Position Sensor for Brake System Designed for Energy Recuperation

AMAA 2013

Bernhard Schmid, Frank Grunwald, Sören Lehmann, Heinrich Acker

17. – 18.06.2013, Berlin

Position Sensor for Brake System Designed for Energy Recuperation

Agenda

1 Regenerative Brake System

2 Linear Position Sensor

3 Summary

Position Sensor for Brake System Designed for Energy Recuperation
Introduction







- Application complexity rises (examples of Continental)
  - 27 different vehicle classes
  - 47 customer groups only for brake systems (32 with ESC)

- System complexity rises
  - From 2011 on all new vehicle models have to have ESC and from Nov. 2014 on all new vehicles
  - Equipment rate of advanced driver assistence function is growing very fast
  - EV from mild hybrid up to full electric propulsion

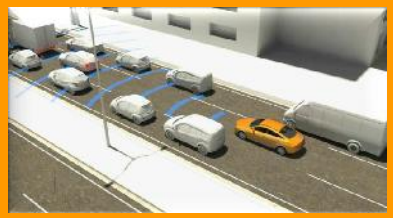
Source of the pictures: Internet

Position Sensor for Brake System Designed for Energy Recuperation

Motivation for a Compact Brake

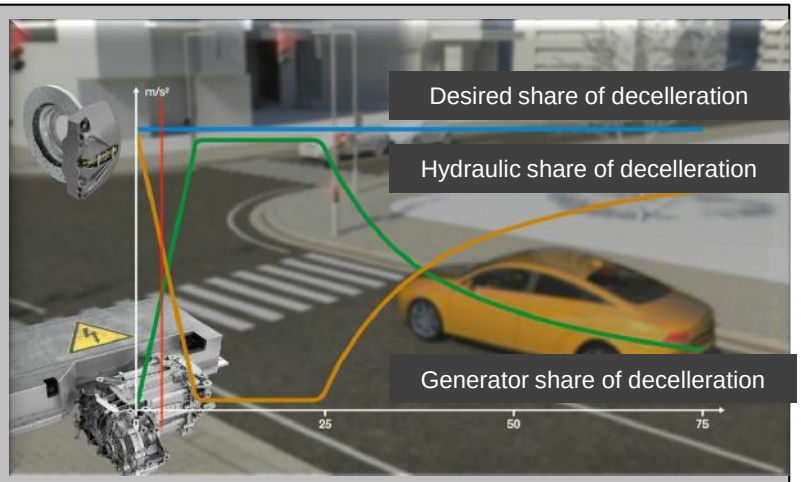
- System demands
  - Compact
  - Scalable
  - Cost optimized

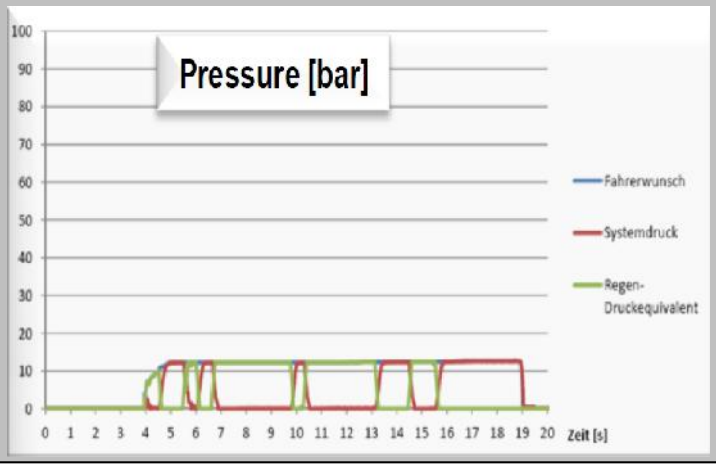
- Optimizing vehicle integration
  - Vacuumless brake system
  - Weight reduction
  - Crash optimization
- Optimizing recuperation
  - Unlimited recuperation
  - Gear shift compensation
  - Support zero drag caliper
- User friendliness
  - Optimized and adaptive pedal feel
  - Overlay of comfort functions
  - Comfortable 4 wheel pressure control
- Optimizing driver assistance functions
  - Maximum collision mitigation
  - Pedestrian protection
  - Fastest stop in autonom. parking
  - Very comfortable ACC
  - Important for E-driving-mode

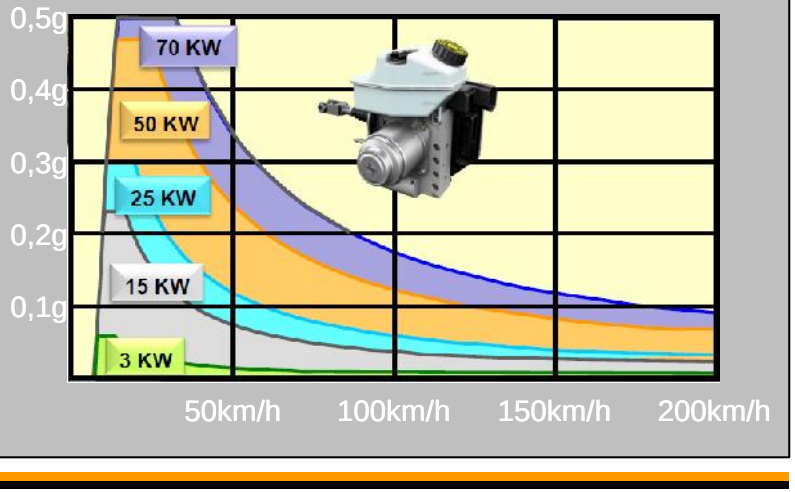


Position Sensor for Brake System Designed for Energy Recuperation
Regenerative Braking

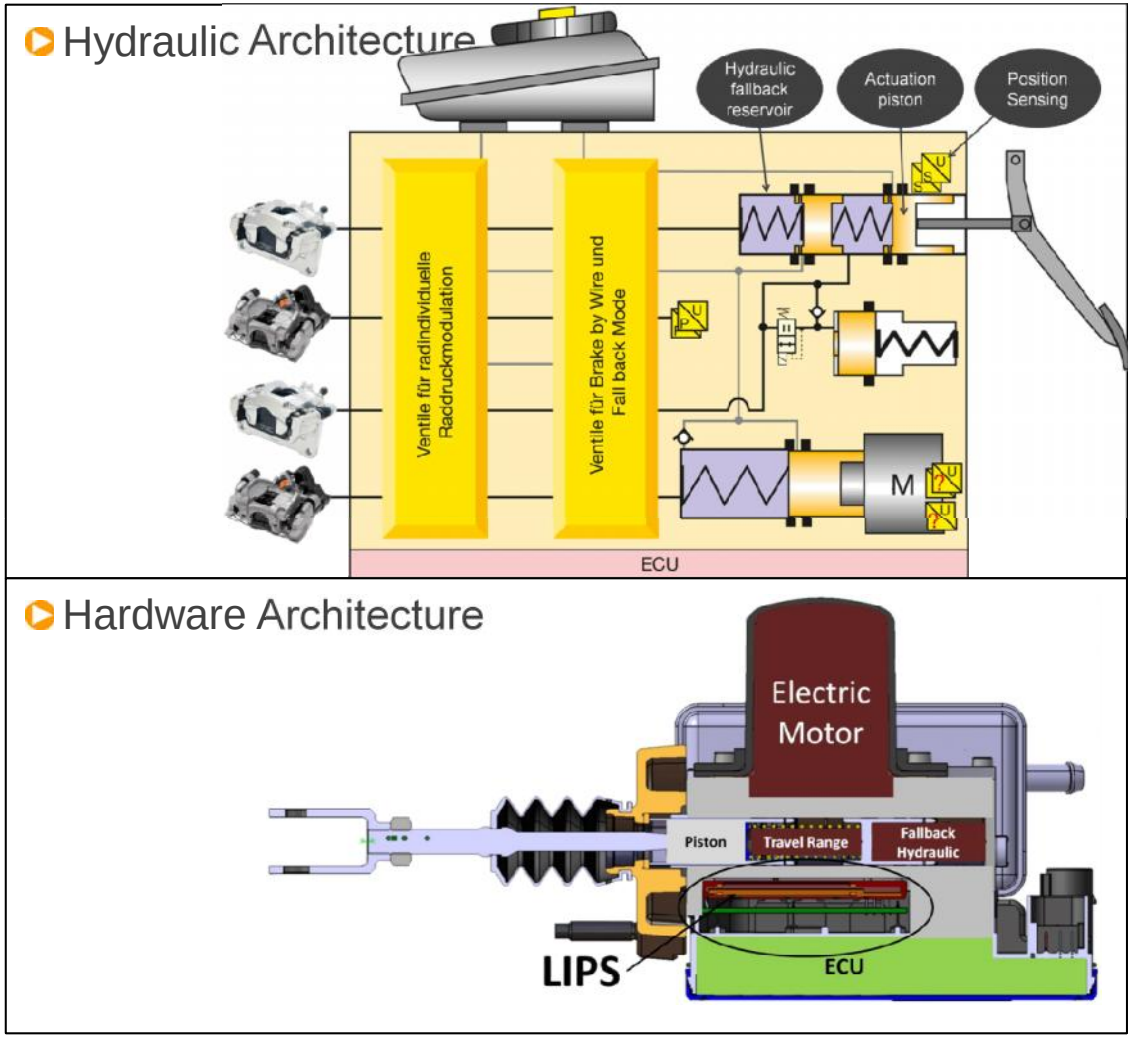
1. Safe and reliable braking at any time
   - Highest safety level (ASIL D) with hydraulic fall back system
2. Maximum recuperation
   - Max. exploitation of generator brake moment
3. Convenient driving comfort
   - Maximum gear shift compensation guarantees constant brake moment when the driver shift gears in the generator mode
   - The brake moment must follow the driver's request free of drag moment
   - Inducing haptic feedback to the pedal in generator mode





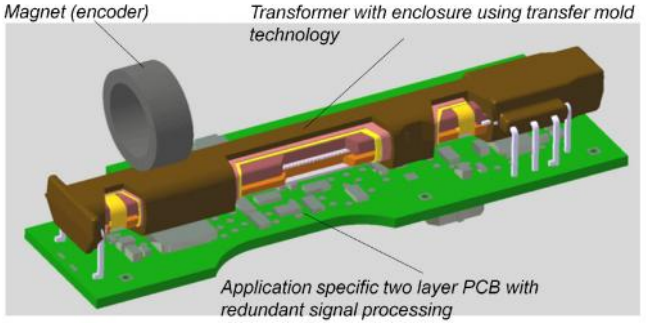


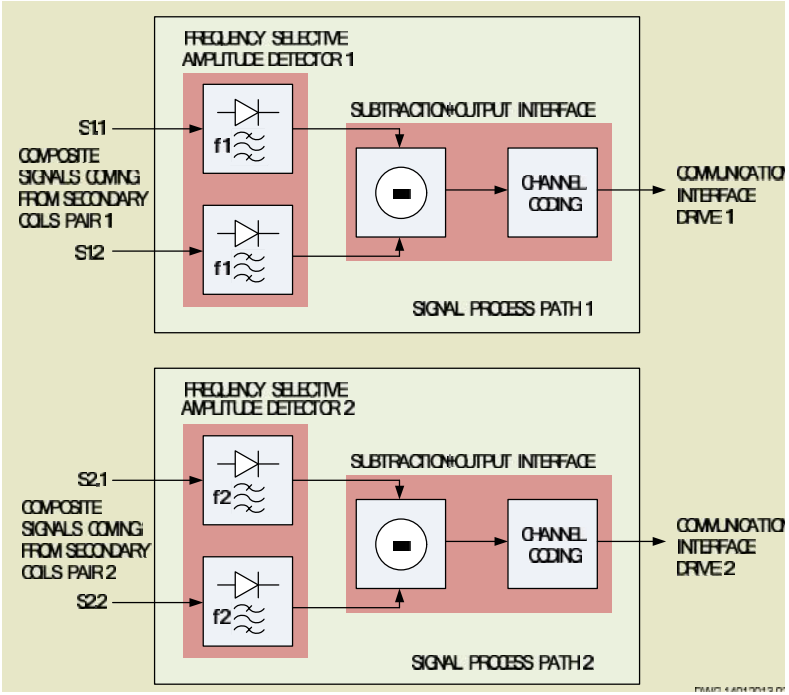
Position Sensor for Brake System Designed for Energy Recuperation
Integrated Brake Request Sensor



Position Sensor for Brake System Designed for Energy Recuperation
Linear Position Sensor Principle

- Transformer measurement principle
- Performance:
  - Measurement range: 20mm (safe operation up to 40mm)
  - Accuracy: ± 0.4 mm
- Safety concept (2 x ASIL B_D)
  - Two redundant secondary coils and signal conditioning paths
  - Driven at two excitation frequencies @ 10 & 13kHz
- Proven and well known manufacturing technologies
- Robust measurement concept

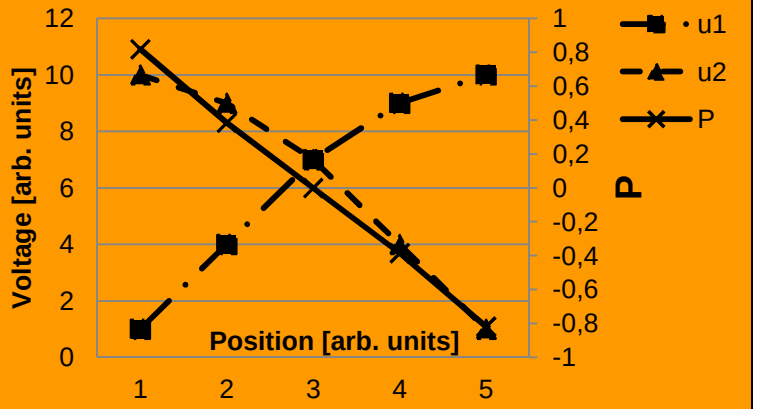


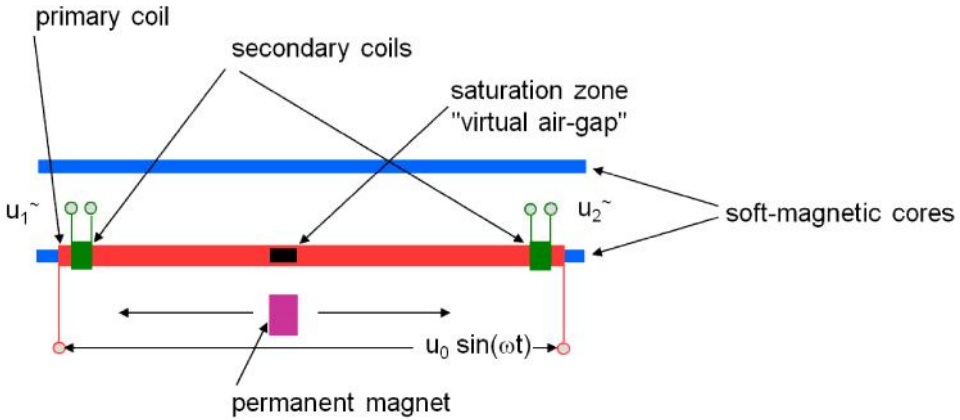


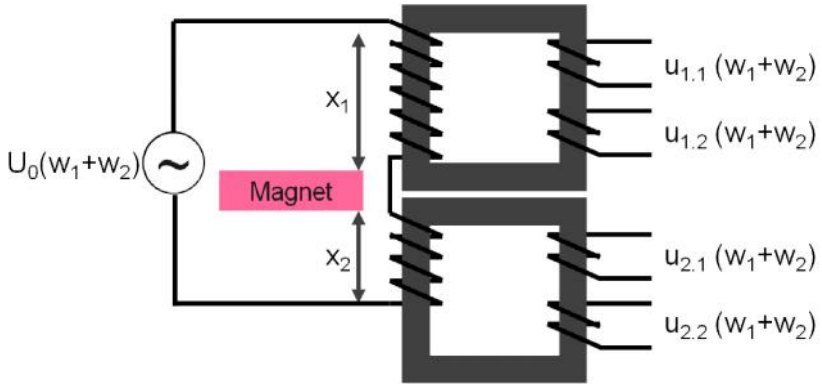
Position Sensor for Brake System Designed for Energy Recuperation
Linear Position Sensor Principle

- Voltage operation mode
  - Alternating current with constant voltage amplitude
- Common mode disturbances are canceled out by the ratiometric calculation and in addition the transducer function becomes linearized

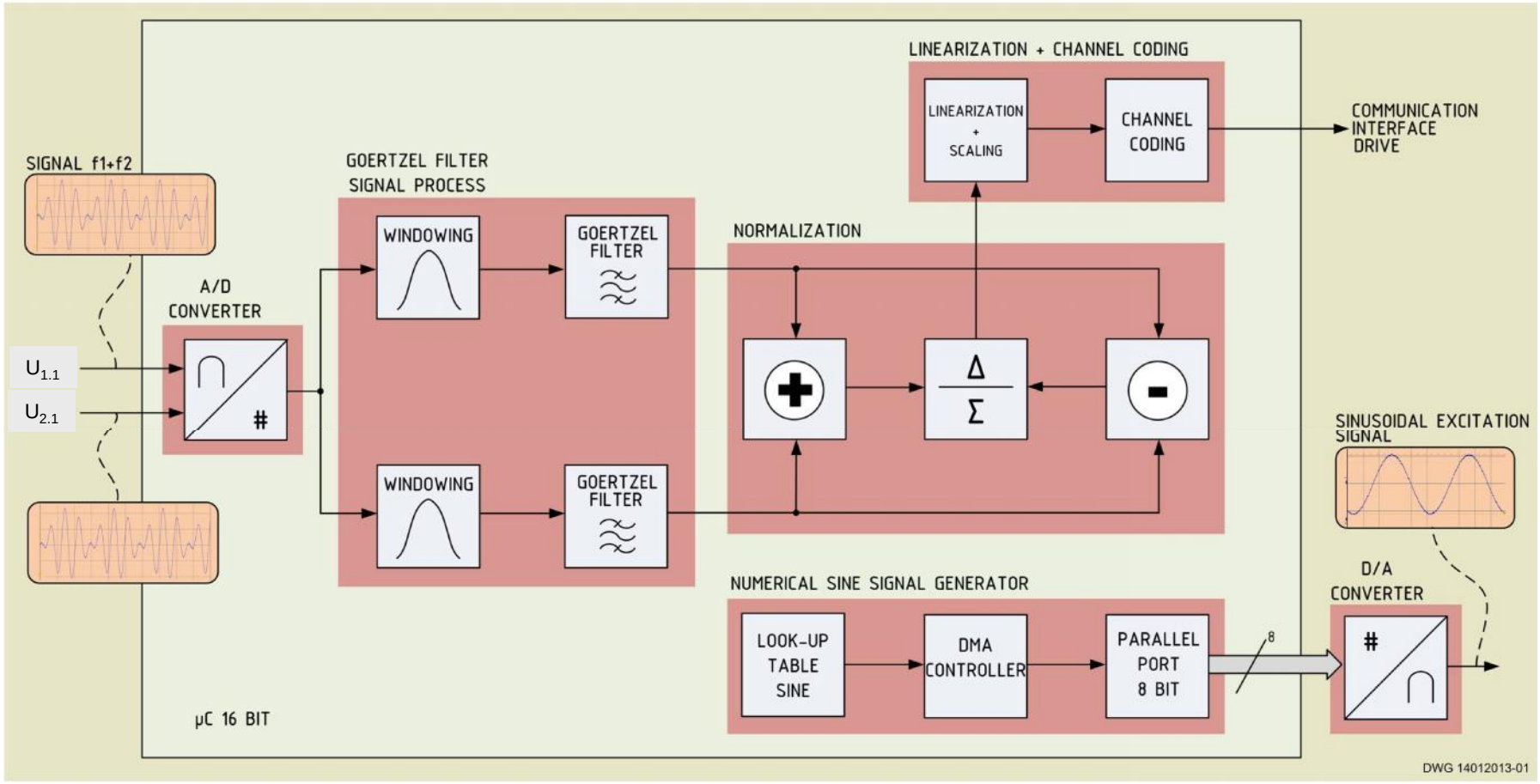
$$P = \frac{u_2^{sec} - u_1^{sec}}{u_2^{sec} + u_1^{sec}}$$





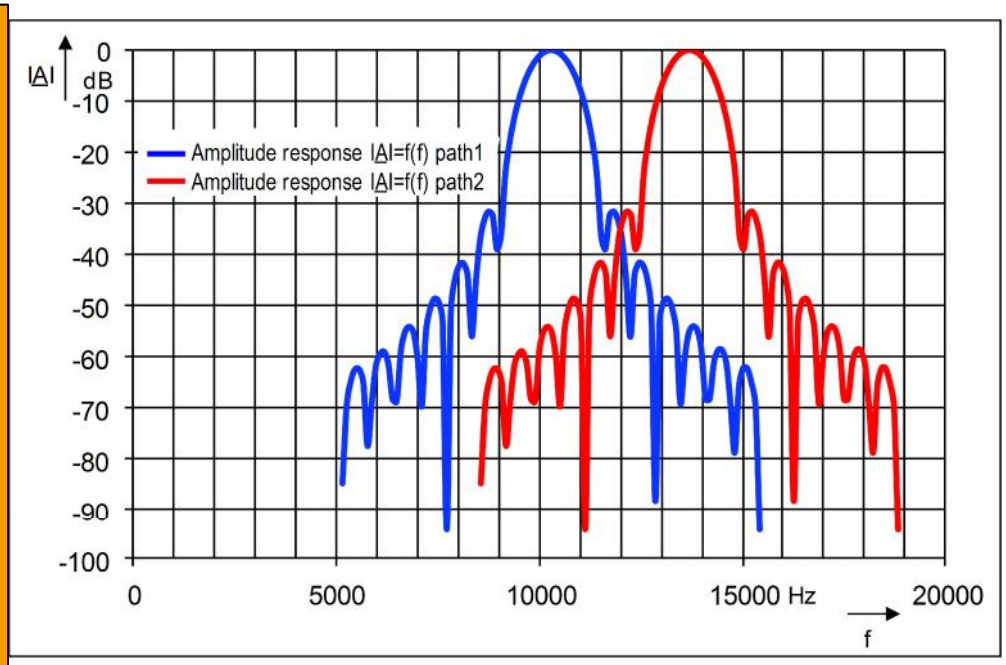


Position Sensor for Brake System Designed for Energy Recuperation
Linear Position Sensor Circuit



Position Sensor for Brake System Designed for Energy Recuperation
Linear Position Sensor Filter Characteristics

- Frequency selective signal processing with Goertzel filters
  - Advantages as discrete Fast Fourier Transformation (DFT) at 1 frequency
  - Decimation (N:1 oversampling) increases the S/N ratio significantly
  - Suits well due to only one carrier frequency selection.



fs= 164.38 kHz
fk= 10.273 kHz (blue)
N= 240

fs= 164.38 kHz
fk= 13.698 kHz (red)
N= 240

fs= sampling frequency
fk= predefined center frequency
N= number of samples within a block length

Position Sensor for Brake System Designed for Energy Recuperation
Linear Position Sensor Optimization by Simulation

Reduction of sensor development costs and optimized loop time of

- …inductive transformer geometry regarding the application environment
- …signal conditioning

…by SPICE simulation

Approach I: FEM

- Pro:
  - Continued transient results
  - Delivers accurate results of the physical reality
- Drawback:
  - very complex model
  - Enormous computing power
  - very long simulation time (~1h for one position)

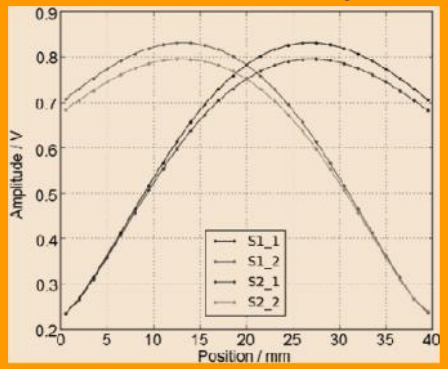
Approach II: SPICE Model

- Pro:
  - Very fast simulation loops
  - Sufficient precision to design optimized test samples
- Drawback:
  - Magnetic world is emulated by discrete coupling elements
  - Very high understanding of the coupling mechanisms for correct simulation setup and results needed

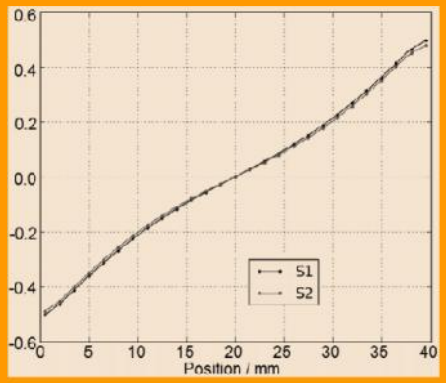
Position Sensor for Brake System Designed for Energy Recuperation
Linear Position Sensor Results

Simulation results

Goertzel filter output



Ratiometric results



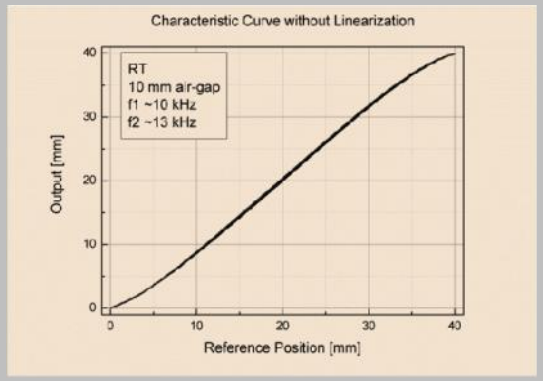
Optimization results

- Higher sensitivity in the measurement range
- Reduction of sensor length without performance reduction

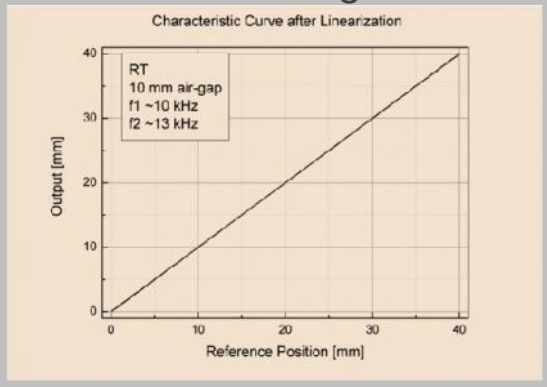
Measurement results

- Ratiometric output already sufficient for MK C1 application
- Nearly temperature insensitive in the range of -40 °C to 120 °C
- High precision with calibration

Ratiometric results



Calibrated signals



Position Sensor for Brake System Designed for Energy Recuperation
Summary

- Electrified vehicles demand for new functionalities like energy recuperation and convenient pedal feeling.
- The highly integrated brake system approach MK C1 cope with this market trends.
- One key for the performance and safety of the brake system is the integrated linear position sensor LIPS.
- Redundant signal paths with the dual frequency approach paired with the performance of the circuit concept cope with ASIL D of the brake system.
- With the SPICE based simulation concept fast and efficient optimization loops led to an optimal transformer design.
- The uncalibrated sensor fulfils the performance requirement, with calibration even high performance can be achieved over the extended measurement range.