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PEIT

Powertrain Equipped with Intelligent Technologies

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Project overview

Vehicle traffic volume is very high in Europe and will even further increase. As a result also the number of accidents will increase together with dramatic socio-economic impacts.

Clearly, reducing the number of accidents – or better preventing them – is of prime importance.

With a new architecture serving as platform for driver assistant systems PEIT has the goal to improve overall traffic safety and traffic efficiency for vehicles to decrease the number of accidents which are up to 97% caused by the driver.

To achieve an overall improvement in safety an intelligent powertrain was developed which provides an interface to serve as a base for all accident prevention and driver assistant functions of the vehicle. The powertrain interface makes it possible to integrate drive by wire application into the system. To connect the distributed functionality and their electronically controlled devices, a failure tolerant central system architecture derived from the avionics fly by wire applications was developed. To demonstrate the benefits and the modularity of the overall system a number of important safety related subsystems were developed and integrated into the PEIT powertrain with the aim of assisting the driver.As one of the most important safety relevant subsystems a steer by wire was integrated and a brake by wire system was developed. It was augmented with an “intelligent tyre” able to determine the road-tyre friction coefficient to calculate the available brake and cornering capacity.

The vehicle dynamic control systems, the ESP (Electronic Stability Program) was enhanced by using additionally the steering control and thus be more effective than differential braking of individual wheels alone. The possibility of additional steering intervention increases the potential of vehicle stability and reduces braking distance.

Obviously, the electrical energy management supplies safety relevant subsystems and components which may never fail. Therefore, the development of a fail-safe energy management was a important subsystem, which was developed in the project.

Although not in the focus of the project, the intelligent powertrain provides more than just accident prevention applications. They will in addition allow assistant functions like on board powertrain diagnoses and maintenance, and finally provide a more comfortable work place for the driver.

1 Project objectives and approach

The technical objectives of PEIT were to develop a fully electronically controlled powertrain which is controlled by an input of a motion vector coming from the human machine interface. A motion task operated within a central architecture based on horizontally distributed applications.

The approach of the work is to build up a basis, a concept for the demonstration of an accident avoiding truck, an almost accident free vehicle, with a high potential to reduce environment pollution and fuel consumption and in the same time the potential to raise economic efficiency

To achieve the objectives a fault tolerant architecture was designed and developed according to layer model shown below.

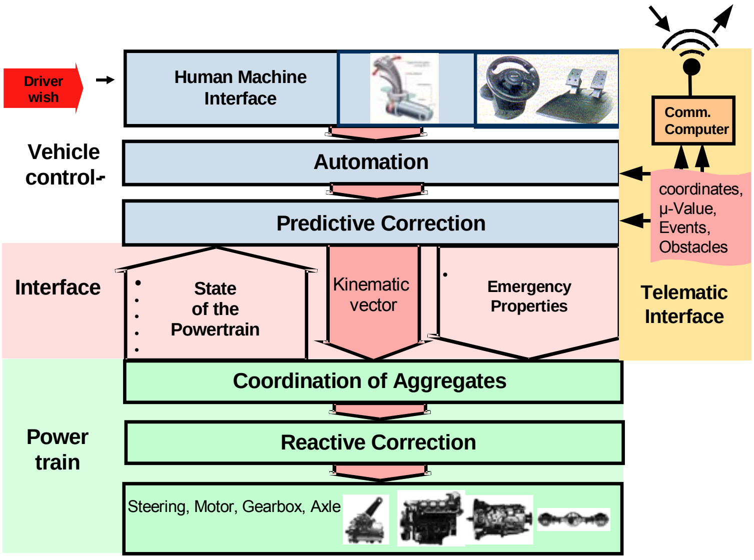


Figure 1: Structure of PEIT architecture

o demonstrate the advances of the vehicle control via the powertrain four intelligent and safety relevant subsystems were developed and integrated into the intelligent powertrain. These are

- a system to measure the tyre surface friction coefficient,
- a 2E brake-by-wire system,
- the integration of steer-by-wire with ESP, and
- fail safe energy management system.

The integrated system has been demonstrated and thoroughly evaluated. It will be measured by its capability to prevent certain dangerous driving situations such as jack knifing and roll overs.

Research studies on accident analyses will support the application scenarios and point to specific requirements, which the technical systems will have to fulfil. As further enabling measures questions on legal issues as well as homologation issues will be analysed. These are prerequisites for the successful market introduction of intelligent powertrain systems.

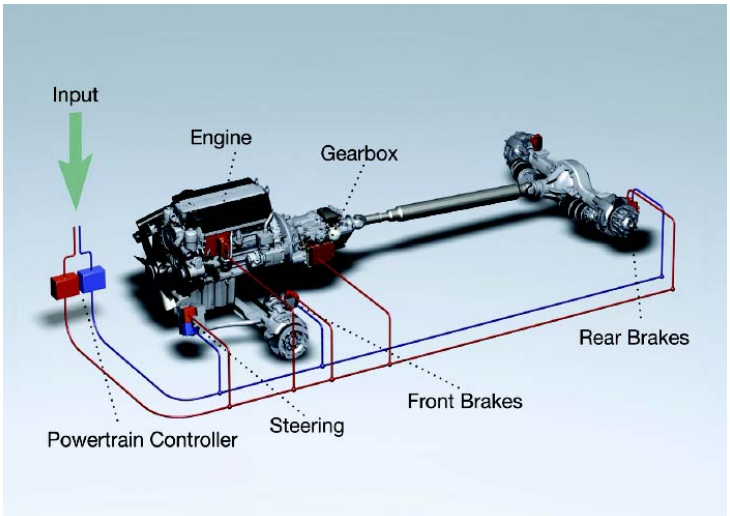


Figure 2 : Central coordinated powertrain

1.1 Summary of the main achievements

One of the most important work packages within the PEIT project which demonstrates the necessity of driver assistant systems was the analysis of the accidents scenarios in Europe. The analysis showed that a giant number of more than 97% of all accidents are caused by the driver (see PEIT deliverable D10). According to these determined facts a huge number of accidents could be avoided respectively minimised in their human and social economic impacts by supporting the driver with driver assistant systems.

The PEIT consortium showed an architecture, on which driver assistant systems could be easily linked in. The approach comes from the means of the most safety relevant transportation area, the avionics. The state-of-the-art aircraft technology like the one established by Airbus with its fly by wire applications supporting the pilot were taken to derive an automotive methodology.

The result is a drive by wire powertrain, controlled by a central ECU the PTC, the so called Power Train Controller. This duo duplex unit with redundant capabilities operates the drive by wire components of brake by wire, steer by wire, shift by wire, accelerate by wire and the energy management out of a fail safe environment. Even in case of a safety critical failure the system is still full operative and supports the driver with all safety functions.

A standard interface was reached coordinating the whole powertrain by using only a motion vector containing speed and steering angle as an input for the PTC.

To ensure the representation of the driver’s motion vector, on to the road a stability assistant was integrated into the vehicle to ensure a stable vehicle dynamic even in critical driving conditions. This assistant system a stability control with an additional steering intervention operates out of the central controller, the PTC. Due to the horizontal distribution and the resulting direct access of the drive by wire powertrain applications within the PTC, the motion task can be easily executed. The architecture is independent whether this motion vector comes directly from a driver or a driver assistant system due to the standard interface. Not directly in the focus of the project but as a considerable advantage of the system philosophy, this architecture reduces drastically the high communication load on the communication busses between the mechatronic elements of the powertrain. The major part of the communication takes place within the PTC itself containing the drive by wire modules of steering, braking, gear shifting, accelerating and energy management with the advantage of a high communication speed between these modules. An additionally advantage due to the high speed communication of this architecture is the improved controlling of vehicle dynamic functionality due to the shortened reaction times. The chosen architecture represents therefore a solution against an increasing complexity of communication load in highly distributed systems.

The architecture is not only restricted for the easy integration of driver assistant systems providing an interface according to the chosen standard of a motion vector also the human steering of the vehicle will no longer be limited to the current conventional human machine interfaces like pedal box and steering wheel. Each interface capable of generating a compatible standard motion vector can be used for steering a vehicle. Side sticks could be a solution for the future like so far already used in the avionics at the airbuses. The effort of the integration of steering systems neither on the right side nor on the left side will cause high implementation costs, only an electrical connector is needed on the left and right side.

Another application developed within the consortium running within the PTC was the determination of the actual friction coefficient between tire and road surface without using any kind of sensors. Only with the information of the drive by wire powertrain a determination of the friction coefficient is possible. The information is used for preconditioning the vehicle. In case of braking and cornering an additional friction coefficient estimation will lead to an increased vehicle stability being in the position for preventive powertrain actions like reduction of speed or preconditioning of the brakes.

An algorithm for the conversion of the determined actual friction value in a vehicle independent friction value was integrated. It is an application which can be used to serve as a basis to inform other motorists and cyclists about the actual road conditions. By the use of an appropriate distribution channel the current friction coefficient data together with correlated data of coordinates of the vehicle on road can be broadcasted and stored in appropriate systems for the traffic environment.

European type approval of new vehicle architectures is a key process to bring new technology on to the market. Within PEIT all German automotive legislative authorities came together with the main goal to develop an European homologation path on how to approve centrally coordinated and horizontally distributed applications based on drive by wire technologies. Together a homologation path was presented on how one can bring PEIT technologies with the current rules to market.

To show and present PEIT technology on an European level and to distribute the advantages of this architecture the PEIT consortium participated on international and national congresses and spread brochures and CD-ROMs to all people interested in PEIT technologies.

1.2 Description of work

To realise the PEIT project two vehicle bases were set up. For a quick and advanced development and validation one vehicle base was used as a vehicle in the loop test bench the other one as a demonstrator. The test bench, a fully equipped heavy truck mounted on a rack with four electric motors is capable of simulating all functional applications in advance before transferring them into the truck, an advantage which safes much time within the test and implementation procedure.

The overall workload was carried out in the following work packages:

- Definition of a fail safe system architecture with a standard interface serving for driver assistant functionality. Only a motion task (motion vector) is needed coordinating all drive by wire powertrain functions (work package 2).
- Development of the individual subsystems for the demonstration of the PEIT functions (work package 3):
    - Intelligent centralised powertrain architecture with horizontally distributed modules which serves as platform for driver assistant systems,
    - Electronic stabilisation program (ESP) with additional steering intervention to improve the vehicle dynamics,
    - Brake by wire system with a two-electronic-circuit architecture,
    - Steer by wire system with a two-electronic-circuit architecture,
    - Fail safe intelligent energy management system for the electric energy supply with a two-electronic-circuit architecture,
    - Intelligent tyre application yielding information on the friction coefficient for braking and cornering capability.
- Integration of the subsystems into the vehicle base (work package 4).
- Demonstration and evaluation of the demonstrator vehicle (work package 5).
- Furthermore, in order to prepare the intelligent powertrain for market introduction, supporting work on legal assessment was part of the project. Also, work was undertaken to assist the formulation of an open European standard (architecture and the interfaces) and homologation of the systems. This was done in work package 6.

- Finally a world wide dissemination of the project via conferences, the world wide web and through traditional channels like brochures and videos on CD-ROMs were performed in work package 7.

1.3 Approach followed to achieve project objectives

The project passed through six phases:

1. Analysis of system requirements and overall specification of the central architecture with it's standard interface,
2. Development of modules and subsystems like powertrain controller, steer by wire, brake by wire energy management intelligent tire,
3. Integration into demonstrator vehicles,
4. Verification and validation of demonstrators in real conditions,
5. Standardisation and exploitation planning,
6. Dissemination of the results.

They were mapped onto five technical work packages (WP02 - WP07) as shown in the figure below. They were supported by an organisational work package (WP01, not shown) covering the operational project management.

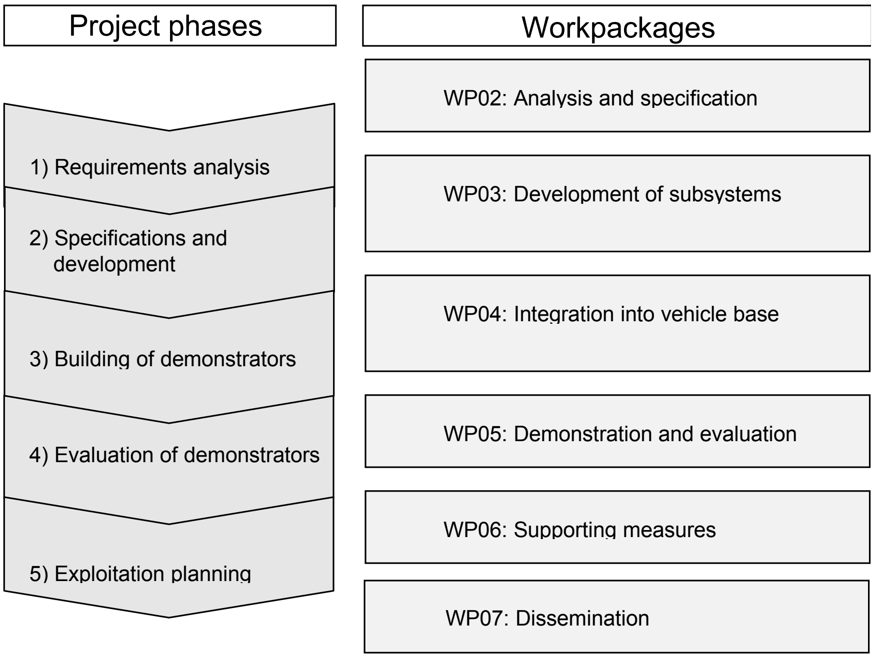


Figure 3: Project phases and work packages

1.4 Consortium composition and roles

The PEIT consortium brought together a partnership that carried all the relevant competences and skills for a successful outcome of the project. All aspects from technologies over to basic research results to homologation were available.

PEIT was made possible by the co-operation of manufacturers, suppliers, research institutes and official institutions. As all commercial participants are among the market leaders in their fields no technical or economical obstacles pose obstruction for the successful completion of the project work.

The official institutions took part in the development process at an early stage and thus were able to influence the work already from the beginning.

The research institutes provided the consortium with the latest research results as well as the basic and fundamental know how.

The consortium consisted of the following companies and institutions

- DaimlerChrysler AG,
- Continental AG
- IQ Battery,
- Knorr Bremse,
- TU Braunschweig,
- TÜV Süd, TÜV Nord, TÜV Rheinland, RWTÜV
- Budapest University of Technology,
- Universität Karlsruhe,
- Univesitat Stuttgart,
- Kraftfahrtbundesamt.

Each of the partners had a specific and well defined role in this project.

On the DaimlerChrysler side, the powertrain business unit participated in the project. It was the coordinating-contractor, and therefore also be responsible for the project management. DaimlerChrysler was involved in all work packages by giving significant contributions to all scientific and technological aspects. It delivered the vehicle base and brought in its know-how in powertrain development.

IVECO AG joined the project as a supporting partner as a heavy truck manufacturer to bring their expertise in this field into the project.

The University of Stuttgart contributed to the system architecture for the powertrain by bringing in its expertise in building safe aeronautic control systems. They provided a substantial contribution on the way to an innovative powertrain.

Continental AG joined the project as a supporting partner in the field of advanced tire technology to bring it knowledge into the group.

IQ Battery has developed an intelligent car battery with the corresponding energy management. The experiences with energy management systems helped to set up reliable power supplies for the PEIT systems.

Knorr Bremse is the world leading brake, suspension and other chassis system supplier for railway and commercial vehicles. The role of the Budapest R&D centre in the project was conception, system development and delivery of the brake and suspension system. Furthermore the implementation of the vehicle dynamic control system in the electronic brake system environment was performed.

The TU Braunschweig was represented by the Centre of Transportation, a foundation of scientists from various disciplines. It acted as an advisory body to stimulate and coordinate research projects. The TU Braunschweig contributed to the enabling measures, mainly by coordinating the research activities concerning legal issues and homologation in close interaction with all German TÜVs.

The TÜVs and the Kraftfahrtbundesamt are the leading independent organisations for approval, examination, certification, consulting and education in various technical areas. Together with the TU Braunschweig they worked out enabling legislative aspects for the market introduction of intelligent powertrain systems.

At Budapest University, the Department of Automobiles participated the project. Among other things it is recognised for controlled vehicle systems and thus contributed to the development of the controlling algorithms for the PEIT ESP with steering intervention.

On the side of the Universität Karlsruhe (TH), the automotive group of the Institut für Maschinenkonstruktionslehre und Kraftfahrzeugbau joined the consortium. It is specialised on research concerning motor vehicles and their characteristics. The automotive group contributed to the work package “Enabling measures” by analysing traffic accidents and the evaluation of transferable friction information.

2 Project results and achievements

2.1 Analysis and specifications (WP02)

This work package defined and specified the overall fault tolerant system architecture for the powertrain and the communication to the subsystems which serve all accident prevention and driver assistance functions of the vehicle with the focus of a standardised platform.

Hazard and fault tree analyses were performed to ensure the safety philosophy of a fail safe drive by wire applications. As a result an architecture consisting out of three layers was defined to meet these requirements of PEIT: The command layer, the coordination layer and the mechatronic layer.

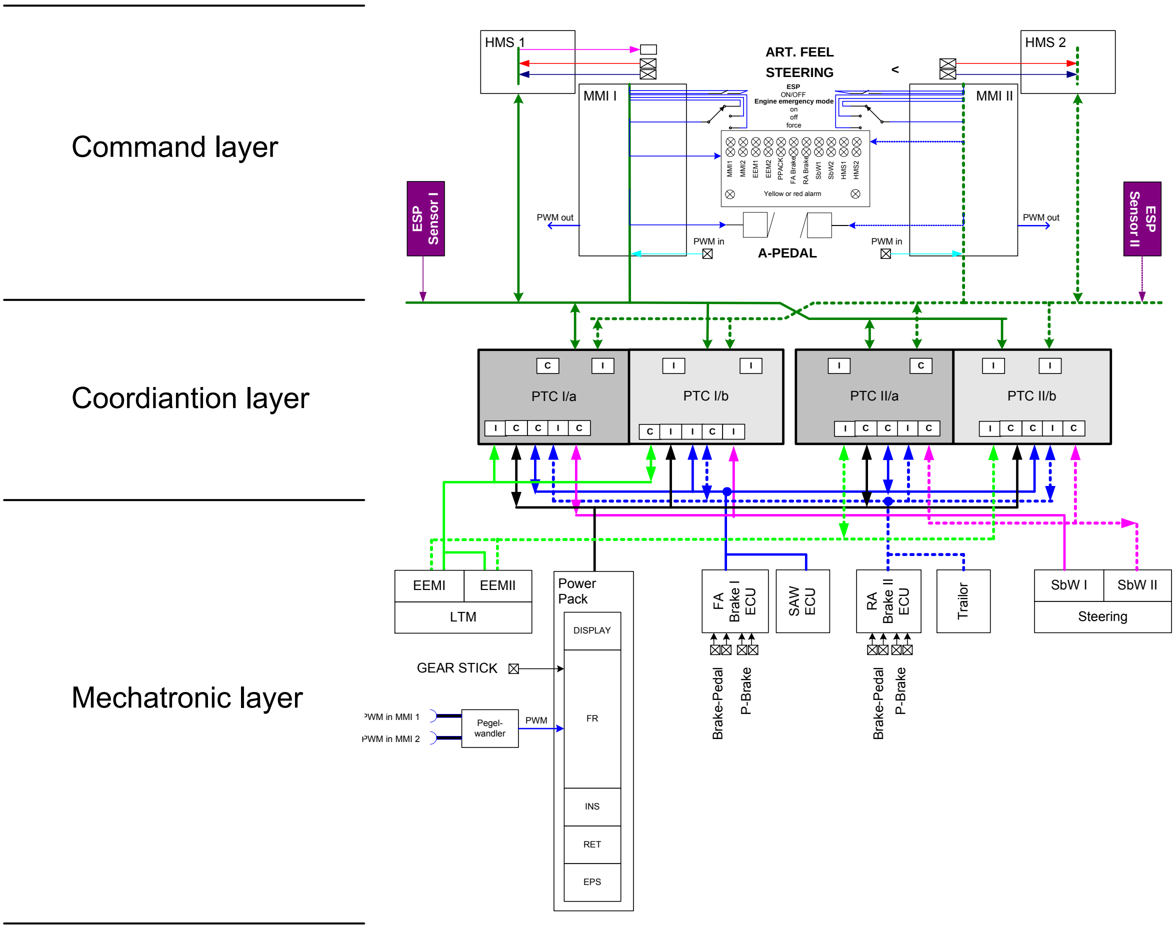


Figure 4: PEIT Overall Architecture

Within the command layer the human machine interface first collects in a redundant fail safe environment the information coming from the driver. Out of this information the motion vector containing the steering angle and the velocity is calculated. This data is then communicated via PEIT standard interface to the coordination layer, a central ECU derived from the avionics. Only the motion vector is needed to steer and control the vehicle. Second the human machine interface further on is communicating via artificial steering wheel feeling (force feedback), visual and acoustical signals the status of the vehicle informing the driver.

The central ECU the PTC represents the coordination layer. There the motion vector is executed. To reach an optimised controlling all modules necessary for the coordination of the drive by wire mechatronics are specified to be within the ECU and horizontally distributed. The demand of safe driving even under worst road and driving conditions leads to an advanced stability control with an interaction of all powertrain components even with steering intervention running within the PTC. Additionally an application determining the friction coefficient was implemented improving braking and cornering capabilities. Via communication channels the drive by wire mechatronics are controlled according the motion vector. To reach a high level of reliability the PTC acts in a dynamical master slave algorithm in which master and slave can be changed among themselves according the current safety conditions.

The mechatronic layer consists out of the mechatronical elements like SbW, BbW, energy management, power pack (motor, gearbox). All safety relevant functions were specified to keep the fail safe philosophy.

2.2 Development of subsystems (WP03)

Within this work package the individual subsystems and their corresponding tools were developed, which were integrated into one homogenous system. The first steps in developing and assembly the PEIT demonstrator was the development and construction of a vehicle in the loop test bench in front. A technical environment serving as a base platform identical to the PEIT demonstrator was developed, a technical twin mounted on a rack inside a laboratory.

Figure 5: Vehicle in the loop test bench

All drive by wire components and applications were developed and tested in this environment before going into operation in the PEIT vehicle, an approach which results in an advanced fast and straight forward process of quick integration and testing procedures. Energy management, brake by wire, steer by wire, shift- and accelerate by wire, the dual duplex ECU's and all their related functions and data communication could be tested very effective before.

2.2.1 Intelligent powertrain architecture

The goal of PEIT was the development of a platform for the easy integration of driver assistant systems. A standard interface was specified which serves as an entry for all assistant systems. Only a motion vector is needed to control the vehicles powertrain. A central redundant ECU the duo duplex structured PTC communicates via communication channels with the drivetrain. Techniques derived from the avionics were taken to reach fail safe behaviour. In the PTC four processors arranged in four lanes set up a fail safe duo duplex environment which assures an extraordinary reliability of the vehicle.

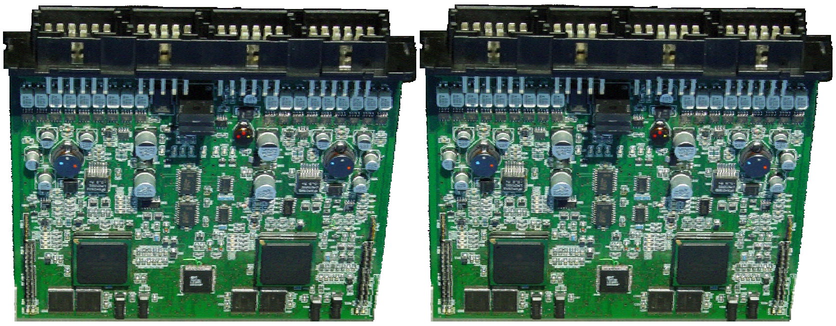


Figure 6: PTC ECUs

2.2.2 Powertrain controller

X-By-Wire systems require new system concepts compared to state-of-the-art technology in the automotive industry.

The most characteristic attribute of the heavy goods vehicle demonstrator that has been built up is the central controller-system (powertrain controller-system = PTS). It has been realised out of two duplex-channels, the so called PTCs.

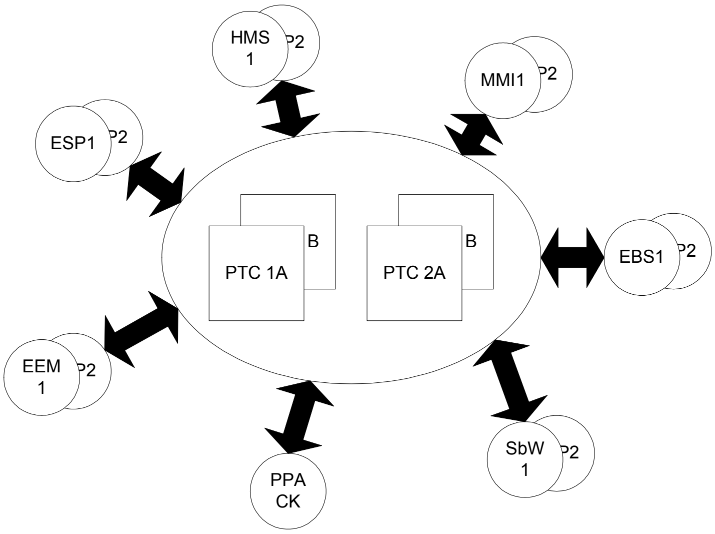


Figure 7: basic system components

As shown in Figure 7 the PTS is the main control-instance of the system. Therein all system data are collected, all subsystems are rated and so all decisions within coordination functions can be made based on the same consistent data basis (system-matrix).

The subsystems being controlled are:

- Steering consisting of actuator-units (SbW1,2) and Steering-Wheel sensor and force-feedback units (HMS1,2).
- Brakes (EBS1,2) consisting of a front-axis brake- module and a rear-axis brake-module
- Redundant ESP-sensors (ESP1/2, fail-passive characteristic)
- PPACK consisting of retarder, engine, clutch, gear box.
- Electrical-Energy-Management 1/2 (EEM1/2) to control the power-supply-circuits 1/2
- Man-Machine-Interface 1/2 (MMI1/2) for switches, display-control.

All components except the non-safety-critical power pack (engine, clutch and gearbox) are realised as duplex-systems. This arose from the fact that each subsystem besides MMIs and EEMs is (slightly modified) commercial of the shelf (COTS) components used in series production as stand-alone self- contained systems.

Most state-of-the-art mechatronic-concepts consist of single dedicated systems like

- Brake
- Steering
- Powerpack

operating almost independently from each other. The challenge was to combine all stand-alone functionality to achieve an integrated powertrain that can be controlled centrally.

The development of complex systems with high integrity is a challenge. However, this technology is already state-of-the-art in the aerospace industry. All new big transport aircraft are fitted with such absolute safety relevant fly-by-wire systems covering all aspects such as

- Design of safety- relevant, high redundant systems
- Design of centralised system-management-software
- Design of fault-detection mechanisms
- Integration and verification of complex systems

Using this know-how and technologies within the EU-project PEIT leads to a new system-platform that is not only improving economy, but especially active safety. The PEIT control-platform provides a centralised consolidated overall system data-base (system-matrix). Access to this information by applications enables the application-developer to read out any system-information and to control the overall mechatronic layer. Further on all applications are able to base their calculations on the same data-set. Such it is possible to:

- improve the interaction between different control-mechanisms
- provide a consistent system-information

The functional description can be split up to the following items:

- Command-principle
- Functional degradation
- Subsystem mode-control

Splitting up sensors and actuators of a vehicle with respect to their functionality, all subsystem can be assigned to one of the three groups:

- Command / control-layer
- Coordination layer
- Mechatronic layer

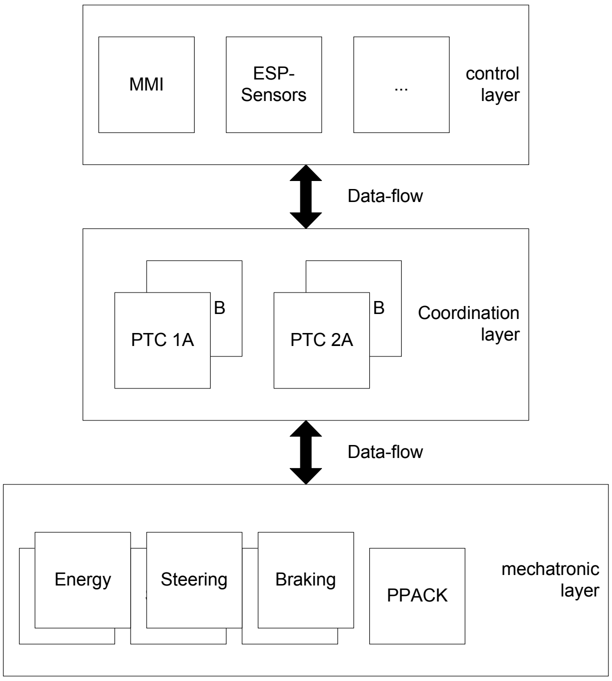


Figure 8: System-component layers

The control-layer reads in the driver's motion-request (Figure 8) that will be sent to the coordination-layer. There this motion-vector can be transformed to actuator-commands for steering, braking and engine with respect to the current overall system, subsystem and environmental conditions.

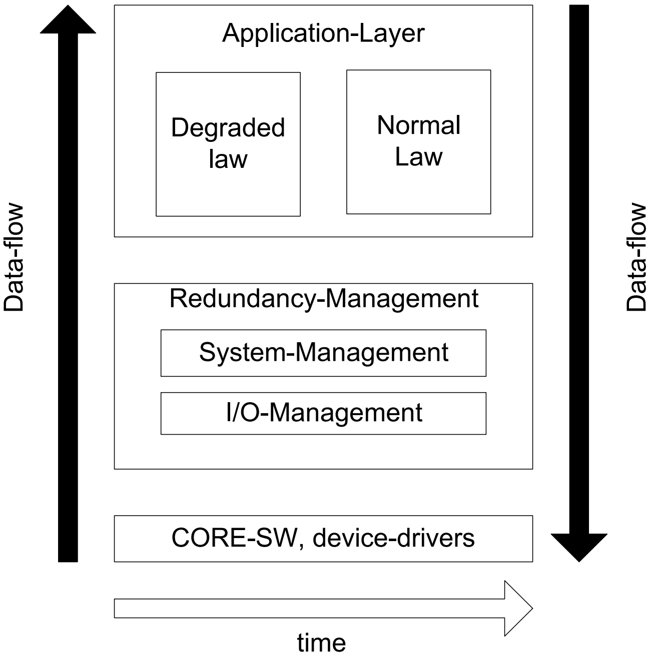
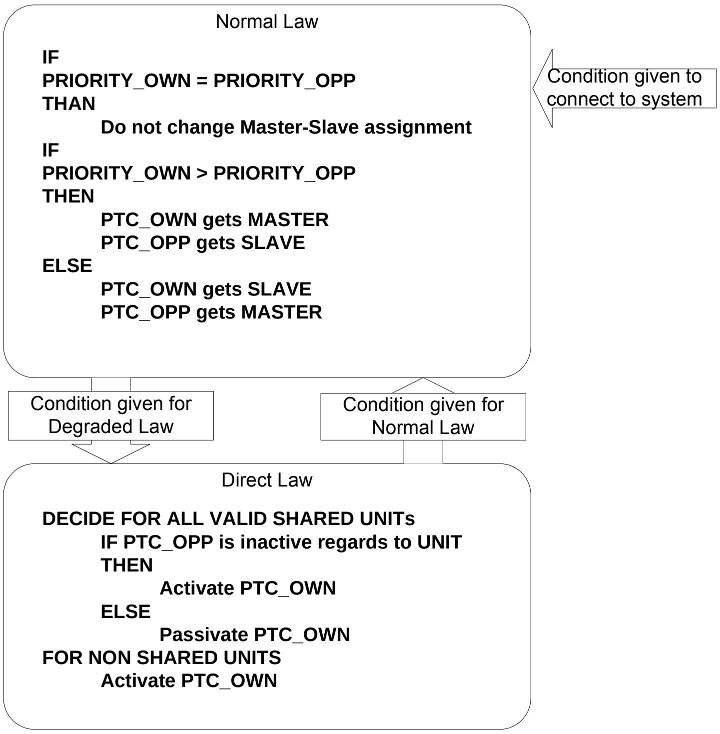


Figure 9: SW-Layers of the central control computers

The overall component availability is determined within each duplex-channel (Powertrain-Controller, PTC).The I/O-Management reads in all the subsystem-information (status, sensor-data), checks it for failures within the time- and value-domain and generates an availability-matrix for the system-management. This information is combined with information of the past and status-information of the PTCs themselves. Based on this overall status-set the functional-degradation is controlled meaning that the active PTC out of both will be selected and the scope of the applications will be set.

The master-slave-selection is used to identify and to activate always the highest degree of performance within a redundant system and is basically derived from the subsystem-status. Out of that a priority-level can be determined with respect to the criticality-level of failures. As long as one PTC will be able to control the overall vehicle in a safe way and the prosecution of the trip will be possible even in case of one more major failure, the corresponding PTC will be able to act in "normal law" as MASTER. Herein complex applications meaning closed-loop control-algorithms can be processed. A switchover to SLAVE-mode will only be necessary if the priority-level gets worse than that one of the opposite PTC, but only if this has a priority-level indicating its capability to control the whole vehicle (Figure 9).



```
IF
PRIORITY_OWN = PRIORITY_OPP
THAN
        Do not change Master-Slave assignment
IF
PRIORITY_OWN > PRIORITY_OPP
THEN
        PTC_OWN gets MASTER
        PTC_OPP gets SLAVE
ELSE
        PTC_OWN gets SLAVE
        PTC_OPP gets MASTER
```

```
DECIDE FOR ALL VALID SHARED UNITs
        IF PTC_OPP is inactive regards to UNIT
        THEN
                Activate PTC_OWN
        ELSE
                Passivate PTC_OWN
FOR NON SHARED UNITS
        Activate PTC_OWN
```

Figure 10: Master-Slave selection and mode degradation

If not a single PTC is able to control all safety-critical actuators in a safe way they will perform degradation to "degraded law" meaning that both PTCs will command all the actuators they are able to command but with respect to the activities of PTC_Opp. A collision-avoidance-mechanism ensures that actuators will not be commanded by both PTCs at the same time.

The scope of applications is controlled in the same way as the switch-over-mechanism between MASTER- and SLAVE-mode of PTCs. Two main operation-modes have to be distinguished for applications:

- Normal Law

- Direct Law

As long as the PTS performs a strict MASTER-SLAVE-behaviour "Normal-Law"-applications can be performed meaning applications with closed-loop algorithms. Because it is not ensured that all subsystems are rated to be valid during "Normal-Law", the corresponding applications have to provide internal degradation-steps:

- Full performance
- Degradation step 1
- Degradation step 2
- …
- Degradation step n

In such a way it is possible to perform a MASTER-mode with some less safety-critical components temporarily not being valid for the PTCs' applications.

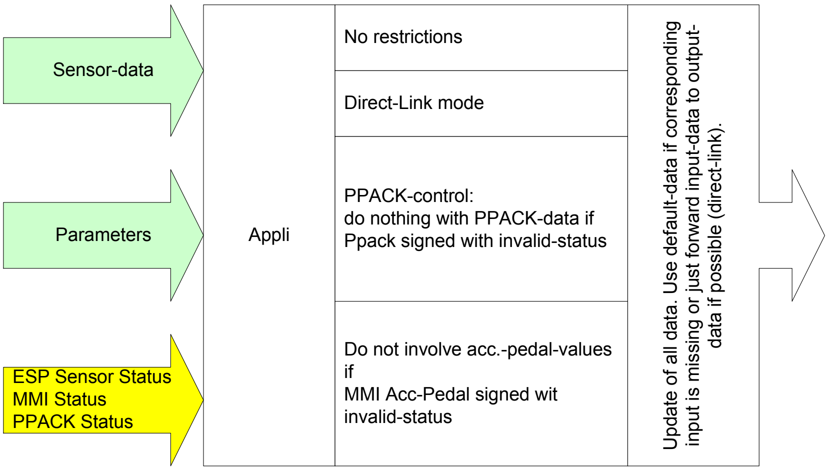


Figure 11: Example application degradation

As shown in Figure 11 the applications being called during "Normal Law" have to generate in any case valid output-data in consideration with the system status-information.

"Direct-Law"-applications are necessary to ensure basic control-functionality of the vehicle even in case of major failures (e.g. loss of rear-axle brakes in PTC2 and loss of steering-actuators in PTC1). The strict MASTER-SLAVE control-mechanism is given up and the command-activity is split up to both PTCs. Further on the activation of both PTCs requires subsystem-specific applications during "direct law": only the applications for the subsystems the PTC is allowed to control will be activated, all others will be disabled.

Comprising there are the following application performance-levels:

- Normal-Law
    - Full performance
    - Reduced performance
    - Initialisation
- Direct-Law
    - Full performance (regards to corresponding target-subsystem)
    - Reduced-performance
    - Default-data
    - Initialisation

Within the EU-project PEIT several not only new developed subsystems but also slightly modified COTS have been used. Therefore the PTCs have to distinguish between two different types of subsystems:

- Slightly modified COTS subsystems
- Newly developed subsystem

Nowadays actuator-subsystems are realised as distributed systems being self-responsible for their correct operation. They check input-data for failures, observe the interactions with loosely coupled subsystems and after a power-up they perform a BIT to check the own system for proper operation. Afterwards they signal that they have entered normal operation to the PTS.

Within a centrally controlled safety-critical system the overall system-responsibility must be placed into the central controller-system. E.g. not any component shall start a BIT-routine if not being commanded by the PTCs.

Following the state-transition-diagram shown in Figure 12 it will be possible to prevent subsystems to perform a BIT after power-interrupts and at undefined times.

Further on each actuator shall be fully controllable by the central controller-system meaning that:

- The PTCs command wake-up and sleep of the sub-system
- The PTCs command activation and passivation of the sub-system
- The PTCs command BIT of the sub-system

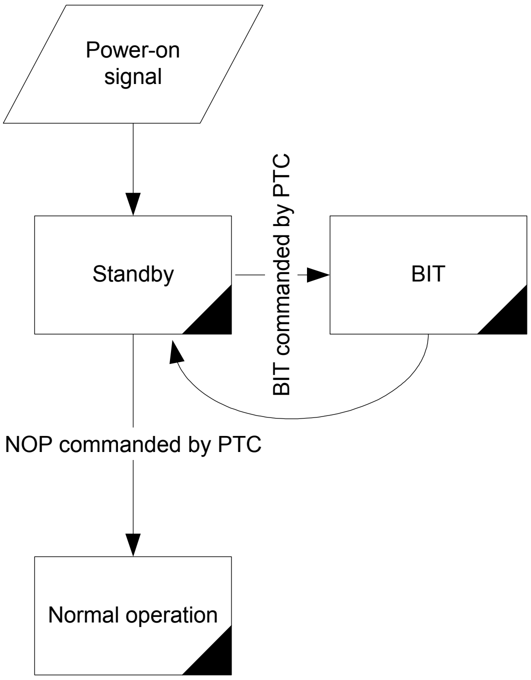


Figure 12: Subsystem BIT-activation

Such control-mechanisms directly lead to a fully controllable system based on a central highly integer and available “knowledge-base”

The overall system-requirements can be split up to the following groups:

- Functional Requirements
- Architectural Requirements
- Communication Requirements

Even in case of one major failure it must be assured that no unsafe situation for the driver and the environment will occur. Anyway a functional degradation will be accepted. This requires the following basic system-characteristics:

- Fail-operational behaviour after one major failure
- Fail-passive behaviour after two major failures

This leads either to a duo-duplex or to a triple-modular-redundant control system. Driven by aspects like economy and handling the consortium decided to build up the HGV-demonstrator of the EU-project PEIT with a duo-duplex control-system.

Subsystems and sensors were built up as follows:

- For safety-critical signals it is possible to identify simplex sensor-faults.
- The probability of a sensor-fault that will not be visible for the central control-system is acceptable.
- For safety-critical signals it is assured to have a fail-operative /fail-passive characteristic, meaning that after one sensor-

failure at least the hot-standby control-unit must be able to read in the sensor-signal in a correct way.

- For less safety-critical signals it is possible to identify simplex sensor-faults.
- For less safety-critical sensors it is possible to have at least a fail-passive characteristic.
- At all times the central controller-system knows the status of all subsystems (sensors and actuators).
- The probability that an actuator fails and that leads to a catastrophic event (multiple-death) is acceptable.

“Acceptable” means that electronically controlled vehicles shall at least have the same reliability as comparable mechanical systems. Moreover the use of central control-systems even increases the safety of drivers and outside traffic participants by interconnecting all sensors and actuators of a vehicle. E.g. first test-results with the advanced ESP coordination-function with steering-interaction showed a decreased brake-distance of 10% by less driver-activities compared to ESP without steering-intervention.

Within the EU-Project PEIT the consortium had to handle the fact that most of the used subsystems are COTS-components and therefore were not yet using safety-critical deterministic communication-systems like e.g. TTP/C or FlexRay. Therefore the PEIT communication-network is based on the well-known CAN-Bus. To increase reliability and to decrease fault-injection from one subsystem to another several so called “private” CAN-busses were used to interconnect the central controller-system with sensors and actuators.

2.2.3 Friction coefficient

The purpose of a friction coefficient application was to build up a combined system which first creates the actual friction coefficient between tire and road during driving of the vehicle and second, to standardise this vehicle-dependent friction coefficient value into a vehicle-independent friction value, which can be useful for other vehicles within the traffic environment. The examination of the whole system in hardware-in-the-loop environment and in real vehicle tests, were also the part of the work package. And last to correct the faults occurred during tests and the continuous improvements of the estimator system.

The conception of the whole friction estimator system can be seen in Figure 13. On the top of the picture there is the purpose, the estimated friction coefficient; in the middle, how the aim can be achieved (test vehicle, Kalman-filter) and in the bottom the block diagram and main parts of the estimator. More information about friction coefficient and about the estimation process can be found in Deliverable D18.

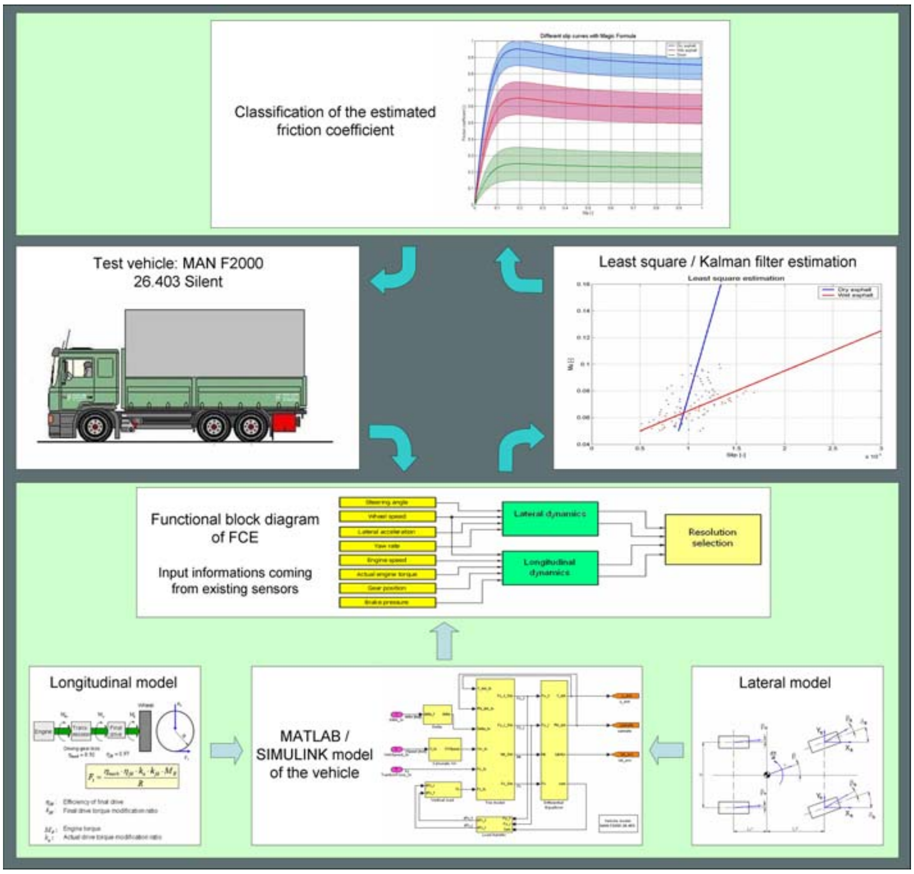


Figure 13: Conception of the whole estimator system

The first version of the algorithm has been tested by simulations and on the bases of those tests the estimator was able to approach the real (preset) friction coefficient. In simulation tests one type of vehicle with it's mass, dimension, load, etc. and the simulation environment were defined. In straight lines and in curve situation the examined system can demonstrate fast enough the rapid changes in real situations (see Figure 13). These sudden changes come from the pre-defined test tracks with stepped friction coefficient. The vehicle has running with constant 80 km/h in the straight line part of the test track. The estimator can calculate friction coefficient both side of the vehicle individually. In Figure 14 the upper is the left side friction, while the lower is the right side one.

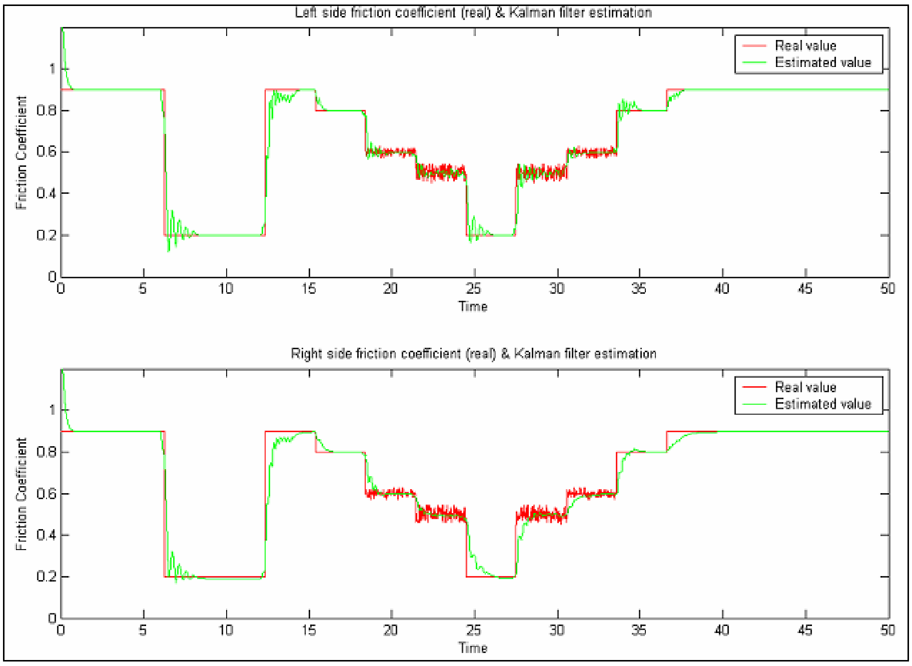


Figure 14: Simulation results

By tuning the parameters of the Kalman-filter of the over all estimator the time behaviour of the estimated parameter dynamic of the algorithm (oscillation in sudden changes, time delay) have been optimised. However, in real environment much more disturbing factors are present (interferences), therefore the system has been tested by real vehicle tests. The algorithm was implemented into a realtime environment. The algorithm of the application has been created by MATLAB/Simulink and has been downloaded to the real-time hardware.

To adapt the system special test tracks were needed with different known friction coefficient values. The Bosch proving ground, Boxberg, Germany (Figure 15) was therefore used.

Due to the restricted conditions of the test tracks only longitudinal measurements were possible. The friction coefficient estimator algorithm has been tested only in longitudinal direction. Validation of the lateral dynamic couldn't therefore be arranged. For the tests in longitudinal direction constant velocity without heavy braking or accelerating has been chosen, a condition on which heavy vehicles are mainly working (transporting on the highway). During heavy braking or accelerating other subsystems could work (ABS, ASR) which could influence the estimation results. Constant speed measurement results can be seen in Figure 16, Figure 17 and Figure 18.

Figure 15: BOSCH Proving Ground – Brake measurements tracks

In our tests the test vehicle (MAN F2000, for further information see Deliverable D5) has gone with different speeds and loads. 50 km/h with 60% load was the “NORMAL Situation” of the tests (see later). Going with other velocity (between 40 km/h and 80 km/h) and load between 0% and 100% results in the same vehicle independent friction coefficient value.

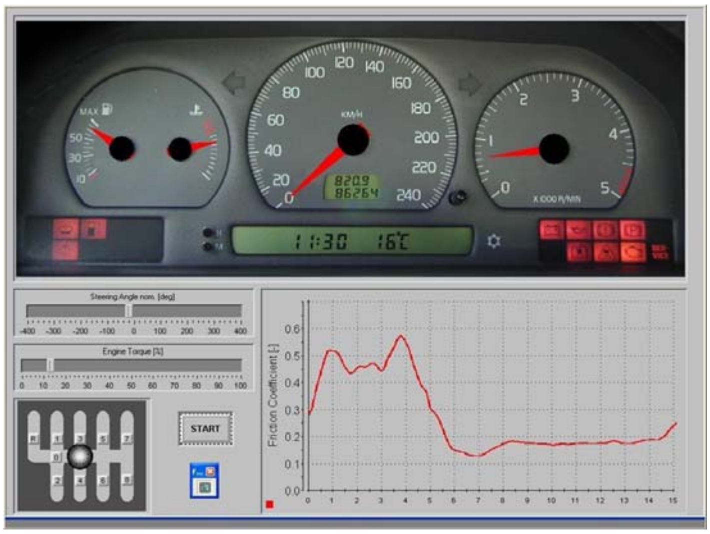


Figure 16: Results on wet ceramics – surface of the measuring system

During the first 3 or 4 seconds the test vehicle has been running on dry asphalt (friction coefficient is between 0.5 and 0.6), and then it has driven on wet ceramics (see Figure 16), wet concrete (Figure 17) and wet basalt (Figure 18). All three cases underlay a time delay a tuning process of the estimator (see Figure 17) as long as new friction coefficient value is calculated. During friction changes (time delay) the estimator cannot predict exactly the real friction coefficient, but the sudden changes can be recognised.

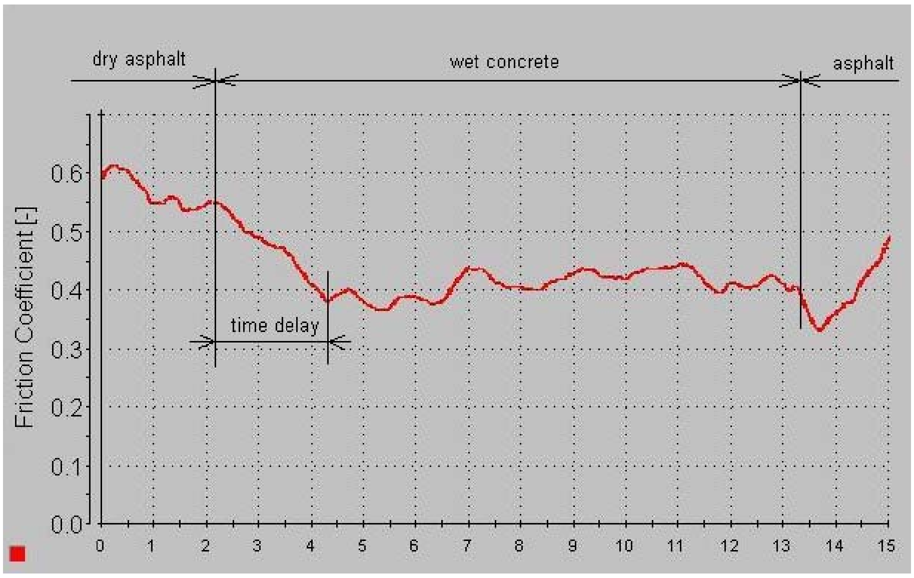


Figure 17: Results on wet concrete

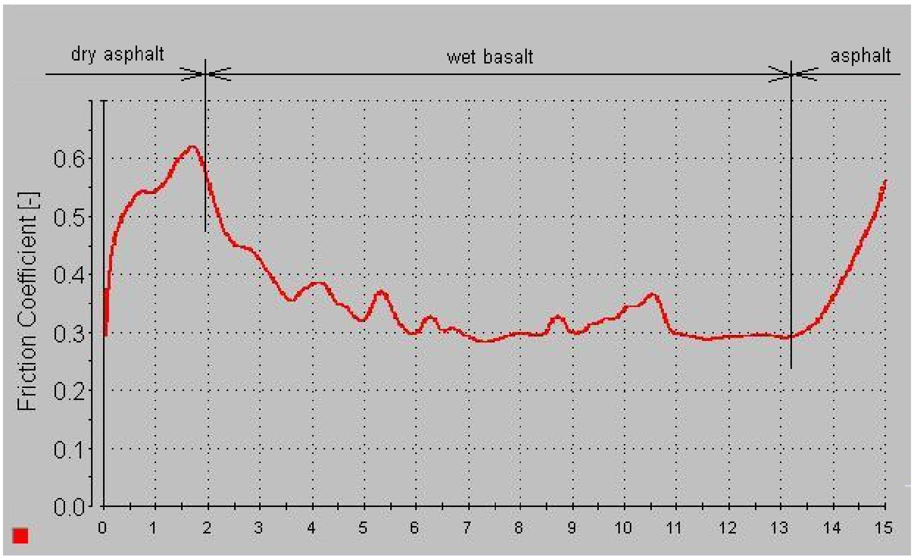


Figure 18: Results on wet basalt

Measuring in longitudinal direction has shown that the estimator algorithm is suitable to estimate the current friction coefficient between tire and road. In this state of development it can estimate friction coefficients in straight driving with constant speed. To improve estimator much more driving situations and critical events should be investigated. The most important tasks of such an estimator are to recognise sudden changes in friction values, and sharing the information with others in the traffic.

2.2.3.1 Conversion of friction force limit

The friction coefficient or friction force limit (FFL) obtained by the Friction coefficient estimation algorithm (FCE-algorithm) is very useful for a pre-conditioning of driver and the vehicle's safety systems. It would be even more advantageous to share this information with other vehicles in the surrounding, allowing them to precondition their own systems in the same way. The calculated FFL is only valid for the vehicle in which it was determined under the actual driving conditions. Thus the FFL-value is different for each vehicle on road and must therefore be converted into a standard value dependent only on the road, but independent of the vehicle and it's running conditions. However, it is difficult to generate friction force limit information which is completely independent from the vehicle on road. The solution to this problem is the creation of a value which represents the current friction force limit of a defined reference vehicle on the section of road currently being passed. This friction force limit is only dependent on the road surface and the previously defined reference vehicle and is designated as the reference friction force limit.

To obtain the reference friction force limit information for a vehicle on road in any driving situation, a method was developed, that converts the current, vehicle-specific friction force limit of the actual vehicle into the vehicle-independent reference friction force limit. This conversion (see Figure 19) is done in two steps.

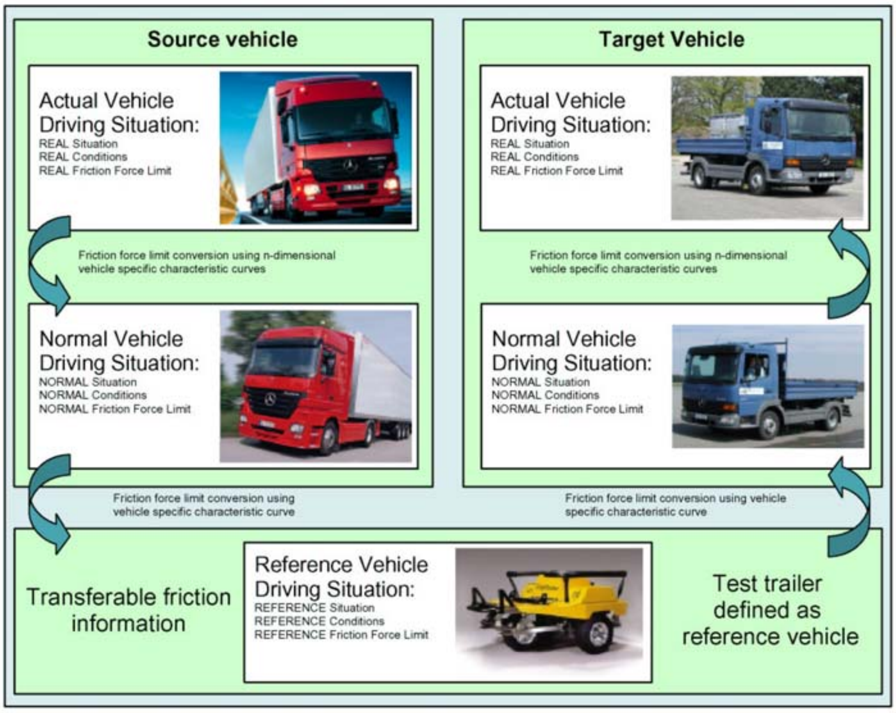


Figure 19: Fundamental functional description of the friction force limit conversion algorithm

In the first step, the friction force limit (called real friction force limit) of the vehicle calculating the friction coefficient, driving under actual running conditions is converted into the friction force limit of the actual vehicle in the so called normal situation. This normal situation is a specific, pre-defined running situation in which all relevant running parameters that influences the friction force limit of the actual vehicle are determined as specific, predefined values (specific, pre-defined load, specific, pre-defined speed, etc). Therefore the friction force limit is named normal friction force limit.

The conversion between the real friction force limit and the normal friction force limit is calculated using a n-dimensional characteristic neural net. The number of dimensions of this neural net is determined by the number of parameters which influences the friction force limit. The characteristic neural net also contains the dimensions of the two friction force limits to be inter-converted. For the creation of the neural net many measurements with various parameter combinations were done with a test truck.

The second step is to convert the normal friction force limit of the actual vehicle into the reference friction force limit. This conversion is done by a function that was obtained by measurements with the test truck (in normal situation) and the reference vehicle (test trailer in reference situation) on different road surfaces with different road conditions. With the reference friction force limit transferable friction force limit information is available and can be communicated.

For the communication use of the transferable friction force limit information with any vehicle in the surrounding it is necessary to convert the reference friction force limit into a real friction force limit that is specific for the respective vehicle receiving the transferable friction force. The conversion is conducted in the two directions simultaneously, so a vehicle can therefore be the supplier and the recipient (and thereby user) of the transferable friction force limit information at the same time.

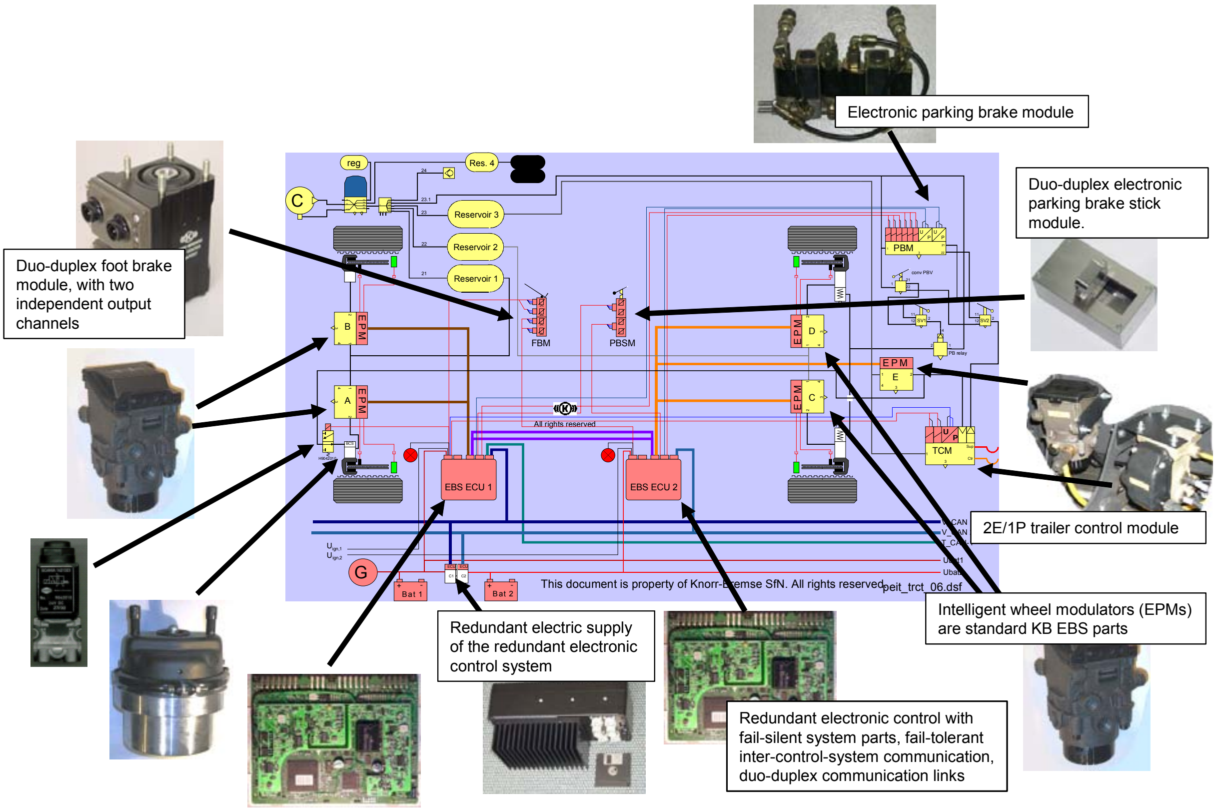
2.2.4 Brake by wire system

The target in project PEIT was to develop a brake-by-wire system as far as the control is concerned in order to increase the flexibility of the total vehicle electronic architecture, to reduce the component and system cost, and installation complexity, and furthermore make several design changes in the vehicle cabin, chassis and the interface possible.

The PEIT system architecture is a compromise, which can be found between the 1E+1P “conventional, serial” electronic braking systems (E = electronic, P = pneumatic)and the fully fail-tolerant 2E solution (two electronic circuits), but provides an ultimate solution for fulfilling the requirements of the automated driving and the related standards, and also the cost/installation requirements of the customer. This architecture provides several features, which result in enhanced system performance even if – as a consequence of a single failure – one of the circuits is not intact, and as such, provides enhanced safety in comparison to the 2P, 1E+2P and 1E+1P systems.

The brake-by-wire system of the PEIT truck is responsible for all wheel slip controlled braking manoeuvres. These are mainly brake force distribution optimized braking, economy optimized braking, ABS braking, ESP intervention, vehicle combination stability optimized braking.

The brake system is totally controlled by means of electronic circuits and electronic/electric commands/signals. Actuation however remained pneumatic, as compressed air is necessary on board anyway and pneumatic actuators are very economical and effective.


Electronic parking brake module

Duo-duplex electronic parking brake stick module.

Duo-duplex foot brake module, with two independent output channels

2E/1P trailer control module

Intelligent wheel modulators (EPMs) are standard KB EBS parts

Redundant electric supply of the redundant electronic control system

Redundant electronic control with fail-silent system parts, fail-tolerant inter-control-system communication, duo-duplex communication links

Figure 20: Brake by wire architecture and components

The production of compressed air happens as in conventional vehicles. The compressed air of the brake system is then stored in 3 independent reservoirs. Separation is solved by a four circuit protection valve. Though conventional systems require also 3 reservoirs, the number of them hasn’t got to be increased in the current fail safe system, as conventional brake systems have already been fail safe, being safety critical.

Reservoir 1 supplies the front axle’s EPMs (Electro-Pneumatic Modulators), EPM A and B and so provides brake actuation energy there. Reservoir 2 supplies the rear axle’s EPMs (EPM C and D), while reservoir 3 supplies the parking and trailer brake systems. This configuration makes a fail-safe function possible, where in case of a fault, there is some – legally accepted – degradation in braking performance.

Electric energy supply also has to be redundant. It is enough to have one ultimate source like alternator and then store energy in redundant storages (batteries), which are separated. They supply the EBS (Electronic Brake System) ECUs separately.

It is Important that the brake system is supplied by a dual electric supply. These are EBS1 and EBS2. All other components are supplied through the ECUs. The intelligent components like electro-pneumatic modulators are organized into two groups. Group one (EPM A and EPM B) is supplied by EBS1, while group two (EPM C, EPM D and EPM E) are supplied by EBS2. Controls, like foot brake module (FBM) and parking brake stick module (PBSM) are themselves one-piece duo-duplex units, so these are supplied by both ECUs so, that galvanic isolation is solved. The parking brake module is a one-piece duo-duplex unit, but it has only electric coils in it, which are driven by either EBS1 or EBS2 so that galvanic isolation is guaranteed. The trailer control module (TCM) is a component of the shelf used in simplex EBS, so its duo-duplex electronic control required that its electrically controllable interface is connected to EBS1, while its pneumatically controllable interface (control pressure input) is connected to EPM E, which is controlled by EBS2.

There is no mixing of electric power supplies, not even through semiconductors.

Control of the PEIT brake system will be done by the driver as before, or by the superior electronic control called PTC. Complex modes are possible too, where the PTC modifies the driver’s input in case of e.g. ESP situations.

This dual behaviour is achieved by a simple logic. EBS controls the brakes in a closed control loop, based on the driver’s demands. In such a case EBS will control the brakes based on the values received from the superior ECU (PTC).

If the brake system is controlled by the driver, then (s)he can use the usual brake controls: the pedal (FBM) and the lever of the parking brake (PBSM). These are exclusive electronic ones.

There are two “central” EBS ECUs, but there is one vehicle to be controlled, so a control strategy had to be set up. In the case of PEIT service brake one has to distinguish between physical and logical control. Physically there are two groups of electro-pneumatic modulators, each subordinated to exclusively one of the main ECUs. EBS1 controls the front and EBS2 the rear axle physically. Logical control means, where the current control parameters of a given axle come from. There are two communication paths between EBS1 and EBS2. Using these, it is possible that EBS1 builds a command, sends it to EBS2 and EBS2 transmits to their EPMs bind to it.

For the control of parking brake a two way electro-pneumatic modulator has been worked out consisting of six valves. This arrangement assures a fail-tolerant brake function, which exceeds the safety level that of state-of-the-art electronic brake systems of today. In case of a fault in one path (of any reason), the path can be locked and the remaining one can still function without any performance decay.

There is an additional valve at wheel A1L, controlled by EBS1. The valve is mated by a special – dual – brake cylinder. This is necessary for vehicles with certain geometry and the centre of gravity setting like the PEIT tractor. If the front axle brake circuit – of any reason – is out of service, the rear axle brake has to decelerate the whole vehicle mass. The PEIT tractor has a disadvantageous mass distribution on the axles, so the rear one has not enough load and therefore not capable of achieving legally prescribed deceleration (secondary brake performance). By the use of the valve, control pressure of the trailer can be lead into the special brake chamber of A1L and so still one wheel of the well loaded front axle can be involved in the braking.

This structure of the brake system permits of fulfilling the regulations in case of a single failure. On the other hand there is an additional level of fail-tolerant behaviour. As mentioned above there are two EBS ECUs, which physically control different axles, but logically constitute one safety critical electronic brake system. The EBS controls the brakes in a closed control loop. The main inputs of this mechanism are brake pedal signal, the wheel speeds and the actual pressures on the wheels. EBS1 and EBS2 have all these inputs directly or via the IEC (inter-ECU communication) interface. Both ECUs calculate the pressure demands depending on the inputs, which are applied to the brakes. This calculation is not distributed but it is in parallel, which results a hot connection between EPMs and ECUs using the IEC.

The EBS1 has an important role it is the master and decides which ECU controls the braking manoeuvre.

This possibility is utilized in the PEIT brake system, a control algorithm decides, which control parameter to which direction will be passed and finally, which brake will be logically controlled by which ECU.

If EBS1 controls, the result of its calculation is considered by EBS2. In this case, if a driver deceleration demand is appeared by pushing the brake pedal the EBS1 collects the wheel speeds and actual pressures directly from EPM A and B and via the IEC from EPM C and D using the EBS2 as a gateway. In the given situation, after calculating the pressure demands, those are sent partly to EPM A and B via brake CAN1 and to EBS2 using IEC. ESB2 transmits to their EPMs (EPM C and D). The procedure goes in the opposite direction if EBS2 is active in control.

Control of the PEIT brake system can happen by the superior electronic control called PTC. In ESP situation PTC can command the EBS to modify its behaviour sending different target slip than usual or apply additional pressures on wheels. ESP application can brake a wheel if it sends additional pressure demand and corresponding slip command. The ABS module helps to realize the ESP intervention.

Since each EBS ECU knows the status of the other EBS ECU, in case of any failure they can take the missing function over because of the parallel execution and communication link between them.

For the mentioned complex functions we could find an economic and simple structure. The brake system consists of several components. Many are series ones, though some had to be modified prior to installation. Some other components have been made from scratch to pioneer the way of creating brake-by-wire systems. The component set is optimal for the purpose with the remark, that some of those have to be integrated or re-designed in case of a series production.

The main components are as listed:

- Foot brake module (FBM) – built up by a duo-duplex manner – to convert and transmit driver’s brake demand. The duo-duplex foot brake module is a new creation, as such has never existed before.

  The sensor component - of which two has been applied - is a standard one.

The following pictures show the CAD plan, the created FBM and as it is mounted on the vehicle, outside the firewall.

Figure 21: Duo Duplex of brake pedal box

- Parking brake stick module (PBSM) – built up by a duo-duplex manner – to convert and transmit driver's parking brake demand. The duo-duplex PBSM is also a new component from scratch. Due to short deadlines, it should be regarded as a functional sample.

  There are two doubled sensing elements in it, delivering signals to both central ECUs.

  The next figures show, how it looks like:

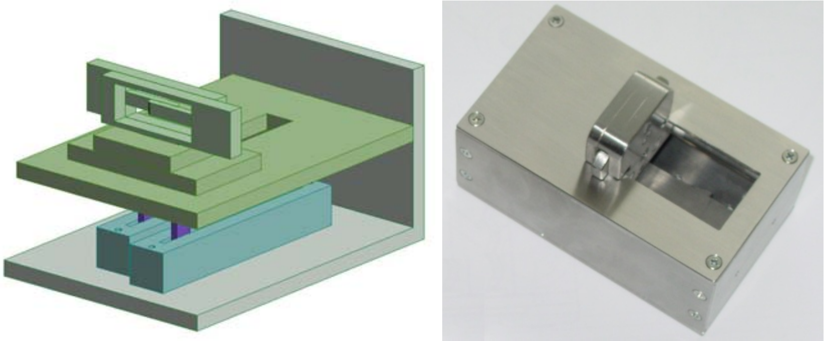


Figure 22: Dual duplex parking brake module

- Main ECUs to control all brake system activities by the driver's input and/or by a superior ECU pair. (there are two of them – communicating with each other – to provide a fault-tolerant feature). The two central ECUs of the brake-by-wire system have been derived from the ECU of a conventional EBS. Modifications spread to the whole SW, partly to the main board's hardware and an additional piggy-back printed circuit board had to be designed and created. As application required the board has been redesigned two times.

  The next figure shows one central ECU as it looks today:

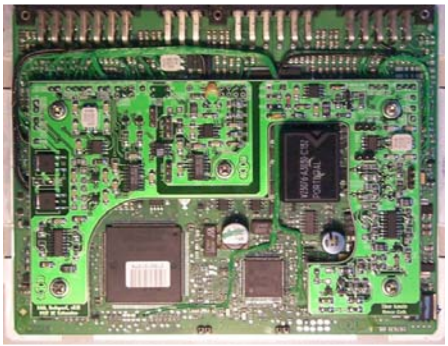


Figure 23: Failure tolerant ECU

- Intelligent electro-pneumatic modulator (EPM) at each wheel to control the corresponding brake actuator.

  EPMs are responsible for the precise pressure control of the corresponding brake chamber. This component is intelligent. It gets digital messages from the central ECU and controls pressure based on this.

  Figure 24: EPM module

  There is one more EPM used (EPM E) to control the TCMs pneumatic control input (trailer control module). The corresponding picture will be shown at the TCMs section.

- Trailer control module (TCM) is responsible to control the trailer’s brake. The trailer control module could not have been modified in the frame of PEIT – being a complex pneumatic component - so it has been interfaced to the brake-by-wire system by using an additional EPM (EPM E) and additional software in EBS2.

  The next picture shows not only the TCM (f), but the controlling EPM (e) and components of the air supply like air dryer (a), four channel protection valve (b) and the regeneration reservoir (c) for the air dryer.

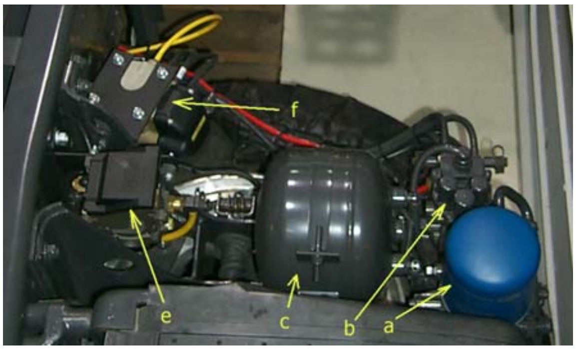


Figure 25: Brake components

Figure 26: Electro pneumatic moduls

- Parking brake module (PBM) to control the parking brake on the tractor and the trailer. Parking brake module is a new design, consisting of six electro-pneumatic valves. Due to its dual path layout it is a fail-tolerant one. As it was not possible to create a one-piece PBM, off-the-self valves have been combined to achieve the required function.

  The next figures show the PEIT PBM.

Figure 27: Parking brake module

2.2.5 Steer by wire system

A requirement to realize the PEIT–functionality, was to equip the truck with a steer by wire system. Although the SbW is derived from an already existing system a lot of modifications had to be implemented to adapt and open it for the PEIT - architecture.

The SbW-system installed in the PEIT-truck was derived from the system that has passed extensive tests in an Mercedes Benz Unimog and reached type approval for the Unimog.

The control transmission is electronic, the power transmission electric, hydraulic and mechanic. Instead of a mechanical connection between the steering wheel and the steered axle (steering gear) there is an electronic control in the SbW system. Input signal is the angle position of the steering wheel, and output signal is the position of the steered wheels. The position of the steering actuator is controlled by a comparison of the desired and actual value, which is measured redundantly by angle sensors. SbW is activated by the ignition switch of the vehicle and keeps active until all actions of the vehicle stopped.

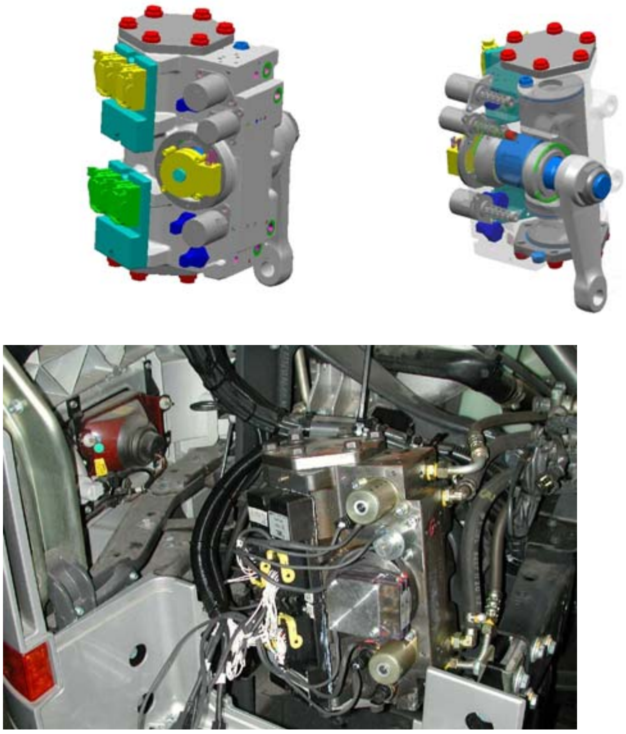


Figure 28: SbW actuator installed into the PEIT truck

The hydraulic system is also realized redundantly. The hydraulic power of the main circuit is supplied by a pump driven by the combustion engine of the vehicle. The hydraulic pump of the backup circuit is driven by a DC motor.

In normal operation the main circuit is active and the redundant circuit is in stand-by testing itself permanently. If an error occurs in the main circuit, the backup circuit takes over. The valves are of special design that allows safe function and monitoring.

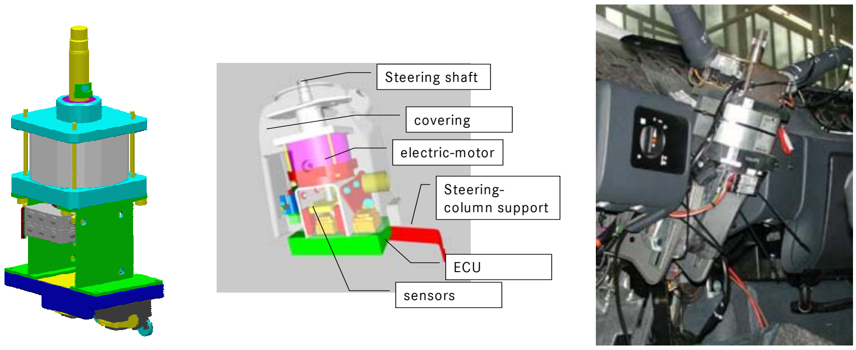


Figure 29: Force-feedback actuator assembled in the PEIT truck

The main and the backup circuit are controlled by ECU 1 and 2. Since there is no mechanical connection to the steering wheel the feedback-force for the driver has to be generated by an electric motor. Depending on the actual driving situation (e.g. wheel position or speed of the vehicle) comfortable forces are calculated by ECU 3a. The ECU 4 controls the DC motor of the redundant hydraulic pump

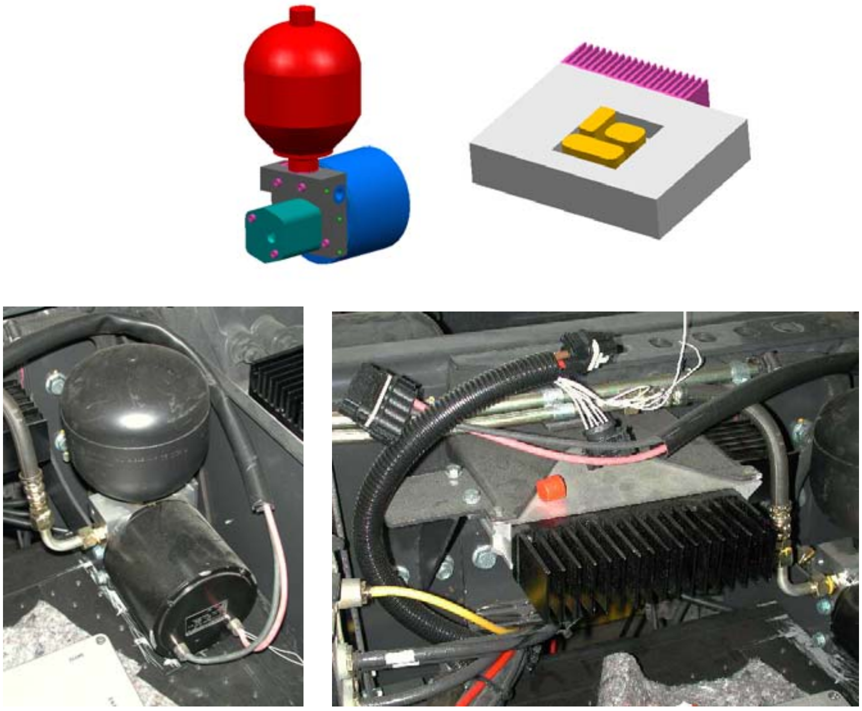


Figure 30: Redundant steer by wire circuit

A special feature of the PEIT system is ECU 3b. In the PEIT project, the angle signals are conditioned by the PTCs, e.g. for an ESP functionality.

Figure 31: SbW ECUs 3a / 3b

To assure an operation of SbW even when the main electric supply brakes down a second electric power source is essential to supply the hydraulic and electronic backup units.

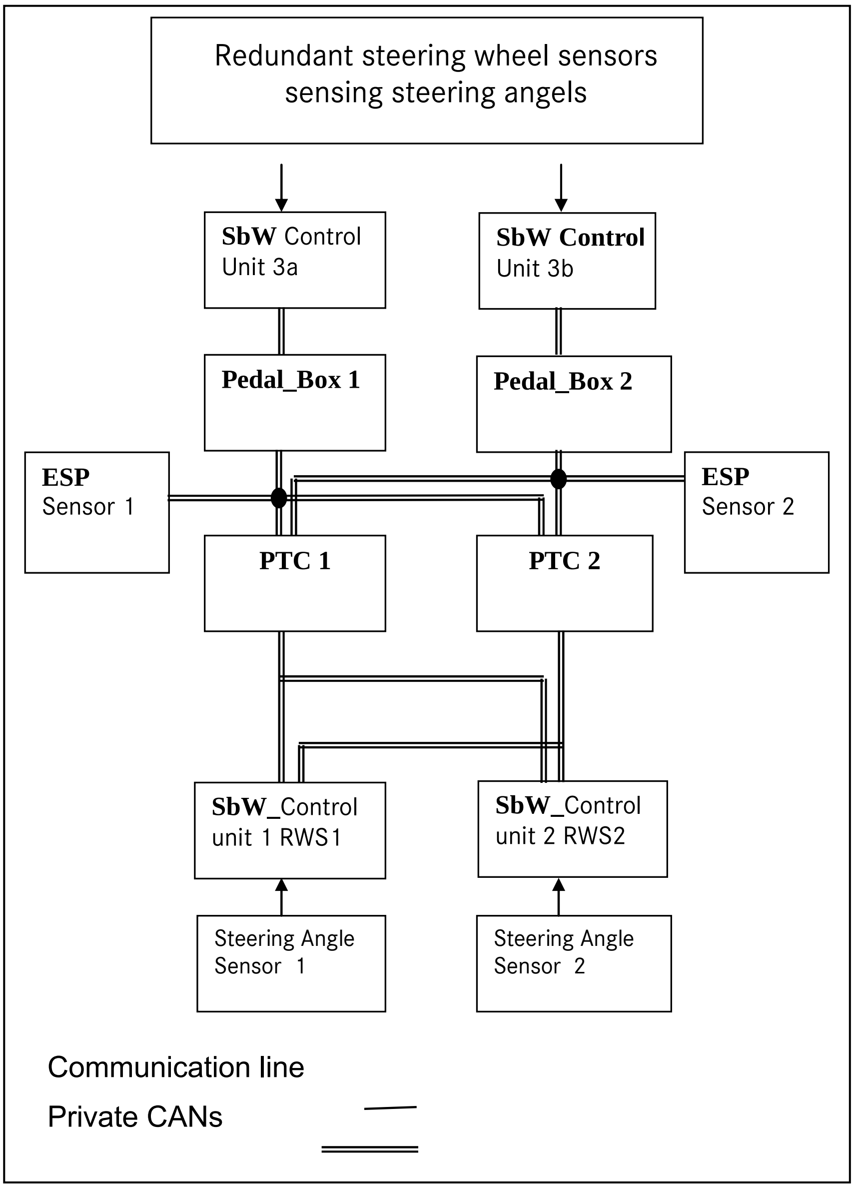


Figure 32: Steer by wire architecture

In the PEIT project, a system wide fail safe energy management is installed which guarantees electric power supply in every situation.

All information that is relevant for the functionality of SbW is permanently monitored. If an internal error occurs it is indicated with the help of two alarm lamps and buzzers, moreover the PTC system is notified. Due to the redundancy of the system the steering remains possible so even in case of a malfunction the driver can steer the vehicle safely until the vehicle stops.

2.2.6 ESP with steering intervention

The ESP (Electronic Stability Program) with steering intervention developed by Technical University of Budapest, Department of Automobiles is aiming to stabilize the motion of the vehicle in all critical driving situations. This means an automatic control system sets the dynamics of the vehicle exactly to the driver's wish and prevents safety critical driving conditions. To achieve this, driving decisions the driver is not skilled for have to be taken away from the driver and be given to a driving assistant system (partly taking the driver away from the control loop) to maintain drive stability and also to reduce braking distance.

The ESP intervenes in the following driving situations, which could become safety critical in a quick way:

- oversteer turning,
- understeer turning,
- μ-split circumstances (braking or starting),
- braking in curve,
- sidewind or inclined road surface, etc.

A driving situation is safety critical if the difference between driver's wish and the actual motion of the vehicle is excessively big. In this case the motion of the vehicle can become more and more unstable and if there is ESP installed it has to intervene to prevent the non-desired motions of the vehicle.

According to this determination the ESP system has to define the desired motion by the driver and also the real motion of the vehicle. The ESP intervention has to be adapted to the difference between the desired and real motion of the vehicle.

A current electronic stability program will perform a selective; differential braking of the wheels of the vehicle to prevent it's departing from the desired trajectory. The innovation of combining ESP with steer-by-wire functionality yields a much-improved manoeuvrability of the vehicle, because a manipulation of the vehicle's lateral dynamics can be done much more effectively by the steering system than by the brakes alone – steering affects the lateral control of the vehicle directly.

The PEIT ESP subsystem possesses the main components:

- algorithm application (programmed into PTC),
- sensor unit on the vehicle frame.

In addition it uses the following subsystems of the vehicle as sensors and actuators:

- brake-by-wire (BbW),
- steer-by-wire (SbW),

- engine management system's sensors and actuators.

The ESP algorithm communicates with other subsystems and the sensor unit via CAN (according to ISO 11898).

The ESP system of the PEIT project means an algorithm that runs in the PTC of the vehicle (both of the 2 PTCs). The ESP algorithm needs the following inputs from the sensor unit, brake-by-wire and steer-by-wire systems:

- lateral acceleration (a_{lat}),
- longitudinal acceleration (a_{long}),
- yaw rate (YR or $\dot{\psi}$),
- wheelspeeds (v_{wi} – all wheels),
- brake pedal position (α_b),
- gas pedal position (α_a – as desired acceleration),
- steering wheel angle (δ_D),

From these data the logic computes the desired and real motion characters. Then it compares the values and determines the actual driving condition. If the driving condition is safety critical then the ESP intervenes through the brake-by-wire, steer-by-wire and/or the engine-management systems. The intervention signals may be:

- additional steering angle ($d\delta$),
- modifying brake pressure (dp_i – for each wheel),
- engine torque limitation (T_{lim}).

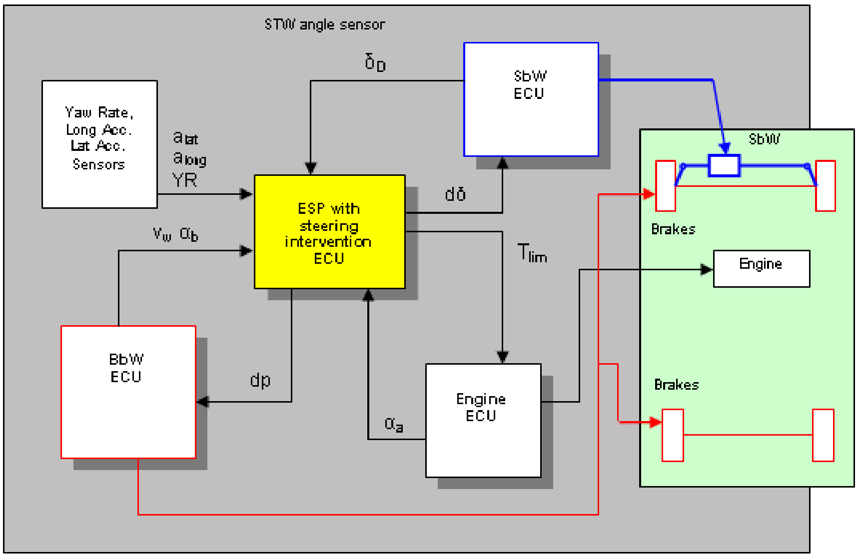


Figure 33: ESP system architecture

Figure 33 shows the architecture of the whole ESP system. The transferred data between the subsystems are the inputs and the outputs of the ESP with steering intervention system. The intensity of the ESP intervention depends on the difference between driver's wish and the actual motion of the vehicle.

2.2.7 Energy management

The determination of electrical energy management subsystem is a safe electrical energy supply for safety related x-by-wire functions (steer-by-wire, brake-by-wire, drive-by-wire). All such x-by-wire functions (subsystems) need a safety and reliability electrical energy supply in all operational states of a vehicle.

The five possible states of a vehicle will determine the actual need for electric energy. Each power state requirement depends on the:

- Load profile (which electrical loads are switched on or off)
- Driving profile (stop / go, cruising, low speed, high speed)
- Environment (uphill, downhill, day / night, winter / summer)

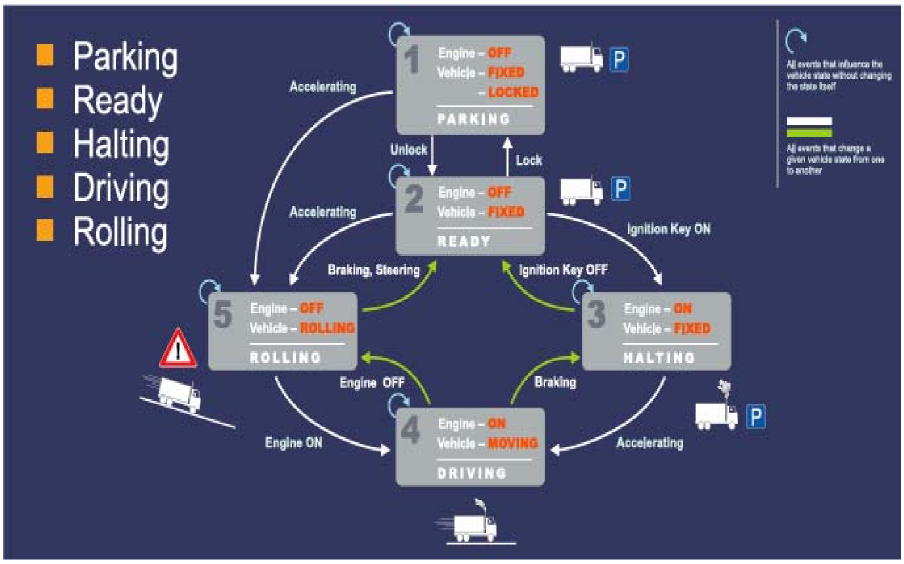


Figure 34: Operational state diagram for a vehicle

The target in project PEIT was, to develop an energy management system foundation for x-by-wire technologies within vehicles. That mission included:

- Provide electric power reliably
- Design false tolerant architecture
- Avoid interferences with other components
- Detect components failures on an early stage, warn of failure and resolve if possible
- Warn of pending energy-source failure

As a result of an overall vehicle hazard analysis possible risk and hazards with significant influence of the electrical energy supply were shown.

- One source (generator) to generate electrical energy.
- We must generate and / or provide electrical energy in any operational states of a truck, up to the point in time, when the truck is in a safety state (still stand).

- Two ore more independent power supply circuits are necessary.
- All the power supply circuits must be free of interaction.
- The energy management system must be fail safe.
- Components of energy management have to be observed to detect safety critical events and conditions when possible far advanced.
- The driver must have information in safety critical cases at a right time.

Functional description

The following figure shows all functions of the energy management system. These functions are implemented in several components, which fulfil these functions.

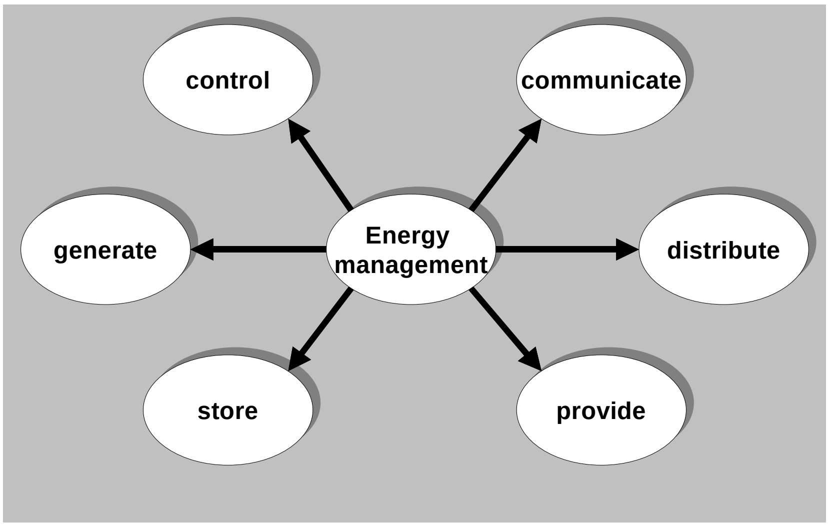


Figure 35: Energy management functions

Figure 35 describes the energy management architecture. The Generator (GEN) generates electrical energy. The power supply circuits (NET) distribute electrical energy to the connected components of the drive by wire subsystems (e.g. BbW, SbW, PTC). The load-separating module (LSM) makes the split into two power supply circuits isolated against each other so that both circuits can not influence the other. The result is a redundant distribution of electrical energy. Every circuit have a separate Battery (BATT) for storing and providing electrical energy. These Batteries and this is new, generate their own status of health and capacity and transmit it to the LSM.

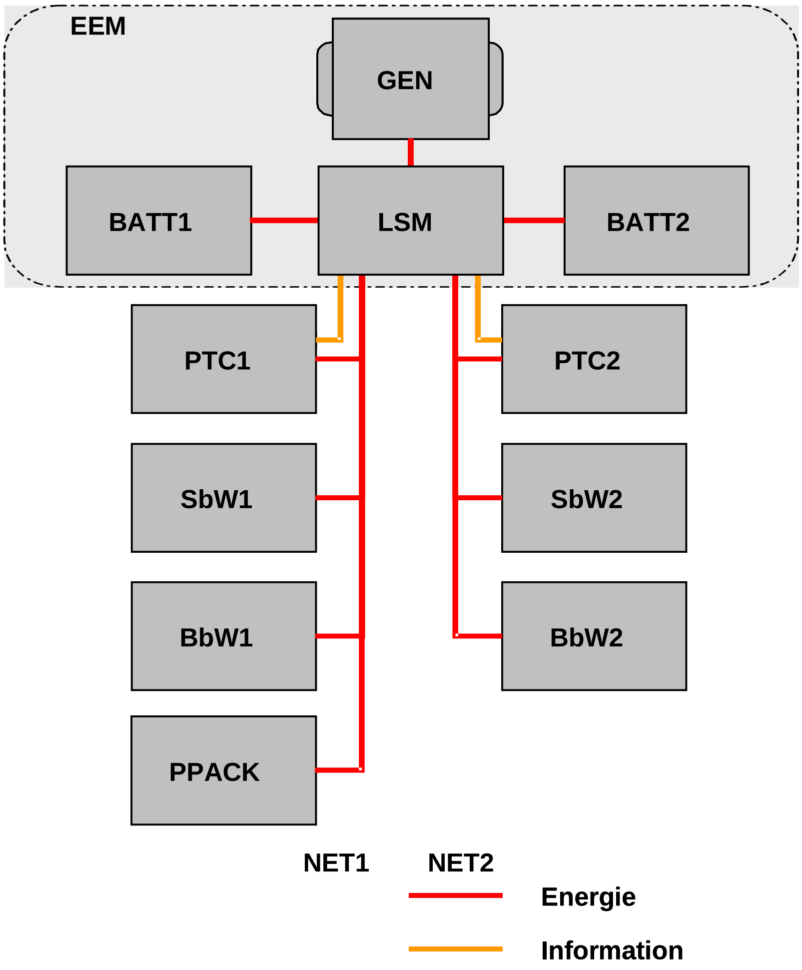


Figure 36: Concept of the energy management system

The control function of the energy management is a part of the load-separating module, a component new developed with the properties of:

- controlling and monitoring the energy management system components and the working parameters of this subsystem,
- receives the battery status,
- calculates state signals,
- communicates the subsystem state signals to the Powertrain controller (PTC),
- reacts on commands received from the powertrain controller (PTC).

In safety critical cases the PTCs build a warning or alert indication for the driver

The architecture of today's power supply has not the potential to become the foundation of future x-by-wire functions. This statement will be explained by the following scenarios:

If there is a short cut marked by the yellow symbol (Figure 37), the voltage of the overall system will break down. This is very dangerous situation and therefore not acceptable because of this, all electronic control units (ECU) of the connected x-by-wire components will fail immediately.

To avoid this critical situation, the total new architecture of above Figure 36 was investigated. Therefore, the x-by-wire functions forces two fold redundant energy storage elements (batteries as well).

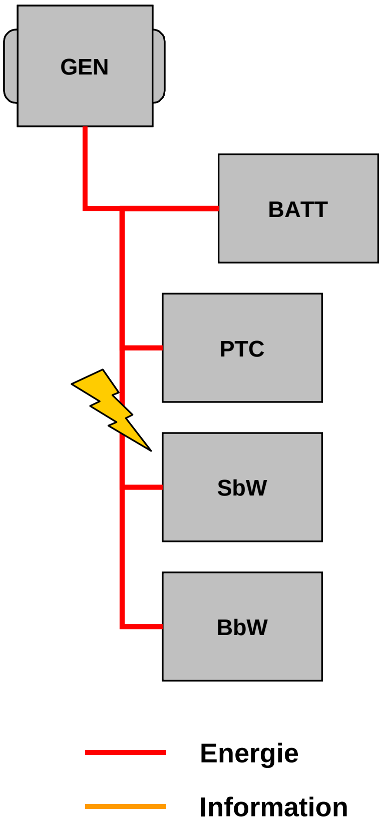


Figure 37: Example for a failure situation in a single supply circuit

event	Effect	Action
Short circuit on a power line	The build in solution by vehicles of today is not acceptable for drive by wire. It would lead to a disastrous situation.	Second redundant circuit needed to split the power supply into two independent circuits (e.g. NET1 and NET2).

The next scenario shows the safe case. The subsystem energy management is failure tolerant. That means: If one relevant component fails all the remaining components must still have to guarantee the functionality and safety for a limited time.

If there is a shortcut at the marked line (Figure 38, yellow symbol), only the voltage of circuit 2 breaks down. This failure is acceptable, because all redundant ECU´s are able to continue working with the voltage of circuit 1. There will be no impact of the shortcut to NET1, Generator GEN and Battery BATT1 are still working properly.

Nevertheless such a critical failure event (safety critical conditions or a kind of components failure) is indicated to the driver by the HMI via the PTC so that the driver can bring the vehicle in a safe state (e.g. full stop).

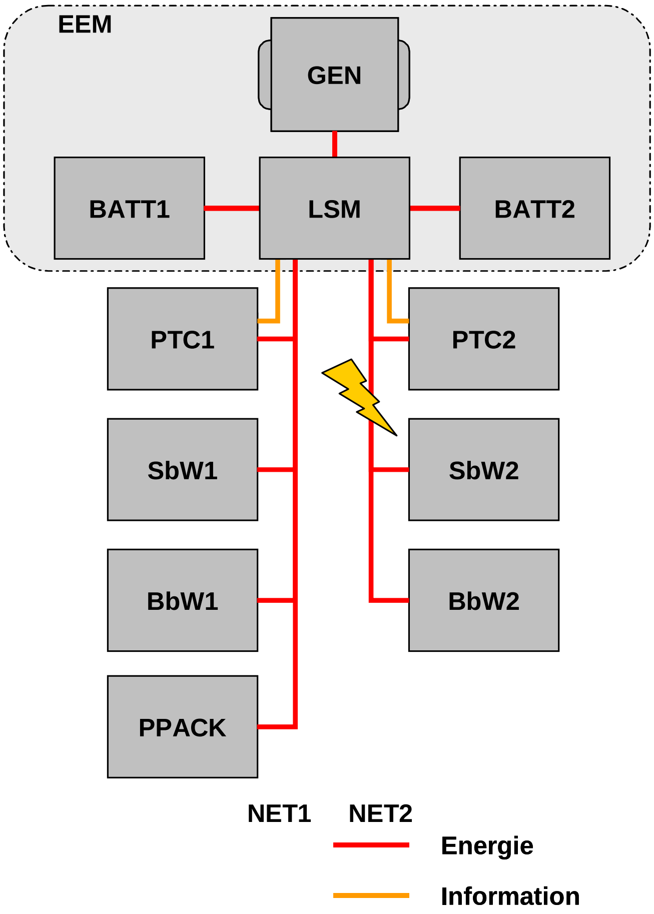


Figure 38: Example for a failure situation

event	effect	action
Short circuit on a power line NET2	Circuit 2 will brake down. Through to the proposed solution there will be no impact on NET1	The driver will get an indication to have the possibility to bring the vehicle in a safe state.

In the next scenario the generator fails (see Figure 39, yellow symbol), through to this NET1 and NET2 will no more be supplied with electric energy by the generator (e.g. see Figure 34 operational state diagram state 5).

Even in case of such a failure all ECU´s of the connected, safety relevant x-by-wire components are able to work, because both set of batteries are supplying electric energy. Nevertheless in this failure mode it is important to display the driver the status of the energy available before running out of electrical energy.

This warning has to be given in time to bring the driver into the position steering the vehicle into a safe state.

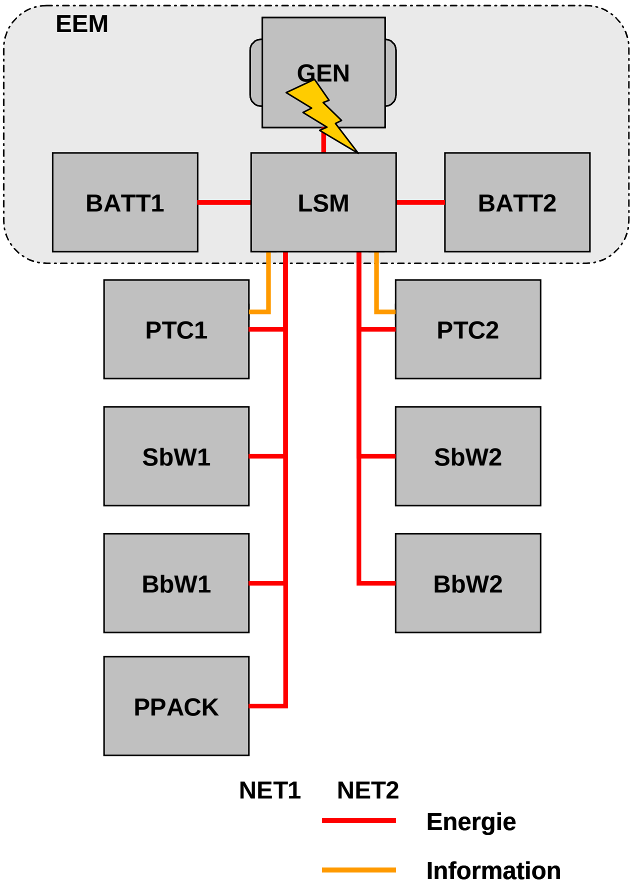


Figure 39: Example for a failure situation

event	effect	Action
The Generator fails	Both batteries of each circuit provide energy for the electric consumer of each specific net for a limited time.	In this case both batteries provide energy to bring the vehicle in a safe state within a limited time. The driver will have an indication for state of charge and state of health (SOC/SOH) of each batterie.

Solution for PEIT-Project

The following pictures show where the energy management components, Battery BATT1, BATT2 and the load-separating module LSM within PEIT-Truck are located.

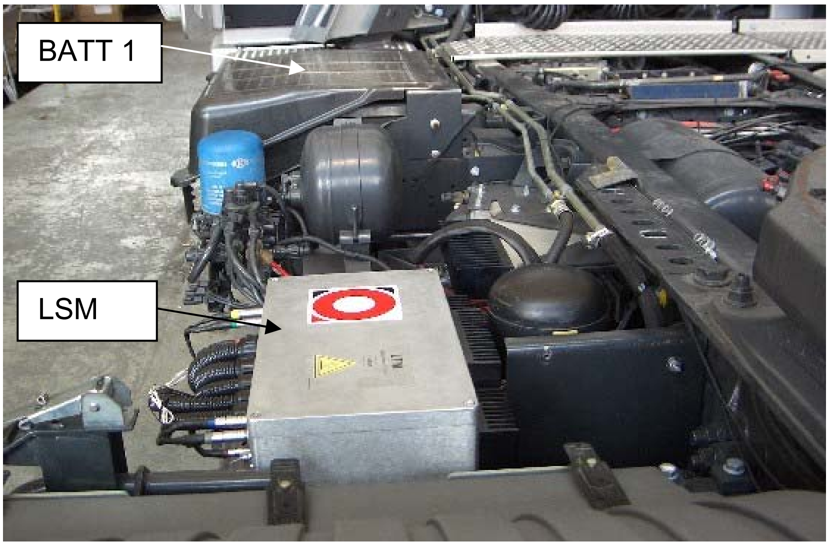


Figure 40: locations of LSM, BATT1, BATT2

Figure 41: Location of LSM, BATT2

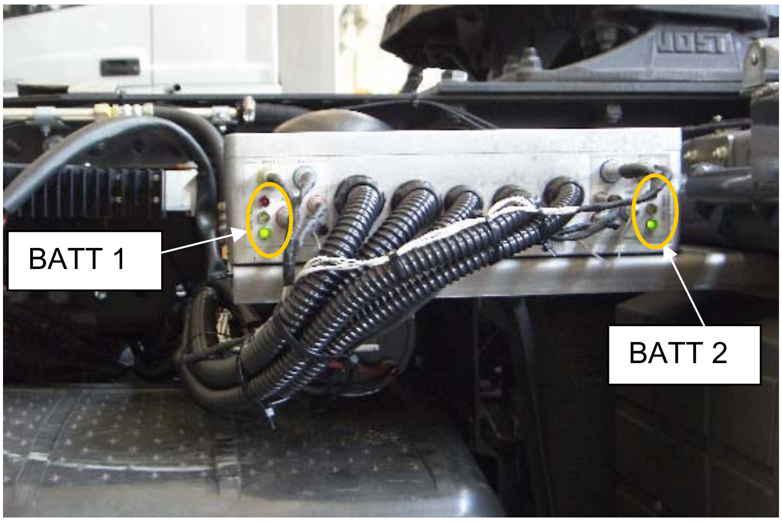


Figure 42: State indication (SOC/SOH) of Battery (BATT1, BATT2) location at LSM, BATT2

Depending on the actual battery status (SOC/SOH), the indication of the battery status is:

- If the SOC/SOH is greater than a defined limit, then
  the driver has no warning or alert indication and
  the related SOC/SOH indicator on LSM shows green.
- If the SOC/SOH is between a upper and lower limit,
  then the driver will have a warning indication and
  the related SOC/SOH indicator on LSM shows yellow.
- If the SOC/SOH is less than the lower limit, than
  the driver has an alert indication and the related
  SOC/SOH indicator on LSM shows red.

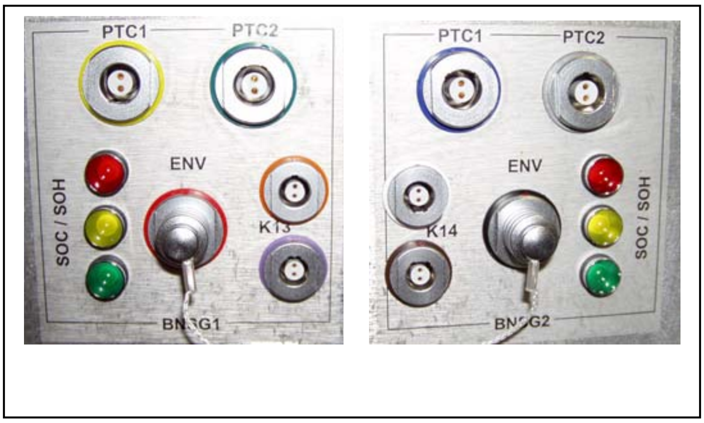


Figure 43: State indication for Battery BATT1, BATT2

The combined indication SOC/SOH of Batteries has three levels:

- Green means that the battery is working well by a high level of charge and that the battery and isn't aged
- Yellow means that the battery has actually a low level of charge and should be recharged. If the indicator does not come back to green after appropriate charging the batteries, the yellow indicator has the meaning that the battery became old and is close to the end of its life cycle.
- Red means that the battery has a very low level of charge only for a defined emergency stop or it will fails in the near future or the communication with a Battery is faulty.

Conclusions

- sufficent energy must be available at every time (see Figure 42)
- the topology of the power supply circuits for high safety should be a "star structure"
- the electrical energy management must have a minimum of two independent power supply circuits
- in the future the batteries will be safety related components
- for using the x-by-wire technology, diagnostable batteries are needed
- an early warning for low or inadequate power is recommended
- a realtime reporting of energy status is very important
- in case of emergency, the driver has to have enough time to bring the vehicle in a safe operating state.

2.3 Integration into vehicle base (WP4)

In this work package all subsystems needed for the intelligent powertrain were integrated into the vehicle base of the demonstrator truck.

- Installation and integration of the estimation of friction coefficient,
- Installation and integration of the brake-by-wire system,
- Installation and integration of the steer-by-wire system,
- Installation and integration of the energy management system.

The process of the integration of the subsystem was done in two phases. Accelerating the implementation part of the project first a vehicle in the loop test bench was built. This test bench was capable of simulating nearly the overall real environment of a vehicle on road. All functions and applications were tested in advance according their specifications. All hazard scenarios and their corresponding actions from the subsystems to eliminate those hazards derived and analysed within the definition phase were proven and checked to ensure the fail safe system behaviour. So for example loss of communication and loss of energy supply wrong transferred signals were checked by each partner who developed a system part to be integrated into the PEIT demonstrator. The test bench consisting out of a real truck (a twin of the PEIT demonstrator) which was adapted in such a manner that manoeuvring was possible in a clean laboratory environment. Mounted on a rack with the wheels connected to electric motors components could be checked at every speed range even at high speed conditions. Different trajectories with dynamic curve radius and varying slopes were simulated. Exclusive and only if the subsystems had proven there fail safe behaviour successfully within the test bench they were in a second step implemented and assembled in to the PEIT demonstrator vehicle. In the PEIT demonstrator the pre tested and verified application were tested further on according their correct interplay of all subsystems. These tests were conducted on the test track in Boxberg in Germany and Kiskunlacháza in Hungary. Their aim was to prove that all intelligent powertrain functions are properly performed and that the truck is ready for evaluation from the technical point of view.

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Figure 44: Vehicle in the loop test bench

Figure 45: Boxberg driving tests

2.4 Demonstration and evaluation (WP5)

The objective of this work package is to demonstrate the intelligent powertrain in representative applications ('accident prevention scenarios') and to evaluate the system performance with respect to the requirements.

The work will thus comprise in the development of a test plan followed by the execution of tests and demonstrations. A thorough evaluation of the results of the tests will demonstrate the benefits of the system but may also reveal eventual deficiencies and thus point to directions for further developments and improvements.

2.4.1 Overall system

The tests of the brake-by-wire and steer by wire system can be divided into two parts. Those tests belong to the first group, which show the behaviour of the fail-safe system. After checking the functionality of the whole system, a failure simulation was done. During these tests, the behaviour of the brake and steering system was examined against the failures.

Testing of a complex system like drive by wire applications has different levels. The next figure shows, how the central ECUs are embedded in a hardware-in-the-loop simulation environment.

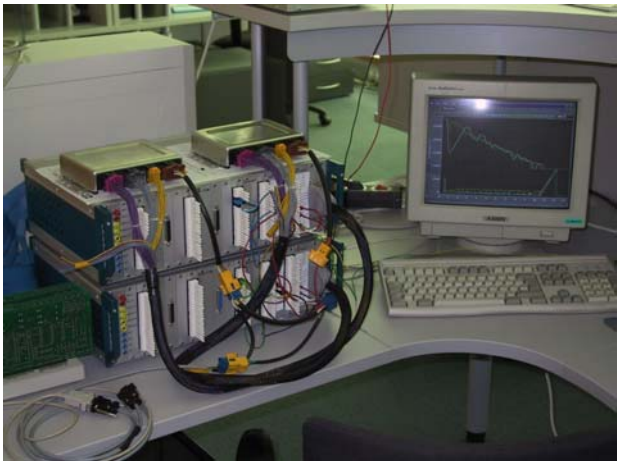


Figure 46: Hardware in the loop simulation

After installing all series and newly developed components and integrating them into the intelligent powertrain, the tests were executed on the real prototype (PEIT ACTROS) at Kiskunlacháza and Boxberg test facilities.

Figure 47: Check of manoeuvrability on test track

The behaviour, the feeling and the performance of the service brake and steer by wire were tested. Fundamentally, the operation of the system is adequate. The counteractive force of the footbrake pedal provides good regulation, but the system can be overcontrolled in the lowest range. In case of full braking on dry asphalt, the expected deceleration fulfils the requirement of the legislative regulations by far. On slippery road (wet, chill epoxy) the control and the manoeuvrability are very good. The force feedback signal from the steering wheel gives good feeling no difference can be felt against a vehicle with steering column. The system fulfils also the requirements of the legislative regulations.

The new ESP algorithm with steering intervention was developed and integrated into the powertrain controller due to the excellent contacts with the Technical University of Budapest. Their active steering control can effectively enhance the handling performance and stability of the vehicle and reduce the stopping distance despite external disturbances and critical road situations.

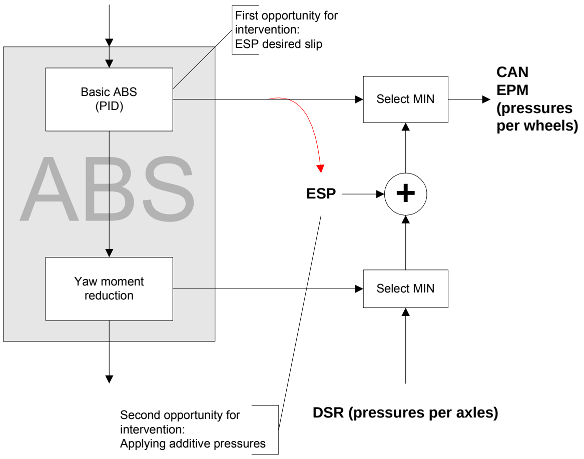


Figure 48: Influence of ESP control commands

In case of ESP intervention the interface and the communication were checked. In ESP situation PTC can command the EBS to modify its behaviour sending different target slip than usual or apply additional pressures on wheels. ESP application can brake a wheel if it sends additional pressure demand and corresponding slip commands. The ABS module helps to realise the ESP intervention.

The ESP brake intervention is shown in the following figure.

Figure 49: Plot of brake pressure while in ESP mode

The additional pressures were applied to the front axle wheels (A1L: 5.0 bar, A1R: 4.8 bar) with 60% slip. The ABS tried to control the wheels to the given slip and the ESP command was executed successfully.

Another request from the ESP was to limit the engine torque. The interface was modified and tested. It is necessary, because there is no ASR function implemented in the EBS ECUs and in this state of the project it was the only possibility to reduce the engine torque aided by EBS ECUs.

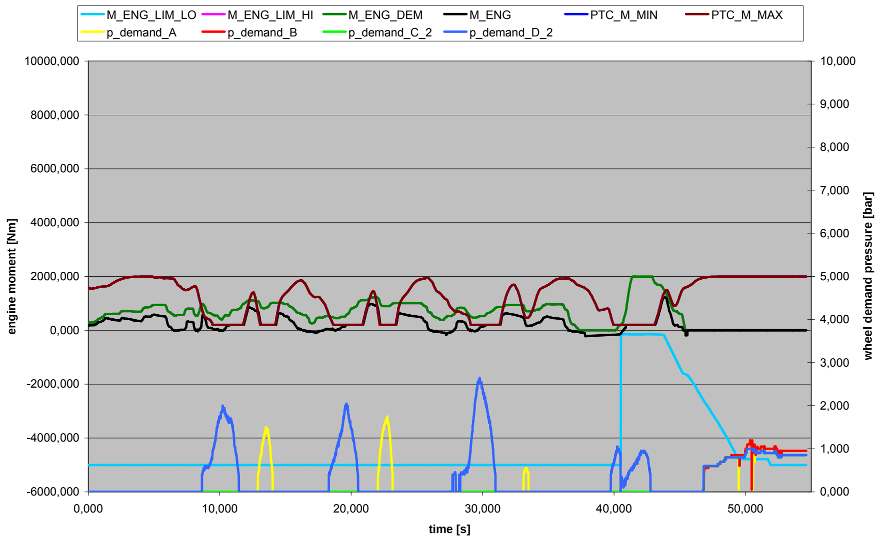


Figure 50: Plot of powertrain signals / parameters while in ESP mode

The steering and the brake intervention are appreciable and they help the driver in the critical situations. It is very important because this ESP extension increases the safety of the system.

2.4.2 Demonstration of the drive by wire powertrain functionalities

Within this chapter the PEIT vehicle demonstrates the coordination of the whole drive by wire powertrain functions and the connected subsystems. The motion task has to be operated in an ensured fail safe manner. The systems were tested in different ways. After almost a year of simulation tests and HIL tests, the ESP has been also tested on a real truck under real driving circumstances. Detailed results of the tests executed with HIL, vehicle in the loop test bench, and rapid prototyping tools are available in PEIT deliverables D6 and D7.

Because of the nature of ESP, it is difficult to create specific tests to compare different levels of its functionality. ESP is a driver assistant system, which is only “reactive active” in severe driving situations, means when the stability of the vehicle is partly or totally lost, and the vehicle tends to be under/oversteered or is already heavily under/oversteered. Because of these facts, the selected test scenarios can be divided to the following categories:

Vehicle under- and oversteered:

This test is very hard to reproduce exactly even by a high skilled test driver; every test differs from the other. During the test, the vehicle is first driven straight on a low-friction surface. The driver starts from there to steer the vehicle from this surface to a surface with high friction coefficient. Caused by the low-µ condition, the vehicle understeers because of the small lateral forces acting on the contact area between tire and surface. The vehicle moves therefore really slowly to the side the driver steers for. This fact leads to a steadily increased steering wheel angle from the unskilled driver who has the impression to have to steer more due to the slow steering reaction coming from the vehicle.

But after one of the front wheels of the vehicle leaves the low-friction surface and gets in contact with the high-friction area, the vehicle suddenly turns very quickly and hard to the steered side. The reaction is coming so heavily, that even a high skilled driver is loosing control by it's counter steering actions trying to stabilise the vehicle. Even a standard conventional ESP will show no stability effects because trying to stabilise the vehicle by a yaw rate clockwise only by conventional selective braking would lead to the action that the right rear wheel is decelerated (by the track change from the right to the left), with no stabilising effect because of the low friction on this wheel side. The vehicle becomes oversteered, instable and starts skidding.

With the driver assistant function of ESP with steering intervention the vehicle can be stabilised even within such worse and rough conditions. A quick counter steering is sufficient to stabilise the vehicle's motion (see Figure 51).

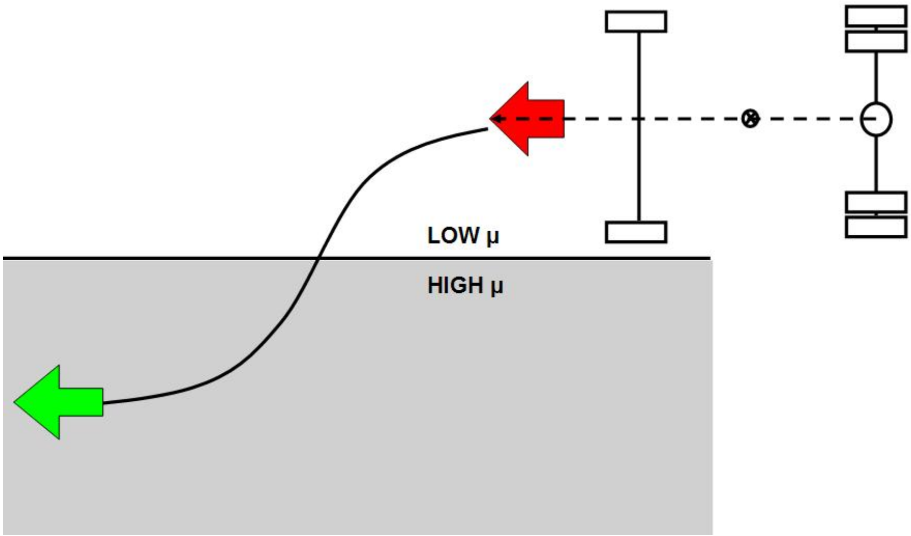
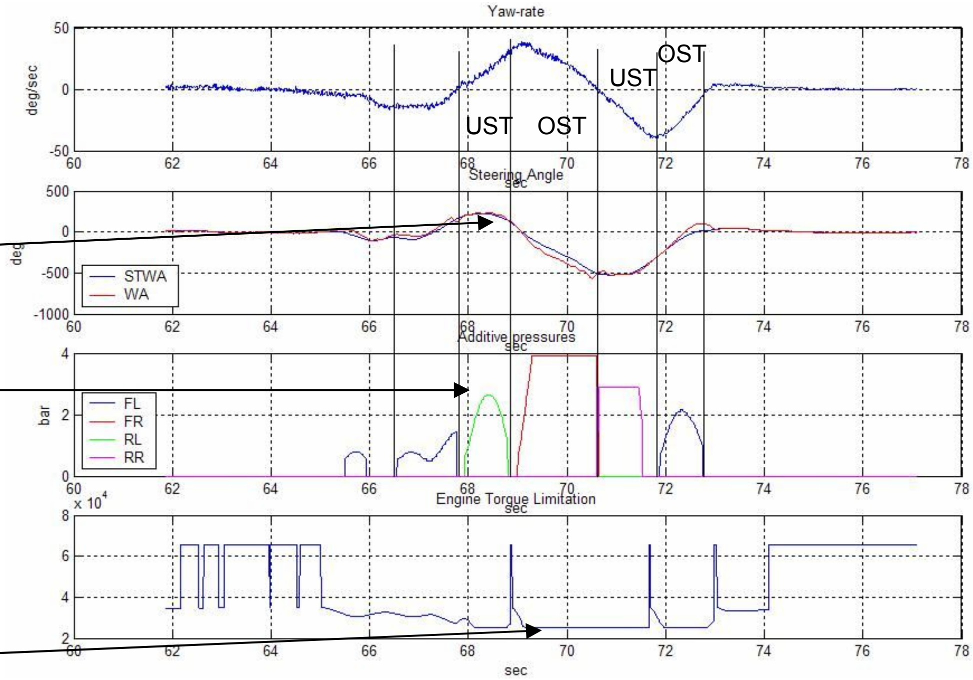


Figure 51: Test for under- and oversteered behaviour

These tests are usually executed in winter condition with huge areas for skidding and spinning (frozen lakes, etc.), since they have to be conducted with high speeds (> 50 km/h) that make them especially difficult and dangerous. Tests executed in this scenario have been evaluated only by test drivers.

Figure 52 contains test results. During the test the vehicle changed its behaviour (under- and oversteered) a few times, depending on the friction coefficient of the road and the driving circumstances. After detecting the under- or oversteered behaviour, ESP calculates brake pressures to specific wheels and also limits the engine torque. Also note how the ESP tries to stabilize the vehicle by modifying the steering angle of the vehicle. (Figure 52 and the magnified steering diagram on Figure 53) The different phases of over- and understeering can be seen. OST, Oversteering, UST: Understeering, WA: Wheel angle, STWA: Steering wheel angle.

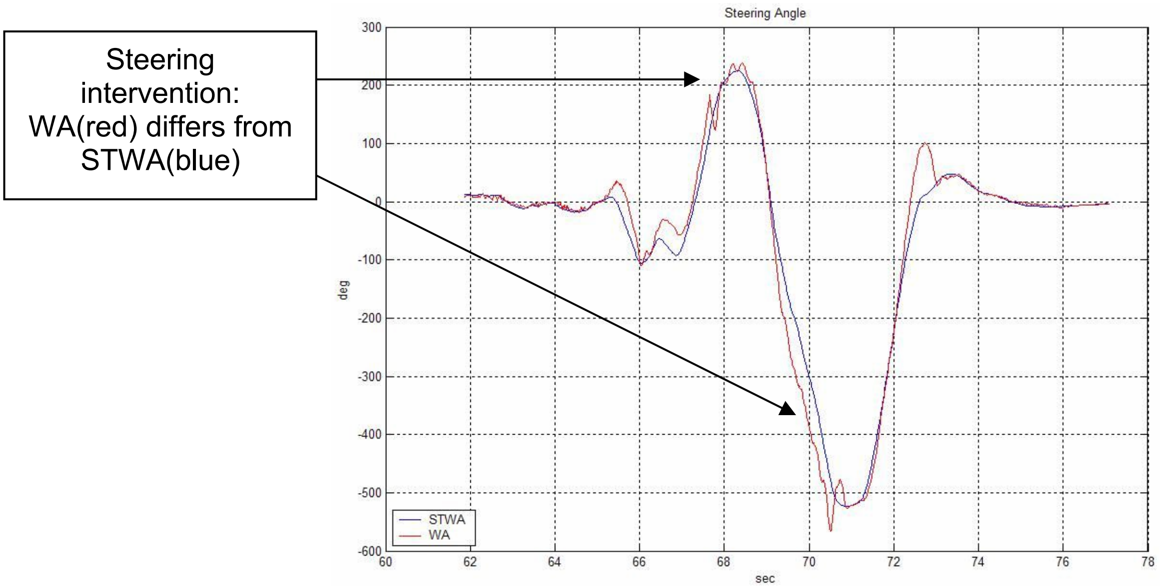


Steering intervention: WA(red) differs from STWA(blue)

Braking on the specific wheels

Limiting the engine torque

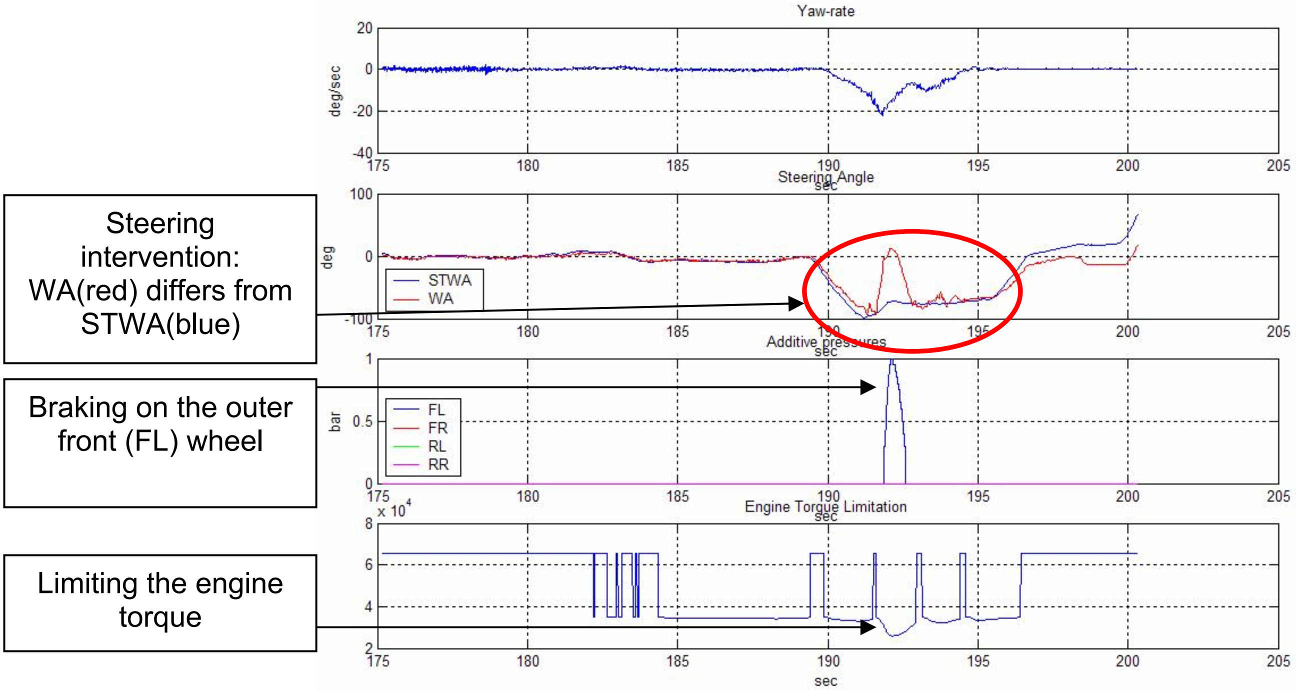
Figure 52 Results of under- and oversteered manoeuvre



Steering intervention: WA(red) differs from STWA(blue)

Figure 53: Steering intervention during the test

- **Driving on a circular path**: Driving on a circular path is a test case for curve driving on road, with mid or low friction coefficient. Accelerating or decelerating produces a characteristically response specific to the vehicle means the vehicle reacts in a under- or oversteered manner. In this test procedure oversteered behaviour was reached by heavy decelerating within the turn (because of the load transfer to the front axle the rear axle and therefore the tires lose tire normal forces and therefore side forces). When the vehicle's behaviour changes, normally the driver in order to keep the vehicle on the desired trajectory, starts with heavy counter-steering, and reduces the driving force. In case of ESP with steering intervention the driver assistant system intervenes automatically. No counter steering from the driver's side is needed. The assistant system coordinates the whole powertrain, steering, braking, engine management in such a way that the trajectory coming from the driver is operated without additional counter actions from the driver's side.



Steering intervention: WA(red) differs from STWA(blue)

Braking on the outer front (FL) wheel

Limiting the engine torque

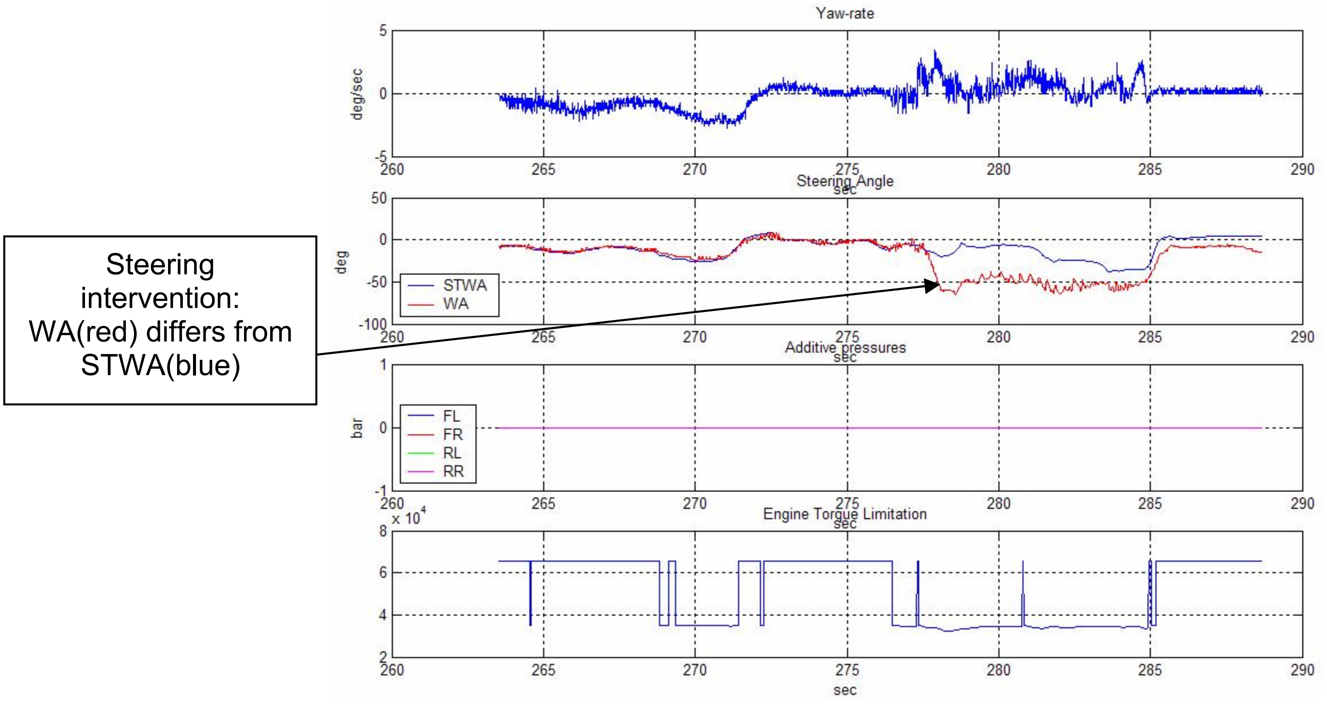
Figure 54: Measured values at oversteered behaviour

When the ESP detects an oversteered behaviour it intervenes in the following procedure:

- First the ESP starts to reduce the oversteered behaviour with steering intervention: the ESP reduces the steering angle of the wheels, even if it reaches the countersteering (changes the sign of the steering). On Figure 54 one can see how the two values, the steering wheel angle and the wheel-steering angle start to differ from each-other.
- When the control of the wheel angle is not sufficient to stabilise the vehicle the ESP starts additionally to limit the engine torque in order to reduce the drive force having the physically provided side-forces on the driven wheels available. (See Figure 54).
- Parallel to the intervention of the engine-control, the driver assistant system ESP exerts brake pressure to the left front wheel – this force generates a to the steering intervention coming yaw moment an additional yaw moment on the centre of gravity of the vehicle which acts and turns the vehicle against the spinning (oversteered) direction (See Figure 54).

- **Braking on unbalanced friction surface** (µ-split braking): Means when the road surface on the right and left side of a vehicle differs with a significant deviation between the friction coefficients. During heavy braking manoeuvres under such conditions the vehicle drifts from the desired trajectory the driver wants for due to the generated yaw moment in the direction oft the high friction coefficient. Current systems increase therefore the brake pressure on the wheels with high friction slowly so that the necessary counter steering coming from the driver to keep on track is in a range where even unskilled driver can react. This results in the disadvantage of an extended braking distance. This test can be easily reproduced and was one of the main tasks during the entire test procedure. It is important to note, that this test is not accustomed to be executed as ESP test. It is only special to the steering-enhanced ESP. While braking under µ-split conditions the advantage of the driver assistant ESP with steering intervention is first a reduced braking distance because the vehicle can directly go in to full ABS mode and second as like described before the driver has no need for intensive counter steering actions. To reduce the braking distance further on within such an environment a predictive ESP mode was investigated observing the brake pressures to react even far advanced before the vehicle becomes unstable.

The measured values can be seen on Figure 55. The results indicate that the counter-steering effort from the driver is reduced as a result of the autonomous counter-steering of the ESP. The STWA is close to zero while the actual WA is around 50 degrees. Figure 56 shows two steering plots for the same test: the upper is the STWA (blue) when the ESP is turned OFF, the lower plot shows the STWA and the actual wheel angle with the ESP turned ON. Note that there is a significant difference between the two steering-wheel curves, there is no need for quick and heavy countersteering while the brake-distance even shrinks.



Steering intervention: WA(red) differs from STWA(blue)

Figure 55: Results of µ-split braking

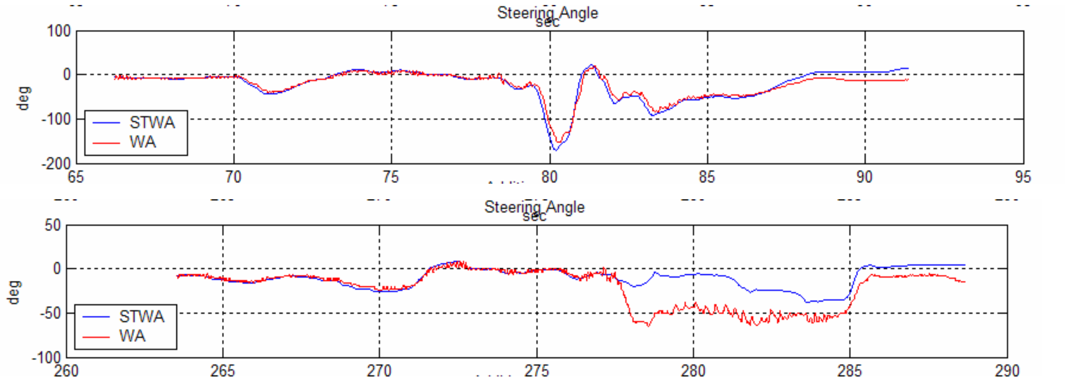
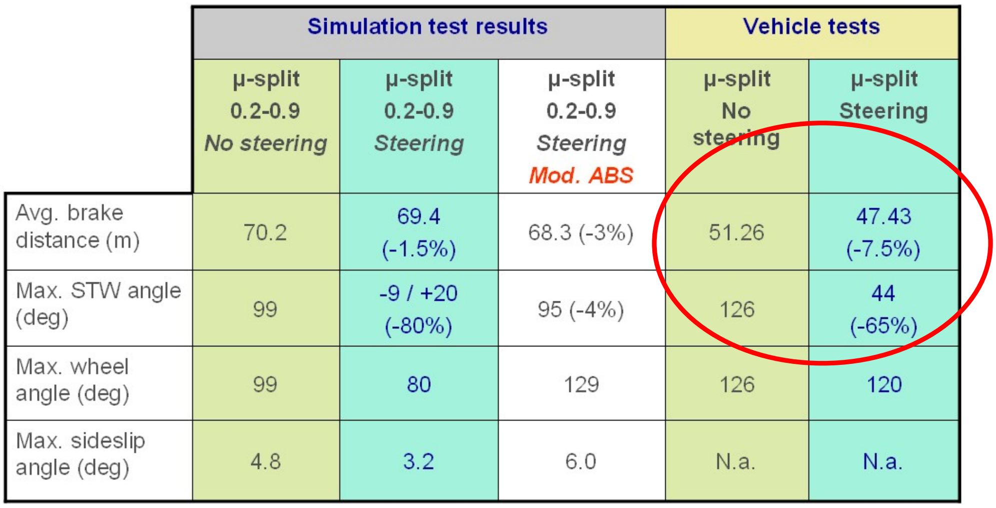


Figure 56: Steering angles without and with ESP

Below (Table 1.) the results of the simulation and field tests (field tests executed with rapid-prototype tools) can be compared. No Steering means ESP OFF, Steering means ESP ON. The simulation and real tests cannot be compared directly, because the test surface and other environmental conditions were not identical, though the trends and procedures can be compared. The results show, that steering-enhanced ESP significantly reduces the counter steering required from the driver. As a result, the driver doesn't have to produce quick and heavy countersteering, he can drive more relaxed while still maintaining even a higher level of stability.



	Simulation test results			Vehicle tests	
	μ-split 0.2-0.9 *No steering*	μ-split 0.2-0.9 *Steering*	μ-split 0.2-0.9 *Steering* *Mod. ABS*	μ-split No steering	μ-split Steering
Avg. brake distance (m)	70.2	69.4 (-1.5%)	68.3 (-3%)	51.26	47.43 (-7.5%)
Max. STW angle (deg)	99	-9 / +20 (-80%)	95 (-4%)	126	44 (-65%)
Max. wheel angle (deg)	99	80	129	126	120
Max. sideslip angle (deg)	4.8	3.2	6.0	N.a.	N.a.

Table 1: Comparison of μ-split braking results

An additional result to the stability enhancement of the ESP with steering intervention is the significant reduction of the brake-distance: even with unmodified brake system (ABS) of the tractor the brake-distance has dropped by around 7%. This result is caused mainly by the following two issues:

- The automated and controlled steering intervention performs an accurate and quick counter steering. The autonomous counter steering is partly performed based on the predictive calculation of the Yaw-moment arising from the unbalanced conditions of the left and right sides of the vehicle. The quicker counter steering means more stable vehicle behaviour with smaller time delay.
- The quick steering intervention has a major result: The vehicle body sideslip angle of the vehicle is reduced. The smaller sideslip angle of the vehicle means concurrently smaller side-slip angles on the wheels, which means that there will be a bigger longitudinal friction coefficient available.

2.5 Enabling measures (WP6)

Analyses on legal and homologation issues

One of the goals of the PEIT project was to design an on-highway capable vehicle that can be legally operated anywhere on Europe’s roads. A task force within the PEIT project was installed to identify methods for homologation and standardisation in order to facilitate the introduction of the PEIT architecture.

The work to reach the objective was the definition of safety relevant criteria, description of necessary performance of the system and definition of specific design rules, which lead to a modification of existing directives and homologation procedures. The proposed harmonised procedures take into account the results of other EU projects as well as the exchange of opinions with relevant ministries, other experts, technical services and approval authorities as well.

The approach was to investigate the path on how the homologation and the standardisation may be achieved. Based on an evaluation of the approvability in respect to the current relevant EEC-Directives and ECE-Regulations for braking- and the steering-systems the path on how the homologation may be achieved through amendments to update the existing requirements to the new technology has been investigated. This investigation includes proposals to amend the relevant existing legal standards to the new technology.

Basic requirement for the granting of a national whole vehicle type approval is the following:

As in most of the industrial developed countries also in Germany there is existing a prescription that is found in paragraph 30 StVZO (German traffic regulation) and has the following contents:

“Vehicles have to be designed and equipped in a way that the usual participation in road traffic does not hurt anybody or endangers hinders or inconveniences anybody more than it is inevitable. The passengers have to be protected especially in the case of accidents as much as possible and the amount and the consequences of injuries have to be as little as possible”.

Conditions for braking system:

ECE Regulation 13 in its actual valid version (R13.09) is setting up the conditions according to which a complex drive by wire vehicle control system as far as brakes are concerned has to be designed.

Because of the new technologies that are implemented in the PEIT vehicle it seems to be necessary that some modifications – possibly most of them of formal character – will be necessary. A concrete detailed evaluation of the PEIT systems according to whether they are in line with the legal prescriptions in force is possible as soon as there is existing an over-all description of the system with all the necessary documents and information together with the homologation test results. This occurs mainly according to the special safety requirement of complex electronic vehicle control systems annex 18 deals with.

Conditions for steering system:

At the moment it seems that the new amendment revising ECE Regulation 79 will come into force in February or March 2005. It is not expected, that the contracting parties rise objections against the new amendment, because they voted in favour for it in AC 1. As the PEIT concept is not yet entirely described and homologation tested it may be possible that to type approve the PEIT system regarding the steering equipment as well as already mentioned in connection with the braking system this may only be possible either via an exemption according to article 8.2 c) of Directive 70/156/EEC or in a way that there are applied modifications also to the ECE Regulation 79.

Conditions for horizontally distribution of modules within in a centralised architecture

ECE Regulations are on the way to be changed as far as vertical ECE Regulations are concerned and there may come into force a first horizontal ECE Regulation dealing with complex electronic vehicle control systems after the already existing horizontal regulation according to electro-magnetic compatibility to be found in ECE Regulation 10. This development will make it easier at a later point of time to come to a homologation of the PEIT system, avoiding exemptions according to Article 8.2.c. of frame work Directive 70/156/EEC.

Accident Analysis

An analysis of traffic accidents was carried out to work out background and causes of traffic accidents that mostly occur or lead to severe accidents.

The planned approach was to analyse traffic accident reports with regard to several characteristics, such as specification and condition of the driver, kind and state of the vehicle. Therefore several data sources and organisations were contacted and asked to provide reliable information on accident scenarios:

- National accident databases

- Automobile insurance companies
- Engineering companies
- Vehicle manufacturers
- Transport companies
- Research institutes

A major problem of the research was the fact that the most owners of data sources did not provide any information to third parties due to data safety reasons, and as a consequence, they could not be statistically evaluated within the time frame of our research project. An additional problem was the evaluation of accidents with involvement of heavy goods vehicles (HGV), as such accident scenarios are often not given sufficient attention which makes it difficult to obtain specific data on that accident category.

However, it needs to be mention that the definition "accident cause" and the resulting reliability of the accident data (the actual accident cause) vary greatly among data sources.

In recent years a great number of European publications dealing with the comparability of accident databases and the methods of accident data recording have appeared. Emphasis has been placed on the urgent necessity to establish an international, uniform data recording method. In addition to this uniform recording method, a European-wide accident database is being established, simplifying research in this field. The accident database project CARE will be able to offer this service in the future, if all countries can be motivated to participate in that project.

As reliable data for whole Europe was missing, the causes for traffic accidents were elaborated based on the differentiated data of the national department of statistics in Germany, Austria, Switzerland, and Hungary. The obtained results were scaled with general European data (total number of accidents). Additionally, an in-depth investigation made in the German state of Bavaria has been used.

Since the various national databases use quite different definitions (accident causes, accident circumstances, accident type) for the differentiation of accidents a direct comparison of the statistic data is not possible. To solve this problem the definition "accident scenario", a combination of different explanation, has been used for the description of those accidents.

An important result of this study is the fact that only approximately 3% of the accidents are caused by technical problems / failure of the vehicles. Amongst these failures, tyres and brakes are the most frequently failing vehicle systems.

As consequence the major percentage of accidents with heavy goods vehicles involved is caused by driver errors or drivers misjudgements of the situation.

Within the category of heavy goods vehicles (HGV) analysed, six accident scenarios (see Figure 57) occurred most frequently. Summarised, they make 2/3 of the total of all accidents.

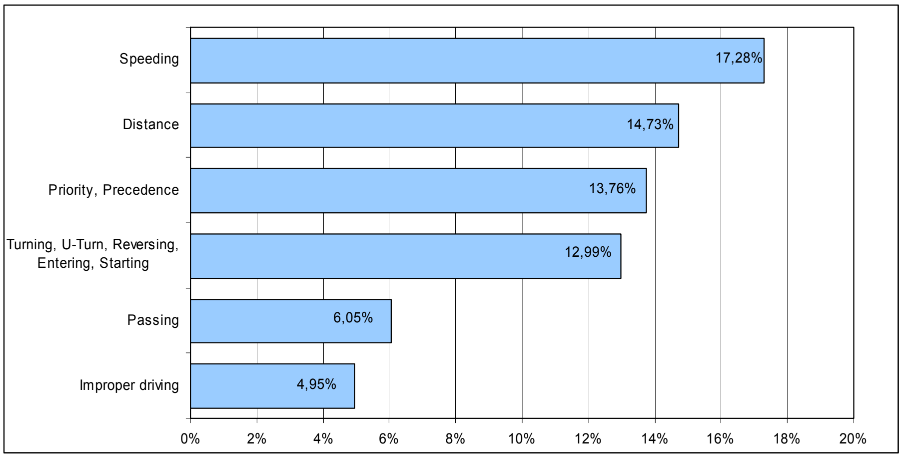


Figure 57: Accident scenarios that mostly occur

The percentage distribution of these most frequently occurring accident scenarios have been calculated using a weighted mean of data obtained from the national statistics. The total of all accidents in the countries mentioned have been used for weighting.

Accident scenarios of severe accidents with casualties have been calculated based on the German figures previously verified by the statistics of other nations (a weighted calculation was impossible due to the highly different accident categories). The result can be seen in Figure 58.

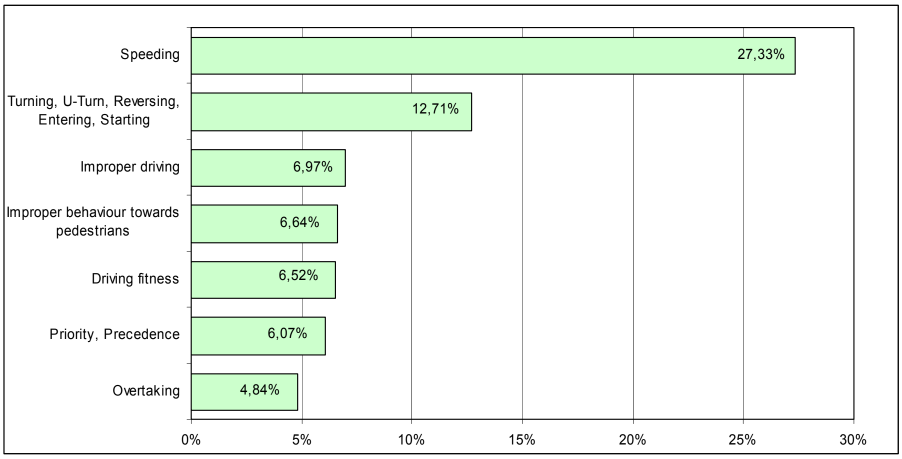


Figure 58: Accident scenarios for severe accidents with casualties.

The involvement of those seven accident scenarios amounts to 2/3 of the over all accidents with casualties.

In order to significantly influence these accident scenarios and, as a consequence, reducing the number of injured individuals and casualties, driver-supporting systems are necessary. In many cases it also may be necessary to correct the driver's manoeuvres. This interaction for corrective purposes requires the integration of the latest technologies in the Drive-by-Wire field a platform for driver assistant systems. Technologies developed in the PEIT project.

Conversion of Friction Force Limit

The friction force limit between a vehicle and road is depending on the type and the condition of the road surface. Additionally this friction force limit is influenced by the vehicle; through specific vehicle parameters. This statement becomes apparent when the stopping distances of two strongly differing vehicles are compared.

For example, a modern car equipped with ABS requires a stopping distance of approx. 42 m after emergency braking from 80 km/h, whereas a HGV requires approx. 65 m to come to a standstill on the same road surface and from the same speed. The stopping distance is therefore extended by a factor of about 1.5.

Some of the reasons for the heavily differing braking distances are caused in the frictional characteristics of rubber, which depend on many parameters like contact stress or relative speed, but also in the different brake systems. This means that the factors which influence the friction force limit have to be separated into road-specific and vehicle-dependent effects. While the vehicle is running both of these effects have to be taken into account.

In work package three an algorithm was developed (see 2.2.3) to separate the vehicle-dependent effects from a measured friction force limit. With the obtained friction force limit, information is available which no longer applies to the measured vehicle, but is independent of the vehicle and describes only the type and condition of the road surface.

With this road specific, but vehicle independent friction force limit information and a combination with additional geographic data it is possible to create a friction force limit map. This map information can be broadcasted for the use of predictive actions taken into account by driver assistant systems (ABS, ESP) equipped with the necessary receiver systems.

If a vehicle is only partly capable of the functions to determine the friction force limit and cannot broadcast one, it can still be a user for transferable friction force limit information. Many vehicles would thereby be in the position of calculating their actual, real friction force limit by broadcasted friction information.

2.6 Project dissemination (WP7)

Project dissemination was an important part of the PEIT project to demonstrate the possibilities and advantages of our doings. Representatives of the consortium participated in important national and international congresses to spread the idea of a new architecture serving for future assistant systems to experts and specialists dealing with new technologies. Papers were written and published. An internet portal was launched (www.PEIT-EU.net) to provide a world wide access to the information of PEIT. Public appearances in universities were performed to demonstrate the next generations of upcoming engineers the automotive future of tomorrow. Days of open doors were organised to demonstrate the technical results achieved in PEIT to a broad interested public. Handouts and multi media CD Rom applications were printed, produced and distributed on conferences and events. The Feedback coming from outside was always positive. For a European wide project communication PEIT was member of the ADASE consortium (Advanced Driver Assistant Systems in Europe). From there an effective communication exchange was possible to other European projects and their technical developments.

3 Lesson learned and future activities

3.1 Lessons learned

The analyse of accident statistics reveal that an enormous number of accidents in Europe occurs each year. On European streets 42.000 people are dieing and 1.7 million of people are injured (figures year 1996).

In Germany alone more than 6000 people were killed by vehicle accidents which causes additional to the personal grief a social economic impact of 36 billion Euros per year (figures year 2004).

The statistics reveal also that 97% of these vehicle accidents are caused by the driver and only 3% are caused by technical impacts first of all tire and brake problems.

So supporting the driver in critical situations is of prime importance. Driver assistant systems are the answer. Active reactive systems, systems which act after a critical situation occurs and active predictive system, means system which act in advance when a critical situation is predicted to avoid dangerous conditions.

The PEIT project demonstrates the how easy driver assistant systems can be integrated by using of a standardise platform acting together with drive by wire technology coordinated via centralised platform strategy.

3.2 Future developments

PEIT serves as a platform for future driver assistant systems. Via the central architecture and the standardised interface, only a motion vector, a motion task is necessary to control a whole drive by wire powertrain out of one redundant ECU. It is obviously that further developments will be based on this platform due to the easiness of integrating new functionality. No knowledge of the under knees lying powertrain components is necessary in operating the motion task.

A further European project was launched in 2004 which was named SPARC the abbreviation for **S**afe **P**ropulsion using **A**dvanced **R**edundant **C**ontrol. SPARC is the consequent continuation of PEIT a step forward direction an accident avoiding vehicle. Several demonstrators will be built up. From a small passenger car up to a heavy goods vehicles with trailers 5 vehicles will be demonstrated from vehicle in the loop test benches up to demonstrator vehicles, all driven by centrally coordinated drive by wire technique using a standard interface. The project demonstrates the consequent extension of the command layer from the PEIT project. There only the driver generates a motion task. Compared to PEIT the command layer in SPARC consists additionally out of a virtual co pilot. This co-pilot assists the driver. Via camera and radar the environment of the vehicle is observed. In the case the co-pilot predicts in front of the driver a dangerous situation which would need very quick actions from the driver's side the implemented decision control system can react in front with an ensured motion vector which is communicated to the powertrain controller via standard interface to ensure the safe motion of the vehicle. SPARC will be a big step forward towards an accident free vehicle.

4 Conclusions

Within the duration of the PEIT project a demonstrator vehicle was set up together with a vehicle in the loop test bench (a technical hardware twin with full functions of the demonstrator vehicle mounted on a rack) by the consortium under the coordination of DaimlerChrysler.

A proven from the avionic derived drive by wire concept was chosen to demonstrate the possibility of a central coordinated powertrain concept. The main goal of the project was to develop an interface capable of serving all future driver assistant systems. Only the vehicle motion describing parameters of velocity and steering angle are necessary to control a PEIT vehicle. There is no further need of additional information of the mechatronics under knees contained in the powertrain for such assistant functions.

The central architecture with the powertrain coordinating dual duplex electronic control unit the so called powertrain controller (PTC) contains all functional modules for the control of the powertrain mechatronics.

The fail safe ECU with its dual duplex structure an architecture also used in the Airbus 380 aircrafts in the primary and secondary flight control. It combines the advantage of reduced data transfer and enhanced and improved control algorithms major caused on the one fact that a system matrix is available within the ECU which reflects all relevant powertrain parameters. This means no additional time consuming requests to specific mechatronic applications respectively parameters within the powertrain periphery are necessary and the other fact that all the functional applications are running as software modules in one central ECU. This means that data transfer from one to the other module can be achieved by the enormous speed of the PTC ECU clock compared to the reduced high speed communication bus clocks when the applications are distributed.

The mechatronic elements providing the functions of steering, braking, accelerating, gear shifting, and energy management were based on full drive by wire technologies. All safety relevant functions were specified as fail safe. This is the base for future driver assistant systems overruling the driver with the main task of avoiding accidents and protecting driver and environment. All safety relevant applications developed like BbW, SbW and energy managements exceed the current state of the art technologies regarding safety and reliability.

To demonstrate a horizontally distributed safety function an electronic stability assistant with the possibility of steering intervention was developed. This driver assistant system enhances the possibilities of a conventional ESP by the additional use of the steering system. Instable vehicle conditions can be more effective eliminated with the advantage of a reduced braking distance of up to 7%.

Another horizontally distributed function which was shown was the determination of the actual friction coefficient and the transformation of the value in a vehicle independent standard value usable for other vehicles in the surrounding. With this application it was possible to calculate the actual braking distance not only for the vehicle which is determining the friction coefficient. Even vehicles in the surrounding without such an application can use the value as it can be standardised by a special broadcast application to calculate the braking distance.

The decision of building up a vehicle in the loop test bench brought an enormous advantage within the test and validation phase. All functions could be tested and validated in advance before going into the demonstrator vehicle. The necessity of time consuming test drives on a proving ground together with a test driver was drastically reduced.

Due to the fact that such presented technology is not approved the consortium analysed within a task force the possibility of a homologation path for type approval to bring PEIT technology on market.

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Abbreviations

ABS	Antilock brake system
ARP	Aircraft Recommended Practice (SAE)
ART	Adaptive cruise control
BbW	Brake by Wire
BN	Vehicle power supply
CAN	Controller Area Network
COTS	Components commercial of the shelf
DbW	Drive by Wire
DCAG	Daimler-Chrysler AG
ECU	Electronic control unit
EEM	Electronically energy management
EMC	Electromagnetic compatibility
EPM	Electropneumatic modulator
ESP	Electronic stability program
FA	Front axle
FB	Parking brake
FMEA	Failure mode and effect analysis
FTA	Fault tree analysis
G	Generator
GA	Danger analysis
HGV	Heavy goods vehicle
HMS	Manual torque adjuster
HW	Hardware
LKW	Truck
LWS	Steering angle sensor
ME	Mechatronic layer
PB_1	Pedal brake
PB	Pedal box
PBM	Parking brake module
PEIT	Powertrain equipped with intelligent technologies
PTC	Powertrain controller
PTI	Powertrain interface
PWM	Pulse width modulated

RA	Rear axle
SAE	Society of Automotive Engineers, Inc.
SbW	Steer by Wire
SOC	State of charge
SOH	State of health
StVZO	German licensing regulations
SW	Software
TCM	Trailer control module
TÜV	German Technical Inspection Association
VE	Command layer
WS	Position sensor
Fail silent	The system/subsystem/device switches off automatically when a fault is detected internally and no longer actively participates in communication
Fail safe	The system/subsystem/device switches the outputs (state) into a safe specified state when a fault is detected.
Fail operational	The system/subsystem/device continues to operate with a full or limited functionality even after a fault. The system is designed to be tolerant of faults. The time and value thresholds are selected so that the system remains active even when faults of this kind occur (short-term or with a modified* functionality if necessary).

Annex 1: Deliverable and other outputs

A comprehensive overview of the project deliverables, articles and conference presentations is included in the following tables.

Deliverables The following deliverables were produced in the PEIT lifetime.

Deliverable code & name	Planned delivery date	Actual delivery date	Responsible partner
D01 - Project Presentation	Periodic		DCA
D02 - Specification document of powertrain architecture and interfaces	Month 9	Month 11	DCA
D03 - Specification report of PEIT components	Month 12	Month 16	DCA
D10: Accident analysis	Month 12	Month 14	UKA
D11: First version of algorithms for the creation of a transferable friction information (methodology)	Month 24	Month 28	UKA
D04: PEIT components ready and tested	Month 24	Month 25	DCA
D05: Demonstrator trucks tested and ready for demonstration and evaluation	Month 30	Month 36	DCA
D06: Test report	Month 30	Month 36	DCA
D07: Test plan for evaluation	Month 30	Month 36	DCA
D12: Improved algorithms for the creation of a transferable friction information (methodology)	Month 30	Month 36	UKA
D13: Final algorithms for the creation of a transferable friction information (methodology)	Month 36	Month 36	UKA
D14 Report on legal issues for market introduction, report on homologation and standardisation and issues for market introduction	Month 36	Month 33	DCA
D08 Demonstration and test with prototype vehicle	Month 36	Month 36	DCA
D09 Evaluation report	Month 36		DCA
D15 Final report	Month 36		DCA
D16 Exploitation plan and technology implementation plan	Month 36		DCA
D18 Friction coefficient estimation	Month 36	Month 36	DCA

Dissemination The following dissemination activities were performed within PEIT.

No.	Date	Title	Presenter

No.	Date	Title	Presenter
1	24.10.01	ADASE 2 Concertation meeting, Brussels, Belgium	G. Spiegelberg and A. Sulzmann attended the meeting and presented the goals and approach of the PEIT project.
2	Jan. 2002	Automotive congress in Braunschweig, Germany	A. Maisch and G. Spiegelberg presented PEIT contents
3	15-16.04.2002	Euroforum Düsseldorf	G. Spiegelberg presented PEIT contents
4	13-14.05.2002	IER Mechatronik Seminar Mannheim	G. Spiegelberg presented PEIT contents
5	13.06.2002	Branchenforum Mechatronik Göppingen	G. Spiegelberg presented PEIT contents
6	25.06.2002	Status und Zukunft der Nutzfahrzeuge	G. Spiegelberg presented PEIT contents
7	29.10.2002	ADASE 2 Concertation meeting, Brussels, Belgium	A. Sulzmann presented the project.
8	23-24.10.02	CRF drive by wire conference, Torino, Italy	A. Sulzmann presented the project.
9	27.11.02	Nutzfahrzeugforum Augsburg, Germany	G. Spiegelberg presented PEIT contents
10	7-8.12.02	GTÜ Forum, 7-, Willingen, Germany	G. Spiegelberg presented PEIT contents
11	11.-12.02.03	Automatisierungs-und Assistenzsysteme, Braunschweig, Germany	G. Spiegelberg
12	7.-8.05.03	VDI-Mechatronik-Tagung, Fulda, Germany	G. Spiegelberg
13	20.05.03	'Bayern Innovativ' Nürnberg, Germany	G. Spiegelberg presented PEIT contents
14	2.-3. 06.03	VDI-Fahrzeug-und Verkehrstechnik, Braunschweig, Germany	Dr. Spiegelberg
15	04-06.06.03	IIR Forum, Munich, Germany	G. Spiegelberg presented PEIT contents
16	25.06.03	Day of open door, Technical University of Budapest	PEIT team & students
17	14.-16.07.03	Project Path, Berkeley, USA	Dr. Sulzmann
18	24.09.2003	Safe Comp, Edinburgh, England	Dr. Spiegelberg. Mr. Rooks
19	13.-15.10.03	Teletronic, Stuttgart	Dr. Spiegelberg
20	14.-15.10.03	Symposium Driver assistant systems. Nürtingen, Germany	Dr. Spiegelberg
21	16.-20.11.03	IST Kongress Madrid, Spain	Dr. Maisch, Dr. Spiegelberg, Dr. Sulzmann
22	25.11.03	International Commercial	Dr. Spiegelberg

No.	Date	Title	Presenter
		Vehicle symposium, Manheim, Germany	
23	19.01.04	ADASE Concertation meeting	Dr. Maisch
24	10.02.04	Conference Sensoric Köln	Dr. Spiegelberg
25	05.04.04	Presentation of PEIT at FH Aalen	Dr. Spiegelberg
26	16.04.04	Presentations of PEIT at FH Karlsruhe	Dr. Maisch
27	14.06.04	Series of lectures about SPARC and PEIT FH Esslingen	Dr. Maisch
28	22.06.04	Day of the open door	Dr. Spiegelberg
29	27.09.04	PEIT final event and demonstration	PEIT team and public audience

Webs and articles

The following articles and papers were presented within PEIT.

Date and Type	Details
PEIT Internet appearance	Site www.eu-peit.net became operative on 28.02.2002
Conference Paper	Automotive congress in Braunschweig, Germany
Conference paper	CRF drive by wire conference, Torino
Conference paper	Nutzfahrzeugforum Augsburg
Conference paper	GTÜ Forum, Willingen, Germany
Conference contribution	'Bayern Innovativ' Nürnberg, Germany
Conference contribution	IIR Forum, Munich, Germany
Article	Article "Vom Airbus lernen" for the magazine "Automobil Industrie" 3/2004
Article	Drive-by-wire closer than you think. IST Result Server.
Article	The intelligent highway

Annex 2: Project management and coordination

The project management was performed by DaimlerChrysler as a service to the consortium. Each partner shared the cost for this overall management. The actions of the management were transparent to the partners and controlled by the same mechanisms as for the work packages.

Given the compact size of project and consortium a light management structure was chosen, that allowed good control as well as transparent delegation and clear reporting lines

The project management committee (PMC) performed the operational management of the project. The PMC consisted of the project manager and the work package managers of the partners. Decisions concerning the normal running of the project were be taken by the project management committee. They were always reached unanimously. A so-called the project control board (PCB), consisting of senior managers of the partners, to make final decisions had never to be called in.

The project manager from DaimlerChrysler performed the day-to-day management of the project. This included contractual commitments, and budget as well as technical control. Sub- responsibilities were delegated to:

- Project support, to provide supportive services for the project work,
- Project controlling to exercise financial and budget control, and
- Work package management, responsible for the coordination and planning of the tasks in the specific work packages.

In order to achieve the project goals, a comfortable and efficient communication between all project partners and the project management had to be assured. Therefore, an appropriate communication strategy was established to ensure a proper both internal and external information sharing and to keep all partners fully informed about the project status. All project documentation (internal and external) was standardised in terms of common rules for files/report exchange, SW tools, format, etc..

The project progress was controlled by executing a navigation cycle "planning, execution, analysis, revision" every three months. The navigation cycle was executed on occasion of the three monthly meetings of the PEIT project management committee (PMC).

The project planning was performed by the project manager together with the work package managers (technical contents, milestones) and the project controller (budgets and resources). Work progress was reported on task level on a three monthly basis on occasion of the PMC meetings.

The deliverables were produced within the individual work packages. As a quality assurance measure they were subjected to an internal 'Peer Review' before submitting them to the EC and external experts.