology have been made with software-based electronic systems. This especially becomes clear if one considers the degree of networking in vehicles – as this article from Vector Consulting GmbH and Audi AG shows.

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1 The Challenge: Stable and Reliable Vehicle Bus System

Since the production-run introduction of the CAN protocol in 1989 with three bus participants, the number has increased today to over 70 electronic control units and several bus systems (CAN, LIN, and MOST) that are linked using gateways. And, with this goes an increasing distribution of the ever-more-complex functionality. In the future, this development will advance even more quickly.

Therefore it is essential for all vehicle manufacturers to ensure stable and reliable communication between electronic control units and the individual bus systems.

The challenges that arise are comparatively new for all participants. In the past many different suppliers had developed electronic control units with various hardware and software solutions in different variants that have been integrated into vehicles by vehicle manufacturers. However, there has been minimal or in some cases no communication between these electronic control units. In the last three to five years, the networking of electronic control units as well as the distribution of functions has increased steadily while system complexity has grown, **Figure 1**.

Due to this development, it cannot necessarily be guaranteed that the whole system of networked electronic control units demonstrates the defined properties. Audi AG has identified three important success factors in which electronic control units will work together in defined operating modes within the vehicle bus system:

- Standardization of the hardware and software components
- Improve information flow between development partners, especially from the manufacturer to the supplier
- Integration reviews of the standard hardware and standard software connecting to the vehicle bus system.

Audi uses a combination of these three success factors during the entire development process. Their use as well as their interaction will be explained in more detail below.

2 Success Factor: Standardization

The software implemented in electronic control units can be divided into the so-called infrastructure software on the one hand (that is, operating system, communications software such as CAN network connection and basic input/output services) and application software (that is, the actually-desired functionality) on the other hand. An important prerequisite for the interoperability of electronic control units is the use of standard hardware and standard software components connecting the vehicle bus system. At Audi AG, these standard components are used for the CAN and LIN bus systems.

2.1 Standard Hardware

Audi makes available to its suppliers clearly defined specifications for the communication interfaces of the CAN and LIN bus systems by supporting interface requirement specifications. These detailed specifications

are made for the CAN inductors and the CAN transceivers as well as their circuits, **Figure 2**.

2.2 Standard Software Components

Audi makes available to its suppliers the standard software components for integration into the electronic control units depicted in **Figure 3**. Standardization of hardware and software components connecting to the CAN or LIN bus has significant advantages. The use of standard components in the course of an architecture-based design allows the vehicle manufacturer or supplier easier portability and reuse of the actual application on different electronic control units. It also ensures better quality and reuse of technical specifications. In conjunction, both the supplier and the manufacturer require the following tasks.

2.3 Tasks of the Supplier

Despite the support by the vehicle manufacturer, two important tasks remain for the supplier:

- On the hardware development side, correct implementation of the requirement specifications into the electronic control unit, such as the realization of the voltage supply specification or the CAN transceiver circuits.
- On the software development side, the integration of standard modules developed by others into one's own software. Here above all, the complexity of the interplay of the standard components and the configurability of the individual modules always leads to questions and integration problems.

2.4 Tasks of the Automobile Manufacturer

Requirements in the automotive electronics sector are also themselves subject to a permanent development process, especially in case of new developments. The development process for the requirements must be synchronized continuously with the suppliers' electronic control unit development process. This applies mainly for the standard components, if definition gaps in the individual requirement specifications are not identified and corrected through a meticulous collaboration between the manufacturer and supplier during vehicle development, this can lead to significant deviations and considerable problems in the integration of the entire network.

The standardization of software and hardware components poses a solution for a stable and reliable vehicle bus system; however, it brings along with it new tasks on the level of collaboration between automobile manufacturers and suppliers. Therefore, additional, flanking measures are necessary in order to make the transition "from theory to life" (Goethe).

3 Success Factor: Improve Information Flow

From the points discussed thus far, it has become clear that, due not just to the technical but also the organizational complexity, there is no clear, and complete communication between automobile manufacturers and suppliers as might be desired. Furthermore, the complexity of the communication between both must adjust to the complexity of the technical and organizational systems [1,2].

A communication relationship on the level of electronic control unit functionalities is therefore no longer sufficient. Additional communication channels also on the level of the connection of standard hardware and standard software components to the vehicle bus system must be established.

For this purpose, Audi is holding workshops with all its electronic control unit suppliers on the topic "Diagnostics and CAN / LIN / MOST software," which pursues three goals:

- First, the background for particular manufacturer requirements is explained and "tips and tricks" for the integration of diagnosis functions, network drivers, network management, and standard software modules are treated.
- Second, problems identified in the past are discussed so that these will not be repeated during the new development of vehicles.
- Third, the workshops offer a forum for general information exchange between the automobile manufacturer and the suppliers as well as among suppliers.

These workshops have been very positively received by the suppliers - here is an example of the general theme of participant feedback: "(...) the workshop created transparency in the entire bus topology of Audi," and "(...) the consequences of implementation errors for Audi became clear."

Specification gaps on the manufacturers' side and information gaps on the suppliers' side as well as the provision of additional contact people for the connection of standard hardware and standard software components in the vehicle bus system can therefore be reduced significantly by such workshops.

However, even with such measures it is not ensured that standard components will be integrated according to the requirements. There are two main reasons for this: first, the information in a workshop is not sufficient to consider all variants and specific difficulties of every electronic control unit supplier. Secondly, even detailed information does not guarantee that these specifications will be implemented accordingly. Therefore, a third measure is necessary for completion: integration reviews.

4 Success Factor: Integration Reviews

In order to complete the chain of success factors that consists of standard hardware and standard software requirements and components (success factor 1) along with improvement of the information flow (success factor 2), integration reviews are carried out at Audi in an early development phase. The purposes of these are the verification, in cooperation with the suppliers, and the integration of the standard hardware and standard software into the vehicle bus system.

The integration reviews complete the first two success factors in a central manner [3, 4, 5, 6, 7].

- Since the responsibility for system integration in the vehicle rests with the automobile manufacturer, suppliers do however realize the implementation of specifications in the electronic control unit. Integration reviews guarantee early identification and correction of deviations and integration flaws.
- Since the integration solution of each supplier is always subject to specific basic conditions, integration reviews offer the opportunity to clarify individual questions and difficulties and to solve them in the best interest of both parties.

If one considers integration reviews in the course of the V–model, it becomes clear that the cooperation between automobile manufacturer and supplier in the development process can now be realized consistently. Instead of just communicating requirement specifications "at the upper edges" of the V-model and testing their integration with sample acceptance, common development efforts occur through integration reviews also in the "middle range" of the architecture design and the integration test, **Figure 4**.

This "moving together" of manufacturer and supplier into a "systems engineering team" is necessary due to the increasing number and complexities of electronic systems in the vehicle, a complete test coverage of all electronic control units participating in the bus system is no longer possible offhand.

The central objections to integration reviews are time and resource efforts required by all participants. These can only be justified if integration reviews produce verifiable time and cost savings for all participants to the bottom line.

When weighing this cost-benefit aspect, Audi AG, with the support of Vector, has de-

cided to carry out reviews of the integration of the standard hardware and software in a pilot study with ten new electronic control unit suppliers and then examine the cost and benefit aspects that arise in as much detail as possible.

4.1 Contents and Process of Integration Reviews

The basis for carrying out the integration reviews was a specification defined by Vector and Audi together, which defined the testing objects and testing criteria as well as the review process with its associated roles and responsibilities.

The goal of the integration review, as mentioned above, is to identify and correct early on any integration flaws in the incorporation of the standard software and standard hardware components into the vehicle bus system.

From this goal was derived the central testing criterion: the interplay of hardware and software for the assurance of the "sleep" and "wake-up mode". Both these definitions formed, in turn, the basis for the determination of the testing objects. The following objects belonged to the scope of the integration reviews in the partial area of the standard hardware: voltage supply specification, watchdog specification, interfaces between transceivers and microcontrollers and between transceiver and bus system, tolerance details, CAN and LIN bit timing, and the circuits of the transceiver.

The following objects stood at the center of the review in the partial area of standard software: CAN drivers, network management, transport protocol, diagnosis, component protection, and flash/bootloader. On the basis of the defined goals, contents, and testing criteria, the following circle of participants was defined in order to ensure an effective and efficient execution of the integration reviews:

- Review service provider (Vector): Moderator, Standard software and network management experts
- Automobile manufacturer (Audi AG): Software experts, Hardware experts, Electronic control unit Developement Engineers
- Electronic control unit suppliers: Project leader, Hardware developer, Software developer.

This circle of participants has worked together on the process flow depicted in **Figure 5**.

Based on the defined goals and testing criteria, Audi and Vector together sent out a questionnaire that was answered in writing by the electronic control unit suppliers before the review session.

The referees at Audi and Vector evaluated the questionnaire and noted flaws as well as open issues and questions in a preparatory report, which formed the basis for the review session, which took place either at the supplier or at the automobile manufacturer. In the review session, the suppliers started by presenting their integration concept. Next, the points of the preparatory report noted by the referees were discussed in order and classified.

In individual cases, particular functions were verified using circuit diagrams or code sequences; a deeper discussion during the review session was not allowed, however. Thus it was possible to ensure that all findings could be identified, classified, and documented with terms and responsibilities in a period of four hours' duration on average. Thus after the end of the review session, there was still time for the discussion of detail questions and solution approaches.

The target-oriented control of the review session was the task of the external moderator, who also summarized the results and measures derived from the session in a concluding report.

Rework of the identified flaws and open issues occurred in writing so that suppliers and manufacturers did not have to meet once again. The moderator also carried out the examination of the adherence to all time-phased measures.

4.2 Results of Integration Reviews

With respect to the results of the integration reviews, three points are of special interest:

- Which findings were identified?
- Did the expenses and utility of the integration reviews stand in a reasonable relationship to one another?
- What kind of not-directly-measurable "useful side-effects" have the reviews produced?

4.2.1 Which Findings were Identified?

The classification of findings that were identified on average in the ten integration reviews were distributed as follows, **Figure 6**:

- 12 % A-findings that were classified as "customer-relevant" and "not acceptable";
- 11 % B-findings that were qualified as "uncomfortable" and "disturbing";
- 11 % C-findings that were rated "object of improvement";
- 66 % open issues for which the suppliers could not give the answer to the questions posed or could not produce particular documents or proof.

With respect to the testing object, 34 % of the findings were allotted to hardware topics and 66 % of the findings to software topics. Of these, in the following testing objects, integration errors were common:

- CAN transceiver circuit
- CAN transceiver handling
- Power-up initialization
- CAN drivers
- Data consistency
- Specifications and integration of incorrect versions.

4.2.2 Expenses and Utility of the Integration Reviews

Per identified finding, there was an average effort of approximately three person-days, which was distributed between the supplier and organizer in an approximate relationship of 70:30. If one compares this cost-benefit relationship with experiential values from later testing procedures, the relationship per identified finding is 3.4 times better than an error search in the C-sample phase and 37.8 times better than an error identification in the pre-series; **Figure 7**.

4.2.3 Useful Side-Effects of the Integration Reviews

In addition to the quantitative utility aspects, according to the suppliers' feedback to the integration reviews, there is a whole series of not-directly-measurable advantages that must also be considered in the total evaluation.

- Conceptual ideas: integration reviews produced many helpful impulses to "think over" one's own integration concept in some places.
- Early error discovery by the suppliers themselves: due to the questionnaire sent in advance, aspects in need of improvement could already be recognized and eliminated by the supplier prior to the review session
- Safeguarding: through the integration review, the suppliers received a founded and detailed reinsurance with respect to their integration concepts.
- Implementation aids: the combination of review session and subsequent discussion provided the suppliers with helpful information for the implementation of their own concept.

4.3 Lessons Learned from Integration Reviews

The lessons the promoters have learned from the preparation, execution, and evaluation of the integration reviews may be summarized as follows:

- Integration reviews represent an optimal complement to the success factors standardization and intensification of the information flow in order to achieve the goal of a reliable and stable vehicle bus system. On the one hand, they complete the approach of standardizing hardware and software components in that they not only specify the integration of the components, but also check

it. Thus integration flaws are identifiable and correctable with justifiable effort.

■ On the other hand, the information flow between manufacturers and suppliers is further improved by integration reviews and a platform is constructed by making suppliers' concepts more transparent for the manufacturer and for considering individual specifics sufficiently.

With respect to the review process, suppliers have repeatedly confirmed that the separation of the questionnaire and the review session was very effective and efficient and brought to light a multitude of findings. On the other hand, there is room for improvement in the execution of the integration reviews; suppliers suggested the following:

■ The questionnaire as a core element of the integration reviews must be developed further in order to reduce room for interpretation and previously existing doubled work.

■ Timing of the integration reviews should be better coordinated with the individual suppliers' development process.

■ Reviews for the integration of standard hardware and standard software components into the vehicle bus system must be established for all electronic control units as a mandatory measure of Quality Assurance in automobile manufacturers' development process.

5 Solution Approaches for a Reliable and Stable Vehicle Bus System

The question in the beginning was: How might solutions look that are adequate for the complexity of the conceptual formulation "realization of a reliable and stable vehicle bus system"?

The authors have answered this question here by pointing out, that measures must be defined and implemented on three different levels.

■ On the level of the hardware and software, connecting the individual electronic control unit to the vehicle bus system is clearly defined and structurally implemented specifications for standardization and reuse.

■ On the level of communication between automobile manufacturers and suppliers, a clear improvement of the information flow during the entire vehicle development process.

■ On the level of the development process itself, the establishment of integration reviews as a mandatory measure of Quality Assurance.

This procedure can be optimized further with additional measures such as the use of supporting process tools (8). In any case, sustained consideration of all three levels is important. Otherwise, the solution would not be adequate for the complexity of the conceptual formulation.

References

[1] Watzlawick, P.; Beavin, J.H.; Jackson, D.D.: Pragmatics of Human Communication. A Study of Interactional Patterns, Pathologies, and Paradoxes, New York 1967

[2 Ashby, W.R.:Introduction to Cyberbetics, New York 1964

(3] Fagan, M.E.: Design and Code Inspections to Reduce Errors in Program Development, in: IBM System Journal, No.3 (1976), pp. 182-211

[4] Fagan, M.E.: Advances in Software Inspections, in: IEEE Trans. On Software Engineering, SE-12 (7th edition) (1986); pp.744–751

[5] Freedman, D.P.; Weinberg, G.M.: Handbook of Walkthroughs, Inspections, and technical Reviews. Evaluating Programs, Projects, and Products, Boston / Toronto 1982

[6] Gilb, T.; Graham, D.: Software Inspection, London / New York 1993

[7] IEEE Std.1028-1988, Standard for Software Reviews and Audits, in: Software Engineering Standards 1993

[8] Lederer, D.; Fetzer, J.; Heling, G; Baumann, G: Automotive Systems Engineering – The Solution for Complex technical Changes?, in: Bargende, M; Wiedemann, J. (Ed.): Kraftfahrwesen und Verbrennungsmotoren, Renningen 2003; pp. 593–607

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