• GaN increases efficiency, reduces size, weight and system cost from 20 W to 20 kW
• GaN E-HEMTs use similar design techniques to what designers do today
• Ecosystem of support components
• Creates new topologies, enhances existing topologies
• GaN E-HEMTs lowest switching losses
• GaNPX® packaging allows for cost effective superior thermal solutions
GaN Systems - Company Overview

- **Market leader for gallium nitride (GaN) power transistors**
  - Enhancement mode devices
  - 100V & 650V devices.
  - High current devices (100V to 90A, 650V to 60A)
  - Industry’s most robust gate drive with +10/-20V range

- **Global company with decades of GaN experience**
  - Overnight shipping through distribution since 2014
  - HQ and R&D in Ottawa, Canada
  - Global Sales & Applications support
  - World-class fabless manufacturing and advanced packaging
# GaN product portfolio

## Products

### 650 V

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Voltage [V]</th>
<th>Current [A]</th>
<th>Rds(on) [mΩ]</th>
<th>Dimensions [mm]</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS66502B</td>
<td>650</td>
<td>7.5</td>
<td>200</td>
<td>5.0 x 6.6 x 0.51</td>
<td>Bottom-side</td>
</tr>
<tr>
<td>GS66504B</td>
<td>650</td>
<td>15</td>
<td>100</td>
<td>5.0 x 6.6 x 0.51</td>
<td>Bottom-side</td>
</tr>
<tr>
<td>GS66508T</td>
<td>650</td>
<td>22.5</td>
<td>67</td>
<td>5.6 x 4.5 x 0.54</td>
<td>Top-side</td>
</tr>
<tr>
<td>GS66508B</td>
<td>650</td>
<td>30</td>
<td>50</td>
<td>7.0 x 8.4 x 0.51</td>
<td>Bottom-side</td>
</tr>
<tr>
<td>GS66508P</td>
<td>650</td>
<td>30</td>
<td>50</td>
<td>10.0 x 8.7 x 0.51</td>
<td>Bottom-side</td>
</tr>
<tr>
<td>GS66508T</td>
<td>650</td>
<td>30</td>
<td>50</td>
<td>6.9 x 4.5 x 0.54</td>
<td>Top-side</td>
</tr>
<tr>
<td>GS66516T</td>
<td>650</td>
<td>60</td>
<td>25</td>
<td>9.0 x 7.6 x 0.54</td>
<td>Top-side</td>
</tr>
<tr>
<td>GS66516B</td>
<td>650</td>
<td>60</td>
<td>25</td>
<td>11.0 x 9.0 x 0.51</td>
<td>Bottom-side</td>
</tr>
</tbody>
</table>

### 100 V

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Voltage [V]</th>
<th>Current [A]</th>
<th>Rds(on) [mΩ]</th>
<th>Dimensions [mm]</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS61004B</td>
<td>100</td>
<td>45</td>
<td>15</td>
<td>4.6 x 4.4 x 0.51</td>
<td>Bottom-side</td>
</tr>
<tr>
<td>GS61008P</td>
<td>100</td>
<td>90</td>
<td>7.0</td>
<td>7.6 x 4.6 x 0.51</td>
<td>Bottom-side</td>
</tr>
<tr>
<td>GS61008T</td>
<td>100</td>
<td>90</td>
<td>7.0</td>
<td>7.0 x 4.0 x 0.54</td>
<td>Top-side</td>
</tr>
</tbody>
</table>

### Eval kits, reference designs & power modules

- FAQs, Datasheets, CAD symbols, STEP files, Thermal models, Pspice, LTspice models, Application Notes

---

**Low Resistance. Low Gate Charge. High Voltage. Very High Currents. Simple Gate Drive**
Customers have proven the value proposition

**EV Battery Charger**

- **Power Density**
  - Si
  - SiC
  - Other GaN
  - GaN Systems

- **Efficiency**
  - Si
  - SiC
  - Other GaN
  - GaN Systems

- **5X size reduction**
- **>3X loss reduction**

**Inverter**
- in Silicon & 5X smaller in GaN

**Solar**
- in Silicon & 2X smaller in GaN
Fundamentals of GaN Systems E-HEMT

GaN Enhancement mode High Electron Mobility Transistor (E-HEMT):
• Lateral 2DEG (Two-dimensional electron gas) channel formed between AlGaN and GaN layers
• Positive gate bias turns on 2DEG channel
• 0V or negative gate voltage shuts off 2DEG and blocks forward conduction (allows reverse conduction)
• Voltage driven: Gate driver charges/discharges \( (C_{GD} + C_{GS}) \)
• No DC gate driving current needed: gate leakage current only \( (I_{GSS}) \)

Simply put – A GaN E-HEMT is just like a MOSFET but much much faster.
Traditional PQFN + Wire Bond

Proven embedded packaging for high speed GaN device:
- Extremely low inductance: high frequency switching
- Near Chip Scale embedded Packaging
- No wire bonding: high reliability
- Lower thermal resistance $R_{\theta JC}$

$T_{\text{source}} \approx 0.4 \, \text{nH}$

High $dv/dt$
Low $V_{DS}$ overshoot
Better EMI

Benefiting from the full capability GaN requires the right package
Driving GaN is Straightforward

650V GaN Gate driver design
- Voltage driven similar to Si MOSFETs:
  - +5-6V for turn-on, 0V or negative for turn-off
  - Maximum +7/-10V, transient +10/-20V
- High side / half bridge gate drive:
  - Choose driver with high CMTI (>100V/ns)
  - Recommend isolated DC/DC, for Bootstrap:
    - Bootstrap voltage stability: post-regulation
    - Watch for bootstrap diode loss at higher f_{sw}

100V GaN gate driver design
- R_{G(on)} \simeq 3-6.8 \, \Omega, minimize gate and power loop inductance
- Typically use half bridge driver IC with bootstrap, 0-5/6V

Simpler to drive than SiC and IGBT. Lower voltage than MOSFET to fully enhance.
Eco System of Partnerships with Industry Leaders

Gate Drivers
- Silicon Labs
- Analog Devices
- Peregrine Semiconductor
- Linear Technology
- Avago Technologies
- Heyday Technologies

Magnetics
- Hitachi
- TDK
- Delta
- Eaton
- Payton Planar
- Allied SiC

Modules
- Sharp
- CeramTec
- Ferrotec
- Hivron

Working with GaN is mainstream
PFC – A comparison of topologies

Boost PFC
- Fixed large diode bridge loss
- Challenge to achieve higher than 98% efficiency

2-phase semi-bridgeless PFC
- High component count and low component utilization
- Additional return diodes D₃/D₄
- D₁/D₂ needs to be fast-recovery diodes
- No bidirectional capability

MOSFET-based bridgeless TP PFC
- DCM mode → High inductor current ripple
- CrCM mode → Complicated control
- CCM mode → Reverse-recovery loss due to Q_{rr}

GaN enables most desired PFC topology ... Bridgeless Totem Pole
The Value of GaN

- No parasitic BJT and Body Diode
- Zero Reverse Recovery
- Reverse conduction, anti-Parallel Diode not required

Smaller Size

- Higher frequency → Smaller filters
- Better topology → Fewer parts
- Lower loss → Smaller heatsink

Better Efficiency

- Increases from 97.5% to 99%

Lower System Cost

- Smaller EMI filter → less expensive
- Smaller heatsink → less expensive

GaN makes smaller, more efficient, lower cost PFC solutions possible
A smaller $C_{oss}$ leads to:

- Air gap $\downarrow$ $P_{trans\_loss} \downarrow$
- $L_m \uparrow$ $\rightarrow$ $P_{trans\_loss} \downarrow$
- $f_s \uparrow$ $\rightarrow$ $P_{sw\_cond} \downarrow$

$T_{dead} \geq 16 \times C_{oss(ER)} \times F_s \times L_m$

Sufficient deadtime
Sufficient inductive energy from $L_m$

High efficiency
High power density

Better switching characteristics of GaN improve LLC efficiency and size
Application – Power Supply 200W AC/DC

**Silicon**
- 92% efficient
- 16.5 W losses
- 12 W/in³

**GaN**
- 96% efficient
- 9 W losses
- 30 W/in³

GaN lowers losses by > 45% and increases density by 2.5 times compared to silicon
Let’s compare GaN to SiC

### GaN E-HEMT Daughter Board

- Isolated Gate Driver
- GaN E-HEMT X 2

### SiC MOSFET Daughter Board

- SiC MOSFET X 2

<table>
<thead>
<tr>
<th>Comparison</th>
<th>GaN E-HEMT</th>
<th>SiC MOSFET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package</td>
<td>GaNPX®</td>
<td>D2PAK</td>
</tr>
<tr>
<td>V_{DS\text{max}}</td>
<td>650 V</td>
<td>900 V</td>
</tr>
<tr>
<td>I_D@25°C</td>
<td>30 A</td>
<td>35 A</td>
</tr>
<tr>
<td>R_{DS(on)}@25°C</td>
<td>50 mΩ</td>
<td>65 mΩ</td>
</tr>
<tr>
<td>V_{GS(op)}</td>
<td>-10/+7 V</td>
<td>-4/+15 V</td>
</tr>
<tr>
<td>C_{ISS}</td>
<td>260 pF</td>
<td>660 pF</td>
</tr>
<tr>
<td>C_{OSS}</td>
<td>65 pF</td>
<td>60 pF</td>
</tr>
<tr>
<td>C_{RSS}</td>
<td>2 pF</td>
<td>4 pF</td>
</tr>
<tr>
<td>Q_G</td>
<td>5.8 nC</td>
<td>30.4 nC</td>
</tr>
<tr>
<td>Q_{GS}</td>
<td>2.2 nC</td>
<td>7.5 nC</td>
</tr>
<tr>
<td>Q_{GD}</td>
<td>1.8 nC</td>
<td>12 nC</td>
</tr>
<tr>
<td>Q_{RR}</td>
<td>0 nC</td>
<td>245 nC</td>
</tr>
</tbody>
</table>

Same PCB layout for **both boards**
- 2 oz. copper
- 4 PCB layers
- Homogeneous thermal vias

GaN and SiC boards created to exhibit same external parasitic effects
Switching Waveforms: GaN and SiC

- GaN E-HEMT (650V/50mΩ) vs SiC MOSFET (900V/65mΩ)
- Switching test performed at 400V/15A half bridge hard switching double pulse test
- Use same gate driver Silab Si8271 and $R_{G(on)} = 10\, \Omega$, $R_{G(OFF)} = 1\, \Omega$ for both GaN and SiC

GaN has 4x faster turn-on and 2x faster turn-off time than SiC MOSFET
Turn-on and Turn-off losses: GaN and SiC

400V/15A Eon measurement

GaN E-HEMT: $E_{on} = 41.15 \mu J$

SiC MOSFET: $E_{on} = 118.3 \mu J$

400V/15A Eoff measurement

GaN E-HEMT: $E_{off} = 11.02 \mu J$

SiC MOSFET: $E_{off} = 33.8 \mu J$

400V/15A half bridge switching losses
(Si8271GB-IS, $R_{G(on)} = 10 \Omega$, $R_{G(on)} = 2 \Omega$, $T_J = 25^\circ C$)

GaN switching losses ~ 3x lower than SiC
Temperature Effects: GaN and SiC

Lower losses benefits
- Decrease heatsink size
- Increase power density
- Reduce operating cost
- Increased lifetime

Switching Energy Loss v.s. Junction Temperature
$V_{ds}=400V$, $I_{ds}=10A$

GaN has lower losses across full temperature range
Synchronous Buck DC/DC System Efficiency and $T_J$
400V-200V, 200kHz, $T_{amb} = 25^\circ C$

**GaN increases efficiency up 1%**

**GaN is more than 60 °C cooler**

---

**Power Loss and Junction Temperature Comparison at $P_{OUT} = 900$ W, $f_{sw} = 200$ kHz**

<table>
<thead>
<tr>
<th></th>
<th>GaN E-HEMT Solution</th>
<th>SiC MOSFET Solution</th>
<th>GaN advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>package-area (mm²)</td>
<td>31</td>
<td>160</td>
<td>5X smaller</td>
</tr>
<tr>
<td>Conduction Loss (W)</td>
<td>0.27</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>Switching Loss (W)</td>
<td>6.1</td>
<td>11.4</td>
<td></td>
</tr>
<tr>
<td>Total Loss (W)</td>
<td>6.4</td>
<td>11.8</td>
<td>~50% lower</td>
</tr>
<tr>
<td>$T_j$-Tamb (°C)</td>
<td>32</td>
<td>91</td>
<td>3 times better</td>
</tr>
</tbody>
</table>

GaN’s lower switching losses $\Rightarrow$ lower temp rise $\Rightarrow$ better, more reliable performance.
Accelerating the Design Effort - IMS Evaluation Platform

**GSP65R25HB-EVB or GSP65R13HB-EVB**

- GaN High Power Half Bridge evaluation assembly
- (Gate Driver pcb + IMS HB)

**GSP65MB-EVB**

- High Power Full Bridge evaluation platform mother board

IMS Half Bridge Boards
- (w/o parallel and single transistor)

Uses design concept of higher power GaN intelligent power modules (IPM).
Vertical Mounting of HB IMS +Driver EVB makes good use of vertical height available in high power (> 5kW) designs.

Optimized driver board minimizes both power and gate driver loops. Minimizes common source, power and gate driver loops.

IMS based evaluation platform augments the thermal and layout benefits of GaNPX.
GaN Systems today

<table>
<thead>
<tr>
<th>Category</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer</td>
<td>TV, laptop, charger, air conditioner</td>
</tr>
<tr>
<td>Datacenter</td>
<td>Server, switch, memory module</td>
</tr>
<tr>
<td>Industrial</td>
<td>Motor, pump, solar panel, AC adapter, wireless power, OBC</td>
</tr>
<tr>
<td>Transportation</td>
<td>Car, forklift, scooter</td>
</tr>
</tbody>
</table>

**#1 in GaN**
- Highest current; broadest voltages
- Best electrical performance
- Best die & best package
- Most widely used by customers

**Shipping since 2014**
- Offices in 7 countries
- Worldwide disti & direct sales

**Customer successes**
- Solar Inverter and ESS
- Motor Drives and Pumps
- Wireless Power and Charging
- AC Adapters
- Datacenter Server and Rack Power
- Automotive Onboard Charger
GaN E-HEMTs in practical design solutions - Summary

- **GaN-based power designs are more efficient, smaller, lighter**
  - Higher efficiency (cuts losses 50-90%)
  - Smaller Size (reduces to 1/4 the size) – higher volumetric power densities (kW/l)
  - Lighter (typically 1/4 the weight) – higher gravimetric power density (kW/kg)

- **Easy to use**: similar drive to MOSFETs, low external parasitic effects

- **Enable BTP PFC topology**
  - No body diode ⇒ Zero Reverse Recovery yet
  - Reverse conduction Capable ⇒ anti-Parallel Diode not required

- **Improve existing LLC topology**
  - Low $C_{OSS}$, reduces Xformer losses, reduces rms current to reduce conduction losses

- **Superior thermals**: cost effective GaN PX® packaging

- **Lower costs**: system, shipping, installation, maintenance and operating costs
Thank You for your time today .... Questions?