Semiconductor Technologies for High Power Applications

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Low Power vs. High Power Applications

Thermal Requirements

Low-Medium Power (<~2 kW)
- Computing, Consumer, Telecom
- Ac-Dc or Dc-Dc (some Dc-Ac)
- Short development time
- Cost, Efficiency, Reliability
- >1-2 % efficiency improvement worth the effort
- “Low Profile”

High Power (> ~5 kW)
- Industrial, Automotive
- Dc-Ac or Dc-Dc
- Long development time
- Reliability, Efficiency, Cost
- >0.1-0.2% efficiency improvement worth the effort
- “High Profile”
We need more power!

- 300M photos uploaded each day
- 300 hours uploaded every minute
- 10B hours watched per month

- More data movement = more power
- Faster processing = more power
- Same/smaller space = higher power density

"Ten years ago, average power draw per cabinet was probably 700 to 800 watts," said Jason Black, VP of data center services at Cosentry. "Five years ago, it was 1.5 kW. Now, 3 kW. On current trend, we'll see five or six kilowatt average power draw in five years."
Automotive Growth

- Electrified, Autonomous, and Shared
  - Implications for power electronics – Electrification solutions and adopting Changing reliability
**EV Charging Power Content**

1. **Level 1: Home, Office, Mall**
   - AC, Unidirectional; $5 – $10/charger

2. **Level 2: Office, Mall**
   - AC, Unidirectional; $10 – $20/charger

3. **Level 3: Fleet**
   - DC, Bidirectional; ~$200/charger

4. **Level 4: Highway, Fleet**
   - DC, Unidirectional; $500 – $1k/charger

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**Time to full charge**

- **5-7 min**: Ultra fast
- **25-35 min**: Fast
- **3h**: Medium
- **10h**: Slow

**EV Charging Power Semiconductors**

- 30% CAGR
- $Millions
- 2017: 100
- 2018: 200
- 2019: 300
- 2020: 400
- 2021: 500
- 2022: 600

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*CPSS CHINA POWER SUPPLY SOCIETY*
Dramatic Increases in Power Semiconductor Content

**Efficient Motors**
(HVAC, Fans, Pumps, Power Tools, etc.)

- **Brush Motor**
- **3 Phase BLDC Controller**

1 Power Switch or Relay → 6 Power Switches, Drivers/Controller

**Increasing PowerSemi Content**

<table>
<thead>
<tr>
<th>1 Power Switch or Relay</th>
<th>6 Power Switches, Drivers/Controller</th>
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<tr>
<td>$0.25</td>
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**Renewable Energy**

- **OLD**
  - No Semi Content
- **NEW**
  - Large Power Semiconductors for Power Conversion

**Coal to Electricity**

- **OLD**
  - Coal Heater for Single story house
  - No Semi Content
- **NEW**
  - Compressor
  - Fans
  - Blowers

**Implementing the electronics industry A Power Technology Roadmap**

**China Power Supply Society**
Standards Driving a Surge in Semiconductor Content

- Cellphones, automobiles and PC unit shipments show moderate growth while semiconductor unit shipments show explosive growth.

- Semiconductor content per system grew from 23.4% in 2012 to record-high 31.4% in 2018.

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Government Regulation Timeline

- **NEV Mandate**: 10% & 12% in 2017 & 2018, respectively.
- **ZEV Mandate**: 8% & 20% in 2021 & 2022, respectively.
- **ICE Ban**: UK & France in 2025.
- **California (+9 other states)**: NEV Mandate in 2030.
- **California & New York**: 50% Renewable by 2030 Mandate in 2030.
- **EU 20-20-20**: Approved 2008.
- **EU 2030**: Invest $360B.
- **EU 2050**: Low-Carbon Economy.
- **DoE FER**: Announced 2014.
- **Coal-to-Electricity**: 34% in 2017.
- **Motor Efficiency Mandates**:
  - **IEC**: 2015 - IE3 (7.5-375kW), 2016 - Premium Efficiency (1-500HP), 2017 - IE3 (0.75-375kW).
  - **NEMA**: 2015 - IE3 (7.5-375kW), 2016 - Premium Efficiency (1-500HP), 2017 - IE3 (0.75-375kW).
Power Device Technology Positioning

Switching power (kW)

- GaN HEMT
- Thyristor
- Si Bipolar
- IGBT/IPM
- MOSFET
- SiC

Operating frequency (Hz)

- Grid
- Wind
- Rail
- PV
- UPS
- EV/HEV
- Power supplies for servers
- AC adapters
- Switching power supplies
- Audio equipment
- Medical equipment

Power supplies for servers
- UPS
- Rail
- Grid

EV/HEV
- Wind
- Rail

Medical equipment
- UPS
- Rail

Switching power supplies
- IGBT/IPM
- MOSFET
- SiC

Audio equipment
- IGBT/IPM
- MOSFET

China Power Supply Society (CPSS)

ON Semiconductor®

Empowering the electronics industry
A Power Technology Roadmap
IGBT Technologies Evolution

Field Stop IGBT Features & Performance

- Low conduction and switching losses
- Positive temperature coefficient for easy parallel operation
- Maximum junction temperature: $T_j = 175^\circ C$
- Tight parameter distribution
- Large SOA (Safe Operating Area)

IGBT at 750V and 1200V IGBTs are most suited for drivetrain electrification at its current development stage

Higher Power in development
IGBT Technology for Safe Operations

The IGBT Triangle

- On-state Voltage Drop
- Turn-off Loss
- Ruggedness

Trade-off Relationships

- Power Efficiency
- Reliable Operation
- \( E_{\text{off}} \)
- \( V_{\text{ce-sat}} \)
- \( T_{\text{sc}} \)

Technology evolution = moving towards the trade-off chart origin
Technology optimization = application specific tuning
Technology Trend (in Auto) = Gain performance but maintain system ruggedness in short circuit and latch-up performance
IGBT Innovation Through Package

- Benefits of Integrated Power Modules
  - Increase Integration
  - Reduces footprint
  - Lower stray inductance
  - Minimize switching losses
  - Better Thermal
  - Improve reliability
  - Simplifies assembly
  - Easy control with reference driver board

- Smart IGBT features
  - On die or on board current sense
  - Over-current detection with soft-shutdown
  - Under-voltage lockout
  - Temperature sense for safe operations

- Other Automotive modules in development
  - Optimized cooling with innovative modules

Automotive High Power Half Bridge Module

Three Phase Motor Control Power Module
Traction Inverter Market Trend

- Traction inverter has an **aggressive cost cutting** roadmap
  - Cut $/kW
  - Cut weight
  - Cut volume
- To meet market demand, ON Semiconductor is determined to:
  - Develop **innovative module packaging** with high performance thermal solution
  - Utilize its **best in class silicon** technologies
  - Provide **comprehensive reference designs**
  - Offer **high reliability** automotive qualified products

![Traction inverter power electronics target roadmap (100kW Continuous Inverter)](chart.png)
## EV PIMs Power Module Platforms

### <50kW
- **Single side Cooling**

### 50kW to 200kW
- **SS Direct Cooling**
  - In Case Modules

- **Dual Side Cooling**
  - In transfer molded casing

### Next Gen
- **Dual Side Direct Cooling**
  - Top coolant path
  - Bottom coolant path

#### Current development of EV PIMs
- **Pkg Performance:**
  - Output power = 60kW
  - Nom. cost = ref$/KW

- **Pkg Performance:**
  - Output Power = 150kW
  - Nom. cost = -21%

- **Pkg Performance:**
  - Output Power > 160kW
  - Nom. cost = -32%

- **Pkg Performance:**
  - Output Power > 200kW
  - Nom. cost = -45%

#### TECHNOLOGY EVOLUTION

- **Addressed by discrete solutions**
Automotive Expectations for Reliability

• Design-in Quality/Reliability
  • Not limited to component reliability testing. Requirements from development through and past End-of-Life

• High Performance Electronics
  • System integration on package level
    • System in Package (SiP)
  • Higher integration/Multichip Modules
    • Power Integrated Modules (PIM)
    • Intelligent Power Modules (IPM)
    • Automotive Power Modules (APM/AHPM)
Approach to Provide Better Value to Customers

**High Power Appl’**

- Electric Power Steering
- Braking & ARS
- 48V E-Compressor
- 48V E-Super Charger
- 48V B(i)SG
- 48V DC/DC Converter
- 12V/ 48V Battery Switch
- On Board Charger/ HV DC DC

**Product Definition**

- Variety of Silicon Options
  - 30V, 40V, 80V, 100V, 150V, 650V & WBG

**Passives Selection**

- Temperature sensing
- Current Sensing – Hall IC/Shunt
- Snubber Circuit

**Package Technology**

- DBC Substrate Options
- Wire Bond vs. Clip
- Interconnection Options: soldering, welding, press-fit, screw

**Benefit To Customer**

- Thermal Performance
- Compact Size (Power Density)
- Electrical Performance
  - High Current
  - Inductance
  - Resistance
  - EMI
- Assembly Cost
- Proven Reliability
- Proven Reliability
Industrial Modules for Solar Applications

- Distributed systems (80-150 kW) gaining acceptance
- 1500V solar panels => 950/1000V IGBT nodes
- Multi-level topologies for higher efficiency
- Fast switching IGBTs & Unique topologies => Easier with modules
- Hybrid or Full WBG modules on horizon

Customized Circuit Configurations (↑Efficiency)

Key Package Platforms
Transfer Molded Power Integrated Module (TMPIM)

- TMPIM: transfer molded module for medium power application

Features

- **Transfer molded**
  - Robust
  - Corrosion resistant

- **DBC substrate**
  - Low thermal resistance

- **Leadframe with pin selective removable**
  - Design flexible

- **No IC integration**
  - Cost effective
Summary: Market/Application Trends

Trends

• High performance EVs
• Fast Charging (High voltage)
• High Power (>200 kW) Traction/OBC

• China labor shortages
• MFG in high cost regions (Tariffs)
• Automation, Robotics (Servo motors)

• Alt Energy + storage (↑ ROI)
• Fast Charging (Hi-pwr EVC)
• Higher Data center PUEs (High Eff UPS)

• High power Custom PIMs

Scalable DSC Module (100kW – 200kW – 350kW)

Integrated Power Modules (IPM)

Application Specific PIMs
Thank You

谢谢

Questions?