Best Practices Using Voltage Acceleration for Reliability Testing of High Voltage GaN

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APEC 2020

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Highest Performance, Highest Reliability GaN

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Agenda

- Conservative reliability testing and modeling
- Why do we need to use Voltage Accelerated Testing
  - Si MOSFET example
- Setting conditions for Voltage Accelerated Testing
- Creating a model for Voltage Accelerated Testing
- Early life failure testing/rating
- Switching lifetime
- 900V Qualification Data

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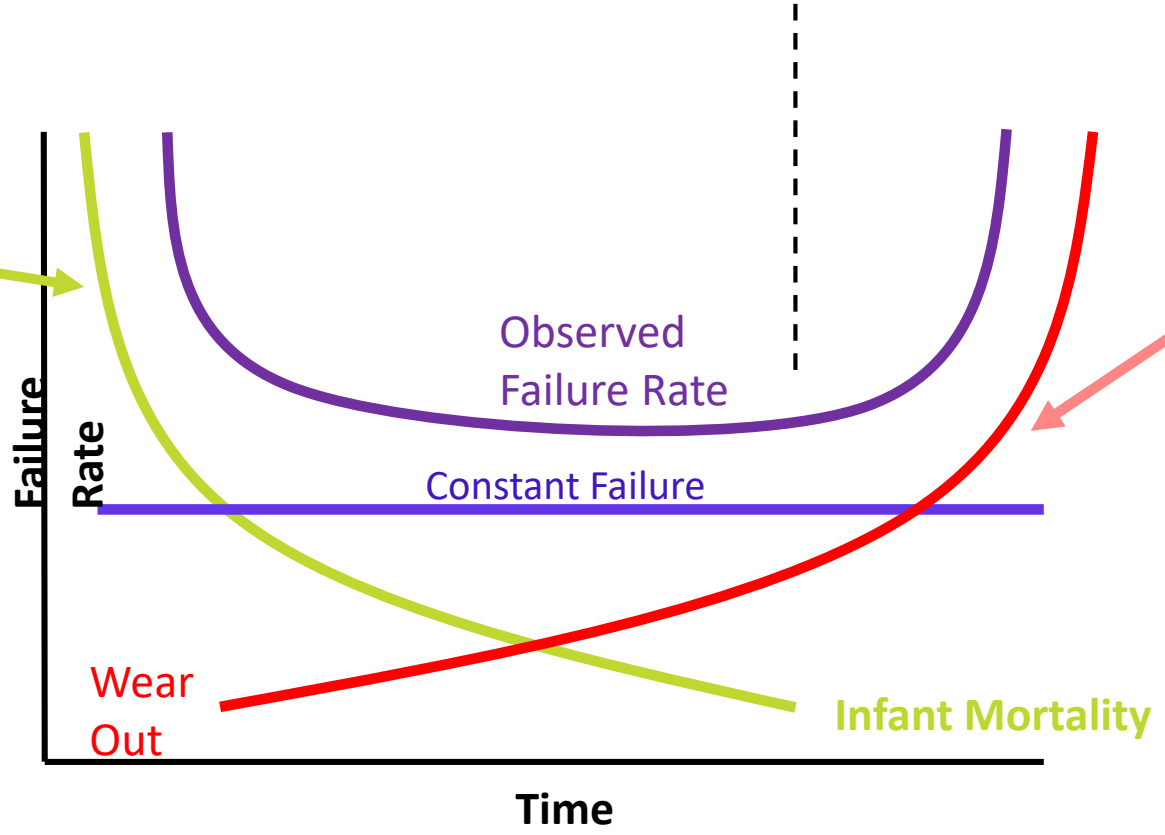
Breaking Down the Bathtub Curve

Voltage Acceleration for Reliability Prediction

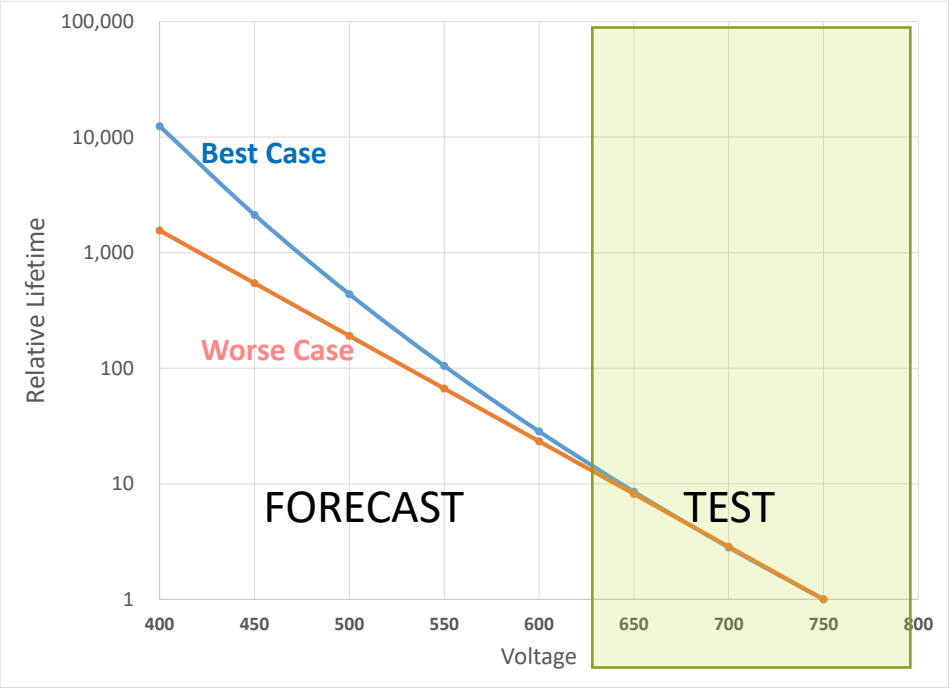
Extrinsic Reliability
Early Life Failure
Infant Mortality
Failure Rate Decreases with time



Intrinsic Reliability
Wear Out Failure
Failure Rate Increases with Time

Conservative Reliability Analysis

- When more than one model fits the data, pick the model with the "worse" reliability
- Select test conditions that accelerate only one failure mode at a time
- Always pick the lowest acceleration factor that fits the data or model
- $ttf_{use} = ttf_{test} * AF$
  - ttf_{use}: time to fail use case (application)
  - ttf_{test}: time to fail test conditions
  - AF: acceleration factor



Reliability forecast involves extrapolating device behavior under low stress conditions from high stress test conditions The high stress conditions cannot always be used to select a model.....always pick the "worse" case

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Reliability Units: typical targets below <<100 ppm year

PPM / Year	MTBF hours	FIT (Failures per Billion Device Hours)
1	8,760,000,000	0.1
10	876,000,000	1.1
100	87,600,000	11.4
1000	8,760,000	114

Note: these conversions all assume *constant failure rate* that is neither increasing nor decreasing with time. Using these conversions during wear-out or infant mortality are either inaccurate, invalid or misleading

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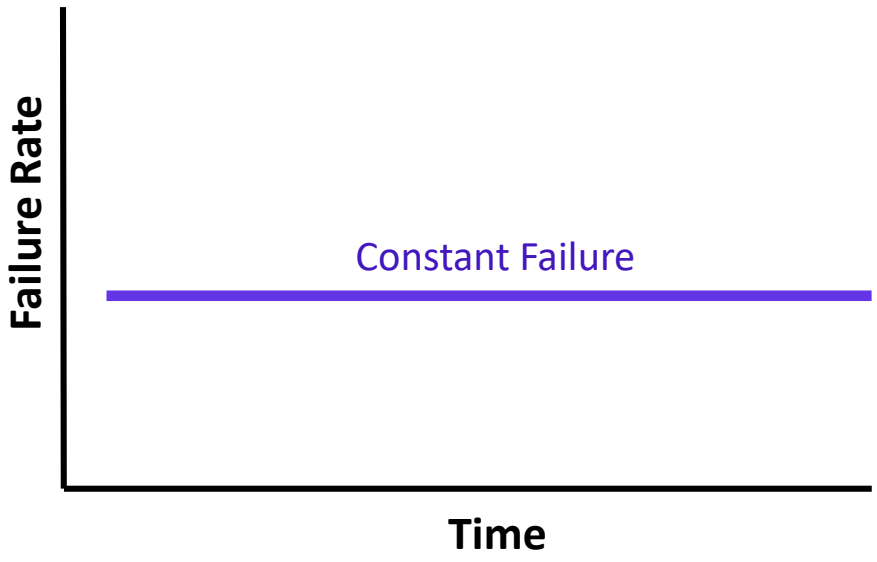
Voltage Acceleration for GaN Reliability Testing Case Study: Silicon MOSFET

Silicon MOSFETs: Temperature Acceleration for Early Life Failures

- Repeat HTRB @ 80% Vds and Tj Max until achieve desired quality level
- Assume Ea = 0.7 eV
- Assume constant failure rate
- No infant mortality
- No voltage acceleration factor
- Only predict ELF at reduced temperatures
- Problem with power devices which are typically used a relatively high temperatures



Constant Failure Rate enables use of FIT as a reliability measure

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Silicon Case continued:

How large a sample does it take to test to a FIT of 1?

Standard HTRB Testing (Assume 1 FIT)		
Number of Devices per 1000 Hour Test		
Use Temperature (C°)	AFt	Sample Size
150	1	915,000
125	3	273,860
100	13	69,728
85	33	27,997
60	180	5,096
50	382	2,395
25	3,151	290

- **AFt=exp [(Eaa/k) X (1/Tu – 1/Ta)]**
  - AFt: temperature acceleration factor
  - Eaa: apparent activation energy: 0.7eV
  - k: Boltzman constant
  - Tu: use temperature in K
  - Ta: acceleration temperature in K: 150+273
- **Sample Size = (10^9 * χ^2) / (2 *AFt * test-time * #FIT)**
- χ^2 : chi squared statistic, 60%CI, 2df (zero failures): 1.83
- test-time: 1000 hours
- #FIT: target FIT rate: 1.0

ONLY APPLIES TO SILICON, HOWEVER GAN WILL HAVE SIMILAR PROBLEMS

SOLUTION FOR GAN IS TO USE VOLTAGE ACCELERATION TO REDUCE SAMPLE SIZE

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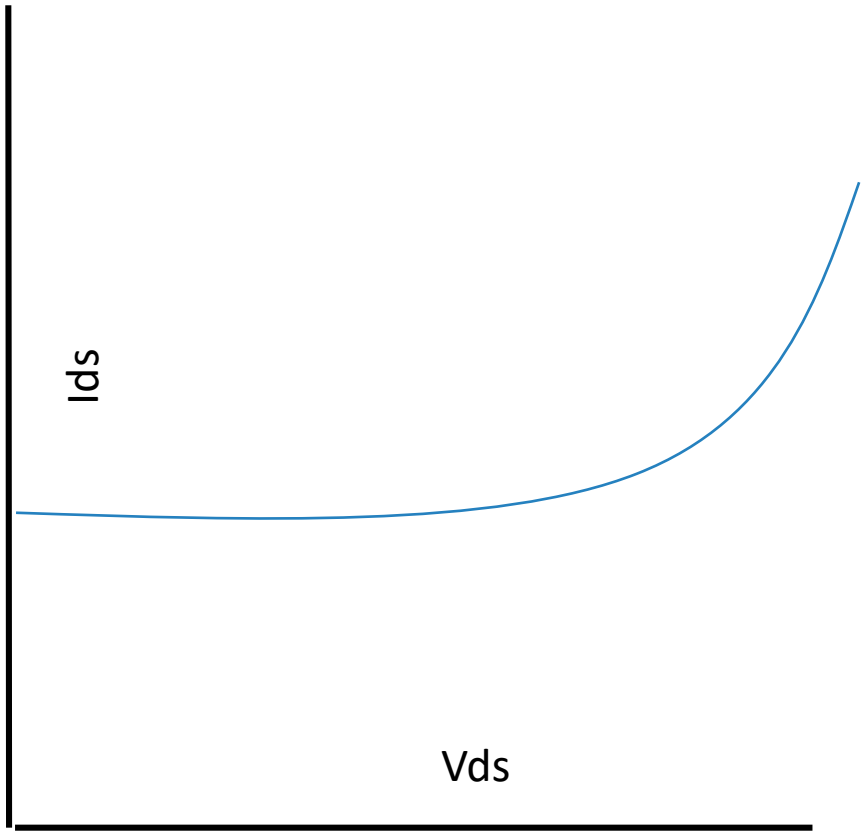
Setting Conditions: Voltage Accelerated Testing and Creating a Model

Picking Voltages Must be Chosen Carefully

- GaN devices do not avalanche with increased V_{DS}, they leak instead
- Voltages used for reliability studies must be in a “low leakage” region
- Voltage acceleration factors created with variable leakage may be inaccurate, misleading, invalid.

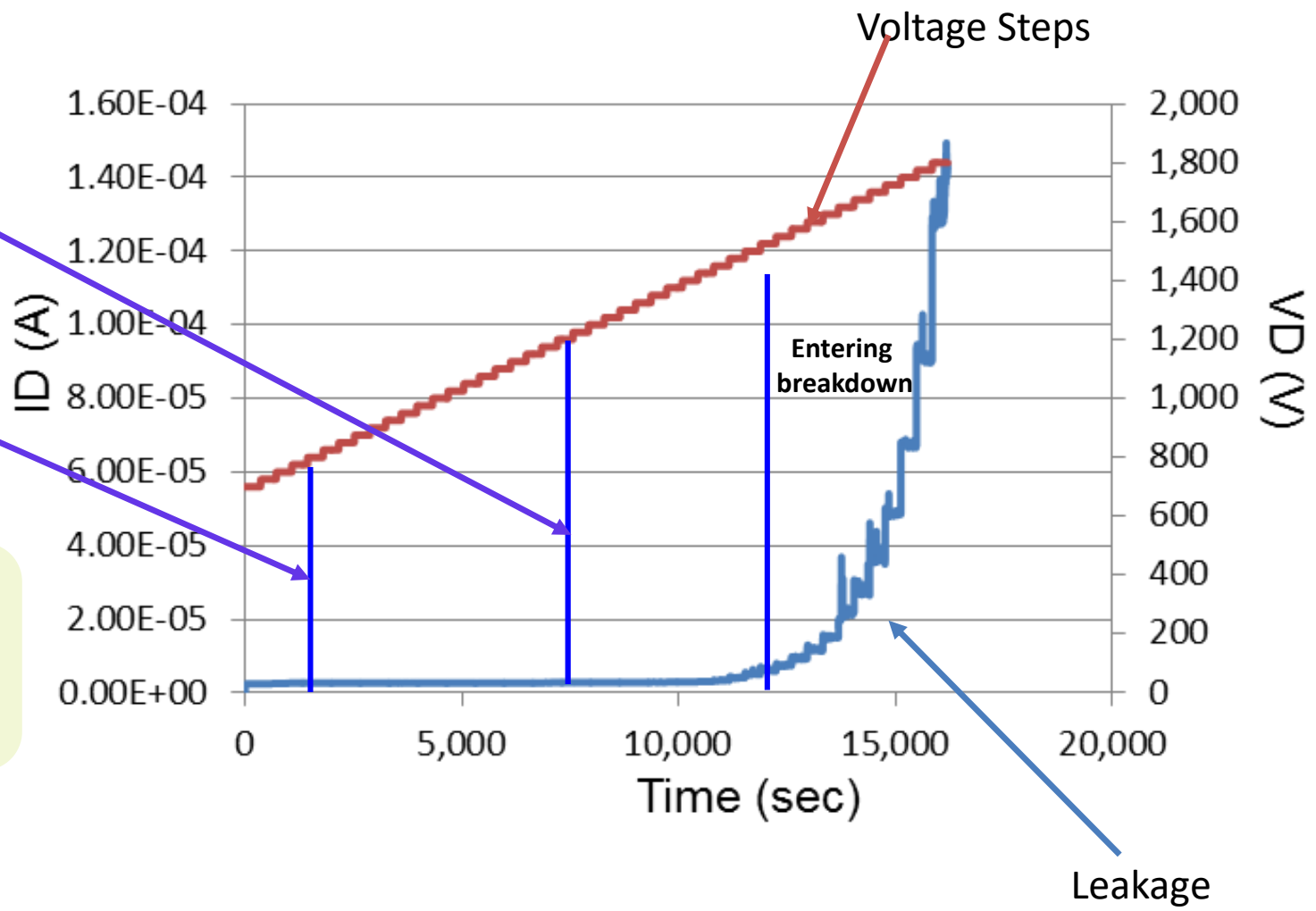


Voltage Settings for Wearout vs. Infant Mortality

Optimized for failure condition being tested

Wear Out Testing ~1200V

Infant Mortality Testing ≤ 900V

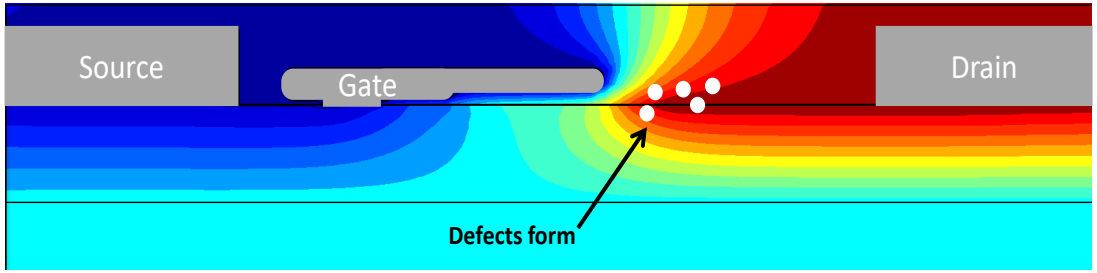


By running these tests at two different voltages we can keep the failure modes separated

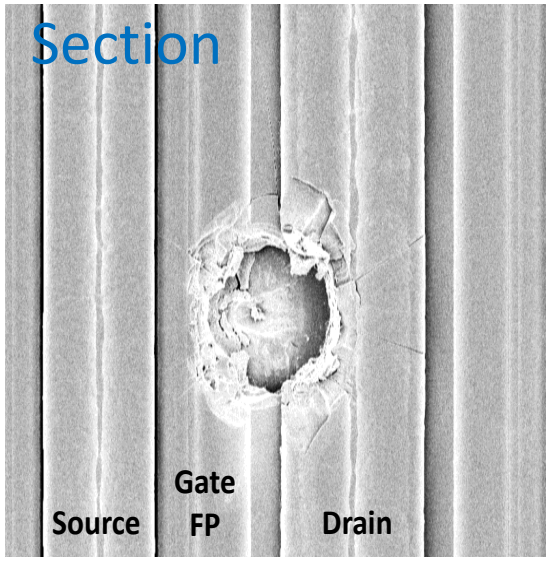
Acceleration Factor Needs to be Calculated Against Known Failure Mode(s)

- Under high electric field defects form in the dielectric
- Dielectric failure allows short from Gate-to-Drain
- Same mode observed in Infant Mortality, Useful Life and Wear out
- Failure mode limits the lifetime of the device in most mission profiles

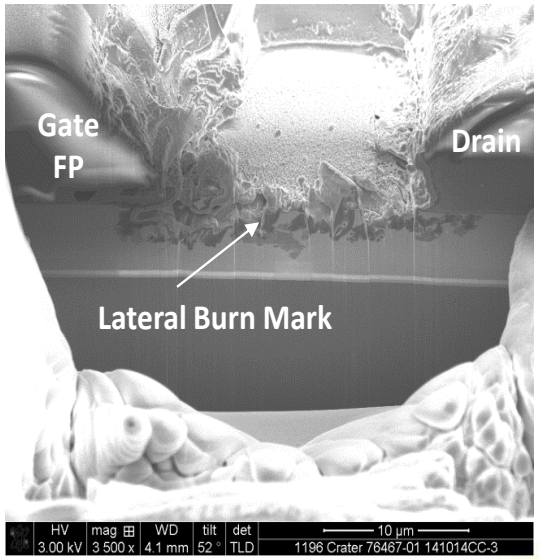
High Electric Field



Overhead View

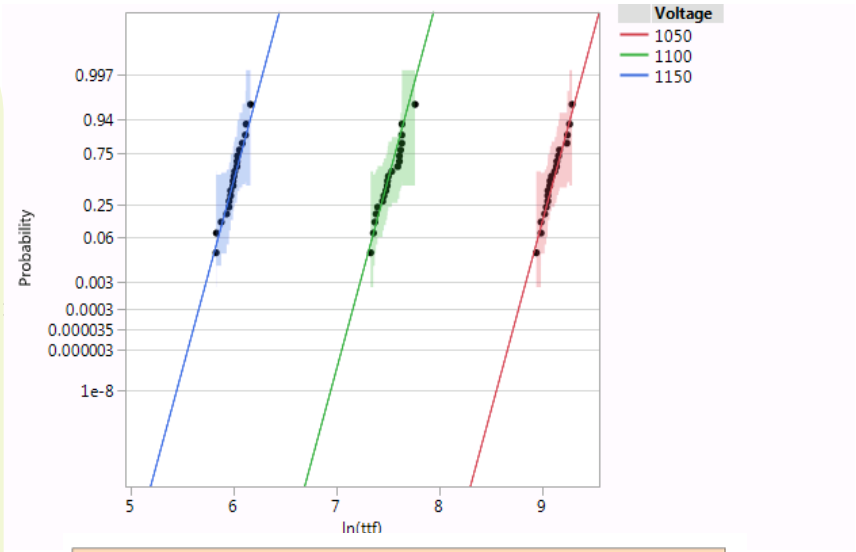


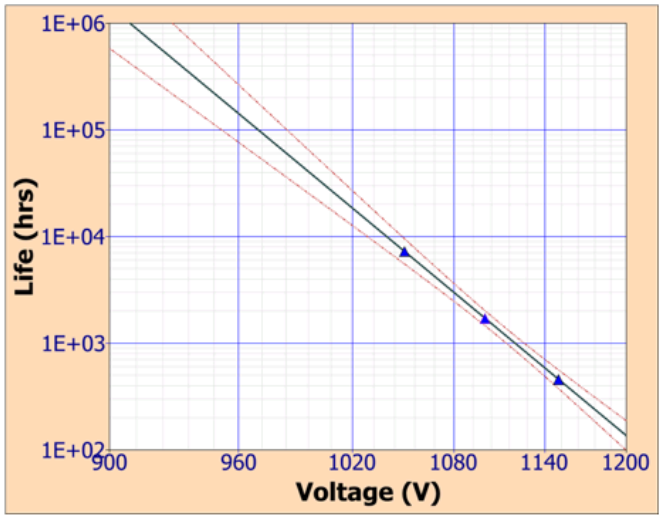
Cross



Voltage Acceleration Factor Determination has Two Phases

- Data Collection
  - Select three voltages minimum
  - Test representative samples
  - Test until ~70% of sample fails (100% preferred)
  - Determine mean time to fail each condition
- Model Building
  - Pick acceleration model
    - Based on physics and/or Conservative Principles



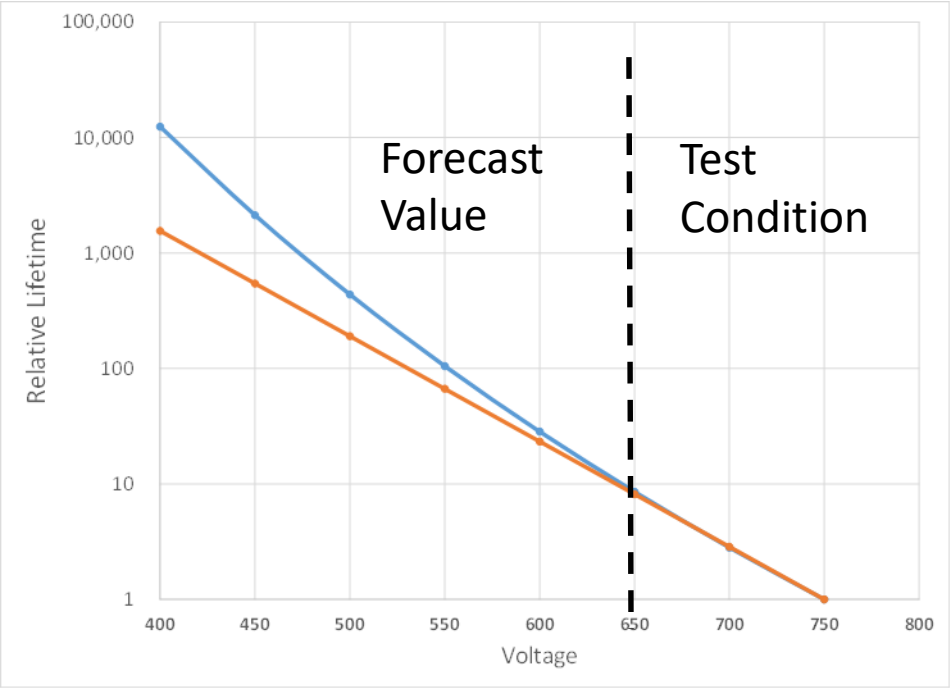


Lifetime Calculations Based on "Power Law" Model May Give a False Sense of Security

Power Law $AF_{voltage} = (V_{stress}/V_{op})^n$

Exponential $AF_{voltage} = \exp[\gamma (V_{stress} - V_{op})]$

RELATIVE LIFETIME			
Voltage	Power	Exponential	
750	1	1	TEST CONDITIONS
700	3	3	
650	9	8	
600	28	23	FORECAST VALUE
550	105	67	
500	438	191	
450	2,127	545	
400	12,446	1,556	



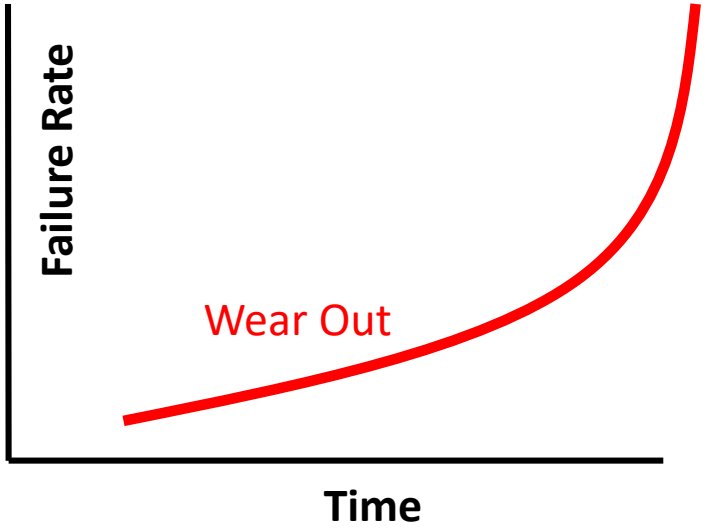
Simulated data using reasonable values for power law and exponential from literature

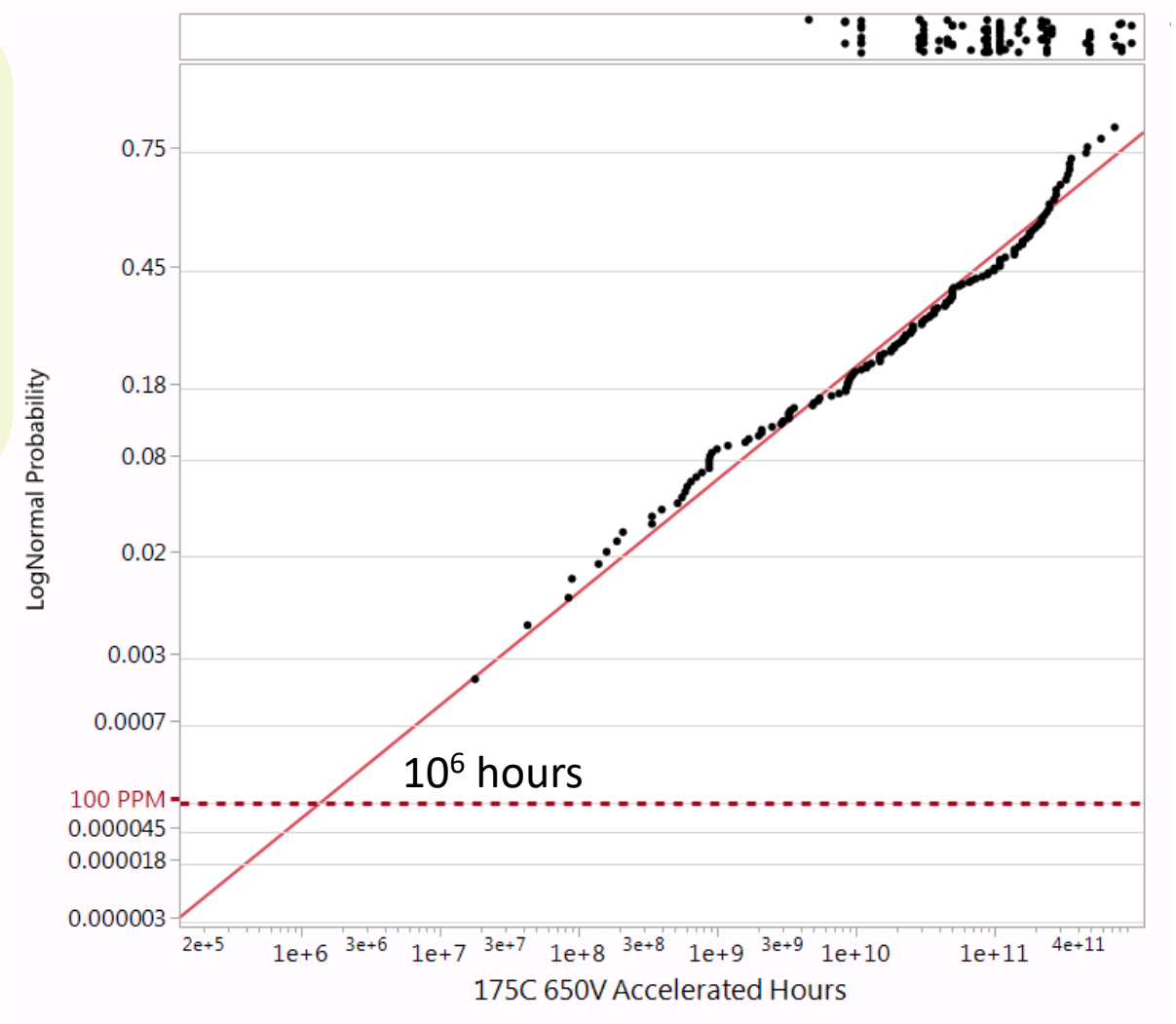
Test data does not let you differentiate between Power and Exponential Models....

Create Use Plot

Voltage Data Combined with Temperature Acceleration Data

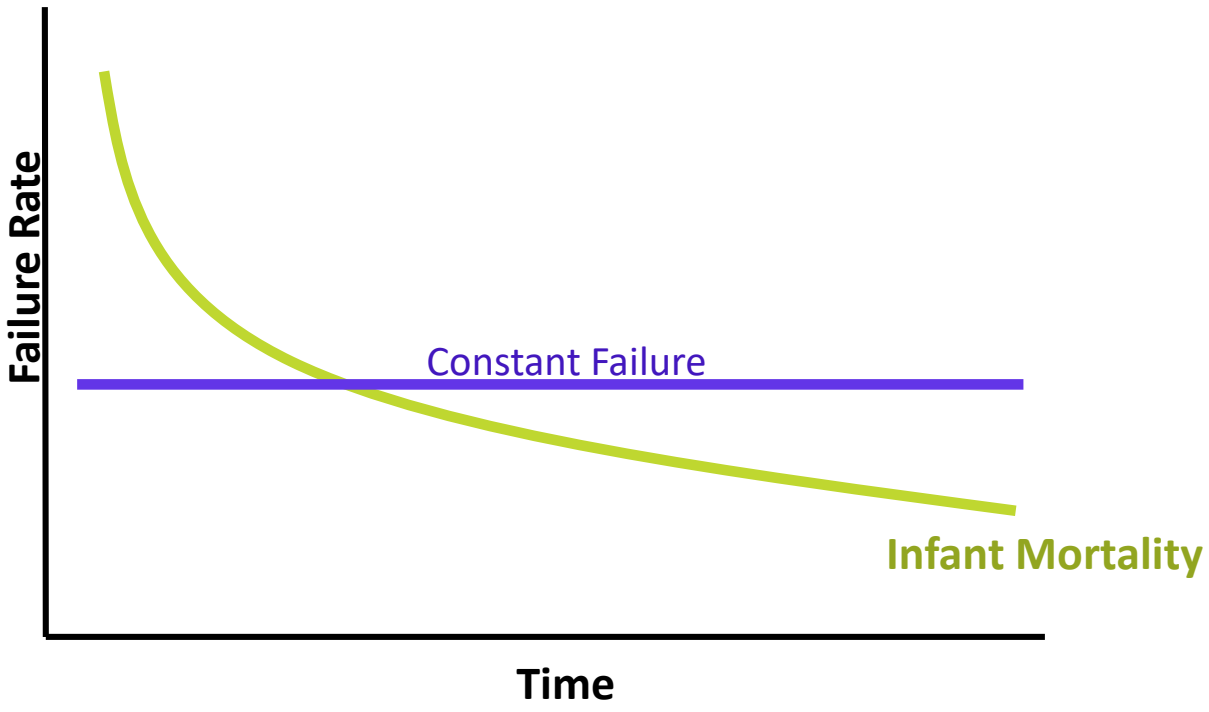
- $AF_{total} = AF_{voltage} * AF_{temp}$
- Data from all tests can be combined and normalized to single set of conditions, using the calculated/modeled acceleration factors





Early Life Failure Testing with Voltage Acceleration

Infant Mortality/Early Life Failures
Weibull Shape β Can Have a Large Effect on PPM



Example:

- **1st Year PPM Level**
- **1.5 x 10^9 device hours**
- **zero failures**

β	PPM 1st year
1	18
0.8	43
0.6	104
0.4	252
0.2	606

Constant Failure Rate Curve is a special case of the Weibull with β = 1.0, but should not be used without supporting data

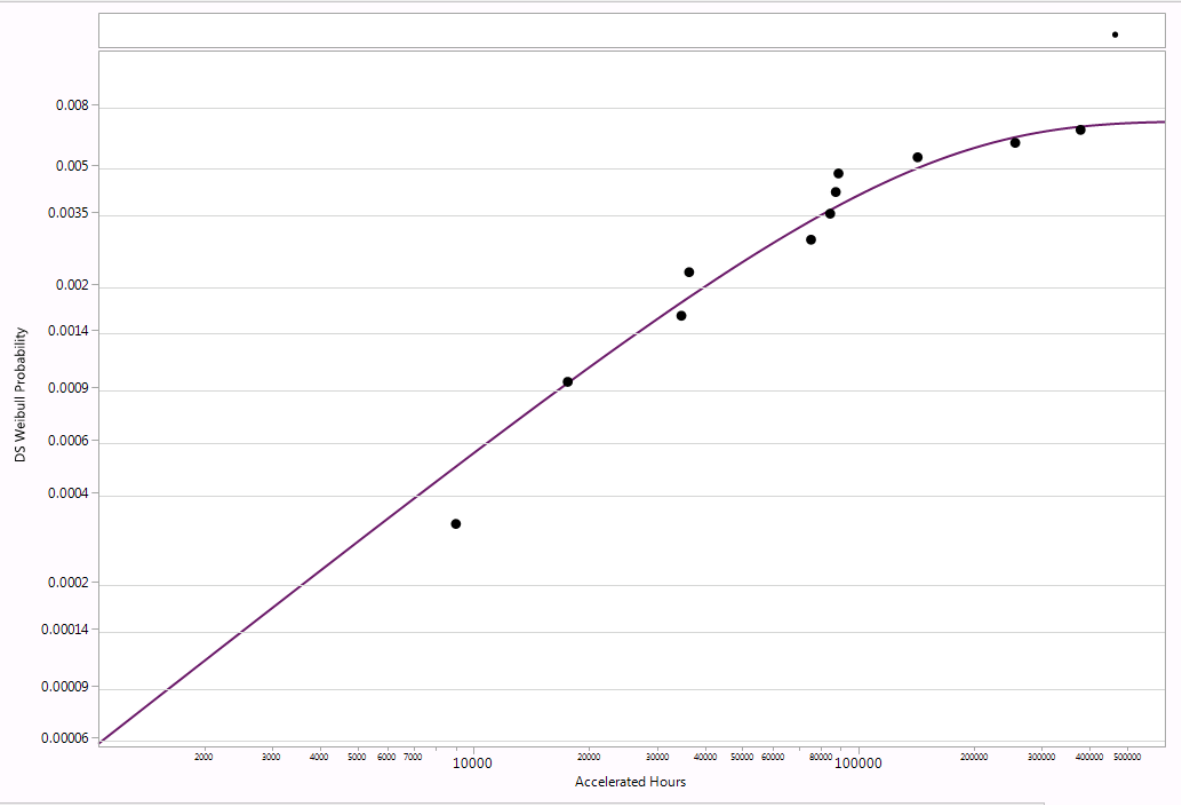
Determine Weibull Shape Parameter (m, β)

Using "Blind Build" Testing

Lifetime Testing	
Skipped reliability screening	1200 devices
Stress conditions	800 V / 85°C
Continuous monitoring	~1% catastrophic failures
Fit distribution	DS Weibull
Calculate shape parameter	β = 1.0

Early Life Failure Testing:

- Testing how well we screen out those failure from out population. So we need to characterize what those failure would look like if NOT screened out



Voltage Acceleration Test for Infant Mortality Risk

Test Conditions:

- Temperature: 85°C
- Voltage: 800 V
- # of Devices, N= 2200
- Test Time, t_A =500 hours
- Device Hours: $1.1e^6$
- F = zero failures
- d = 2f + 2° of freedom
- c = 60% confidence interval

Acceleration Factor

- $\Delta V = V_{test} - V_{use}$
- $\gamma = .026$
- $AF = e^{\gamma \Delta V}$
- $t_U = t_A * AF$

F(ELF) =Fraction Failing from time = 0 to time = t_{ELF}

- $CDF = \chi^2_{c,d} / 2N$ Statistical uncertainty
- $\eta = t_U / ((-\ln[1-CDF])^{1/\beta})$ Weibull Characteristic Time
- $F(ELF) \text{ in ppm} = 10^6 \times (1-\exp(-(t_{ELF}/\eta)^\beta))$

Voltage	F (1st Year) PPM
520	5.33
480	1.88
400	0.24

JESD 74A

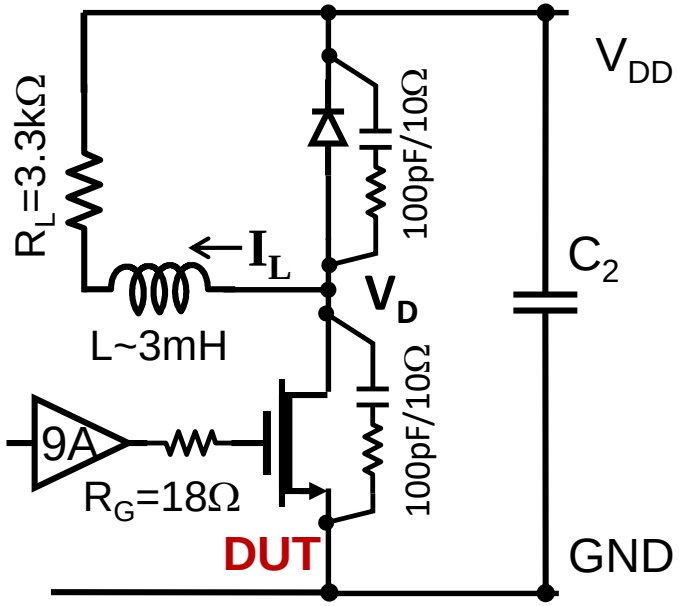
- Early Life Failure Rate Calculation Procedure for Semi Conductor Components

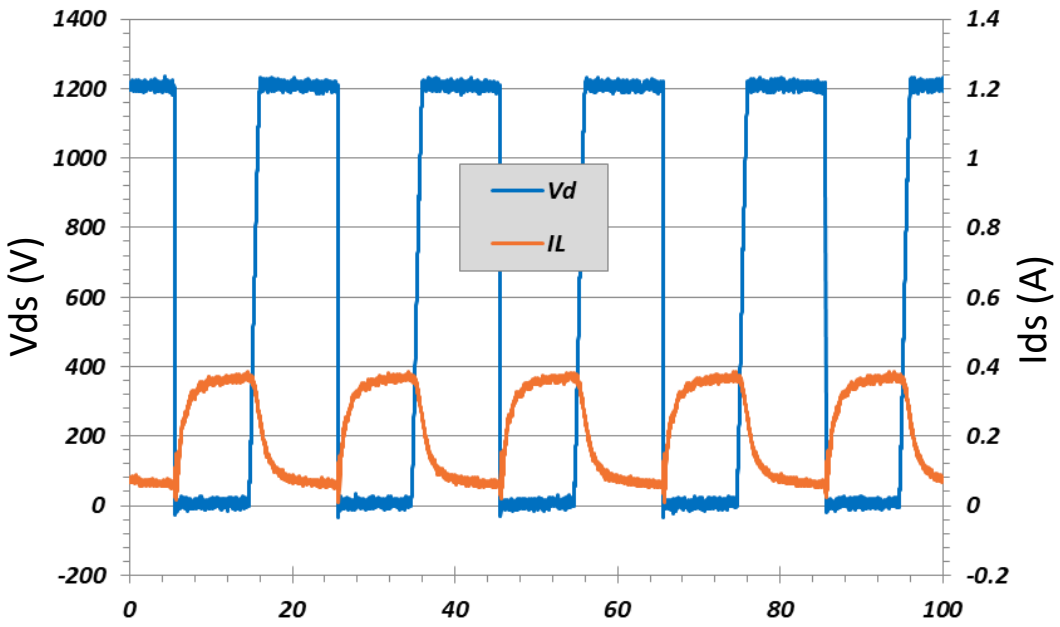
Samples were taken from ~30 different lots across months of production to sample consistency of the process

Switching Stress Data

Switching Stress Tests Compared to DC Stress

Switching Test Circuit



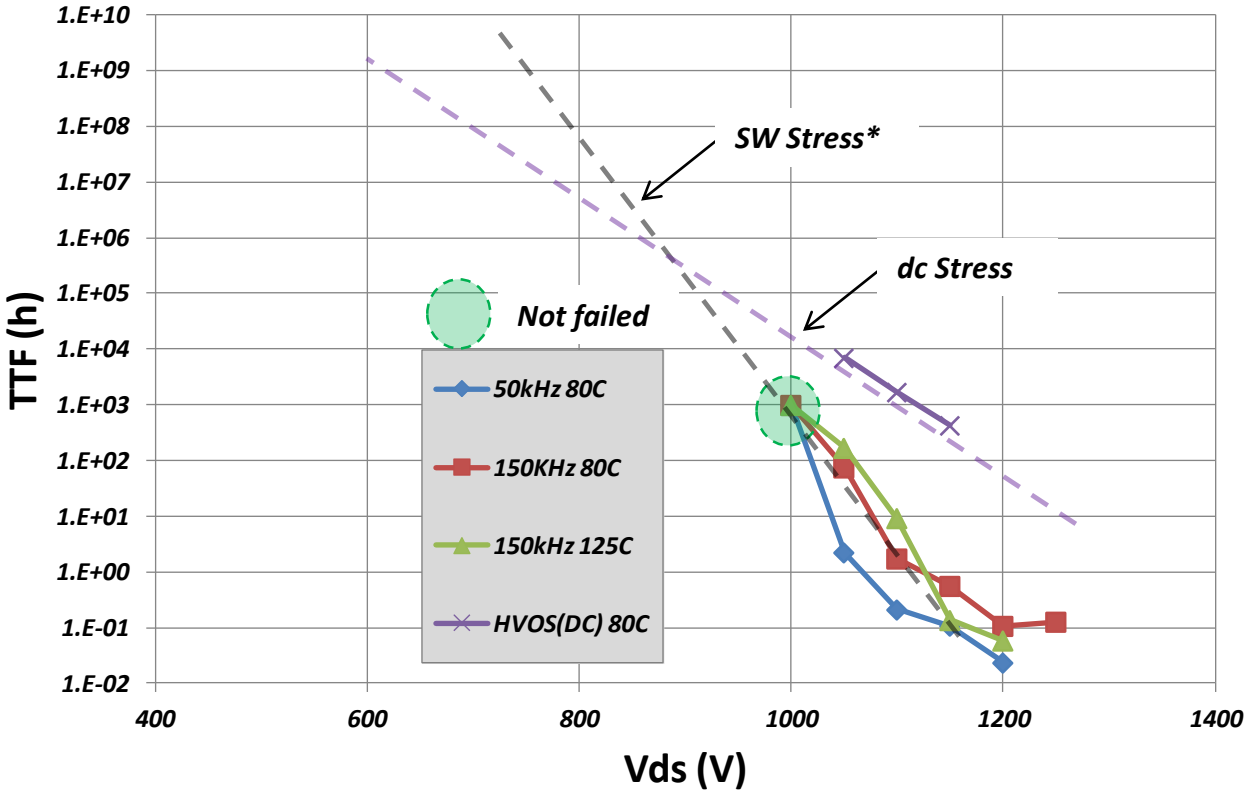


Test Conditions:

- V_{DD} = 1000 V to 1200 V
- Frequency = 50 kHz, 150 kHz
- Temperature (T_J) = 80 to 125°C

- Focus on switching effect at external current levels
- Internal switching energy stress is up to 5x higher than at 400V

Switching Stress Tests Compared to DC Stress



- Switching stress test shows steeper voltage acceleration.
- Little dependence on T_J.
- Higher Frequency longer time to failure (TTF)
- *Even conservative projection predicts longer 600V SW TTF than dc.

900 V Product Introduction

First 900 V GaN Device in Production

transphorm **TP90H180PS**

900V GaN FET in TO-220 (source tab)

Description
The TP90H180PS 900V, 170mΩ Gallium Nitride (GaN) FET is a normally-off device. It combines state-of-the-art high voltage GaN HEMT and low voltage silicon MOSFET technologies—offering superior reliability and performance.

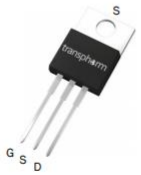
Transphorm GaN offers improved efficiency over silicon, through lower gate charge, lower crossover loss, and smaller reverse recovery charge.

Related Literature
- AN0009: Recommended External Circuitry for GaN FETs
- AN0003: Printed Circuit Board Layout and Probing
- AN0010: Paralleling GaN FETs

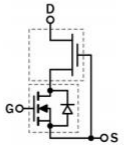
Ordering Information

Part Number	Package	Package Configuration
TP90H180PS	3 lead TO-220	Source

TP90H180PS
TO-220
(top view)



Cascode Schematic Symbol



Cascode Device Structure

Features
- JEDEC qualified GaN technology
- Dynamic $R_{DS(on)eff}$ production tested
- Robust design, defined by
  - Intrinsic lifetime tests
  - Wide gate safety margin
  - Transient over-voltage capability
- Very low Q_{RR}
- Reduced crossover loss
- RoHS compliant and Halogen-free packaging

Benefits
- Enables AC-DC bridgeless totem-pole PFC designs
  - Increased power density
  - Reduced system size and weight
  - Overall lower system cost
- Achieves increased efficiency in both hard- and soft-switched circuits
- Easy to drive with commonly-used gate drivers
- GSD pin layout improves high speed design

Applications
- Datacom
- Broad industrial
- PV inverter
- Servo motor

Key Specifications	
V_{DSS} (V)	900
$V_{(TR)DSS}$ (V)	1000
$R_{DS(on)eff}$ (mΩ) max*	205
Q_{RR} (nC) typ	49
Q_G (nC) typ	10

* Dynamic on-resistance; see Figures 19 and 20

November 22, 2017
tp90h180ps.0

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1

- Device: TP90H180PS
- Voltage: 900 V
- On Resistance (typ.): 170 mΩ
- Robust gate: ±18 V
- Package: TO-220
- JEDEC Qualified

Buy Now

All Transphorm devices and evaluation kits are available through Digi-Key.

- TP90H180PS 900V GaN FET in TO-220 (source tab)

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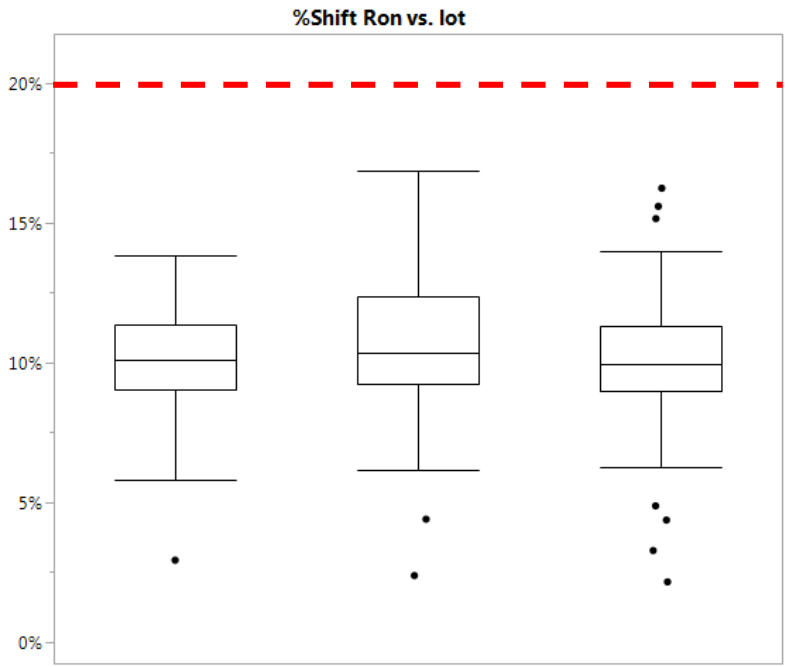
900 V product passed JEDEC qualification

Device	TEST	SYMBOL	CONDITIONS	SAMPLE	RESULT
TP90H180PS	High Temperature Reverse Bias	HTRB	T_J=150°C V_{DS} = 720V 1000 HRS	3 lots 77 parts per lot 231 total parts	0 Fails **PASS**

- Improve epitaxy and device structures to minimize trapping effect and manage electric field
- Passing HTRB 1000 hours with V_{DS}=720V at 150C
- $R_{DS(ON)}$ shift before and after HTRB is within 17% (beyond JEDEC requirement)



$R_{DS(ON)}$ shift after HTRB1000

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Transphorm TP90H050WS Press Release

Transphorm Strengthens 900 V GaN Portfolio with Second FET

New Generation III GaN-on-Si FETs Capable of Powering Three-phase Broad Industrial
Power Supplies and Automotive Converters

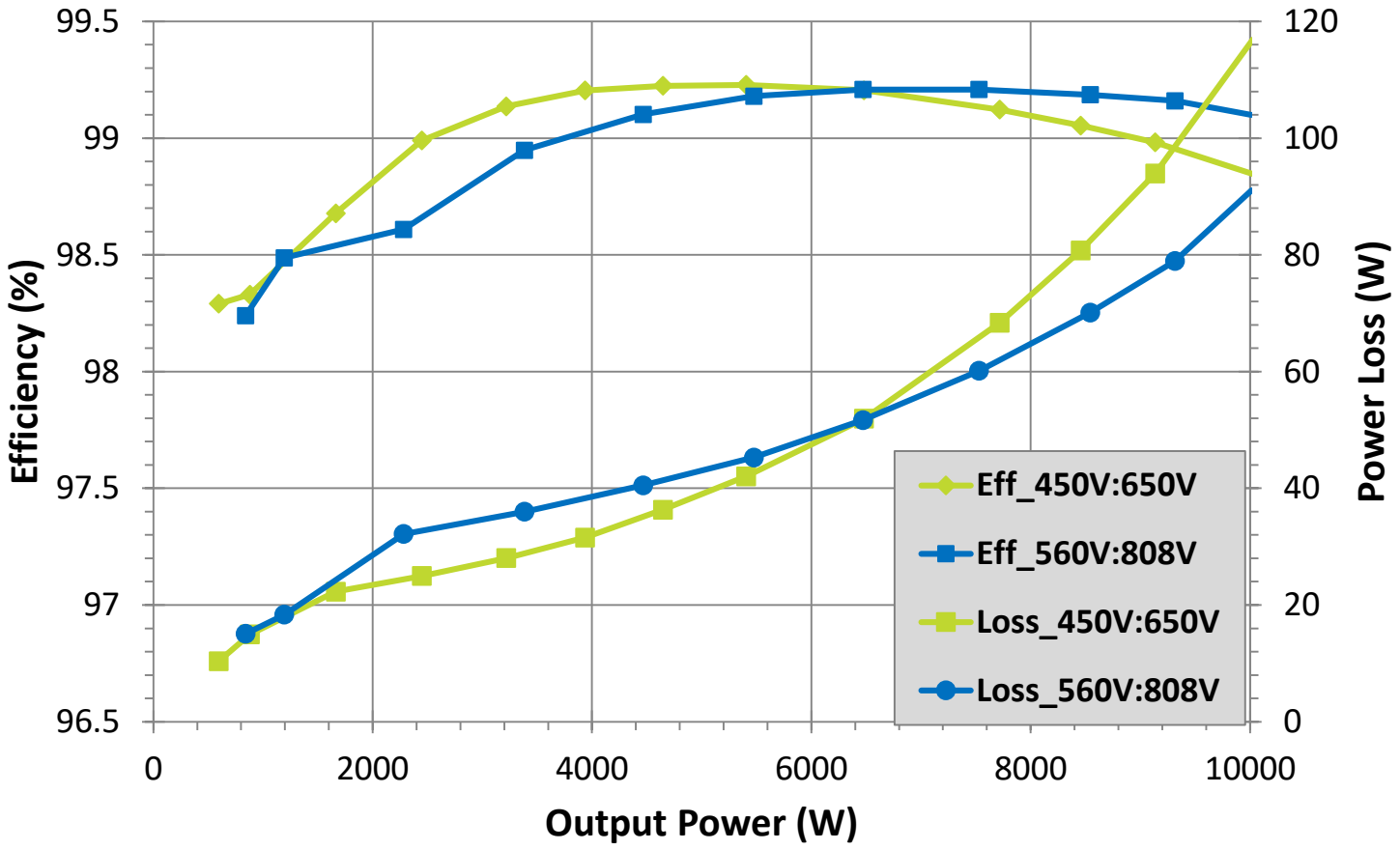
Transphorm Inc.—the leader in the design and manufacturing of the highest reliability high-voltage (HV) Gallium Nitride (GaN) semiconductors—today introduced its second 900 V FET, the Gen III TP90H050WS, enhancing the industry's only 900 V GaN product line. These devices now enable three-phase industrial systems and higher voltage automotive electronics to leverage GaN's speed, efficiency and power density. Further, the new FET's platform is based on Transphorm's 650 V predecessor, the only JEDEC- and AEC-Q101-qualified HV GaN technology. As such, system developers can design with confidence in its quality and reliability.

The TP90H050WS has a typical on-resistance of 50 mOhm with a 1000 V transient rating, offered in a standard TO-247 package. The TP90H050WS can reach power levels of 8 kW in a typical half bridge while maintaining greater than 99 percent efficiencies. Its figures of merit for Ron*Qoss (resonant switching topologies) and Ron*Qrr (hard switching bridge topologies) are two to five times less than those of common superjunction technologies in production—indicating highly reduced switching losses. While a JEDEC qualified version is slated for Q1 2020, customers can design 900 V GaN power systems today.

Transphorm's first 900 V device, the TP90H180PS, with a typical on-resistance of 170 mOhm in a TO-220 package is JEDEC qualified and has been available through Digi-Key since 2017. It can reach a peak efficiency of 99 percent, demonstrating its suitability for 3.5 kW single-phase inverters.

Transphorm's 900V GaN Device Half-bridge Performance

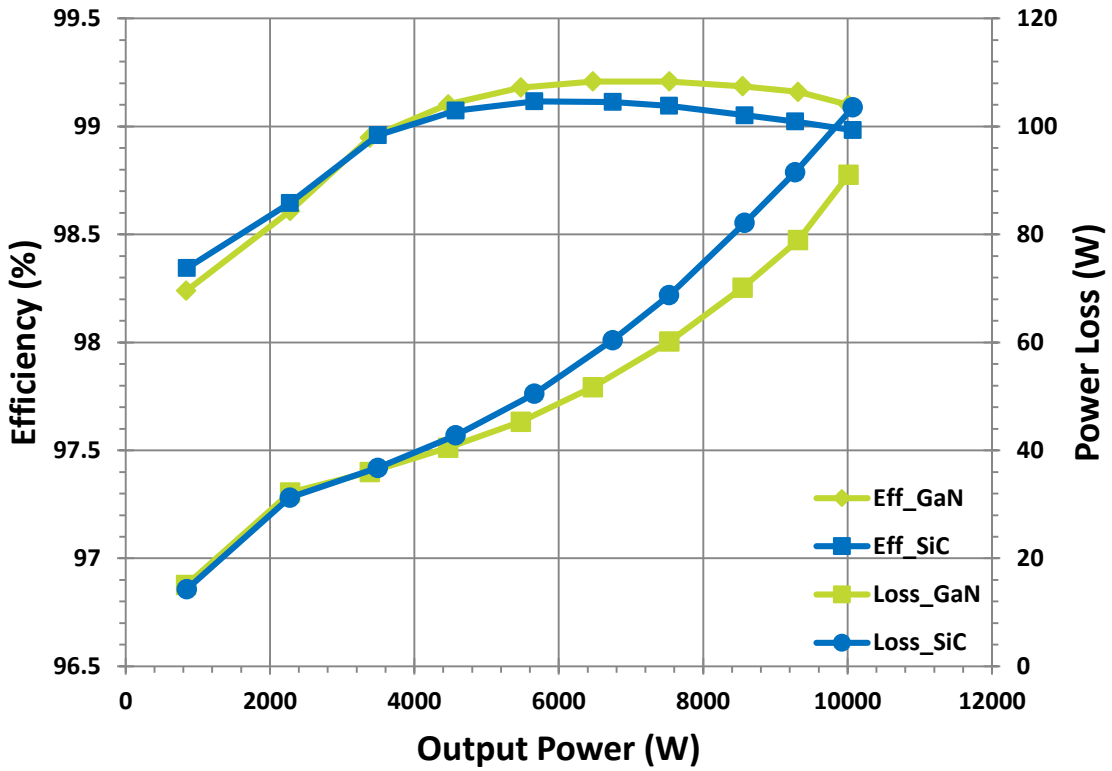
(Hard switching boost converter at 100kHz)



✓TPH 900 V GaN (50 mΩ) half-bridge operated to > 800 V with 99% efficiency at 10 kW

GaN Exceeds SiC in 800 V Converter Operation

Half Bridge Boost Converter: 560 V:808 V at 100kHz



- GaN shows higher efficiency than SiC in 800 V converter and at a lower cost
- Commercially available SiC MOSFET: 1200 V / 40 mΩ / TO-247
  - Similar on resistance at 125°C

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Conclusion

- Voltage Acceleration Testing Power Tool for forecasting reliability of high voltage GaN devices
- Reliability of new Technology should always be evaluated from a conservative point of view
- Test conditions must be selected so that only voltage (field) is being evaluated
- Voltage acceleration models must also be chosen with conservative view, exponential model as the default
- Early Life Failure must be backed up with appropriate data to determine Weibull parameters
- Switching lifetime is longer than DC prediction and should be used with caution (DC is the default)
- 650V is not the ceiling for GaN! 900V devices have been released

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Welcome to the Revolution

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Highest Performance, Highest Reliability GaN