Advances in GaN Power ICs: Efficiency, Reliability & Autonomy

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Navitas
Energy • Efficiency • Sustainability

The Enabling Force

- **20x** Faster Switching
- **3x** Smaller & Lighter
- **Up To 40%** Energy Savings
- **Up To 3x** Higher Power Density
- **3x** Faster Charging
- **20%** Lower System Cost
Power-Hungry Smartphones Use GaN

Bigger screens, bigger batteries

More power, go GaN

Silicon
GaN
TBD

Screen Size (cm²) vs. Battery Size (mAh)

Charging Power (W) vs. Release Year

Bigger screens, bigger batteries

More power, go GaN

Translated from Chinese:
Bigger screens, bigger batteries

More power, go GaN
### Chargers go GaNFast

#### Tier 1 OEMs

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lenovo</td>
<td>Let’s go GaNFast</td>
</tr>
<tr>
<td>DELL</td>
<td>Let’s go GaNFast</td>
</tr>
<tr>
<td>LG Electronics</td>
<td>Let’s go GaNFast</td>
</tr>
<tr>
<td>Navitas</td>
<td>Let’s go GaNFast</td>
</tr>
<tr>
<td>Nvidia</td>
<td>Let’s go GaNFast</td>
</tr>
<tr>
<td>Xiaomi</td>
<td>Let’s go GaNFast</td>
</tr>
</tbody>
</table>

#### Aftermarket Examples

<table>
<thead>
<tr>
<th>Example</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amazon</td>
<td><img src="image" alt="Amazon" /></td>
</tr>
<tr>
<td>Baseus</td>
<td><img src="image" alt="Baseus" /></td>
</tr>
<tr>
<td>HyperCharger</td>
<td><img src="image" alt="HyperCharger" /></td>
</tr>
<tr>
<td>AUKEY</td>
<td><img src="image" alt="AUKEY" /></td>
</tr>
<tr>
<td>Spigen</td>
<td><img src="image" alt="Spigen" /></td>
</tr>
<tr>
<td>Belkin</td>
<td><img src="image" alt="Belkin" /></td>
</tr>
<tr>
<td>ZETRONIC</td>
<td><img src="image" alt="ZETRONIC" /></td>
</tr>
<tr>
<td>Anker</td>
<td><img src="image" alt="Anker" /></td>
</tr>
</tbody>
</table>

#### Key Figures

- **160+** GaN Chargers In Mass Production
- **150+** GaN Chargers In Development (MP 2021-2022)
- **90%+** Mobile OEMs Designing With Navitas GaN ICs
- **30M+** GaN ICs Shipped (1)
- **Zero** GaN Field-Failures (1)

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**Note:** Charger metrics as of November 2nd, 2021. Shipments as of October 31st 2021.

(1) Based on no customer-reported consumer failures for production shipments through October 31st 2021.
The GaNFast Evolution

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

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 Mode
- 800 Vmax
- 2KV ESD
- Over-Temperature Protection

- Autonomous Over-Current Protection

Exposed gate

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

- Autonomous Standby
- Autonomous Protection
- Loss-less Current Sensing
- High Precision
- High Efficiency
# Critical Integration: GaNFast

<table>
<thead>
<tr>
<th>Driver</th>
<th>Parasitics</th>
<th>Power Device</th>
<th>Speed</th>
<th>Power Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive, control &amp; protection</td>
<td>Limit speed &amp; efficiency</td>
<td>Si or GaN</td>
<td>Switching Frequency</td>
<td>Faster Charging, Smaller Size</td>
</tr>
<tr>
<td>Silicon Discrete</td>
<td>$L_G R_G$</td>
<td>(in system controller)</td>
<td>&lt; 100 kHz</td>
<td>&lt;0.5 W/cc</td>
</tr>
<tr>
<td>GaN Discrete</td>
<td>$L_G R_G$</td>
<td>(complex circuit)</td>
<td>&lt; 200 kHz</td>
<td>&lt;1 W/cc</td>
</tr>
<tr>
<td>Navitas GaN IC</td>
<td></td>
<td></td>
<td>Up to 2 MHz (3-10x faster)</td>
<td>&gt;&gt;1 W/cc</td>
</tr>
</tbody>
</table>
Loss-Less Current Sensing: Why?

• Reduce $R_{DS(ON)}_{\text{TOTAL}}$ by 50%
• Efficiency increased +0.5%

• No $R_{CS}$ PCB hotspot (-85°C)
• No $R_{CS}$ PCB footprint (-30 mm²)
Loss-Less Current Sensing: How?
Autonomous Standby Mode

- External $V_{CC}$ cut-off circuit required
- Requires system enable signal
- Autonomous standby mode
- Enters STBY during no PWM
- Fast wake-up at next PWM
- Standby power reduction (-17%)
- Removes 5 components
- Enters STBY during no PWM signal
- Wakes up again at each burst

HFQR, no load

<table>
<thead>
<tr>
<th>$P_{IN}$ (no load)</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>

17% Lower Standby Loss
The Efficiency Benefit

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

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

- NV6136
  - $R_{CS(HOT-SPOT)} = 0 \text{ m}\Omega$
  - $R_{ON(TOT)} = 170 \text{ m}\Omega$

0.5% higher efficiency, same $R_{DS(ON)}$, lower $R_{ON(TOTAL)}$
The System Cost Benefit

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

- NV6125 (170mOhm)
- NV6134 (260mOhm)

**Similar Worst Case (90VAC) Efficiency**

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

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

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

**60W HFQR, 90V\textsubscript{AC}, 20V/3A, 1 Hour**

No $R_{CS}$

Similar Temperatures
Autonomous Over-Current Protection (OCP)

**Uses QR controller OCP function**

\[ T_{OCP} = 180 \text{ ns} \]

**Autonomous OCP**
- Real-time self-protection
- Cycle-by-cycle protection
- Excellent robustness

**QR controller OCP**
- Slow turn-off time (180 ns)

**NV6136 OCP**
- Fast turn-off (30 ns)

**6x faster protection**

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

**QR controller PWM output**

**Integrated SCP function**

**NV6136 GaN FET V_{DS}**

**QR controller OCP slow turn-off time (300 ns)**
Over-Current Protection (OCP) cont.

- NV6134A in double pulse tester
- CS signal matches $I_{DS}$ current, independent of temperature
- OCP uses CS signal, and the trip point is consistent over temperature
- OCP is cycle by cycle, and limits inductor current
Over-Temperature Protection

Discrete GaN

- \( T_j \) vs. time
- Danger Zone! Thermal Destruction!
- GaN FET still switching \( T_j > T_j-\text{max} \)

GaNSense IC w/OTP

- \( T_j \) vs. time
- Safe turn OFF of GaN Power FET \( T_j < T_j-\text{max} \)
- Safe RESTART of GaN Power FET

- \( V_{DS} \) vs. time
Leaders in Reliability

Integrated Gate Reliability

- 400 V VDS
- IL > 30 A

- Exposed gate
- Faulty switching
- Dangerous ringing & glitching!
- Significant reliability risks

Exposed gate
Faulty switching
Dangerous ringing & glitching!
Significant reliability risks

- Integrated gate drive
- Clean switching
- Safe, robust and reliable performance

Integrated Drain Reliability

- Wide Range VCC (10-30V)
- Regulator ensures VGS within SOA
- PWM Hysteresis for noise immunity
- No inductance or ringing in gate loop
- Protected gate (Not pinned out)

Wide Range VCC (10-30V)
Regulator ensures VGS within SOA
PWM Hysteresis for noise immunity
No inductance or ringing in gate loop
Protected gate (Not pinned out)

UVLO protects driver & FET when full power unavailable

UVLO protects driver & FET when full power unavailable

Navitas GaN Power IC

As of October 31st, 2021

<table>
<thead>
<tr>
<th></th>
<th>30,000,000+</th>
<th>116B+</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaNfast power ICs shipped</td>
<td>Failures</td>
<td>ppm</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0.16</td>
</tr>
<tr>
<td>FIT Rate</td>
<td>Equivalent Device Hours Tested</td>
<td></td>
</tr>
<tr>
<td>30,000,000+</td>
<td>116B+</td>
<td></td>
</tr>
</tbody>
</table>

900V Production Test
800V = Transient VGS
650V = Continuous VGS
650V = 80% of VGS,(Continous)
520V = 80% of VGS,(Continous)

... large drain voltage design margin

Flyback Voltage Waveform

As of October 31st, 2021

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Precise Gate Voltage = Excellent Reliability

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

Si Avalanche Testing

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

Navitas GaN IC Surge Testing

- 3,600,000,000 spikes, no failures!
- Negligible energy loss during overvoltage
- No $R_{DS(ON)}$ shift
- No $I_{DSS}$ shift

100μs pulse width, $V_{DS} = 800$ V
Reliable: Double-Pulse Test

**Discrete**

- VGS
- VDS
- IL

**NV6136 GaNSense**

- IL
- VDS

- 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

Ringing causes glitching!

Gate ringing
Production Reliability Monitoring

- Reliability monitoring of production material throughout 3 years of production
- 7,276 units tested on high-frequency, soft-switching application-focused stress testing from over 70 fab lots.

Reliability Statistics

*Calculated for High Line condition using HTOL (ZVS) results*

- Equivalent Device Hours tested
- FIT Rate demonstrated since launch
- > 5.8 Billion device hours stress tested since launch

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**Graphs:**

- Equivalent Device Hours vs. Use Temperature
- FIT Rate vs. Use Temperature

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**Legend:**

- Q218-Product launch
- Q219 ORM
- Q220-ORM
- Q121-ORM
# GaNSense Mass Production: 65W

<table>
<thead>
<tr>
<th>Feature</th>
<th>65W 2CA</th>
<th>65W 2C</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powertrain</td>
<td>Discrete GaN</td>
<td>NV6134 GaNFast with GaNSense</td>
<td></td>
</tr>
<tr>
<td>Size (cc)</td>
<td>105</td>
<td>75</td>
<td>30% Smaller</td>
</tr>
<tr>
<td>Power Density (W/cc)</td>
<td>0.6</td>
<td>0.9</td>
<td>50% Higher</td>
</tr>
<tr>
<td>Efficiency (%) (1)</td>
<td>89.15%</td>
<td>92.50%</td>
<td>3.4% Higher</td>
</tr>
<tr>
<td>Loss (W)</td>
<td>7.1</td>
<td>4.9</td>
<td>30% Energy Savings</td>
</tr>
<tr>
<td>Drive, Protection Components</td>
<td>19</td>
<td>5</td>
<td>75% Fewer</td>
</tr>
<tr>
<td>PCB Area (mm²)</td>
<td>83</td>
<td>15</td>
<td>80% Smaller</td>
</tr>
<tr>
<td>T&lt;sub&gt;CASE&lt;/sub&gt; max (°C) (1)</td>
<td>85°C</td>
<td>&lt;77°C</td>
<td>8°C Cooler</td>
</tr>
</tbody>
</table>

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(1) Based on comparison with traditional Silicon-based solutions.
120W Xiaomi GaNFast

- DCM boost PFC:
  - Silergy SY5072B
  - NV6134 GaNFast with GaNSense
- HFQR DC-DC
  - Onsemi NCP1342
  - NV6134 GaNFast with GaNSense
  - Planar transformer (shown)
120W
GaNFast with GaNSense

- 4,500 mAh battery
- Graphene Li-Ion
- 0-100% in 17 minutes
- 20% smaller

Read More
**Environment / Reduced CO₂ Emissions**

- **4x-10x** lower component CO₂ footprint than silicon

- **28% lower** lifetime CO₂ footprint for chargers / adapters

- **Accelerate** transition from ICE to EV by **3 years**, saving **20%/yr** of road sector emissions by 2050

- GaN addresses **2.6 Gton / year** by 2050

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- Power Electronics Partners
- Design Houses
- Customers
- Manufacturing Partners
- Consumers
- Investors
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