GaN Power ICs
Drive Efficiency and
Size Improvements in BLDC Motor Drive Applications
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GaN power ICs drive Efficiency and Size Improvements in BLDC Motor Drive Applications

• Introduction
• Selection criteria for GaN power switches in motor inverters
• Design considerations
• Experimental results
• Conclusions and future works
Motor inverters: 3-phase topology

- IGBT: “Workhorse” of the industry; slow switching speed, low losses at high power
- MOSFET: Faster switching, better light-load efficiency
- GaN: Almost no switching losses, no reverse recovery

<table>
<thead>
<tr>
<th>Switch Type</th>
<th>Light load efficiency</th>
<th>Full load efficiency</th>
<th>Switching losses</th>
<th>Dead time</th>
<th>Switching frequencies</th>
<th>Bus voltages</th>
<th>Power range</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGBT</td>
<td>-</td>
<td>++</td>
<td>-</td>
<td>&gt; 2 µs</td>
<td>up to 20 kHz</td>
<td>high</td>
<td>up to MW</td>
</tr>
<tr>
<td>MOSFET</td>
<td>++</td>
<td>+</td>
<td>-</td>
<td>&gt; 2 µs</td>
<td>up to 60 kHz</td>
<td>400 V</td>
<td>4 kW</td>
</tr>
<tr>
<td>GaN</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>&lt; 100 ns</td>
<td>&gt; 100 kHz</td>
<td>400 V</td>
<td>4 kW</td>
</tr>
</tbody>
</table>
**GaN FETs have lowest switching losses**

- IGBTs and silicon MOSFETs show „reverse recovery“
  - PN junctions in the current flow: Charge removal needed for blocking voltage
- Recovery time can be 1 µs or longer (>3% of the total switching period at 16 kHz, not available for the control loop)
  - Large current peaks cause noise
- GaN FETs do not have reverse recovery → dead time in the halfbridge topology can be reduced to < 100 ns

⇒ Control loop response can be optimized
⇒ Reduced motor current harmonics (noise, wear)
⇒ Much lower power losses
⇒ Reduced EMI

(Source: Infineon, CPSS, 2017)
Eliminate > 70% of the switching losses with GaN power ICs

Application case:
• Bus voltage 400 V
• Current 7 A RMS
• Motor power 2 kW
• Switching 6 V/ns
• GaN and MOSFET same conduction losses

Using GaN FETs, the inverter efficiency increases by 2.5% (96%→98.5%) and total losses are halved (15 W→6.8 W)

➡ Significant reduction in cost, weight and size of thermal mgmt (like heatsink, fans, other thermal components)
➡ Benefit even larger at higher switching frequency
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Selection criteria – Power dissipation budget

- Previously, IGBTs and MOSFETs were selected for roughly equal conduction and switching losses at full load.

- GaN power ICs offer **new options**:  
  - Reduce total power dissipation budget to a point where no (or small) heatsinks are needed.  
  - Select higher $R_{DS(ON)}$ switch at lower cost to use the previous switching loss budget.  
  - Operate at higher carrier frequency for same (or lower) losses, enabling a change in modulation scheme.  
  - Operate at higher carrier frequency for same (or lower) losses, to enable new motor types and construction.
**Selection criteria – Driver & Protections**

- **High, stable and repeatable performance** → design margins can be reduced
  - Very low prop delay for best control loop performance
- Controlled gate drive conditions enable **outstanding reliability**
- **Much reduced component count** → system size and cost reduced, enabling motor-integrated inverters
- Easy to use → **fast time to market**
- Lossless current sensing **removes shunt resistors** → cost, size, reliability and performance improvement
- Fast and precise overcurrent protection → improved **system robustness**
- On-chip temperature sensing for better thermal design margin
- Precise overtemperature turn-off → improved **system robustness**

**GaNSense™ enable digitally controlled power stages**

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Selection criteria – Overcurrent protection

Autonomous OCP:
• Fast-acting self-protection
• Cycle-by-cycle protection
• Excellent robustness
• GaN FET on-time gets truncated at each OCP event
• OCP latch gets reset at next PWM rising edge

Very fast overcurrent turn-off $\rightarrow$ excellent protection
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Reference design
300W motor integrated inverter

- Target: 300 W motor power at smallest size
- Using 3x NV6247 fully integrated GaN power half-bridge IC
- Inverter only (w/o supply, EMI filter, control)
- Works with most controllers

Schematic (one leg shown)
Halfbridge connection diagram
Straightforward PCB layout

- Low-side VCC Supply (9 to 24 V)
- Low-side gate drive supply (internally generated) (with RDDL turn-on control)
- CS output (loss-less current-sensing programmable with RSET)
- Large Thermal Pads
- PWM inputs
- Enable input

High-side supply pins

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Reference design
300 W motor integrated inverter

Board diameter 56 mm

Thermal scan @ 300 W, 20 kHz
Reference design
99% inverter efficiency with GaN power ICs

- Very high inverter efficiency across whole load range
  - $V_{bus} = 300V$
  - $f_{SW} = 20kHz$
- Little impact of switching speed
Reference design

Cool operation at high speed

- Very high inverter efficiency across whole load range
  - $V_{bus} = 300V$
  - $f_{SW} = 20kHz$
- GaN power ICs with same footprint allow scaling of motor power and losses in same PCB
  - NV6245: 2x 275 mΩ
  - NV6247: 2x 170 mΩ
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Conclusion

• Through GaNFast™ / GaNSense™ integration, GaN power ICs are ready now
  • Reliable and repeatable performance of e-mode GaN power transistors
  • Smallest form factor and lowest losses
  • Easy to use digital power stage

• Massive performance improvement over silicon alternatives

• Potential to move to higher carrier frequency

• Very good availability and plentiful supply chain – re-using older silicon fabs with little additional expense and waste

GaN power ICs enable the next level of performance, reliability and robustness in motor inverter applications
Thank you for your attention!

I'm pleased to answer your questions.

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