48V Architectures for Enabling High Efficiency

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Introduction
Innovation is Accelerated by CO₂ & Emission Regulations

- GHG and fuel economy regulations are “Driving Innovation”
- 48 Volt systems not considered viable less than 5 years ago
- Four times the power of 12V, safer than full hybrids (<60V lethal threshold), less expensive electrical components
- Brings 70% of the benefits of full hybrid at 30% of the cost to both gasoline and diesel vehicles
- Many suppliers and OEMs commercializing 48V technology
- First commercial introduction in Audi SQ7 diesel in Europe more in 2017 timeframe
Electrification – Tailored to Fit the Need
Scalable Modules for Different Customer + Market Demands

Fuel saving with low voltage technology

Fuel saving and electric driving

100% electric driving

* Saving Potential Tank-to-Wheel in NEDC, w/o Eco Innovations

CO₂ Saving Potential NEDC

< 5% CO₂

12 V Start-Stop

48 V Eco Drive

6 - 20kW

7 – 10%

< 5kW

20 - 30%

20 - 40kW

20 – 30%

50 - 90kW

50 - 75%

100%

Electric Vehicle

Plug-in Hybrid

Full Hybrid

High voltage

Electrification

Driving Innovation Workshop
Washington, DC

September 13, 2016
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48V Hybrid System
Component Overview

- 48V electric motor
  - Belt starter generator (BSG, 7-15 kW)
  - Integrated starter generator (ISG)
- DC/DC converter links 12V and 48V systems
- 0.5 kWh Li-Ion Battery

Features:
- Energy recuperation
- Engine-off coasting (sailing)
- Torque assist and electric driving
- Power 48V devices (electric turbo)

Fewer simple components control costs
48V System Configurations
Mild Hybrid System Roadmap

**P0 configuration**
- Low cost integration
- Belt Starter generator
- Torque limited

**P1 Configuration**
- Crankshaft mounted
- High torque

**P2 configuration**
- Side attached BSG or ISG
- Higher cost
- More recuperation
- Additional hybrid functions

**P3 & P4 Configurations**
- P3: eMotor torque on transmission
- P4: eMotor torque directly on axle drive
- Highest energy recuperation potential
### 48V System Configurations

#### Fuel Economy Benefit

<table>
<thead>
<tr>
<th>CO₂ Reduction Potential</th>
<th>Cost per gCO₂/km Ratio</th>
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</thead>
<tbody>
<tr>
<td>P0 BSG</td>
<td>-7.4%</td>
</tr>
<tr>
<td>P1 BSG</td>
<td>-8.7%</td>
</tr>
<tr>
<td>P2 BSG</td>
<td>-10.7%</td>
</tr>
<tr>
<td>P4</td>
<td>-13.2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>P0 BSG</th>
<th>P1 BSG</th>
<th>P2 BSG</th>
<th>P4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recuperation, electric torque assist, engine-off coasting</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Engine-off A/C</td>
<td>✗</td>
<td>✗</td>
<td>✔</td>
<td>✗</td>
</tr>
<tr>
<td>eCreeping/Sailing</td>
<td>✗</td>
<td>✗</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

**Diagram:**
- P0+P4: Rightmost bar with +35% increase.
- P0 BSG, P1 BSG, P2 BSG, P4: Bars indicating CO₂ reduction percentages.

**Note:**
- P0: BSG with recuperation and engine-off coasting.
- P1: BSG with recuperation and electric torque assist.
- P2: BSG with eCreeping/Sailing.
- P4: BSG without any additional features.
48V P0 Hybrid Transient Performance
15% Acceleration Benefit from Electric Torque Assist

2nd Gear
Acceleration from 800 rpm to 
~3000 rpm

3rd Gear
Acceleration from 800 rpm to 
~3000 rpm

The electric torque assist was limited to 50 Nm on crankshaft
Improved low-end-torque

Source: Ford

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48V Allows for Auxiliary Component Electrification
More Efficiency and Further Benefit

Possible 48 Volt Devices

- Electric Valve Train
- Variable Valve Train
- Dynamic Roll Stabilization
- Variable Compression Ratio
- (Transmission) Oil Pump
- Electric Vacuum Pump
- Water Pump
- Radiator Cooling Fan
- A/C Compressor
- Engine Oil Pump Twin Drive
- Power Steering
- Front Window Heating
- Rear Window Heating
- Front Seat Heating 2x
- Window Lifter 4x
- High Beam
- Front Wiper
- Power Steering
- Electric Booster
- PTC Heater

Power-On Time

- 100%
- 75%
- 50%
- 25%

Power (max.)

- 100 W
- 300 W
- 500 W
- 750 W
- 1 kW
- 2 kW
- 3 kW
- 4 kW
- 5 kW

0

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48 Volt Technology – More than a Mild Hybrid
Benefits Over and Above CO₂ Reduction

› 48 Volt electrification is driven by CO₂ and emission reduction regulations.
› Future 48V powertrain designs will enabling even greater CO₂ savings.
› Recuperated energy can be utilized for safety, comfort, and efficiency functions.
› Auxiliary components can be electrified to reduce power load on engine.
› Rapid development to commercialization in next few years