Navitas

Let's go GaNFast™

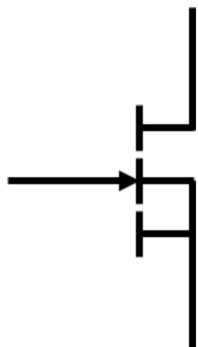
Reliability Testing and Qualification of GaN Power Integrated Circuits

IEEE PEAC 2018 Industry Session: "Power Devices and Applications" November 6th, 2018

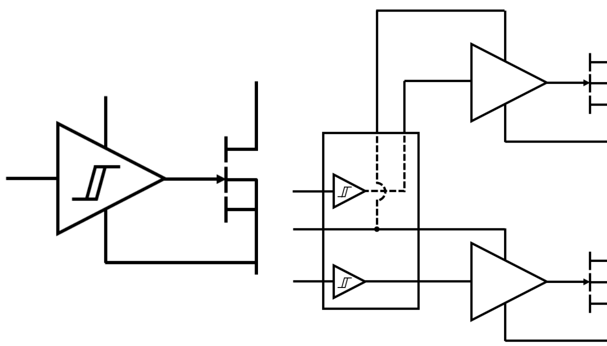
Dr. Nick Fichtenbaum, Co-Founder & VP Engineering
Nick.Fichtenbaum@navitassemi.com

World's First GaNFast™ Power ICs

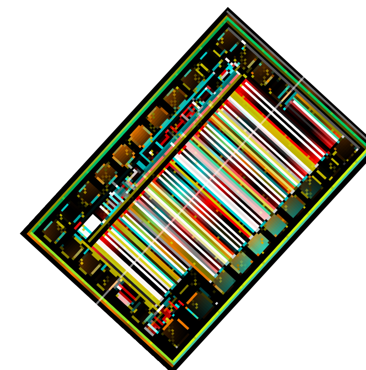
Fastest, most efficient GaN Power FETs



First & Fastest Integrated GaN Gate Drivers



World's First GaNFast™ Power ICs



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

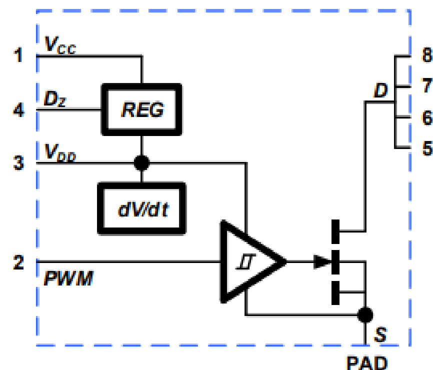
>3x faster than any other gate driver
- Proprietary design
- 30+ patents granted
- Fast, protected gate, no need for negative drive

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

Up to 40MHz switching, 5x higher density & 20% lower system cost

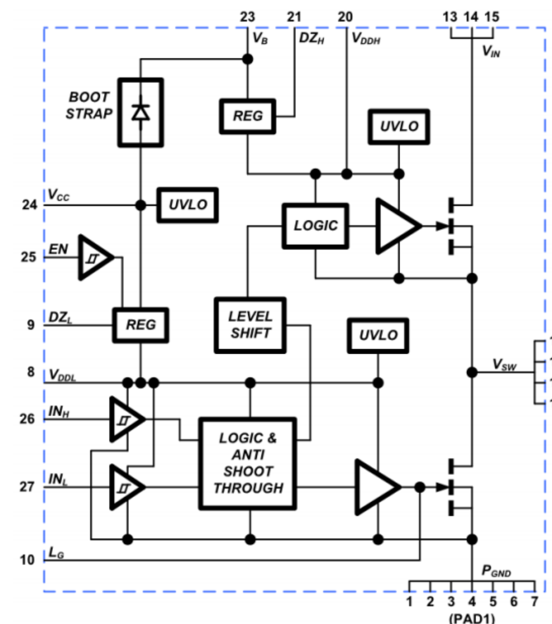
Power GaN IC Product Portfolio

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

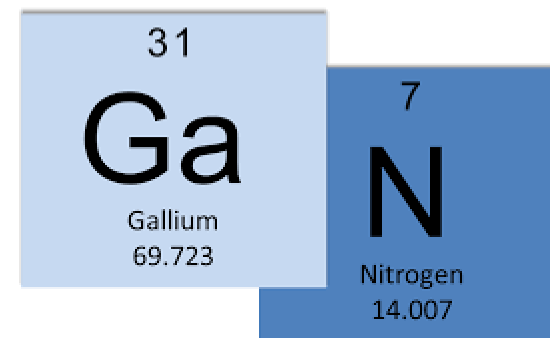
Is Typical Si JEDEC Qual Sufficient?

GaNFast™

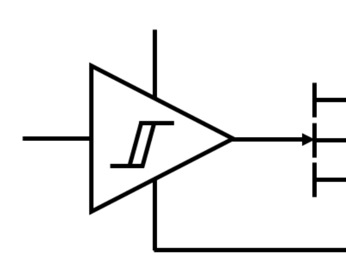
Typical Si MOSFET Qual Plan

Category	Reference	Test Conditions	Duration	Lots	S.S.
Package Stress	JESD22-A113 J-STD-020	Preconditioning (MSL1): Moisture Preconditioning + 3x reflow: HAST, UHAST, TC & PC	N/A	3	308
Package Stress	JESD22-A104	Temperature Cycle: -55°C / 150°C	1,000cy	3	77
Package Stress	JESD22-A122	Power Cycle: Delta Tj = 100°C	10,000cy	3	77
Package Stress / Die Stress	JESD22-A110	Highly Accelerated Stress Test: 130°C / 85%RH / 100V V_{DS}	96hrs	3	77
Die Stress	JESD22-A108	High Temperature Reverse Bias: 150°C / 520V V_{DS}	1,000hrs	3	77
Die Stress	JESD22-A108	High Temperature Gate Bias: 150°C / 6V V_{GS}	1,000hrs	3	77
Die Stress / ESD	JS-001-2014	Human Body Model ESD	N/A	1	3
ESD	JS-002-2014	Charged Device Model ESD	N/A	1	3

New Elements in GaN Power ICs



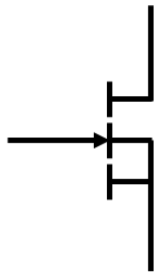
GaN

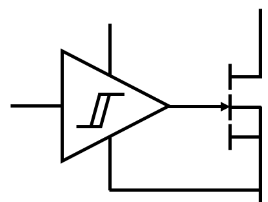


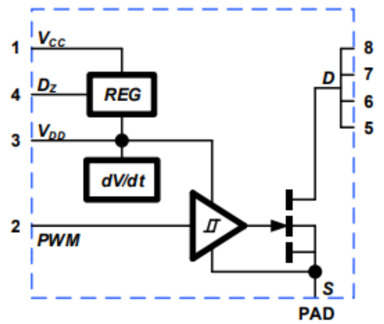
Integrated Circuit + Power Transistor

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





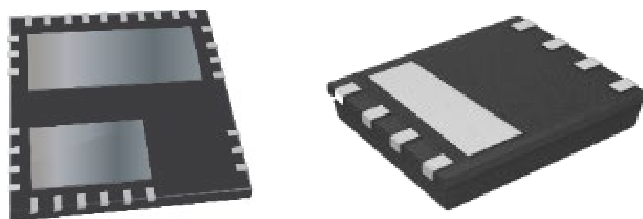


Package Qualification	Traditional FET Tests	JESD47I (IC Qual Standard)
UHAST	HTRB	HTOL
HAST	HTGB	ELFR
THB	HAST	ESD
TC	THB	WLR
HTSL		

Package Qualification

GaNFast™

PQFN Technology



Package Qualification Tests

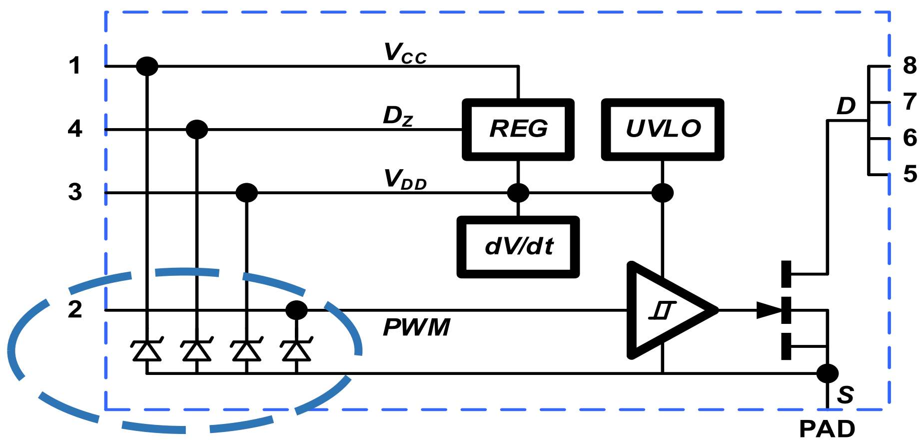
Reference	Test Conditions	Duration	Lots	S.S.
JESD22-A113 J-STD-020	Preconditioning (MSL1): Moisture Preconditioning + 3x reflow: HAST, UHAST, TC & PC	N/A	3	308
JESD22-A104	Temperature Cycle: -55°C / 150°C	1,000cy	3	77
JESD22-A122	Power Cycle: Delta Tj = 100°C	10,000cy	3	77
JESD22-A110	Highly Accelerated Stress Test: 130°C / 85%RH / 100V V_{DS}	96hrs	3	77

- ✓ 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

Integrated ESD Protection

GaNFast™

GaN Power IC



Integrated ESD Protection

HBM, CDM > 1,000 V

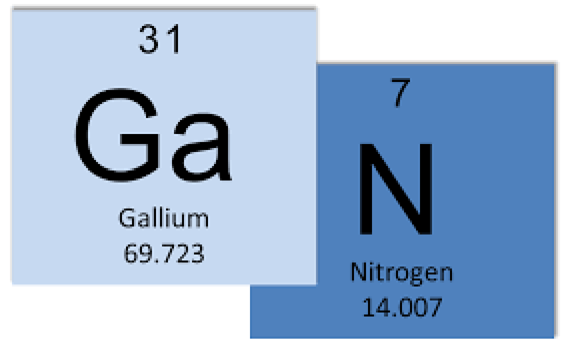
ESD Qualification Tests

Reference	Test Conditions	Duration	Lots	S.S.
JS-001-2014	Human Body Model ESD	N/A	1	3
JS-002-2014	Charged Device Model ESD	N/A	1	3

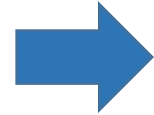
- ✓ Same ESD testing as Si devices can be applied to GaN
- ✓ Latch up testing not required in GaN devices

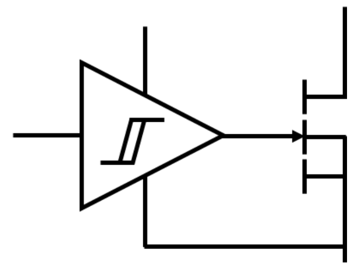
Use Mission Profile to Define GaN Qualification

New Elements in GaN Power ICs



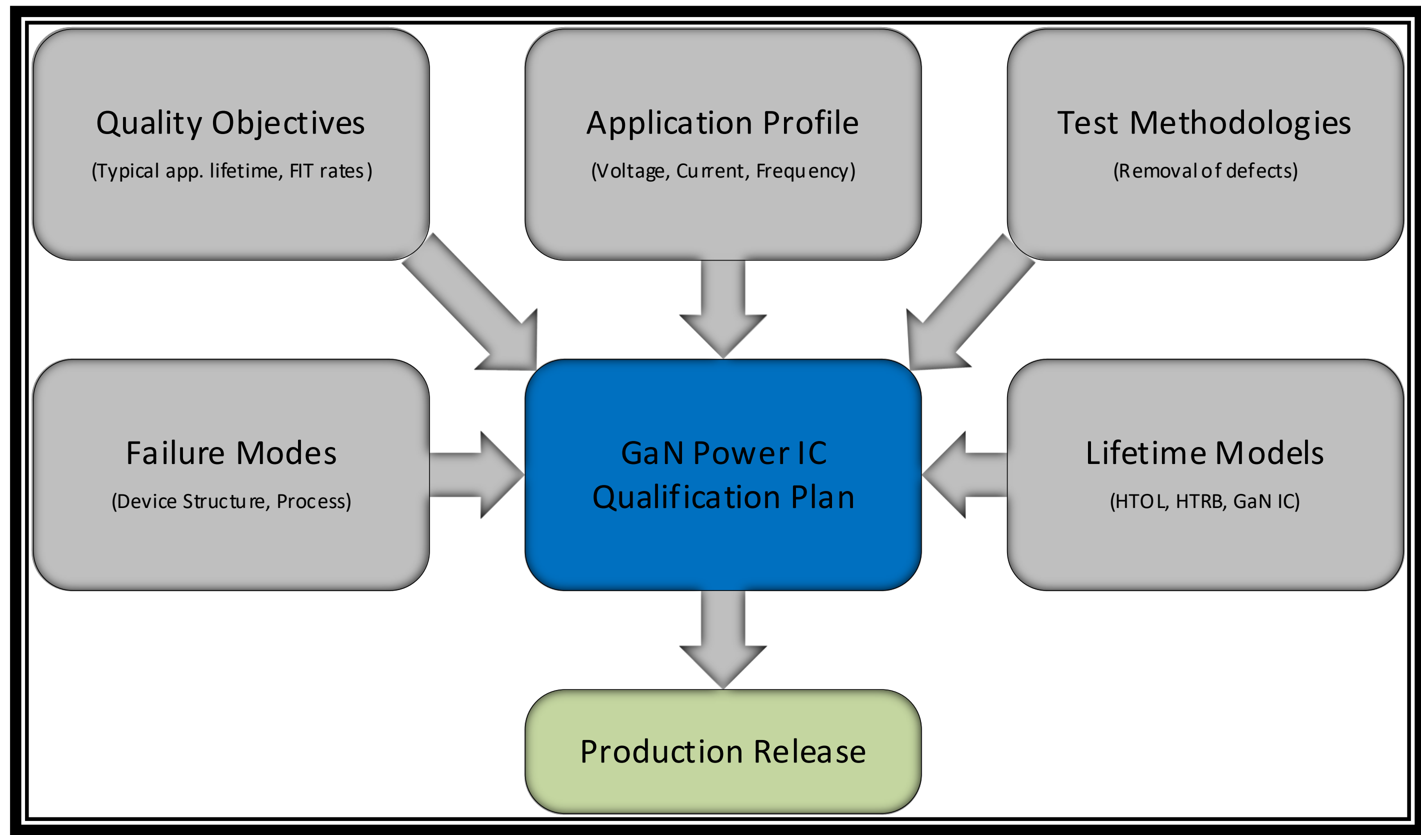
GaN





Integrated Circuit + Power Transistor

Mission Profile

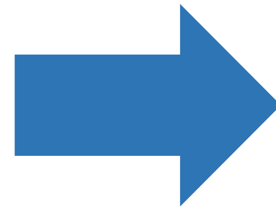


Typical Application (Consumer Chargers)

GaNFast™

MacBook <100 kHz

<6.5 W/in³, 92%

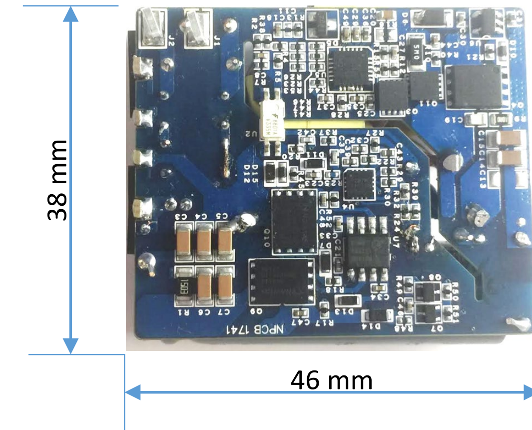


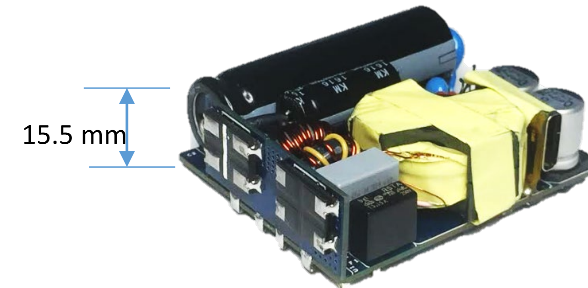
- ACF (ZVS) Topology
- 300kHz – 1 MHz
- 120 V – 240 V AC

Navitas ~300 kHz

24 W/in³ , 94%

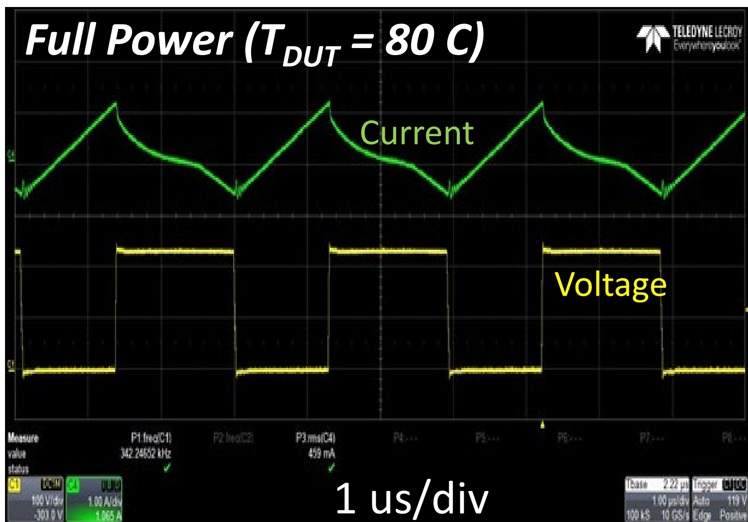
= 45 cc cased

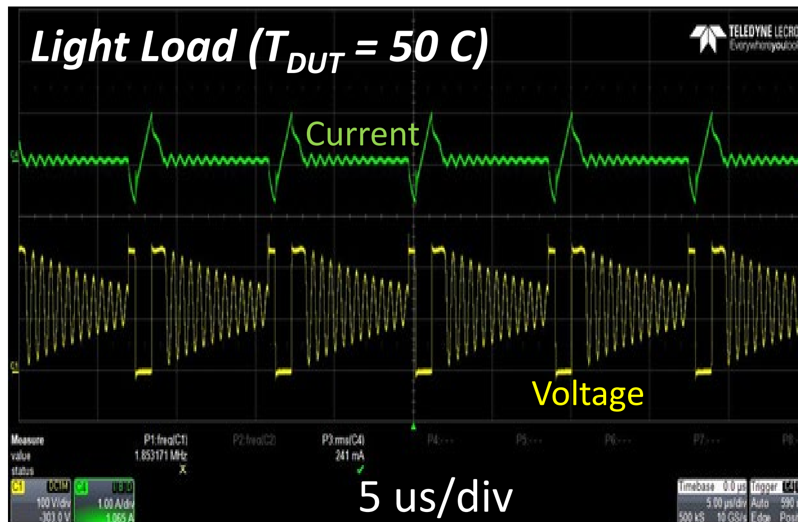


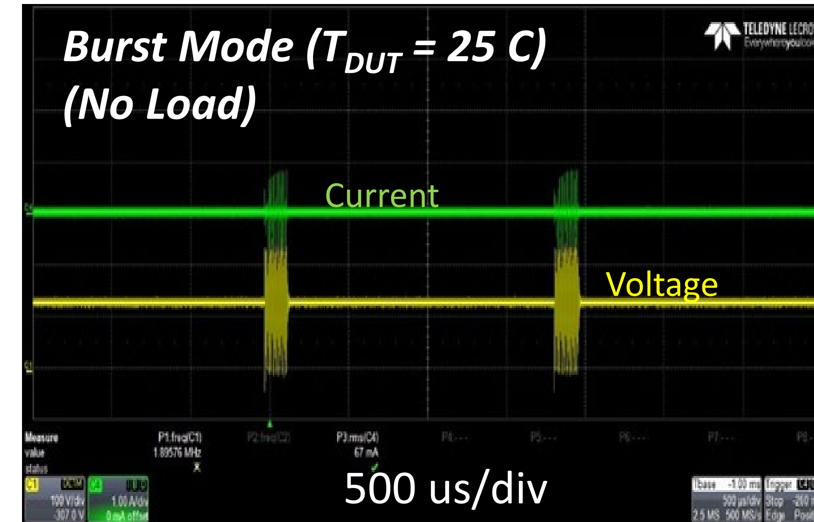


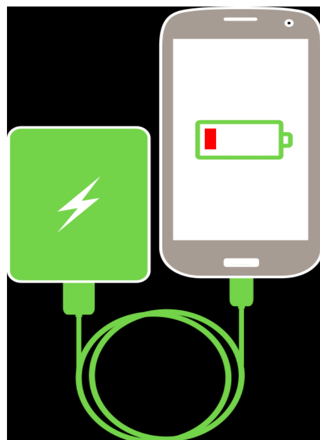
65W USB-PD

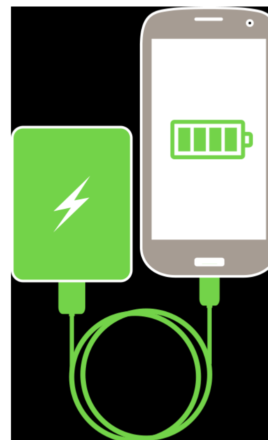
Application Profile for ACF Charger

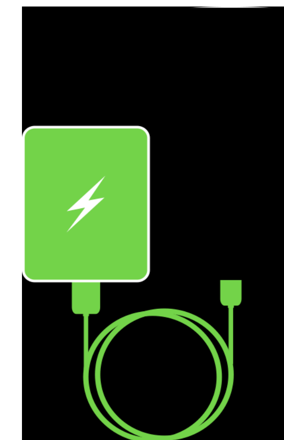




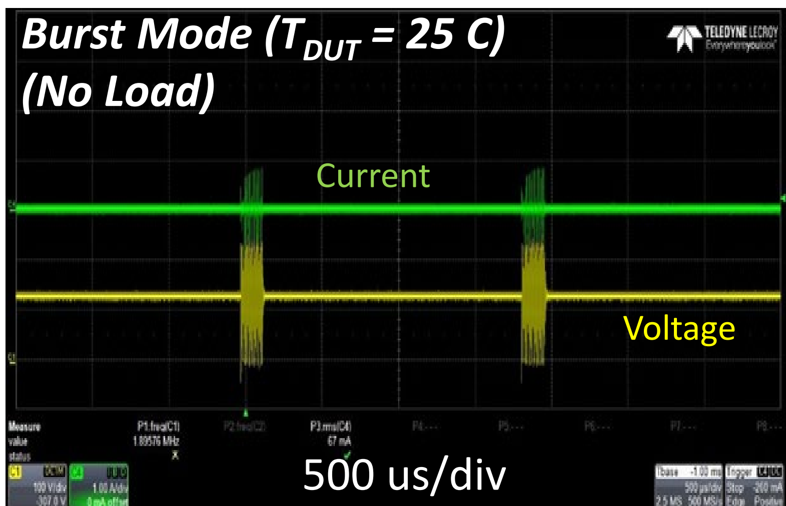


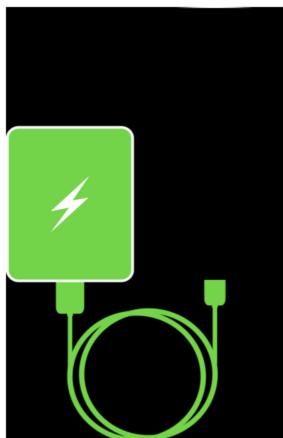






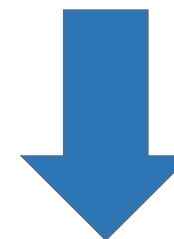
Application Profile for ACF Charger





No Load Profile

- Voltage = $\sqrt{2} * VAC$ → 170 – 340 V
- T = 25 C
- f_{BURST} = 0.1 - 1 kHz (<50 mW standby power loss requirement) – Approximate as DC



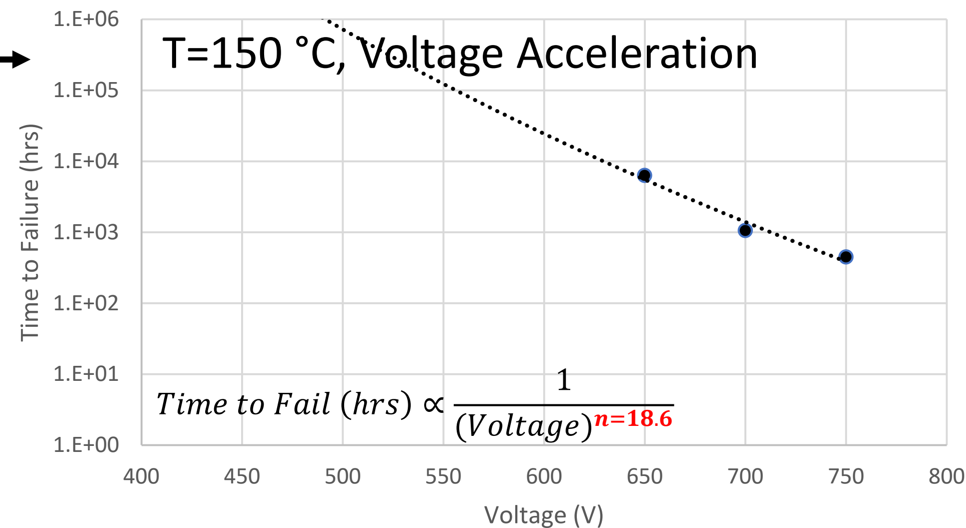
High-Temperature Reverse Bias (HTRB)

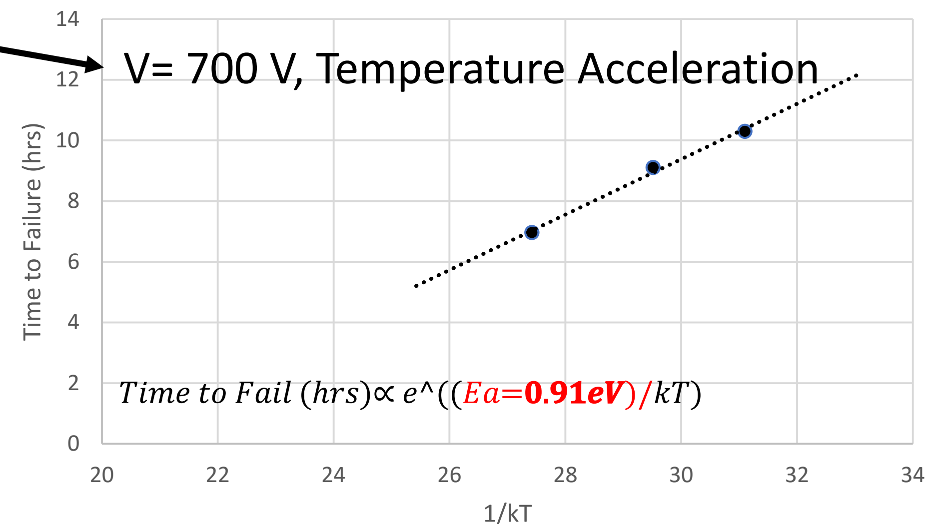
HTRB Acceleration Factors

GaNFast™

Voltage/ Temperature	100	120	150
650			✓
700	✓	✓	✓
750			✓

$$Lifetime = A \times (V^{-\gamma}) \times (e^{\frac{E_A}{kT}})$$

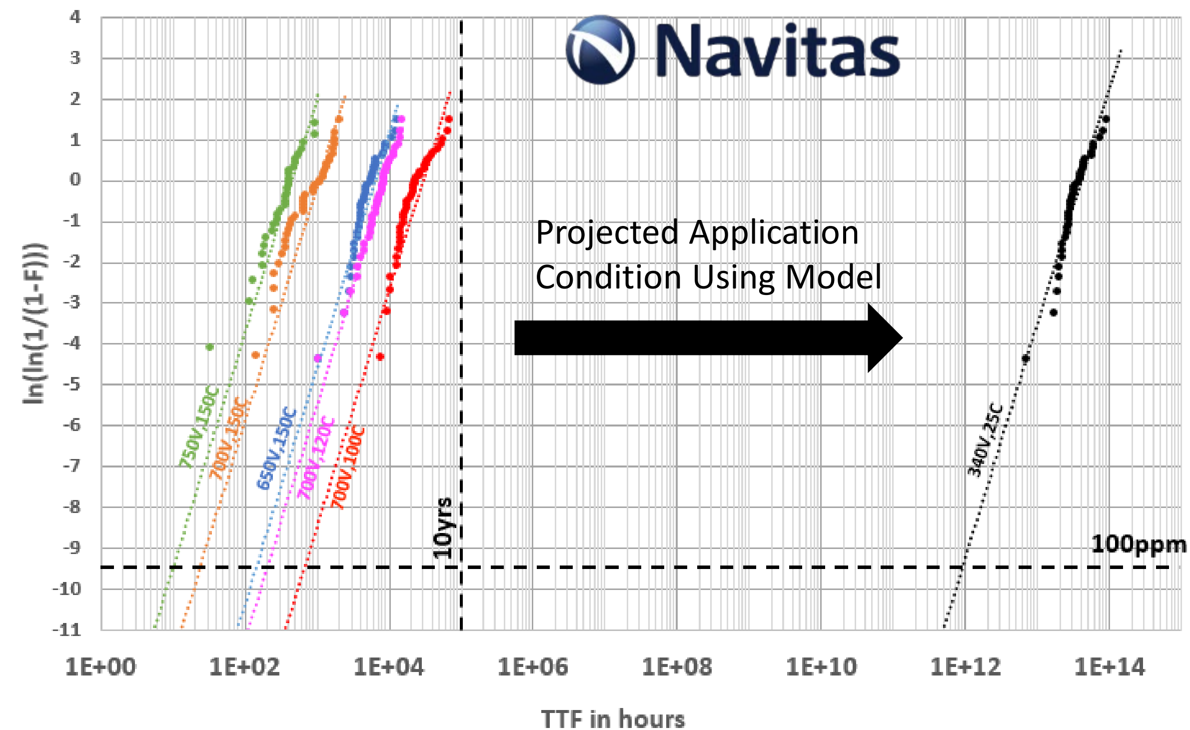




HTRB Lifetime Model

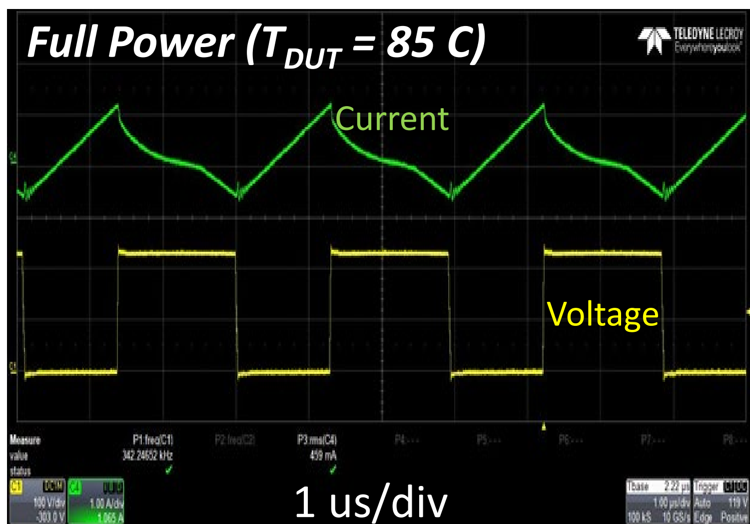
$$Lifetime = A \times (V^{-\gamma}) \times (e^{\frac{E_A}{kT}})$$

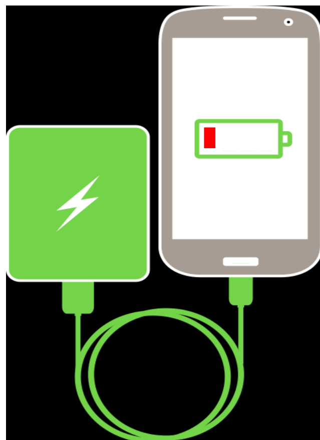
Voltage/ Temperature	100	120	150
650			✓
700	✓	✓	✓
750			✓



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

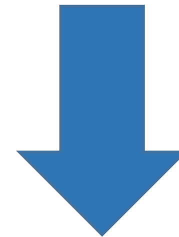
Application Profile for ACF Charger





Full Power Profile

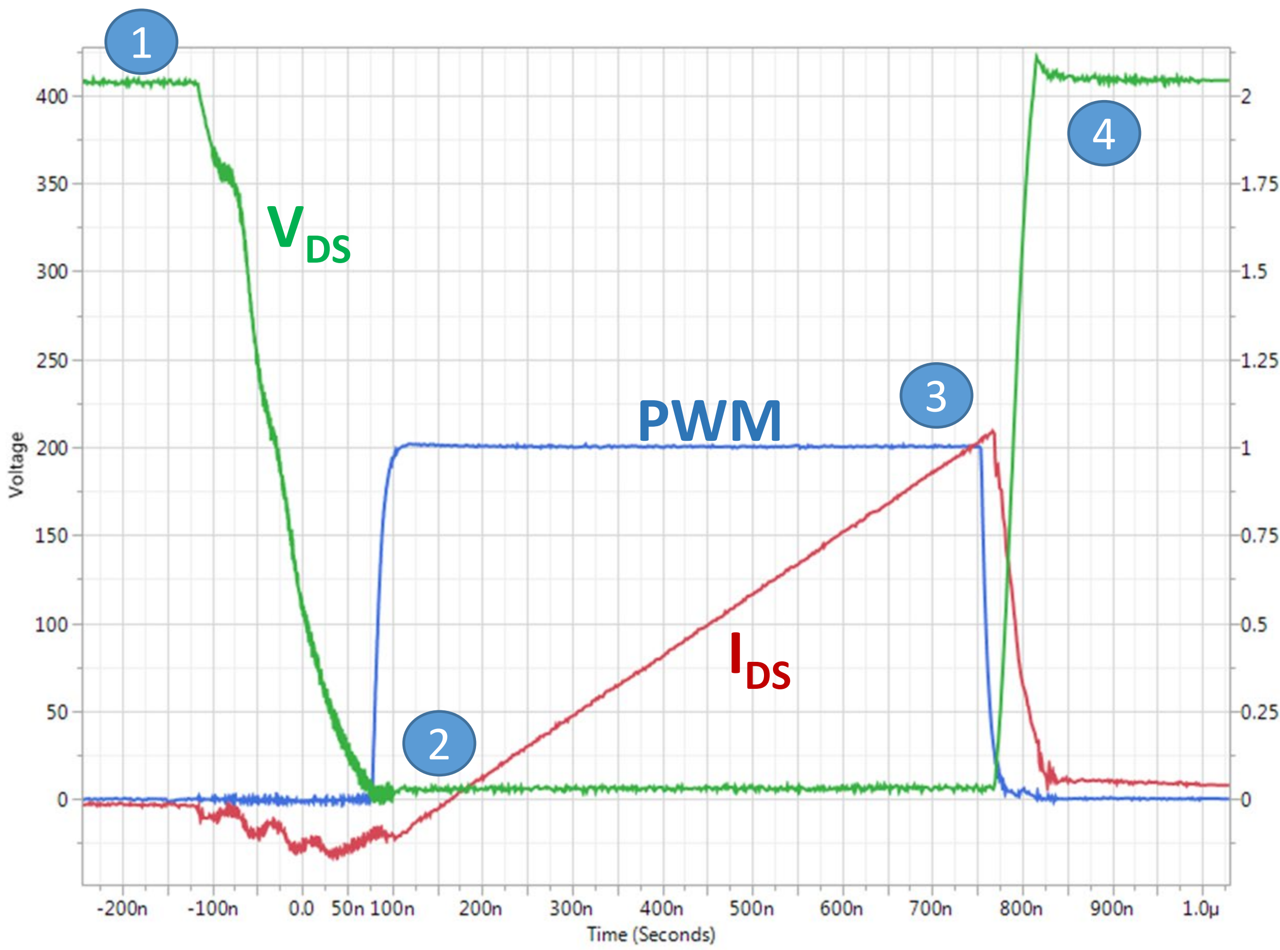
- Voltage = ($\sqrt{2} * VAC$) + V_{CAP} → 270 – 460 V
- T = 85 C
- Frequency = 200 - 600 kHz
- Soft-Switching → Zero Voltage Switching (ZVS)
- Current: 0.5 – 3 A



High-Temperature Operating Life(HTOL)

ZVS Application Profile (FET)

GaNFast™



I_{DS} vs. V_{DS} (Load Line)

'Soft-Switching' or ZVS (Zero-Voltage Switching) represents an application relevant stress on the power FET

ZVS Application Profile (IC)

GaNFast™

V_{CC} stress applied to regulator and startup circuits

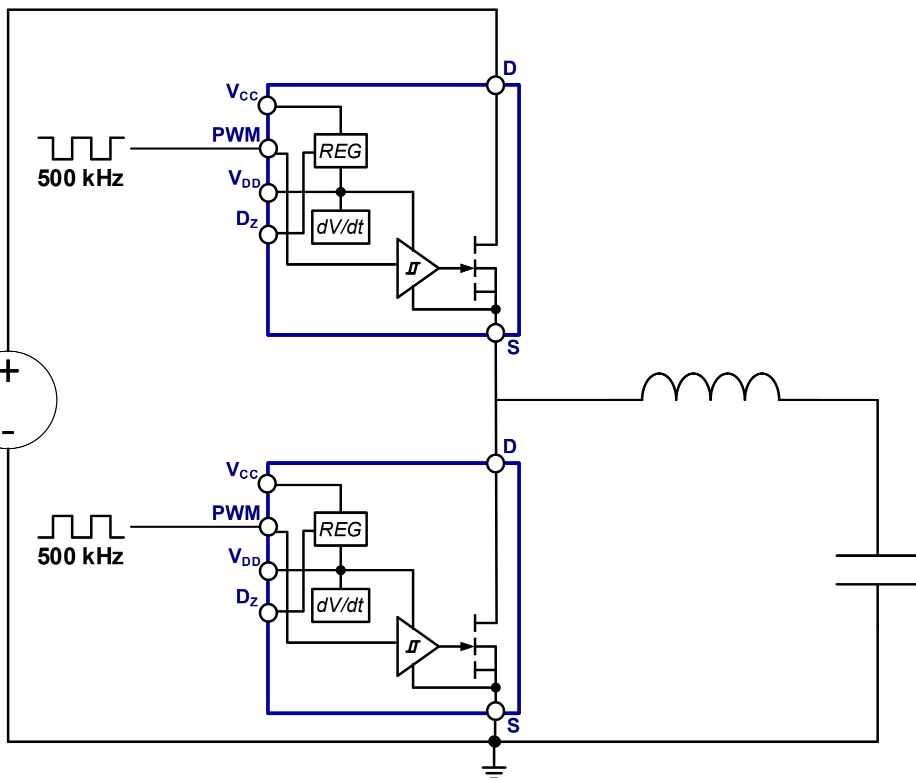
V_{DD} stress applied to driver circuit and gate

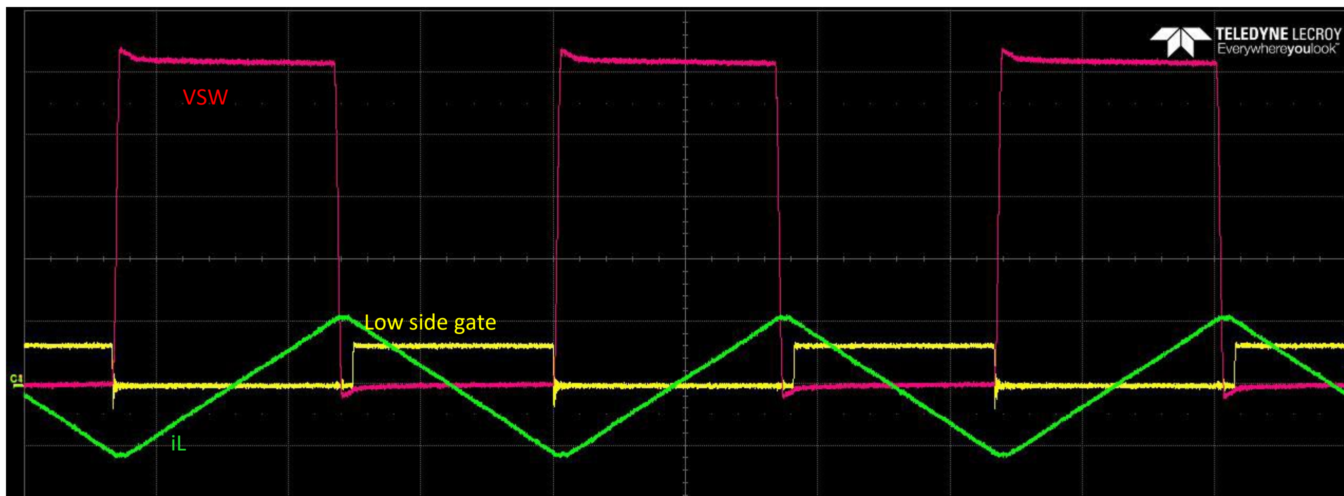
$C\frac{dV}{dt}$ current applied to driver output stage on each switching cycle

Driver run at application frequency & duty cycle

Driver components stressed with switching frequency and V_{DD} bias

ZVS High Temp Op Life (HTOL) Circuit GaNFast™





HTOL Circuit Variables

- Voltage
- Current
- Frequency

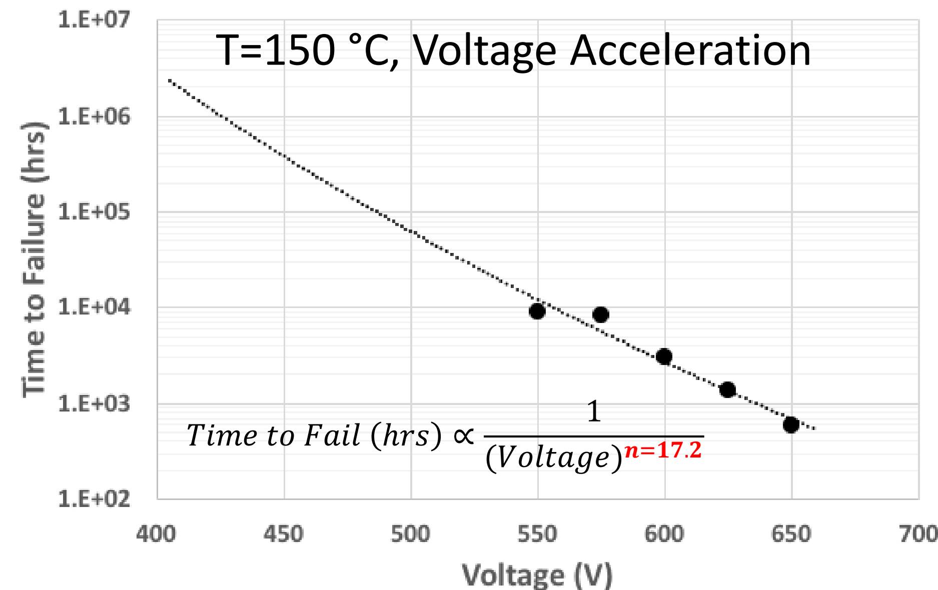
- Temperature
- Duty Cycle

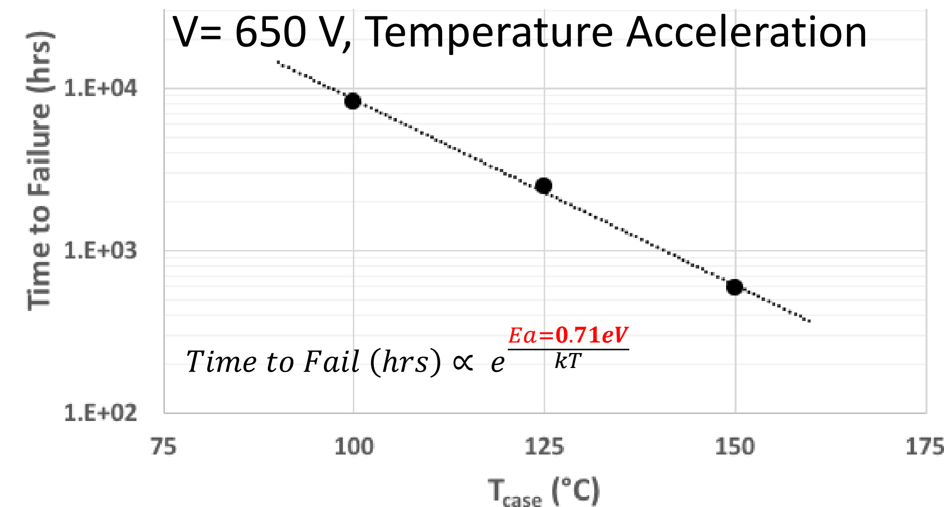
- ✓ L-C load applied to half-bridge topology along with complementary inputs & dead time setting to achieve soft-switching
- ✓ Power consumption is the only loss elements (DUT, Inductor) since energy is recycled → many cells in parallel
- ✓ Circuit allows for same application stress on GaN Power IC as customer application (Voltage, Current, Frequency)
- ✓ Applies application conditions to the driver & integrated IC so power IC is also qualified in the same test

HTOL-based Lifetime Model

GaNFast™

Voltage/ Temperature	100	125	150
550			✓
575			✓
600			✓
625			✓
650	✓	✓	✓





Lifetime Estimation in Charger Application

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

$E_a = 0.71\text{eV}$

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

$n = 17.2$

$$Total\ Acceleration\ Factor(AF_{Total}) = AF_{TEMP}\ x\ AF_{VOLTAGE}$$

$$Lifetime\ estimate\ in\ application = AF_{Total}\ x\ Time\ to\ failure\ in\ reliability\ (TTF_{reliability})$$

ACF Charger Full-Power Profile →

AC line Voltage (V)	Rectified AC voltage (V)	Reflected Voltage (V)	Switch Voltage (V)	Full power Temp (°C)
120	170	120	290	85
240	340	120	460	85

$$Lifetime\ = AF_{Total}\ x\ TTF_{reliability} = \mathbf{233\ years}\ @\ 240V\ AC\ input, MTTF$$

$$Lifetime\ = AF_{Total}\ x\ TTF_{reliability} = \mathbf{30\ years}\ @\ 240V\ AC\ input, 100ppm$$

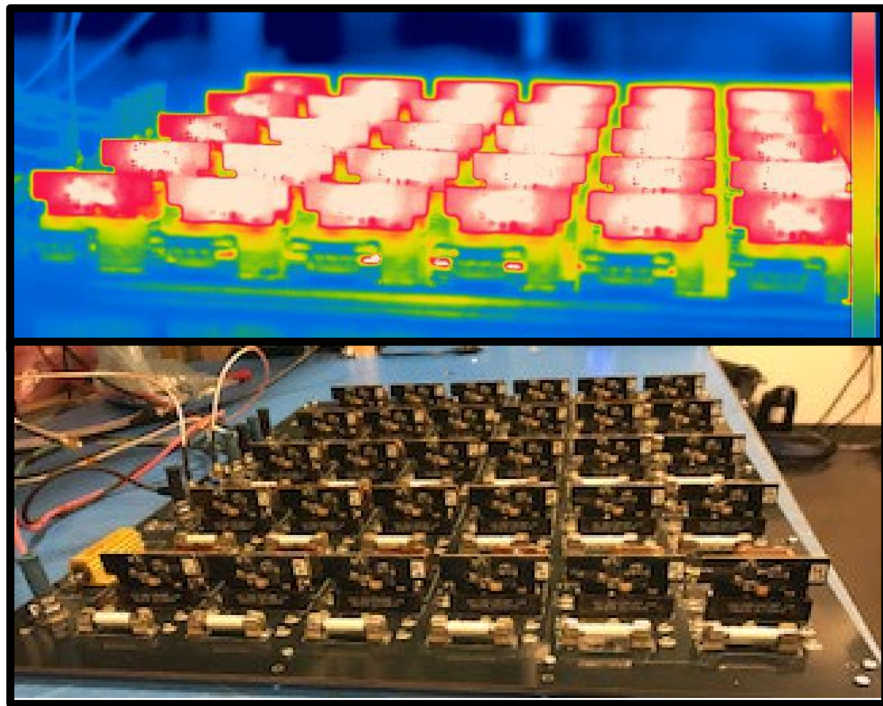
Predicted lifetime in charger application (ACF) exceeds 10yr lifetime requirement

ZVS HTOL Applied to Statistical Sample Sizes

GaNFast™

- ✓ 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

HTOL Mother Board



Qualification — 3 Lots x 77 Parts

Lifetime Models — Voltage, Current, Frequency, Temperature

Early Life Failure Rate — 3 Lots x 1,000 Parts

Comprehensive View of Product Quality, Reliability, & Lifetime

GaNFast™

Qual Plan for GaN Power ICs

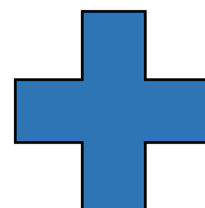
GaNFast™

GaN PowerIC Qual Plan

Package Stress

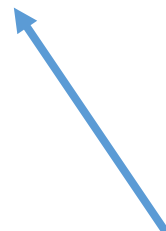
Die Stress

Reference	Test Conditions	Duration	Lots	S.S.	
JESD22-A113 J-STD-020	Preconditioning (MSL1): Moisture Preconditioning + 3x reflow: HAST, UHAST, TC & PC	N/A	3	308	PASS (0/308)
JESD22-A104	Temperature Cycle: -55°C / 150°C	1,000cy	3	77	PASS (0/231)
JESD22-A122	Power Cycle: Delta Tj = 100°C	10,000cy	3	77	PASS (0/231)
JESD22-A110	Highly Accelerated Stress Test: 130°C / 85%RH / 100V V_{DS}	96hrs	3	77	PASS (0/231)
JESD22-A108	High Temperature Reverse Bias: 150°C / 520V V_{DS}	1,000hrs	3	77	PASS (0/231)
JESD22-A108	High Temperature Gate Bias: 150°C / 6V V_{GS}	1,000hrs	3	77	PASS (0/231)
JESD22-A108	High Temperature Operating Life	1,000hrs	3	77	PASS (0/231)
JESD22-A108	Early Life Failure Rate	24 hrs	3	1,000	PASS (0/3,000)
JS-001-2014	Human Body Model ESD	N/A	1	3	PASS 0/3
JS-002-2014	Charged Device Model ESD	N/A	1	3	PASS 0/3



Lifetime Models (HTOL, HTRB)

Failure Modes Established



Application Specific HTOL Test Bench

GaNFast™

Let's go GaNFast™

&