DRC
77TH DEVICE RESEARCH CONFERENCE
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Navitas

Let's go GaNFast™

GaN Power Integrated Circuits

Dr. Nick Fichtenbaum, Co-Founder & VP Engineering

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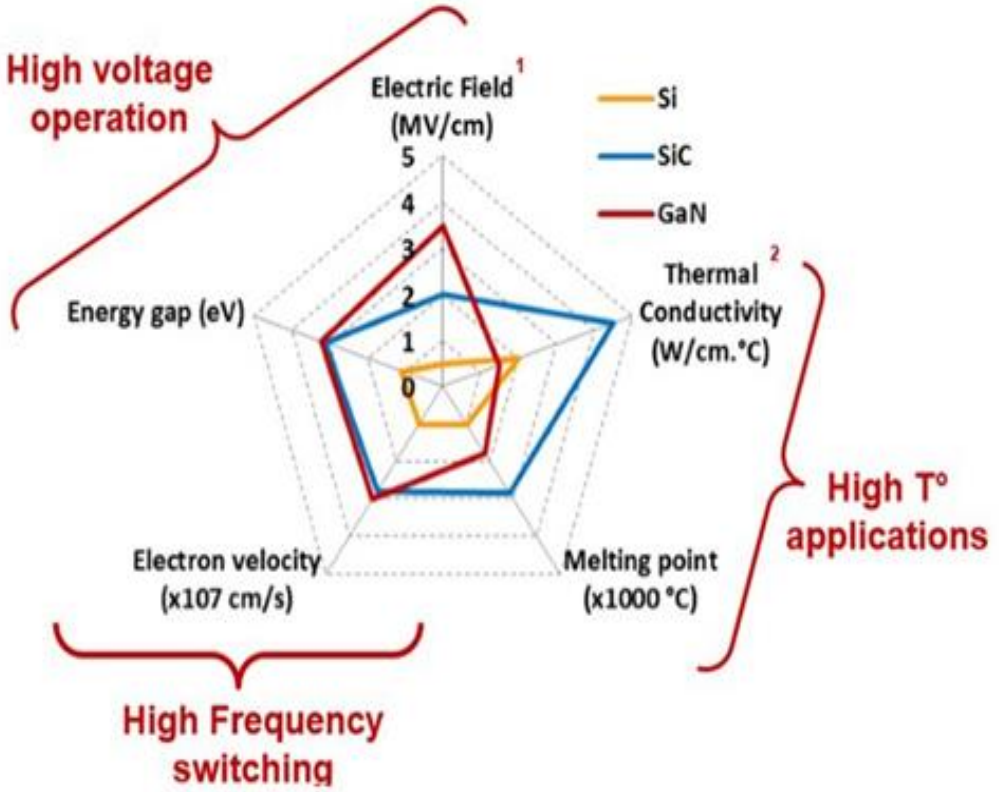
Outline

- Why GaN Power ICs
- How to make GaN Power ICs
- Features of GaN Power ICs
- Commercial requirements for GaN products
- Products using GaN Power ICs

Potential of GaN Power Devices

GaNFast™

Important Material Attributes



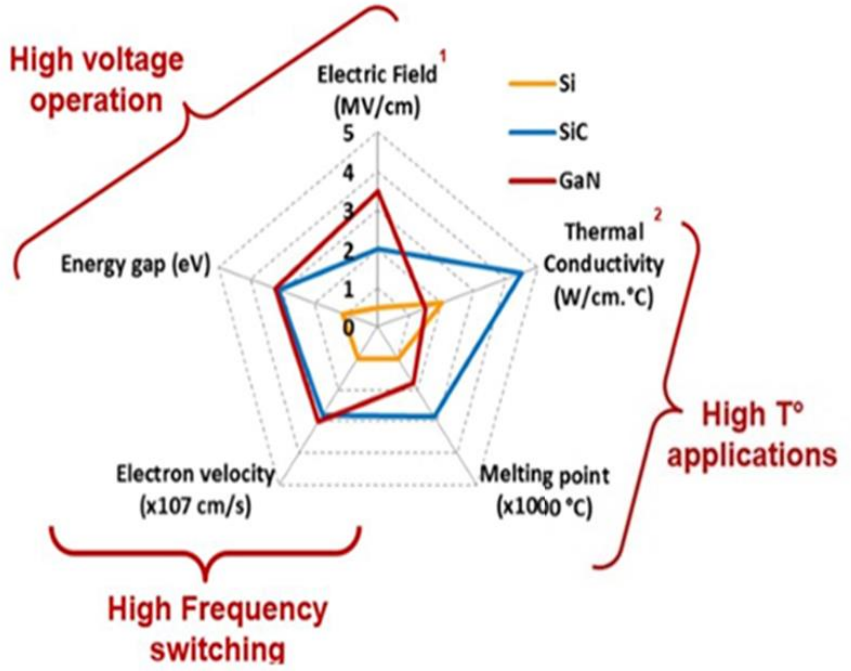
System Benefits

- ✓Efficiency
- ✓Cost Savings
- ✓Power Density

Unlocking GaN's Value

GaNFast™

Fundamental GaN Material Properties

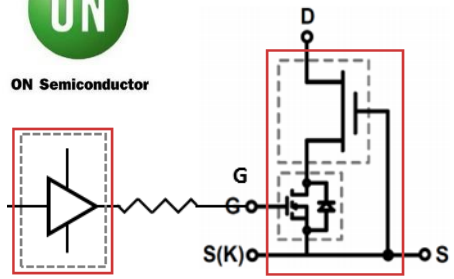


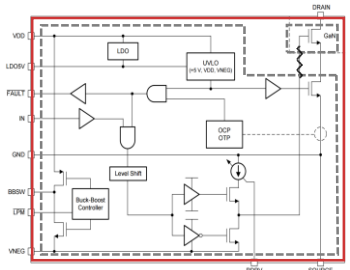
dMode

eMode

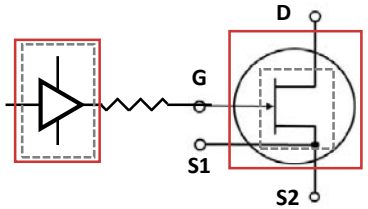
transphorm

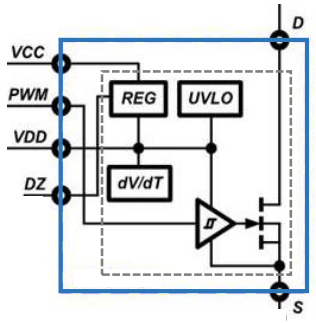
ON Semiconductor





Texas Instruments





Panasonic

Infineon

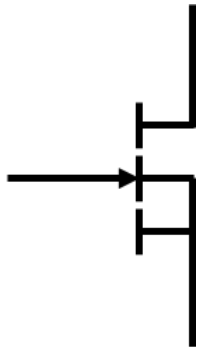
GaN Systems

EPC EFFICIENT POWER CONVERSION

Navitas

World's First GaN Power ICs

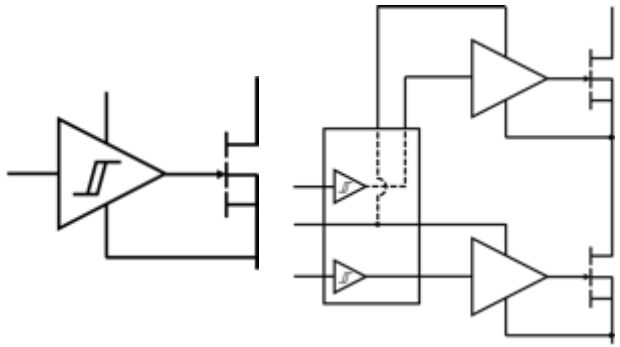
Fastest, most efficient GaN Power FETs



>20x faster than silicon
>5x faster than cascoded GaN
Proprietary design

+

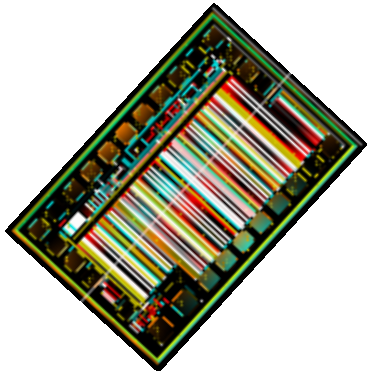
First & Fastest Integrated GaN Gate Drivers



>3x faster than any other gate driver
Proprietary design
75+ patents granted/applied

=

World's First GaNFast™ Power ICs

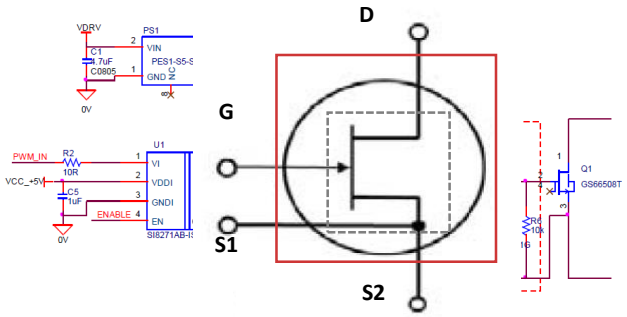


Up to 5x higher density & 20% lower system cost

The Drive for Better Drivers

- Low V_{TH}
- Low R x Q
- Low V_{GS_Max}

Discrete FET + Discrete Driver

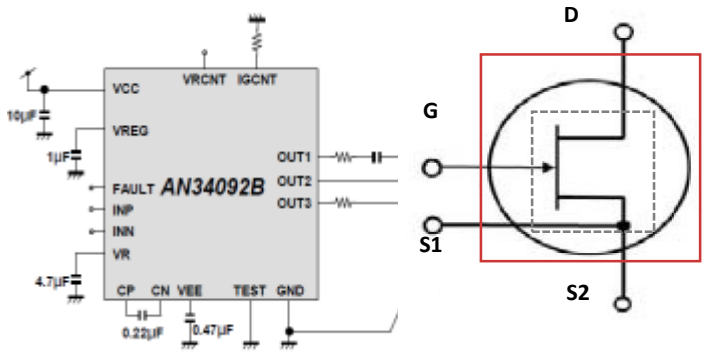


Gate Drive Challenges	Discrete FET + Discrete Driver	Discrete FET + Custom driver	GaN Power IC
Eliminate Gate Oscillations	✓		
Eliminate dV/dt Induced Turn-on	✓		
Regulate Gate Drive Voltage	✓		
Gate Overvoltage Protection	✓		
Reduce Design Complexity	✗		
Manage Noise Sensitivity	✗		
Fast Turn-on/off Speed	✗		
Gate ESD Protection	✗		
Layout Insensitive	✗		
Lowest PCB Area	✗		
Lowest Cost	✗		
Remove Negative Drive	✗		
Fast Start-up	✓		
Eliminate Standby Loss	✓		

The Drive for Better Drivers

- Low V_{TH}
- Low R x Q
- Low V_{GS_Max}

Discrete FET + Custom Driver



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Reduce Design Complexity	✗	✓	
Manage Noise Sensitivity	✗	✓	
Fast Turn-on/off Speed	✗	✓	
Gate ESD Protection	✗	✗	
Layout Insensitive	✗	✗	
Lowest PCB Area	✗	✗	
Lowest Cost	✗	✗	
Remove Negative Drive	✗	✗	
Fast Start-up	✓	✗	
Eliminate Standby Loss	✓	✗	

The Drive for Better Drivers

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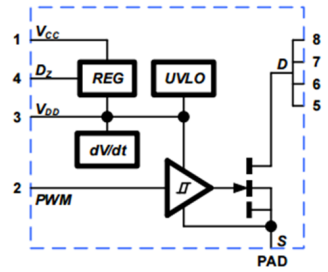
GaN Power IC



No compromises

Gate Drive Challenges	Discrete FET + Discrete Driver	Discrete FET + Custom driver	GaN Power IC
Eliminate Gate Oscillations	✓	✓	✓
Eliminate dV/dt Induced Turn-on	✓	✓	✓
Regulate Gate Drive Voltage	✓	✓	✓
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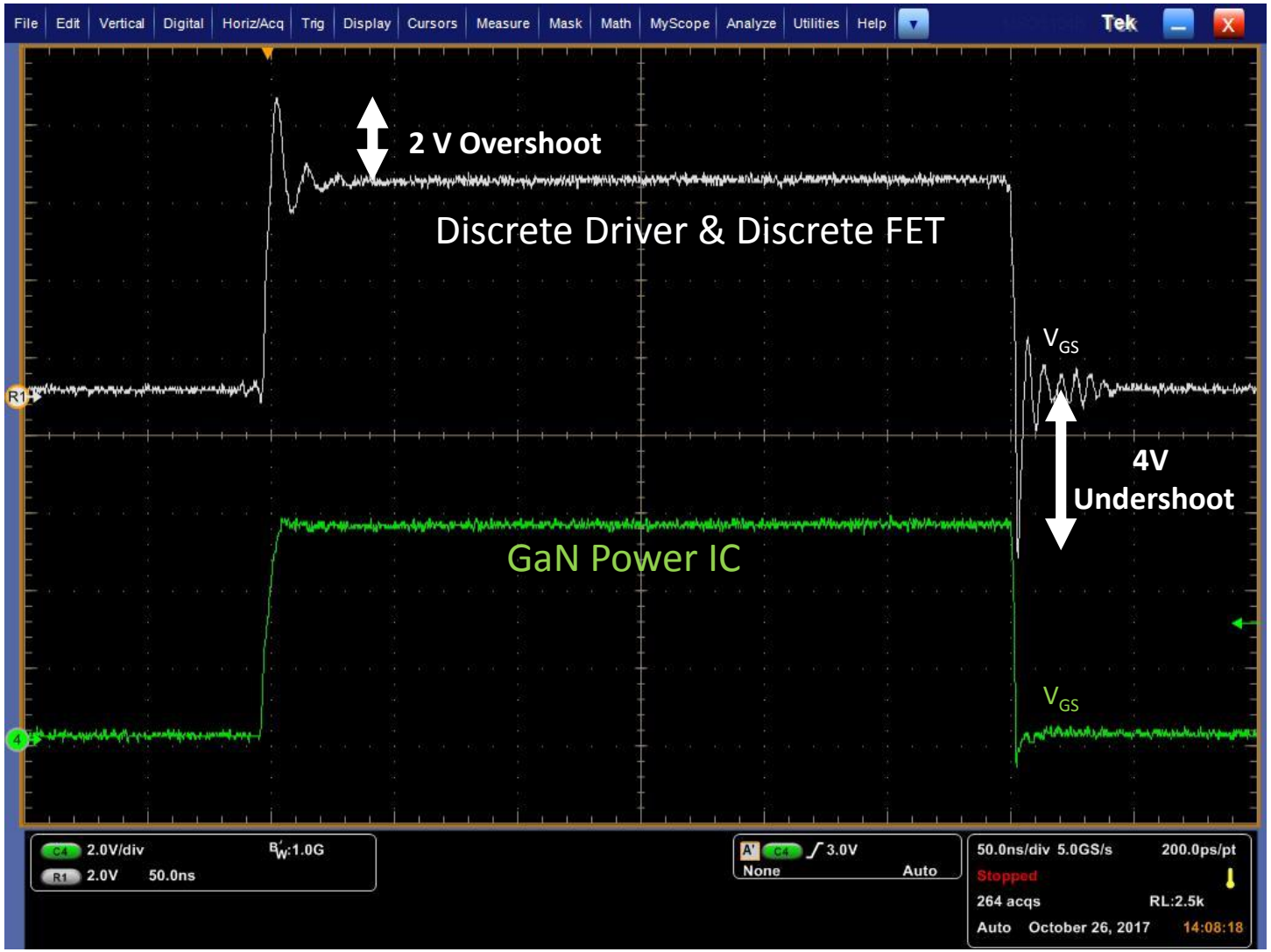
Fast Turn-on/off Speed	✗	✓	✓
Gate ESD Protection	✗	✗	✓
Layout Insensitive	✗	✗	✓
Lowest PCB Area	✗	✗	✓
Lowest Cost	✗	✗	✓
Remove Negative Drive	✗	✗	✓
Fast Start-up	✓	✗	✓
Eliminate Standby Loss	✓	✗	✓

Clean, Controlled, Easy to Use

- **Discrete driver**
  - Gate loop inductance creates overshoot
    (even with good layout)
  - Reliability concern
- **GaNFast™ GaN Power IC**
  - No gate loop parasitic
  - Clean and fast gate signal

- **GaNFast ICs unlock the efficiency, cost, and power density of GaN while making the customer experience easy to use and reliable**



Outline

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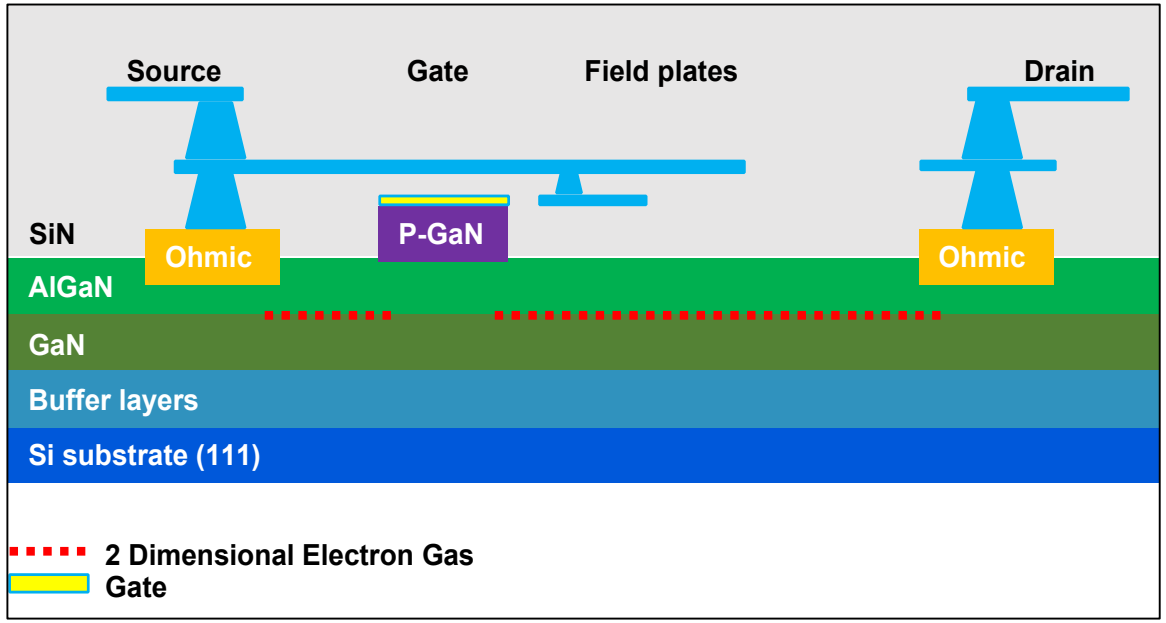
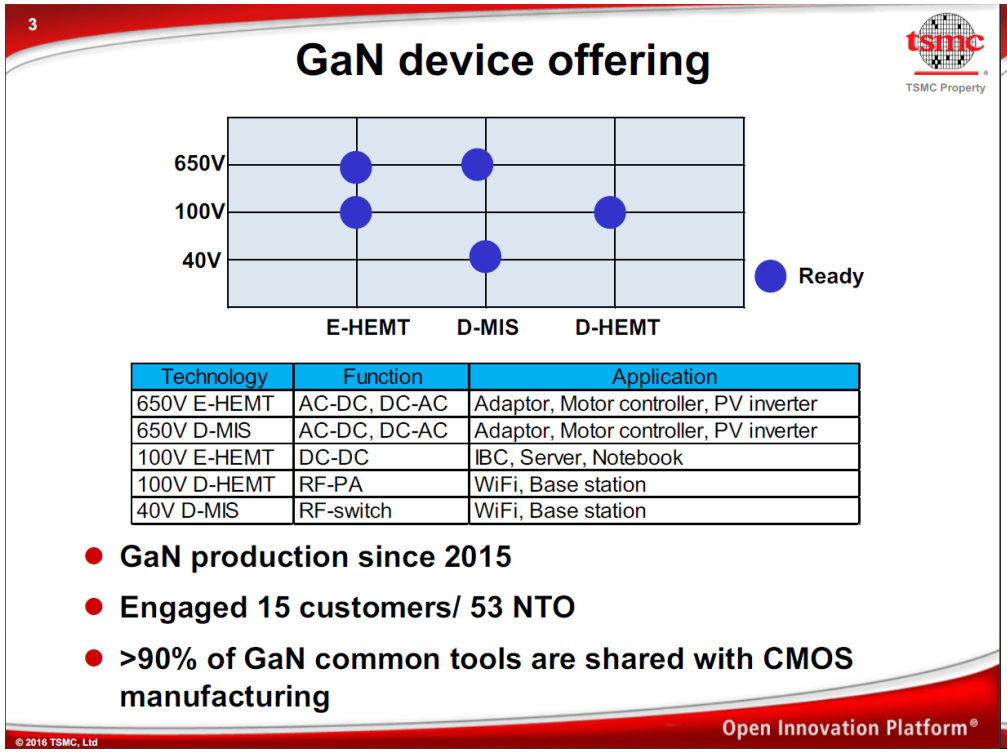
- How to make GaN Power ICs?
- Features of GaN Power ICs
- Commercial requirements for GaN products
- Products using GaN Power ICs

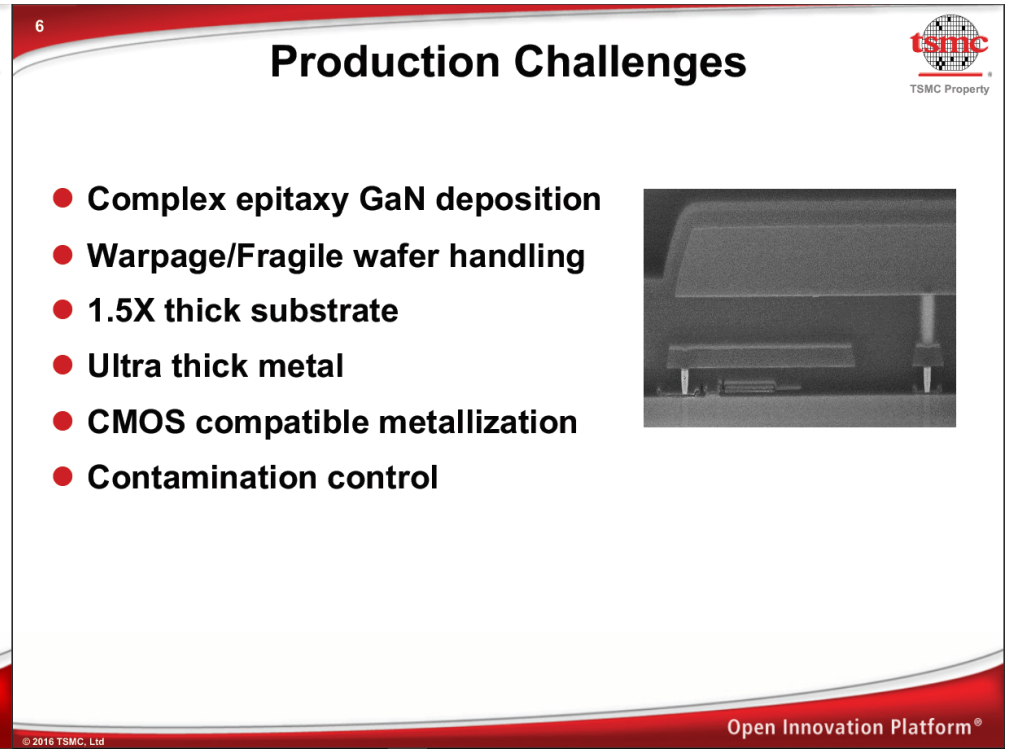
Navitas eMode Power FET Technology



- Lateral device technology → Convenient isolation and easy voltage scaling
- High breakdown field (10X) and high mobility (2X) → Low $R_{DS(ON)}$, Low Q_{OSS}
- Lateral device technology → Low Q_G, easy to drive, easy to integrate
- Third quadrant operation, ie: bidirectional current flow, zero reverse recovery
- Processed in established CMOS line → High yield, high capacity
- Multiple metal technology using standard CMOS processing equipment

Navitas' Unique Characteristics: Fabless with its own PDK





GaN HEMT is still an emerging technology in the market.

➔ Majority of GaN technologies and products developed are for high-voltage/power applications.

➔ Also, GaN devices are only available in unipolar n-type.

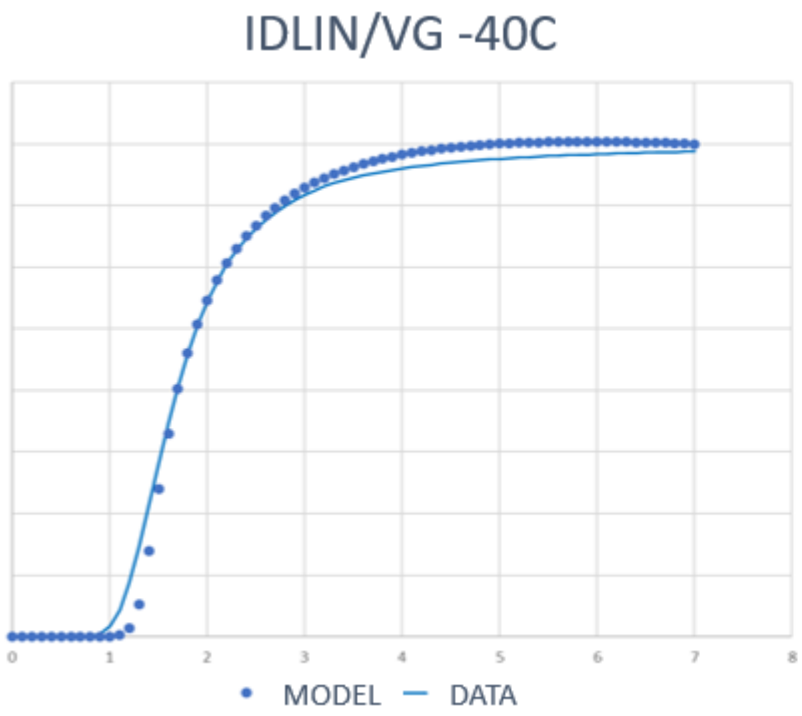
Navitas team has strong knowledge and capability to develop its own device and circuit libraries even with such handicaps.

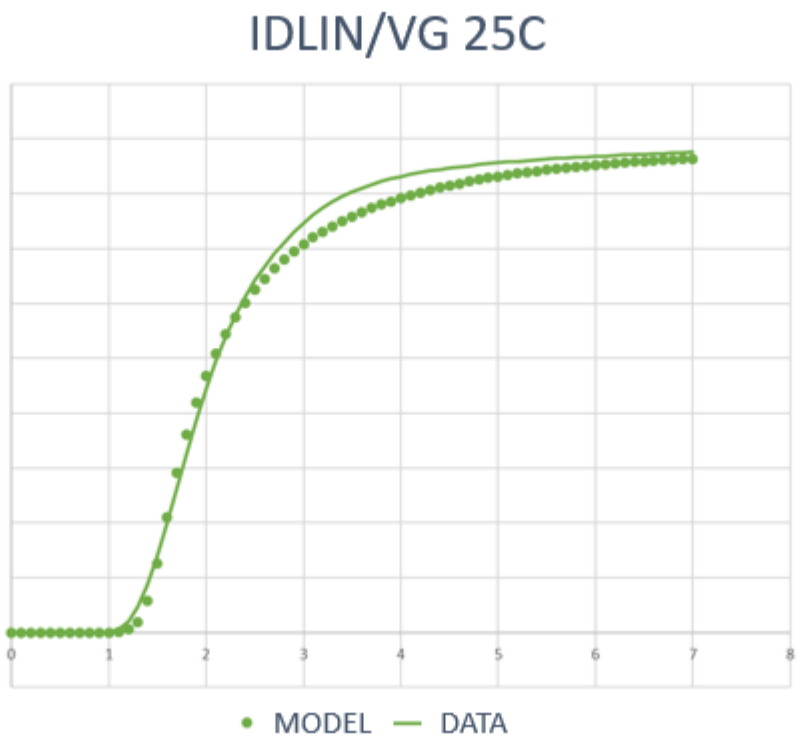
Power IC Models / PDK

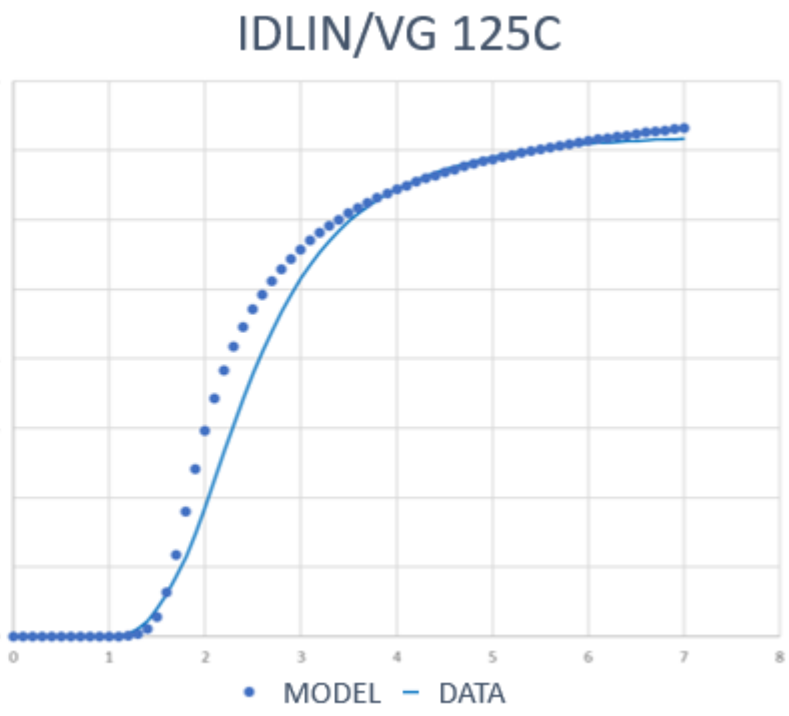
- Excellent process design kit:
  - Device symbols
  - Pcells for automated device construction
  - Scalable, accurate
  - Verified for schematic and layout rules
  - Layout parameter extraction
- Angelov, ASM and silicon models are not suitable
  - Lack dMode, scalability, flexibility, speed
- Navitas GaN eMode FET scalable VerilogA model
  - Flexible: customized features/equations
  - High correlation between simulation and product
  - High-speed simulations

Accurate over Temperature

- GaN FET I_DV_G Model with Temperature Effects
  - Solid lines = measured, dotted lines = Cadence simulation



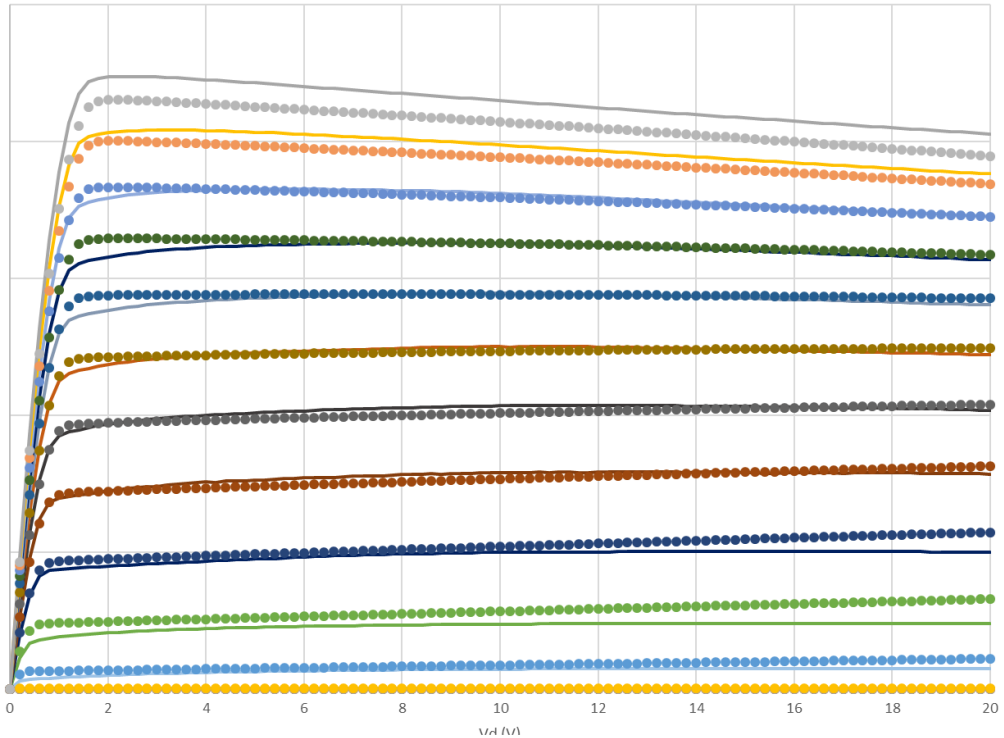




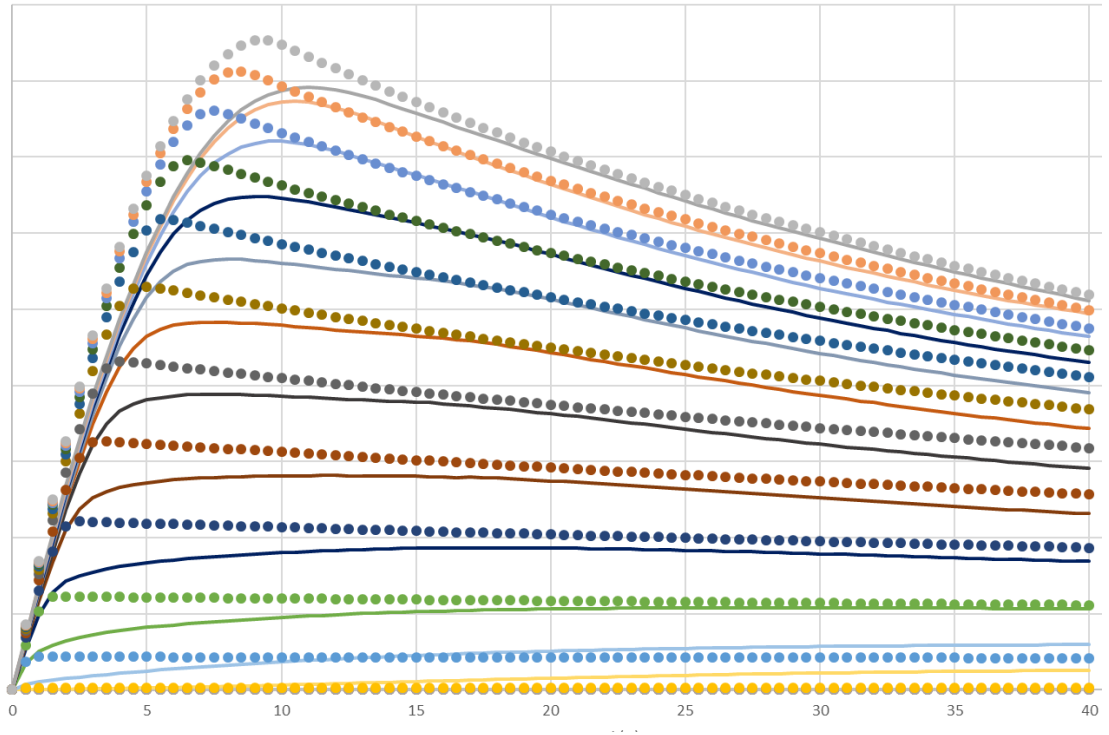
Accurate over Drain Voltage

- Solid lines = measured, dotted lines = Cadence Spectre

- 20V rated eMode FET

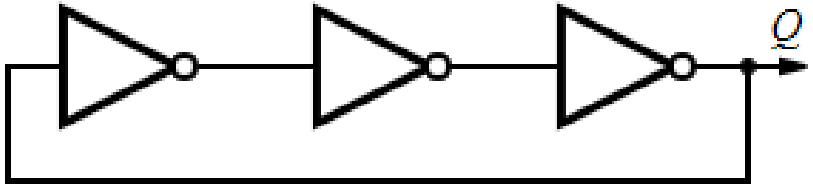


650V rated eMode FET



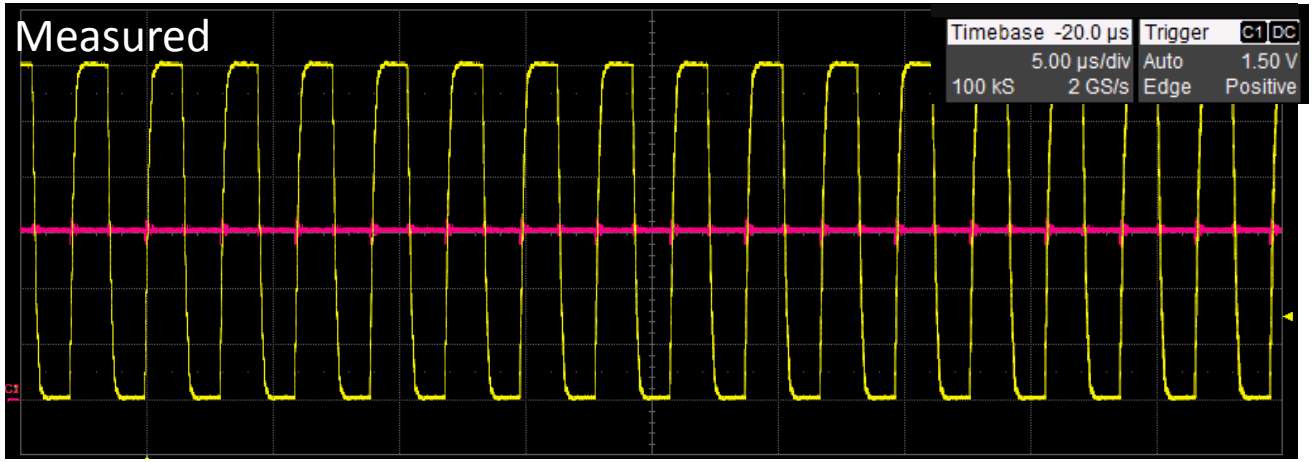
PDK Verification

Ring Oscillator

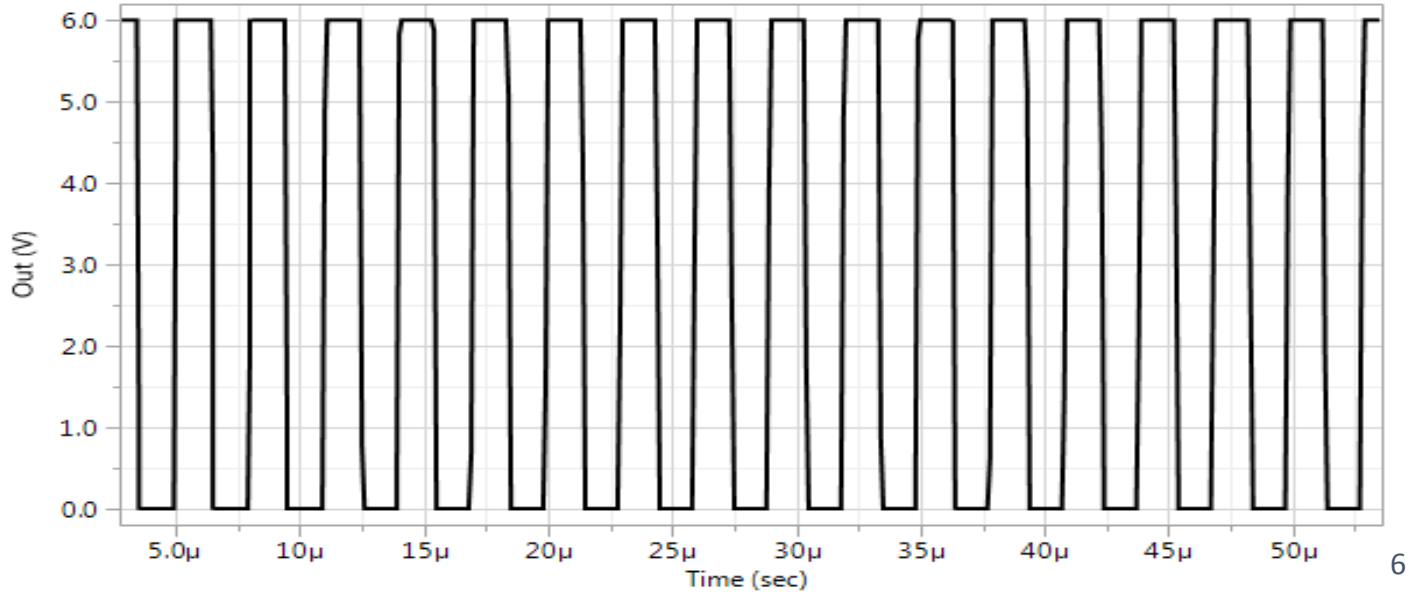


- Use simple ring oscillator structure to verify accuracy of PDK models
- Excellent agreement between simulated and measured performance
- Needs to include parasitic effects

Measured

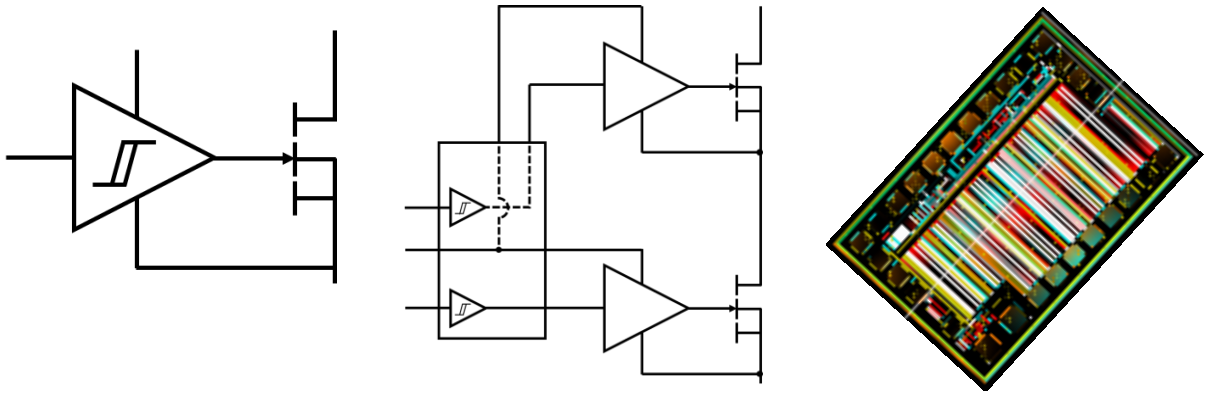


Simulated



Navitas GaNFast™ IC Platform

First & Fastest Integrated GaN Gate Drivers



Navitas GaN IC PDK

- PDK developed independent of the foundry
- Offers great deal of design flexibility
- Fast design/tape out cycle time
- Enables seamless integration of new devices and features
- Scalable models, streamlined for process corners

Navitas Proprietary GaN Building Blocks

- eMode and dMode transistors (7V - 650V)
- Integrated capacitors (7V – 650V)
- Integrated resistors
- Inverters
- Buffers
- Logic gates
- Pulse generators
- Level shifters
- ESD I/O circuits

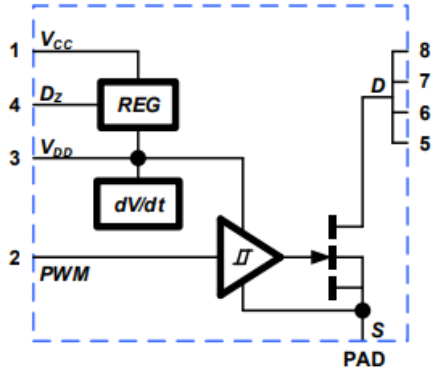
Outline

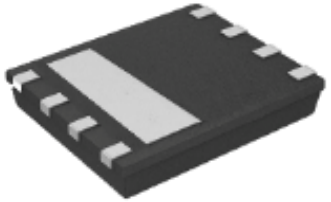
- Why GaN Power IC?
- How to make GaN Power ICs?
- Features of GaN Power ICs
- Commercial requirements for GaN products
- Products using GaN Power ICs

Power GaN IC Product Portfolio

GaNFast™

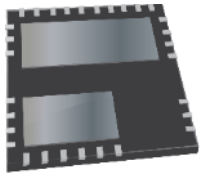
Single Switch (“Singles”)

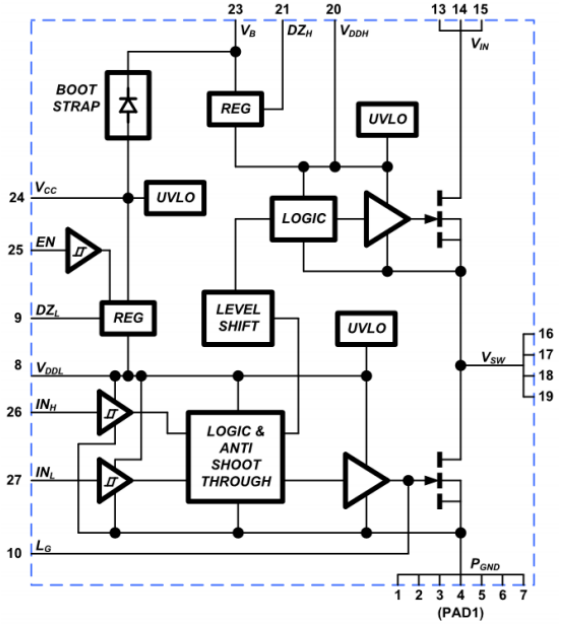




- ✓ 650 V eMode FET
- ✓ $R_{DS(ON)}$ 120-300mΩ available
- ✓ Integrated Gate Drive
- ✓ Programmable dv/dt Control
- ✓ Integrated Regulator

Two Switch (“Half-Bridge”)





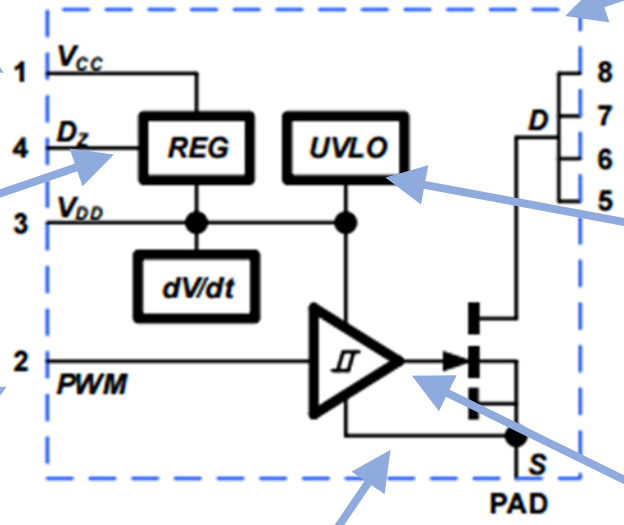
- ✓ 2 x 650 V eMode FETs (Half-bridge)
- ✓ $R_{DS(ON)}$ 120-500mΩ available
- ✓ Symmetric and Asymmetric $R_{DS(ON)}$
- ✓ Integrated Gate Drive
- ✓ Shoot-through Protection
- ✓ Integrated Regulators
- ✓ Integrated Level-Shifter
- ✓ Integrated Boot-strap

Integrated Drive→ *Simple & Robust*

GaNFast™

Wide Range V_{CC} (10-30V)

Total layout flexibility & simplicity



Regulator ensures V_{GS} within SOA

Under voltage lockout protects the driver & FET when full power supply is not available

PWM Hysteresis for noise immunity

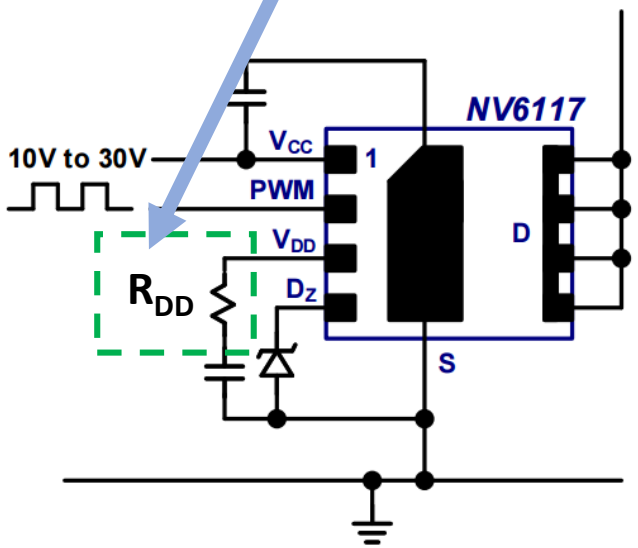
Gate protected from external noise (Not pinned out of package)

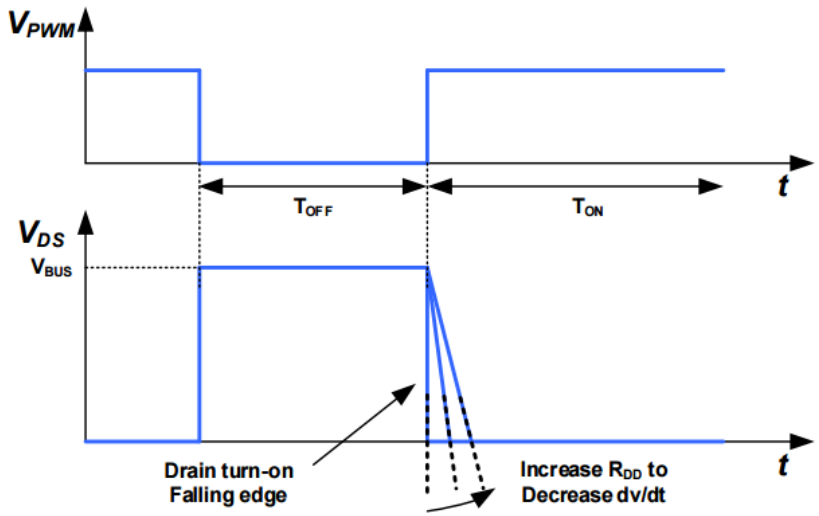
No inductance or ringing in gate loop

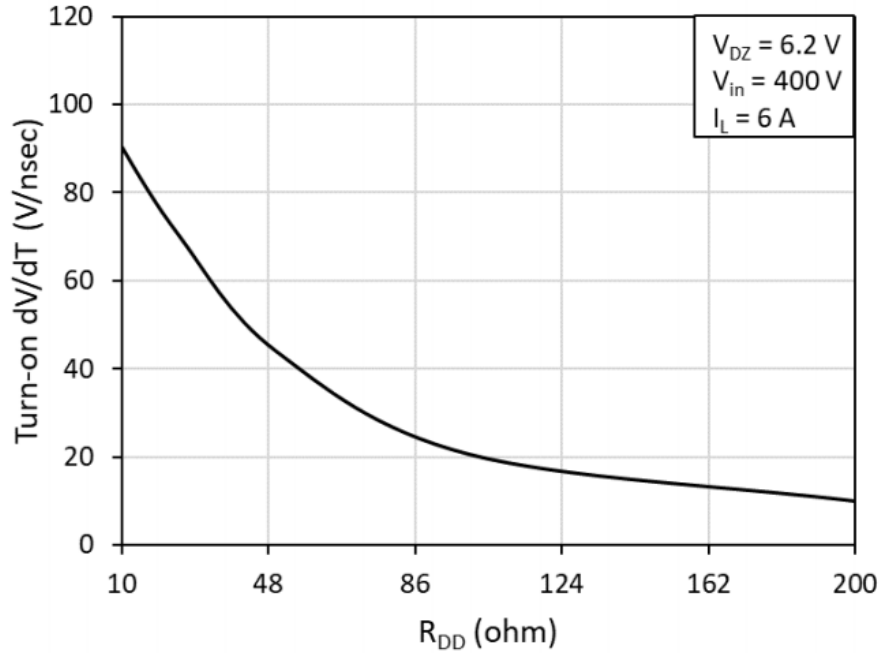
Voltage Slew Rate Control … Easy EMI Tuning

GaNFast™

dV/dt controllable with R_{DD} from 10 V/ns to 90 V/ns



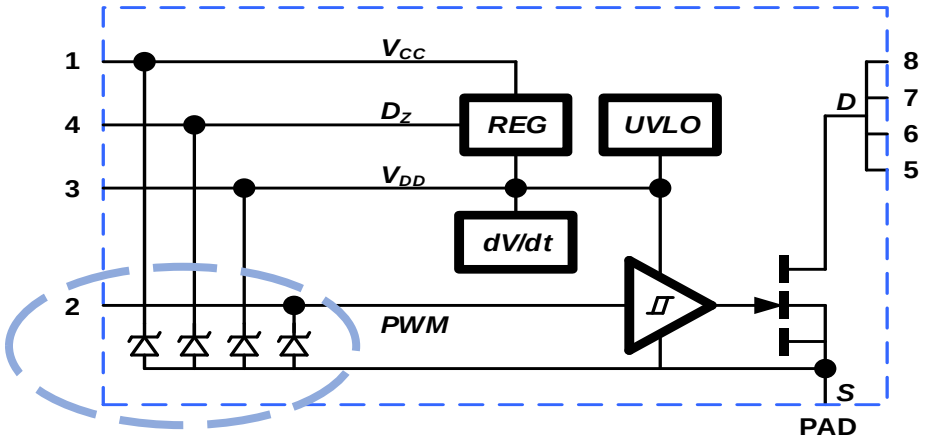




Integrated ESD Protection

GaNFast™

GaN Power IC



Integrated ESD Protection

HBM, CDM > 1,000 V

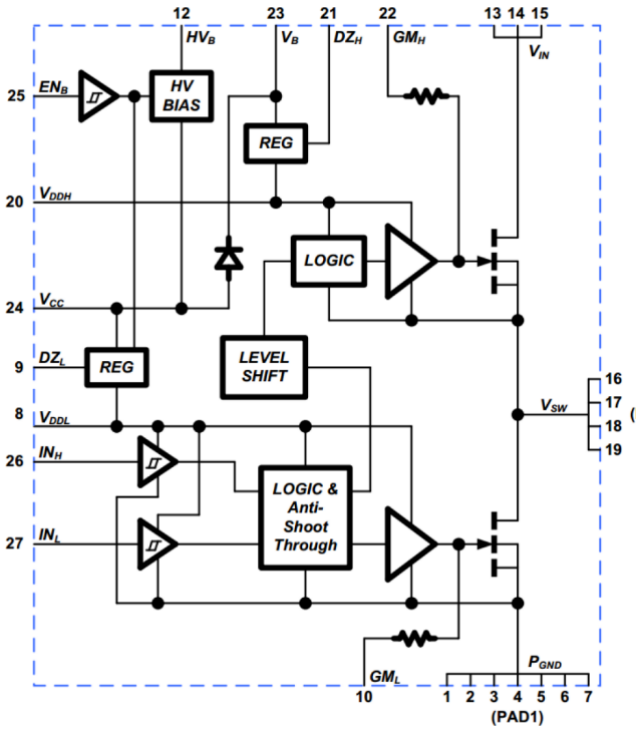
ESD Qualification Tests

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

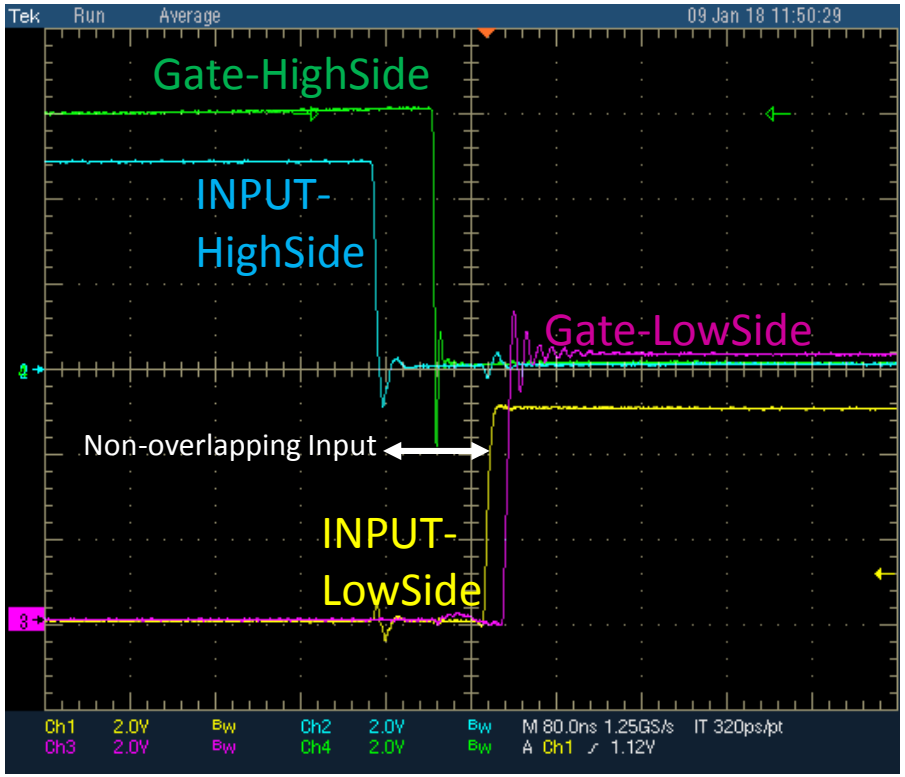
- ✓ Same ESD testing as Si devices can be applied to GaN
- ✓ Latch up testing not required in GaN devices

Shoot-Through Protection in Half-Bridge

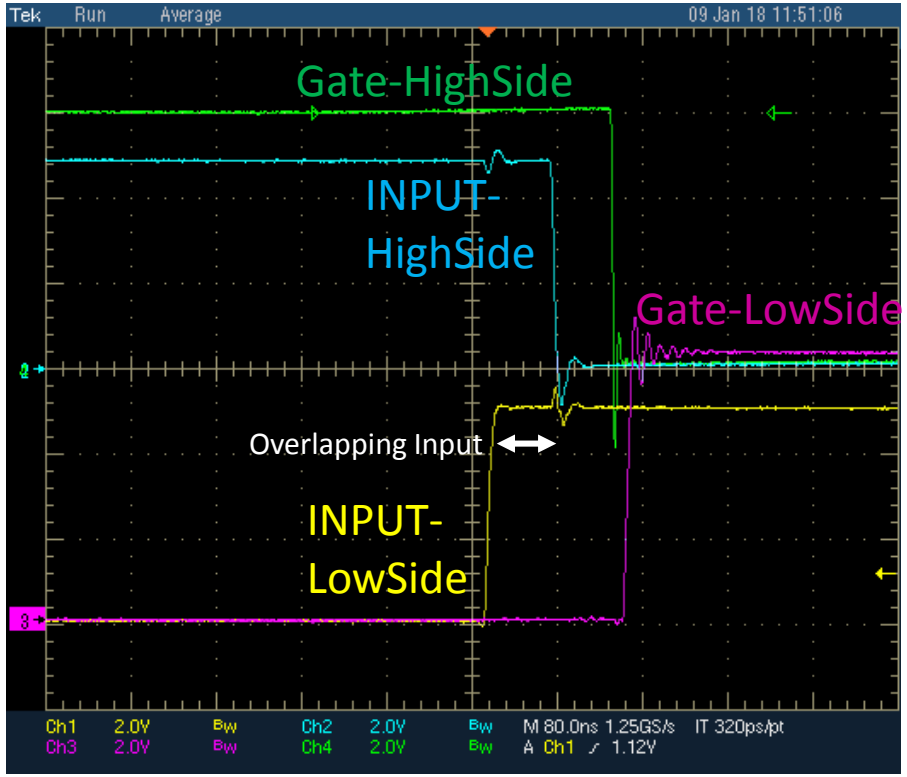
Half-Bridge GaN Power IC



Non-Overlapping Logic Input
(Typical Operation)



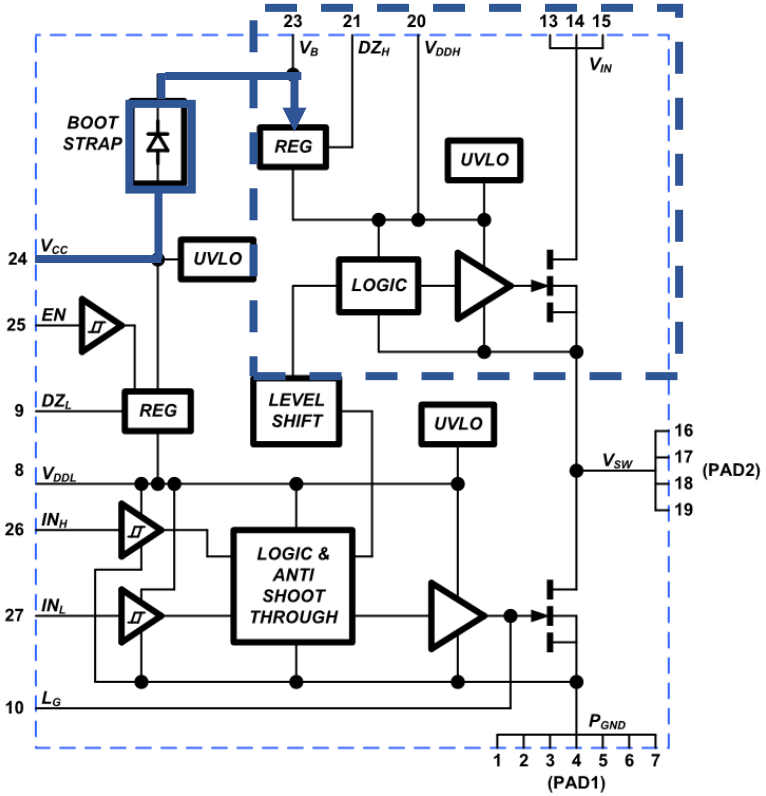
Overlapping Logic Input
(Power IC Protection Mode)

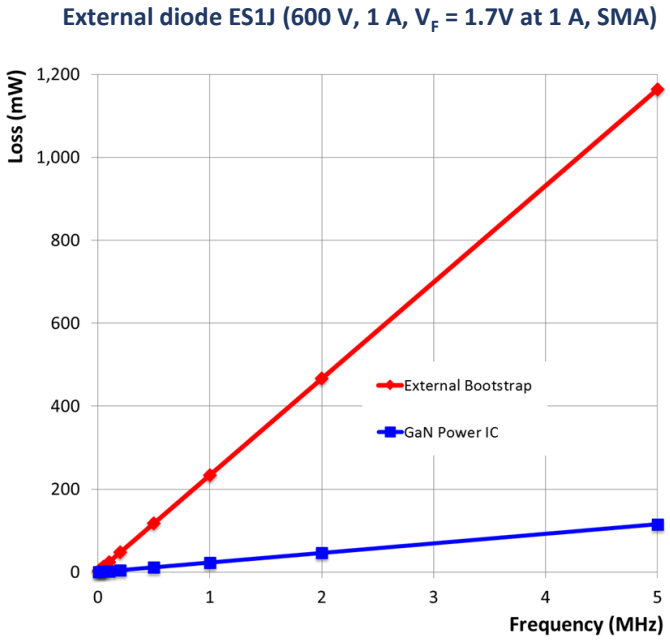


High-side and Low-side gates never overlap due to shoot-through protection in power IC

Integrated Bootstrap

Floating High Side





Bootstrap Diode Loss

$f(C_{diode}, Q_{rr}, F_{sw})$

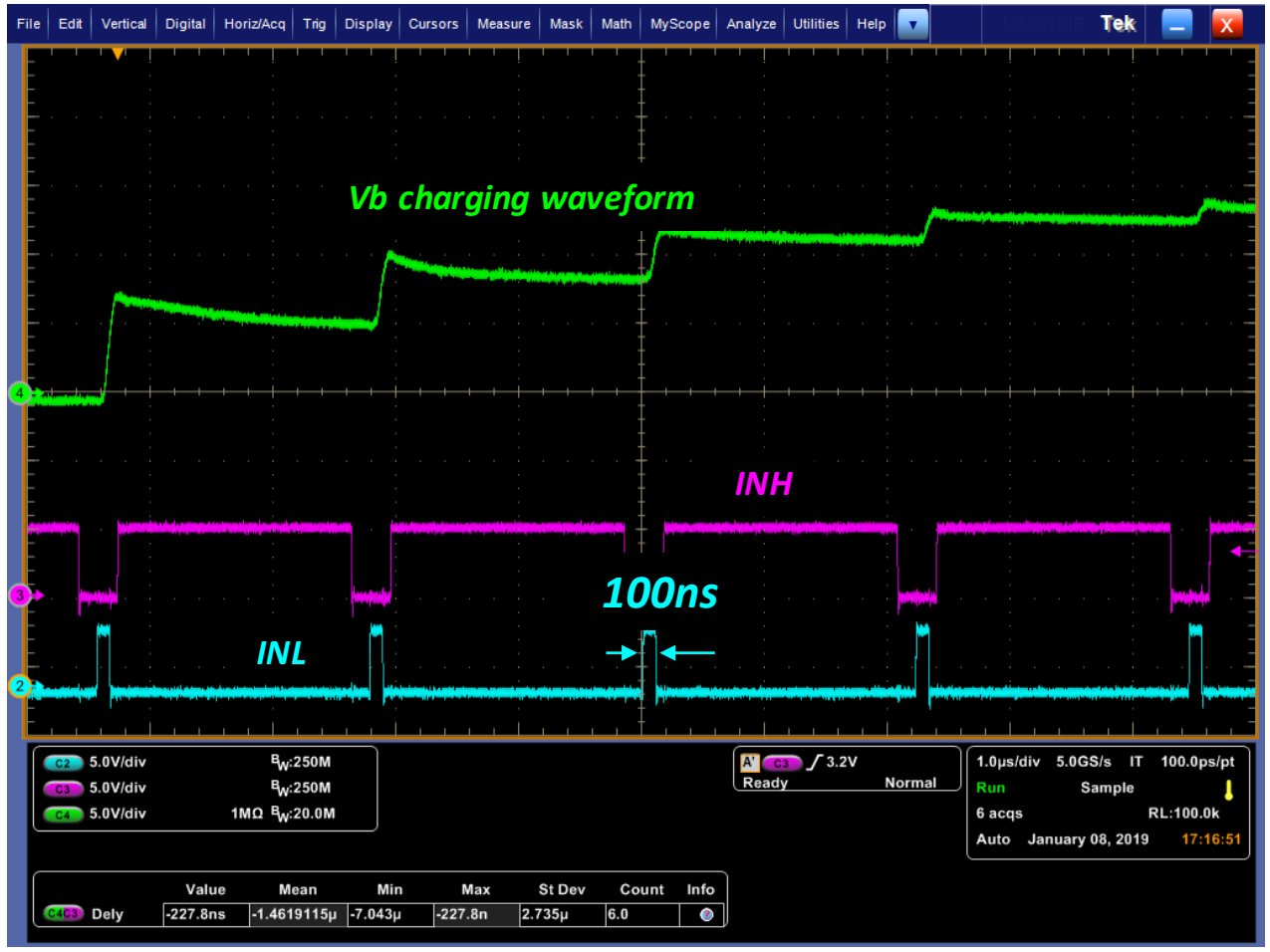
Bootstrap Diode Integration Benefits:

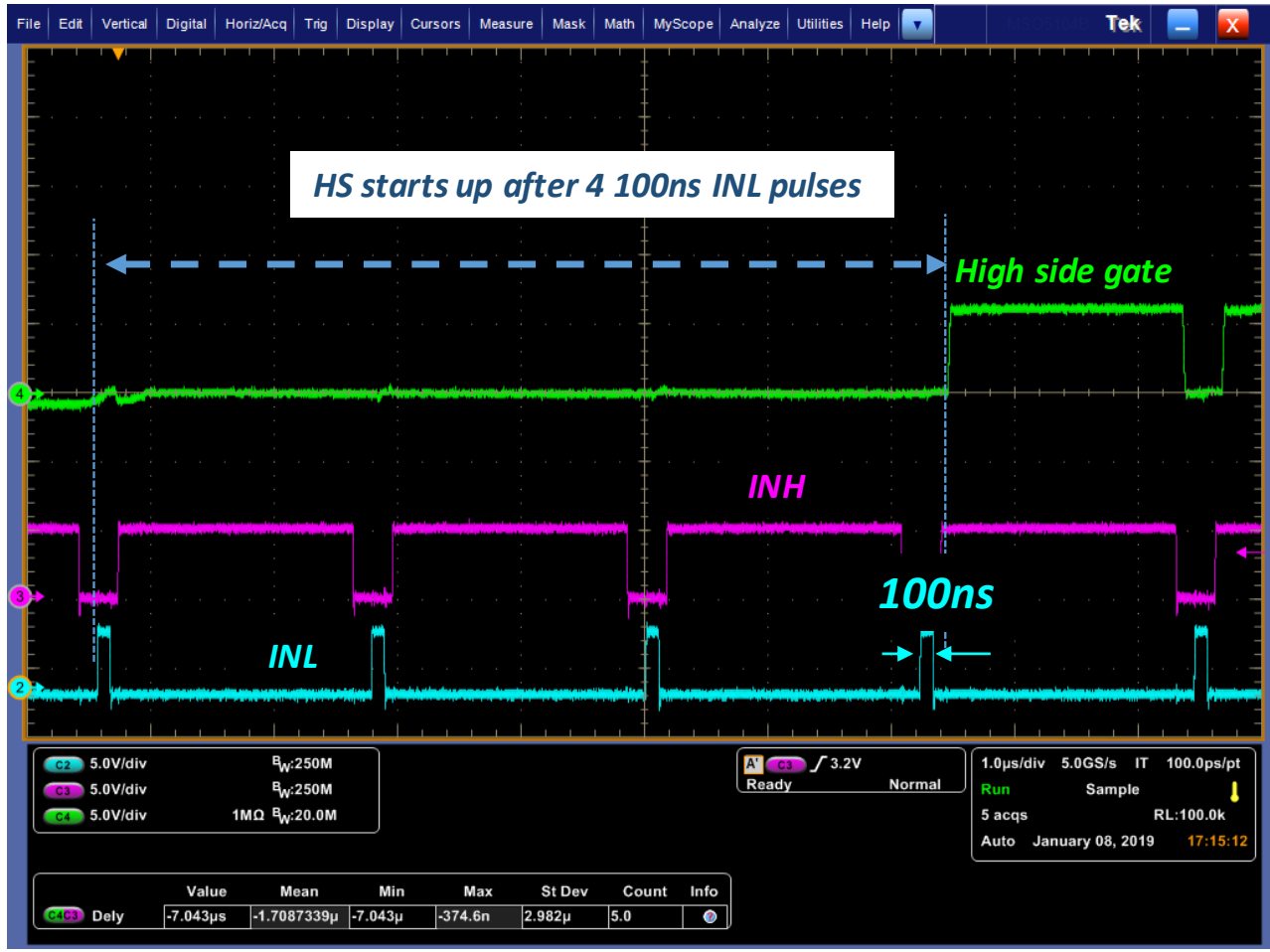
- Avoids risk of dV/dt induced diode failure
- Eliminates diode Cj and Irr power loss
- Eliminates necessity of using SiC at high F_{sw}
- Saves cost, especially if SiC is required
- Charges bootstrap capacitor losslessly
- Assures full charge/voltage is delivered
- Eliminates lossy current limiting resistor
- Saves board space in HV system

https://www.onsemi.com/pub/Collateral/ES1J-D.PDF

Bootstrap Startup

High-side Startup Characteristics





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Successful Commercial Products

- ✓System Value (Features, Efficiency, Density)
- ✓Reliability
- ✓Cost

Successful Commercial Products

- ✓System Value (Features, Efficiency, Density)
- ✓Reliability
- ✓Cost

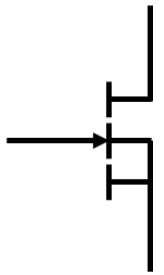
Approach to Reliability of GaN Power ICs

GaNFast™

Well Established Package Technology

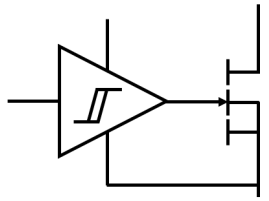
+

650 V GaNFast Power FETs



+

Integrated GaN Gate Driver



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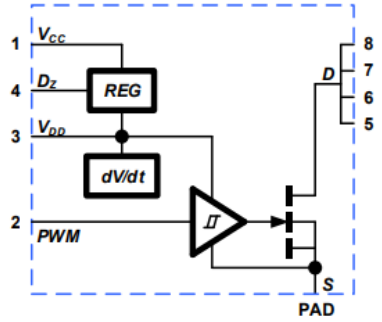
GaNFast™ Power IC with exceptional Quality & Reliability



Package Qualification
UHAST
HAST
THB
TC
HTSL

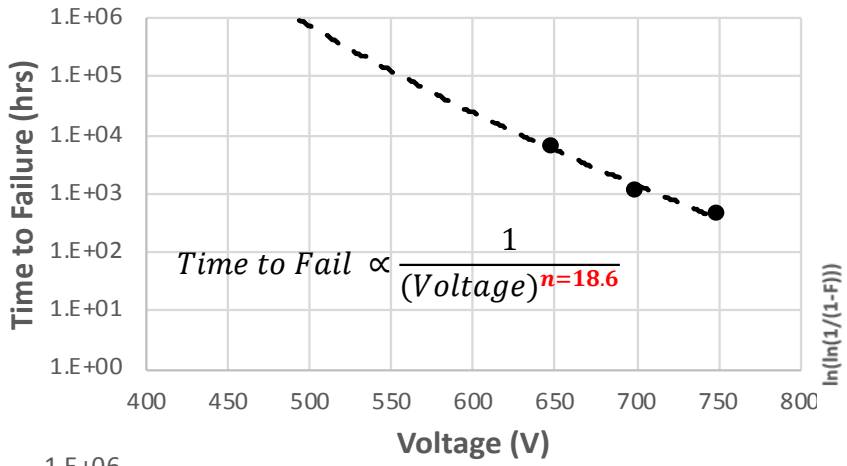
Traditional FET Tests
HTRB
HTGB
HAST
THB

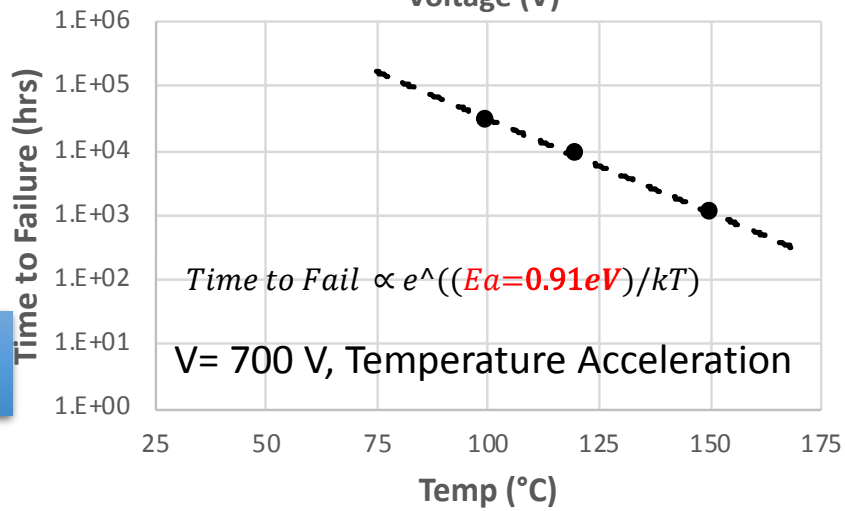
JESD47I (IC Qual Standard)
HTOL
ELFR
ESD
WLR

HTRB Acceleration & Lifetime Models

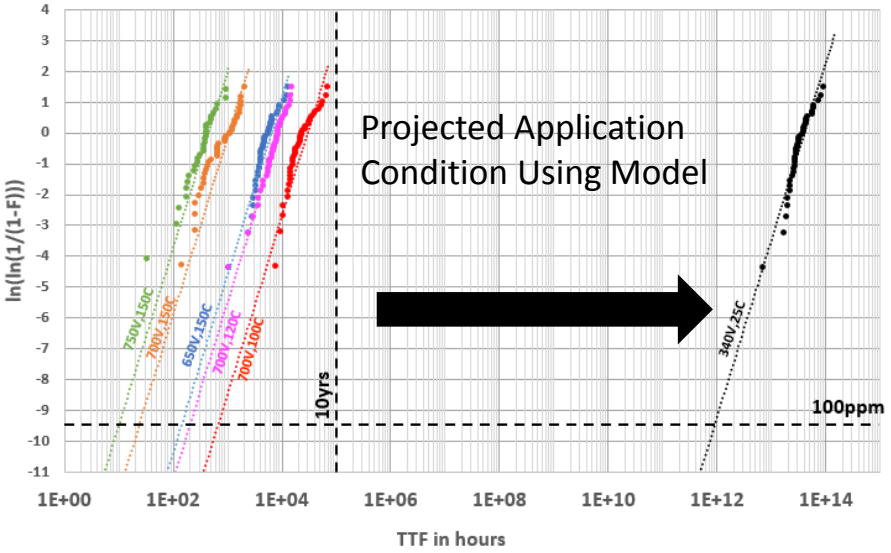
Voltage/ Temperature	100°C	125°C	150°C
650V			✓
700V	✓	✓	✓
750V			✓

T=150 °C, Voltage Acceleration





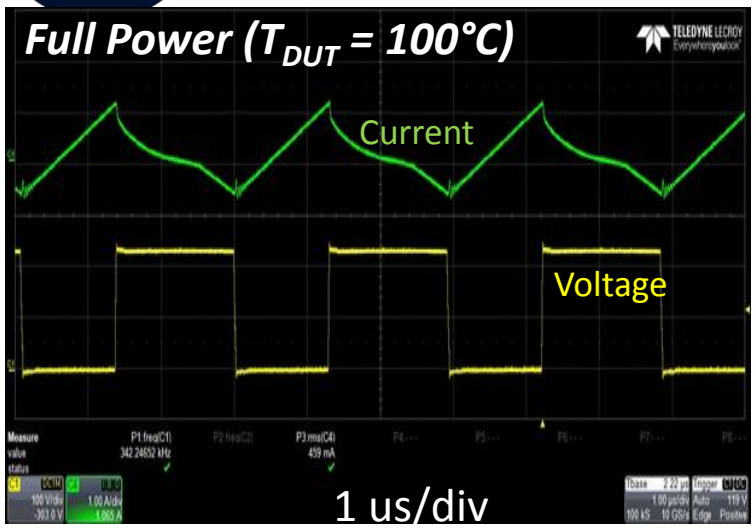
V= 700 V, Temperature Acceleration

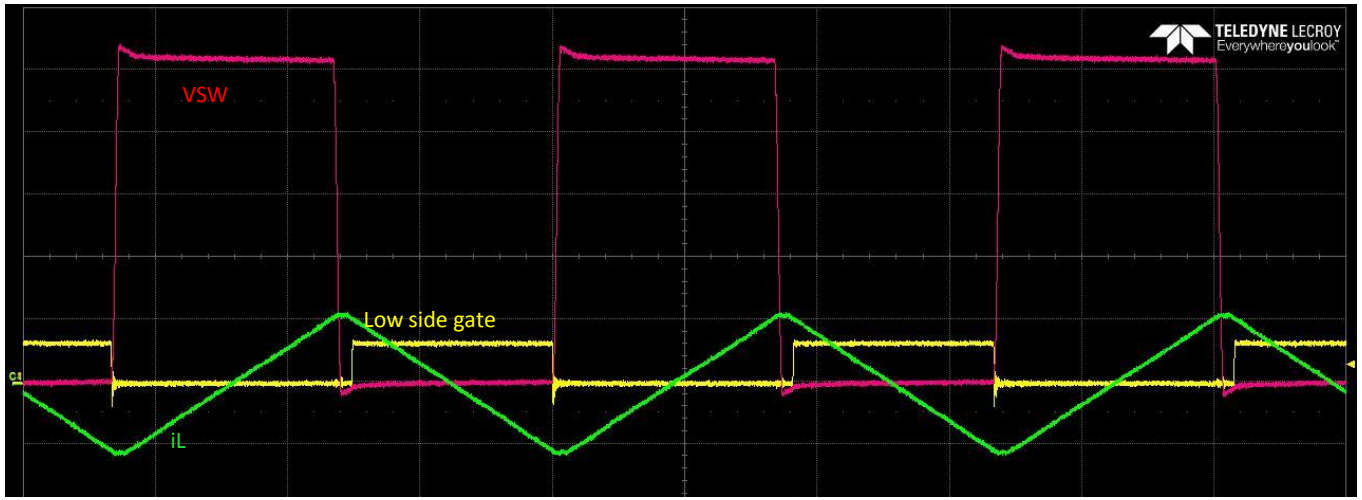


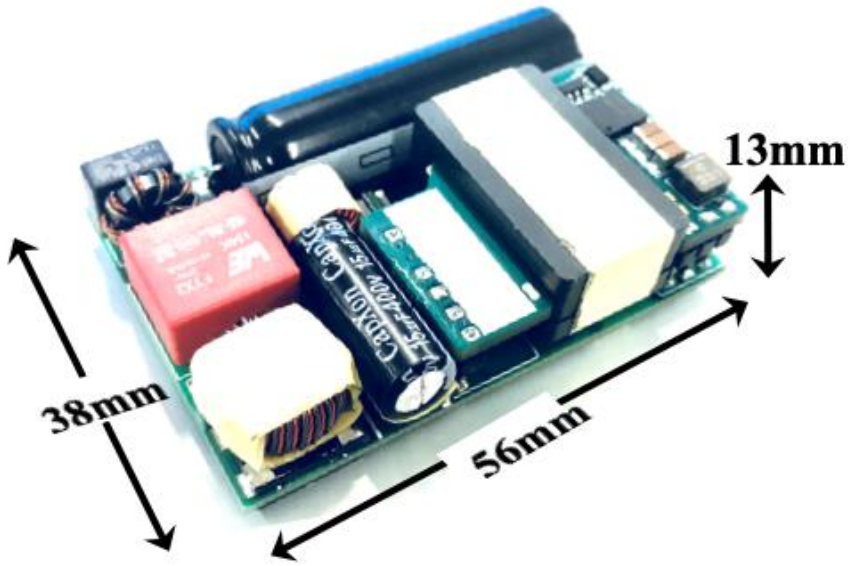
$$Lifetime = A \times (V^{-n}) \times (e^{\frac{E_A}{kT}})$$

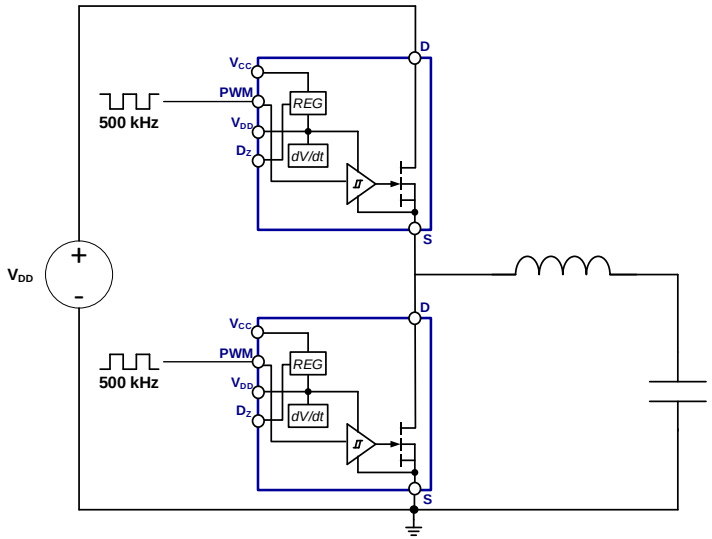
Lifetime in no load condition is >1E8 years, significant built-in margin

Mission Profile Driven HTOL (ZVS)





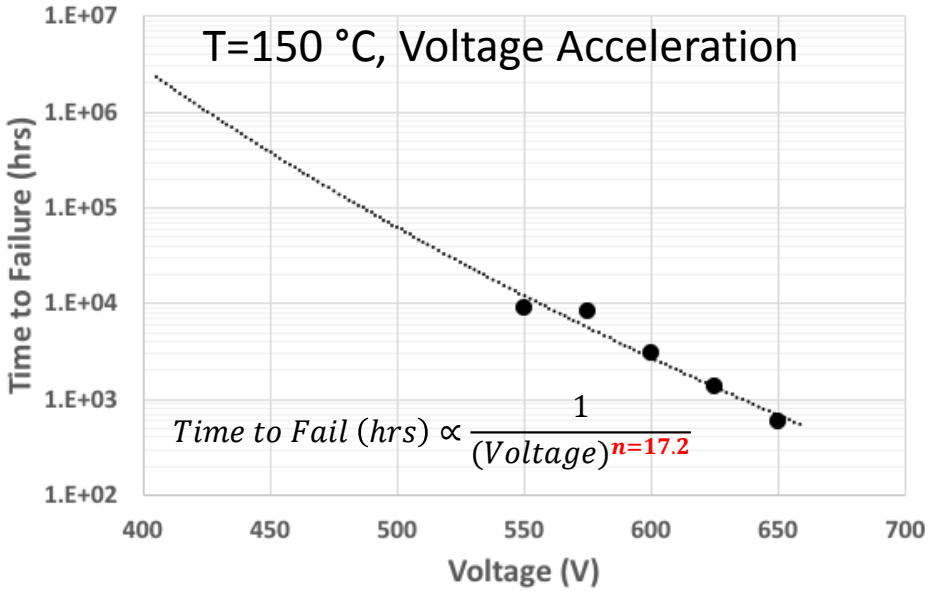


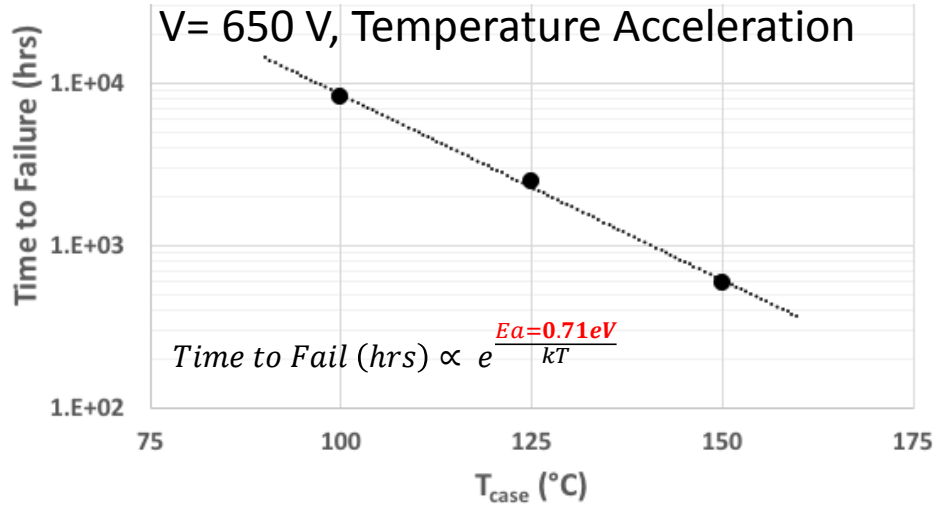


ZVS test bench replicates stresses seen in ACF application

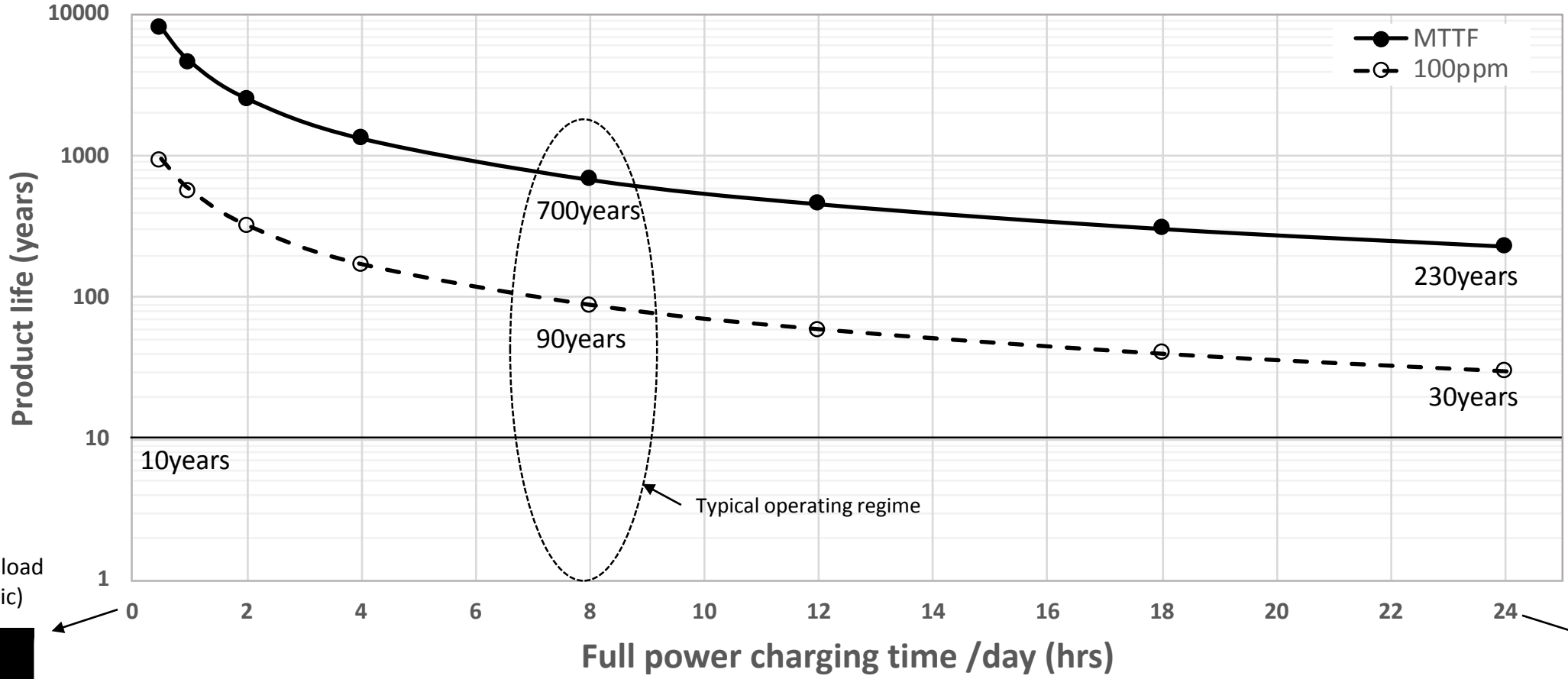
HTOL-based Lifetime Model

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

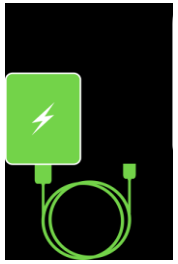




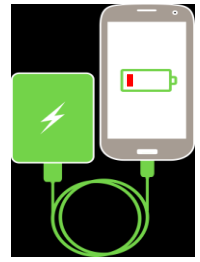
Lifetime Estimation in Charger Application



100% No load (unrealistic)



100% full power (unrealistic)



Significant built-in reliability margin → even at worst case conditions (exceeds 10+ year lifetime requirement)

Outline

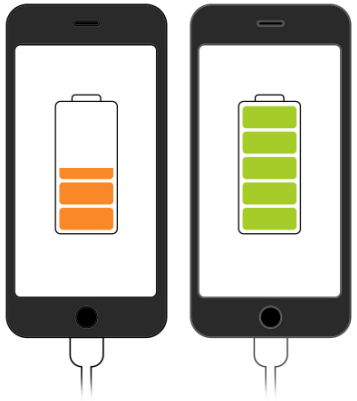
- Why GaN Power IC?
- How to make GaN Power ICs?
- Features of GaN Power ICs
- Commercial requirements for GaN products
- Products using GaN Power ICs

GaNFast USB-C Chargers Have Arrived

GaNFast™

Fast

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



Mobile

Half the size & weight
of traditional chargers

Universal

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

AUKEY

27W

24W

30W

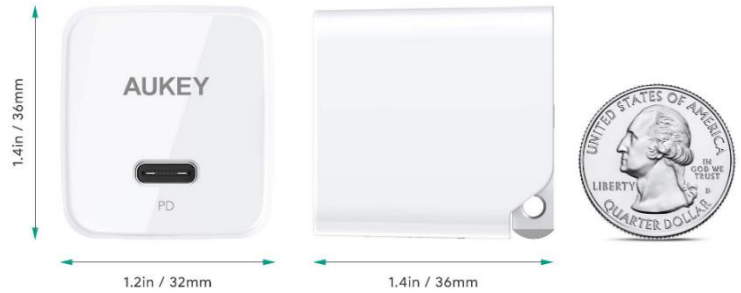
MADE IN MIND

45W

RAVPOWER®

45W

Latest Releases



ANKER

- ***World's smallest 27W USB-C***
- 41.5 cc, 0.65 W/cc
- Available now from amazon.com

- ***World's smallest Charger 42W (30W-C + 18W-A) + Battery Pack (5,000 mAhr)***
- 31.5 x 85.5 x 81.5 mm
- Available now from Apple Store

Questions?

Let's go GaNFast™