Automotive Auxiliary Motor Drives from Semiconductor Perspective

Dr. D. Graovac, T. Liebetrau, T. Otter
Agenda

1. Introduction
2. Impact of Control Architecture
3. Motor Control Partitionings & System Examples
Agenda

1. Introduction
2. Impact of Control Architecture
3. Motor Control Partitionings & System Examples
ADAS, CO₂ reduction and adoption of premium features drive semiconductor growth

<table>
<thead>
<tr>
<th>Vehicle production</th>
<th>Drivers for semiconductor content per car</th>
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<tbody>
<tr>
<td></td>
<td><strong>CO₂ reduction</strong></td>
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<td>Driven by legislation</td>
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<td>Improvements of ICE (e.g. electric steering, electric pumps and motors)</td>
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<td>Adoption of EV/HEV</td>
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<td><strong>Advanced safety</strong></td>
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<tr>
<td>› ~2% growth p.a.</td>
<td>Current: crash avoidance</td>
</tr>
<tr>
<td>› Further growth in Western Europe, China, and ASEAN</td>
<td>Next: assisted driving</td>
</tr>
<tr>
<td>› Electro-mobility gaining momentum, especially in China</td>
<td>Future: autonomous driving</td>
</tr>
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<td><strong>Comfort, premium</strong></td>
</tr>
<tr>
<td></td>
<td>Premium cars are early adopters of high-end comfort and safety features</td>
</tr>
<tr>
<td></td>
<td>Trickling down to mid-range</td>
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</table>

~9% p.a. through-cycle growth

Courtesy: BMW

Courtesy: Audi

Q3 FY2016

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Market growth based on car production growth and increasing number of features

Light vehicle production forecast

Semiconductor value per car by region

Source: IHS, September 2015

Source: Strategy Analytics, based on LMC production forecasts Q1 2015
Market for electric motors in cars

~3.4 billion electric automotive motors in 2020
Unit CAGR of 5.7%

About 102 million cars expected to be produced in 2020

2.3 billion electric automotive motors in 2012
Approximately 68% were DC brushed and 15% were DC brushless

Source: IHS, "Electronic Motors in Automotive Applications - World - 2015"
CO2 reduction is not only xEV, but also possible through smart electrification of pumps and motors

**Market trends**

**CO2 reduction through motor electrification**

- **Water pump (cooling)**
  - Saves ~4g CO2/km

- **Vacuum pump (braking)**
  - Saves ~1.5g CO2/km

Source: Infineon estimates

**Market forecast for motor electrification**

![Bar chart showing market forecast for motor electrification from 2011 to 2017.](chart)

**Infineon’s system offering**

- Estimated water pump semi content: ~EUR 5-6
- Microcontrollers
- Bridge Drivers
- MOSFETs
- Power Supplies
- Transceivers

**Comments**

Many motors are still on-off state driven while pumps are still belt-driven, thus always on. **Smart electrification** means pumps and motors are only activated on demand.

Source: Strategy Analytics, worldwide market 2013
1. Electrical motors replace mechanical solutions

2. Dynamic DC motor control (PWM) improves efficiency, comfort, safety

3. Brushless DC (BLDC) motors for permanent loads enable higher reliability, less size, improved EMC
Solution comparison
Multi-dimensional criterias

- Power
- Voltage
- Size
- Weight
- Noise
- Efficiency
- Safety (ISO26262)
- etc.

- Temperature
- Specific conditions (cold start)
- Communication
- Car architecture
- etc.

- Development Resources
  - SW Reuse (microcontroller)
  - Second source
  - etc.

- Technology roadmap
  - Product portfolio
  - Support ability
  - etc.
Various users
Different constraints

› I want to use my microcontroller platform.
› I need the cheapest BOM.

› I'm looking for integrated, ready-to-use systems.
› I do not want to invest into own electronic solution.

› I'm looking for a special feature.
› I need to balance between development and BOM costs.

Purchasing driven

...and many more

Preferring Turn Key

Technology focused

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## Drives applications vs. safety requirements

<table>
<thead>
<tr>
<th>Potential ASIL level</th>
<th>Small drives</th>
<th>Power drives</th>
</tr>
</thead>
<tbody>
<tr>
<td>No or low safety requirements</td>
<td>ASIL QM ASIL A/B</td>
<td>Ventilation flaps, Seat adjustment, Headlight range adjustment, Adaptive light functions</td>
</tr>
<tr>
<td>High safety requirements</td>
<td>ASIL C/D</td>
<td>Steering wheel lock, Power braking lock, Clutch and gearbox actuators</td>
</tr>
</tbody>
</table>
Agenda

1. Introduction
2. Impact of Control Architecture
3. Motor Control Partitionings & System Examples
Motor control using remote electronics

Generic ECU

U-Chip

Supporting Functionality
(Position Measurement, Switch Panel Inputs, Output Driver)

Power Supply

Micro-controller

Current Measurement

Bridge Driver or Relay Driver

MOSFET or Relay

Motor Wiring

Long

2phase (DC Brush Motor)

3phase (Brushless DC Motor)

+12V from Battery

PWM LIN CAN

Input Signals

Generic ECU

Fuel Pump (DC motor)

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Integrated Motor Control Into Motor or Gear Housing

+12V from Battery

PWM LIN CAN

Input Signals

Motor or Gear Housing

Supporting Functionality
(Position Measurement, Switch Plate Position, Switch Poles)

Current Measurement

Bridge Driver or Relay Driver

Power Supply

Micro-controller

Position Sensor

System-on-Chip

Series Solution: Integrated Window Lift
Source: Küster ADS GmbH http://www.kuester.net

Infineon Demonstrator Board
Full Integration into motor housing

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Examples of Distributed Motor Applications

Benefits of distributed motor intelligence
- Minimized wiring
- Reduced weight/space
- Reduced overhead/complexity for options
- Distributed computing power
- Improved diagnostics
- Balanced power dissipation
- Improved EMC performance
- Standardized and low-cost physical layer/protocol handler
Example: Door module architecture
Centralized electronics – central door module ECU

- Low wiring effort
- Low scalability
- Optimized for full featured door electronics
- Premium cars
Example: Door module architecture
Smart WL architecture – Motor integrated electronics

› Cheap bus system
› High Scalability

› Higher wiring effort

› Limited capability for sophisticated options
› Global car platforms

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Agenda

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3. Motor Control Partitionings & System Examples
Motor control
Generic block diagram

+12V from Battery

- Power Supply
- Discrete Control or Microcontroller
- Bridge Driver or Relay Driver
- MOSFET or Relay
- Position Sensor

Supporting Functionality
(Position Measurement, Switch Panel Inputs, Output Driver)

Input Signals

PWM LIN CAN

M (2-phase (DC Brush Motor))
or
M (3-phase (Brushless DC Motor) - BLDC -)

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Motor control
Various chip integration levels

- Low development effort
- Simple design
- No software
- Discrete control scheme
- Integrated Switch with incorporated protection concept

Simple unidirectional motor drive (fans, blowers)

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Motor control
Various chip integration levels

- Low development effort
- Free micro-controller choice
- Software flexibility
- Integrated motor full-/half-bridge with incorporated protection concept
- SBC with supply and bus interface

Small uni- and bidirectional drives
Application example
HVAC control module

Example with 12-fold half-bridge for 6, 11 or 3 motors

- SBC TLE9263
- 16/32-bit Microcontroller XC22xx
- 8-bit Microcontroller XC8xx
- 12-fold half-bridge driver
- TLE94112EL
- 6 motors Non cascaded < 0.8A
- 5 motors Cascaded < 0.8A
- 3 motors High current < 1.6 A
Application example
HVAC control module

2/3 Flap System or 1 High Current Motor or 2 bi-stable relays

- SBC TLE9263
- 16/32-bit Microcontroller XC22xx
- 8-bit Microcontroller XC8xx
- 4-fold half-bridge driver TLE94x04EP
- 2 motors Parallel < 0.9 A
- 3 motors Cascaded < 0.9 A
- 1 motor High current < 1.8 A
- Bi-stable Relays <0.9A

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Electrical parking brake
Safe and easy to design with integrated half bridge

Source: Brose
Product Webpage Electric Parking Brake
NovalithIC™
½-Bridge system in a package

**R\textsubscript{DS, on-path} = 10\text{m}\Omega**

@ 25°C (typ.)

BTN8982

› Integrated Current Sense
› Low Emission (EMC)
› Current Limitation and Temperature Protection

http://www.infineon.com/novalithic
http://www.infineon.com/trilithic
Motor control shield with BTN8982 for Arduino

Power Shield for Arduino with 2x BTN8982 Half-Bridge NovalithIC™ drives
› Two uni-directional Brushed DC Motors, or
› One bi-directional Brushed DC Motor in an H-Bridge configuration
› Compatible with the Infineon XMC1100 Boot Kit

Benefits
› Easy & low cost evaluation & test of Infineon Motor Control Solution
› Professional support from the huge Arduino Open Source Community
› Software Examples for Arduino Uno and XMC1100 Boot-Kit (DAVE™)
Motor control
Various chip integration levels

+12V from Battery

Power Supply
Micro-controller
Bridge Driver or Relay Driver
MOSFET or Relay
Position Sensor

Supporting Functionality (Position Measurement, Switch Panel Inputs, Output Driver)
Current Measurement

U-Chip

› High integration level
› Free micro-controller choice
› Software flexibility
› Given U-chip feature set
› Less current limitation

All applications

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De-centralized motor control electronics
U-chip TLE7184/86

Key Feature
› Integrated N-Channel MOSFET Driver
› PWM interface
› Voltage supply for μC

Main Benefit
› Well known at customers
› Optimized system cost for applications with PWM interface (without LIN)
Motor control
Various chip integration levels

System-on-Chip

+12V from Battery

Power Supply

PWM LIN CAN

Microcontroller

Bridge Driver or Relay Driver

MOSFET or Relay

Supporting Functionality
(Position Measurement, Switch Panel Inputs, Output Driver)

Current Measurement

Position Sensor

M

M

Input Signals

 › Least internal wiring effort
 › Least components
 › Smallest installation space
 › Given microcontroller
 › Dedicated bus interfaces
 › Less current limitation

Designed for specific applications, expanding scope
Infineon® embedded power – system on chip solutions
Integration & flexibility

- Standard CPU
- Smaller footprint
- System cost reduction
- Customer Microcontroller Strategy
- Software Migration Effort

Reduced Board Space & Component Count

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Infineon® embedded power IC: 3rd generation based on Industry standard ARM μC

Standard μC core

Leading edge automotive qualified technology

ARM®

32-bit ARM® Cortex™-M3

Integrated on Infineon 130nm BCD process

Intelligence and Power on a single die
Infineon® embedded power IC
TLE986x/TLE987x product family

One Product Family for DC and Brushless DC Motor Control

Further motor applications
TLE986x and TLE987x key features
Inspired by automotive target applications

### Target Application Fields

› High-End Sunroof
› Power Window Lift
› Advanced H-Bridge DC Motor Control
› Pumps
› Blowers
› 3-Phase Motor control

### Key Features

› **ARM® Cortex™-M3 processor**, 24/40MHz
› Enables **field oriented** motor control
› Scalable **Flash** memory: 36kB to 128kB
› Current programmable **NFET driver**
  – optimized **EMC behavior**
  – **Scalable** MOSFET driver

› **Integrated PWM/LIN transceiver**
  compatible with LIN standard 2.x and SAE J2602-supports fast programming via LIN
› 10-Bit SAR ADC for current sensing **synchronized** with the internal **PWM signal generation** unit
› Wide Operating Range, $V_s=5.4V$ to $28V$

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Key Features

› Vertical Hall for In-Plane Sensing – sensor can be mounted parallel to magnetic encoder Direction Detection
› Index Counting
› 3.5V to 32V operating supply voltage
› Overvoltage capability up to 42V without external resistor
› Over current and over temperature protection
› Low jitter (typ. 0.3us)
› SMD package PG-TSOP6-6-5
› ESD (HBM): 2kV, 6kV (ISO10605)
Index counting with the TLE4966 family

2 Sensing elements are used

TLE4966 double Hall sensors combine 2 sensing elements in one sensor

Index counting for Power Closing Systems

Window Lifter
Sunroof
Electronic Doors
Trunk Power Closing
Vertical hall elements in TLE4966V-1K – open up new design flexibilities

Established Concept
- using TLE4966K

Vertical measurement Concept
- with TLE4966V

The new vertical measurement principle:
› saves space
› easy mounting of sensor and PCB board
› allows for more mounting flexibility
› enables new, compact systems designs

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Motor control
Various chip integration levels

+12V from Battery

- Power Supply
- Discrete Control
- Bridge Driver or Relay Driver
- MOSFET or Relay
- Position Sensor
- Position Sensor

Supporting Functionality
(Position Measurement, Switch Panel Inputs, Output Driver)

Current Measurement

Input Signals

PWM
LIN
CAN

Safety Applications

- Additional safety measures
- High Power
- Full Discrete Approach
- Shared functionality

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Electric power steering
High safety level using discrete components

+12V from Battery

**Electric Power Steering ECU**

- TLE 35584 Safety Power Supply with integ. WD
- 32-bit Multi Core MCU AURIX™ TC23xL
- CAN Transceiver TLE 6251D TLE 7250G
- 3-Phase Driver IC TLE 7183 TLE 7185 TLE 7189 TLE 9180
- Rotor Position/Current Sense TLE 4997 TLE 4998 TLE 4906
- Torque Sensor TLE 5012 TLE 4997 TLE 4906
- Steering Angle TLE 5012 TLE 4941
- Speed TLE 4941

**Safety Path**

- Reverse Protection

**Infineon OptiMOS™-T2 40V**

- New TO Leadless package

**Rotor Position**

- iGMR Sensor TLE 5009 TLE 5012
- Differential Hall IC TLE 4990 TLE 4997 TLE 4998

**Current Sense**

- (Shunt Substitute)

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Fail operational actuators for automated/autonomous driving
BOM to grow by factor 1.3 with Level 3-5

© ZF Lenksysteme

Safe Power Supply
Diverse Range of technical & economic constraints lead to high variety of solutions and dedicated products

Functional integration of electronics into specific devices due to cost and size reduction

Integrated motor bridges provide safe solution, simple to use at low development effort

Discrete solution using best-in-class MOSFETs for larger currents and high safety functionality
<table>
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<th>Current</th>
<th>Current</th>
<th>Micro-controller</th>
<th>Bridge Driver</th>
<th>MOSFET</th>
<th>Micro-controller</th>
<th>Integrated Motor Bridge</th>
<th>Embedded Power</th>
<th>MOSFET</th>
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<tbody>
<tr>
<td>Protection</td>
<td>Protection</td>
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<td>Benefits</td>
<td>Benefits</td>
<td>Higher Ambient Temperatures</td>
<td>Low Development Effort</td>
<td>Small uni- and bipolar drives</td>
<td>Least Wiring Smallest Space</td>
<td>Motor Integrated Drives</td>
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