2022中国电力电子与能量转换大会
暨中国电源学会第二十五届学术年会及展览会
2022 China Power Electronics and Energy Conversion Congress
& The 25th China Power Supply Society Conference and Exhibition

"GaN Integration Drives Next-Generation Power Systems"

Tony Liu

Navitas

Energy • Efficiency • Sustainability

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Note disclaimers. Information is as of the date specified only.

Content

- Introduction GaN Power
- Discrete VS Integrated GaN
- Navitas Integrated GaN IC
- Summary

Why GaN

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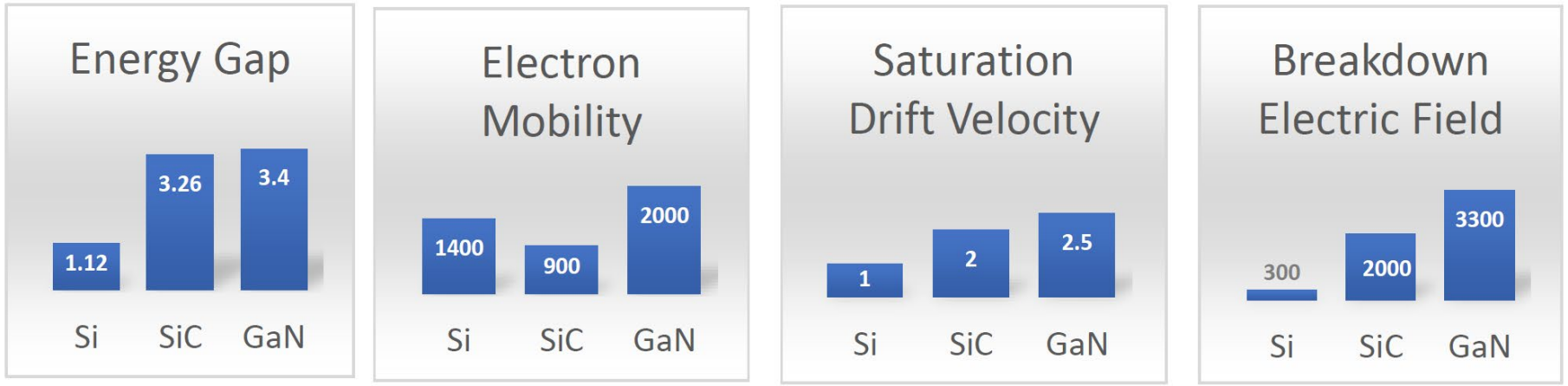
Technology Comparison



Stable/robust/ low leakage

Fastest switching

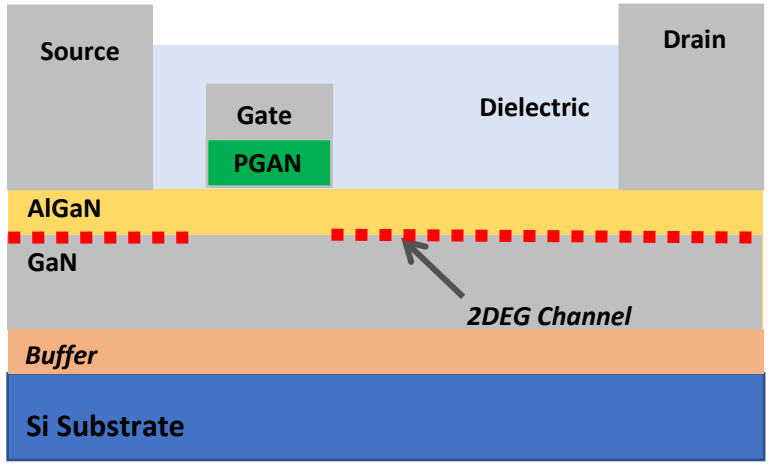
Smaller die

Excluding the three semiconductors (Ga_2O_3, Diamond, AlN) for which commercial devices are not available, GaN is the semiconductor with

- The largest energy gap
- The largest critical field
- The highest saturation velocity

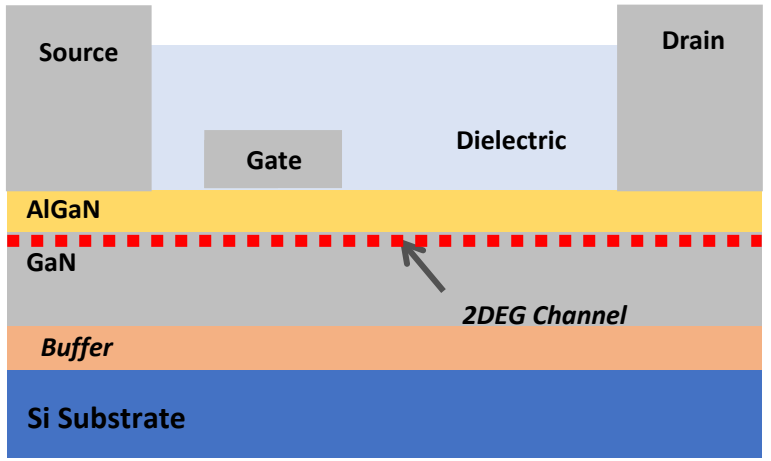
Industry GaN Solutions

Emode



- **Vgs>Vth**, FET on
- **Vgs=0**, FET off

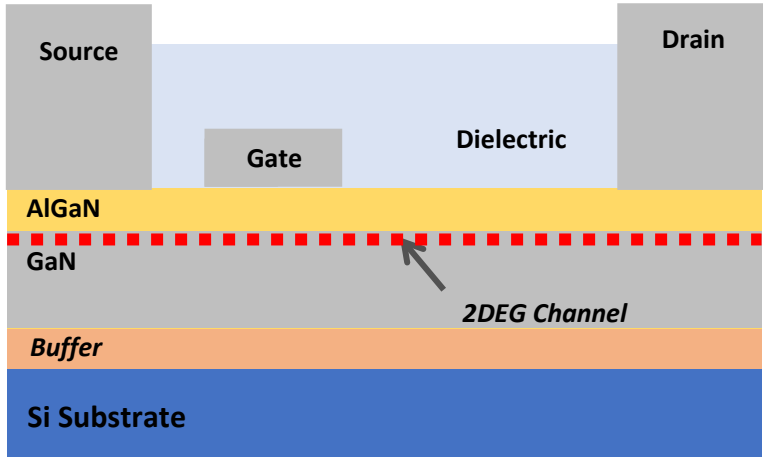
Dmode



- **Vgs=0**, FET on
- **Vgs<|Vth|**, FET off

DMODE GaN Solutions

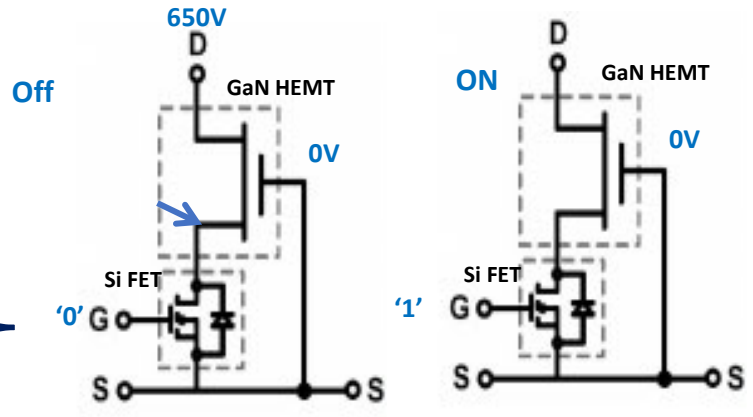
D mode



- **Vgs=0**, FET on
- **Vgs<|Vth|,** FET off

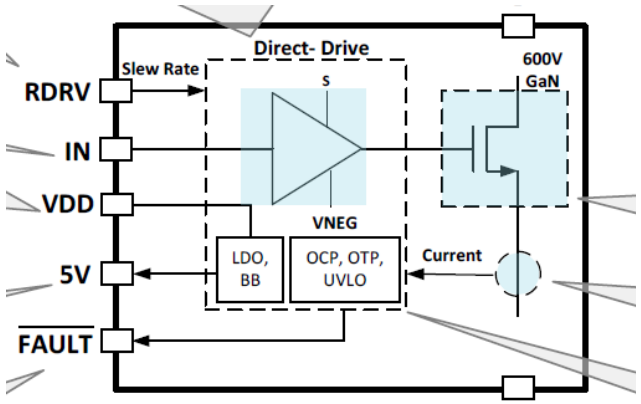
Not for switching power by itself

Cascode (Dmode GaN + LV Si FET)



- ✓ Compatible with existing Si driver
- ✓ Low reverse conduction voltage
- × Reduced benefits from all GaN power stage due to the increased Rdson*Qg , reverse recovery etc.
- × Large dies
- × Not easy for parallel application

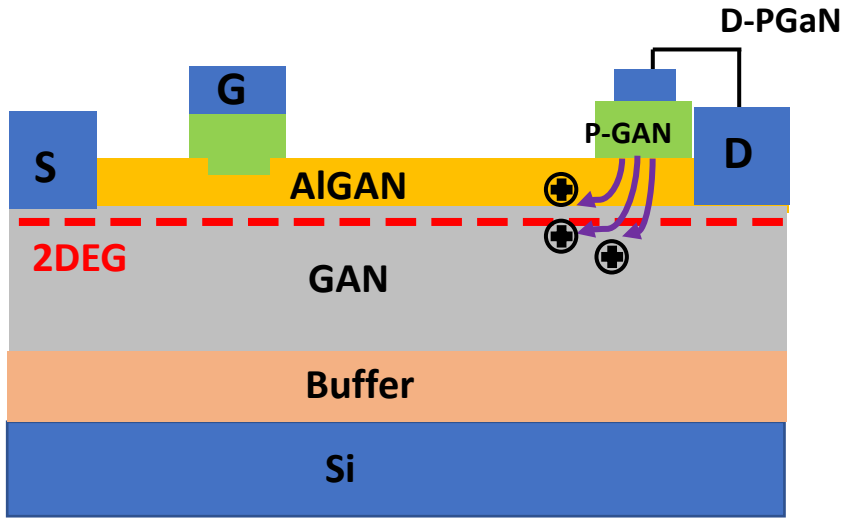
Direct Driving Dmode GaN



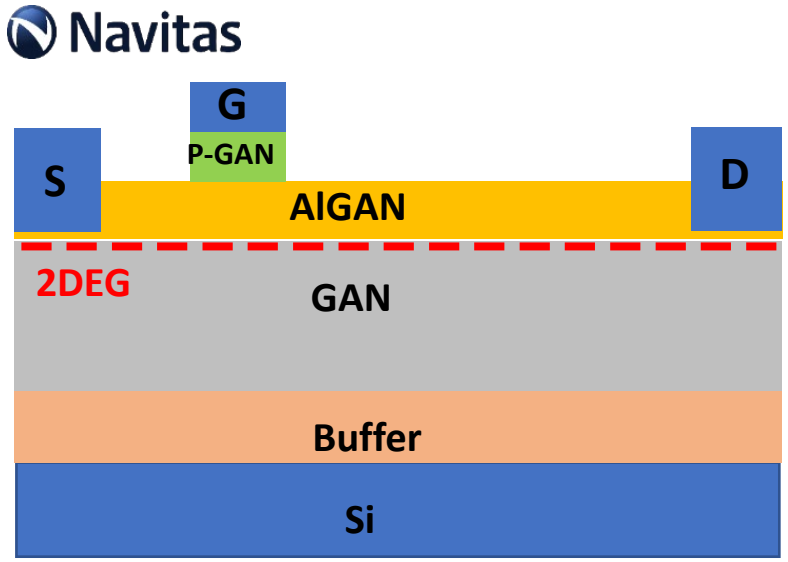
- ✓ Direct driving dmode GaN
- × More complicated negative voltage gate driver

EMODE GaN Solutions

E mode



- Recessed Gate
  - ✓ Potential high Vth
  - × Challenging process control
  - × Potential Gate leakage challenge



- pGaN Gate Process
  - ✓ Process control
  - × Lower Vth, typ.<2V
  - × Limited gate SOA range

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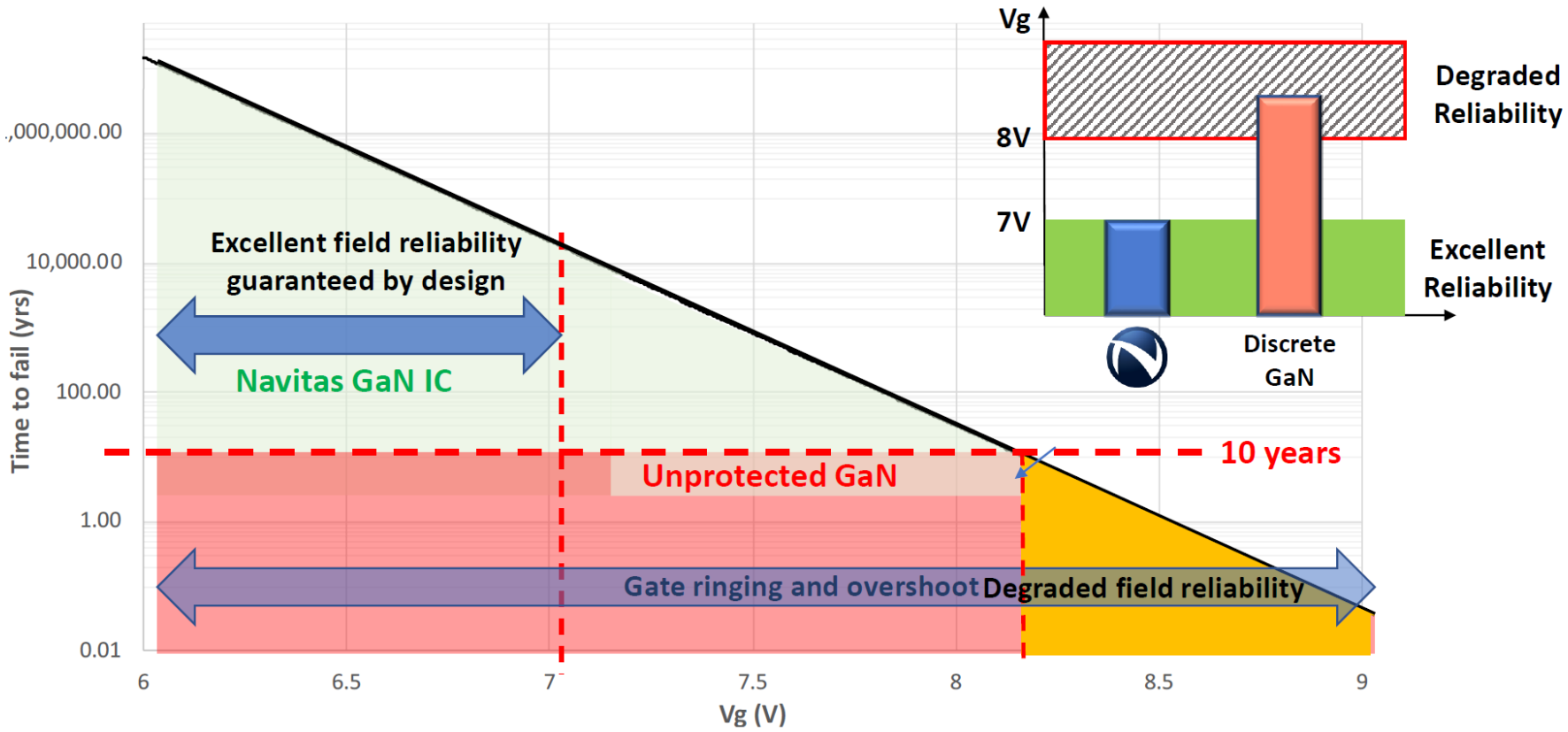
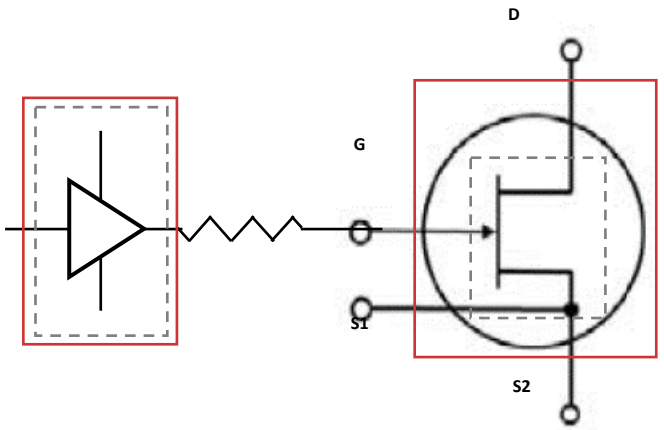
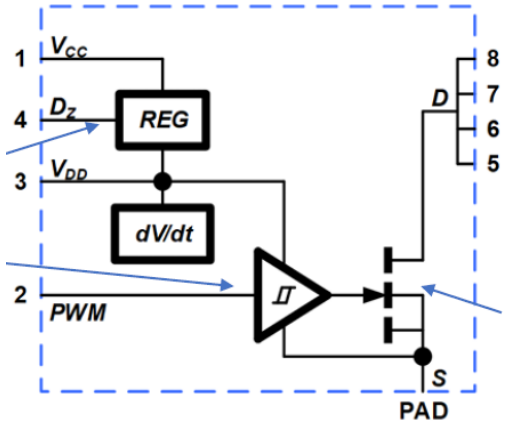
One Major Challenge in Emode GaN



- Gate generally needs to be > 6V to get the GaN ISAT/Rdson benefits, but its reliability is degraded when Vg >8V or less. Unlike Si powerFET, it left very narrow margin in system board design if the powerfet is used as discrete.
- High Vgs SOA GaN technology is not mature yet for wide mass production.

Discrete (or Copak) Vs Integrated GaN





Discrete (or GaN + Si copak)

- Gate driver is on a separate die in the same package or a separate chip.
- PowerFET gate is exposed in internal die level or package level.

Integrated

Gate Reliability Challenge

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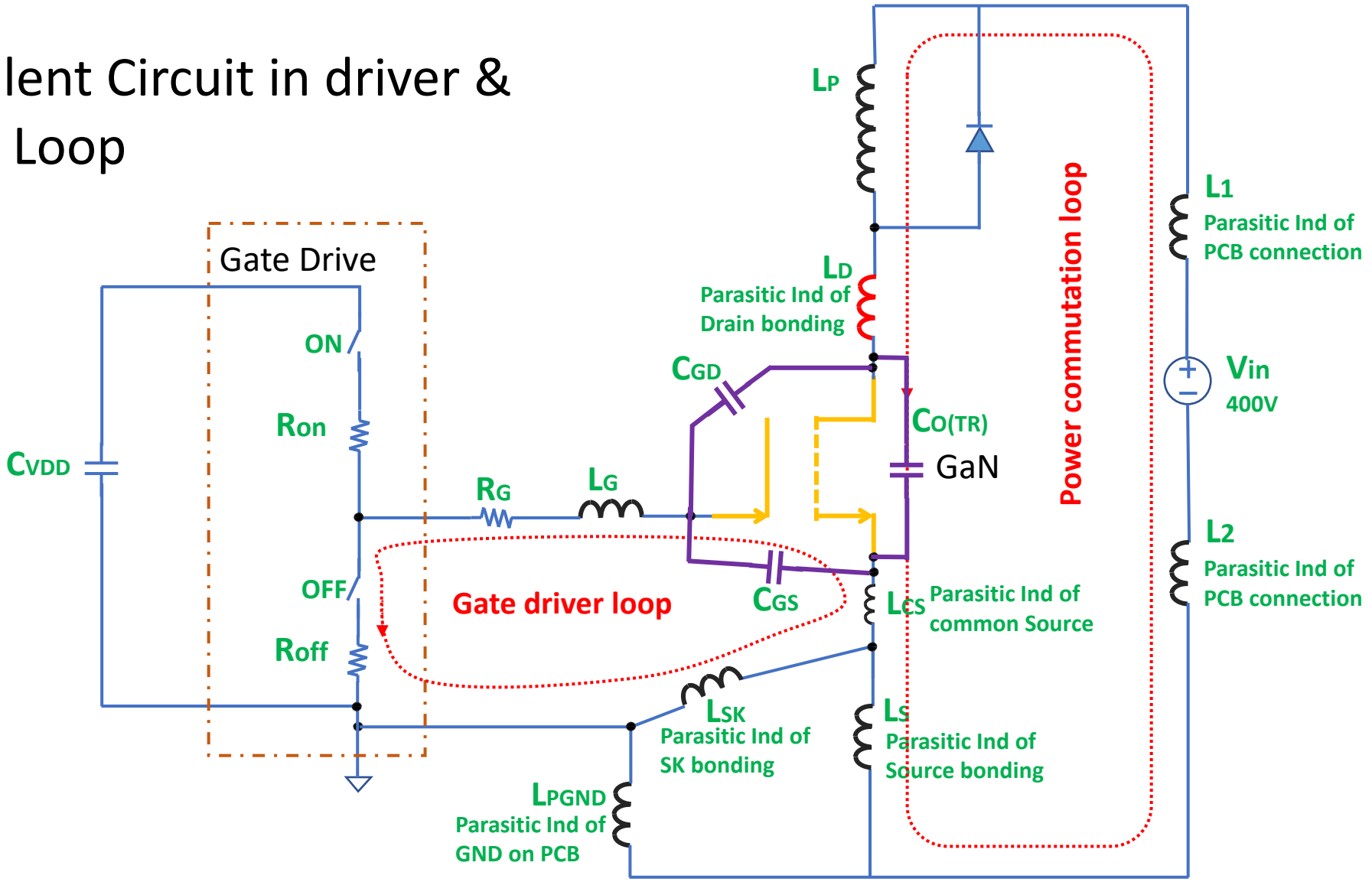
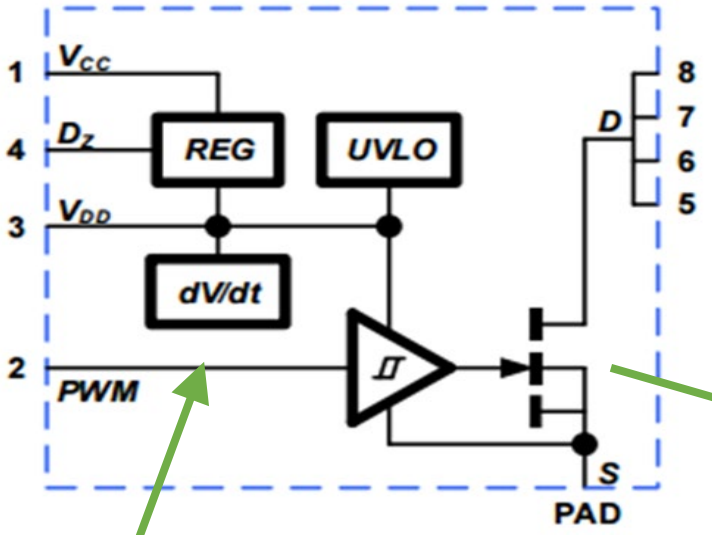
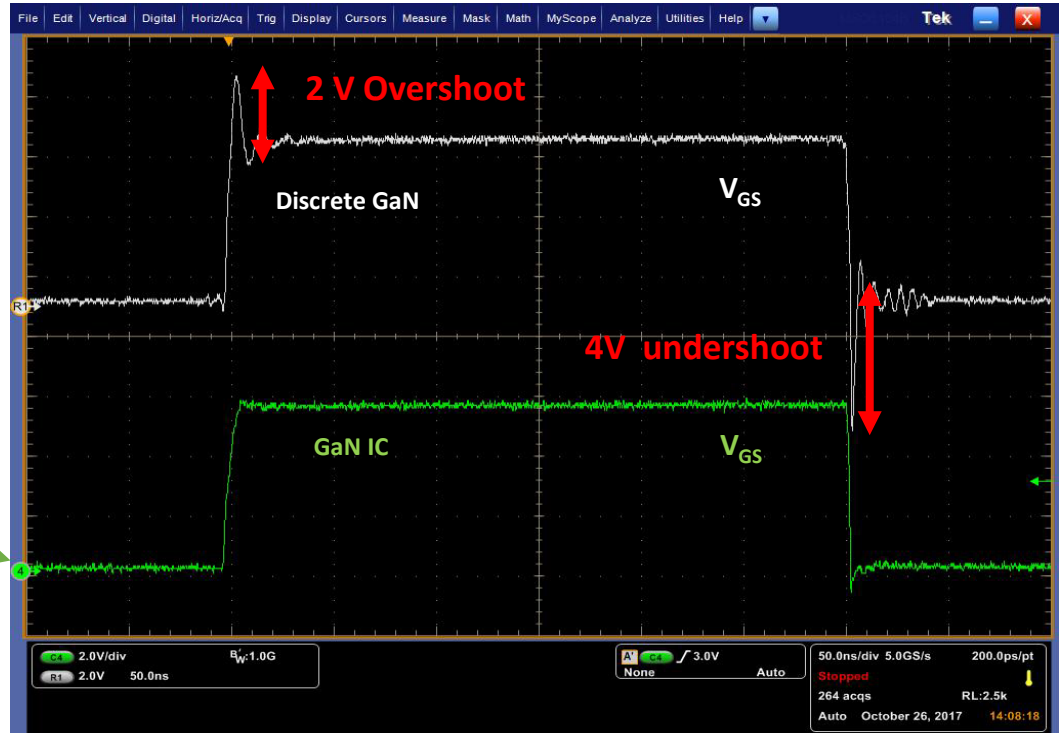
Equivalent Circuit in driver & power Loop



Navitas Integrated Solution



PWM Hysteresis to suppress input noise



Discrete GaN vs Integrated GaN

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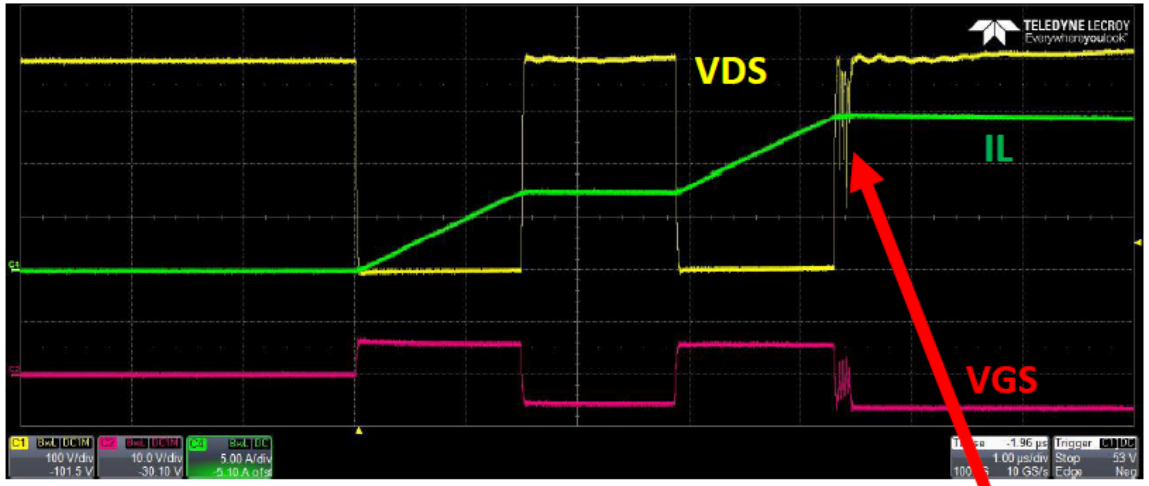
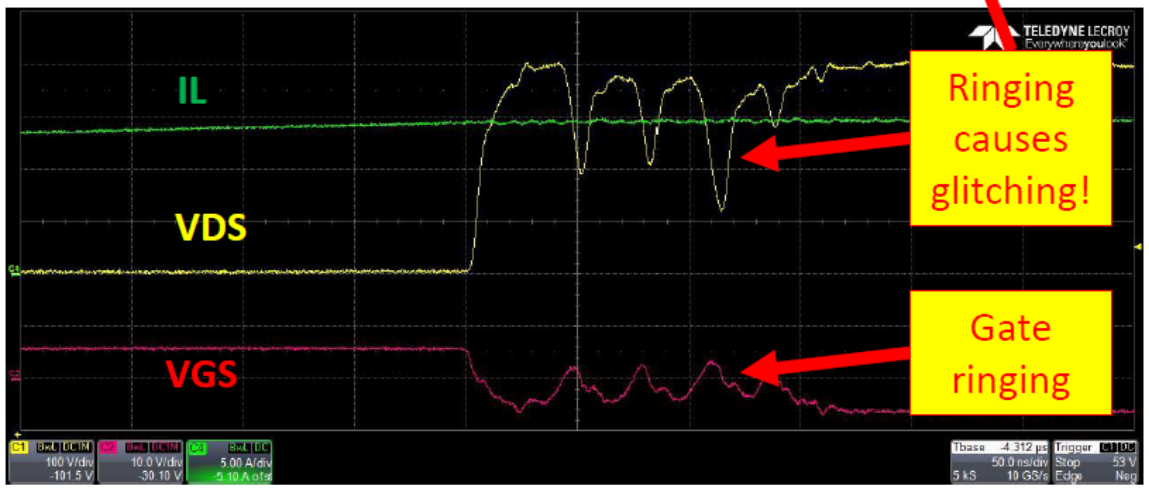
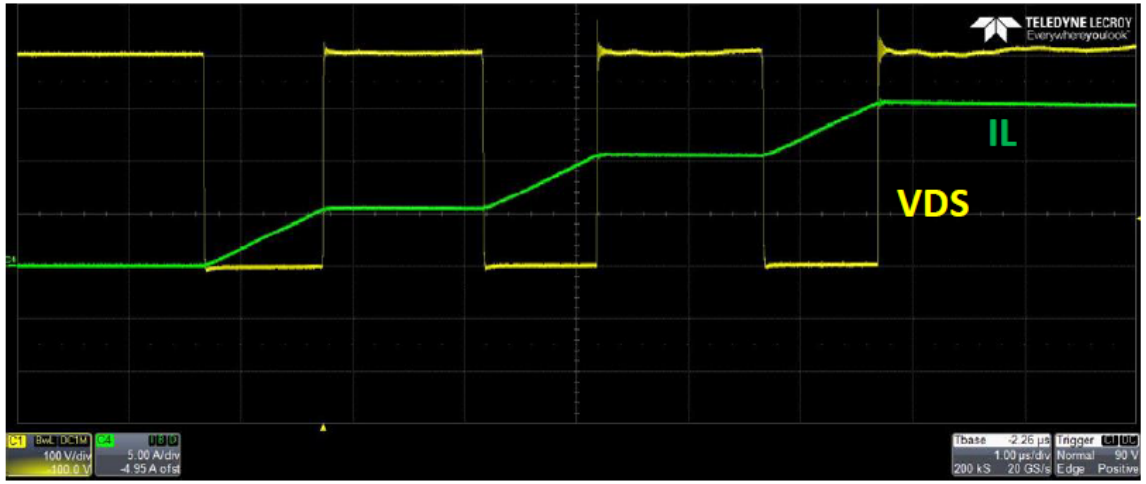
Discrete GaN





GaNFast with GaNSense Technology



- Clean switching, no ringing and no glitching

- Ringing can lead to gate voltage over-stress, poor gate reliability, reduced lifetime
- Glitching can lead to poor EMI and device failure

GaN Integration for Efficiency, Speed & Stability

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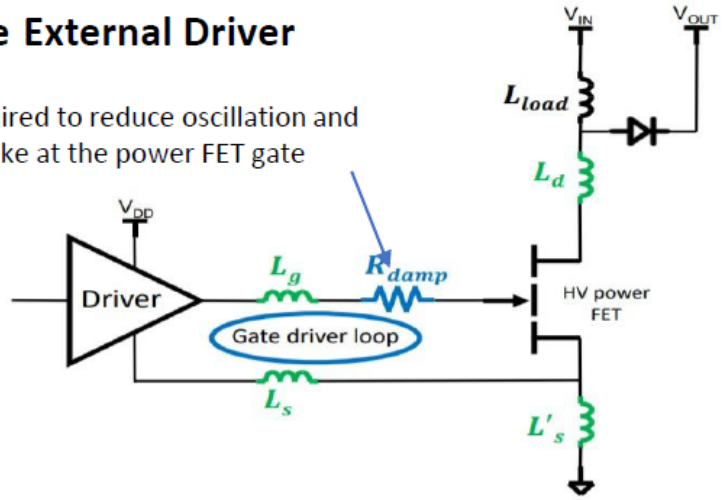
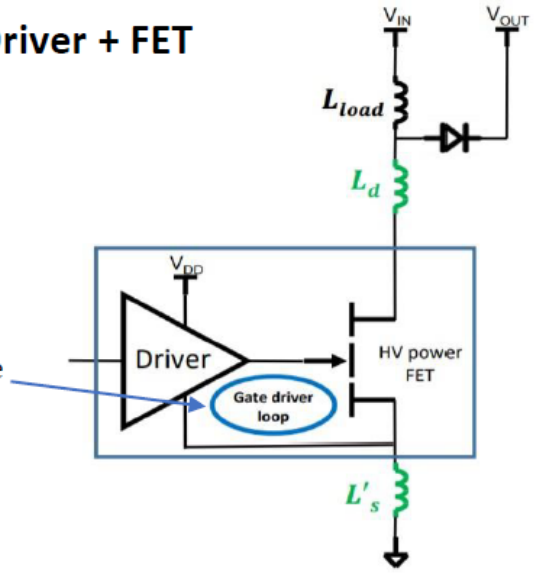
Discrete External Driver

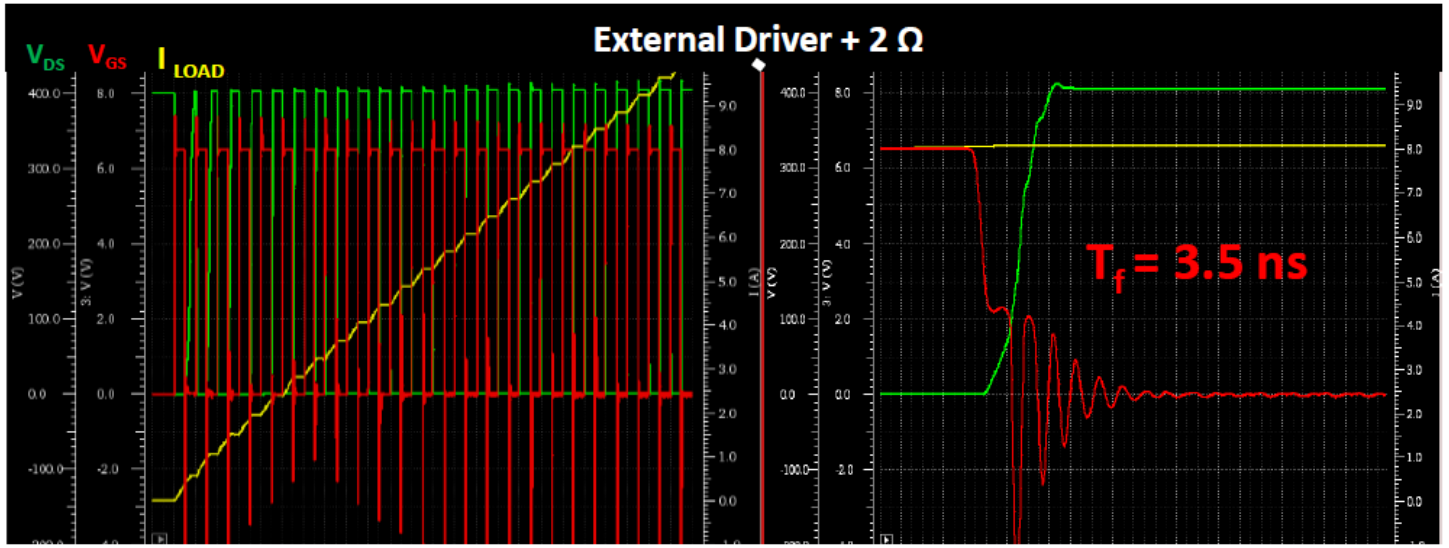
R_{DAMP} required to reduce oscillation and voltage spike at the power FET gate

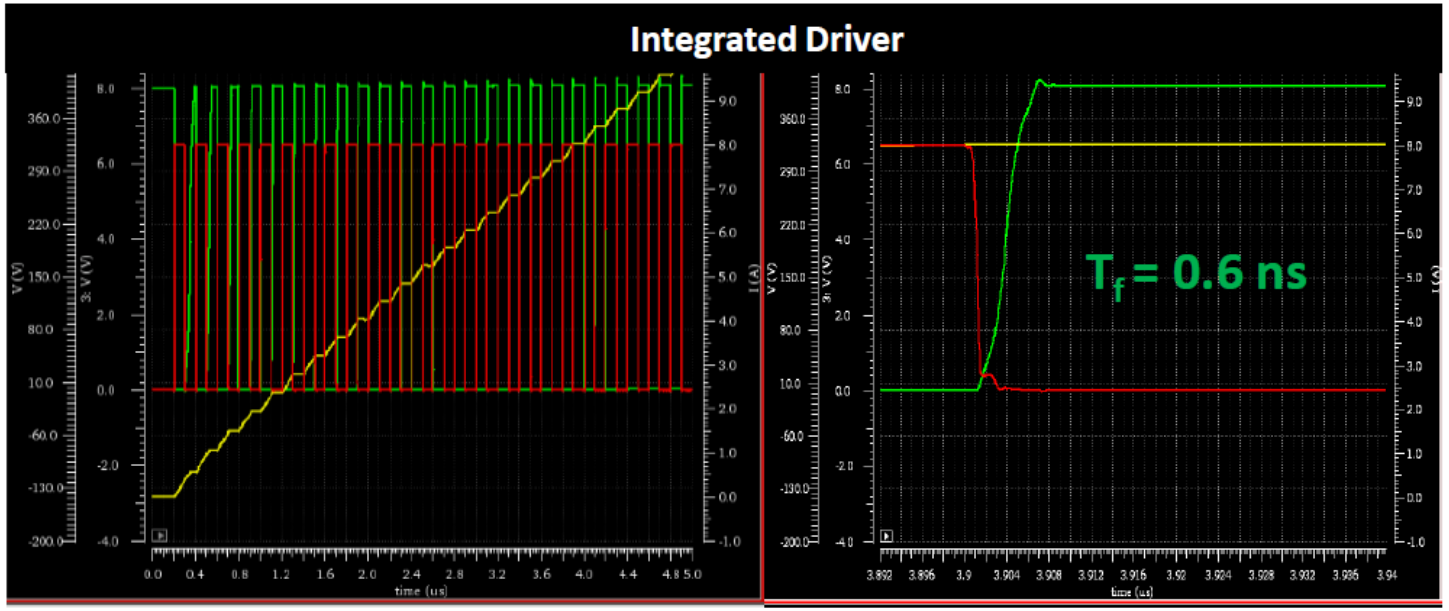


Monolithic GaN Driver + FET

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







Integrated GaN Driver is a Must in High Power GaN IC

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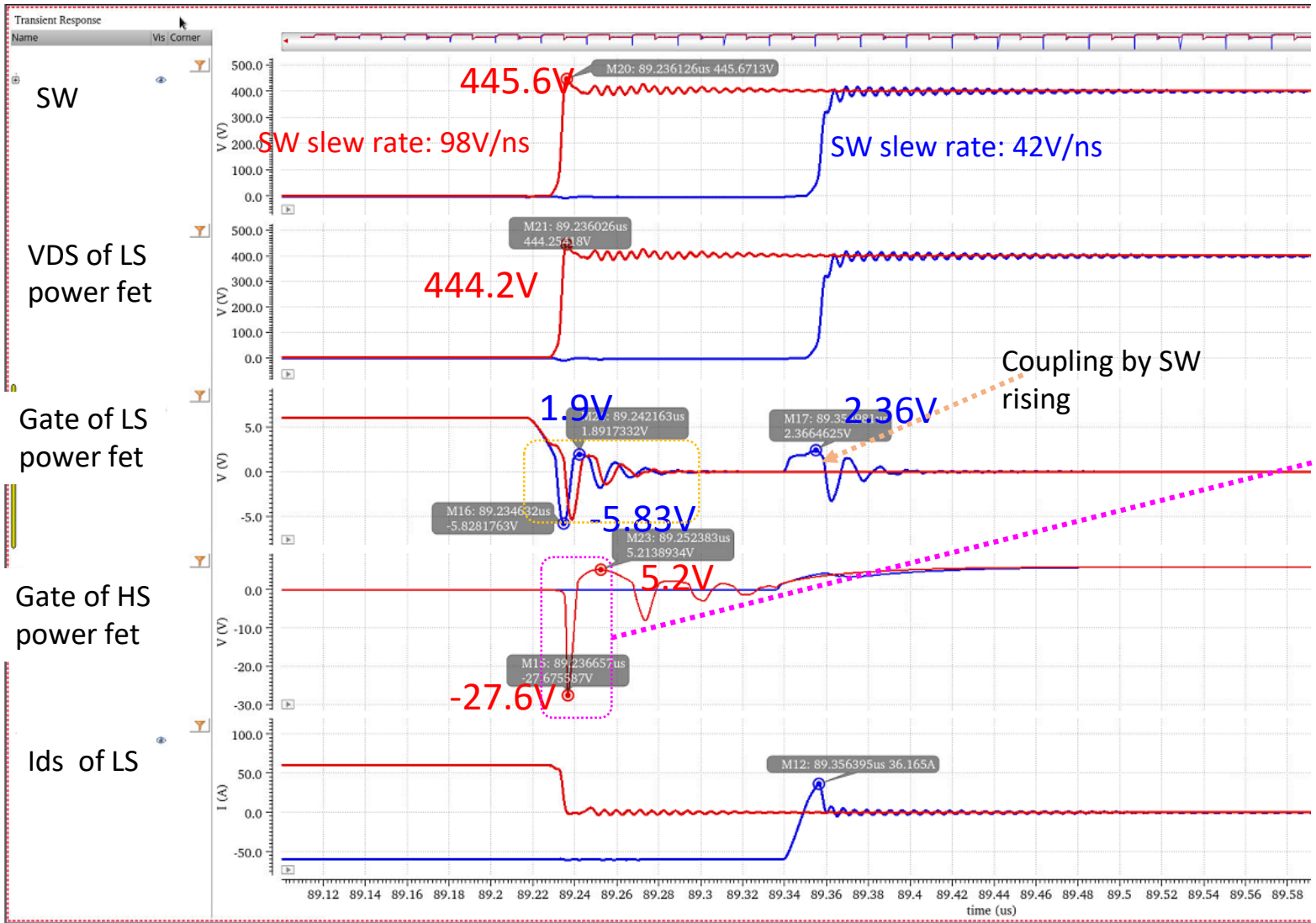
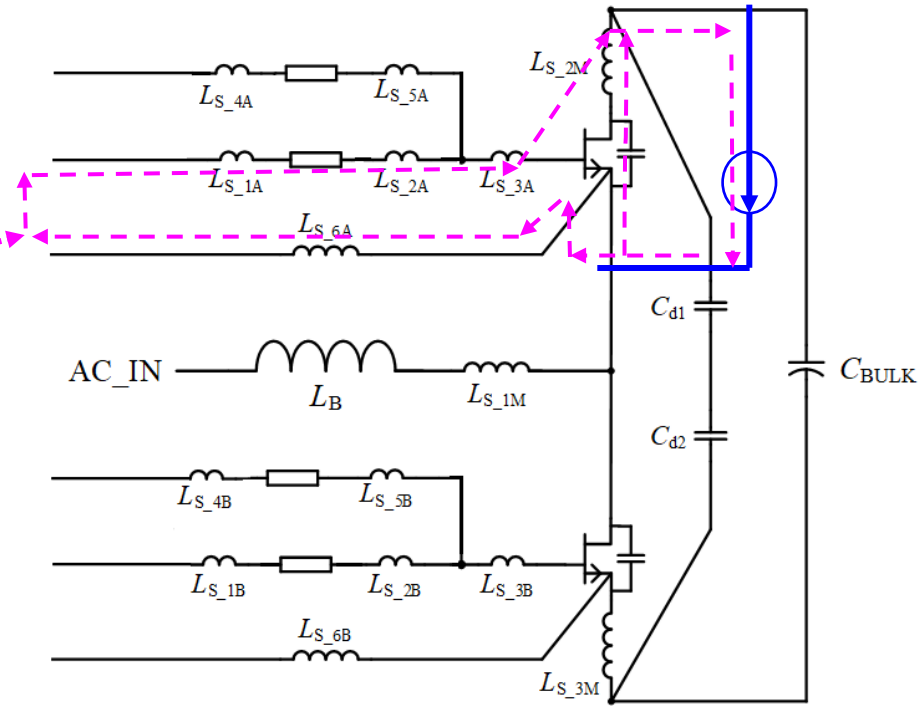
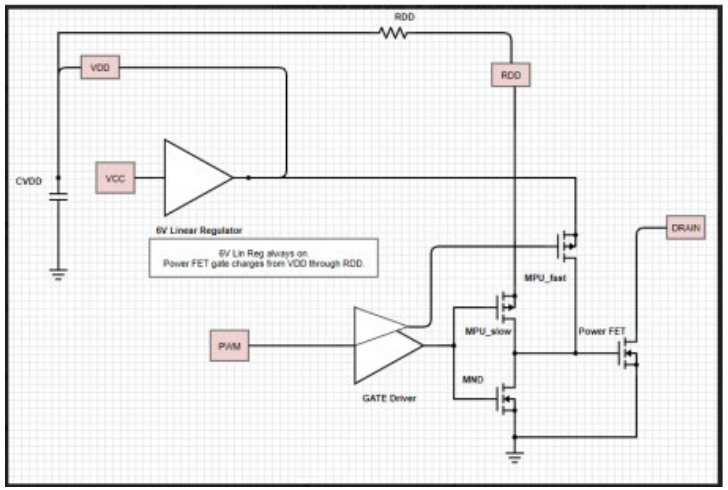
Buck Mode Iload=60A
Boost Mode Iload=60A



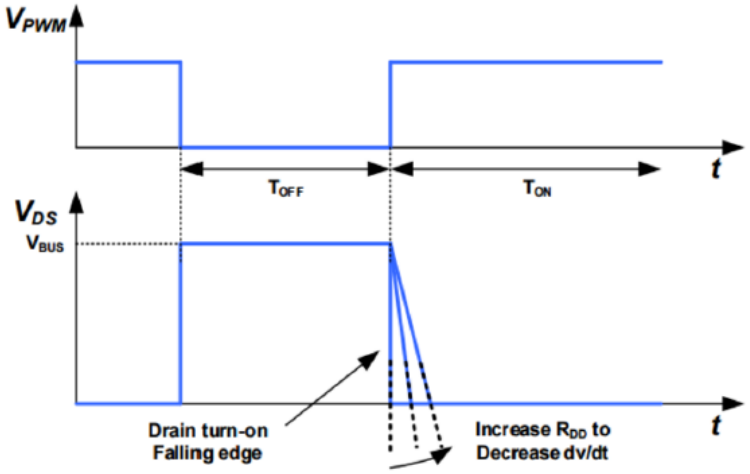
- Excessive gate overshoot / undershoot can be seen in GaN high power systems if powerFETs are discrete and there are noticeable PCB level patristic inductances.
- Setup: 60A load, 20mohm Rdson HS and 20mohmohm Rdson LS buck/boost modes simulation.



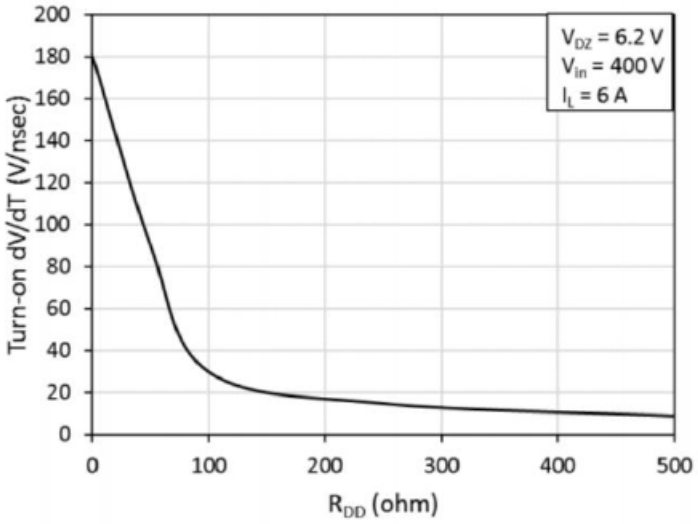
Navitas Patented Integrated Turn On dv/dt Control



Advanced multiphase Gate Shaping for turn on dv/dt control

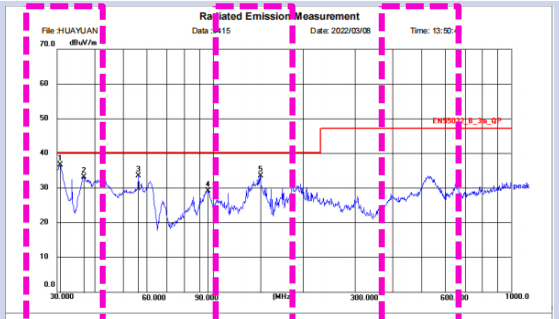
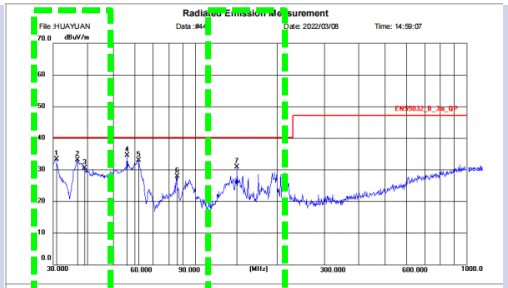
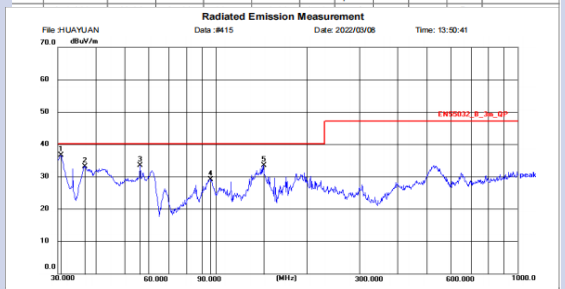
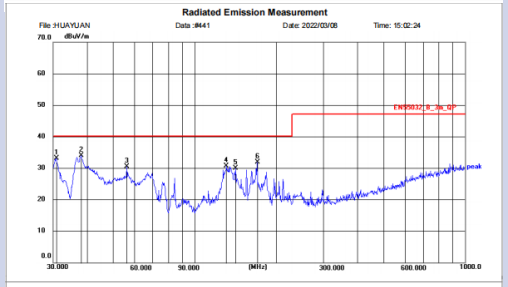


Dv/dt controlled by programmable external Rdd



Cross reference of RDD vs dv/dt

Navitas Patented Integrated Turn Off di/dt Control

	No Turn Off Di/Dt Control NV6134A	With Turn Off Di/Dt Control NV6134C	Summary
230V 20V/4A			**Gen4 added patented turn off di/dt control** • 2-3db better at 30-40Meg • 5db better margin at 100Meg • 10db better margin at 550Meg
230V 11V/6.1A			**Gen4 added patented turn off di/dt control** • 2-3db better at 30-40Meg • 3db better margin at 100Meg • 10db better margin at 550Meg

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The GaN Revolution: Ultimate Integration

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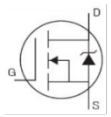
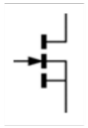
Silicon FET



- Old, slow
- High Q_g
- High C_{OSS}
- F_{SW} < 100 kHz

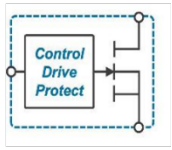
Discrete GaN



- Exposed gate
- External gate drive
- dV/dt sensitivity
- Layout sensitivity
- ESD sensitivity
- Unknown reliability
- Unknown robustness

GaNFast™

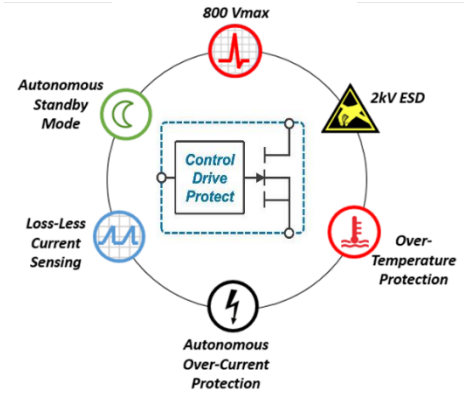
200-300 kHz



- ✓ Internal Gate
- ✓ Integrated Gate Drive
- ✓ dV/dt Immunity
- ✓ Layout Insensitive
- ✓ 2 kV ESD rating
- ✓ Proven Reliability
- ✓ Proven Robustness

GaNSense™

500 kHz

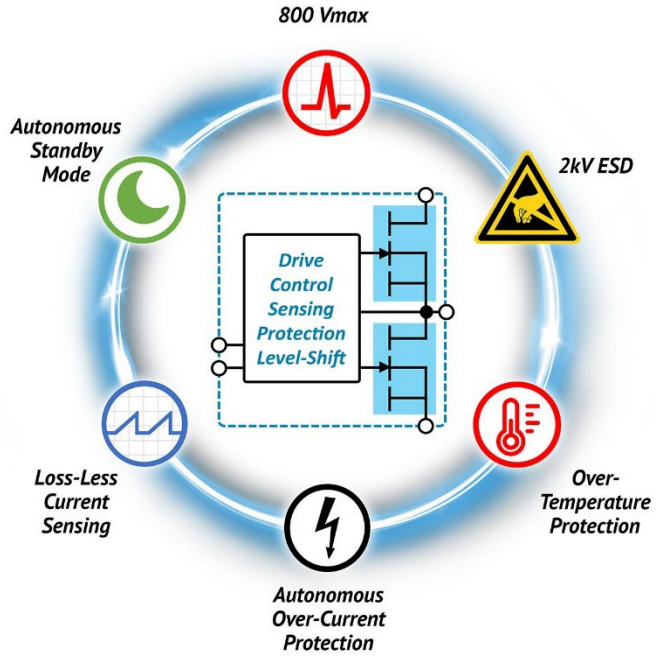


GaNFast plus:

- ✓ Autonomous Standby
- ✓ Autonomous Protection
- ✓ Loss-less Current Sensing
- ✓ High Precision
- ✓ High Efficiency

GaNSense Half-Bridge

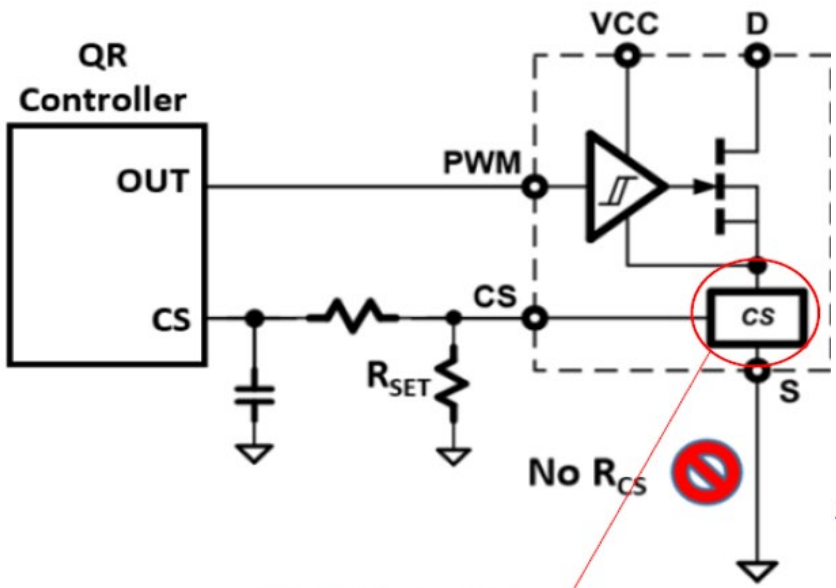
1 MHz



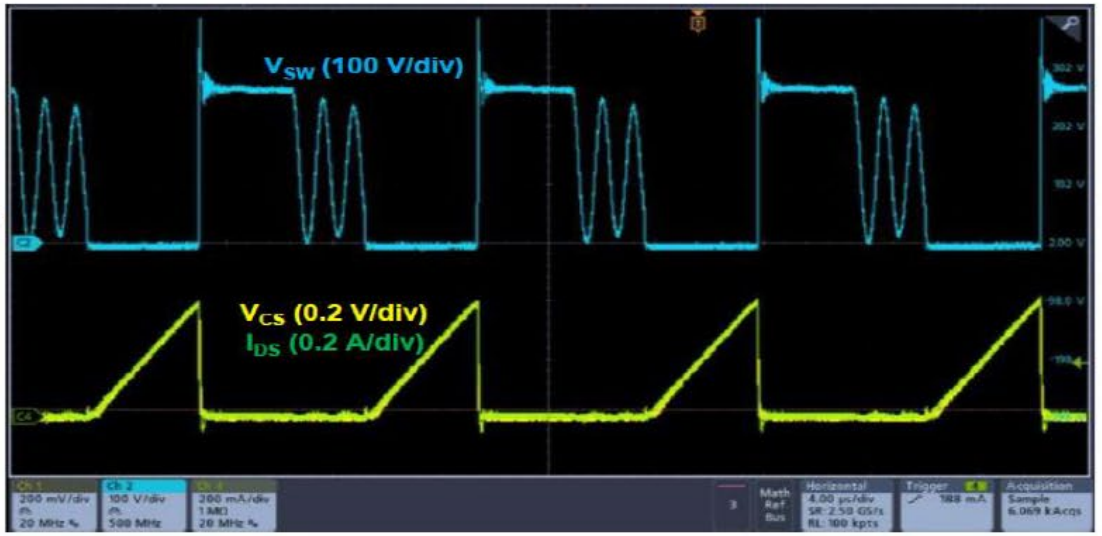
GaNSense plus:

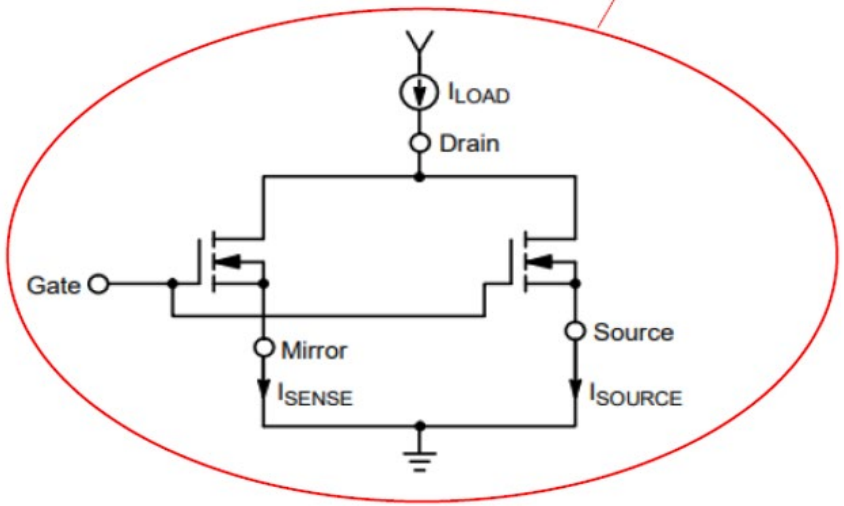
- ✓ Highest integration
  - ✓ integrated HS and LS FETs
  - ✓ Integrated level-shift isolation
  - ✓ integrated boot-strap
  - ✓ Shoot-through protection
  - ✓ Enlarged cooling pads
- ✓ Fastest switching
- ✓ Highest efficiency

Lossless Current Sensing

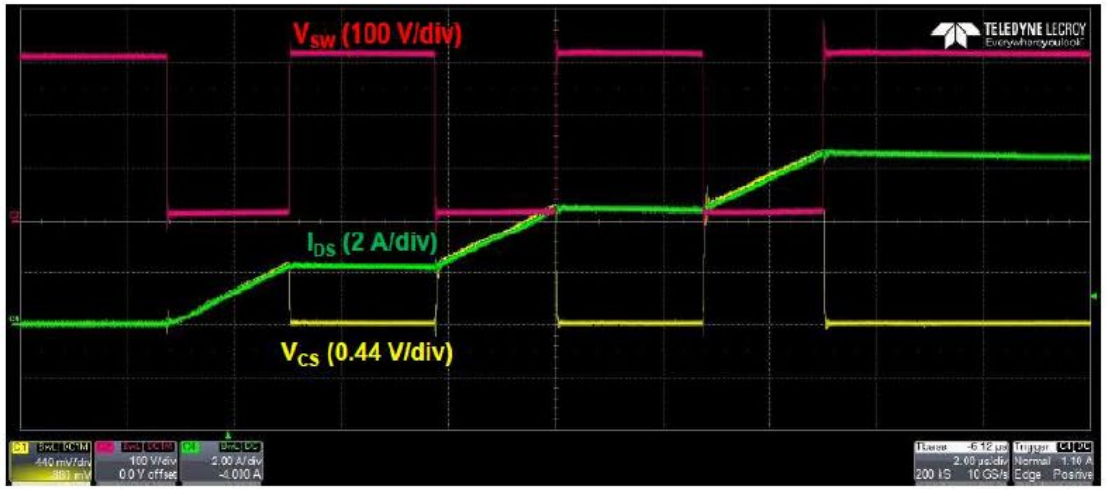


DCM Tracking
Example @ 192KHz





CCM Tracking
Example @ 200KHz



Lossless Current Sensing Efficiency Benefit

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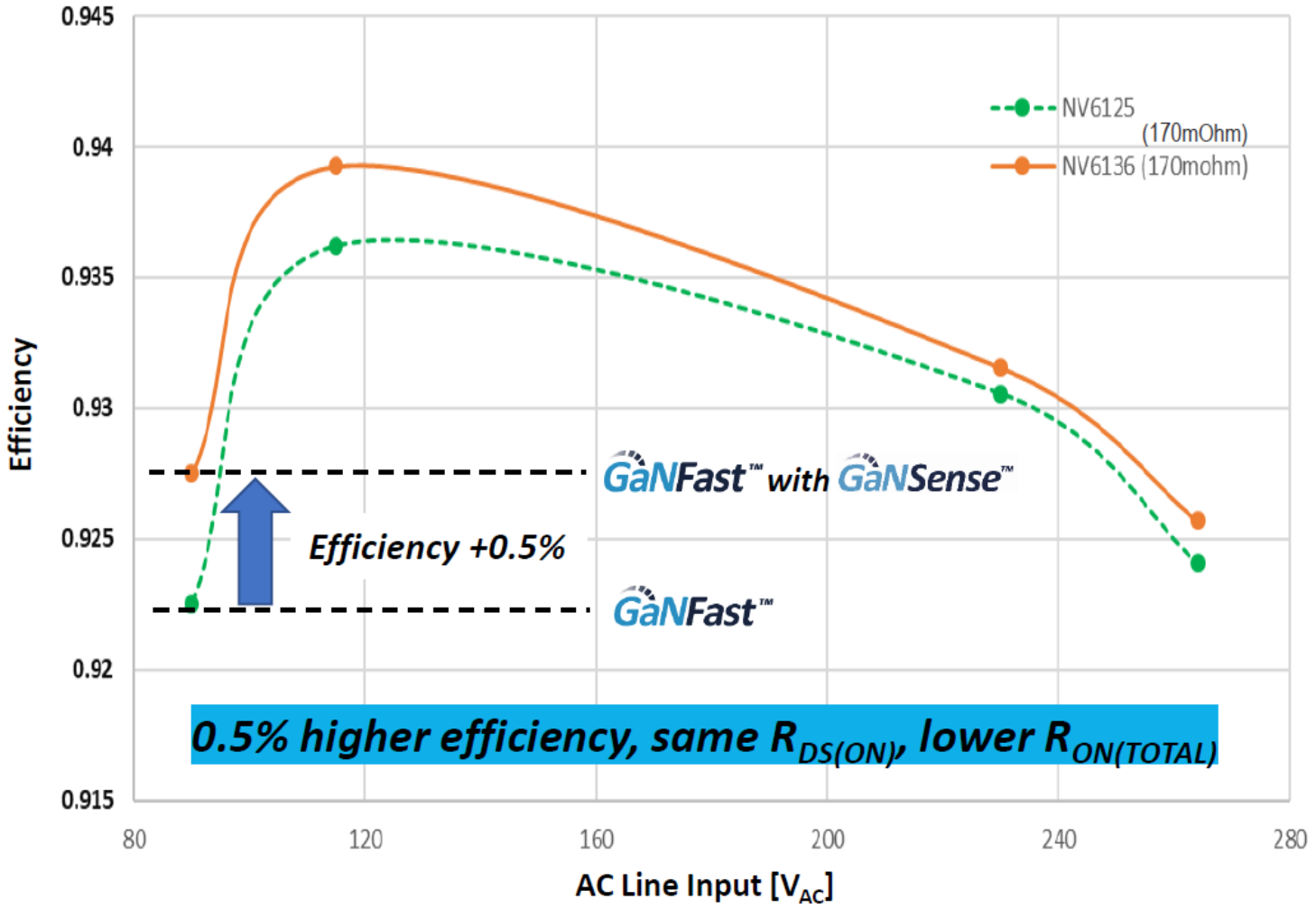
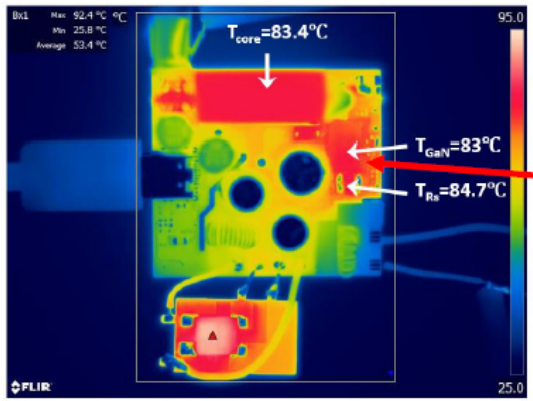
Efficiency (60W HFQR, 20V/3A)



60W HFQR, 90V_{AC}, 20V/3A, 1 Hour

GaNFast™

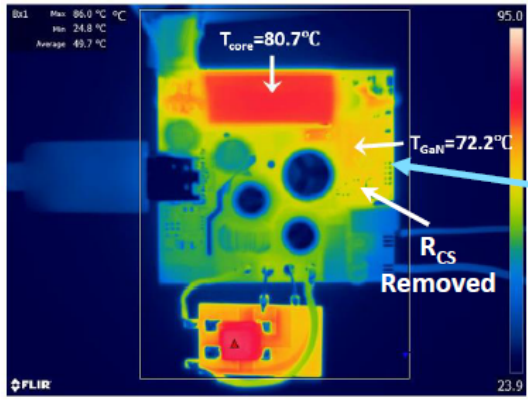


NV6125

$R_{DS(ON)}$ = 170 mΩ
R_{CS} = 170 mΩ
$R_{ON(TOT)}$ = 340 mΩ

R_{CS} HOT-SPOT = 85°C!

GaNFast™ with GaNSense™



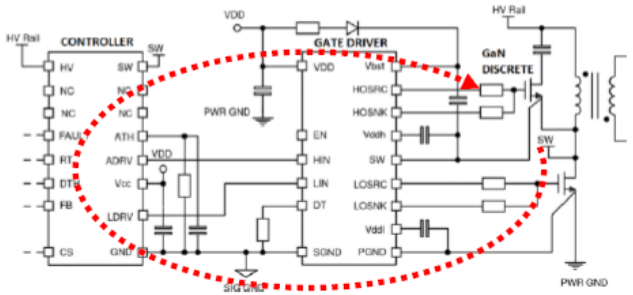
NV6136

$R_{DS(ON)}$ = 170 mΩ
R_{CS} = 0 mΩ
$R_{ON(TOT)}$ = 170 mΩ

NO HOT-SPOT
T_{GaN} 10°C Cooler

Autonomous Over-Current Protection (OCP)

Discrete GaN Solution

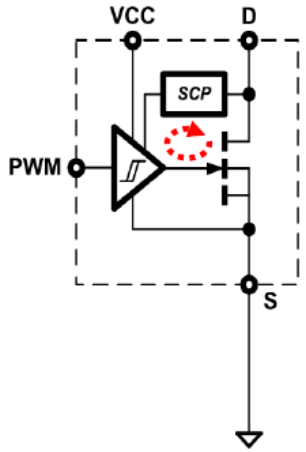


Uses QR controller OCP function

T_{OCP} = 180 ns

- *Existing solutions use ext. R_{CS}*
- *Filter + controller delay slow*

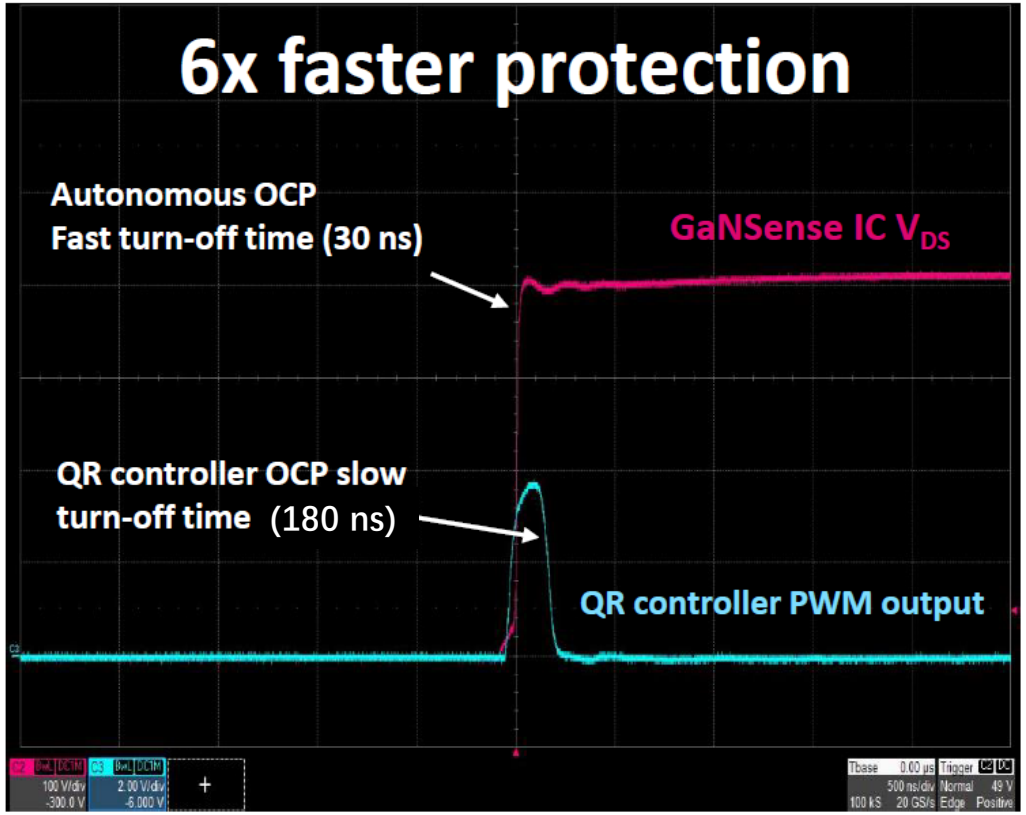
GaNFast™ with GaNSense™



Integrated SCP function

T_{OCP} = 30 ns

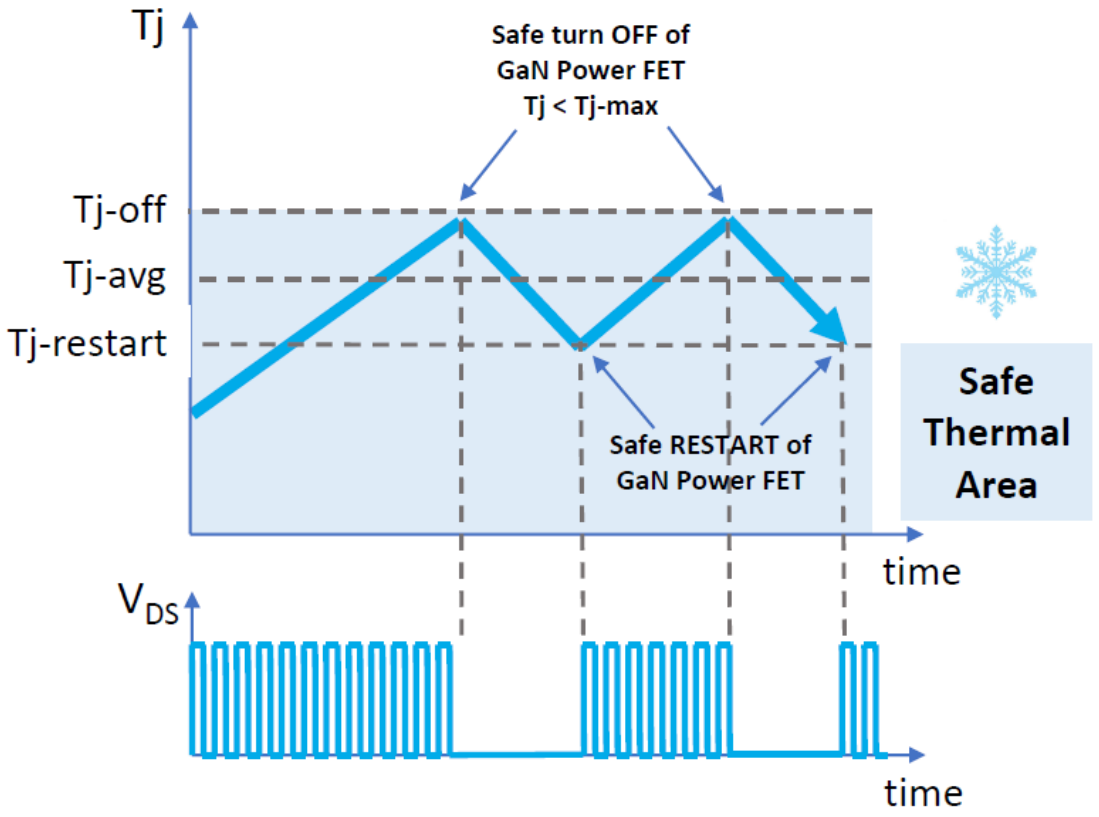
- *Autonomous OCP*
- *Fast-acting self-protection*
- *Cycle-by-cycle protection*
- *Excellent robustness*



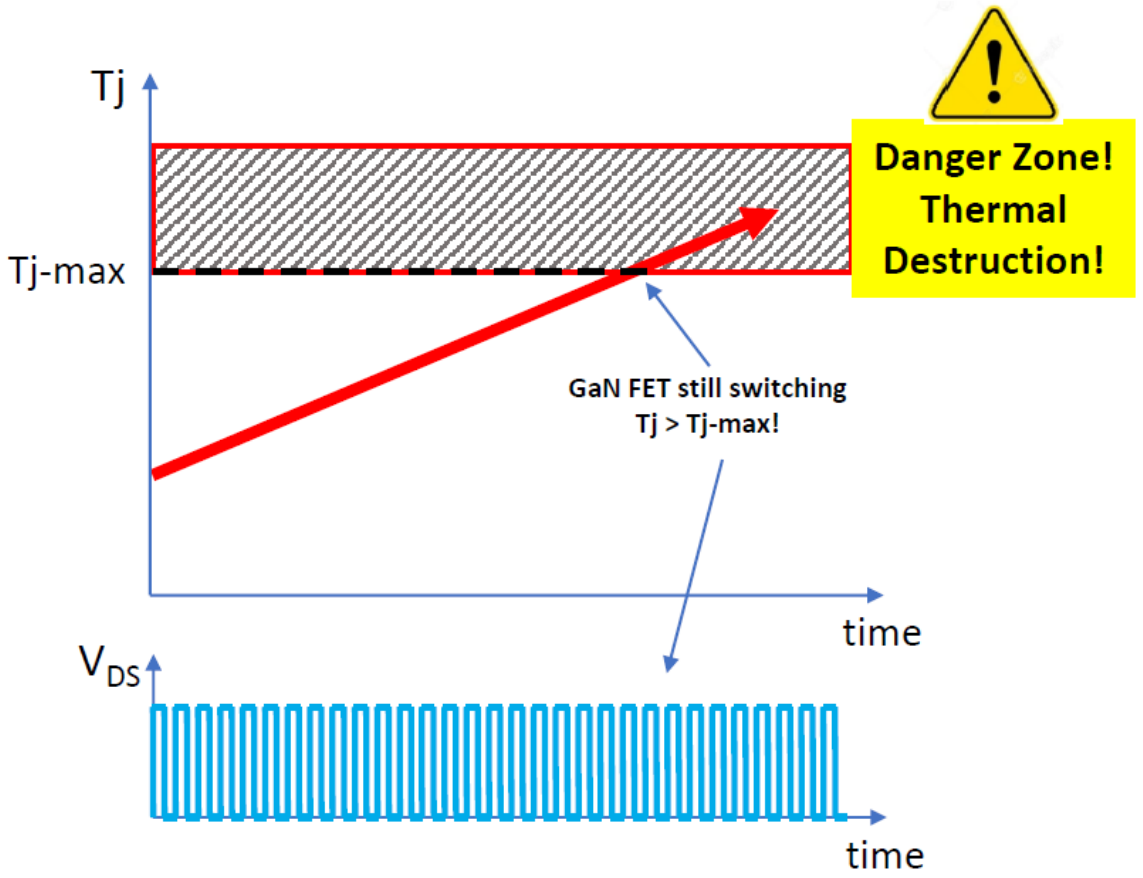
- *QR controller OCP = slow turn-off (180 ns)*
- *NV6136 OCP = fast turn-off (30 ns)*

Over Temperature Protection (OTP)

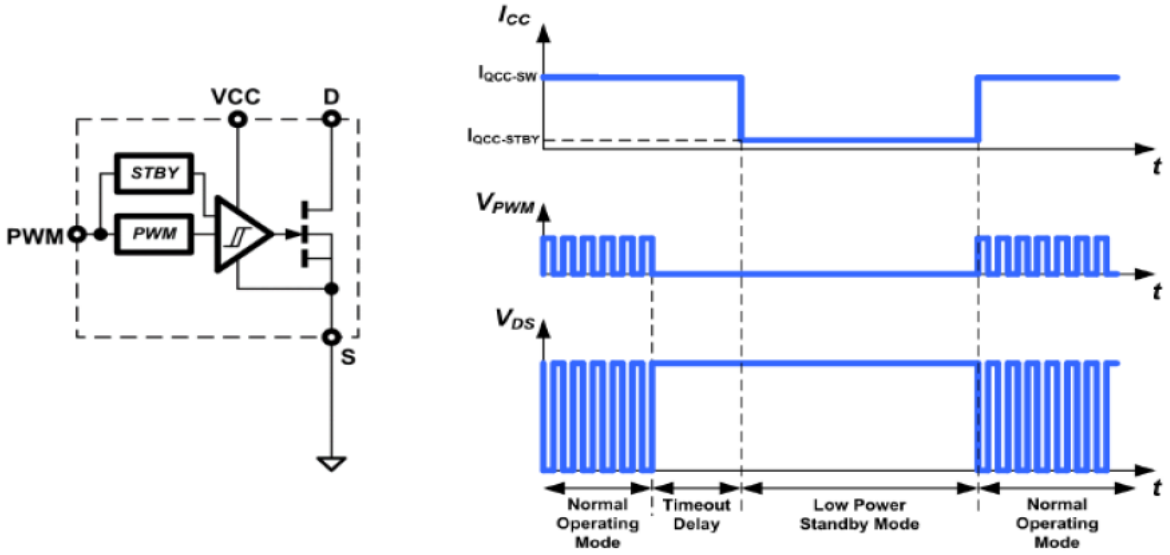
GaNSense IC w/OTP



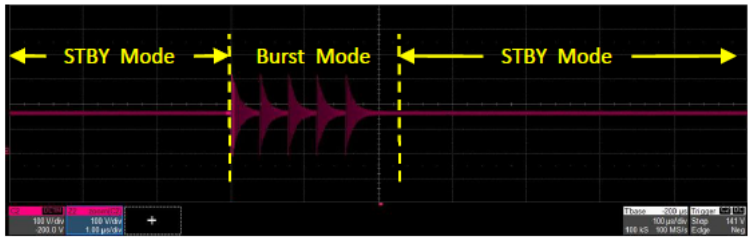
Unprotected GaN



Autonomous Standby Mode



Autonomous low-power standby mode simplified circuit and timing diagram



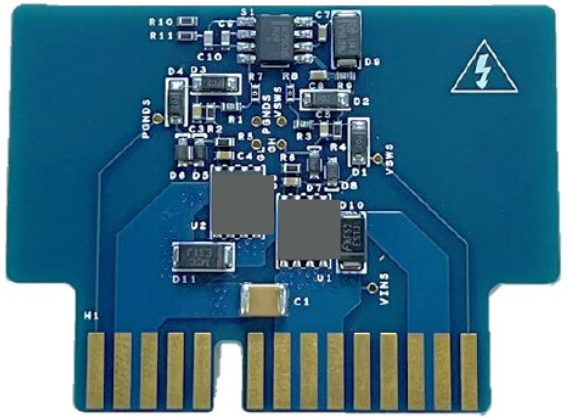
HFQR, no load

P_{IN} (no load)	115 V_{AC}	230 V_{AC}
NV6125	39 mW	40 mW
NV6136	33 mW	33 mW

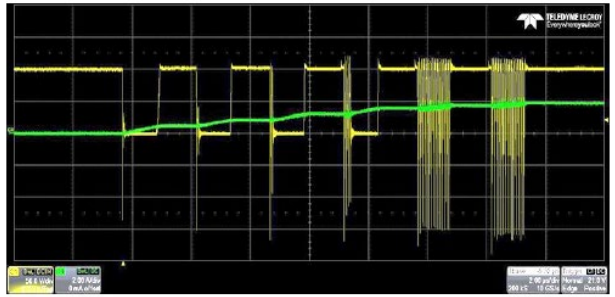
- GaN IC autonomously enters standby mode in the absence of PWM signals.
- Super fast wakeup at next PWM rising edge.
  - No discernable effect on propagation delay, current sense performance, etc…
- In the High Frequency QR Flyback no load example above, **full system standby losses are reduced 17%**
  - NV6125 Gen 2 GaNFast part (175mΩ typical).
  - NV6136 Gen 3 GaNSense part (170mΩ typical).

Navitas Integrated GaN HB IC

Discrete GaN



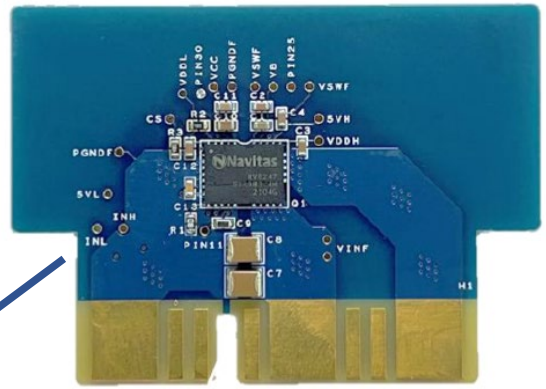
2x Discrete GaN
+28 components



Risky, Erratic, Lossy

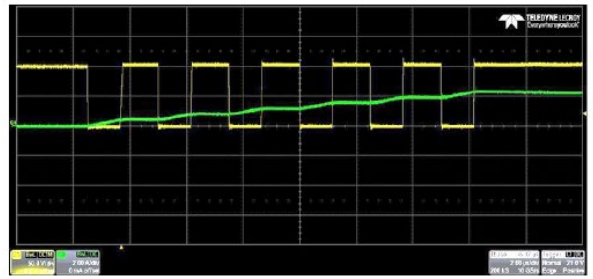
2x fewer components
3x Smaller design
Internal Gate protection
No Gate Ringing

GaNFast IC



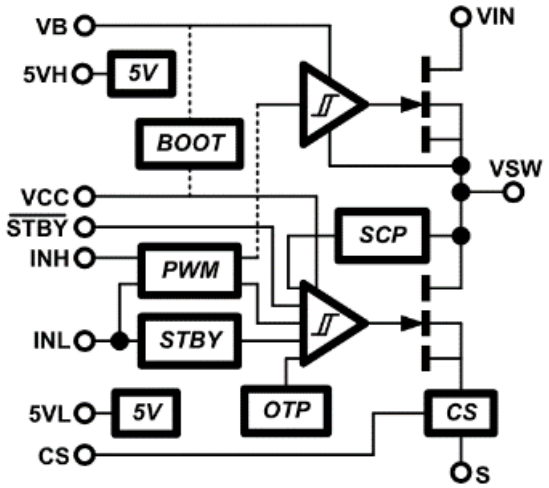
1x GaN Power IC
+14 components

1/2 the Components
1/3 the Area



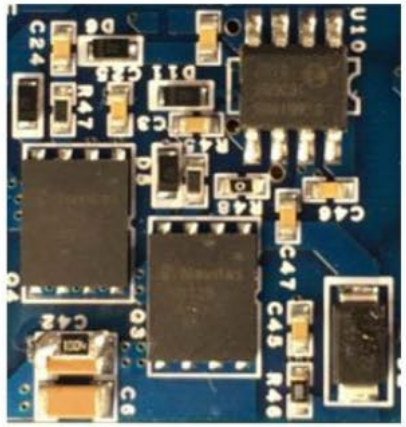
Reliable, Predictable, Efficient

NV624x HB Family

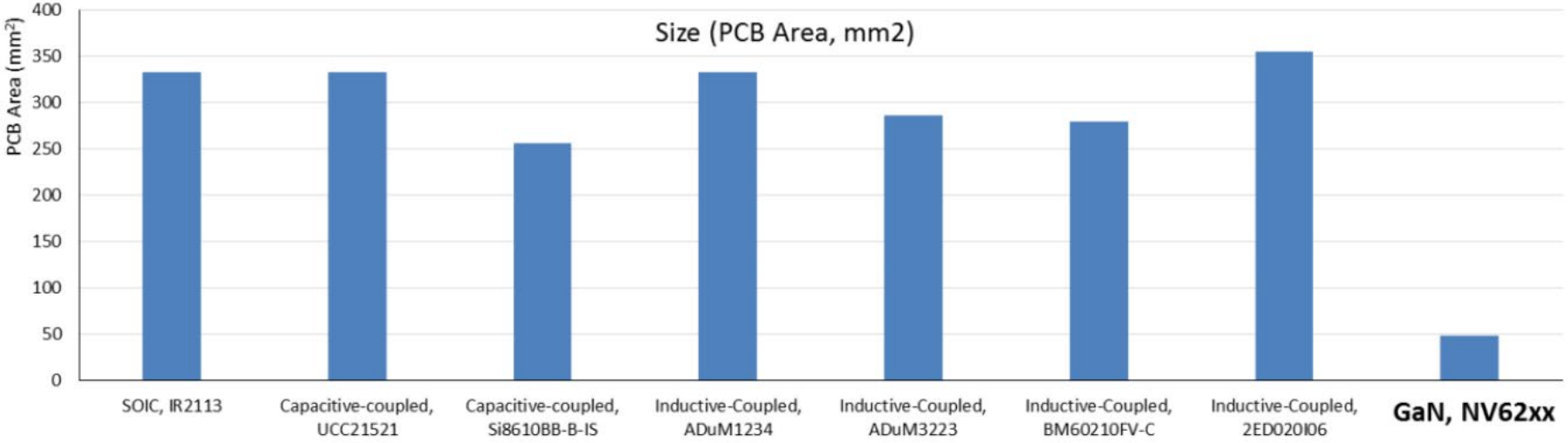


Navitas Integrated GaN HB IC

Digital Isolator
2x Single GaN Power ICs
Bootstrap diode
Passives

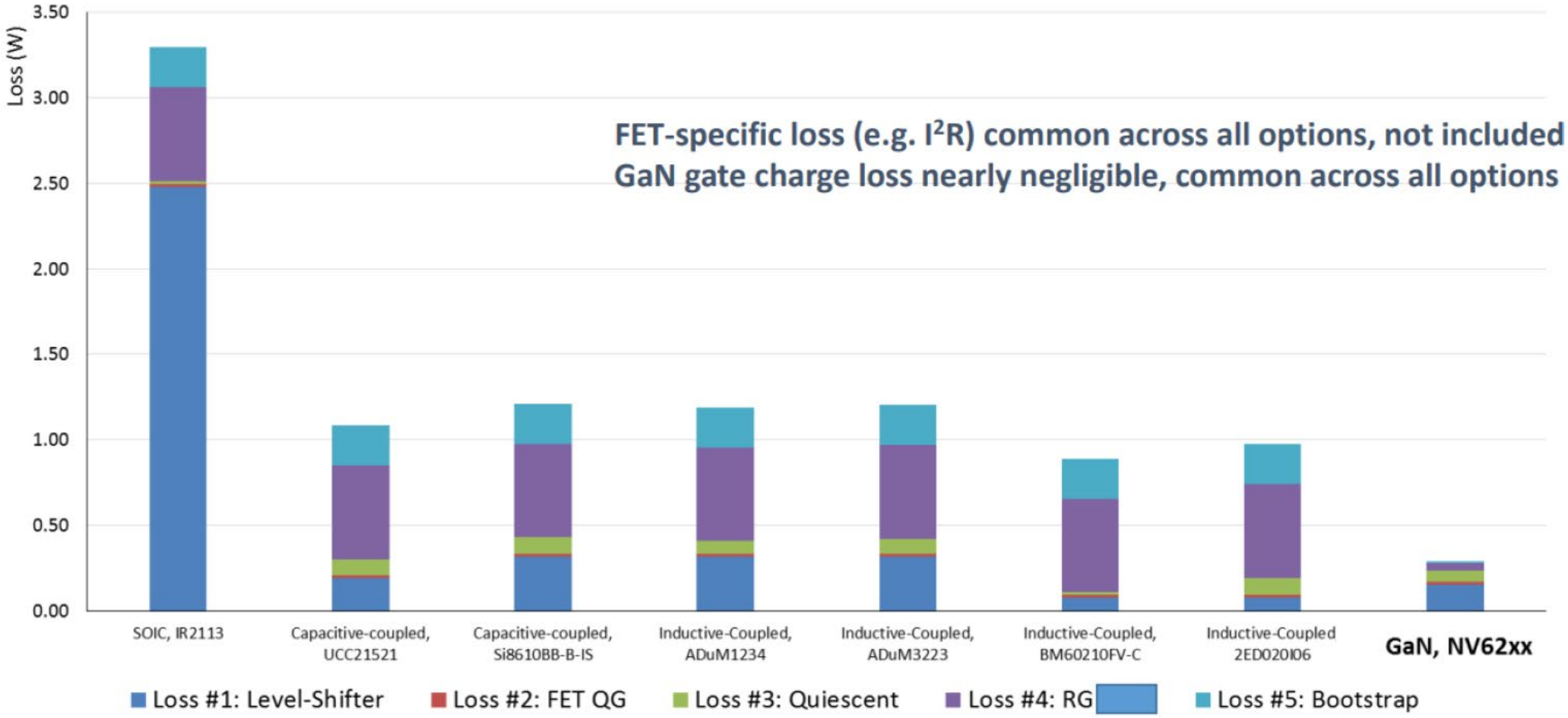


Half Bridge GaN Power ICs 5X smaller than alternatives



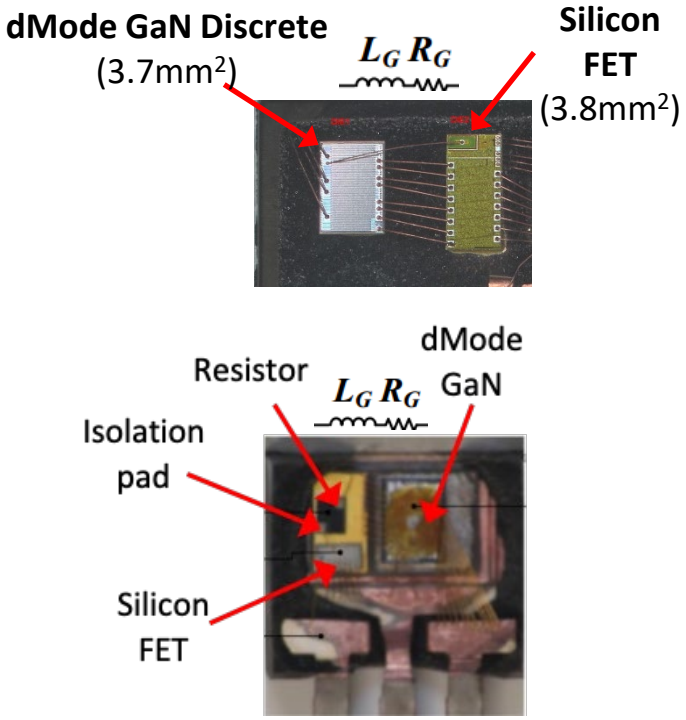
Navitas Integrated GaN HB IC

- 3x Lower Drive and Level Shift Loss at 1 MHz



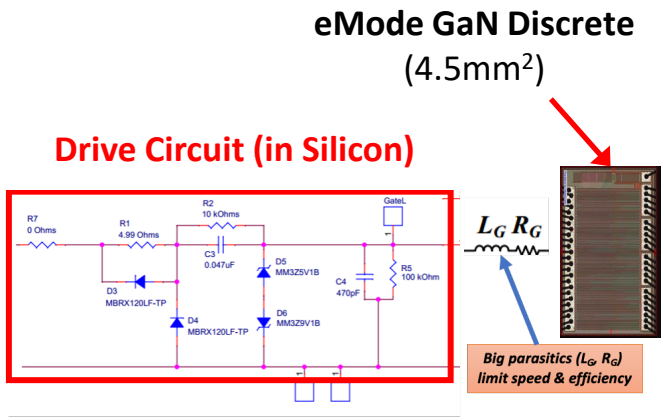
Navitas GaN IC: Smaller, Faster, More Reliable

Discrete dMode GaN



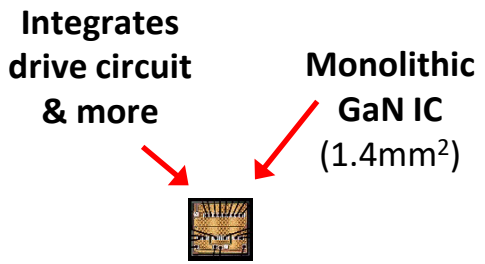
- Extra Si FET + other
  - Cost & complexity
  - Adds parasitics & delay
  - Limits speed & efficiency

Discrete eMode GaN



- Extra Si driver circuit

Navitas eMode GaN IC



- No extra circuits
- No parasitics & delay
- Drive & power matched in GaN
- Integrated features, functions
- Highest speed & efficiency
- Highest robustness and reliability
- Simple customer design
- 50-80% smaller chip

(1) 'dMode' = depletion mode = 'normally on' transistor, causes short circuit unless additional transistor added.
(2) 'eMode' = enhancement mode = 'normally off' transistor.

Summary

- GaN is the next generation power semiconductor that offers superior performance.
- GaN power devices require monolithic integration of driver and power stage to enable highest frequency, performance, and reliability.
- Further integration of real time protection and features delivers highest efficiency, performance, and reliability.

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