Power Architecture Implications and Challenges for Power Electronics

IEA IA-HEV task 17 expert workshop
Berlin
April 16, 2015
Power Architecture - Implications and Challenges for Power Electronics

- HELLA at a Glance
- Power Architecture
- Power Electronics
- Conclusions
HELGA Group
Overview

• Partner of the automotive industry and the aftermarket for over 100 years since its foundation in 1899
• Global family-owned company with more than 100 locations in over 35 countries
• Sales of € 5.3 billion FY 2013/2014
• More than 30,000 employees worldwide, with over 5,800 in Research & Development
• One of the top 50 automotive suppliers in the world and one of the 100 largest German industrial companies

Business Segments

<table>
<thead>
<tr>
<th>Automotive</th>
<th>Aftermarket</th>
<th>Special Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>Electronics</td>
<td></td>
</tr>
<tr>
<td>Headlamps</td>
<td>Body Electronics</td>
<td></td>
</tr>
<tr>
<td>Rear Lamps</td>
<td>Energy Management</td>
<td></td>
</tr>
<tr>
<td>Small Lamps</td>
<td>Driver Assistant</td>
<td></td>
</tr>
<tr>
<td>Interior Lighting</td>
<td>Systems</td>
<td></td>
</tr>
<tr>
<td>Lighting Electronics</td>
<td>Sensors</td>
<td>Special Original</td>
</tr>
<tr>
<td></td>
<td>Actuators</td>
<td>Equipment</td>
</tr>
<tr>
<td></td>
<td>Electric Power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steering</td>
<td>Industries</td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>

Europe without Germany
11,079 employees

Germany
9,814 employees

NAFTA/ South America
3,980 employees

Asia /Pacific /Rest of World
5,819 employees

12% global market share in lighting business, top 2 Europe
Business Division Electronics
Electronics Organisation

- Energy Management
- Driver Assistance Systems
- Body Electronics
- Sensors
- Electrical Power Steering
- Actuators
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→ HELLA at a Glance

→ Power Architecture

→ Power Electronics

→ Conclusions
CO₂ emissions and oil supply
Worldwide CO₂ emissions and sectors

Global CO₂ emissions from 2000 to 2010 (in million tons)

- Residential building: 6%
- Others: 10%
- Industry: 20%
- Transport: 23%
- Energy: 41%

Peak Oil reached → distribution of limited resource oil
Electrification of vehicle as a whole necessary, not just powertrain

Source: CDIAC


Power Architecture and Power Electronics | Dr. Ulrich Köhler | E-AES | Lippstadt, 16 April 2015
## External influences governing fuel consumption

### CO₂ emission regulations timeline

<table>
<thead>
<tr>
<th></th>
<th>2010 Actual value</th>
<th>2015</th>
<th>2020/2021 (In discussion)</th>
<th>2025 In discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>🇺🇸 USA</td>
<td>187 g</td>
<td>167 g</td>
<td>121 g</td>
<td>91 g</td>
</tr>
<tr>
<td>🇯🇵 Japan</td>
<td>131 g</td>
<td>125 g</td>
<td>105 g</td>
<td>105 g</td>
</tr>
<tr>
<td>🇨🇳 China</td>
<td>185 g</td>
<td>167 g</td>
<td>117 g</td>
<td>117 g</td>
</tr>
<tr>
<td>🇪🇺 EU</td>
<td>142 g</td>
<td>130 g</td>
<td>95 g</td>
<td>85 g</td>
</tr>
</tbody>
</table>

*Source: ICCT*

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**Most stringent CO₂ emission limits will be in Europe as of 2021**

As of May 2014
Why power architecture is important
System

→ power architecture: efficient power distribution
→ energy efficiency
  • wiring / harness
  • components (ECUs, power modules …)
  • weight
→ manufacturing efficiency
  • number of components
  • space (harness & components)
  • layout
→ boundary conditions
  • safety and resilience
Power architecture of current (H)EVs examples show variety of topologies
Power net architecture
Generalisation for ICE/mild/hybrids

12V architecture with DCDC for stabilization

12V architecture with Ultracap for stabilization

12V architecture with sec. battery for stabilization

48V for high power loads

Floating alternator with Ultracap for regen

48V for boosting, regen & high power loads
Power architecture of current (H)EVs

Power and HV level

- 400V as virtual limit
- Differences even within marques (Civic 144V, Insight 100V)
- Hardly a correlation between power and HV level, except for low-power (H)EV -> 48V as alternative
Power architecture of (H)EVs
Multitude of Possible Realizations
Power architecture: concept comparison
different topologies

<table>
<thead>
<tr>
<th></th>
<th>Power Backbone</th>
<th>Power Ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main supply wires weight</td>
<td>Ca. 900g</td>
<td>Ca. 1100g</td>
</tr>
<tr>
<td>Weight of load power supply wires</td>
<td>Ca. 2100g</td>
<td>Ca. 1800g</td>
</tr>
<tr>
<td>Power supply redundancy</td>
<td>--</td>
<td>++</td>
</tr>
</tbody>
</table>
## Power architecture: concept comparison using 3 level architecture

### 3 DCDC converter
- **+ full flexibility**
- **- Most expensive solution**

### 2 DCDC (parallel configuration)
- **+ good system efficiency if 48V load consumption is much smaller than 12V load consumption**
- **- Expensive solution**
- **- No direct connection between 48V and 12V**

### 2 DCDC (serial configuration)
- **+ good system efficiency if 48V load consumption is around 12V load consumption**
- **+ Cheapest solution**
- **+ Scaleability to 48V/12V architecture**
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Power Architecture - Implications and Challenges for Power Electronics
interim summary

→ choice of power network architecture determines

  • number of converters, power and isolation levels
  • number of networks at different voltage levels

→ as function of vehicle constraints

  • power requirements (drive, comfort, auxiliaries)
  • space and cost

→ conclusio:

  • work on single components (example 48V/12V for series configuration)
  • general considerations
Power electronics
Energy flows

correlation of voltage levels

omnidirectional
HV ↔ 48 V ↔ 12 V ↔ HV

bidirectional
HV ↔ 48 V ↔ 12 V
HV ↔ 12 V ↔ 48 V

unidirectional
(HV → 48 V) & (HV → 12 V)
HV → 48 V → 12 V

other scenarios
HV ↔ 12 V ↔ 48 V
HV ↔ 48 V → 12 V
Power Electronics: 48V DC/DC Converter Platform
Advantages of Platform Concept

**Power Modules**
- Simple driving solution for switches
- Hardware realization by standard components
- Few components per module

**Assembling and Connection Technologies**
- Modularized PCB
- Cooling concept

**Control Logic**
- Feedback loop for dynamic and stable system
- Safety monitoring
- Symmetry between the modules

**Software**
- Standardized and qualified software architecture (e.g. Autosar)
- Communication interface (e.g. LIN, CAN, FlexRay,…)

**Platform**
- Utilization in versatile applications
- Multiphase architecture
- Overall control mechanism
- Partial power mode in failure case
Power Electronics: 48V DC/DC Converter Platform Efficiency

Advantages
• Broadening high efficiency over whole range of operation
• Smaller components
• Current sharing → smoothing, less filtering
• Reduced component stress
Power Electronics: 48V DC/DC Converter Platform
Component Requirements

**new challenges**

- higher nominal voltage
- voltage transients
- package size
- manufacturability

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**coil**
- design
  - smd
  - discrete
- core type
  - ferrite
  - iron powder
- switching frequency
  - skin effect
  - proximity effect
  - hysteresis losses

**transistor**
- dynamic power losses
  - low $C_{DS, GS}$
  - small $Q_{rr}$
- static power losses
  - low $R_{DS, on}$
- low breakdown voltage: min. 75V
- $R_{th,JC} \leq 1.5K/W$
- preferred smd package
  - today: $D^2$PAK
  - future: package with lower ESL

**capacitor**
- low ESR, ESL
- high ripple current rating
- max. impulse current
- $U_{BR} > 60V$
- safety (ceramic)
  - open mode
  - flex/soft-termination
# 48V DC/DC Converter Platform

## Analyzing Power Dissipation

<table>
<thead>
<tr>
<th></th>
<th>Coil</th>
<th>MOSFET</th>
<th>Capacitor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conduction Losses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{L,RMS}^2R_{wire}$</td>
<td></td>
<td>$I_{D,RMS}^2R_{ds,on}$</td>
<td>$V_F I_D$</td>
</tr>
<tr>
<td><strong>Dynamic losses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skin effect</td>
<td></td>
<td>Gate charge</td>
<td>Reverse recovery</td>
</tr>
<tr>
<td>Proximity</td>
<td></td>
<td>Output capacitance</td>
<td>Voltage/current spikes</td>
</tr>
<tr>
<td>Eddy current</td>
<td></td>
<td>Turn on/off delay</td>
<td></td>
</tr>
<tr>
<td>Hysteresis</td>
<td></td>
<td></td>
<td>$I_{C,RMS}^2ESR$</td>
</tr>
<tr>
<td><strong>Parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core type</td>
<td></td>
<td>$C_{DS}$, $C_{GS}$, $C_{OSS}$</td>
<td>$Q_{rr}$</td>
</tr>
<tr>
<td>Number of turns</td>
<td></td>
<td>$Q_{tot}$</td>
<td>$I_{RM}$</td>
</tr>
<tr>
<td>Switching frequency</td>
<td></td>
<td>$V_{DSS}$</td>
<td>$t_{rr}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Driver dynamic</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ESL (package)</td>
<td>$ESR$</td>
</tr>
</tbody>
</table>

**Parameters:**
- $C_{DS}$, $C_{GS}$, $C_{OSS}$
- $Q_{tot}$
- $V_{DSS}$
- Driver dynamic
- ESL (package)

**Dynamic losses:**
- Skin effect
- Proximity
- Eddy current
- Hysteresis

**Conduction Losses:**
- $I_{L,RMS}^2R_{wire}$
- $I_{D,RMS}^2R_{ds,on}$
- $V_F I_D$

**Channel:**
- $V_F I_D$

**Body Diode:**
- $I_{C,RMS}^2ESR$
48V DC/DC Converter Platform
Thermal design

- optimise thermal resistance chain
  - Every transition has to be taken into consideration

- $R_{th,JC}$: Package type
- $R_{th,PCB}$: Internal cooling concept
- $R_{th,PA,D}$, $R_{th,Sink}$: PCB-Heatsink coupling
- $R_{th,SinkAmbient}$: External cooling concept
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power density

→ increase power density by means of

1. increase in switching frequency
   • savings in magnetic circuit design and passive components' volume

2. innovative mounting technologies
   • component integration
   • reduction of thermal resistances, different temperature levels of various components (lifetime!)

3. increased efficiency
   • components
   • technology
   • passive cooling

way out: wide bandgap semiconductors

\[ E = h \cdot v \]

\[ n \sim e^{-\frac{E}{kT}} \]
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Conclusions

→ very diverse E/E architecture, will stay diverse
  • different OEM strategies
  • different hybridisation strategies

→ power electronics will have to adapt
  • modularisation
  • downscaling in weight and volume

→ wide band gap semiconductors *conditio sine qua non*
  • higher frequencies of operation
  • higher operating temperatures

→ other requisites
  • thermo management of components/systems incl. mounting
  • magnetic circuits design
  • EMC e.g. through suitable converter topologies, component packaging with low parasitic R/L/C