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FAIL-SAFE
THROUGH
INNOVATION

The role of pedal sensors for the electric brake system

by

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Agenda

- Brake pedals and brake pedal sensors
- Driver-to-Car Interface (HMI)
- Functional requirements for the brake pedal unit
- Potential hazards
- Safety strategy and concepts
- Haptics
- Implementation of functional solutions
- Examples of current solutions
- Commercial feasibility
- Alternatives to pedals

Brake pedals and brake pedal sensors

Why are the brakes operated by pedals?

The forces required to operate any mechanical (hydraulc) brake system are in general beyond the range of direct human capabilities. Historically, several technical supports have been invented. The first support was a simple lever which was reducing the actuating force. Later with the introduction of boosters, the brake pedal operating force has been further decreased, but the enhancement by the lever remained.

The electric brake systems don‘t have mechanical link between the pedal and the brakes. For such systems, the pedals have lost their primary function of amplifying the force.

Current sensors for monitoring the brake pedal movement

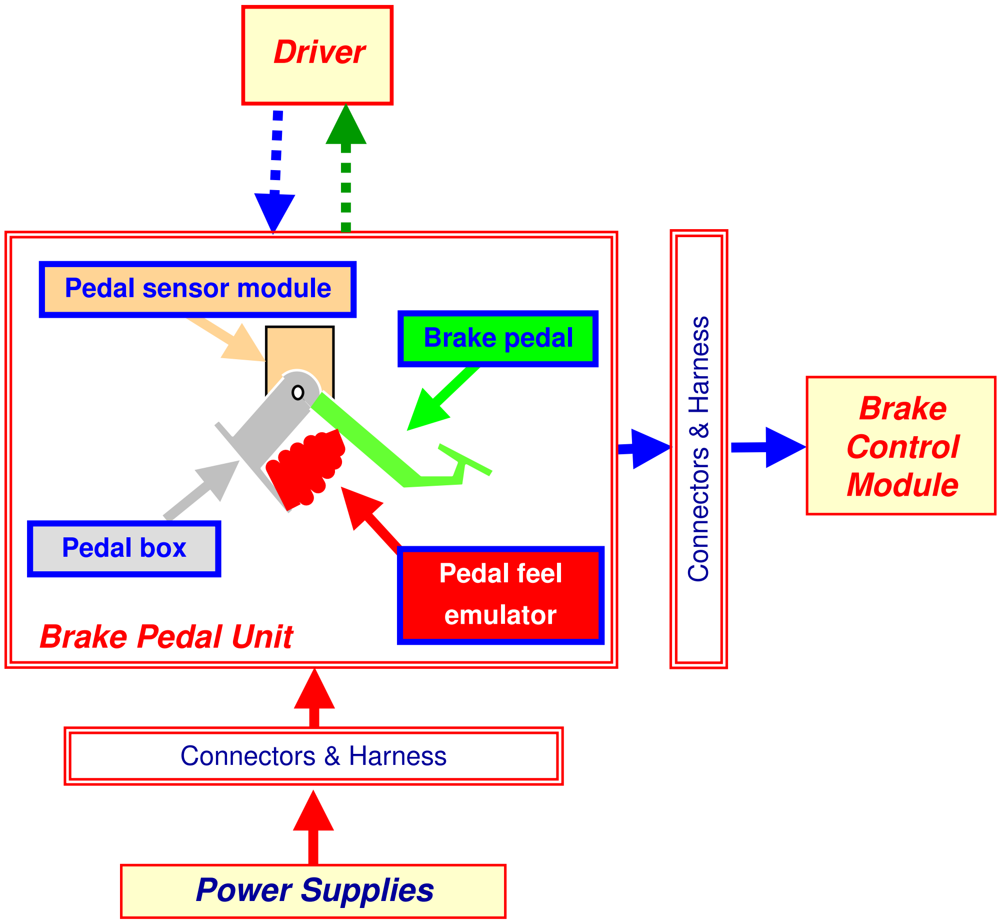
In the past, simple switches have been installed signalizing the actuation of the pedal, mainly controlling directly the brake lights. Since the functional vehicle complexity was increasing, complex switches have been developed or replaced by position sensors. Due to limited packaging space in the pedal box region, the pedal movement is often monitored indirectly by the sensors installed elsewhere within the hydraulic system.

Pedal sensors for electric brakes

The functional requirements for the actuation of the electric brakes cannot be fullfilled by the conventional controls for the mechanical systems. Therefore, appropriate sensing systems have to be developed for new challenges.

Driver – to - Car Interface (HMI)

The basic function of the brake pedal unit for the electric brakes is to transfer driver's wish of applying brakes to the control module.



Since there is no force to be transmitted from the pedal to the brakes, the system must provide an artificial haptic feedback to the driver.

Functional elements for the Brake Pedal Unit

- Driver's operational interface
- Pedal rotation system
- Power supply interface
- Sensing system
- Signal interface

Functional requirements

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- Safety aspects:
  - No mechanical fall back system for the electric brake systems.
  - Fail-safe mode cannot be defined for braking systems.
  - Safe system architecture with fail-silent / fail-operational modes is required.
- Fast response:
  - Sensor data (position, force, etc.) have to be transmitted fast to the brake control module (<= 1 ms).
  - The gradients of the sensor data have to be available in the system.
- Wake-up system on the pedal movement:
  - The sensor module must have a sleep-down mode and it must wake-up the brake system on pedal movement instantenousely (few ms).
  - Low current consumption in the sleep-down mode.
- Pedal feel emulation:
  - Driver should get appropriate feedback.

Potential hazards

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Several hazardous situations can be created by some malfunctions of the brake pedal unit. These malfunctions could be caused by either mechanical or electrical failures within the brake pedal unit. They have to be eliminated by proper system design.

Loss of brake

Brake cannot be activated since the driver's wish could not be transferred to the system.

Reduced deceleration

Braking distance increases due to wrong pedal position (or force) information or slow data processing/transmission.

Undesired increased deceleration

Deceleration increases although the pedal was only at low travel, due to wrong pedal position (or force) information.

Undesired sudden braking

Unwanted abrupt braking applied to vehicle due to wrong pedal position (or force) information or mechanical defect.

Undesired constant braking

Brakes are constantly activated whilst vehicle is moving due to incorrect pedal rest position (or force) information.

Retarded braking

Greater pedal travel needed to activate brake due to misalignement of the sensors, mechanical or electrical defects.

Safety strategy and concepts

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- Comprehensive self-diagnostics.
- Dynamic and analytic redundancy.
- Combined design redundancy and design diversity.
- Local intelligence for fast and reliable data processing.
- Adaptive learning system for the pedal rest position.
- Data communication using an appropriate bus system.
- Prevention of common cause failures by using:
  - Three independent power supplies.
  - Two different sensing principles.
  - Galvanic separation of the sensors.
  - Galvanic separation of the microcontrollers.
  - Mechanical separation of the connectors.

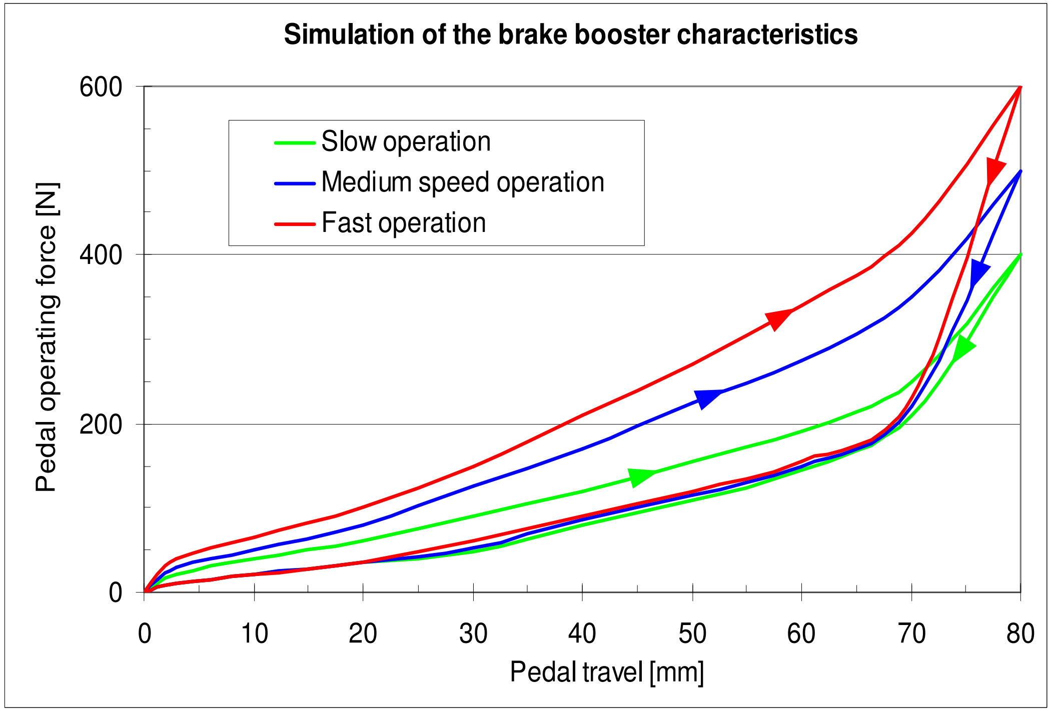
Haptics

There are several opinions regarding the haptics of the brake pedal unit which vary from simple non-linear spring characteristics over simulation of the current booster characteristics up to full active feedback.

While the simple spring doesn't represent a technical challenge, the realisation of an active feedback with a feasible technology may be possible in the future. The most realistic haptics - but at the same time technically challenging –is the simulation of the current booster characteristics.

The force feedback given by the booster depends on the operational speed of the pedal. The pedal force and its gradient is low at slow operation, but high at fast operation.

Carry-over haptics of the current booster technology will help to achieve acceptance of the electric brake systems.

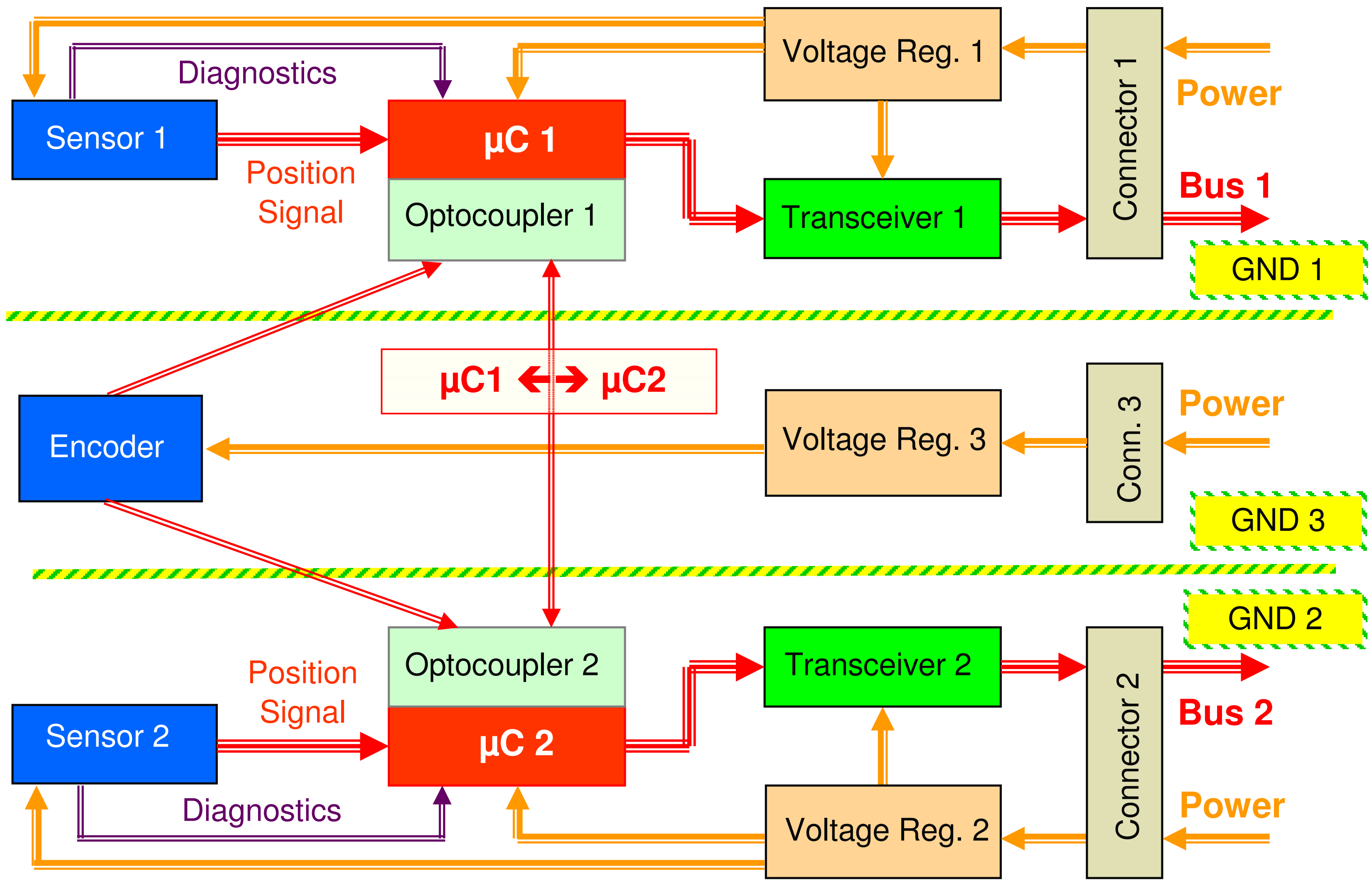


Implementation of functional solutions

For the implementation of the solutions, many aspects have to be considered:

- Synchronization of multiple sensors due to mechanical and electrical tolerances.
- Loss of global accuracy due to tolerances of multiple sensors.
- Relationship between different sensing parameters (i.e. position and force).
- Current consumption in the sleep-down mode.
- Local validation of all sensor signals.
- Calibration strategy.
- Manufacturability for high volume production.
- Serviceability.

Pedal sensor module schematics *



* Architecture proposed by Methode Electronics Malta, 2002

Fail-silent/fail-operational matrix *

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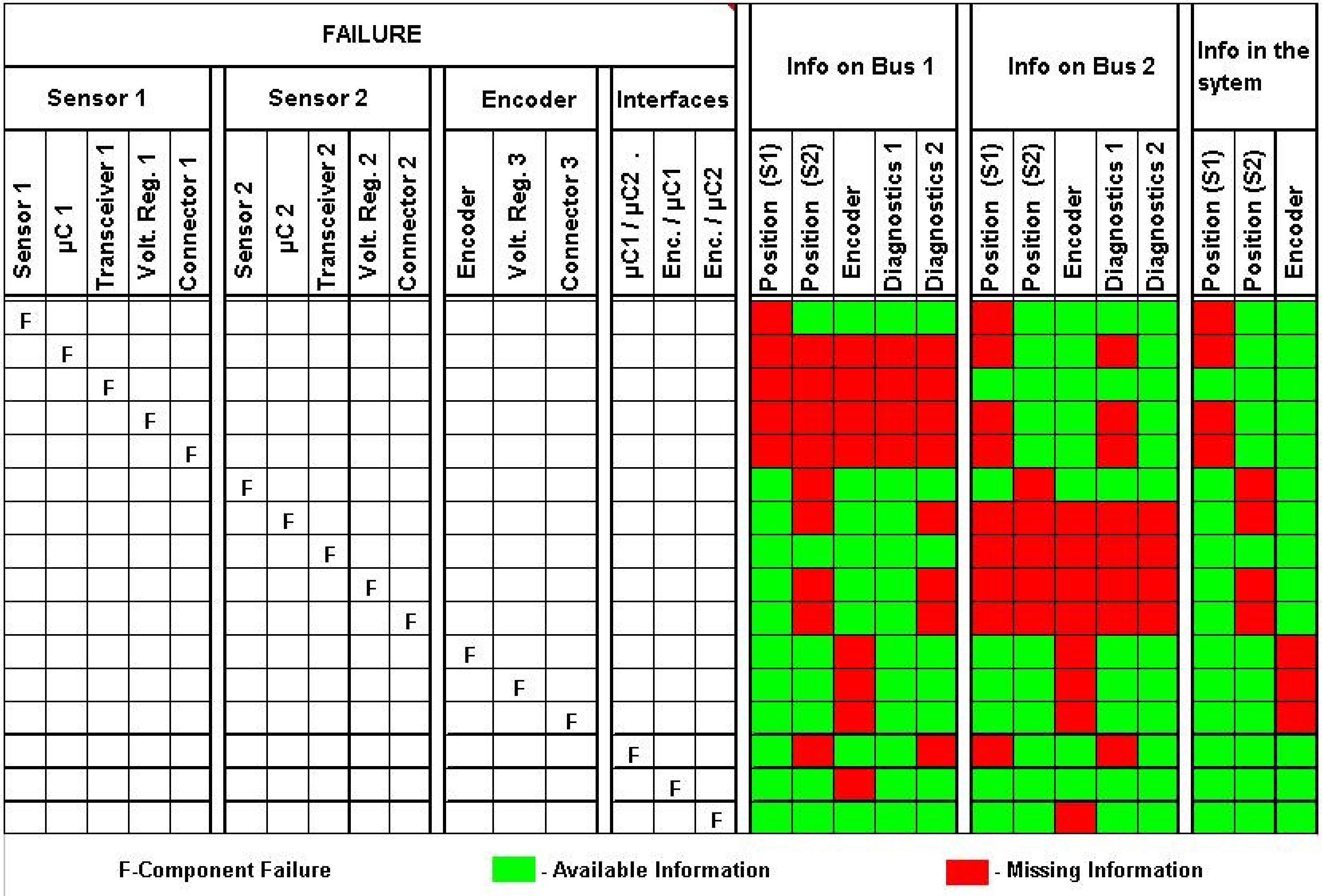

* Definition by Methode Electronics Malta, 2002; Published in AutoTechnology 6/2002

Prototype of a brake pedal unit

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The first prototype of a brake pedal unit from Methode Electronics Malta was produced for the test vehicles from TTTech for AUDI in 2002.

Technology

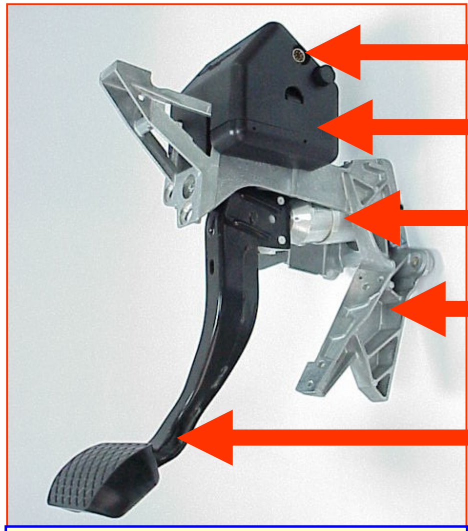
TTTech, November 2002

- The pedal box and the pedal are carry-over parts from series production from AUDI A6.

- Two eddy current analogue position sensors and one 3-bit Hall-effect encoder are giving redundant position signals to two independent microcontrollers.

- Pedal feel emulator is a non-linear spring with low hysteresis.

- Conditioned signals are transferred from each microcontroller via one private CAN node to the TTP/C bus.

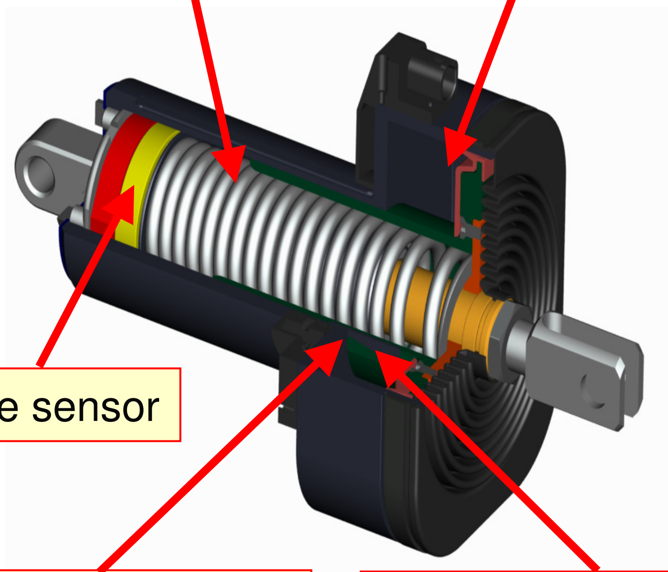


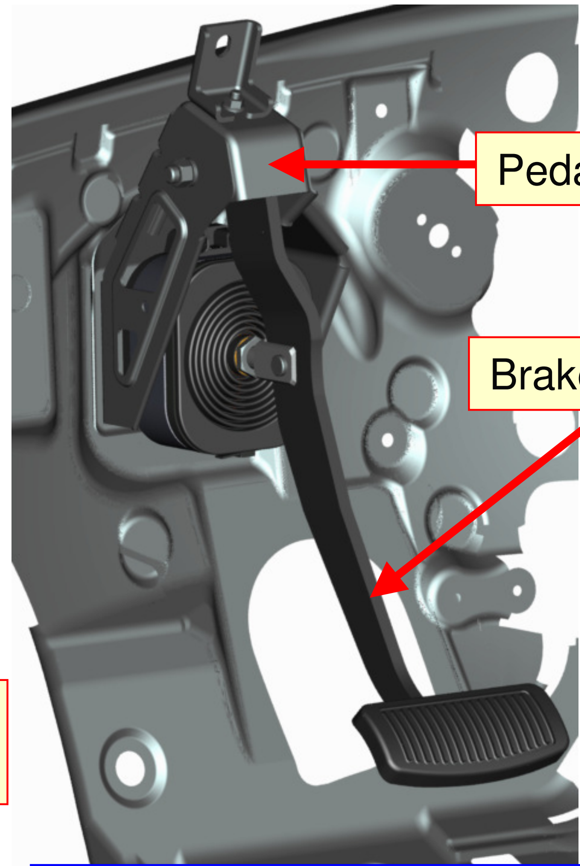
Methode Electronics Malta, February 2002

Information on each of the two bus channels

- Pedal position Sensor 1
- Pedal position Sensor 2
- Pedal position 3-bit Encoder
- Pedal velocity Sensor 1
- Pedal velocity Sensor 2
- Data matching validation factor
- Diagnostics µC 1
- Diagnostics µC 2
- Synchronization control counter

Brake pedal unit with pneumatic damper





Methode Electronics Malta, developed for Siemens VDO, 2007

Commercial feasibility

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The estimated costs of the currently proposed solutions for the functional requirements are beyond the targeted costs.

The main cost drivers are:

- Carry-over haptics of the current booster technology.
- Multiple connectors and harnesses.
- Galvanic decoupling of redundand components.
- Data communication by a bus.
- Low volume production.

Since the safety cannot be compromized, feasible solutions could be achieved by:

- Lowering the operational forces => using cheaper mechanical components.
- Removing the force feedback dependence of the pedal operating speed

  => removing the costs for the pneumatic damper with its accessories.
- Finding alternatives to galvanic decoupling of redundand components.
- Looking for a cheap but sufficiently fast point-to-point data transfer.
- Integration of electronic components.

Alternatives to pedals

The operation of the brakes by foot pedals had big advantages for the conventional hydraulic brake systems since forces of more than 500 N can be realized by the human foot.

Since the electric brakes don‘t have mechanical link between the driver and the brakes, the pedal operating forces could be very low.

In this case the Driver-to-Car interface could be something else than just a modification of the rudimentary brake pedals for hydraulic systems. The requirements for such new devices could lead to new sensor solutions.

Such technical inventions need customer acceptance.

Alternatives to pedals

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„Novanta“
SKF, 2001

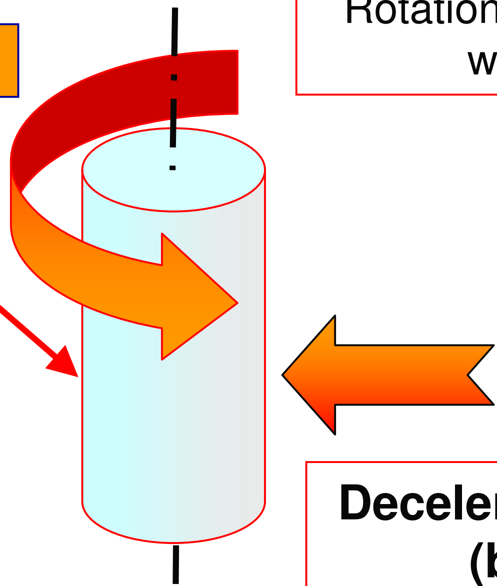
X-By-Wire technologies developed by SKF are implemented in „Novanta“

All „pedal“ controls are integrated with the steering wheel in the door handle

Symmetric (redundant) operation of the controls

Alternatives to pedals (cont.)

Steering wheel grip



Acceleration control (gas):

Rotation of the steering wheel grip

Deceleration control (brakes):

Radially applied force on the steering wheel grip