Advancing GaN Power ICs with Efficiency, Reliability & Autonomy

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#1 in GaN, now the only pure-play WBG company
Energy sources and uses are being electrified…

…creating a $40B GaN + SiC opportunity by 2050

Fossil-fuel vs renewable ratios adapted from IRENA 2020 “Global Renewables Outlook”. Shift required to meet “Transforming Energy Scenario, 9.5 Gton target in 2050”, per Paris Agreement’s 1.5°C rise. Market opportunity $ from Yole Développement, 2020 and Navitas analysis.
GaN + SiC: The Future of Power Semis

Voltage Rating

Note: Axes not to scale
Note (1): 2026E potential, Source: Yole, DNV, IRENA, Fraunhofer ISE, IHS, Cisco, Hyperscale, Peer annual reports, Wall Street research.
GaN is Positioned To Be The Future Of Mobile Charging

Larger Mobile Screens And Batteries Need More Power

Screen Size and Battery Size Continue to Increase\(^{(1)}\)

- Over $2.5B GaN IC opportunity\(^{(3)}\)
  - 2.5Bu per year of mobile wall chargers shipped
    - Phone, tablet, laptop and after-market
  - Over $1 of GaN content per charger and increasing over time

Fast
Up to 3x more power
Up to 3x faster charging

Mobile
Half the size and weight of traditional chargers

Universal
One charger for ALL your devices
One and Done!!

65W Multi-Port GaN Wall Charger\(^{(2)}\)

- 3 Silicon Chargers
- 1 GaN Charger

- 3x smaller, 3x lighter, and less expensive

Mobile is Moving to GaN Fast Chargers, Creating a Multi-Billion Dollar GaN IC Opportunity

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\(^{(1)}\) Includes Huawei, Xiaomi, OPPO, RealMe, Samsung, Apple and Google.

\(^{(2)}\) Based on Navitas measurements of select GaN-based mobile wall chargers compared to Si-based chargers with similar output power.

\(^{(3)}\) Based on estimates from IDC PC Tracker, USB-C research, Yole Research and Navitas estimates.
The GaN Revolution

GaNFast benefits plus:
- Autonomous Standby
- Autonomous Protection
- Loss-less Current Sensing
- High Precision
- High Efficiency

GaNFast benefits:
- Internal Gate
- External gate drive
- dV/dt sensitivity
- Layout Insensitive
- ESD sensitivity
- 2KV ESD rating
- Proven Reliability
- Proven Robustness

GaNSense Singles benefits plus:
- Highest integration
  - integrated HS and LS FETs & level-shift isolation
  - integrated HS boot-strap
  - Shoot-through protection
  - Enlarged cooling pads
- Fastest switching
- Highest efficiency

• Old, slow
• High Qg
• High Coss
• Fsw < 100kHz

• Exposed gate
• External gate drive
• dV/dt sensitivity
• Layout Insensitive
• ESD sensitivity
• 2KV ESD rating
• Unknown reliability
• Unknown robustness

Silicon FET

Discrete GaN

GaNFast

GaNSense Half-Bridge
GaN Integration for Efficiency, Speed & Stability

Discrete External Driver

- $R_{\text{DAMP}}$ required to reduce oscillation and voltage spike at the power FET gate.

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

Monolithic GaN Driver + FET

- Integrated Driver

- $T_f = 0.6$ ns

- $T_f = 3.5$ ns

Ref: “Next-generation GaN Isolators / Level-Shifters for High Frequency, High Efficiency Power Conversion”, APEC 2017 Industry Session, Oliver & Giandalia

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Discrete GaN Half-Bridge

- 33 components
- 250 mm² footprint
- External HB driver HVIC
- External. HV bootstrap
- 2x HV bypass diodes
- 2x external gate drives
- Exposed gates

GaNSense Half-Bridge IC

- 13 components
- 90 mm² footprint
- Level shifters
- Bootstrap
- Gate drivers
- No exposed gates

61% fewer components
64% smaller footprint
Complete integration

Severe Ringing & Glitching!
No Ringing, No Glitching!
Integrated, Loss-less Current Sensing

Integrated, programmable loss-less current sensing

- Integrated Level-shifter & Bootstrap
- Integrated Gate Drivers

No R_{\text{SENSE}} = increased efficiency

- No R_{\text{SENSE}} = increased efficiency
- No R_{\text{SENSE}} = no hot-spots or heat transfer

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

0.5% higher efficiency, same R_{\text{DS(ON)}} lower R_{\text{ON(TOT)}}

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Programmable Turn-on $dV/dt$ Control

- Limits the slew rate ($dV/dt$) of the drain of the power FET during turn-on
- First start-up pulses or during hard-switching conditions
- Reduce EMI or reduce circuit switching noise
Cycle-by-Cycle Over-Current Protection (OCP)

- If $V_{CS} > 1.9\,\text{V}$, internal gate driver will turn off the GaN IC, ending the on-time
  - OCP response ‘detect-to-protect’ in 30 ns! 6x faster than conventional controllers
- Accurate, user-programmable current set-point (based on $I_{DRAIN} \to I_{CS}$ ratio, $R_{SET}$)
- Turn-on OCP blanking time prevents noise from triggering the fault, is optimized for protection

Over-Current Protection DCM Timing Diagram

Cycle-by-cycle over current protection in CCM boost configuration

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Over-Temperature Protection (OTP)

**Discrete GaN**

- **Tj-max**: The maximum operating temperature of the GaN FET.
- **Tj**: Temperature of the GaN FET.
- **GaN FET still switching Tj > Tj-max!**
- **V_DS**: Drain-Source voltage over time.

**GaN Sense IC w/OTP**

- **Tj-off**: Safe turn OFF of GaN Power FET Tj < Tj-max.
- **Tj-avg**: Tj < Tj-max
- **Tj-restart**: Safe RESTART of GaN Power FET

**Danger Zone! Thermal Destruction!**

Safe turn OFF of GaN Power FET
Tj < Tj-max
Safe RESTART of GaN Power FET

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Soft Switching & GaN ICs = High Efficiency & Frequency

Primary Switch Power Loss using Silicon FETs:

\[ P_{\text{FET}} = P_{\text{COND}} \times k + P_{\text{DIODE}} + P_{\text{T-ON}} + P_{\text{T-OFF}} + P_{\text{DR}} + P_{\text{QRR}} + P_{\text{QOSS}} \]

- \( R_{\text{DS(ON)}} \) loss
- Duty cycle loss
- Reverse conduction loss
- Switch-ON transition loss
- Switch-OFF transition loss
- Gate Drive loss
- Reverse recovery loss
- Output Capacitance loss

Primary Switch Power Loss using GaN Power ICs:

\[ P_{\text{FET}} = P_{\text{COND}} \times k + P_{\text{DIODE}} + P_{\text{T-ON}} + P_{\text{T-OFF}} + P_{\text{DR}} + P_{\text{QRR}} + P_{\text{QOSS}} \]

- MINIMIZED
- MINIMIZED

Soft-switching and GaN ICs **ELIMINATE** turn-on & reverse recovery losses & **MINIMIZE** drive, deadtime, and device charging losses

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Enabling Next-Gen, High-Speed Topologies

**Efficiency**

- **High frequency**
- **High efficiency**
- **High integration**
- **High power density**

**Power**

- **HFQR**
- **GaNFast™**
- **GaN®/Silicon®**

### Efficiency Options

- **<= 65 W**
  - **< 100 kHz**
  - **90% Eff.**
  - **0.5 W/cc**

- **<= 65 W**
  - **200 kHz**
  - **92.5% Eff.**
  - **1.0 W/cc**

- **<= 65 W**
  - **500 kHz - 1 MHz**
  - **93% Eff.**
  - **1.2 W/cc**

- **<= 65 W**
  - **200 kHz**
  - **92.5% Eff.**
  - **1.4 W/cc**

- **120-240 W**
  - **500 kHz – 1 MHz**
  - **94.5% Eff.**
  - **1.6 W/cc**

**Technical Details**

- **200-300 W**

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GaNSense Half-Bridge ICs Enable Inverter Motor Integration

- **Motor Drive**: compact, high efficiency, reduced thermal management
- **TTP PFC**: highest efficiency, fewest components and smallest footprint
- **Aux Supply**: compact, efficient HFQR topology

- Significant reduction in cost, weight and size of thermal management (heatsink, fans, etc.)
- **GaN Power ICs** into a 2kW motor drive
  - Inverter efficiency increases 2.5% (96% → 98.5%)
  - Total losses reduced 50% (15W → 6.8W)

Ref: “Autonomous GaN Power ICs Deliver High-Performance, Reliable Motor Drives”, white paper, Hesener, May 2022
Complete integration of Half-Bridge phase into a single IC provides the most compact, efficient, fastest-switching, reliable and simplest solution for a wide variety of motor applications, such as fans, pumps, blowers, and compressors.

<table>
<thead>
<tr>
<th></th>
<th>Discrete IGBT (Baseline)</th>
<th>Discrete (SJ) MOSFET</th>
<th>Discrete SIC</th>
<th>IPM (Gate Driver + 6 Switches)</th>
<th>Discrete GaN (Standalone)</th>
<th>Discrete GaN (Cascode)</th>
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<tbody>
<tr>
<td><strong>Electrical Efficiency</strong></td>
<td>0</td>
<td>+</td>
<td>++</td>
<td>0</td>
<td>+++</td>
<td>+</td>
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<tr>
<td><strong>System Size (e.g. heatsink)</strong></td>
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<td>+</td>
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<td>+</td>
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<td><strong>Number of Components</strong></td>
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<td>0</td>
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<td><strong>Design Effort and Time</strong></td>
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<td>0</td>
<td>++</td>
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<td>0</td>
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<td><strong>Inverter Robustness</strong></td>
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<td>-</td>
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<td><strong>Inverter Reliability</strong></td>
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<td><strong>System Cost</strong></td>
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<td>+</td>
<td>+</td>
<td>++</td>
<td>+</td>
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**GaNFast** with **GaN Sense**
Summary

• Navitas’ mission is to Electrify the World to create a more sustainable future.

• Next-gen WBG (GaN and SiC) offer superior performance, and significantly lower CO₂ footprint in device and system manufacturing.

• Monolithic integration of driver and power stages enabled GaNFast power ICs to establish new benchmarks in efficiency, density, and reliability and lead the GaN market.

• GaNSense technology delivers new capability to integrate many useful drive, sensing, protection and autonomous control features.

• Complete integration of GaNSense Half-Bridge with additional sensing, monitoring, and protection delivers exceptional and cost-effective performance in the major power converter and inverter applications.

• It is time for legacy silicon to step to the side, as wide band gap is ready to take over.