Advanced Microsystems for Automotive Applications 2011

Smart Systems for Electric, Safe and Networked Mobility
Preface

Fundamental transformations are imminent for the automobile: propulsion technologies are going to shift from combustion engines to electric motors; cars will soon be safer than ever before; and traffic will become increasingly efficient on prospectively more intelligent roads. Currently, the most evident future trend is the electrification of the car, which means the replacement of two major building blocks of its propulsion system, the engine and the gas tank, by completely different technologies, namely an electric motor and a battery.

One of the unique features of the electric power train is that it is controlled by electronic signals rather than by mechanical forces. The flow of energy and information between batteries, motors and wheels, and at the interface to the power grid can thus be managed by smart systems. So far, distributed functionalities can be easily integrated into one single subsystem, for example the intelligent wheel. This helps to optimize the energy efficiency and the driving range of the electric vehicle. Smart systems can successfully address challenges arising from the increased level of integration such as safe operation of a wheel carrying out acceleration, breaking and energy recovery functionalities at the same time.

It is often said that electrification requires more information and communication technologies to be integrated into the car. However, it can also be seen as an opportunity to fundamentally review the electric and electronic architecture of the automobile, and to generally reduce the complexity of propulsion, safety and comfort functions. In combination with the full potential of networking capabilities, this may lead to a completely new platform for sustainable and connected individual mobility.

The papers published in this book cover novel components, future architectures and smart systems that enable the automobile and road transport of the future. They have been selected from the submissions to the 15th International Forum on Advanced Microsystems for Automotive Applications (AMAA 2011) "Smart Systems for Electric, Safe and Networked Mobility" held in Berlin (Germany) on 29 and 30 June 2011. Organizers of the AMAA are VDI/VDE Innovation + Technik GmbH on behalf of the European Technology Platform on Smart Systems Integration (EPoSS), supported by the two EU-funded Coordination Actions of the Public Private Partnership European Green Cars Initiative, ICT4FEV and CAPIRE.

We would like to thank all AMAA authors for their time and effort to summarize the excellent results of their recent work and to present these to the
worldwide community of automotive engineers and managers from the industry as well as academic scholars at the conference. We are also much indebted to the members of the AMAA Steering Committee for their important help in selecting the best papers and speakers. And, finally, we would like to acknowledge the substantial support provided by industrial sponsors and public funding authorities, particularly the European Commission.

In our role as editors and conference chairs of the AMAA 2011 we are very thankful for the great assistance provided by an enthusiastic team of colleagues at VDI/VDE-IT. In particular, we would like to thank Iohanna Gonzalez for her engagement and commitment in running the AMAA office, and Rene Stein and Anita Theel for all the hard and excellent work of preparing the book at hand. Last but now least, we would like to express our great appreciation to Wolfgang Gessner for his most valuable advice and continuous support.

Berlin, June 2011

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Partial Networking in the Electrical Vehicle

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Abstract

When talking about electrical mobility, we mainly think of extending the cruising range of vehicles. Energy management works while driving, charging, or parking. System requirements for e.g. energy saving brings management of control networks to a higher complexity level and results in new and extended requirements for semiconductor devices. These are mainly "selective wake-up capability" to realize Partial Networking (PN) and "longer product lifetime", e.g. battery charge cycle adds to time of active drive. A PN standard for high-speed CAN physical layer is developed by the SWITCH group, a composition of car makers and semiconductor suppliers and is planned as extension to ISO11898. In networks, featuring PN, electronic control units wake up from sleep mode when a certain wake-up message is detected. Compared to existing ISO 11898-5 conform CAN physical layer products, additional functionality in the transceiver is needed to detect wake-up commands. This has to operate properly in a harsh environment of electrical vehicles (EV).

1 Introduction

What is important for EVs? What are trends in in-vehicle networking when we compare an EV to a conventional car with combustion engine? To what extend can paradigms be sustained that have been built with conventional cars?

The following summarizes the system challenges of an EV with impact on in-vehicle networking:

- Mobility: predictable cruising range, telematics, energy efficiency, size, and weight
- Lifetime and safety: introduction of new safety-relevant embedded systems
- System complexity: new energy sources and new power train result in new network demands
- Robustness: harsh automotive environment, fast transients in power electronics in electrical drive
In the context of electrified vehicles:

- Isolation towards human interface: high voltages above 60V DC across the vehicle network

## 2 Networking Trends within Electrical Vehicles

### 2.1 Network Domain Boundaries are Newly Set

Safety requirements and power saving in EVs are main drivers for in-vehicle networking architectures. Traditional categories in conventional cars are body, chassis, and powertrain. The EV system partitioning is mainly based on the used voltage levels. Background is the need of isolation and preparation to handle high voltage in safety-critical situations such as an accident. Of course, the traditional categories keep their relevance. Here, we see the trend that more and more functions are distributed amongst electrical control units, e.g. telematics, driver assistance.

### 2.2 Networks have Longer Duty Time

The EV never sleeps. Its network is never completely switched off while networks of conventional cars shut down when parking. EVs have, again, to be alert for critical situations such as failures in the system or the high-voltage battery or car crash; hits another car or is hit. Depending on the incident, the system is prepared to prevent battery from deep drainage and then damage or to separate high-voltage battery from rest of the vehicle for safety reasons.

The anticipated role of an EV as a medium in the public energy grid to store energy [1] illustrates as well that an EV will have extended operation with the energy network and accordingly communicates with the "grid" while parking.

### 2.3 Network Management Implementation Principle is Changed

Network management in conventional cars expects modules to distribute status messages on a regular base. Does this comply with the need for energy efficiency? We anticipate a move to an "event-trigger based" implementation, i.e. showing activity in the network only when needed. Number of maintenance messages is reduced to a minimum.
2.4 Network is Part of the Energy Management System

Some EV functions are always in operation (e.g. battery monitoring, energy management) and create bus traffic. This keeps modules in CAN networks active even when these modules do not contribute to a.m. system functions. A mechanism is needed that allows switching off/on functions while other functions remain active and exchange data via network, optimized for operation modes such as drive, park, and charge. Fatal for the energy balance if all modules wake up by bus traffic. This impacts the energy balance in a negative way and reduces cruising range [2]. PN provides the necessary feature for networks to switch off modules and quickly reactivate these when needed.

For example, a journey with the EV is scheduled and energy is to be stored in upfront in the battery. Before charging the battery, the amount of energy will be calculated that is needed to drive to the wished location. Navigation and traffic information functions are switched on for the route calculation. When route calculation is finished, results are communicated via the communication network and then navigation and traffic functions are switched off. Charging of the battery starts and accordingly only the involved functions for this operation communicate.

2.5 Paradigm Change in Networking from Conventional Car to EV

- Safety aspects dominate architecture and network choice (separation of voltage domains)
- Control network becomes an important means of energy management in the vehicle
- Parts of the control network are always active

3 What is Partial Networking About?

The usage of PN in conventional cars is typically with comfort modules (functions) that can be switched off during drive or are to be configured during start of the car. Some functions are still expected to be available when ignition of the conventional car is turned off. Examples are trunk lift, seat, window lifter, pre- or auxiliary heating, and sunroof. As described before, we expect a paradigm change within EVs. PN will become an important part of the energy management system. Easiness of implementation, robustness, and attached costs are criteria to successfully employ the PN feature in EV architectures on HW and SW (module) as well on system (network) level.
3.1 Definition

The ability to operate a certain part of a network in a certain moment is called PN. See Fig.1 where a green box means a module is switched on and a gray box that a module is switched off (right car). In ISO11898-5 CAN networks, all modules are switched on when at least two modules communicate (left car). Exceptions are realized by today by switching off supply of a selected module or by using dedicated wake-up wires. Each option is hard-wired and does not offer flexibility in its configuration. With PN, modules wake up by a certain message sent via network.

3.2 Standardization of Partial Networking

German car makers initiated the SWITCH (Selective Wake-able and InteroT†or vendors like NXP joined this interest group. SWITCH developed between July and December 2010 a draft for the extension of ISO11898 introducing a new wake-up mechanism. In short, a valid wake-up message is detected when the received ID matches to a predefined ID, the received data length code matches to the predefined data length code, and the received data field matches to a predefined data field content.

![Fig. 1. Vehicle without and with Partial Networking](image)

3.3 Partial Networking Transceiver Architecture

From the system perspective, modifications in HW (control mechanism) and SW (network management extension) are needed to implement the PN feature. We start with the HW architecture changes of a transceiver.
In order to realize the selective wake-up function, the receiving part of a CAN protocol controller has to be integrated into a PN transceiver as well as the oscillator that clocks this internal protocol controller. Compatibility to standard transceivers in SO14 package is required by the German car makers. Therefore, there is no option to connect an external oscillator like crystal or ceramic resonator to the transceiver. Such external component requires more supply current than an integrated oscillator and would be in conflict with power saving targets. Furthermore, would add costs and space to a printed circuit board. Fig.2 depicts exemplarily the new transceiver architecture.

In fact, all functional blocks except the transmitter need to be supplied directly from battery because they need to be operational also in low power modes (standby and sleep) when 5V supply is switched off in the according module.

If activity occurs on the network that wakes up ISO 11898-5 conform transceivers, the PN transceiver will not signal a wake event on RxD and INH pins. However, would activate receiver, protocol decoder, oscillator, and message filter & compare logic. If the bus remained silent for a certain period in time, these blocks would get deactivated, again. The wake-up event is signalled on RxD and INH in case the configured wake-up message has been received.

Overall, the challenge for the hardware implementation of PN is to find an on-chip oscillator design of certain accuracy, i.e. with perfect compensation for
temperature, supply voltage variation, production spread, and ageing in order to comply with the robustness requirements of the harsh environment of an EV.

3.4 Network Management Modifications

Besides HW modifications, the PN implementation requires changes in the network management. This impacts different levels of the SW architecture. An instance such as a gateway needs to keep track which modules have been switched off on purpose or due to error condition. These questions are addressed in subgroup “Efficient Energy Management” of Autosar work package WP-1.1.1. PN functionality is available with Autosar release 3.2.1 [3].

Fig.3 summarizes SW elements implemented in Autosar standard transceiver driver level (left hand) and needed additions to support PN (right hand). These are APIs, SPI support package, wake-up reasons, a PN configuration container for general PN support, wake-up frame configuration (ID, DLC, mask, data etc.), and baud rate. Important is the support of different shutdown sequences for PN transceivers, as the bus is not idle during network shutdown.

Fig. 3. Autosar Release 3.2.1, Incorporation of CAN Transceiver Driver
3.5 Architectural Changes on Module Level

The CAN network architecture in the vehicle as well as the HW architecture on module level does not change when PN is introduced. The PN transceiver with its selective wake-up function is responsible for detecting the wake-up event on the network and controls the activation of the voltage regulators for the entire module. This is identical to the operation of a standard transceiver according to ISO11898-5. Fig. 4 shows how a standard High-speed CAN transceiver like the TJA1041 or TJA1043 can easily be replaced on module level by a PN transceiver TJA1145. However, since the configuration of the wake-up message is necessary, the TJA1145 features a SPI interface instead of having error (ERRN) and mode control pins (STBN, EN).

![Module Architecture for Partial Networking](image)

3.6 Benefit of the Introduction of Partial Networking

PN does not require a new network or module HW architecture, will be standardized in ISO11898 as well as in Autosar, offers new functions that are used in conventional cars to increase comfort but also to comply with new governmental rules for energy saving. These advantages can be used in EVs for the implementation of a robust energy management system and ends up in an increased cruising range.

4 Relevance of Partial Networking for Electrical Vehicles

4.1 Mobility

Today, we do not know where we will end up with the cruising range of EVs. Interesting fact is that an EV already in 1909 could drive 259 km with one charge, 1911 already 324 km, and the Tesla Roadster in 2009 raised the bar
with more than 500 km [4]. However, experts expect within the next decade steep improvements in the power density of batteries. Needless to say that each “saved” Watt, directly contributes to the cruising range of an EV. PN excellently contributes with a robust and reliable approach to the energy balance of an EV. Industry expects that power savings in a conventional car may sum up to 70 Watts [5] and is a first reference for EVs. What this means for the extended cruising range depends on the EV characteristics and the efficiency of the chosen EV architecture.

4.2 Safety and Lifetime

EV stands for the introduction of safety-relevant embedded systems, not reusable from the conventional car. A typical EV has three main modes: drive, charge, and park. While in “park” with conventional cars, all functions are switched off, the EV keeps safety-relevant functions active. This links to the battery stack that is always on and is forced to zero leakage in case of a failure in order to avoid damages of the battery by deep discharge. Another aspect to keep the safety sub-system always active is to detach the high-voltage battery from the rest of the vehicle in case of a car crash. Tab.1 shows main system modes versus sub-systems then in operation. As a consequence, the safety sub-system needs to follow extended product lifetime tests.

4.3 Complexity and Lifetime

A discussion took place in the beginning of the SWITCH group how to implement the PN mechanism. On the short list were two options to detect the wake-up message: 1. Detection by CAN controller that is kept active while the rest of the microcontroller, in which it is nested, stops or 2. Add a reduced protocol engine to the silicon of the transceiver. The expert community of the car mak-
ers voted for the second option and limited with this changes in the entire system. With this, we anticipate that on device level the above mentioned product lifetime extension is applied to only one device, the transceiver, but not to the microcontroller, voltage regulators, capacitors, etc. While the requirements on lifetime have not been concluded, yet, a first indication from car makers is around to triple the lifetime testing. This will add to the product development lifecycle as well as to the final product cost for the device. However, and again, good if we limit the number of impacted devices, the PN draft standard does.

4.4 Robustness

When we talk about robustness of in-vehicle networking, we basically think about EMC performance in terms of immunity. The good news is that in the last years big steps have been made and the gained knowledge can also be applied to PN transceivers. Moreover, the SWITCH group has already defined dedicated PN EMC requirements. The bad news is that some experts see in EVs an increasing challenge for EMC due to high voltage and high current transients leading to hazardous electromagnetic fields not known from conventional cars. Thus ISO7637 impulse immunity during operation might become one of the new challenges for the semiconductor suppliers. What does robustness of PN in EVs mean? Do wake-up messages have different vulnerability than other messages? Yes, reason is the fact of two separate reception paths. 1. Potential wake-up messages are received and decoded by transceiver with on-chip oscillator. Power consumption in this reception path is limited to a very low value. Directly connected to battery, supply lines might be disturbed by transients. 2. In normal operation, messages are decoded by microcontroller that is connected to quartz as a reliable clock source. The receiver in the transceiver consumes more power and suppresses noise and stabilizes the supply. It is too early to compare robustness of "wake-up message detection in a PN transceiver" in all PN implementation concepts but already clear that the critical factor is the on-chip oscillator and its resulting stability despite distortions like electromagnetic fields, ringing, sender clock tolerances, as well as cranking pulses on the supply. With the TJA1045, NXP found a smart implementation.

5 Summary

- EV enables new dimension of efficient driving and need for extended energy management
Lifetime aspects in EVs are tremendously important due to embedded safety systems
Paradigm change in networking: conventional car to EV is from comfort to energy management
Partial Networking is excellent means for energy management; parts of EV are always active
Partial Networking contributes into all operation modes of EVs: drive, charge, and park
Multiple disciplines are involved in Partial Networking and standards are driven for HW and SW
Robustness will be key differentiator between PN transceivers; accuracy of the on-chip oscillator

References


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Keywords: electrified vehicles, components and systems, partial networking, SWITCH, autosar, transceiver level driver, selective wake-up, transceiver architecture, ISO 11898
Development of Mathematical Models for an Electric Vehicle With 4 In-Wheel Electric Motors

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Abstract

CIDAUT Foundation is a Spanish non-profit Research and Development Centre for Transport and Energy. One of CIDAUT’s current lines of work is sustainable mobility, involving the electric vehicle and its infrastructure. In order to advance in this direction, CIDAUT has designed and manufactured a technological demonstrator consisting of an Electric Vehicle. Currently, CIDAUT’s research deals with the implementation of Direct Yaw Moment Controls (DYC) in electric vehicles with 4 in-wheel motors. This paper aims to describe the different simplifications and subsystems created to generate advanced control algorithms. This technology belongs to the electronic active systems equipment incorporated in the future in order to have a proper control of the behaviour of the vehicle. This new powertrain system presented in this paper allows control engineers to develop more advanced algorithms due to highly versatile systems where it is possible to generate forces independently on each wheel.

1 Introduction

Nowadays, the high price of the electronic sensors makes engineers build active safety systems based on the knowledge of a reduced number of real vehicle states. As a consequence, many other ones have to be estimated based on simplified mathematical models that manage to reproduce reality. The state of the art presents several different approaches and final targets. In this case, the new possibilities that an independently controlled wheel traction system offer are explored. There exist three remarkable advantages of in-wheel traction systems: motor torque generation is quick and accurate, motors are easily installed in two or four wheels and motor torque can be known precisely. These advantages enable us to easily implement antilock braking and traction control systems, chassis motion control like Direct Yaw Control (DYC) and an estimation of road surface condition.
Hence, yaw moment reference signal detection can be followed not only by braking, but also by giving an increasing torque to wheels in order not to lose any global vehicle velocity.

2 Experimental Vehicle and Numerical Model

A conventional internal combustion engine (ICE) vehicle was used as starting point to develop the electric vehicle technological demonstrator. The first relevant characteristic of this vehicle is the use of two independent motors in the rear axle (Fig. 1.). Each motor is governed by one controller and both are connected to the PLC (Programmable Logic Controller) of the vehicle.

The PLC of the vehicle receives the signals concerning the motors speed as well as the steering wheel position. With this information the PLC calculates the signal to be sent to each motor. Depending on the parameters introduced by the user, the dynamic behaviour of the vehicle can be understeering, over-steering or neutral. The PLC also allows the user to select the kind of driving: snow, economic or dynamic.
The numerical model generated in MSC.ADAMS/Car MDR3 has been built as similar as possible as the real car. Every subsystem has been created in order to have the same dynamic behaviour and they allow us to make correlations of the experimental results. The powertrain subsystem has been built to reproduce the characteristics of the in-wheel motors. Besides, the control algorithm is developed in Matlab/Simulink R2010a to imitate the real components behaviour.

3 DYC System: Logic Description and Components

The motivation for the development of yaw control systems comes from the fact that the behaviour of the vehicle at the limits of adhesion (rain, low μ road, etc.) is quite different from its nominal behaviour. This kind of system pretends to reduce the deviation of the vehicle behaviour from its nominal behaviour and also prevent the vehicle slip angle from becoming large.

The main goal of the control system is to follow the reference yaw moment dictated by a simplified two d.o.f model. As shown in the following figure, the control model is compound of different modules that can be grouped as: direct calculations, estimated states and logic modules. Each of them is described in the next lines to build a complete and easy to follow and tune control system.
3.1 Reference Model

The 2 d.o.f bicycle model is mainly selected by researchers as the reference model to calculate the yaw rate and side slip angle signals. Starting from measured values of longitudinal velocity and steering wheel angle, yaw rate and side slip angle reference signals are calculated in order to be followed as close as possible by the controlled system.

\[
\begin{bmatrix}
\dot{\beta} \\
\dot{r}
\end{bmatrix} =
\begin{bmatrix}
\frac{-C_{af} + C_{dr}}{mv_s} & \frac{-aC_{af} + bC_{dr}}{mv_s^2} & -1 \\
-\frac{aC_{af} - bC_{dr}}{I_z} & -\frac{a^2C_{af} + b^2C_{dr}}{I_zv_s}
\end{bmatrix}
\begin{bmatrix}
\dot{\beta} \\
\dot{r}
\end{bmatrix} +
\begin{bmatrix}
\frac{1}{m}C_{af} \\
\frac{1}{m}C_{dr} \\
\frac{1}{I_z}C_{af} \\
\frac{1}{I_z}C_{dr}
\end{bmatrix}
\begin{bmatrix}
\delta \\
o
\end{bmatrix}
\]  \hspace{1cm} (1)

Once the yaw rate is obtained, it is numerically derived and multiplied by the yaw inertia of the vehicle to finally obtain the reference yaw moment. This variable defines the behaviour of the vehicle during the manoeuvre of cornering.
3.2 Estimation of States

Several real vehicle states need to be estimated so as to measure in vehicle dynamics terminology what the vehicle is actually doing. Standard medium class vehicles only incorporate sensors for measuring wheel speed, throttle signal, yaw rate, brake pressure, longitudinal and lateral accelerations and steering wheel angle. As a result, numerous other variables have to be calculated in an easy manner to be integrated in the control algorithm. In the next lines, these simple models are described briefly just to show how many tools are needed.

- Estimation of the side slip angle of the vehicle at its cog: Taking the basic equations of the transient bicycle model, the lateral acceleration has two components. As a result, the integration of the variation of lateral velocity allows calculating an approximation of the sideslip angle. This method obtains accurate results for simulation data. For real data, sensor errors and noise must be considered so as to introduce filtering or other data treatment techniques.

\[
\dot{a}_y = \dot{V}_y + r V_x, \quad V_y = \int (a_y - r V_x) \, dt, \quad \hat{\beta} = \arctan \left( \frac{V_y}{V_x} \right)
\]  

- Normal tire forces: Steady-State weight transfer models (lateral and longitudinal) have been used to determine the normal forces on each of the four tires. The next step consists on assigning over each tire the corresponding load, according to the reference system selected.

- Slip angle of each tire: Having the values of longitudinal and lateral velocities, yaw rate and other geometrical parameters of the vehicle, it is possible to accurately estimate the slip angle on each tire based on simple trigonometric formulas \([1]\). This calculations are obtained based on the bicycle model.

- Lateral and longitudinal tire forces: a Magic Formula Monte Carlo version tire model is used. The coefficients are fitted according to convenient test carried out.

- Electric motor model and longitudinal force transmission estimation: The conversion of the driver throttle signal into traction torque on each wheel is an important issue for this model. The maximum transmissible force between tire and road is compared to the maximum force that could give the motor in this situation. Once the longitudinal slip is calculated, the value of the friction coefficient is obtained through a lookup table (See Figure 4). This is a simplification of the real model but is also widely used in vehicle dynamics control algorithms \([5]\).

Having the values of normal and lateral force for each time step, using
the friction ellipse approximation is possible to calculate the maximum transmissible longitudinal force to the road.

![Friction Ellipse Diagram](image)

**Fig. 4.** Ideal (simplified) curve for friction coefficient versus longitudinal slip and slip angle

► In parallel, the torque and, therefore, the longitudinal force offered by the electric motor at the current conditions are intended. Making use of the torque vs. angular velocity map of the motor, the measured velocity of each of the wheels allows obtaining the maximum torque in this situation. Then this torque is multiplied by the throttle signal to obtain the final value really developed.

► The last step is to compare the both values previously obtained. The real value developed between the road and the tire is the minimum of them.

► GPS/INS systems are seen to be a near future benchmark for road vehicles. For this reason, their information could be used to increase the accuracy of the control systems. They provide information about the position and velocity of the car which could be really helpful. This improvement will be included in future version of the control system.

### 3.3 ABS and TCS Systems

Antilock Braking (ABS) and Traction Control (TCS) systems are becoming standard systems for advanced vehicle control systems. Both systems are implemented in such a way that they do not work under a velocity threshold imposed by the programmer.

The ABS follows a logic that only allows to work with incremental pressures (relative to the value of the previous instant). This statement means that there exist only three possible actuations as response to the measurements: increase,