Advancing GaN Power Integration: Efficiency, Reliability & Autonomy

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Pioneering Growth: #1 in GaN
GaN: An Expansive Market Opportunity

Application Power

Device Voltage (V)

- 1MW+
- 100kW
- 10kW
- 1kW
- 100W
- 10W

- 600V
- 300V
- 100V
- 30V

GaN (Lateral)

$13.1B+$ Market Opportunity\(^{(1)}\)

SiC (Vertical)

- EV Inverters
- Solar String Inverters
- Wind Turbines
- Utility
- Traction
- EV On-board Chargers & DC/DC Converters
- Solar Microinverters
- 5G Base Station
- TV, Game System
- Industrial Motors, Welders, UPS
- LED Lighting
- Mobile Wireless Power
- Laptop Adapters
- All-in-One PC
- 5G Pico Cell
- Smartphone, Tablet Chargers

Device Structure

- Lateral
- Vertical

Circuit Integration

- Yes (Power + Analog)
- No

Switching Frequency

- Highest (200 kHz – 2 MHz)
- Medium (100 – 300 kHz)

Cost

- Si substrate (very low cost)
- SiC substrate (10x cost vs Si)

Thermal performance

- Same as Silicon (1.3 W/cmK)
- Highest (3.8 W/cmK)

(1) GaN IC potential market based on voltage rating of 80V – 1,000V derived from Yole Développement. Status of the Power Electronic Industry 2020. Reflects estimated GaN market opportunity for power semiconductors by 2026.

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### GaN Adoption into Key Growth Markets

#### Fast Chargers
- 3x faster charging
- 50% smaller size
- 50% reduced weight

#### Consumer
- 3x smaller and lighter solutions
- Low-profile

#### Enterprise
- <10% reduction in datacenter electrical consumption
- Saving >15 TWh / $1.9B/yr

#### Solar
- 25% cost reduction of micro-inverters
- <40% energy savings
- Improve payback by 10%+

#### EV
- 3x faster charging
- 70% energy savings
- 5% longer range / lower battery cost

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Speed and Efficiency Drive Value

- **Size, Weight:**
  - Higher frequency reduces size, weight
  - GaN Discrete vs. GaN IC: 1.0x, 0.6x, 0.35x

- **Energy Savings:** Integration increases efficiency, reliability
  - GaN IC: 40%
  - GaN Discrete: 20%

- **Energy Efficiency:**
  - silicon: 85-90%
  - GaN Discrete: 88-92%
  - GaN IC: 90-95%

GaN power ICs enable up to 3x smaller, lighter (1)

GaN ICs save 40% energy (2), 100x more reliable (3)

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(1) Based on Navitas measurements of GaN-based chargers compared to Si-based chargers with the same output power.
(2) Navitas estimate of GaN-based power systems compared to Si-based systems in the 2024-2025 timeframe, Navitas measurements of select GaN-based chargers vs. Si-based chargers with similar power.
(3) VGS failure distribution based on Navitas internal characterization of Discrete GaN Transistors compared to GaN power ICs.
**GaN Integration for Efficiency, Speed & Stability**

Discrete External Driver

\[ R_{\text{damp}} \] required to reduce oscillation and voltage spike at the power FET gate

Monolithic GaN Driver + FET

Minimized gate loop eliminates any unwanted noise to effect the control and reliability of the device

External Driver + 2 Ω

\[ T_f = 3.5 \text{ ns} \]

Integrated Driver

\[ T_f = 0.6 \text{ ns} \]
Benefits of Integrating Control, Drive, Protection

Discrete GaN
- 2x fewer components
- 3x Smaller design
- Internal Gate protection
- No Gate Ringing

GaNFast IC
- 1x GaN Power IC
- +14 components
- 1/2 the Components
- 1/3 the Area

Risky, Erratic, Lossy

Reliable, Predictable, Efficient
Introduction to GaN Power

- WBG GaN material allows high electric fields so high carrier density can be achieved
- Two-dimensional electron gas with AlGaN/GaN heteroepitaxy structure gives very high mobility in the channel and drain drift region
- Lateral device structure achieves extremely low $Q_g$ and $Q_{OSS}$ and allows integration
- Integration on silicon substrates means mature low-cost wafer fabrication is available

GaN HEMT Device Structure

Interface of GaN/AlGaN forms a plane of electrons (2DEG), creating high electron mobility

Technology Comparison

<table>
<thead>
<tr>
<th>Energy Gap</th>
<th>Electron Mobility</th>
<th>Saturation Drift Velocity</th>
<th>Breakdown Electric Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si 1.12</td>
<td>Si 1400</td>
<td>Si 1</td>
<td>300</td>
</tr>
<tr>
<td>SiC 3.26</td>
<td>SiC 900</td>
<td>SiC 2</td>
<td>2000</td>
</tr>
<tr>
<td>GaN 3.4</td>
<td>GaN 2000</td>
<td>GaN 2.5</td>
<td>GaN 3300</td>
</tr>
</tbody>
</table>

Fastest switching

Stable/robust/low leakage

Smaller die
GaNFast Power IC

- Monolithic integration of GaN FET, GaN Driver, GaN Logic
- 650 V eMode power device
- 10x lower drive loss than silicon
- Driver impedance matched to power device
- Short prop delay (10ns)
- Digital input

- Zero inductance turn-off loop
- High dV/dt immunity (200 V/ns)
- Regulated gate voltage
- Controllable turn-on dV/dt
- Rail-rail drive output
GaN Integration for Efficiency, Speed & Stability

Discrete External Driver

\( R_{\text{damp}} \) required to reduce oscillation and voltage spike at the power FET gate

Monolithic GaN Driver + FET

Minimized gate loop eliminates any unwanted noise to effect the control and reliability of the device

\( T_f = 3.5 \text{ ns} \)

\( T_f = 0.6 \text{ ns} \)
GaNFast: Clean & Efficient

- 500 V Switching
- No overshoot / spike
- No oscillations
- ‘S-curve’ transitions
- Zero Loss Turn-on
- Zero Loss Turn-off
- Sync Rectification
- High frequency
- Small, low cost magnetics
Voltage Slew Rate Control

• dV/dt controllable from 180 V/ns to 10 V/ns for EMI optimization

RDD for optimized dv/dt

Turn off to support system EMI

Cross reference of RDD vs dv/dt
3x Lower Drive and Level Shift Loss at 1 MHz

FET-specific loss (e.g. $I^2R$) common across all options, not included.

GaN gate charge loss nearly negligible, common across all options.
5x Smaller Footprint than Best Single GaN

Digital Isolator
2x Single GaN Power ICs
Bootstrap diode
Passives

Half Bridge GaN Power ICs 5X smaller than alternatives

Size (PCB Area, mm^2)

<table>
<thead>
<tr>
<th>Component</th>
<th>PCB Area (mm^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOIC, IR2113</td>
<td>400</td>
</tr>
<tr>
<td>Capacitive-coupled, UCC21521</td>
<td>350</td>
</tr>
<tr>
<td>Capacitive-coupled, Si8108B-B-4S</td>
<td>300</td>
</tr>
<tr>
<td>Inductive-Coupled, ADuM1234</td>
<td>250</td>
</tr>
<tr>
<td>Inductive-Coupled, ADuM3223</td>
<td>200</td>
</tr>
<tr>
<td>Inductive-Coupled, BM60210FV-C</td>
<td>150</td>
</tr>
<tr>
<td>Inductive-Coupled, 2ED030106</td>
<td>100</td>
</tr>
<tr>
<td>GaN, NV62xx</td>
<td>50</td>
</tr>
</tbody>
</table>
Reliability Benefits

$V_{\text{MAX}}$ on $V_{\text{CC}}$ & $V_{\text{PWM}}$
pins have 30 V rating

Built-in regulator precisely controls
gate voltage applied to eMode gate

Sensitive eMode gate node
protected from system noise and
spikes

ESD protection
integrated into all pins
(>1000 V HBM, >1000 V CDM)

Eliminates parasitic inductance, turn-off
losses, and false turn-on of eMode gate

All benefits while delivering
the performance advantage
of Navitas' GaN Power ICs!
Precise Gate Voltage = Excellent Reliability

- Patented integrated regulator circuit guarantees operation with >>10+ years of estimated life
- Integrated driver eliminates parasitic inductance, delivers precise gate drive and maintains device within SOA

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**Turn-on (Hard Switching)**

**Partner Feedback:**

“Fast and very clean switching”

“Easy to control slew rates”

“Integrated gate allows fast switching”

(dV/dt > 200 V/ns, di/dt > 10 A/ns)

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**Turn-off (Hard Slewing)**

**Partner Feedback:**

“Protected gate removes external parts without restricting switching speeds”

“Minimal ringing optimizes EMI”

“No gate-loop risks”
**Si Avalanche Testing**

- Voltage limited by Avalanche
- Large energy loss during over-voltage
- Usually tested only once at final test
- Repetitive avalanche can lead to failure

**Navitas GaN Surge Testing**

- 3,600,000,000 spikes and zero failures!
- Negligible loss during overvoltage
- No RDS(ON) shift
- No IDSS shift

**Integrated Drain Reliability**

- Large drain voltage design margin
- 800V transient rating
- 900V production test
Reliable: Double-Pulse Test

Discrete GaN

GaNFast with GaNSense Technology

➢ Clean switching, no ringing and no glitching

➢ Ringing can lead to gate voltage over-stress, poor gate reliability, reduced lifetime

➢ Glitching can lead to poor EMI and device failure

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GaNFast Evolution

Silicon FET

- Old, slow technology
- High Qg
- High Coss
- Fsw < 100kHz

Discrete GaN

- Exposed gate
- External gate drive
- dV/dt sensitivity
- Layout sensitivity
- ESD sensitivity
- Unknown reliability
- Unknown robustness

GaNFast

- Internal Gate
- Integrated Gate Drive
- dV/dt Immunity
- Layout insensitive
- 2KV ESD rating
- Proven Reliability
- Proven Robustness

GaNFast™ with GaNSense™

- Autonomous Standby
- Autonomous Protection
- Loss-less Current Sensing
- High Precision
- High Efficiency

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Loss-Less Current Sensing: Why?

- Reduce $R_{DS(ON)}_{TOTAL}$ by 50%
- Efficiency increased +0.5%
- No $R_{CS}$ PCB hotspot (-85°C)
- No $R_{CS}$ PCB footprint (-30 mm$^2$)
Loss-Less Current Sensing: How?

- Integrated sense-FET accurately measures through various techniques.
- $R_{DS(ON)}$ and temperature affects are cancelled out naturally.
- Power loss is negligible, especially compared to shunt resistors.
Lossless Current Sensing – Details

DCM Tracking
Example @ 192KHz

CCM Tracking
Example @ 200KHz

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The Efficiency Benefit

Efficiency (60W HFQR, 20V/3A)

AC Line Input [V]<sub>AC</sub>

Efficiency +0.5%

0.5% higher efficiency, same R<sub>DS(ON)</sub>, lower R<sub>ON(TOT)</sub>

60W HFQR, 90V<sub>AC</sub>, 20V/3A, 1 Hour

NV6125

- R<sub>DS(ON)</sub> = 170 mΩ
- R<sub>CS</sub> = 170 mΩ
- R<sub>ON(TOT)</sub> = 340 mΩ

R<sub>CS</sub> HOT-SPOT = 85°C!

NV6136

- R<sub>DS(ON)</sub> = 170 mΩ
- R<sub>CS</sub> = 0 mΩ
- R<sub>ON(TOT)</sub> = 170 mΩ

NO HOT-SPOT
T<sub>GaN</sub> 10°C Cooler

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The Efficiency Benefit

Efficiency (60W HFQR, 20V/3A)

Similar Worst Case (90VAC) Efficiency

Same efficiency, smaller chip, same $R_{ON(TOTAL)}$

60W HFQR, 90VAC, 20V/3A, 1 Hour

NV6125
$R_{DS(ON)} = 170 \, m\Omega$
$R_{CS} = 170 \, m\Omega$
$R_{ON(TOT)} = 340 \, m\Omega$

$T_{GAN} = 83^\circ C$

NV6134
$R_{DS(ON)} = 260 \, m\Omega$
$R_{CS} = 0 \, m\Omega$
$R_{ON(TOT)} = 260 \, m\Omega$

No $R_{CS}$

$T_{GAN} = 85^\circ C$
Autonomous Over-Current Protection (OCP)

- **Autonomous OCP**
- **Fast-acting self-protection**
- **Cycle-by-cycle protection**
- **Excellent robustness**

- **6x faster protection**

- Uses QR controller OCP function
  - \( T_{OCP} = 180 \text{ ns} \)

- Integrated SCP function
  - \( T_{OCP} = 30 \text{ ns} \)

- **Existing solutions use ext. \( R_{CS} \)**
- **Filter + controller delay slow**

- **QR controller OCP slow turn-off time (300 ns)**

- **QR controller OCP = slow turn-off (180 ns)**
- **NV6136 OCP = fast turn-off (30 ns)**
Autonomous Over-Current Protection (OCP)

• On any given cycle, if the CS output voltage exceeds 1.9V, the internal gate driver will turn off the GaN IC and truncate the on-time.
  – **OCP response time 30ns!** Compare to ~200ns response if relying on most conventional controllers.
• The current at which the IC protects is dependent on the $I_{DRAIN} \rightarrow I_{CS}$ ratio and the value of $R_{SET}$.
• Turn-on OCP blanking time prevents noise from triggering the fault and is optimized for GaN FET protection.
• This protection mechanism is designed to be accurate and user programmable via $R_{SET}$. 
Over Temperature Protection

GaNSense IC w/OTP

- Safe turn OFF of GaN Power FET: $T_j < T_j\text{-max}$
- Safe RESTART of GaN Power FET

Tj, Tj-off, Tj-avg, Tj-restart

$V_{DS}$

Safe Thermal Area

time

Unprotected GaN

- Danger Zone! Thermal Destruction!
- GaN FET still switching: $T_j > T_j\text{-max}$

$T_j$, $V_{DS}$

time

time

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**Autonomous Standby Mode**

- GaN IC autonomously enters standby mode in the absence of PWM signals.
- Super fast wakeup at next PWM rising edge.
  - No discernable effect on propagation delay, current sense performance, etc...
- In the High Frequency QR Flyback no load example above, **full system standby losses are reduced 17%**
  - NV6125 Gen 2 GaNFast part (175mΩ typical).
  - NV6136 Gen 3 GaNSense part (170mΩ typical).

### Table: P_{IN} (no load)

<table>
<thead>
<tr>
<th></th>
<th>115 V_{AC}</th>
<th>230 V_{AC}</th>
</tr>
</thead>
<tbody>
<tr>
<td>NV6125</td>
<td>39 mW</td>
<td>40 mW</td>
</tr>
<tr>
<td>NV6136</td>
<td>33 mW</td>
<td>33 mW</td>
</tr>
</tbody>
</table>
# GaNSense Mass Production: 65W

<table>
<thead>
<tr>
<th>Charger Power, Output(s)</th>
<th>65W 2CA</th>
<th>65W 2C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Powertrain</strong></td>
<td>Discrete GaN</td>
<td>GaNFast IC with GaNSense</td>
</tr>
<tr>
<td>Size (cc)</td>
<td>105</td>
<td>75</td>
</tr>
<tr>
<td>Power Density (W/cc)</td>
<td>0.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>89.15%</td>
<td>92.50%</td>
</tr>
<tr>
<td>Loss (W)</td>
<td>7.1</td>
<td>4.9</td>
</tr>
<tr>
<td>Drive, Protection Components</td>
<td>19</td>
<td>5</td>
</tr>
<tr>
<td>PCB Area (mm²)</td>
<td>83</td>
<td>15</td>
</tr>
<tr>
<td>T&lt;sub&gt;CASE&lt;/sub&gt; max (°C)</td>
<td>85°C</td>
<td>&lt;77°C</td>
</tr>
</tbody>
</table>
**120W GaNFast with GaNSense**

**Si 120W 19V**

Asus 120W (PA-1121-28)
- 84.6%* peak
- 332 cc, 419 g
- 0.36 W/cc

**GaN 120W USB-C PD**

Xiaomi 120W Note 11 Pro
- 90.5%* peak
- 87.5 cc, 147 g
- 1.37 W/cc

*35% lower power losses
6% system efficiency improvement
~4x smaller system size

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**300W Totem-Pole PFC**

<table>
<thead>
<tr>
<th>Input</th>
<th>Universal AC (85-265V&lt;sub&gt;AC&lt;/sub&gt;, 47-63Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td>400V (300W)</td>
</tr>
<tr>
<td>Fast FETs</td>
<td>NV6117 (110mΩ) GaN Power ICs</td>
</tr>
<tr>
<td>Slow FETs</td>
<td>Si Superjunction (62mΩ)</td>
</tr>
<tr>
<td>Freq</td>
<td>300-1,200 kHz</td>
</tr>
<tr>
<td>Size</td>
<td>53.3 x 57.5 x 20 mm = 62 cc uncased (DSP controller board not included)</td>
</tr>
<tr>
<td>Power Density</td>
<td>4.9 W/cc (80 W/in&lt;sup&gt;3&lt;/sup&gt;) uncased</td>
</tr>
<tr>
<td>Target Efficiency</td>
<td>98.5% @ 220V&lt;sub&gt;AC&lt;/sub&gt;, 98% @ 110V&lt;sub&gt;AC&lt;/sub&gt;, 97.5% at 90V&lt;sub&gt;AC&lt;/sub&gt;, full load</td>
</tr>
</tbody>
</table>
1kW HV DC-DC

- 97.8% Efficiency, 800kHz
- 400 VDC\text{IN}, 48V\text{OUT}
- HB LLC

4x Smaller, 80% Energy Savings, 33% More Power

- **Silicon 750W**
  - (XP QHL750300S48)
  - 200 kHz, 92% peak
  - 116.8 x 61 x 12.7 = 90 cc
  - 8 W/cc

- **GaN 1 kW**
  - (Density Power DQB1K0F380S48)
  - 850 kHz, 97.7% peak
  - 58.4 x 36.8 x 14.5 mm = 31 cc
  - 32 W/cc

Efficiencies from Navitas lab measurement of XP device, and Density Power evaluation report.

4x Smaller, 80% Energy Savings, 33% More Power
1.2kW CPRS

- Designed by Navitas Data Center Design Center
- >96% Efficiency for Titanium grade
- Cased 185 x 73.5 x 39 mm (530 cc)
- Power Density: 2.6 W/cc

Exceeds EU ‘Titanium’ efficiency grade


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3.2kW Server Power

- GaNFast ICs for Totem-Pole PFC (MHz) + LLC (MHz)
- 98% Efficiency, 92W/in³
- AC-54V, 48V_{OUT}
- 1U x 2U x 210 mm (800 cc)
- Power Density: 4.4 W/cc (73 W/in³)

2x Smaller, 50% Energy Savings

Silicon 3,200W
(Meanwell DPU-3200-4B)
- 47 kHz, 500 kHz, 94.8% pk
- 325 x 107 x 41 mm = 1,426 cc
- 2.2 W/cc

GaN 3,200W
(UT Austin)
- 1 MHz, 97.7% pk
- 210 x 81 x 43 mm = 731 cc
- 4.4 W/cc

Efficiencies from Meanwell datasheet and UT Austin data

Interleaved CRM Totem PFC

FB LLC

3.2 kW AC-54V converter; 650V GaNFast power ICs for MHz totem-pole PFC and MHz LLC primary with 100V GaN FETs for LLC secondary rectification.

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• Navitas GaNFast ICs exhibit lower losses across all switching frequencies, but significantly as switching frequency increases.
**High Efficiency, Variable Speed Industrial Motors**

- Electric motors use ~70% of total industrial electricity consumption at ~60% efficiency
- WBG enables moving to modern, highly efficient motors, which can improve the total industrial electrical consumption efficiency to >90% and reducing the losses by >80%
- Higher power levels (20kW+) and voltages (690V and higher) enabled through SiC, whereas GaN is preferred for lower voltages

Reduction of 2.5Gt of CO₂ emissions
Summary

• GaN is the next generation power semiconductor that offers superior performance, whilst providing lower CO2 footprint in device and system manufacturing

• GaN power devices require monolithic integration of driver and power stage to enable highest frequency, performance, and reliability

• Device structure, design and manufacturing processes are paramount to quality and reliability.

• Further integration of real-time autonomous sensing and protection delivers highest efficiency, performance, and reliability.
Thank you