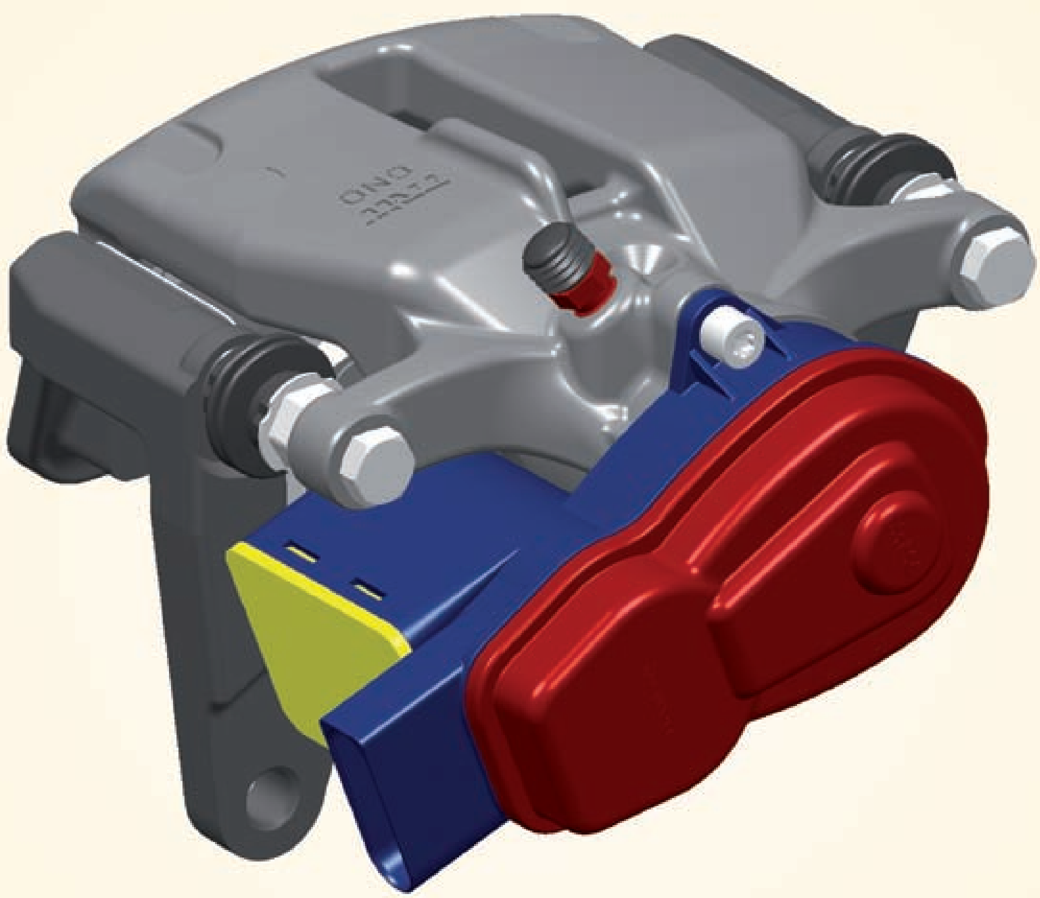
Smart Parking Brake Distributes Electric Park Brake Functions

In 2002, TRW Automotive introduced the first calliper integrated electric parking brake in the world. Since then, the Electric Parking Brake (EPB) has been launched in over 20 vehicle models – from luxury to mid-range platforms. The new Smart Parking Brake (SPB) System presented by TRW removes the requirement for the electric parking brake to have a separate Electronic Control Unit, integrating the EPB into existing systems such as electronic stability control. The new SPB system creates the opportunity for systems integration at a higher level.



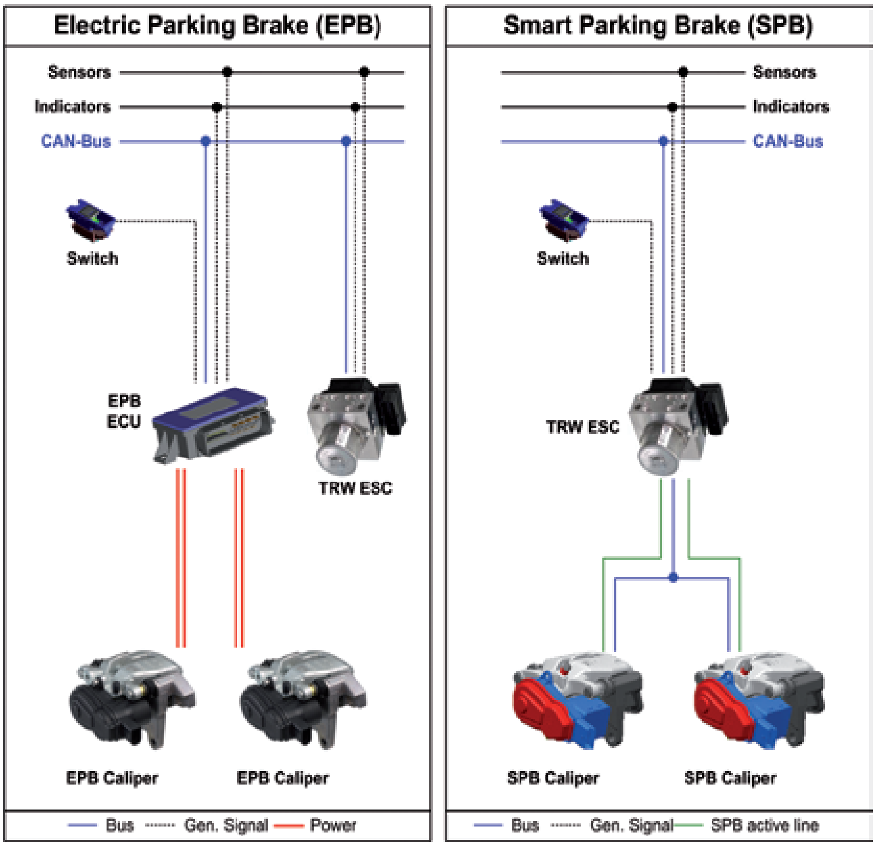


Figure 1: Comparison between EPB and SPB in combination with ESC

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1 Introduction

The electro-mechanical parking brake is a further step in the implementation of a fully electric braking system. The conventional parking brake has been superceded by actuators on the rear wheel brake disc and a dedicated electronic control unit (ECU). EPB helps to enhance driving safety and comfort and offers scope for greater freedom in interior design and packaging. In addition to providing the standard function of a parking brake, EPB is a fully integrated part of the braking system, which also makes emergency braking possible where necessary. As a result of this, emergency braking on all four wheels can be triggered in conjunction with the electronic stability control (ESC) system – if necessary – whereas with a standard parking brake system, the brake is only applied to the rear axle. Nevertheless, EPB provides an additional fall back option for pure electro-mechanical emergency braking, while the ECU keeps the vehicle stable during brake application. The following outlines the components, functions and environment of the Smart Parking Brake system and highlights the differences compared to the standard EPB system.

2 System Description

2.1 System Task

The parking brake system has the important principal task of keeping the vehicle safe on an incline even in the absence of the driver, with the braking parts being purely maintained mechanically in the brake position. The braking effect (and its release) must be capable of being controlled from the driver's seat or, on request, be carried out by other vehicle systems. In addition, the SPB system can support the driver in other functions, for example by automatically releasing the parking brake when the vehicle starts to accelerate, or by a hill-hold function. The SPB system also serves as an ancillary braking system, to guarantee an extra reduced braking effect independent of the service braking system, if it fails (including emergency braking). The vehicle stability must be maintained in this case.

2.2 System Design

Figure 1 left shows the system design of today's EPB in coexistence with the slip control system ESC. In contrast to today's EPB design, Figure 1 right, outlines SPB integrated with ESC – the ESC carries the system controller of the SPB. The EPB consists of two rear brake callipers with integrated actuators and spindle nut devices. The system is controlled by a remote ECU. The human-machine interface is realised by the EPB switch and the indicators such as lamps or buzzers in the dashboard.

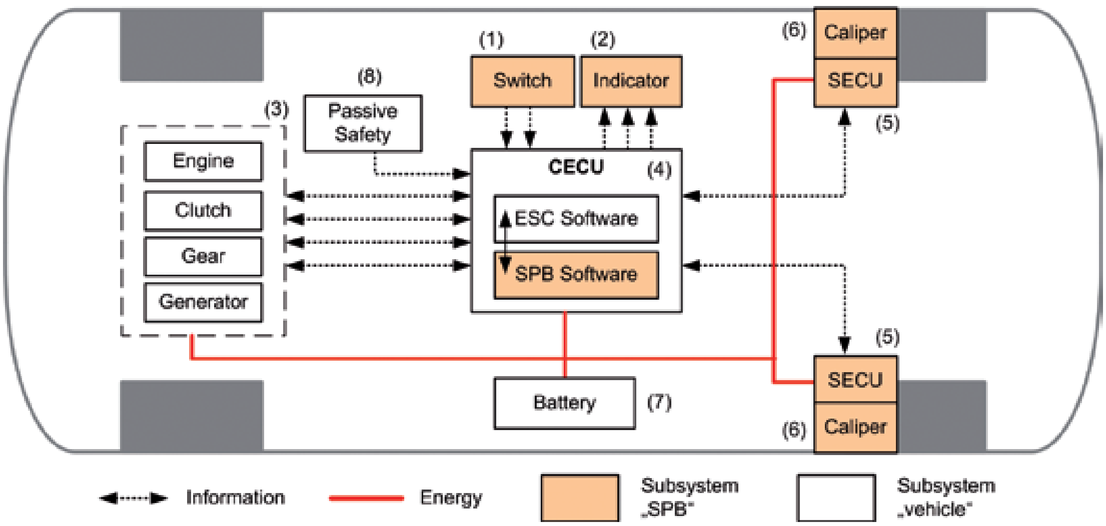

Figure 2: Subsystem interaction

The SPB system replaces the separate ECU with small actuator integrated control units, the so called Smart ECUs (SECU). It does not require a separate control unit for the parking function. Compared to the EPB ECU, these small controllers have very limited intelligence. They are restricted to clamp force control, monitoring functions and selftesting. The system functions, such as comfort, safety and maintenance features are embedded as pure software functions into the ESC system – the ESC is used as Central ECU (CECU). The SECU and CECU communicate via Controller Area Network (CAN) Bus. The special SPB active line is a safety mechanism to switch off or to release the actuator hardwired and independent of the bus in any operational situation.

The sketched system architecture of SPB demonstrates that the division of the EPB ECU into SECU and CECU leads to a system with distributed functions, defined boundaries and interfaces of system and component controllers.

2.3 Interaction with Other Vehicle Systems

The SPB system interacts primarily with the driver and the service brake. Other systems within the vehicle such as the powertrain or passive safety systems with which the SPB system exchanges information are brought together under the umbrella term “vehicle”.

The driver transfers an adjust or decelerate demand to the system. Additionally, the SPB system requires information as to whether or not the driver is present. The service brake can also send adjust demands to the SPB system or receive such demands from it. Furthermore, both systems exchange information about their current status. The vehicle also sends information about the vehicle condition to the system. Essentially, this is information about the speed of the vehicle, the inclination and the current tractive power of the powertrain. The SPB system provides the vehicle with the tension needed for the brake force.

The interactive components are shown in **Figure 2**. The EPB switch operates as the driver operating device in the passenger compartment (1). The driver receives relevant system information from indicators such as lamps, buzzers or text messages (2). The driver presence information is provided by the passive safety system (8). The SPB system receives additional information on the driver’s actions via brake, accelerator and clutch pedals as well as the gear shift (3). The CECU (4), within which the SPB software module works, establishes the connection between the various parts of the system such as vehicle information or driver communication and the SPB actuators (5). A SPB actuator is integrated into every rear-wheel disk brake (6) and generates the tension on the brake system based on information from the CECU. The SPB actuators receive energy directly through the battery (7). The CECU decides on the adjustment, transfers this to the SPB actuator and checks its implementation – it acts as master of the complete system.

2.4 Design

The SPB uses the same building blocks as the standard EPB. It uses the EPB brake calliper – already proven in series production – together with the hydraulic wheel brake. However, in contrast to the regular EPB, the SPB system integrates a more developed actuator with an integrated control unit. The parking brake system is therefore expanded by a modular, adapted housing with additional electronics. The main illustration shows the SPB brake calliper with the smart actuator. It integrates the SECU. The integrated electronics includes a single micro ECU, an Application-specific Integrated Circuit (ASIC), a CAN interface and a motor driver. The connector interfaces are the power supply, the CAN interface and the SPB active line.

The clamp force application occurs via a spindle nut assembly placed in the hydraulic brake piston, **Figure 3**. The actuator applies torque to the spindle on SECU command. The spindle moves towards the brake piston that generates the clamp force in the calliper. The actuator spinning direction defines whether force is applied or released. The spindle assembly has a selflocking character to retain the force level when the electrical power is off.

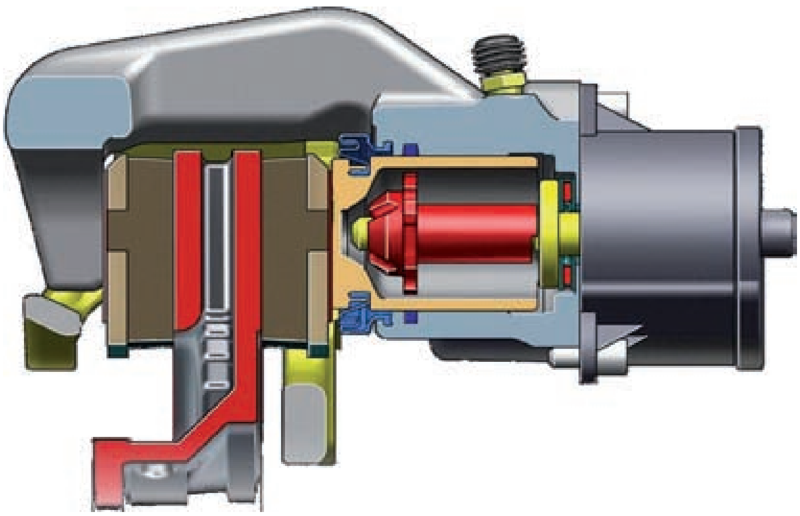

Figure 3: Brake force apply via spindle nut

3 System Benefits

The benefits of SPB are driven by the significant reduction of system complexity compared with today's electronic parking brake system. The benefits can be summarised as followed:

– reduction of line routing effort and minimisation of powered lines on the vehicle (part cost and installation effort)
– sharing of processor memory and computing power with other control units minimises part cost software application and safety engineering effort
– reduction by one ECU housing (part cost and mounting effort)
– coding the SECU for steering wheel bolting
– replacement of the electro-magnetic parking lock in automatic gear boxes by embedding SPB into fault-tolerant system architecture
– improved component control and monitoring
– direct recognition and processing of all relevant signals to the wheel and transmission to the CAN bus.

4 Development Status

As control unit electronics have been moved within the immediate vicinity of the wheels for the first time with the SPB, exhaustive testing has been carried out. Prototypes were constructed and tested. The vibration, temperature and Electromagnetic Compability (EMC) tests carried out on the design sample demonstrated its robustness. **Figure 4** and **Figure 5** show exemplary test results on thermal performance and EMC robustness. Tests on samples near to series production did not show any signs of damage and its functionality is very reliable. As well as component testing, a safety case including fault-tree-analysis and Failure Mode and Effects Analyses (FMEA) was performed on system and component levels. All preliminary results show the technical feasibility of such a concept.

5 Functions and Modes of Operation

5.1 System Functions and Functional Decisions

Just as with the classical EPB, the Smart Parking Brake system also evaluates which of the starting conditions apply, based on the starting information provided; it then selects the appropriate functions from this data. The function with the highest priority is selected and implemented. **Figure 6** provides an overview of the logical functional decision based on predefined starting conditions. The CECU thereby differentiates whether an action has been initiated by the driver (driver-initiated function); whether it is an automatic function, such as automatic retightening of the parking brake; or if it is an external demand. There is an external demand when systems other than the main brake have made demands of the parking brake system.

5.2 System Modes

The system differentiates between static, dynamic and unknown driving conditions. In a static state, the vehicle has stopped or is below a speed threshold defined for this state. The following applies to the dynamic state: the vehicle is in motion or is above the defined speed threshold. If the driving condition is unknown – due to missing vehicle speed – then the state is estimated.

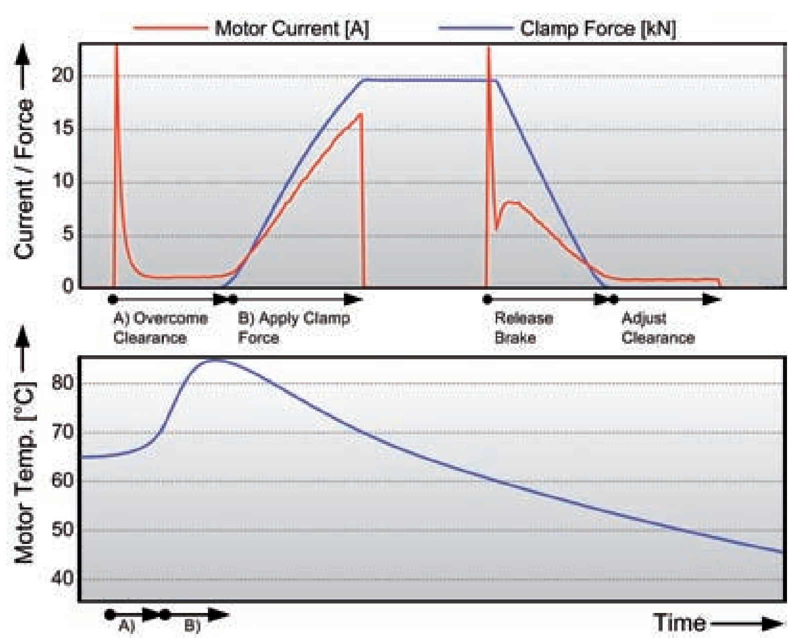

Figure 4: Thermal behaviour

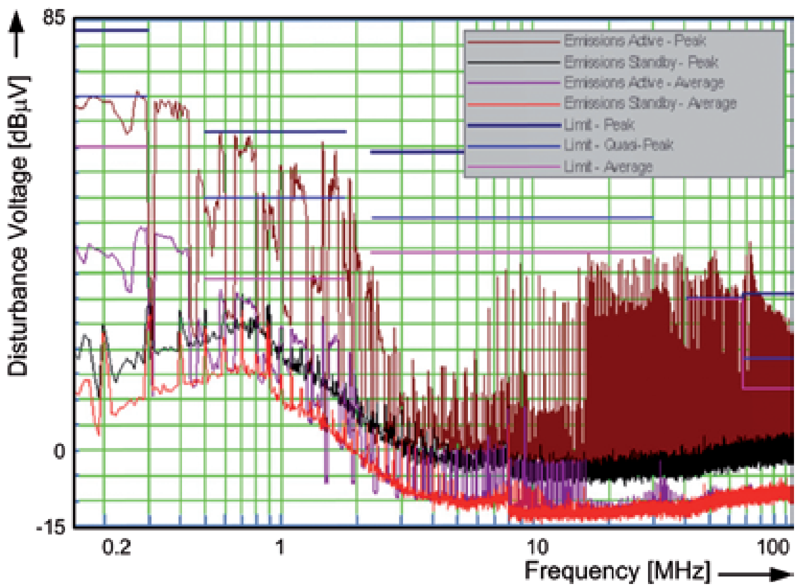

Figure 5: EMC test

5.2.1 Static Condition

If, for example, the system detects the driver-initiated function "close parking brakes on manual switch entry" when in static driving condition, the brake closes irrespective of the ignition state and the previous position of the brake shoe. If the system detects a desired Drive Away Assist (DAA) or start assistant, that is the driver wants to drive off after the brake has been applied – for instance, when stopping at a light – then the parking brake opens automatically depending on the engine torque and the inclination of the road surface. This function integrates automatic closing of the parking brake in case the vehicle engine stalls on starting.

5.2.2 Dynamic Condition

In a dynamic situation, the parking brake system – when the vehicle is moving – operates emergency braking functions. These functions are also available in "ignition off" state. If the system detects the function "brake demand to the main brake system" (Electronically Controlled Deceleration, ECD), it transfers a demand to the main brake system that it should only slow down the vehicle when the driver has activated the switch on exceeding a given speed limit.

5.2.3 Unknown Condition

If the driving condition is unknown due to missing vehicle speed then the state is estimated. Hereby, the parking brake is tensioned slightly when actuating the parking brake button. If vehicle deceleration then changes it is assumed that the driving condition is dynamic. If there is no change in deceleration then this is interpreted as a static state.

5.3 Hierarchy of Functions

Selecting which function has higher priority and is implemented differs depending on the driving condition and the starting state of the actuator. Using a functional hierarchy step-by-step, the system processes targeted requests to collect reliable data on the actual state of the driving situation, so that it can then select the appropriate function. **Figure 7** provides an overview of the functional interfaces by which the information is passed on to the CECU central control

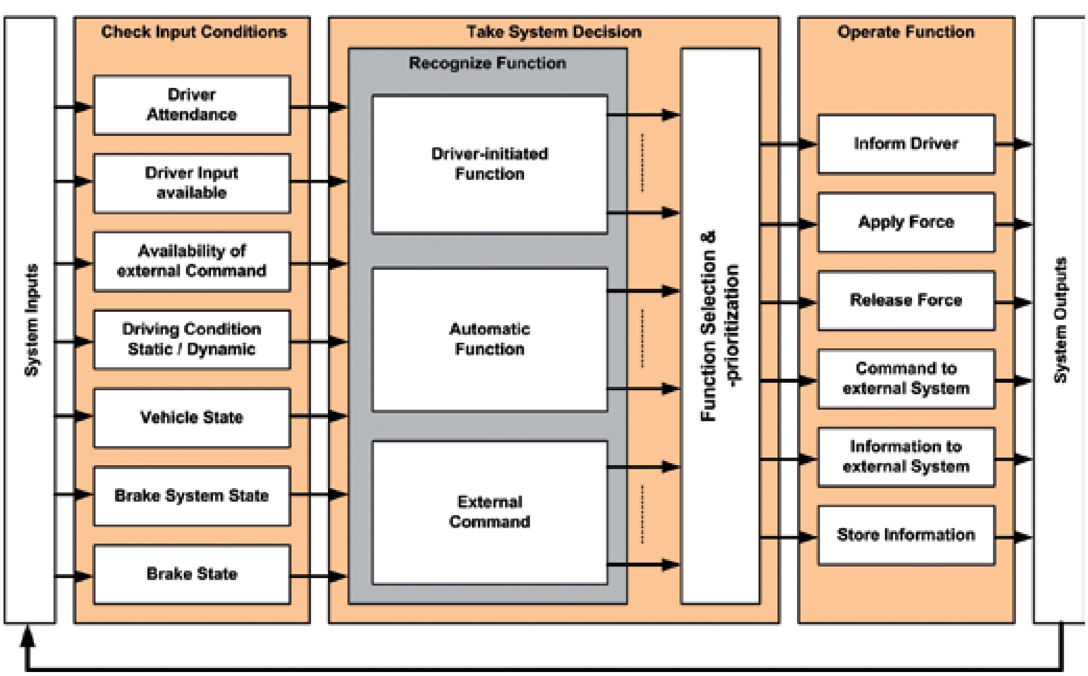

Figure 6: Functional decisions in SPB

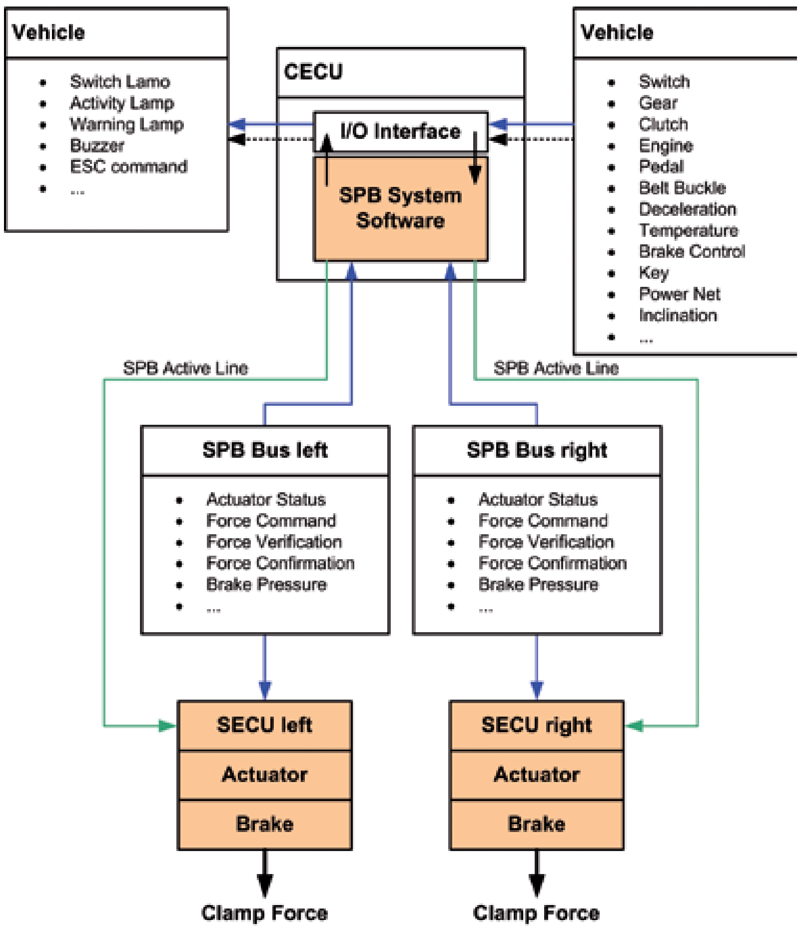

Figure 7: Functional hierarchy of SPB

unit, and which trigger an appropriate action of the Smart Parking Brakes.

6 Functional Division

In the SPB system the software functions are divided between several control units. The interfaces to the vehicle and the SPB actuators are established via the CECU central control unit, which also contains other systems in addition to the SPB software module. System control is from here and the clamping force demands are also output from here to the smart actuators; these each control the clamping force of the brake. The two smart actuators are only controlled by the CECU. There is no independent control of the SPB actuator by the SECU itself. The central control unit CECU takes over the following functions:

- acceptance and transfer of vehicle and SECU information
- evaluation of all system information and selection of the appropriate system function and adjustment demands, for example close and open parking brake
- determination of clamping force demand (level and speed) for each smart actuator
- activation of the SECU via SPB active line
- output of driver information
- system monitoring of the SPB system
- fault storage
- diagnostics interface for the entire SPB system
- output of system status of SPB system
- identification of smart actuators
- switching-off of SPB engine controller in case of a fault (via the SPB active line)
- storage of vehicle parameters.

The Smart ECU (SECU) is responsible for:

- reading and verifying control commands
- apply and release clamp force
- self test and monitoring of actuator components
- monitoring of battery voltage
- signal processing for appropriate quality.

In order to take over the functions of the SPB software module, the CECU needs sufficient processor memory and computing power as well as enough input/output ports. Furthermore, it must provide good quality signals for the SPB signal transmission. Additionally, the design and programming of the CECU must comply with the Safety Integrity Level (SIL) requirements of the SPB system. The software and hardware structure of the CECU complies with the "Autosar" agreements.

7 Summary and Outlook

TRW has already exhaustively tested its electronic park brake system in series production. Now it has developed it further into an even more intelligent parking brake system, by integrating the Smart Parking Brake system. Based on the SPB, in the future, the electronic parking brake can fit within a fault-tolerant architecture. The potential to improve value by integrating functions with a simultaneous reduction of electrical control units is motivation enough to keep developing this design. Testing the system allows additional electronics capability of the components in the vehicle and also sets the standard for future innovative and environmentally friendly technologies. Production is planned for 2011. ■