Power Module for EV Powertrain Systems & Technologies
Agenda

• EV Power Train
• Die Technology
• On Semiconductor’s HV Automotive Power Modules
• Automotive Traction Inverter description
  • Module functionality
  • Power losses
  • Thermal characteristics
• VE-Trac™ Power Module Platform
  • VE-Trac™ Direct SiC
  • VE-Trac™ B2-SiC
  • VE-Trac™ Dual
  • VE-Trac™ Direct
EV Power Train

Body Electronics
Doors, Seating,
Keyless entry,
Gateway Modules

ADAS, Infotainment,
HUD
Doors, Seating,
Keyless entry,
Gateway Modules

ON Board Chargers,
HV Loads
Battery Management

PHEV, EV
DC/DC
HV-LV, 48V-12V

Lighting
Rear, Front, Interior

48V
BSG, Loads

Powertrain
xEV Traction, ECU,
TCU, Safety (Braking,
Parking)

ON Semiconductor
Technologies Enabler
• 650 - 1200 V SiC
   MOSFET
• 650 – 1200 V SiC
   JBS Diode
• 100 – 650 V GaN
• 650 – 1200 V IGBT
• Low – Mid – High
   Voltage FET
• High Voltage Gate
  Driver

Source: ON Semiconductor Corporate Marketing

Public Information
HEV/PHEV/BEV

**HEV** are powered by conventional or alternative fuels as well as electric power stored in a battery.

**PHEV** are powered by conventional or alternative fuels as well as electric power stored in a battery. The battery can be charged by plugging it into an outside power source, by the internal combustion engine, or by regenerative breaking.

**BEV** are propelled by a battery-powered motor, and the battery is charged by plugging the vehicle into the electric grid either at home or at a public charging station.
ON Modules for Automotive

- **Traction Inverter**
  - SSDC (750V/800A): DSC (750V)

- **HV E-Compressor**
  - ASPM27 (650V/50A)
  - ASPM34 (1200V/25A)
  - ASPM34 (1200V/35A)
  - ASPM34 (1200V/10A)
  - ASPM27 (600V/40A)
  - ASPM27 (600V/50A)
  - ASPM16 (750V/75A)
  - ASPM27 (600V/30A)

- **HV Supercharger**
  - ASPM27 (650V/50A)

- **HV DC-DC**
  - APM16 (650V)

- **OBC**
  - APM16 (650V)

- **48V BSG/ISG**
  - APM15 (80V)

- **Battery Cooling Fan**
  - APM27 (650V/50A)
  - SIP-23 (40V/20A)

- **48V DCDC**
  - APM19 (80V)

- **EPS**
  - APM7, 11 (40V)
  - APM20 (40V)

- **48V Oil Pump**
  - ASPM27 (650V/50A)
  - SIP-23 (40V/20A)

- **HV Oil Pump**
  - ASPM27 (650V/50A)
  - SIP-23 (40V/20A)

- **BRAKING**
  - APM20 (40V)

- **Battery Cooling Fan**
  - APM27 (650V/50A)
  - SIP-23 (40V/20A)

- **SIP-23**
  - 40V/20A

- **Public Information**
Power Solutions for OBC

- 650 V IGBTs
- Hybrid IGBTs
- 650 V Rectifiers
- 650 V SJ MOSFETs
- Automotive HV modules
- SiC SBD/MOSFETs
- Gate drivers
- 650 V GaN transistors
- Op-amps & current sense
- DC-DC, LDO, IVN, ASIC

On-Board Charger
ON Board Charger Trend

G2V (Grid to Vehicle)

Uni-directional Charging

Power Flow

PFC (AC→DC)  LLC, 1st DC→AC  LLC, 2nd AC→DC  Battery

Bi-directional Charging

Power Flow

Inverter (AC↔DC)  LLC, 2nd DC↔AC  LLC, 1st AC↔DC  Battery

V2X (Vehicle to Grid, Home, Vehicle..)

Public Information
Existing ON Semiconductor Solution: APM16

APM16 Module value proposition:
- One package outline
- Covers all different circuit configurations of OBC and DC/DC
  *Automotive qualified
OBC Unidirectional

- **FS4 IGBT**: FGBxxT65SQD, FGHxxT65SQD
- **SiC Diode**: FFSB series, FFSP series, FFSH series
- **SuperFET III**: NVBxxxN65S3F, NVHLxxxN65S3F
- **Gate Driver and Isolator**: FAN7191, NCV5183, FAD6253
- **LV Auxiliary Power**: 3.3V
- **LV Battery**: 15V
- **LS Gate Driver**: NCV81071, FAN3224
- **NVMFS6V8xx**
- **NVMFS6V8xx**
- **NCP8871**
- **NCP81071**
- **FAN3224**
- **FAM65HR80, FAM65HR48**
- **ISL9Rxxx**
- **SiC Diode**: FFSB series, FFSP series, FFSH series
- **SiC Diode**: FFSB series, FFSP series, FFSH series
- **OP and Comparator**: NCVx333, NCV2003x, NCV2006x, NCV2250/2
- **OP and Comparator**: NCVx333, NCV2003x, NCV2006x, NCV2250/2
- **APM Module**: FAM65HR80, FAM65HR48
- **Gate Driver and Isolator**: DSC and MCU, Voltage Reference, CAN Interface
- **Gate Driver and Isolator**: DSC and MCU, Voltage Reference, CAN Interface
11KW bidirectional OBC block diagram

Relay Driver NCV840x

APM 32 Module NVXK2VRx0WDT NVXK2HRx0WDT

SiC MOSFET NVH4L0x0N120SC1

Gate Driver NCV5708x NCV5709x

SiC MOSFET NVH4L0x0N65SC1

APM16 Module FAM65HR51/82 SuperFET III NVH4L0xxN65S3F NVH4L0x0N065SC1

OP and Comparator NCV33x NCV2003x NCV2006x NCV2250/2

For 500V to 800V battery

LV Input NCV8871 NVMFS6H8xx

HV Input NCV106x NCV107x

APM 32 Module NCV840x

Gate Driver NCV5708x NCV5709x

SiC MOSFET NVH4L0x0N120SC1

APM16 Module FAM65HR51/82 SuperFET III NVH4L0xxN65S3F

SiC MOSFET NVH4L0x0N065SC1

Gate Driver NCV5708x NCV5709x

SiC MOSFET NVH4L0x0N120SC1

APM 32 Module NVXK2HRx0WDT

Relay Driver NCV840x
ON Semiconductor Power module offer to OBC & DCDC solution needs

Power Ratings

- 3.6kw
- 7.2kw
- 11 kw
- 22 kw

Topologies

- Half Bridge LLC Converter
- Bi-directional 3 phase PFC
- Buck-Boost Converter
- LLC Half-Bridge and Full Bridge
- Output Bridge Rectifier
- Dual Active Bridge Buck Boost
- Interleave PFC
- Bridgeless PFC
- DC DC + PFC

FETs

- Sic FET / Superfet
- Mosfet / IGBT / Rectifier

Customer Selections of module solution per - Price / Auto Reliability / Size / System Assembly (pressfit vs soldering)

Feasible Offer by APM solutions
Achieved High Power Density by APM

[ Thermal Performance ]

[ Electrical Performance ]

- Lower circuit resistance (i.e., double the number of wire bonds comparing with standard discrete package) allows customer to provide higher torque output.
- Reduced stray inductances as a result of physical proximity of the devices and the APM inside pattern on DBC.
- Better dynamic and EMI performance.
- High Isolation Voltage saving additional insulation layer.

<table>
<thead>
<tr>
<th></th>
<th>APM – ON Semi</th>
<th>Discrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{thjc}$ – junction to case (of components)</td>
<td>&gt;</td>
<td></td>
</tr>
<tr>
<td>$R_{thjs}$ – junction to bottom of heat sink</td>
<td>&lt;</td>
<td></td>
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</table>

- APM can enable total low thermal resistance from Junction to heat sink.
**APM in the OBC System**

### EV / HEV On-Board Charger

**OBC Power Device Solutions**
- Wide output voltage range coverage: 200–160V
- High efficiency system: >90% at 96W output
- Compact size for installation flexibility
- Transistor modules for flexible operating conditions
- Full bridge (LLC) for high efficiency and power density
- CAN interface for control and monitoring

**Block Diagram**

**Performance**
- Up to 95% total efficiency at 220Vac
- >0.9 Power Factor

**Discrete design**
- $256 \times 180 \times 60$ mm = 2.7 l

**APM16 design**
- $212 \times 150$ mm = 1.5 l
VE-Trac™

EV Power Module Platform
Cooling / Mechanicals

- Single Side, In-Direct Cooling
- Single Side, Direct Cooling
- Dual Side, In-Direct Cooling
- Dual Side, Direct Cooling
VE-Trac™ (Vehicle Electrification for Traction) Products

Comprehensive Traction Solutions

<table>
<thead>
<tr>
<th>TP/Iso-TP</th>
<th>IGBT</th>
<th>Direct-IGBTs</th>
<th>Dual-IGBTs</th>
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</thead>
<tbody>
<tr>
<td>![TP/Iso-TP Icon]</td>
<td>![IGBT Icon]</td>
<td>![Direct-IGBTs Icon]</td>
<td>![Dual-IGBTs Icon]</td>
</tr>
<tr>
<td>• 650V/750V</td>
<td>• 750V/1200V</td>
<td>• 750V/1200V</td>
<td>• 750V/1200V</td>
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<tr>
<td>• SOP since 2018</td>
<td>• &gt;10 engagements</td>
<td>• SOP from 2019</td>
<td>• SOP from 2019</td>
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<tr>
<td>• Tier 1s/OEMs</td>
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<table>
<thead>
<tr>
<th>Iso-TO</th>
<th>SiC</th>
<th>Direct-SiC</th>
<th>B2-SiC</th>
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<td>![Iso-TO Icon]</td>
<td>![SiC Icon]</td>
<td>![Direct-SiC Icon]</td>
<td>![B2-SiC Icon]</td>
</tr>
<tr>
<td>• 1200V (concept)</td>
<td>• 1200V</td>
<td>• 1200V &amp;900V</td>
<td>• 900V &amp;1200V</td>
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</tbody>
</table>

Products

Comprehensive Traction Solutions
# Portfolio Positioning for 400V DC Bus Inverters

<table>
<thead>
<tr>
<th>Power Class</th>
<th>Rthj-f (K/W)</th>
<th>Direct IGBT</th>
<th>Dual-IGBTs</th>
<th>Direct SiC</th>
<th>B2-SiC</th>
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</thead>
<tbody>
<tr>
<td>80kW</td>
<td>0.23</td>
<td>750V x Flat Base Plate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100kW</td>
<td>0.16</td>
<td>750V, x Pin Fin Base Plate</td>
<td>750V, X DSB/C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120kW</td>
<td>0.15, 0.13</td>
<td>750V, x Flat Base Plate 750V, x Pin Fin Base Plate</td>
<td>750V, X DSB/C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150kW</td>
<td>0.12</td>
<td>750V, 820A Pin Fin Base Plate</td>
<td></td>
<td>750V, 800A DSB/C</td>
<td></td>
</tr>
<tr>
<td>180kW</td>
<td>0.10</td>
<td>750V, 950A Pin Fin Base Plate</td>
<td></td>
<td>750V, X DSB/C</td>
<td></td>
</tr>
<tr>
<td>220-250kW</td>
<td>0.07</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>280-320kW</td>
<td>0.06</td>
<td></td>
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<td></td>
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<tr>
<td>330kW+</td>
<td>0.05</td>
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</table>
## VE-Trac™ Power Module Strategy

### VE-Trac™ Dual (Dual Side Cooling)
- NVG800A75L4DSC
  - 750V, 800A Half bridge, DSC
- NVG400A120L2DSC
  - 1200V, 400A Half-bridge, DSC

### VE-Trac™ Direct (Single Side Direct Cooling)
- NVH820S75L4SPB
  - 750V, 820A 6-pack
- NVH950S75L4SPB
  - 750V, 950A 6-pack
- NVH820S75L4SPC
  - 750V, 820A 6-pack
- NVH820S75L4SPA
  - 750V, 820A 6-pack

### Scalability
- Scalable (80-300kW)
- Best-In-class $/KW
- 2x lifetime

### Industry Standard Pin-out
- Best-in-class performance
- Supply assurance
VE-Trac™ Dual

- Lowest cost $ per kW
- Tjmax = 175°C continuous operation
- Scalable, modular, and compact
- 750V & 1200V voltage classes
- Wirebond-free module for high reliability
- On-chip current and temperature sense
- Ultra low stray inductance of <7nH

<table>
<thead>
<tr>
<th>Device</th>
<th>Current Rating</th>
<th>Voltage Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>NVG800A75L4DSC</td>
<td>800A</td>
<td>750V</td>
</tr>
</tbody>
</table>
Features

- Direct Cooling with Integrated Pin-Fin Heatsink
- Low RDS(ON) and Low Switching losses
- Si3N4 Substrate for Higher Thermal Performance and Ruggedness
- Ag Sintering for Die Attach
- Ultra low thermal resistance up to $R_{thJ-F}<0.09$ k/W
- $T_{j\text{max}} = 175^\circ$C continuous operation

Benefits

- Low System Cost
- Lower Energy Losses
- Higher Inverter Peak Output Power
- Improved Inverter Efficiency
- Optimized for Automotive Traction Applications
- Easy Design and Integration

900 V Line-up

<table>
<thead>
<tr>
<th>Product</th>
<th>Voltage</th>
<th>Current</th>
<th>Configuration</th>
<th>$R_{thJ-F}$ [k/W]</th>
<th>RTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>NXV90VR02WSTB</td>
<td>900 V</td>
<td>TBD</td>
<td>Pin-fin, Si$_3$N$_4$</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>NXV90VR03WSTB</td>
<td>900 V</td>
<td>TBD</td>
<td>Pin-fin, Si$_3$N$_4$</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

1200 V Line-up

<table>
<thead>
<tr>
<th>Product</th>
<th>Voltage</th>
<th>Current</th>
<th>Configuration</th>
<th>$R_{thJ-F}$ [k/W]</th>
<th>RTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>NXVk2VR03WSTB</td>
<td>1200V</td>
<td>TBD</td>
<td>Pin-fin, Si$_3$N$_4$</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>NXVk2VR04WSTB</td>
<td>1200V</td>
<td>TBD</td>
<td>Pin-fin, Si$_3$N$_4$</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

* @ 450 V bus, 10 kHz switching frequency
** @ 650 V bus, 10 kHz switching frequency

Package: 155 mm X 100 mm X 32 mm
**Features**

- Low RDS(ON) and Low Switching losses
- AlN Substrate for Higher Thermal Performance and Ruggedness
- Ag Sintering for Die Attach and Clip to enhance thermal performance and current capability
- Ultra low thermal resistance up to $R_{th(J-F)}<0.115$ k/W
- $T_{j,max} = 175^\circ$C continuous operation and 200 °C for 200 hrs operation over life time

**Benefits**

- Low System Cost
- Lower Energy Losses
- Higher Inverter Peak Output Power
- Improved Inverter Efficiency
- Optimized for Automotive Traction Applications

### 900 V Line-up

<table>
<thead>
<tr>
<th>Product</th>
<th>Voltage</th>
<th>Current</th>
<th>Package</th>
<th>$R_{th(J-F)}$ [k/W]</th>
<th>RTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>NXV90AR02WXT</td>
<td>900 V</td>
<td>TBD</td>
<td>A1HPM</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>NXV90AR03WXT</td>
<td>900 V</td>
<td>TBD</td>
<td>A1HPM</td>
<td>TBD</td>
<td>TBD</td>
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</table>

### 1200 V Line-up

<table>
<thead>
<tr>
<th>Product</th>
<th>Voltage</th>
<th>Current</th>
<th>Package</th>
<th>$R_{th(J-F)}$ [k/W]</th>
<th>RTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>NXVk2AR03WXT</td>
<td>1200V</td>
<td>TBD</td>
<td>A1HPM</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>NXVk2AR04WXT</td>
<td>1200V</td>
<td>TBD</td>
<td>A1HPM</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
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* @ 450 V bus, 10 kHz switching frequency
** @ 650 V bus, 10 kHz switching frequency
VE-Trac™ Dual - Inverter Kit

440VDC, 560Arms, up to 160kW 3-ph Inverter
Compact size: 110 x 240 x 120 mm

Design kit makes it easy to test performance

Time to market
One Power Module: Many power levels

3x VE-Trac™ Dual up to 160kW
Size: 230 (l) x 65 (w) x 25 (h)

3x VE-Trac™ Dual up to 300kW
Size: 230 (l) x 65 (w) x 39 (h)

200% Increase in Output Power
(only a 50% increase in volume)
VE-Trac™ Direct

- High reliability press-fit pin design
- Optimized Pin FIN with lower Rth-ja
- Short term operation up to 175°C

<table>
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<tr>
<th>Device</th>
<th>Current Rating</th>
<th>Voltage Class</th>
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<tbody>
<tr>
<td>NVH820S75L4SPB/SPC</td>
<td>820A</td>
<td>750V</td>
</tr>
<tr>
<td>NVH950S75L4SPB</td>
<td>950A</td>
<td>750V</td>
</tr>
</tbody>
</table>
Key Takeaways

• Better thermal performance and size in APM32

• VE-Trac™ Dual is a dual side cooling module that offers the lowest cost per kW and allows a scalable inverter design with an ultra-low stray inductance

• VE-Trac™ Direct is a drop-in replacement to existing legacy products with an innovative and reliable press-fit pin technology
Thanks