Benefits of a 48V P2 Mild Hybrid

Brian McKay, Ph.D.
Powertrain Technology & Innovation
48V Hybrid System
Component Overview

› 48V electric motor
  › Belt starter generator (BSG)
  › Integrated starter generator (ISG)
  › Electric front/rear axle drive (eFAD/eRAD)
› DC/DC converter & Li-Ion battery

Configuration
› Belt Starter Generator
› DC/DC Converter
› Li-Ion Battery

Features:
› Energy recuperation
› Engine-off coasting. Advanced ESS (<20 km/h)
› Torque assist and electric driving
› Power 48V consumers
48V Topology
Mild Hybrid System Roadmap

**P0 configuration**
- Low cost integration
- BSG on front end accessory drive (FEAD)
- Torque limited

**P1 Configuration**
- Crankshaft mounted
- High torque density
- Axial length restrictions

**P2 configuration**
- Side attached BSG or ISG
- Higher cost and architectural changes
- Additional hybrid functions
- Eliminate engine drag loss

**P3 & P4 Configurations**
- P3: eMotor torque on gear output
- P4: eMotor torque directly on axle drive
- Highest recuperation potential
P0 Architecture
Limited Hybrid Mode Capability

Recuperation

Traction Mode

Boost

Coasting

C = Combustion Engine  D = Dual Mass Flywheel  E = Electrical Machine  T = Transmission
P2 Architecture
Full Hybrid Mode Capability
Kinetic Energy Regeneration by Architecture
P0 vs. P2

- Architectures evaluated in WLTC for a C-segment vehicle class (inertia 1250 kg)
- P2 configuration offers significantly higher energy regeneration benefit of up to 40%
### 48V Topology

**Fuel Economy Benefit**

<table>
<thead>
<tr>
<th></th>
<th>P0 BSG</th>
<th>P1 BSG</th>
<th>P2 BSG</th>
<th>P4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO₂ saving in WLTP (TM_H)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(incl. Eco Innovation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$ per gCO₂/mi Ratio</td>
<td>-7.4%</td>
<td>-8.7%</td>
<td>-10.7%</td>
<td>-13.2%</td>
</tr>
</tbody>
</table>

**Recuperation, electric torque assist, “change-of-mind“, engine-off coasting**

- P0: ✔
- P1: ✔
- P2: ✔
- P4: ✔

**Engine-off climate control**

- P0: ❌
- P1: ❌
- P2: ✔
- P4: ❌

**eCreeping**

- P0: ❌
- P1: ❌
- P2: ✔
- P4: ✔

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**30 September 2016**

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System Level Approach
P0 vs. P2

Gasoline Technology Car I

› Ford Focus 1.0L 3cyl Eco-Boost, CR=10,
› No geometrical changes on the engine
› Fuel Injection System XL3.1 with 200 bar
› 48 V P0 architecture: Belt-driven Starter Generator (BSG)
› Manual transmission with eClutch
› CO₂ emission = 95 g/km (NEDC), Euro 6c

Gasoline Technology Car II

› Ford LIVC 1.0L 3cyl Eco-Boost, raised CR=12
› modified intake camshaft, RAAX™ turbocharger
› Fuel Injection System XL3.1 with 200 bar
› 48 V P2 architecture: BSG between combustion engine and transmission
› Manual transmission with eClutch
› CO₂ emission target < 85 g/km (NEDC), Euro 6c
Powertrain Architecture
Optimized P2 Hybrid
48V Hybrid
CR & LIVC Opportunities

› Increase CR from 10 to 12. Rematch turbocharger.

› Utilize electric driving and downspeeding to address low end torque/turbo lag while minimizing enrichment.
Electrically Heated Catalyst
Cold Start Emission Strategy

› Compliance to SULEV 30 and PM/PN limits requires a balance of catalyst light off with minimal particulate formation.

› Turbocharged engines struggle with catalyst light-off duration.

› Further exacerbated with durations of engine-off.
Powertrain Architecture
Motivation for the 48 V P2 Topology

P2 topology attributes
› Located between ICE and transmission
› Max. recuperation capability (reduced drag torque)
› Engine-off coasting
› Engine-off recuperation
› Pure electric drive (‘active’ sailing)
› Electric launch + electric creeping
› Conservation of air conditioning (engine-off coasting, S/S phases)
Hybrid Module
Clutch Module

Advantages

- High degree of integration
  → optimized axial package space

- Smart clutch modules
  → low functional integration effort

- Belt drive behind DMF
  → reduced torsional vibrations

Hydrostatic clutch actuator
Launch clutch K1
Disconnecting clutch K0
Electro-mechanical clutch actuator
Flange shaft
Belt pulley
Dual mass flywheel
Hybrid Module
Belt Drive

- 48 V E-machine
- Decoupling tensioner
- Drive train pulley
- Belt
- A/C compressor
Hybrid Module

Engine Restart – Acceleration from Coasting Mode

< 600 ms
eCreeping
Extended Functionalities – Traffic Jam

[Graph showing vehicle speed and battery SOC over time]

- Electric motor only
- Recuperation
- Vehicle speed

48V Battery SOC
Distance

Time [s]
Distance [m]
eSailing
Purely Electric Driving with 48V P2 Hybrid

Results from a C-Segment vehicle (intertia 1250 kg)
› Keep vehicle speed constant purely electrically
› 100% state-of-charge (SOC) corresponds to 460 Wh
**CO₂ Reduction Potential**

Selection of System Configuration by Simulation

**Combustion Engine**
- Higher efficiency by high CR

LIVC: Late Intake Valve Closure
CR: Compression Ratio

**Hybrid Concept**
- Increased recuperation capability
- Electric drivability

**Operation strategy**
- System optimization (1+1=3)

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**NEDC**

- Basic Fuel Cons.
- ICE, LIVC, CR 12, RAAX
- 48 V P0 Hybrid
- Down-speeding
- 48 V P2 Hybrid replaces P0
- 48 V EMICAT®

**WLTP**

- Basic Fuel Cons.
- ICE, LIVC, CR 12, RAAX
- 48 V P0 Hybrid
- Down-speeding
- 48 V P2 Hybrid replaces P0
- 48 V EMICAT®

**CO₂ Reduction Potential**

- NEDC: -30%
- WLTP: -12%
# 48V Hybrid

## Cost Sensitivity

<table>
<thead>
<tr>
<th>Electric Machine</th>
<th>System Integration</th>
<th>Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated machine</td>
<td>P0 + P4 (AWD)</td>
<td>1500 Wh</td>
</tr>
<tr>
<td>High efficiency</td>
<td>P1/P2 ISG</td>
<td>1000 Wh</td>
</tr>
<tr>
<td>High power</td>
<td>P2 BSG</td>
<td>460 Wh</td>
</tr>
<tr>
<td>Liquid cooled</td>
<td>P0/P1 BSG</td>
<td>1000 Wh</td>
</tr>
<tr>
<td>Belt driven</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low power</td>
<td></td>
<td></td>
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<tr>
<td>Air cooled</td>
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</tbody>
</table>
Thank you!

Questions?

Contact: Brian McKay
Email: brian.mckay@continental-corporation.com