Reliability Testing and Qualification of GaN Power Integrated Circuits

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World’s First GaNFast™ Power ICs

Fastest, most efficient GaN Power FETs

- >20x faster than silicon
- >5x faster than cascoded GaN
- Proprietary design
- Gate is fragile and sensitive to noise

First & Fastest Integrated GaN Gate Drivers

- >3x faster than any other gate driver
- Proprietary design
- 30+ patents granted
- Fast, protected gate, no need for negative drive

World’s First GaNFast™ Power ICs

- Simple, fast and reliable
- Easy to use and package

Up to 40MHz switching, 5x higher density & 20% lower system cost
Power GaN IC Product Portfolio

Single Switch (“Singles”)
- 650 V eMode FET
- $R_{DS(ON)}$ 120-300mΩ available
- Integrated Gate Drive
- Programmable dv/dt Control
- Integrated Regulator

Two Switch (“Half-Bridge”)
- 2 x 650 V eMode FETs (Half-bridge)
- $R_{DS(ON)}$ 120-500mΩ available
- Symmetric and Asymmetric $R_{DS(ON)}$
- Integrated Gate Drive
- Shoot-through Protection
- Integrated Regulators
- Integrated Level-Shifter
- Integrated Boot-strap
### Typical Si MOSFET Qual Plan

<table>
<thead>
<tr>
<th>Reference</th>
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<th>Duration</th>
<th>Lots</th>
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<tbody>
<tr>
<td>JESD22-A113</td>
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<td>J-STD-020</td>
<td>Temperature Cycle: -55°C / 150°C</td>
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### New Elements in GaN Power ICs

- **GaN**: Gallium Nitride
- **Integrated Circuit + Power Transistor**
Approach to Reliability of GaN Power ICs

Well Established Package Technology

650 V GaNFast Power FETs

Integrated GaN Gate Driver

GaNFast™ Power IC with exceptional Quality & Reliability

Package Qualification
- UHAST
- HAST
- THB
- TC
- HTSL

Traditional FET Tests
- HTRB
- HTGB
- HAST
- THB

JESD471 (IC Qual Standard)
- HTOL
- ELFR
- ESD
- WLR
Industry standard PQFN technology

Low-cost, proven reliability platform

Proprietary leadframe designs for lowest parasitics & highest density

Physics of failure and reliability risks are the same as Si technology

Manufactured on same assembly lines with high volume Si technology

Same package qualification methodology of Si can be applied to GaN Power ICs

### Package Qualification Tests

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<td>JESD22-A104</td>
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Integrated ESD Protection

GaN Power IC

ESD Qualification Tests

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✓ Same ESD testing as Si devices can be applied to GaN
✓Latch up testing not required in GaN devices

HBM, CDM > 1,000 V
Use Mission Profile to Define GaN Qualification

New Elements in GaN Power ICs

- **Ga**: Gallium (69.723)
- **N**: Nitrogen (14.007)

Integrated Circuit + Power Transistor

**GaN Power IC Qualification Plan**

1. **Quality Objectives**
   - (Typical app. lifetime, FIT rates)
2. **Application Profile**
   - (Voltage, Current, Frequency)
3. **Test Methodologies**
   - (Removal of defects)
4. **Lifetime Models**
   - (HTOL, HTRB, GaN IC)
5. **Production Release**

Mission Profile
Typical Application (Consumer Chargers)

MacBook <100 kHz
<6.5 W/in³, 92%

Navitas ~300 kHz
24 W/in³, 94%
= 45 cc cased

- ACF (ZVS) Topology
- 300 kHz – 1 MHz
- 120 V – 240 V AC

65W USB-PD
Application Profile for ACF Charger

**Full Power (T\textsubscript{DUT} = 80 C)**

**Light Load (T\textsubscript{DUT} = 50 C)**

**Burst Mode (T\textsubscript{DUT} = 25 C)** (No Load)

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[Graphs showing voltage and current for each condition]
Application Profile for ACF Charger

Burst Mode ($T_{DUT} = 25 \, ^{\circ}C$) (No Load)

Voltage

Current

500 us/div

No Load Profile
• Voltage = $\sqrt{2} \times V_{AC} \rightarrow 170 \, – 340 \, V$
• $T = 25 \, ^{\circ}C$
• $f_{BURST} = 0.1 \, - \, 1 \, kHz \, (<50 \, mW \, standby \, power \, loss \, requirement) \, \rightarrow \, Approximate \, as \, DC$

High-Temperature Reverse Bias (HTRB)
HTRB Acceleration Factors

### Voltage/Temperature Table

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<th>120</th>
<th>150</th>
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<tbody>
<tr>
<td>650</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>700</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>750</td>
<td></td>
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**Lifetime**

\[ \text{Lifetime} = A \times (V^{-\gamma}) \times \left( e^{\frac{E_A}{kT}} \right) \]

- **T=150 °C, Voltage Acceleration**
  \[ \text{Time to Fail (hrs)} \propto \left( \frac{1}{\text{Voltage}} \right)^{n=18.6} \]

- **V= 700 V, Temperature Acceleration**
  \[ \text{Time to Fail (hrs)} \propto e^{(\frac{E_a}{0.91eV}) / kT} \]
HTRB Lifetime Model

Lifetime of no load application condition is >1E8 years, so will not be a significant contributor to product lifetime

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\[ \text{Lifetime} = A \times (V^{-\gamma}) \times (e^{\frac{E_A}{kT}}) \]
Application Profile for ACF Charger

Full Power Profile

- Voltage = $(\sqrt{2} \cdot VAC) + V_{CAP} \rightarrow 270 - 460$ V
- $T = 85$ C
- Frequency = 200 - 600 kHz
- Soft-Switching $\rightarrow$ Zero Voltage Switching (ZVS)
- Current: 0.5 – 3 A

High-Temperature Operating Life (HTOL)
ZVS Application Profile (FET)

‘Soft-Switching’ or ZVS (Zero-Voltage Switching) represents an application relevant stress on the power FET.
ZVS Application Profile (IC)

- **$V_{CC}$ stress applied to regulator and startup circuits**
- **$V_{DD}$ stress applied to driver circuit and gate**
- **$C \frac{dv}{dt}$ current applied to driver output stage on each switching cycle**

- **Driver run at application frequency & duty cycle**
- **Driver components stressed with switching frequency and $V_{DD}$ bias**
L-C load applied to half-bridge topology along with complementary inputs & dead time setting to achieve soft-switching.

Power consumption is the only loss elements (DUT, Inductor) since energy is recycled → many cells in parallel.

Circuit allows for same application stress on GaN Power IC as customer application (Voltage, Current, Frequency).

Applies application conditions to the driver & integrated IC so power IC is also qualified in the same test.

HTOL Circuit Variables

- Voltage
- Current
- Frequency
- Temperature
- Duty Cycle
HTOL-based Lifetime Model

<table>
<thead>
<tr>
<th>Voltage/Temperature</th>
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<th>125</th>
<th>150</th>
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<tr>
<td>550</td>
<td></td>
<td></td>
<td>✅</td>
</tr>
<tr>
<td>575</td>
<td></td>
<td></td>
<td>✅</td>
</tr>
<tr>
<td>600</td>
<td></td>
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$T = 150 \, ^\circ C$, Voltage Acceleration

$\text{Time to Fail (hrs)} \propto \frac{1}{(\text{Voltage})^{n=172}}$

$V=650 \, V$, Temperature Acceleration

$\text{Time to Fail (hrs)} \propto e^{\frac{E_a}{kT}}$
Lifetime Estimation in Charger Application

Temperature Acceleration Factor ($AF_{\text{temp}}$) = $e^{E_a/k \left( \frac{1}{T_{\text{application}}} - \frac{1}{T_{\text{reliability}}} \right)}$

$E_a = 0.71\text{eV}$

Voltage Acceleration Factor ($AF_{\text{voltage}}$) = $\left( \frac{V_{\text{reliability}}}{V_{\text{application}}} \right)^n$

$n = 17.2$

Total Acceleration Factor ($AF_{\text{Total}}$) = $AF_{\text{temp}} \times AF_{\text{voltage}}$

Lifetime estimate in application = $AF_{\text{Total}} \times \text{Time to failure in reliability (TTF}_{\text{reliability}})$

<table>
<thead>
<tr>
<th>AC line Voltage (V)</th>
<th>Rectified AC voltage (V)</th>
<th>Reflected Voltage (V)</th>
<th>Switch Voltage (V)</th>
<th>Full power Temp (°C)</th>
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<tr>
<td>120</td>
<td>170</td>
<td>120</td>
<td>290</td>
<td>85</td>
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<td>240</td>
<td>340</td>
<td>120</td>
<td>460</td>
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$E_a$ = 0.71eV $n = 17.2$

$AF_{\text{Total}} \times \text{TTF}_{\text{reliability}} = 233$ years @ 240V AC input, MTTF

$AF_{\text{Total}} \times \text{TTF}_{\text{reliability}} = 30$ years @ 240V AC input, 100ppm

Predicted lifetime in charger application (ACF) exceeds 10yr lifetime requirement.
ZVS HTOL Applied to Statistical Sample Sizes

HTOL Mother Board

- Matches all elements of application profile
  - FET & IC
- Many cells in parallel
  - Statistical sample sizes
- Low total power consumption
- Conditions changeable to develop lifetime and acceleration models

Qualification
3 Lots x 77 Parts
Voltage
Current
Frequency
Temperature

Lifetime Models

Early Life Failure Rate
3 Lots x 1,000 Parts
Comprehensive View of Product Quality, Reliability, & Lifetime

- ELFR (HTRB, HTOL)
- Qualification (3x77 to 1,000 hrs) (HTRB, HTOL)
- Lifetime Models (HTRB, HTOL)

Statistical Sample Sizes Using Application Relevant Stress Testing

Failure Rate

Operating Time

Established Package & ESD Reliability Testing

Infant Mortality

Random Failure Rate

Wear Out
# GaN Power IC Qual Plan

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<td></td>
<td><strong>JESD22-A108</strong> Early Life Failure Rate</td>
<td>24 hrs</td>
<td>3</td>
<td>1,000</td>
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**Lifetime Models (HTOL, HTRB)**

**Failure Modes Established**

**Application Specific HTOL Test Bench**
Let’s go GaNFast™

&

Guarantee
Quality
Guarantee