Magnetic Sensors for Autonomous Cars
Outstanding Performance & Safety for Autonomous Driving

Jörg Kock
Senior Director Product Architecture & Innovation magnetic Sensors

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Secure Connections for A Smarter World

NXP Semiconductors N.V. (NASDAQ: NXPI) enables secure connections and infrastructure for a smarter world, advancing solutions that make lives easier, better, and safer.

As the world leader in secure connectivity solutions for embedded applications, NXP is driving innovation in the secure connected vehicle, end-to-end security & privacy, and smart connected solutions markets. Built on more than 60 years of combined experience and expertise, the company has approximately 30,000 employees in more than 30 countries and posted revenue of $9.41 billion in 2018.
A Position of Strength to Better Serve Our 26,000+ Customers

Employees in
30+ Countries
Headquartered in Eindhoven, Netherlands

9,000
Patent Families

60+
Year History

~30,000
Employees

~9,000
R&D Engineers

$9.41B
Annual Revenue¹

¹ Posted revenue for 2018 – Please refer to the Financial Information page of the Investor Relations section of our website at www.nxp.com/investor for additional information
Our Target Markets

- Automotive
- Industrial & IoT
- Mobile
- Communication Infrastructure
Focused Leadership – End Markets

- Broad end market exposure
  - Long product life cycles
  - High barriers to entry
  - Application expertise

- Recognized leadership in
  - Automotive
  - MCU and application processors
  - Mobile transactions
  - RF power solutions
  - Secure identification, mobility, RFID
Automotive
Solutions for Safe and Secure Mobility

Value Proposition

Solution portfolio
Comprehensive System Solutions for fast time to market and scalability

Innovation power
In-house high-performance processing, security and mobile eco-system capabilities

Automotive safety and reliability
Zero defects methodology
Leading with functional security and safety
NXP Makes Safe and Secure Mobility Happen

Technology Leadership

#1 Auto Analog / RF / DSP
#2 Auto Microcontrollers
#1 Auto Application Processors

Applications Leadership

#1 Car Infotainment
#1 Secure Car Access
#1 In-Vehicle Networking
#1 Safety
#2 Powertrain
#1 ABS Sensors

Innovation Leader ADAS
Innovation Leader Security

#1 in Auto Semiconductors

2017 Global Auto Semi Market: $34.5B

1. Based on 2017 Auto TAM
2. Auto RF/DSP includes Secure Car Access, Radio/Audio, V2X and Radar Transceivers
3. Source: Strategy Analytics, IHS Markit, NXP
TODAY: 90% of Auto innovation from Electronics

NXP MAGNETIC SENSORS ARE ESTABLISHED IN DEDICATED APPLICATION SEGMENTS.
Megatrends Transform Automotive Industry

Connectivity

ADAS → Autonomy

Electrification

ZERO
Time Wasted

ZERO
Accidents

ZERO
Emissions

Safe and Secure Mobility
ROAD TRAFFIC ACCIDENTS - the causes

Every year!
- ~1.3 m fatalities
- >50 m people seriously injured
- >$3 trillion cost of road accidents
- >90% caused by human mistakes

We need to get the Human Error out of the equation!

<table>
<thead>
<tr>
<th>Critical Reasons</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver</td>
<td>2,046,000</td>
<td>94%</td>
</tr>
<tr>
<td>Vehicles</td>
<td>44,000</td>
<td>2%</td>
</tr>
<tr>
<td>Environment</td>
<td>52,000</td>
<td>2%</td>
</tr>
<tr>
<td>Unknown</td>
<td>47,000</td>
<td>2%</td>
</tr>
<tr>
<td>Total</td>
<td>2,189,000</td>
<td>100%</td>
</tr>
</tbody>
</table>

Data source: NMVCCS

<table>
<thead>
<tr>
<th>Driver-Related Critical Reasons</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognition Error</td>
<td>845,000</td>
<td>41%</td>
</tr>
<tr>
<td>Decision Error</td>
<td>684,000</td>
<td>33%</td>
</tr>
<tr>
<td>Performance Error</td>
<td>210,000</td>
<td>11%</td>
</tr>
<tr>
<td>Non-performance Error (e.g. Sleep)</td>
<td>145,000</td>
<td>7%</td>
</tr>
<tr>
<td>Other</td>
<td>162,000</td>
<td>8%</td>
</tr>
<tr>
<td>Total</td>
<td>2,046,000</td>
<td>100%</td>
</tr>
</tbody>
</table>
FUNCTIONAL SAFETY: Zero accidents by system failures (ISO 26262)

FUNCTIONAL SECURITY: Zero accidents by system hacks

DEVICE RELIABILITY: Zero components failures (robust design)

ROAD SAFETY: Zero accidents by human error (ADAS)
# Recalls - An Indicator for Functional Safety

<table>
<thead>
<tr>
<th>Category</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airbags</td>
<td>20,807,538</td>
</tr>
<tr>
<td>Ignition keys/switches</td>
<td>16,299,079</td>
</tr>
<tr>
<td>Electrical/Electronics</td>
<td>4,964,662</td>
</tr>
<tr>
<td>Brakes</td>
<td>4,754,297</td>
</tr>
<tr>
<td>Powertrains</td>
<td>3,882,814</td>
</tr>
<tr>
<td>Steering</td>
<td>2,552,484</td>
</tr>
<tr>
<td>Fuel Systems, leaks</td>
<td>2,050,443</td>
</tr>
<tr>
<td>Suspension</td>
<td>1,697,464</td>
</tr>
<tr>
<td>Seatbelts</td>
<td>1,631,278</td>
</tr>
<tr>
<td>Seats (including child-seat latches)</td>
<td>1,253,729</td>
</tr>
<tr>
<td>Engine and Cooling</td>
<td>1,054,061</td>
</tr>
<tr>
<td>Tires, Tire-pressure-systems, Wheels</td>
<td>617,223</td>
</tr>
<tr>
<td>Accessoires and Labels</td>
<td>153,737</td>
</tr>
<tr>
<td>Throttle</td>
<td>19,202</td>
</tr>
</tbody>
</table>

Source: National Highway Traffic Safety Administration

People must be able to trust their cars.

RECALLS - AN INDICATOR FOR FUNCTIONAL SAFETY
RELIABILITY COMPARISON
AUTOMOTIVE VS CONSUMER PRODUCTS

- Failure Rate over Time
- Accumulated Failures over Time

- Burn-in @ $T_0$
- Early life
- Wear-out

- Target < 1 ppm @ 3 years

- Automotive
- Consumer
# Business Line Sensors

*Automotive Sensors: one Foundation to Safety & Highly Autonomous Driving*

<table>
<thead>
<tr>
<th>Motion Sensor</th>
<th>Pressure Sensors</th>
<th>Magnetic Sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airbag Accelerometers</td>
<td>TPMS, Engine Management &amp; Satellite Pressure for Airbags</td>
<td>Angular for Engine Control &amp; steering ABS Speed Sensors</td>
</tr>
</tbody>
</table>

#1 in Automotive Safety Sensors
MAGNETIC SENSORS
over 2B sensors sold to market

Headquarters in Hamburg, Germany
- Sensor (AMR) wafer fab and test
- Process and product development
- Product quality and engineering
- Application support and innovations
- Product and commercial marketing

Tier-1s, EMS & Distributors are our customers
Magnetoresistive Sensor applications and its location under the hood (some examples)

- ABS
- Steering angle
- E-Gas
- Steering torsion
- Window wipers
- Oil, water temperature
- Headlight adjustment
- Variable valve timing
- E-throttle
- EPAS motor positioning
- Active transmission
Benefits of Magnetoresitive Sensing

- Only 3 elements visible to magnetic fields: Fe, Co, Ni + some rare earth
- Wear free: MR elements and magnets are hardly degrading over lifetime
- Robust: no influence by humidity, or dirt within the magnetic field
- Standard Material Housings: standard mold compounds, etc.
- Efficient production: fully integrated onto ASIC technology
  integrated AMR in production moving to integrated TMR
Magnetic Sensing Technologies

NXPs production today

NXPs Next Gen Sensors
NXP Magnetic Sensors focus

Rotational speed movement
- Current pulse output, digital info signals
- Direction recognition
- Air gap information
- Vibration suppression
- Diagnostic functions
- Stray field robustness
- Extreme high repeatability / low jitter

Mechanical angular position
- Analog voltage, digital output signals
- Customer output adjustments
- Magnet loss detection
- Temperature information
- Diagnostic functions

Output voltage / [%VDD]

<table>
<thead>
<tr>
<th>Angle (degree)</th>
<th>0</th>
<th>90</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage</td>
<td>5</td>
<td>95</td>
<td></td>
</tr>
</tbody>
</table>
ABS Sensor evolution

1996
Pure ABS to detect wheel rotation

1997
Add basic ESP functionality

2017
Advanced diagnostic Error messaging

2017
Magnetic stray field suppression

2021
Redundant ABS sensing internal safety
High resolution

2nd order VTMR gradiometer mixed signal ASIC, ADCs, E2PROM, BIST

Increased performance for iTMPS

Digital protocol
Direction, Mounting position
Simple diagnostic

Simple AMR bridge
192 transistors

1996 2021
Why move to TMR

• Based on the need for stray field suppression (hybrid and electrical vehicles)

• AMR has hardly any linear response → difficult to build a gradiometer
• TMR is improved but shares AMRs Crossfield sensitivity
• V-TMR allow a good gradiometer
Comparison of NXPs AMR and V-TMR based speed sensor

- Right diagram summarizes main full bridge V-TMR parameters
- The green line shows the deviation from pure linear characteristics over the complete operation range (< 0.15%, excellent for gradiometer designs)

TMR vortex sensor based advantages:
- Linear working range: ±68 ±8 mT
- Sensitivity $S_V$: 20 1.33 V/T
- Full bridge resistance: 20 5 kΩ
- Cross sensitivity: 0.08 30 %
- Design area: 0.02 0.4 mm²
- SNR (NBW=10kHz): 112 85 dB
- Fold-back >200 ~10 mT
- White spectral noise density: 1 7. nT/√Hz
Simplified Signal Flow ABS Wheel Speed Sensor

Encoder Rotation

A-D Converter

Speed signal: \( S = 2M - A - B \)

Direction signal: \( D = A - B \)

Signal Pre-processing

Zero crossing detection

Vibration detection

Direction detection

Air gap measurement

Protocol generator

Controlled Current Source

Differential MR Bridge

VA

VM

VB

VA

VM

VB

Vcc

GND

Communications interface

configurability

Diagnostic

TMR sensor

Analog blocks

Digital blocks

NXP
Failure Detection and Diagnostic

• Diagnostic features:
  • TMR bridge integrity via three channel comparison
  • ADC channel errors
  • Digital data path failure detection based on BIST and signal plausification
  • Oscillator frequency out of range detection
  • CRC error in the MTP
  • Parity error in the MTP
  • Internal voltage failures

• ISO26262 support: diagnostic coverage for
  • missing/additional pulses ≤ 10 FIT
  • wrong (but valid) direction info ≤ 10 FIT
  • not signalized critical air gap reserve ≤ 10 FIT

• ASIL level B (D)
Future proof features

- Integrated TMR
  ➔ higher robustness due to less bond connections
  ➔ direct thermal coupling of MR and ASIC allows perfect temp compensation

- Extended temperature range -40° to 205° junction

- Linear response leads to outstanding Jitter <0.1%
  ➔ iTPMS in a wide driving range

- Small formfactor enables redundant ABS in same formfactor as single today

- High resolution adding 3 additional pulses
  ➔ movement accuracy of 5mm per individual tire
Advanced sensing platforms and secure connections make self-driving cars a reality

- Robust sensors to sense the own movement (speed, steering engine)
- Functional safety at the highest level to guarantee correct data
- Compact sensor solutions based on optimum technologies
- Secure, high-performance communication
- Reliable and high quality production facilities → ABCD9 TMR