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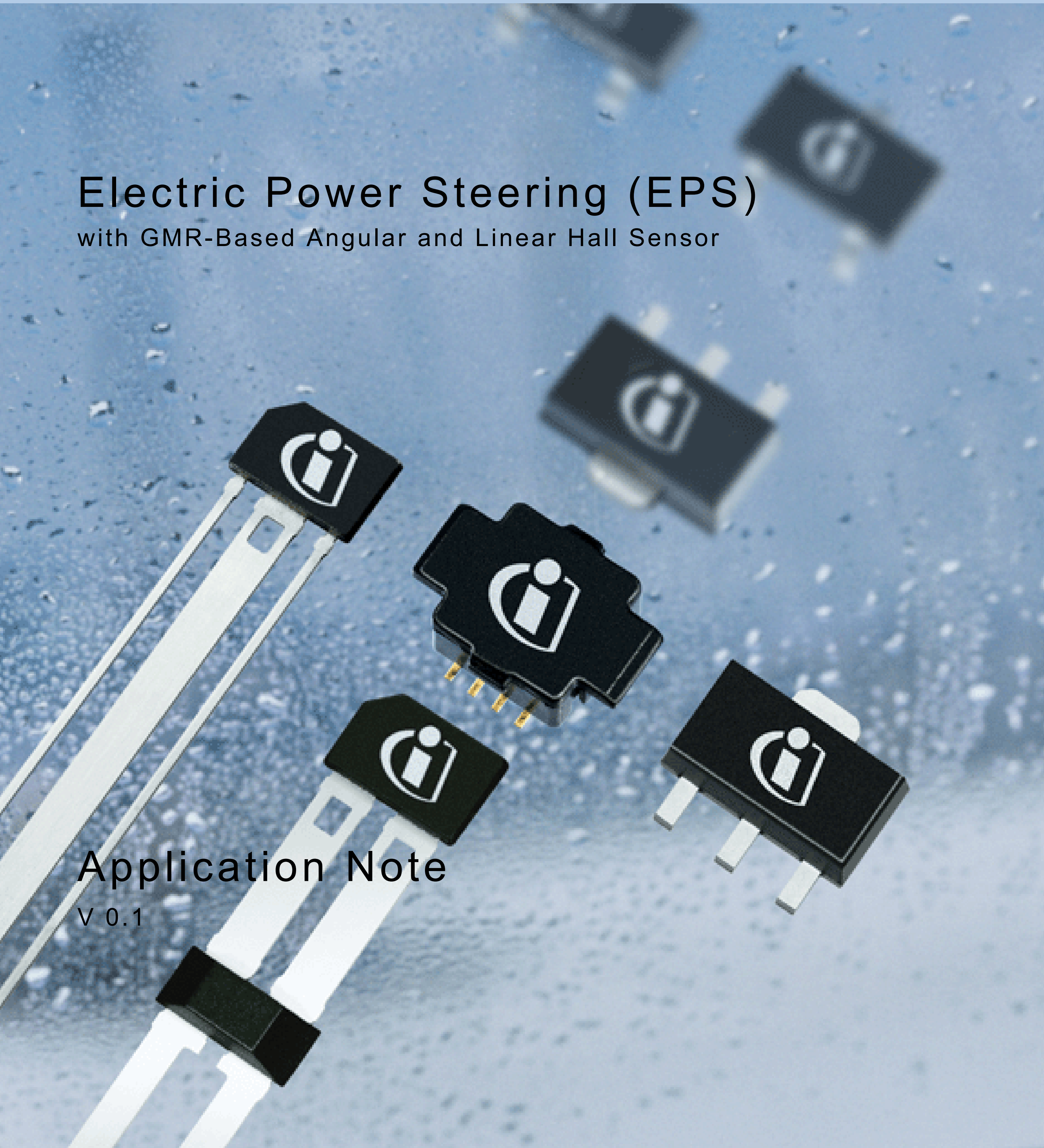
Electric Power Steering (EPS)

with GMR-Based Angular and Linear Hall Sensor



Application Note

V 0.1

Sensors

Never stop thinking

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Electric Power Steering (EPS) with GMR-Based Angular and Linear Hall Sensor

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1 Electric Power Steering with GMR-based Angular Sensors

1.1 Introduction

Power steering is a system for reducing the steering effort on cars by using an external power source to assist in turning the wheels.

Electro **H**ydraulic **P**ower **S**teering **(EHPS)** is an advanced system that uses conventional hydraulic power steering with an electric motor-driven hydraulic pump.

Electric **P**ower **S**teering **(EPS)** is the latest system in which the electric motor ("E-motor") is attached directly to the steering gearbox without a hydraulic system. Sensors detect the motion of the steering column and a processor module applies assistive power via an electric motor. This allows varying amounts of assistance depending on driving conditions.

With electronic systems becoming more and more common in cars, EPS is the future power steering system that they will use. Unlike its conventional counterpart, EPS is active only during the actual steering process. It also eliminates maintenance on steering hydraulics and cuts fuel consumption by as much as 0.4 l/100 km.

2 EPS Systems

Different EPS systems are in use (see **Figure 1**).

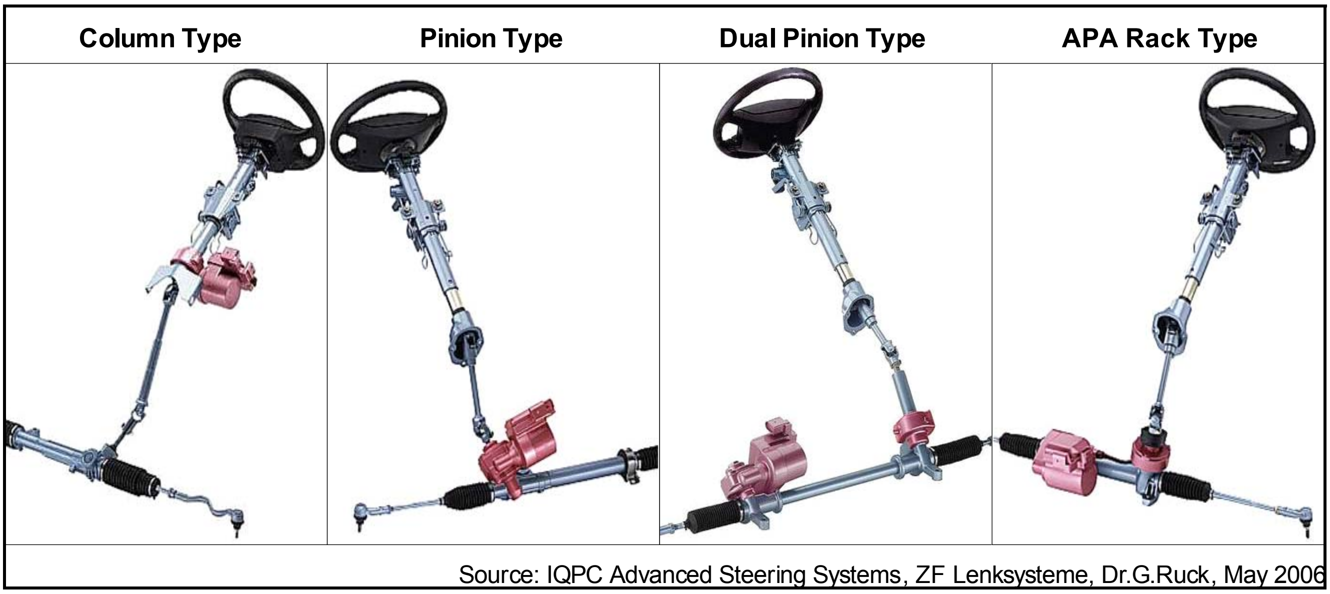

Figure 1 EPS Systems

Which EPS type will be used depends on the steering rack force (see **Figure 2**).

The column drive is used for small and lower mid-sized cars. The motor is located in the passenger compartment. Its advantage is its better performance at reduced temperatures, and sealing.

The pinion drive is used for mid-sized cars, and the dual pinion drive is used for upper mid-sized cars. Both of these drives are located in the engine compartment.

Another possibility is the rack drive. This type is appropriate for large vehicles such as Sports Utility Vehicles (SUVs) and trucks.

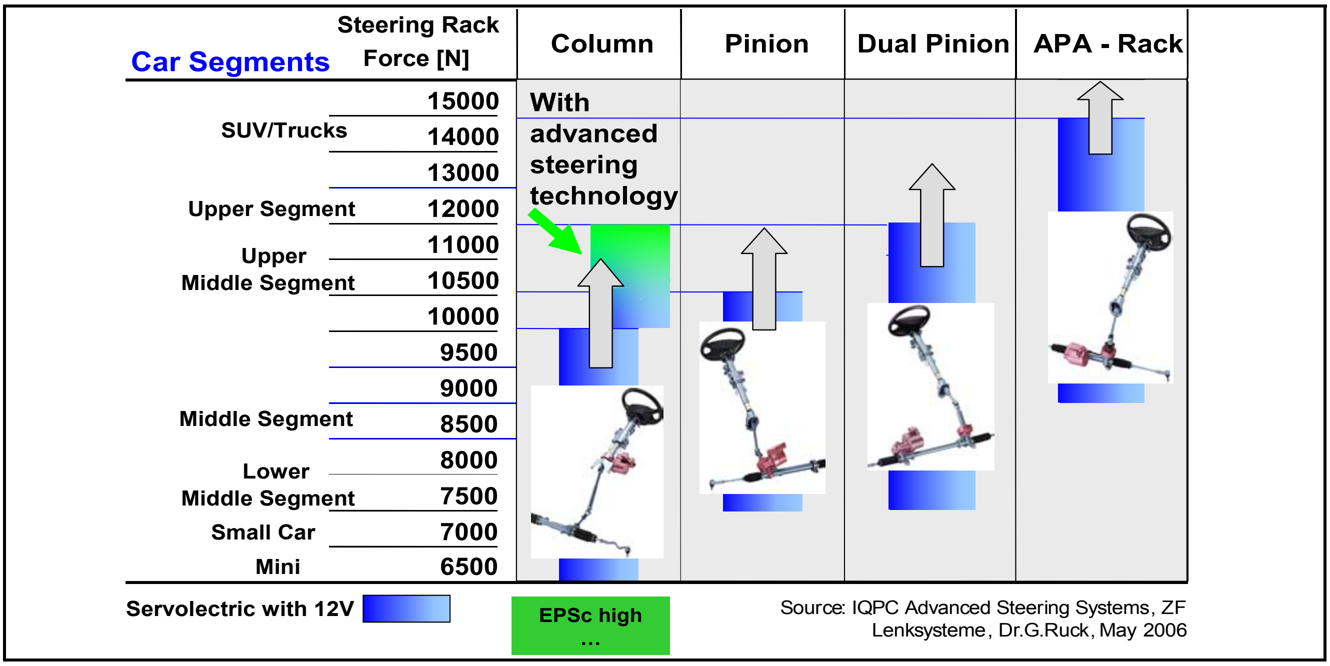

Figure 2 EPS Application

2.1 EPS Electric Control Unit

Each EPS **E**lectric **C**ontrol **U**nit **(ECU)** handles the data from different sensors. The sensors send information about the steering torque, driving speed, and the steering angle. Figure 3 is an example of a block diagram of an EPS ECU. Using this information from the sensors, the ECU calculates the necessary steering assist and controls the 3-Phase Driver.

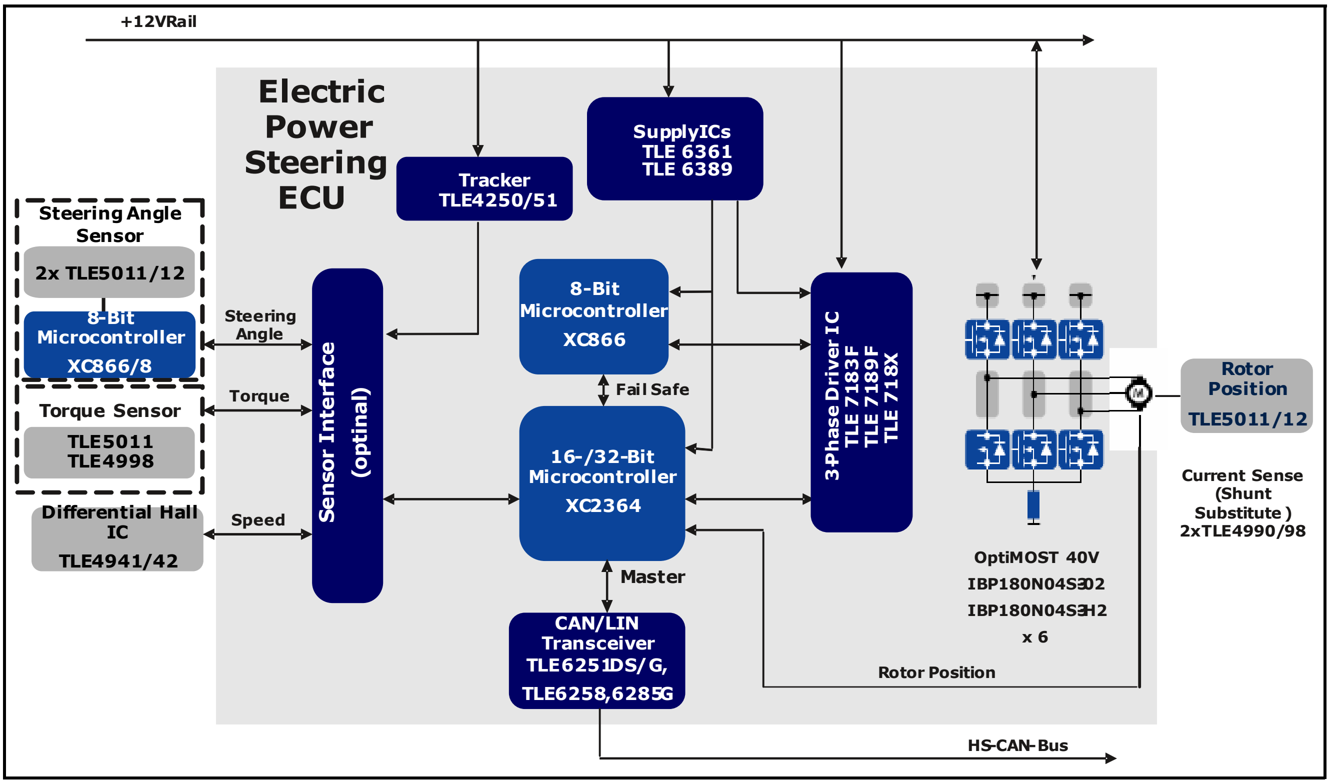

Figure 3 EPS Block Diagram

3 Infineon Sensors

3.1 Infineon Angle Sensors

Infineon offers some angle sensors based on GMR technology. This section gives a short overview of Infineon's angle-sensor portfolio. For more detailed information, please refer to the products' individual datasheets.

3.1.1 TLE5011

The TLE5011 is a 360° angle sensor that detects the orientation of a magnetic field. This is achieved by measuring sine and cosine angle components with monolithic integrated GMR elements. The data communications are accomplished with a bi-directional SSC Interface that is SPI compatible.

The sine and cosine values can be read out. These signals can be processed digitally to calculate the angle orientation of the external applied magnetic field. This calculation can be easily done by using a **CO**ordinate **R**otation **DI**gital **C**omputer (CORDIC) algorithm.

It is also possible to connect more than one TLE5011 to one SSC Interface of a microcontroller for redundancy or any other reason. In this case the synchronization of the connected TLE5011 is done by a broadcast command.

Each connected TLE5011 can be addressed by a dedicated chip-select pin.

3.1.2 TLE5012

The TLE5012 is also a 360° angle sensor. Compared to the TLE5011, this sensor calculates the absolute angle on chip with an implemented CORDIC. This angle value and additional register values can be read out with a bi-directional SSC Interface that is SPI-compatible. A **P**ulse-**W**idth-**M**odulation (**PWM**) protocol and an Incremental Interface are also implemented.

An angle error smaller than 1.0° will be achieved over temperature and lifetime using an internal autocalibration algorithm. This autocalibration is only helpful in applications with an angle range more than 360°. The sensor calculates the calibration parameters and updates the new parameters within a timeslot or within the following angle range.

A revolution counter is also implemented within the TLE5012. This counter counts every full rotation. It is a 9-bit signed value, so ±256 revolutions could be measured.

3.2 Infineon's Linear Hall Sensors

Infineon offers a variety of linear Hall sensors with different programming, package and interface options. This section is a general overview of our sensor portfolio. For more detailed information, please refer to the datasheets for each product.

Table 1 Overview of Infineon's linear Hall sensors

Product	Programming	Package	Interface
TLE4990	Fuses	PG-SSO-4-1	Analog
TLE4997	EEPROM	PG-SSO-3-10	Analog
TLE4998P	EEPROM	PG-SSO-3-10 PG-SSO-4-1	PWM
TLE4998S	EEPROM	PG-SSO-3-10 PG-SSO-4-1	Digital, SENT
TLE4998C	EEPROM	PG-SSO-3-10 PG-SSO-4-1	Digital SPC

3.2.1 TLE4990

The TLE4990 is Infineon's basic linear Hall sensor with analog signal processing and fuse programmability. The sensor is end-of-line programmable, meaning that its gain and sensitivity can be set in a two-point calibration in the module. Due to its thin PG-SSO-4-1 package, it fits in small air gaps. The TLE4990 has been field-proven over the last few years and is well established for automotive applications such as gas-pedal position sensing.

3.2.2 TLE4997

The TLE4997 has been designed to improve on some of the shortcomings of an analog compensation scheme as the one used in the TLE4990 and most competing products, including offset and sensitivity drifts over temperature, range of the programmable parameters, and accuracy. The signal processing in the TLE4997 is entirely shifted to the digital domain, making the influence of the programmed parameters completely deterministic. Temperature effects of the Hall probe can readily be compensated for by pre-calibration in Infineon's fabrication. The TLE4997 is also the first sensor on the market that offers independent, programmable parameters for both first- and second-order temperature coefficients of the application sensitivity. The TLE4997 has an analog, ratiometric output and can be used as a robust replacement for potentiometers. It comes in a small 3-pin PG-SSO-3-10 package and is therefore suited for use in the limited space inside magnetic circuits.

3.2.3 TLE4998P

The TLE4998 family is the successor of the TLE4997, providing innovations on the interface side. The signal processing concept is based on the TLE4997 design, offering high-precision analog-to-digital signal conversion and a deterministic digital signal processing. The TLE4998P features a PWM interface in which the duty cycle carries the Hall signal information. It offers 12-bit resolution on the output, and combined with accurate detection on the microcontroller side, is more accurate than an analog interface.

3.2.4 TLE4998S

The TLE4998S is equivalent to the TLE4998P except for the interface, which is implemented as SAE's[1)] **S**ingle **E**dge **N**ibble **T**ransmission (**SENT**) standard. SENT offers a low-cost alternative to CAN and LIN, but still incorporates a coded digital signal transmission with a **C**yclic **R**edundancy **C**heck (**CRC**) to check the validity of a transmission. Apart from an industry-leading 16-bit Hall value, the transmitted SENT frame includes 8-bit temperature information and 4-bit sensor status information. The status information finally allows for a massive improvement of overall system safety.

3.2.5 TLE4998C

The TLE4998C features a **S**hort **P**WM **C**ode (**SPC**) protocol, which is an extension to the standard SENT protocol and therefore has all the advantages already present in the TLE4998S such as high resolution, status, temperature, and CRC information. The sensor does not, however, send out the measured values indefinitely, but only after being triggered by the ECU. This functionality permits synchronized transmission of data. The protocol makes it possible to select one of four sensors, which are connected to a single bus line.

1) SAE: Society of Automotive Engineers

4 Rotor Position Sensor

The rotor position is very important for correct commutation of the motor, independent of the motor type (**P**ermanent **M**agnet **S**ynchronous **M**otor (**PMSM**); **B**rush **L**ess **D**irect **C**urrent (**BLDC**); **As**ynchronous **M**otor (**ASM**)). For detection of rotor position, a TLE5011 or TLE5012 could be used as depicted in **Figure 4** a.**Figure 5**.

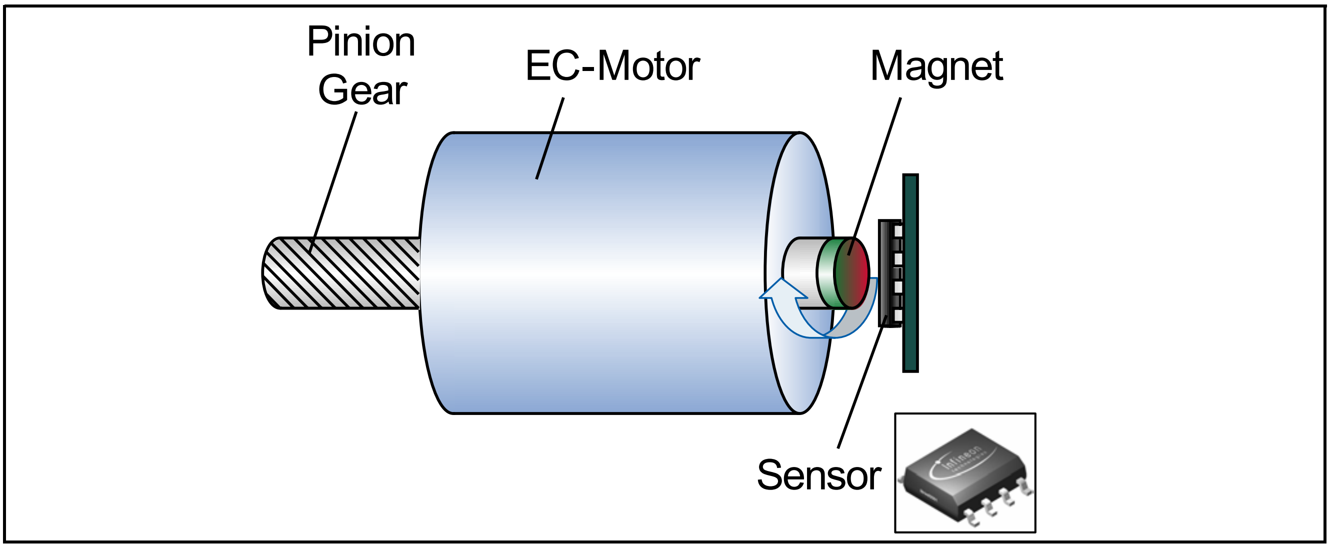

Figure 4 Possible setup for rotor position detection (1)

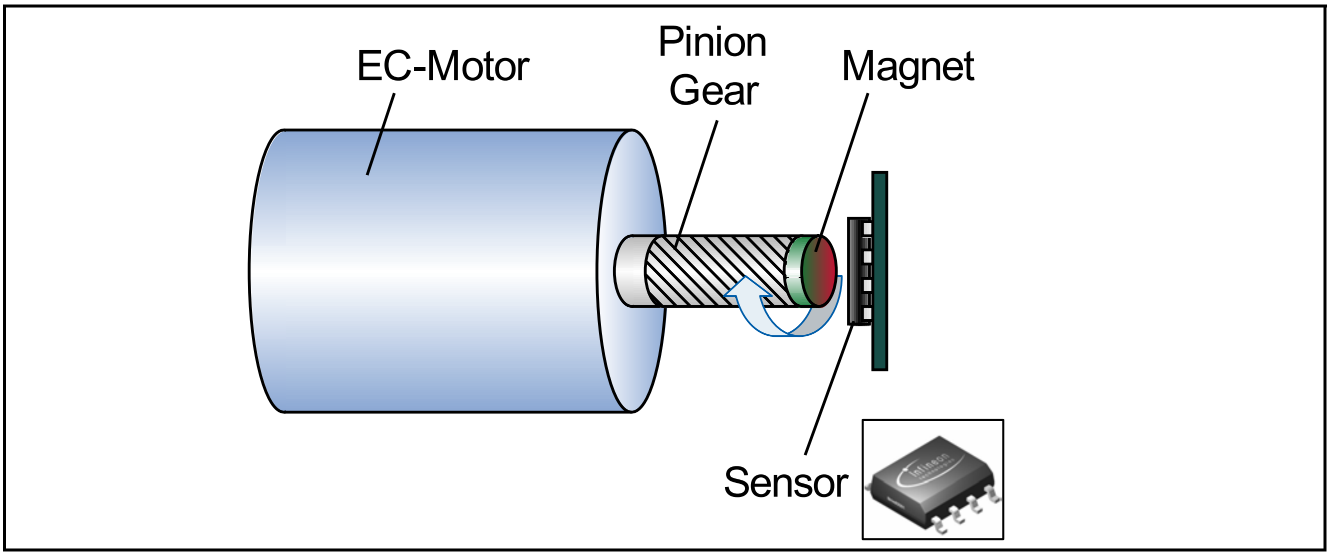

Figure 5 Possible setup for rotor position detection (2)

The angle information tells the system which coil has to be excited next. The angle detection has to be done very fast. Depending on the number of poles used and the rotation speed, an additional error has to be considered for the electrical commutation, which is depicted in **Figure 6**. With one pole pair, the electrical 360° (one period) matches the mechanical 360° (one rotation). With a rotor with two pole pairs, the switching in the coils has to be done two times faster. This means the electrical period must be completed within a half rotation (**Figure 7**).

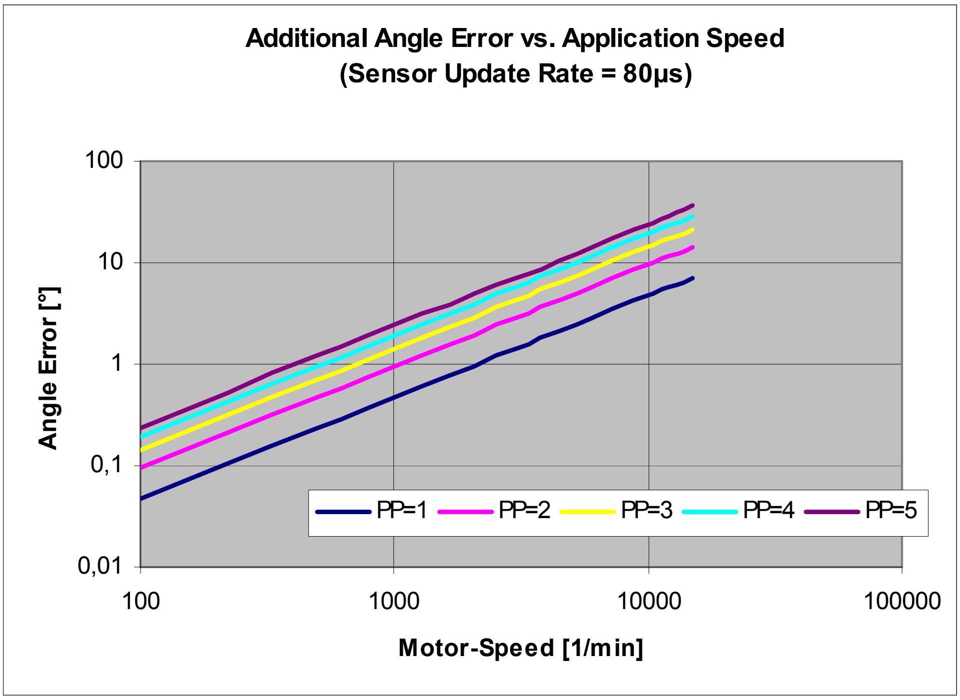

Figure 6 **Additional angle error vs. motor-speed**

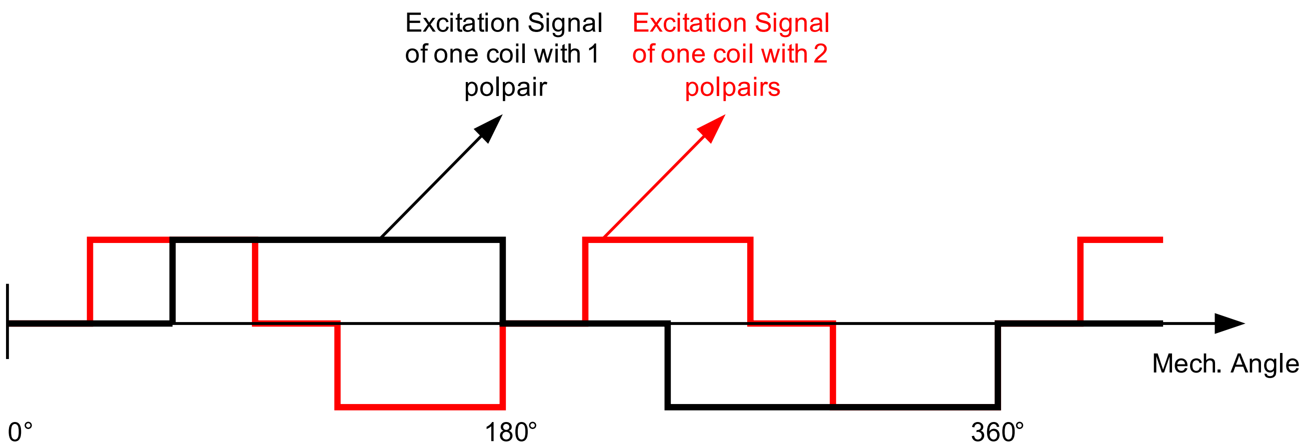

Figure 7 **Excitation signal of one coil vs. rotor position**

5 Steering-Angle Sensor

The steering angle indicates where the driver wants to go. This information is also used by other systems such as the **E**lectronic **S**tability **P**rogram (**ESP**), **A**ctive **F**ront **S**teering (**AFS**), **A**daptive **F**ront **L**ighting (**AFL**), and so forth.

The steering-angle sensor unit is mounted on the steering column, mostly within the passenger compartment.

It is important to determine an angle value at power-on. This true power-on functionality is achievable by the nonius principle. This is patented by Robert Bosch GmbH; **Figure 8** shows an example of how one might build such a steering-angle sensor.

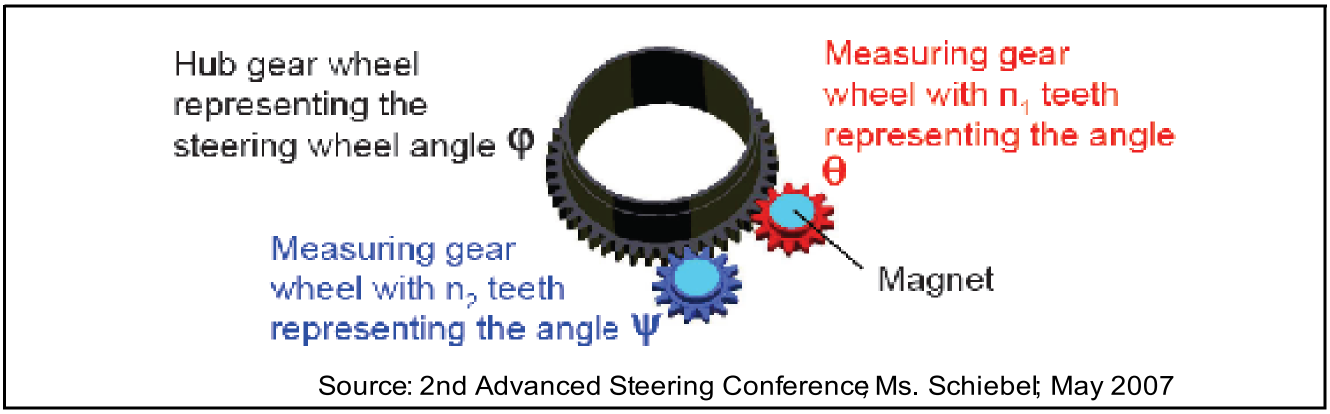

Figure 8 Possible Setup for Steering-Angle Sensor

This module consists of three gear wheels. One hub gear wheel is mounted on the steering column and represents the steering angle φ. The two smaller gear wheels differ by one or more teeth, and there is a magnet in both of them. These magnets, with diametrical magnetization, each rotate above an angle sensor. Due to the different number of teeth, one gear wheel turns faster than the other one. The two measured angle values have the following output characteristics **Figure 9**:

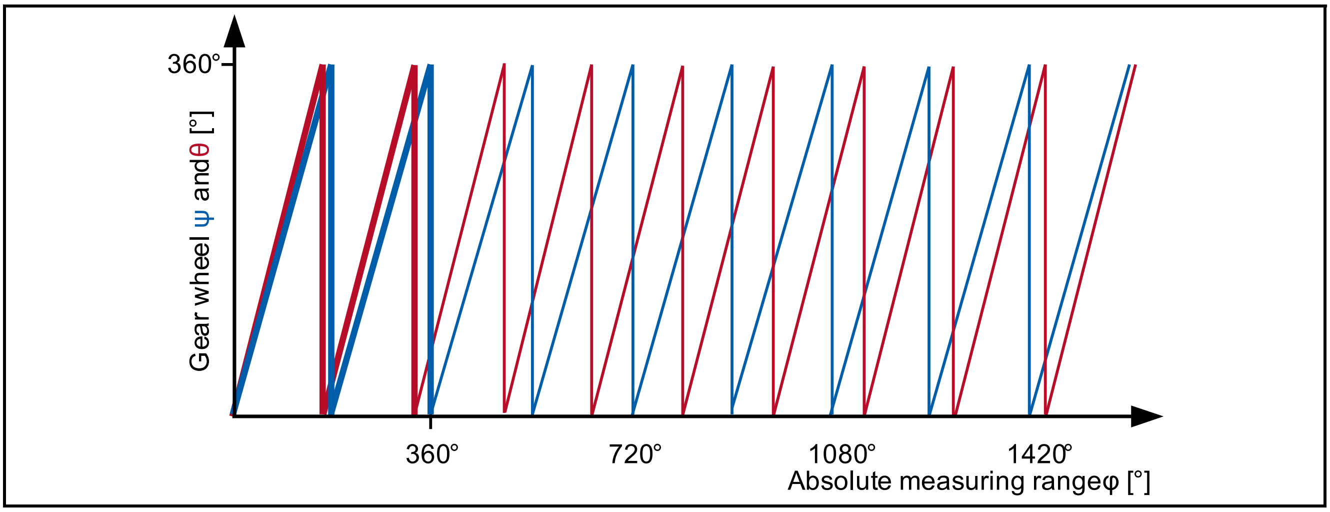

Figure 9 Output

With this principle it is possible to determine an unambiguous steering angle over more than four full turns of the steering wheel. In addition, no standby current is needed. At every startup the sensor knows its position as a result of having both angle values.

6 Torque Sensor

The power-steering control unit uses a torque sensor as the main input for determining the amount of steering assistance needed. The steering column is split into two parts: The input shaft, from the steering wheel to the torque sensor; and the output shaft, from the torque sensor to the steering shaft coupler. The input and output shafts are separated by a torsion bar (**Figure 10**), where the torque sensor is located. The torque sensor measures the shift angle between input and output shaft. One possible torque sensor from **M**oving **M**agnet **T**echologies (**MMT**) is described below. Please note that this design is covered by a patent[1] and should give only an idea how to implement torque sensing with linear Hall sensors.

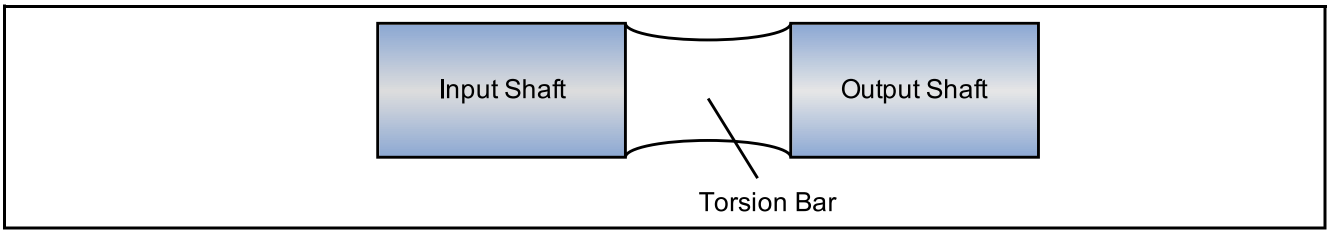

Figure 10 Torsion Bar

The sensor by itself is split into two parts, the rotor and the stator. The rotor, a multipole magnet ring, is mounted on one side of the shaft (**Figure 11**).

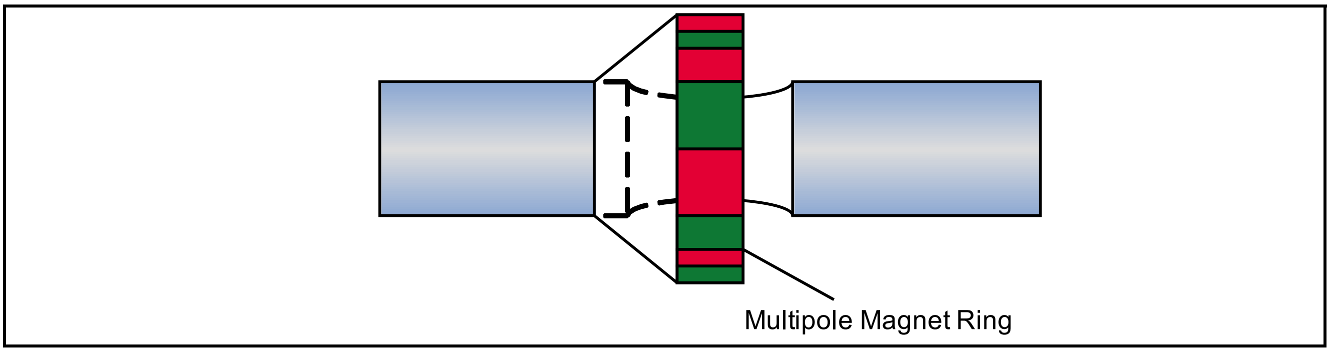

Figure 11 Torque Sensor - Rotor

The stator consists of two parts. They are made of soft ferromagnetic material, and are mounted on the opposite side of the torsion bar (**Figure 12**).

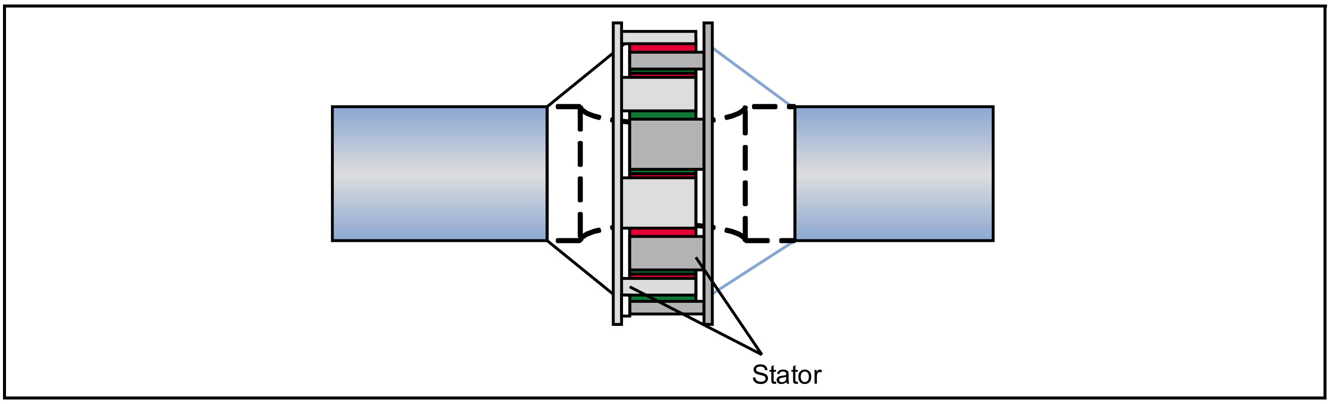

Figure 12 Torque Sensor - Stator

1) US patent 2004-0011138

To detect the shift angle, a stationary fixed concentrator is necessary. This concentrator also contains the linear Hall sensor and is put over the stator (**Figure 13**). When torsion occurs between input and output shaft, a flux variation is detected by the sensor, which is proportional to the shift angle.

This information is processed by the EPS ECU, which controls the EC motor via the 3-Phase Driver IC

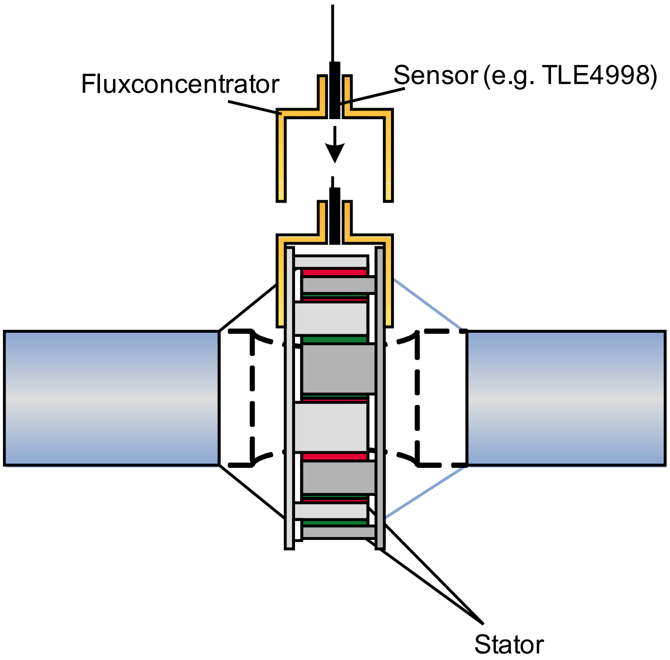

Figure 13 Torque sensor - Concentrator with Sensor

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