PowerAmerica

Advancing GaN Power Integration: Efficiency, Reliability & Autonomy

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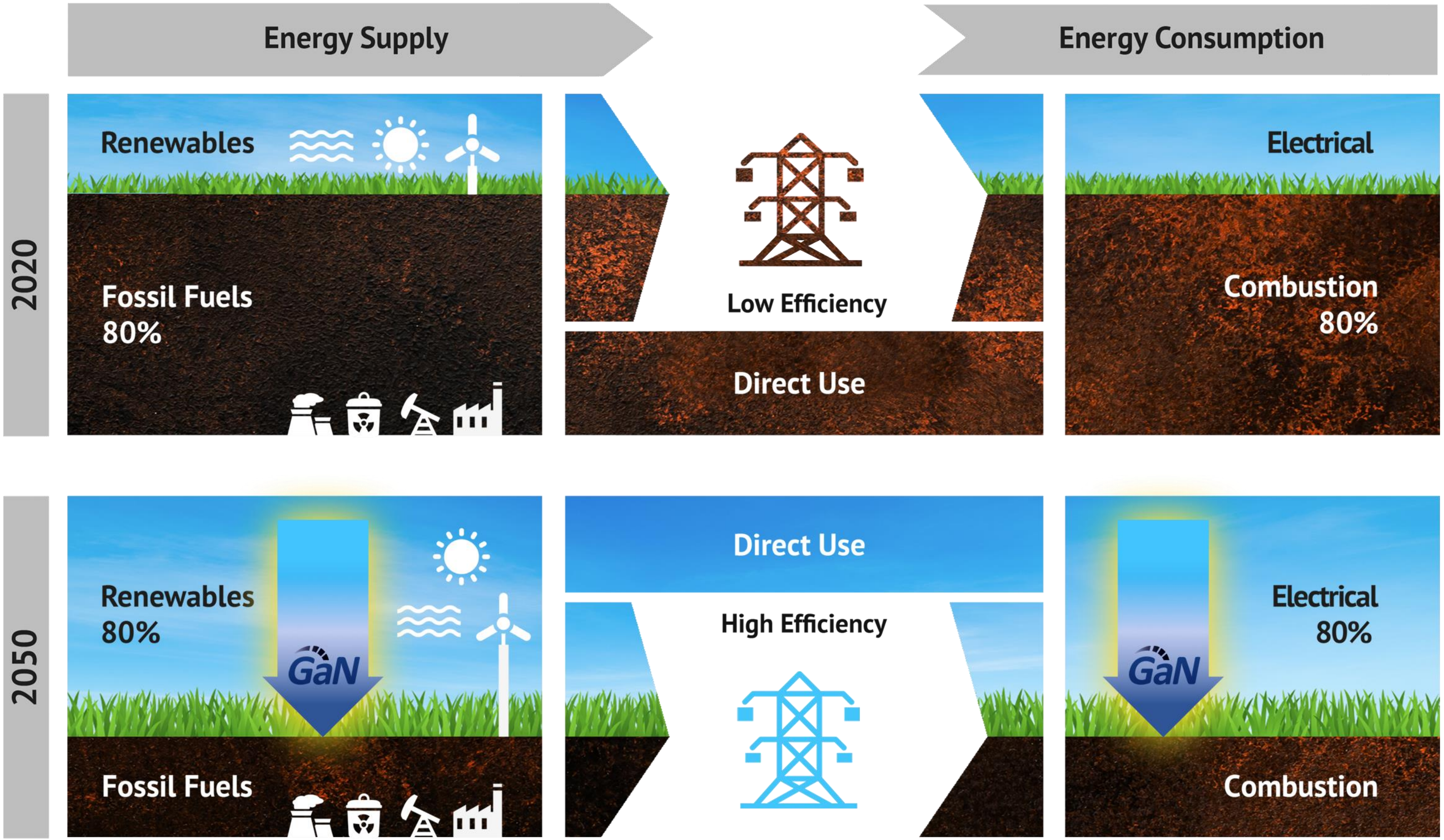
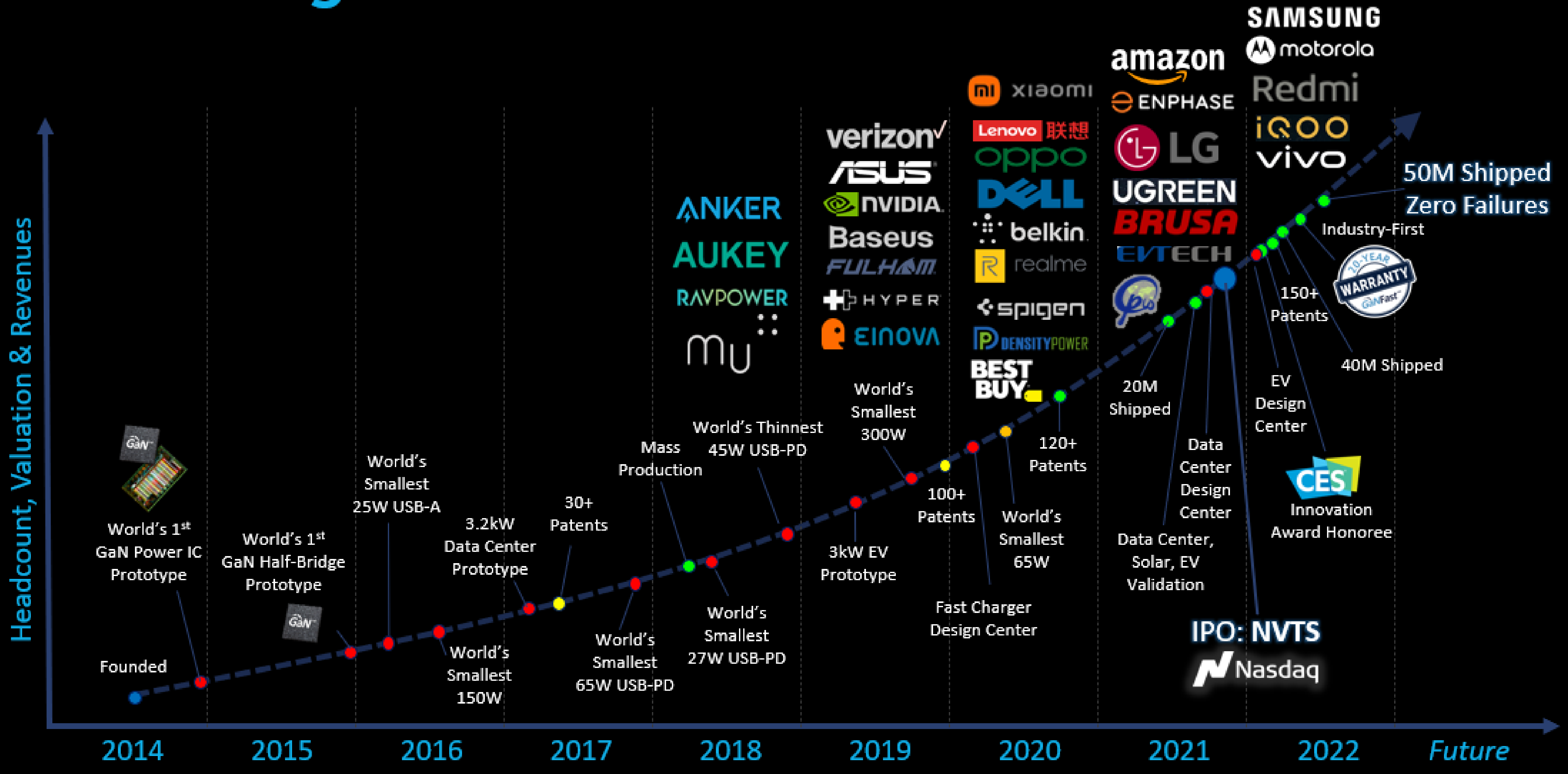
PowerAmerica Summer Workshop, 2nd August 2022

Electrify Our World™

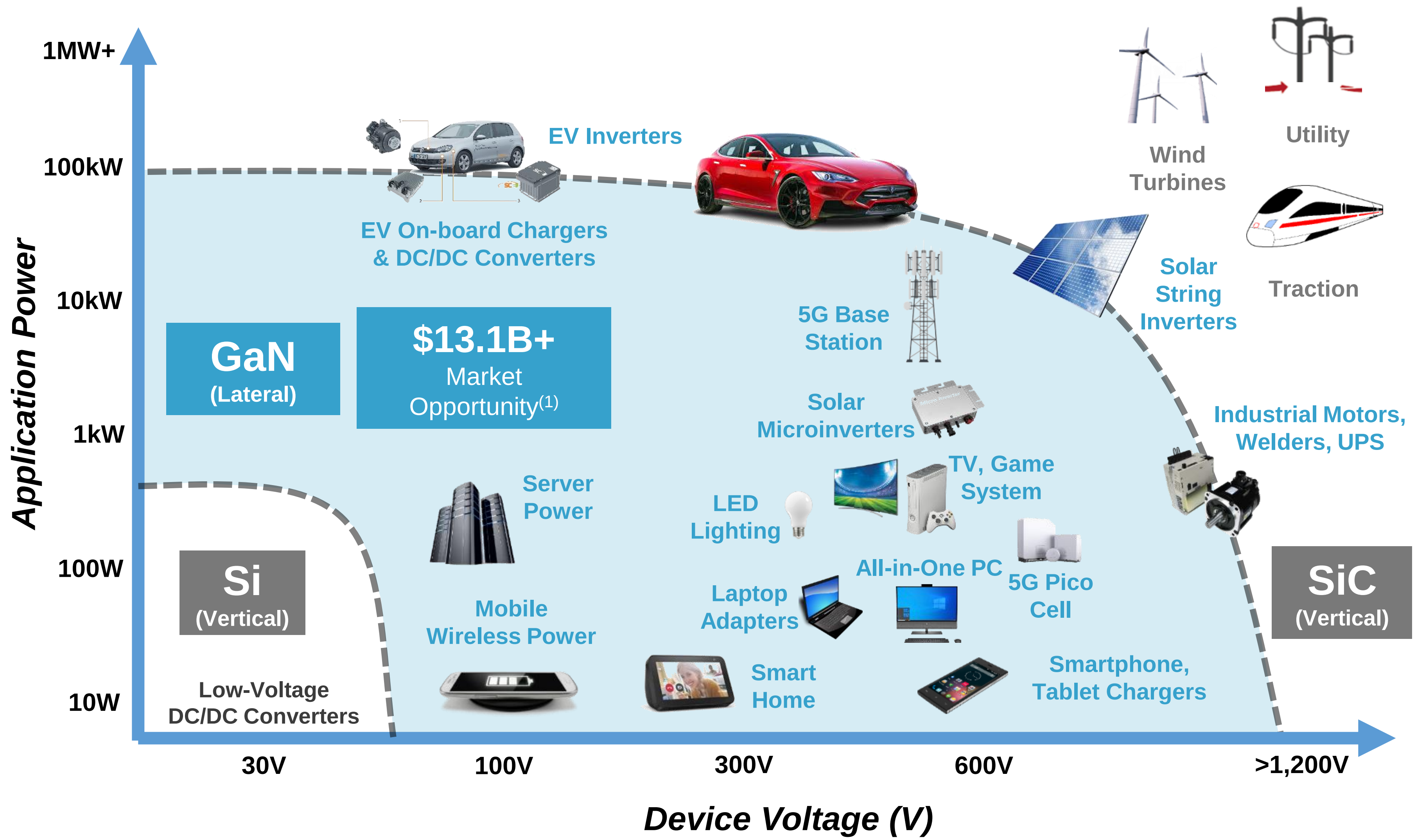


Pioneering Growth: #1 in GaN



GaN: An Expansive Market Opportunity

Navitas



	GaN	SiC
Device Structure	Lateral	Vertical
Circuit Integration	Yes (Power + Analog)	No
Switching Frequency	Highest (200 kHz – 2 MHz)	Medium (100 – 300 kHz)
Cost	Si substrate (very low cost)	SiC substrate (10x cost vs Si)
Thermal performance	Same as Silicon (1.3 W/cmK)	Highest (3.8 W/cmK)

(1) GaN IC potential market based on voltage rating of 80V – 1,000V derived from Yole Développement. Status of the Power Electronic Industry 2020. Reflects estimated GaN market opportunity for power semiconductors by 2026.

GaN Adoption into Key Growth Markets

Navitas

Fast Chargers

- 3x faster charging
- 50% smaller size
- 50% reduced weight

<0.3kW

Consumer

- 3x smaller and lighter solutions
- Low-profile

<1kW

Enterprise

- <10% reduction in datacenter electrical consumption
- Saving >15 TWh / $1.9B/yr

<10kW

Solar

- 25% cost reduction of micro-inverters
- <40% energy savings
- Improve payback by 10%+

<50kW

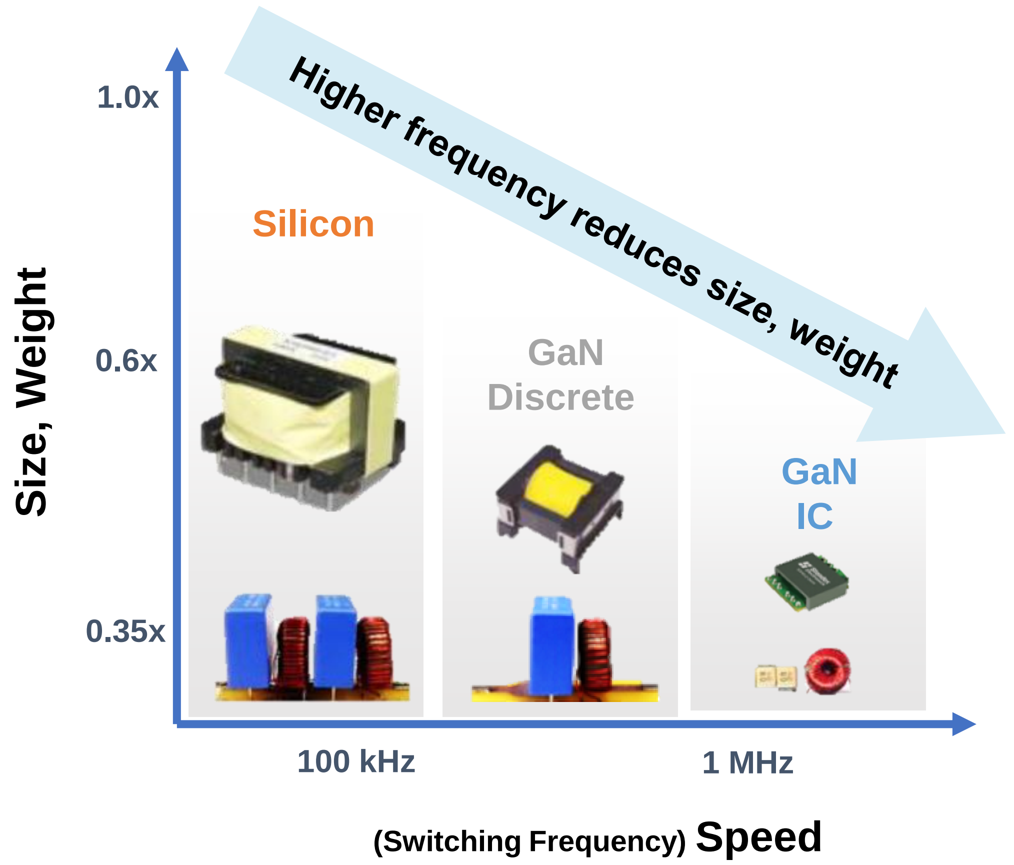
EV

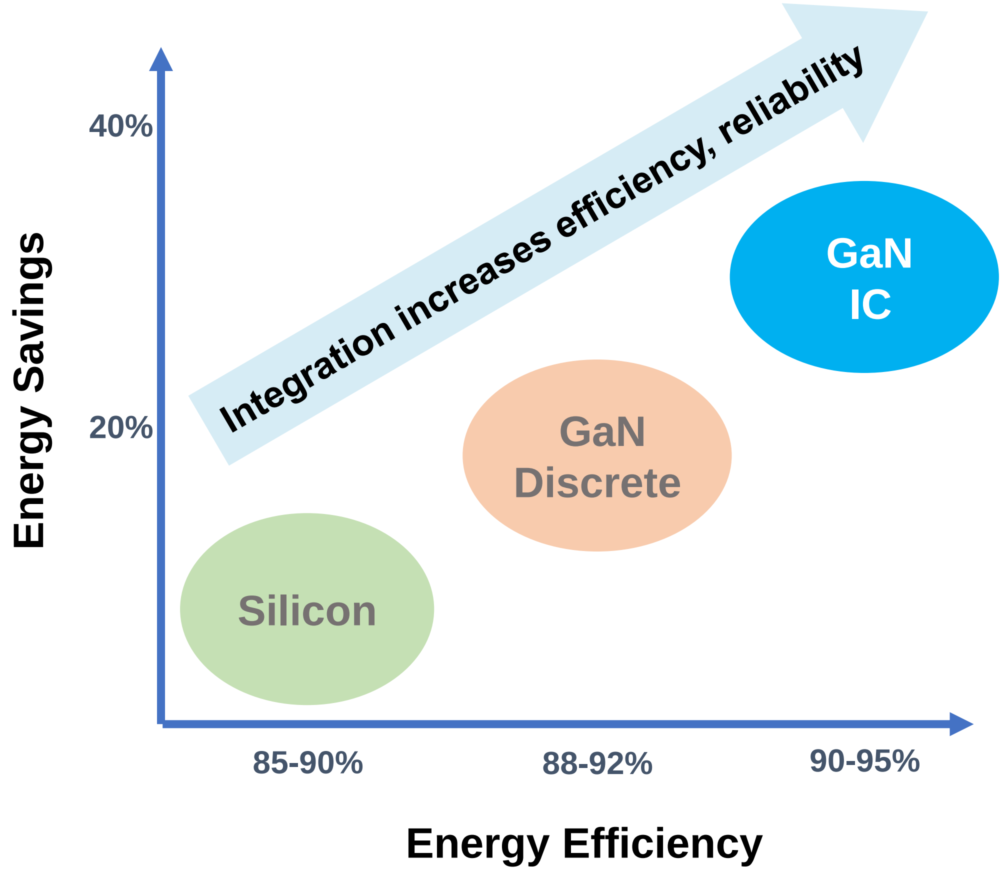
- 3x faster charging
- 70% energy savings
- 5% longer range / lower battery cost

<100kW

Speed and Efficiency Drive Value

Navitas





GaN power ICs enable up to 3x smaller, lighter (1)

GaN ICs save 40% energy (2), 100x more reliable (3)

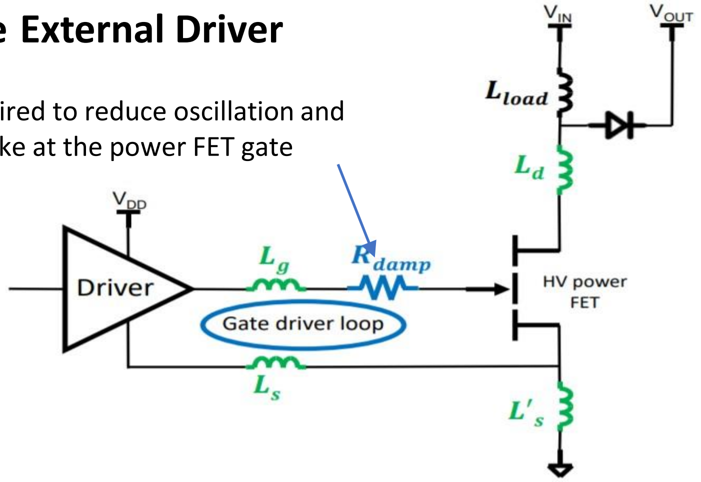
(1) Based on Navitas measurements of GaN-based chargers compared to Si-based chargers with the same output power.
(2) Navitas estimate of GaN-based power systems compared to Si-based systems in the 2024-2025 timeframe, Navitas measurements of select GaN-based chargers vs. Si-based chargers with similar power.
(3) V_{GS} failure distribution based on Navitas internal characterization of Discrete GaN Transistors compared to GaN power ICs.

GaN Integration for Efficiency, Speed & Stability

Navitas

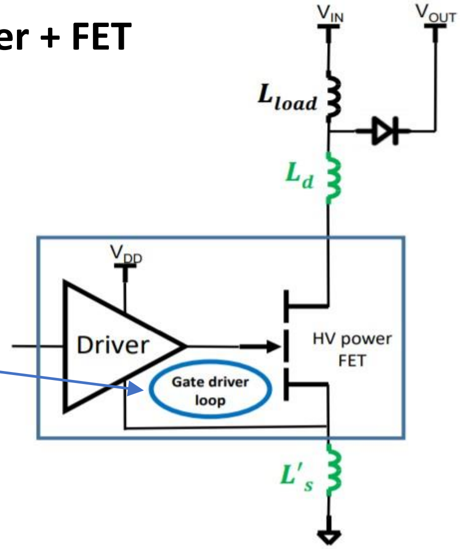
Discrete External Driver

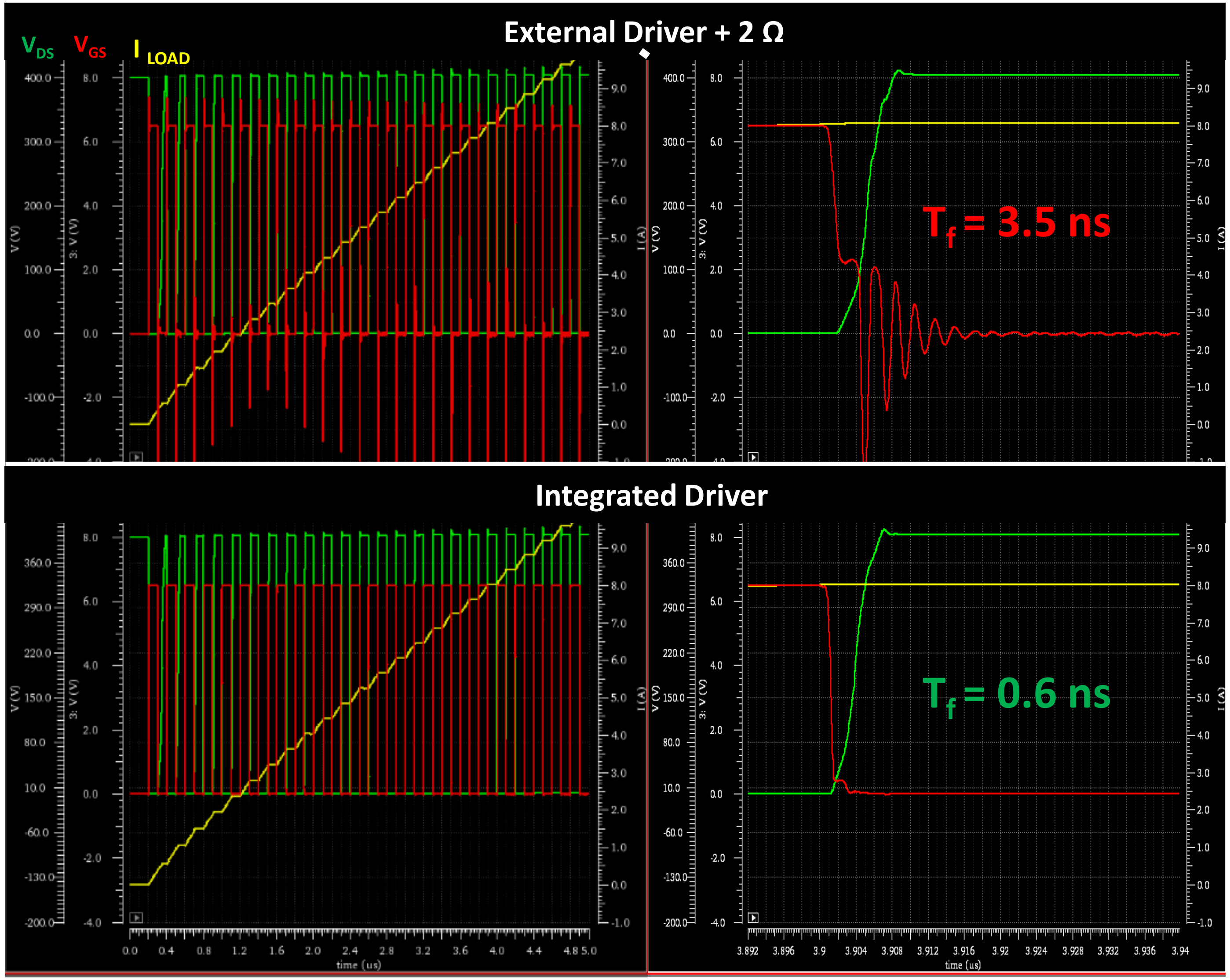
R_{DAMP} required to reduce oscillation and voltage spike at the power FET gate



Monolithic GaN Driver + FET

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





Benefits of Integrating Control, Drive, Protection

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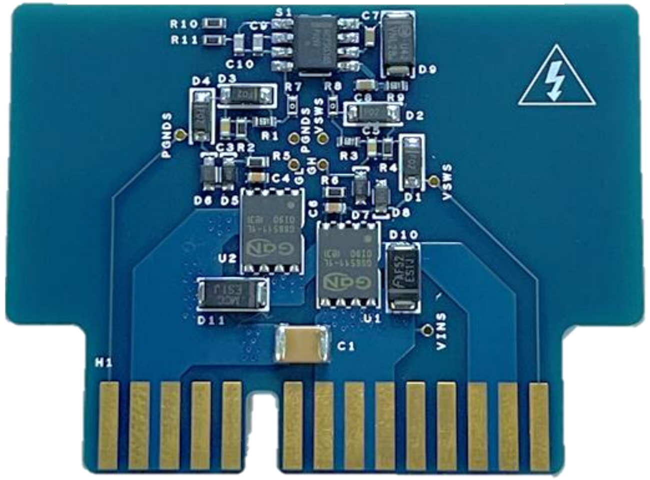
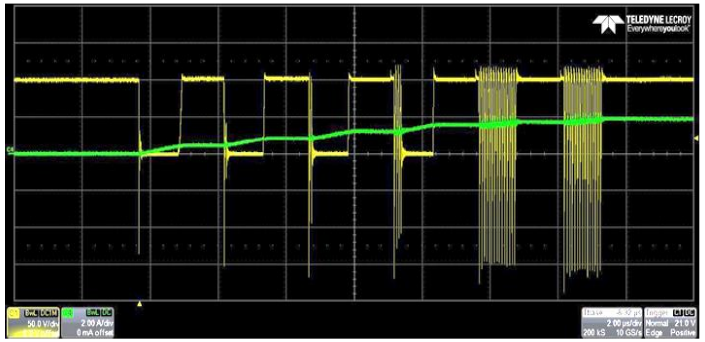
Discrete GaN



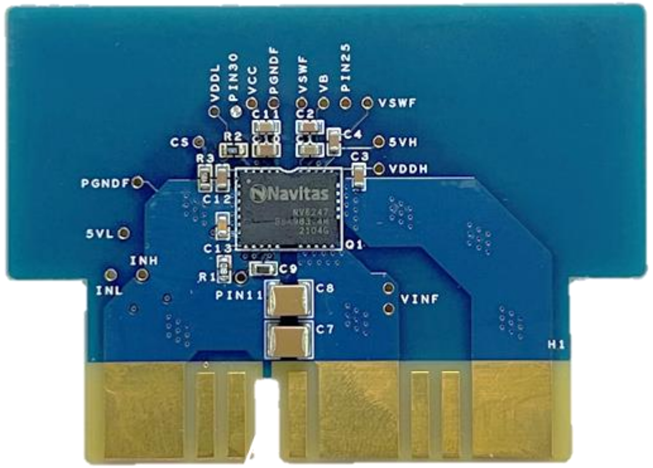
2x Discrete GaN
+28 components



Risky, Erratic, Lossy

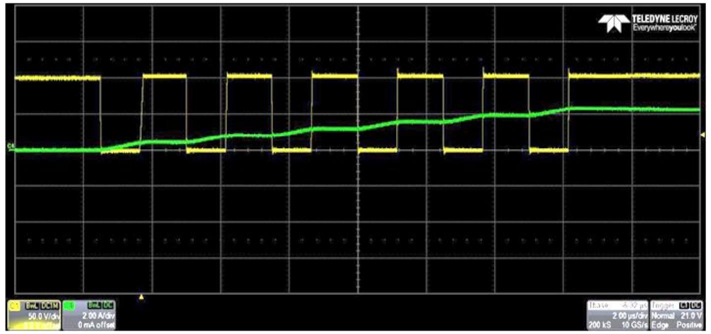
2x fewer components
3x Smaller design
Internal Gate protection
No Gate Ringing

GaNFast IC



1x GaN Power IC
+14 components

1/2 the Components
1/3 the Area



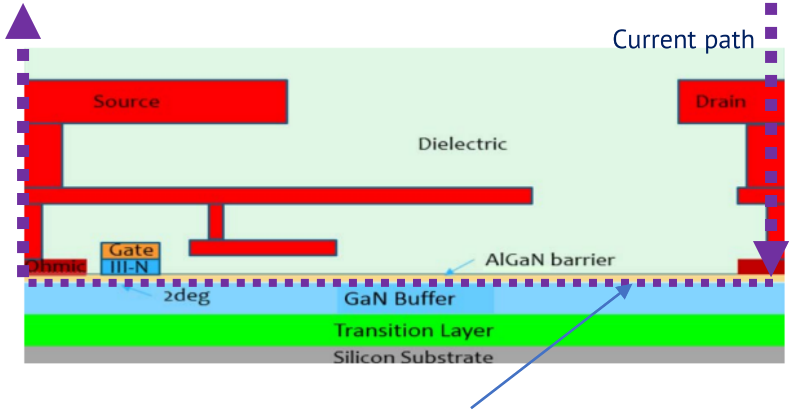
Reliable, Predictable, Efficient

Introduction to GaN Power

Navitas

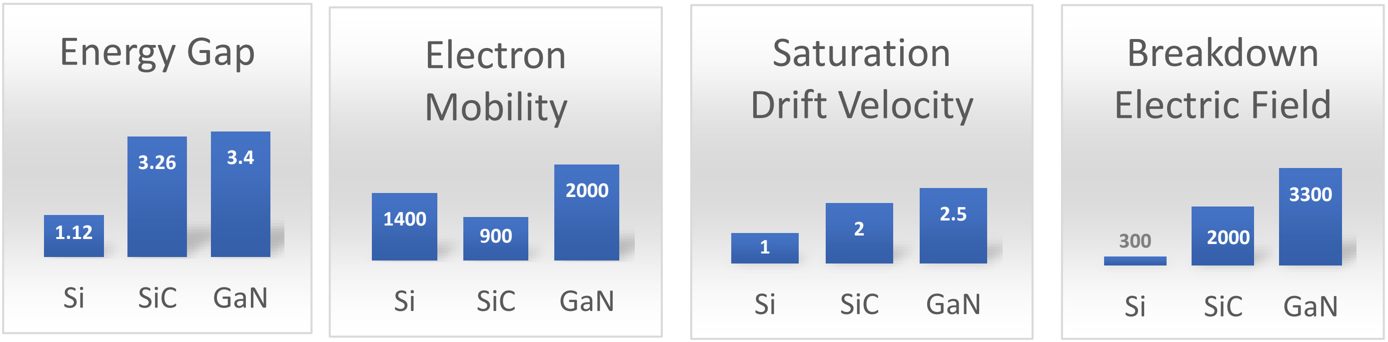
- WBG GaN material allows high electric fields so high carrier density can be achieved
- Two-dimensional electron gas with AlGaN/GaN heteroepitaxy structure gives very high mobility in the channel and drain drift region
- Lateral device structure achieves extremely low Qg and QOSS and allows integration
- Integration on silicon substrates means mature low-cost wafer fabrication is available

GaN HEMT Device Structure



Interface of GaN/AlGaN forms a plane of electrons (2DEG), creating high electron mobility

Technology Comparison



Stable/robust/ low leakage

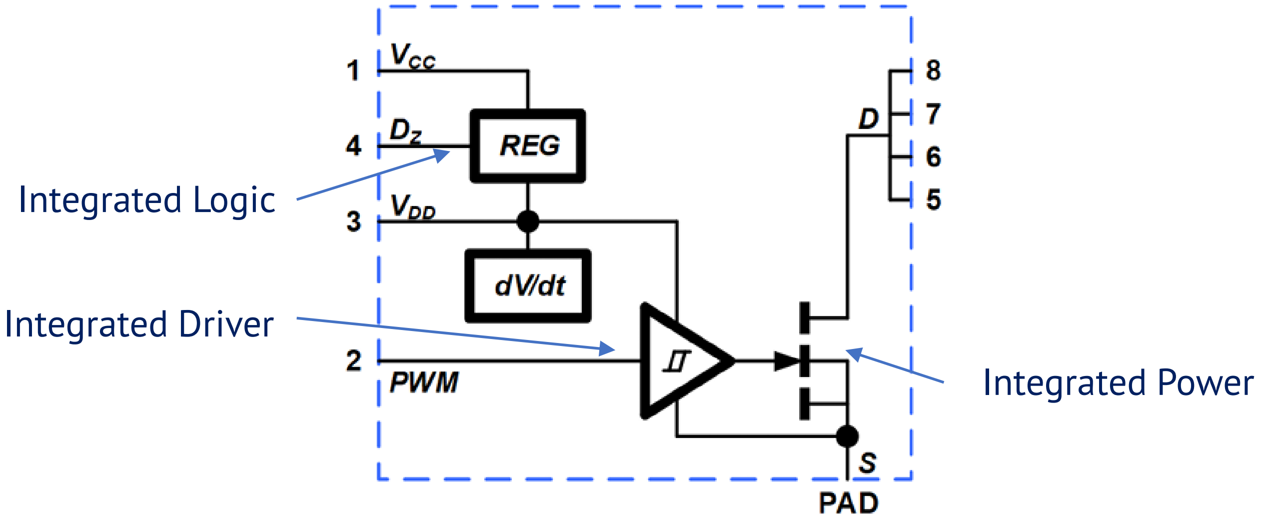
Fastest switching

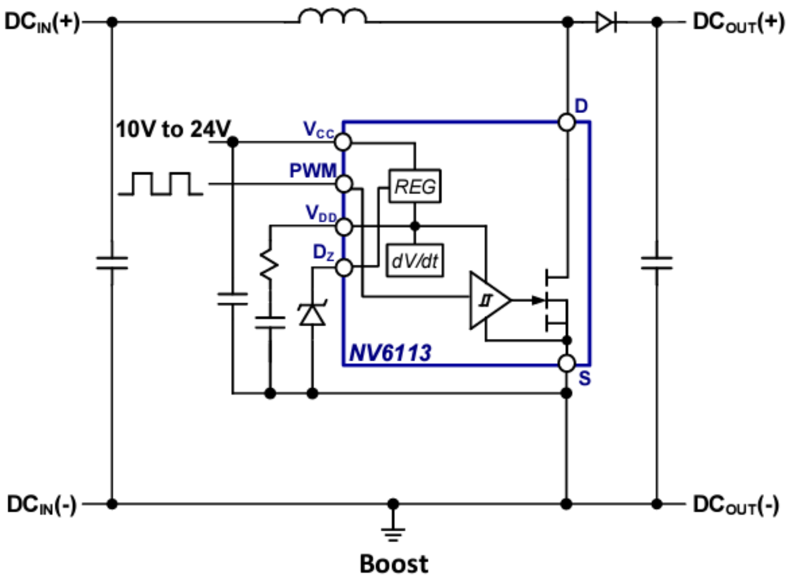
Smaller die

GaNFast Power IC

- Monolithic integration of GaN FET, GaN Driver, GaN Logic
- 650 V eMode power device
- 10x lower drive loss than silicon
- Driver impedance matched to power device
- Short prop delay (10ns)
- Digital input

- Zero inductance turn-off loop
- High dV/dt immunity (200 V/ns)
- Regulated gate voltage
- Controllable turn-on dV/dt
- Rail-rail drive output





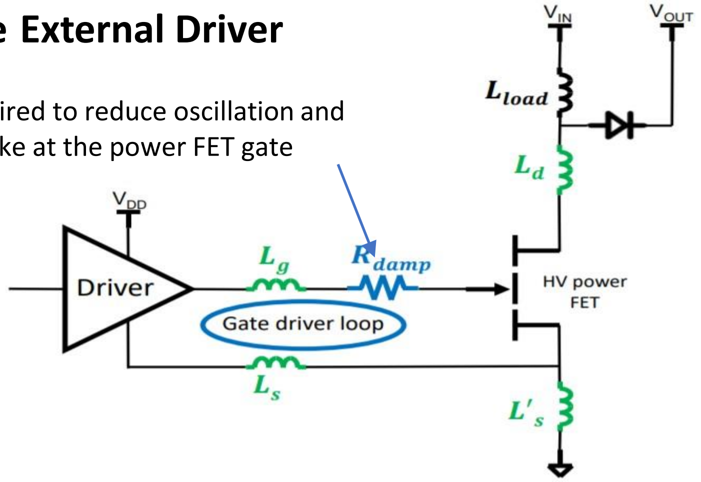
PQFN5x6

GaN Integration for Efficiency, Speed & Stability

Navitas

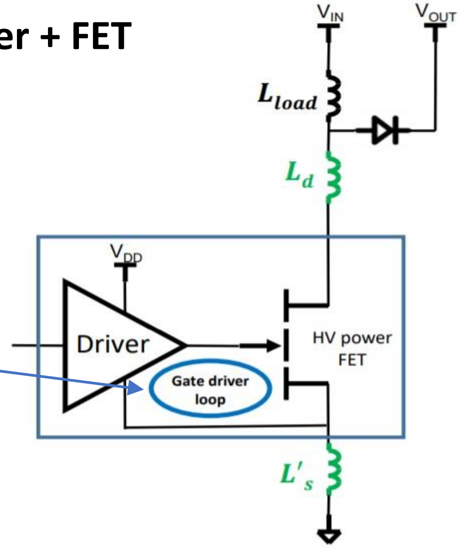
Discrete External Driver

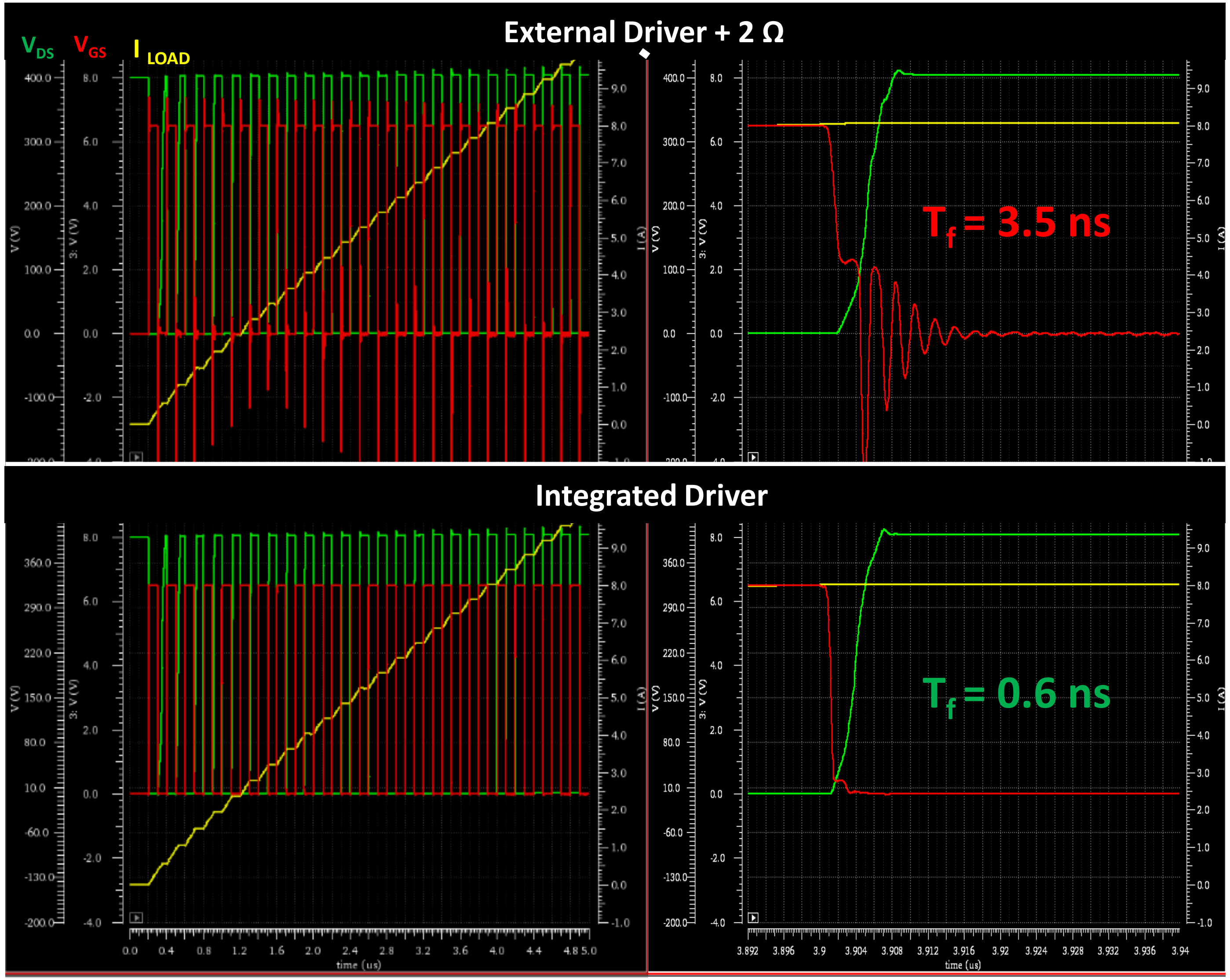
R_{DAMP} required to reduce oscillation and voltage spike at the power FET gate



Monolithic GaN Driver + FET

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

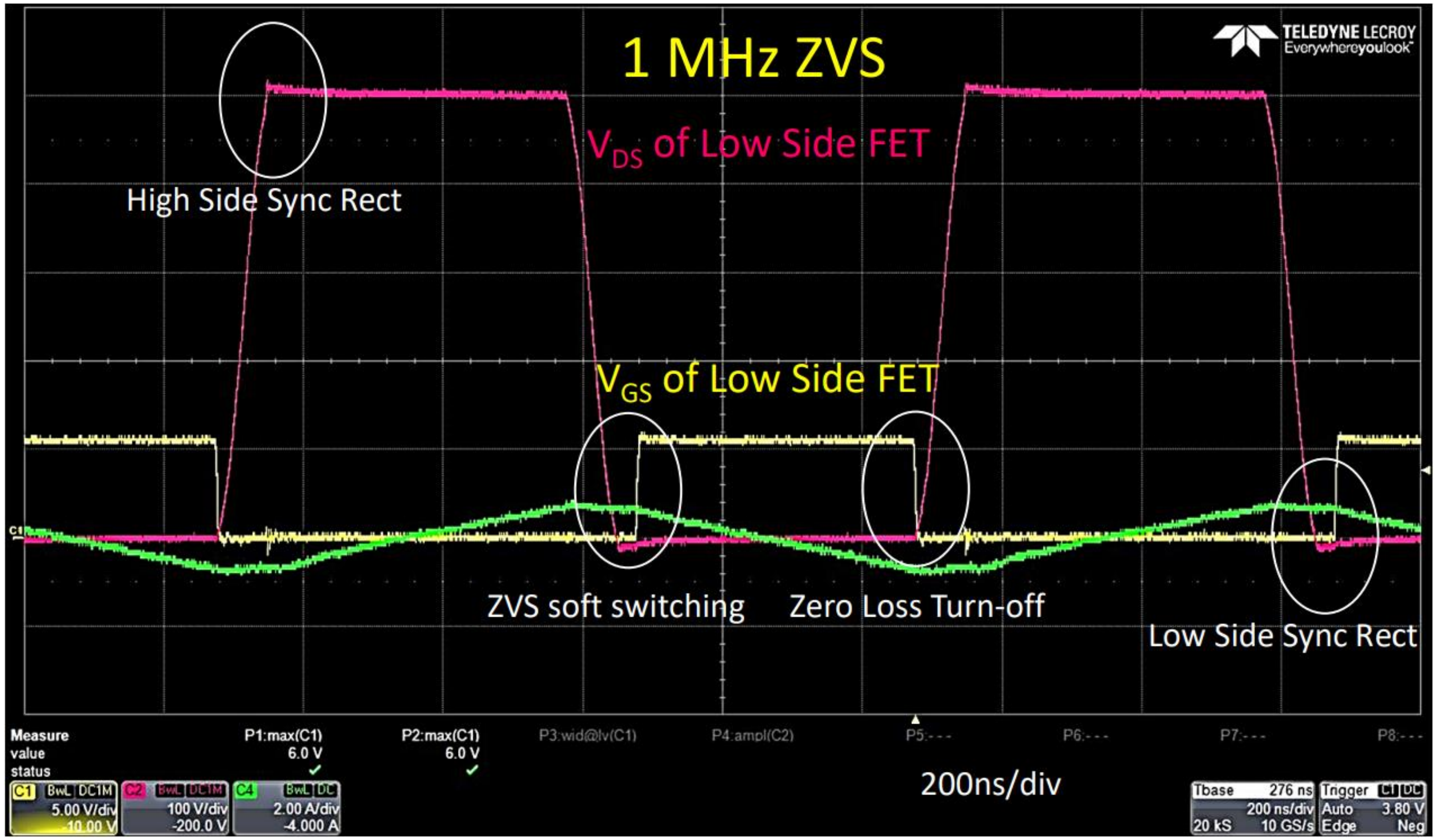




GaNFast: Clean & Efficient

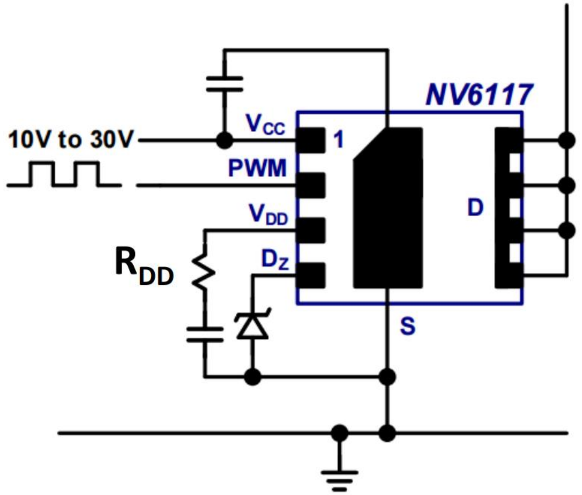
Navitas

- 500 V Switching
- No overshoot / spike
- No oscillations
- ‘S-curve’ transitions
- Zero Loss Turn-on
- Zero Loss Turn-off
- Sync Rectification
- High frequency
- Small, low cost magnetics

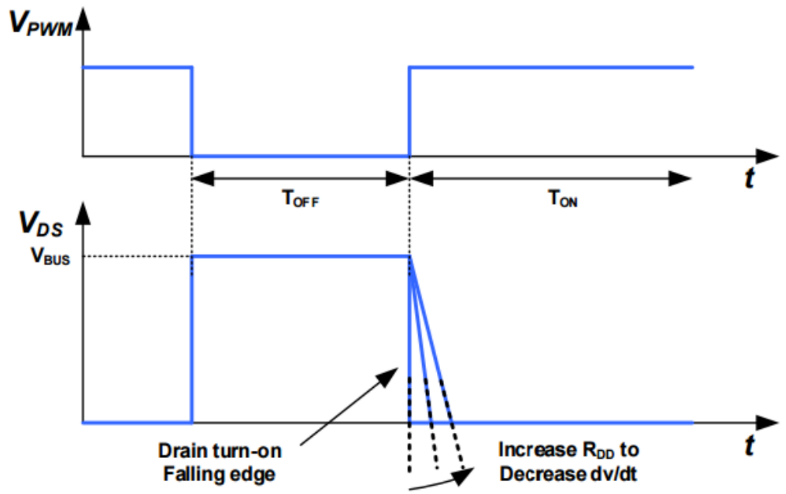


Voltage Slew Rate Control

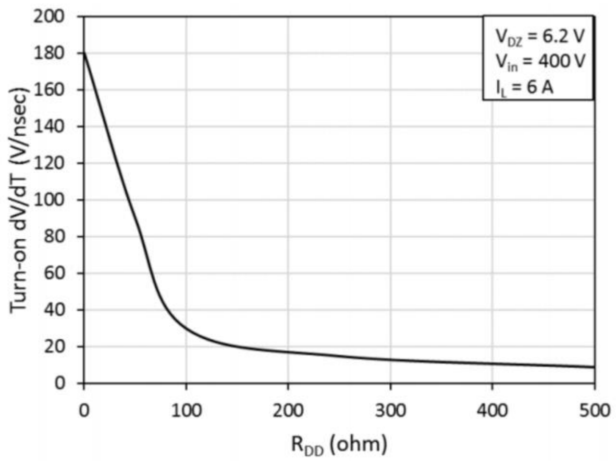
- dV/dt controllable from 180 V/ns to 10 V/ns for EMI optimization



RDD for optimized dv/dt



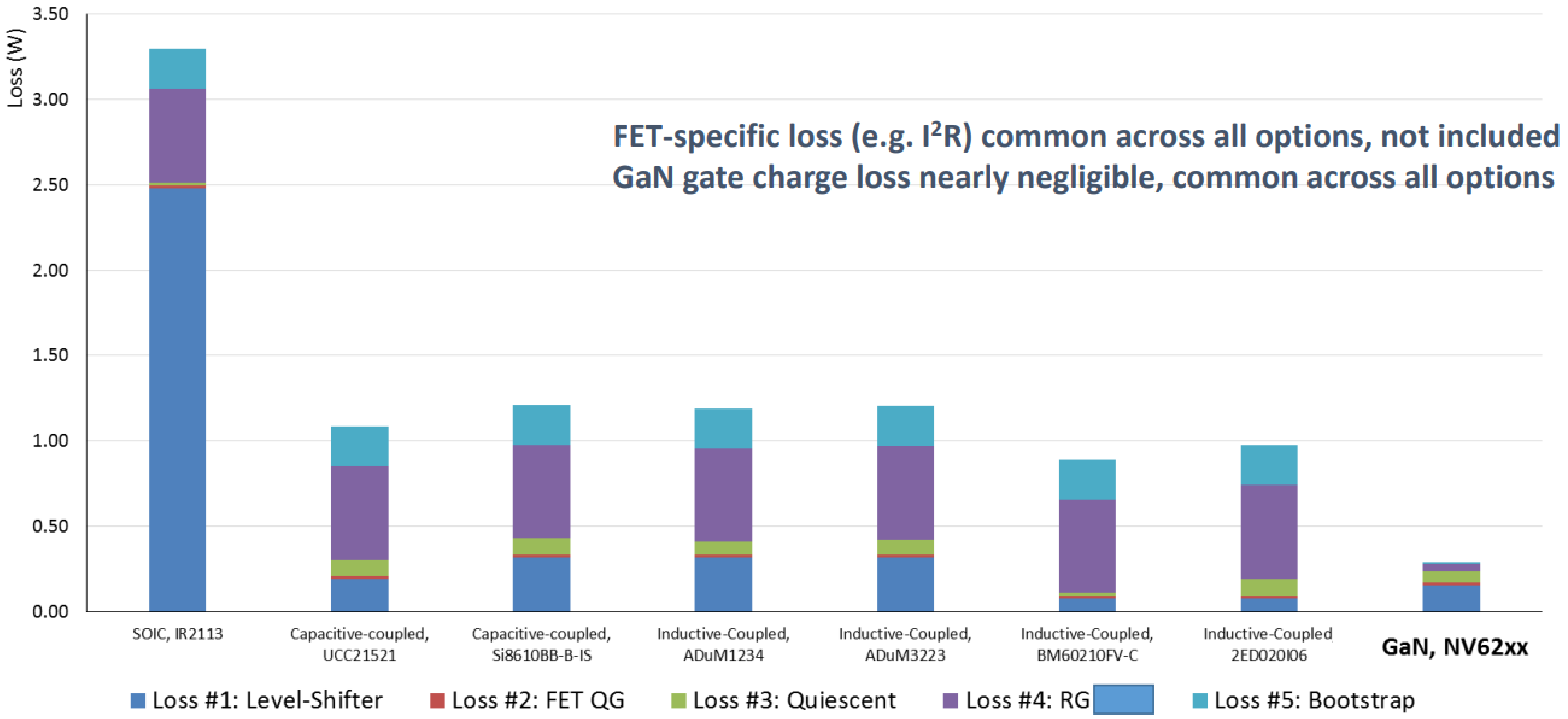
Turn off to support system EMI



Cross reference of RDD vs dv/dt

3x Lower Drive and Level Shift Loss at 1 MHz

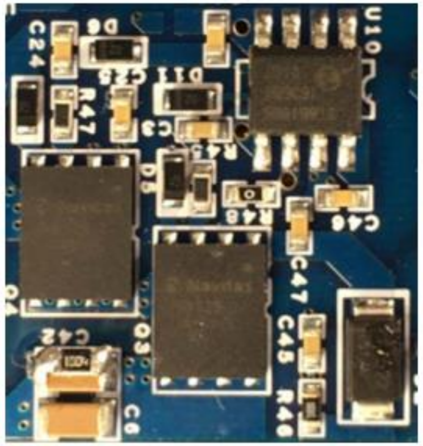
Navitas



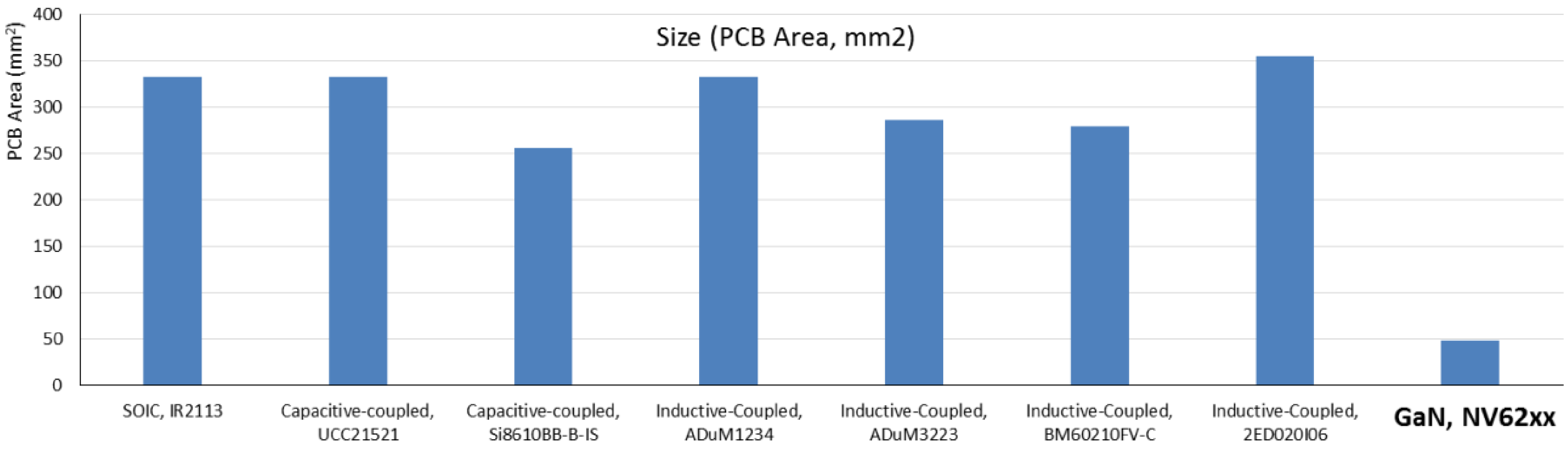
5x Smaller Footprint than Best Single GaN

Navitas

Digital Isolator
2x Single GaN
Power ICs
Bootstrap diode
Passives



Half Bridge GaN
Power ICs 5X smaller
than alternatives

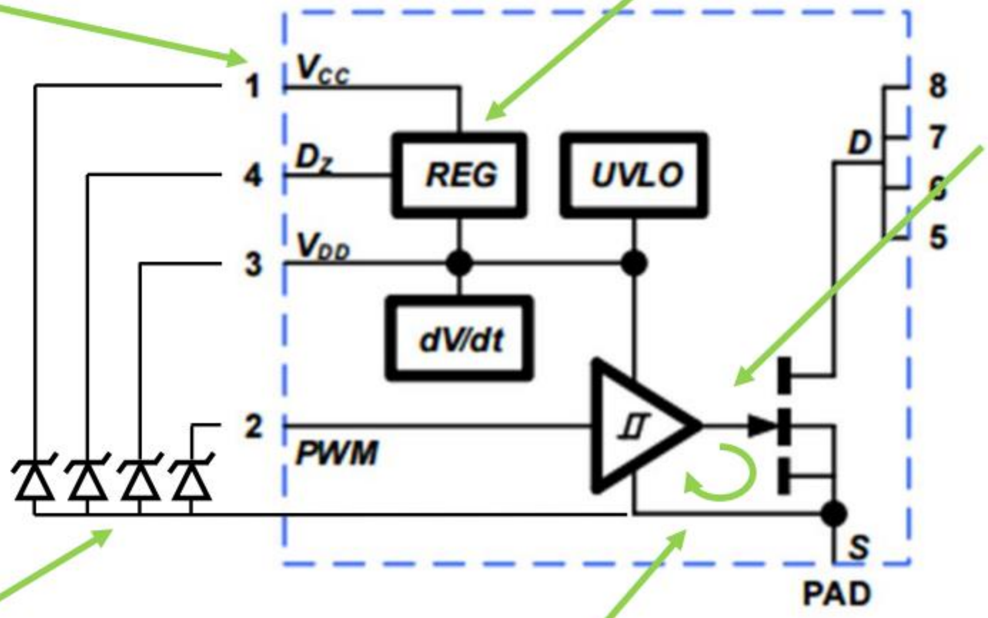


Reliability Benefits

Navitas

V_{MAX} on V_{CC} & V_{PWM} pins have 30 V rating

Built-in regulator precisely controls gate voltage applied to eMode gate



Sensitive eMode gate node protected from system noise and spikes

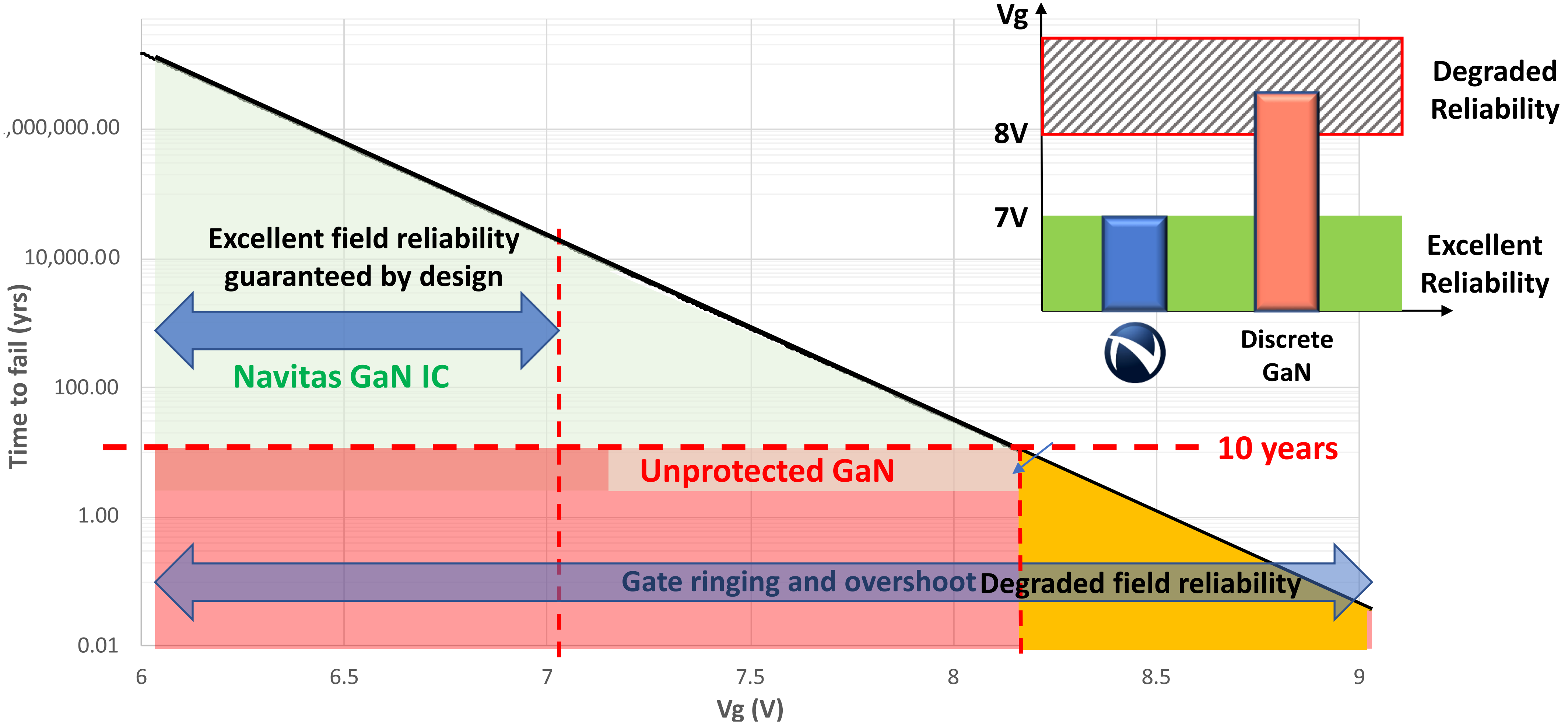
All benefits while delivering the performance advantage of Navitas' GaN Power ICs!

ESD protection integrated into all pins (>1000 V HBM, >1000 V CDM)

Eliminates parasitic inductance, turn-off losses, and false turn-on of eMode gate

Precise Gate Voltage = Excellent Reliability

Navitas

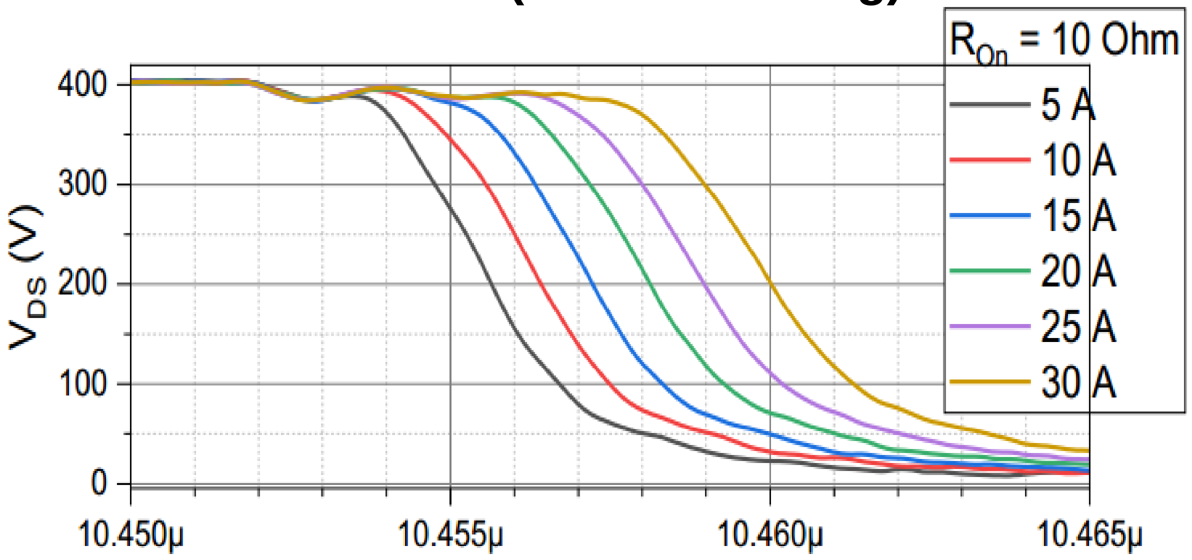


- Patented integrated regulator circuit guarantees operation with >>10+ years of estimated life
- Integrated driver eliminates parasitic inductance, delivers precise gate drive and maintains device within SOA

"Best Semiconductor Switch We've Tested!"

Navitas

Turn-on (Hard Switching)



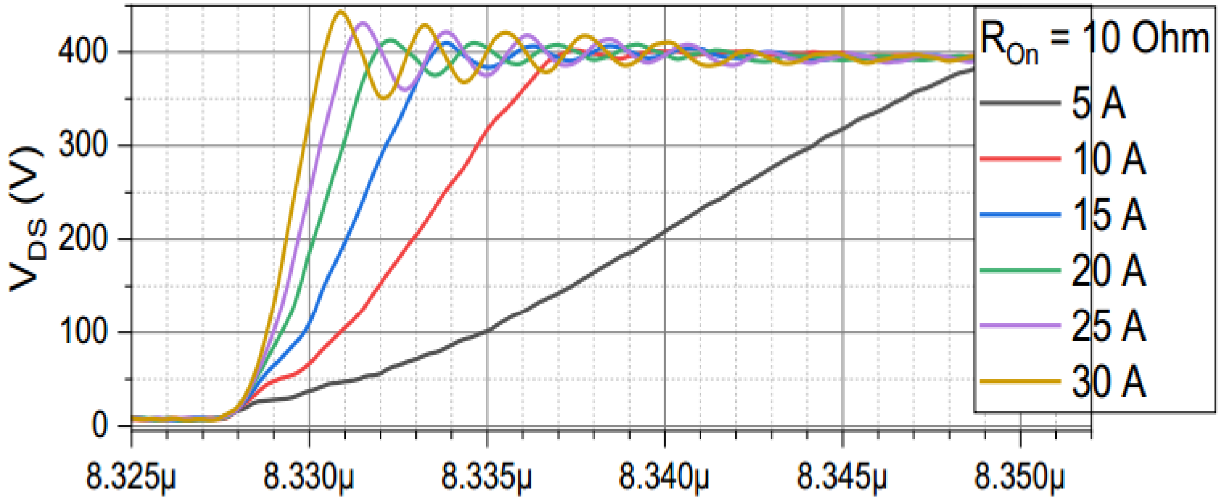
Partner Feedback:

"Fast and very clean switching"

"Easy to control slew rates"

"Integrated gate allows fast switching" (dV/dt > 200 V/ns, di/dt >10 A/ns)

Turn-off (Hard Slewing)



Partner Feedback:

"Protected gate removes external parts without restricting switching speeds"

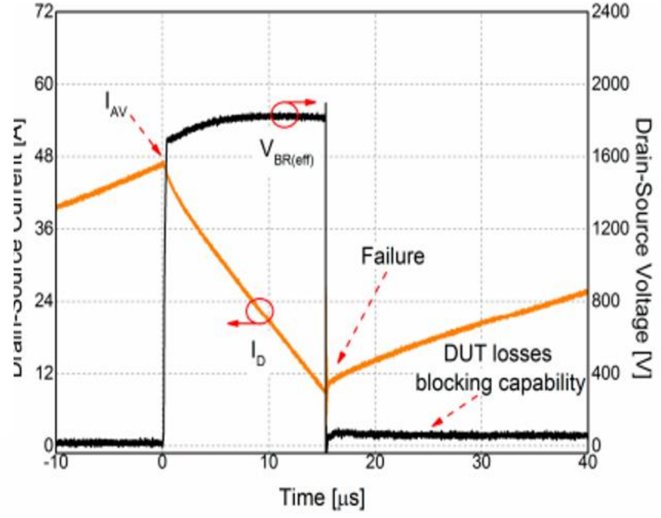
"Minimal ringing optimizes EMI"

"No gate-loop risks"

Voltage-Surge Testing

Navitas

Si Avalanche Testing



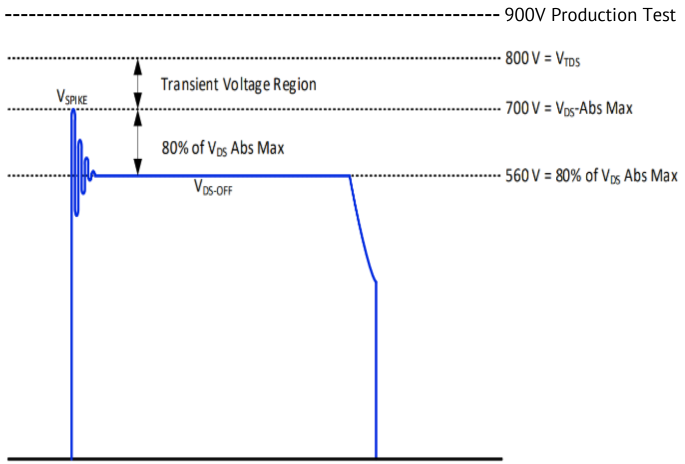
- Voltage limited by Avalanche
- Large energy loss during over-voltage
- Usually tested only once at final test
- Repetitive avalanche can lead to failure

Navitas GaN Surge Testing

100µs pulse width, V_{DS} = 800 V

- 3,600,000,000 spikes and zero failures!
- Negligible loss during overvoltage
- No RDS(ON) shift
- No IDSS shift

Integrated Drain Reliability



Flyback Voltage Waveform

- Large drain voltage design margin
- 800V transient rating
- 900V production test

Reliable: Double-Pulse Test

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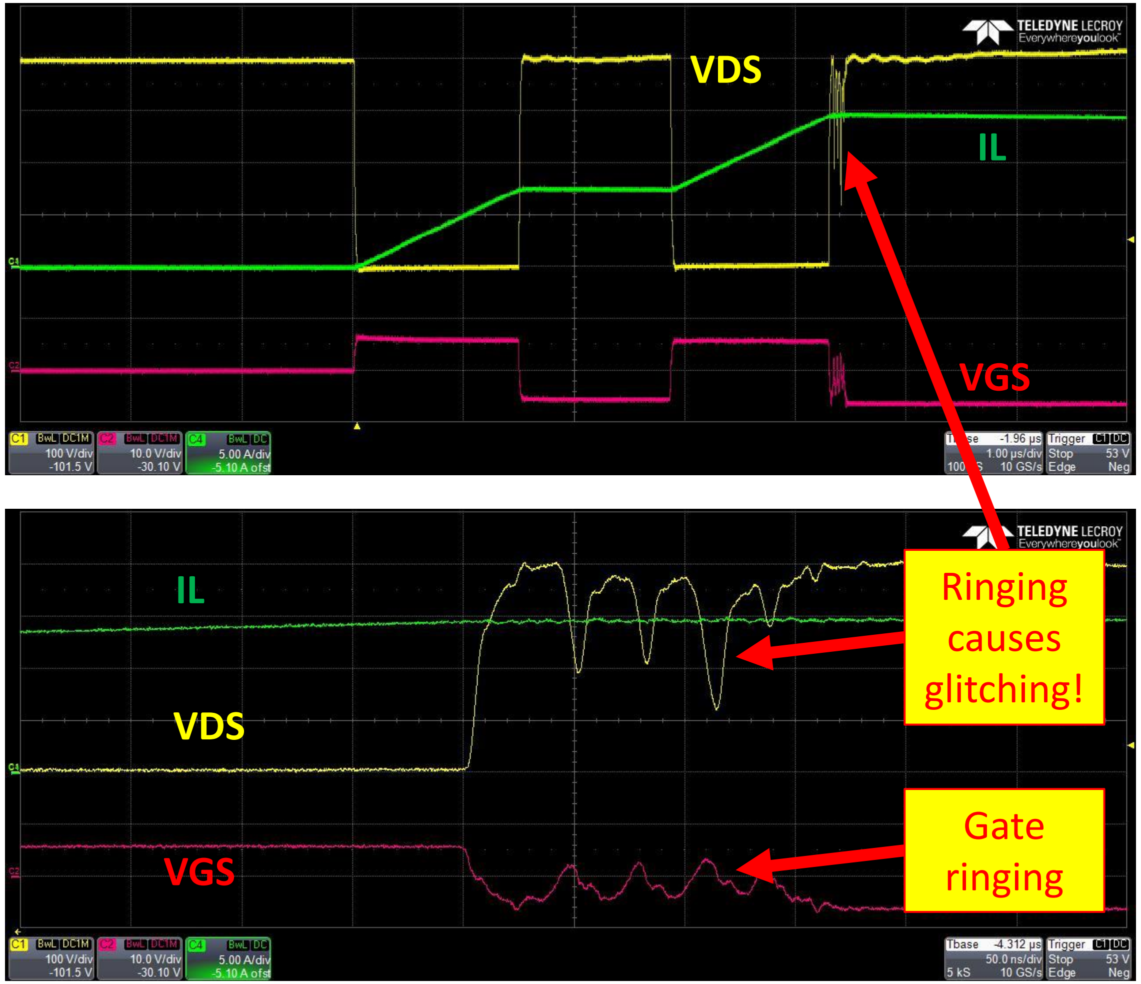
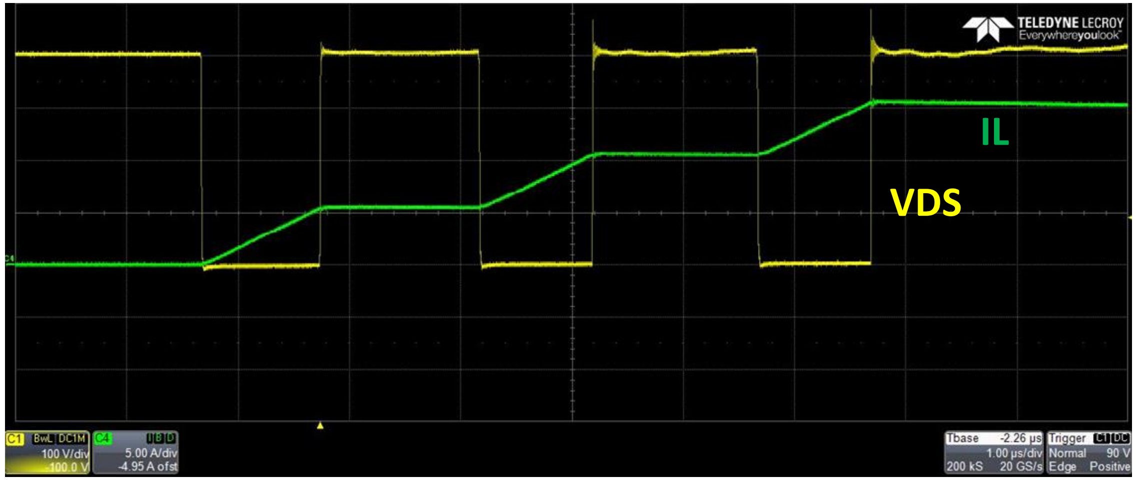
Discrete GaN



GaNFast with GaNSense Technology

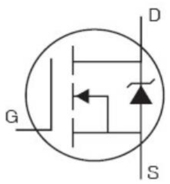


- **Clean switching, no ringing and no glitching**

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

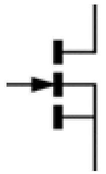
GaNFast Evolution

Silicon FET



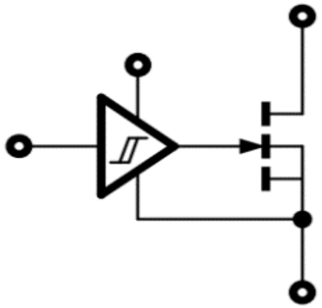
- Old, slow technology
- High Qg
- High Coss
- Fsw < 100kHz

Discrete GaN



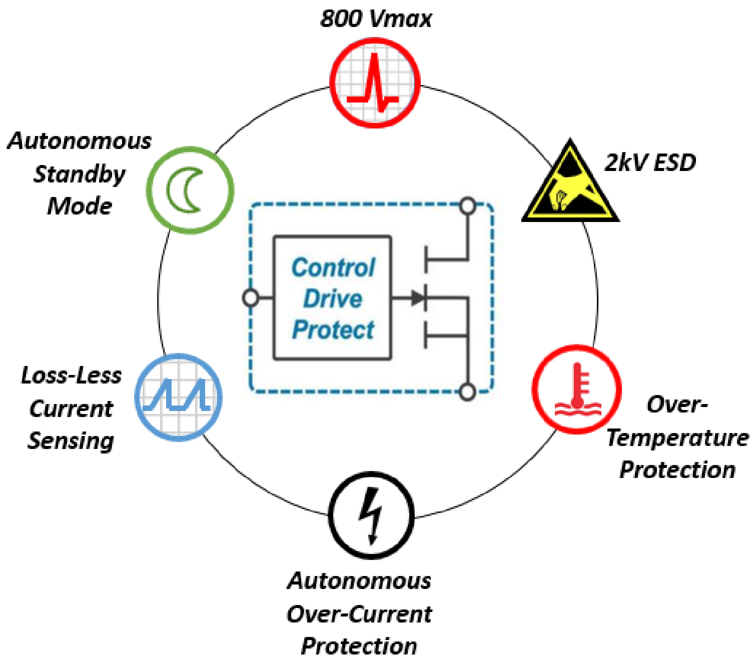
- Exposed gate
- External gate drive
- dV/dt sensitivity
- Layout sensitivity
- ESD sensitivity
- Unknown reliability
- Unknown robustness

GaNFast™



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

GaNFast™ with GaNSense™

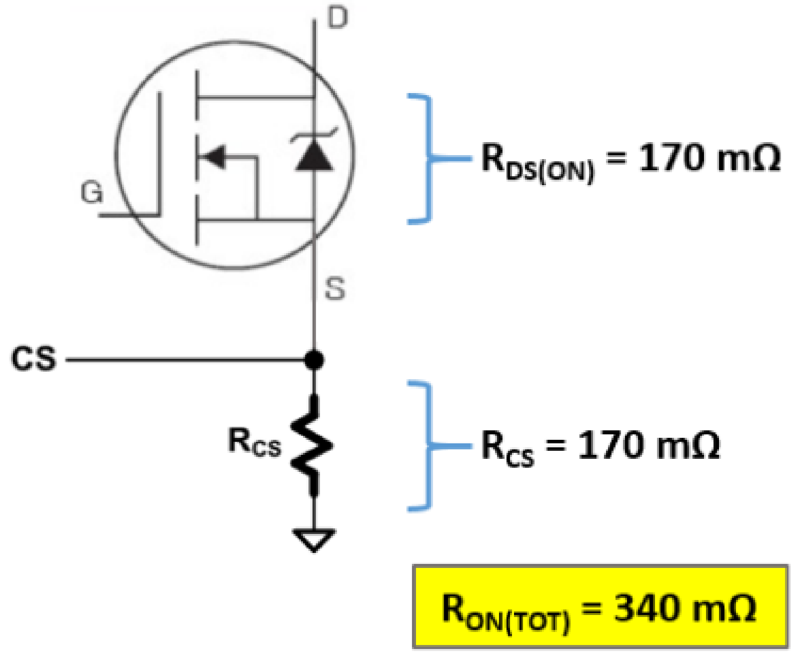


- ✓ Autonomous Standby
- ✓ Autonomous Protection
- ✓ Loss-less Current Sensing
- ✓ High Precision
- ✓ High Efficiency

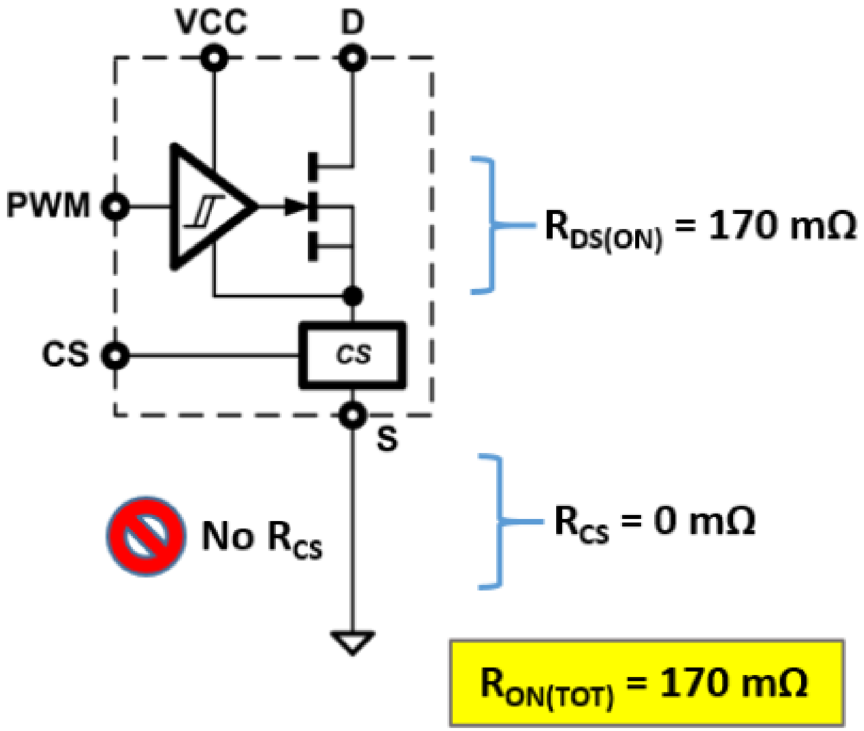
Navitas

Loss-Less Current Sensing: Why?

External Resistor Sensing Method



GaNSense™

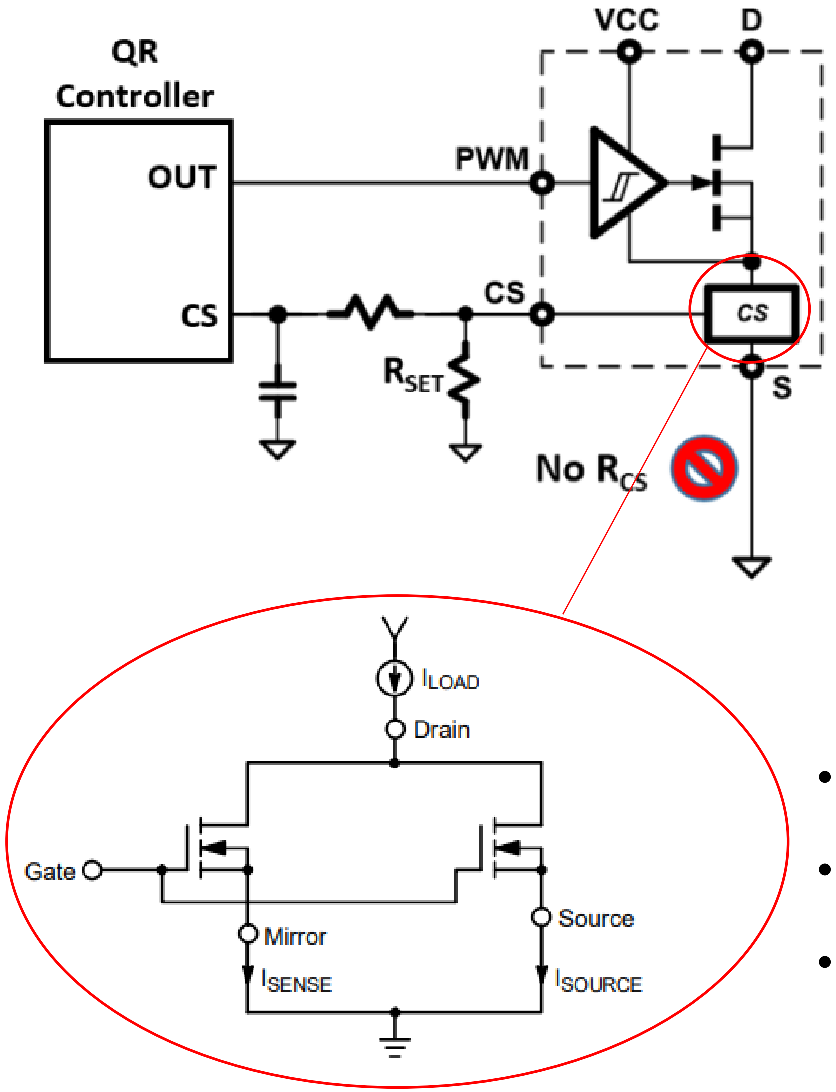


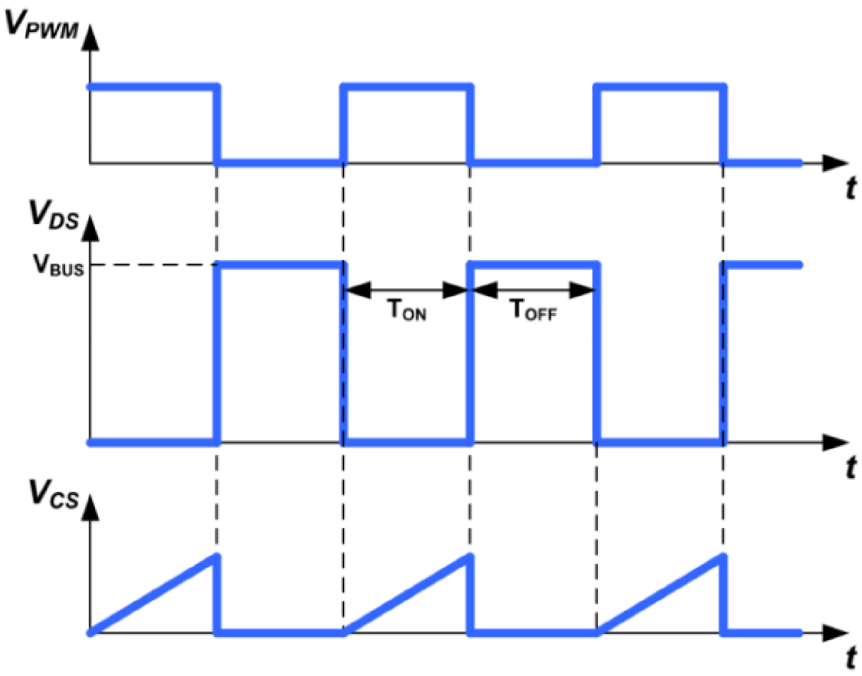
- Reduce $R_{DS(ON)\_TOTAL}$ by 50%
- Efficiency increased +0.5%

- No R_{CS} PCB hotspot (-85°C)
- No R_{CS} PCB footprint (-30 mm^2)

GaNSense™

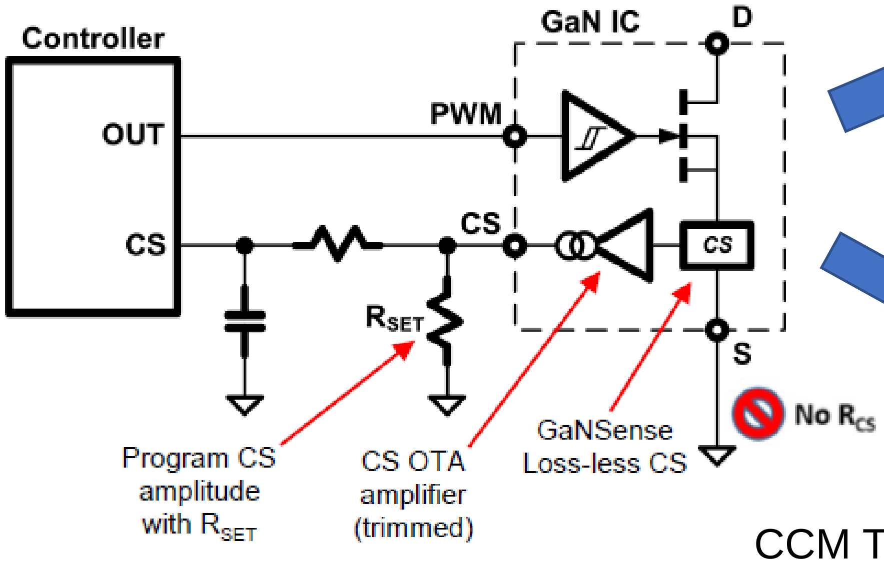
Loss-Less Current Sensing: How?



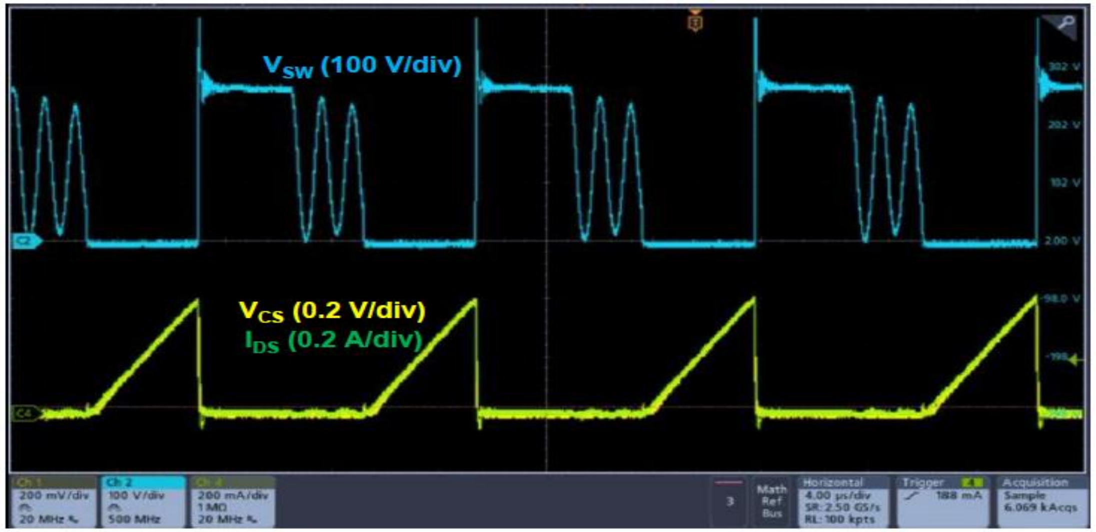


- Integrated sense-FET accurately measures through various techniques.
- $R_{DS(ON)}$ and temperate affects are cancelled out naturally.
- Power loss is negligible, especially compared to shunt resistors

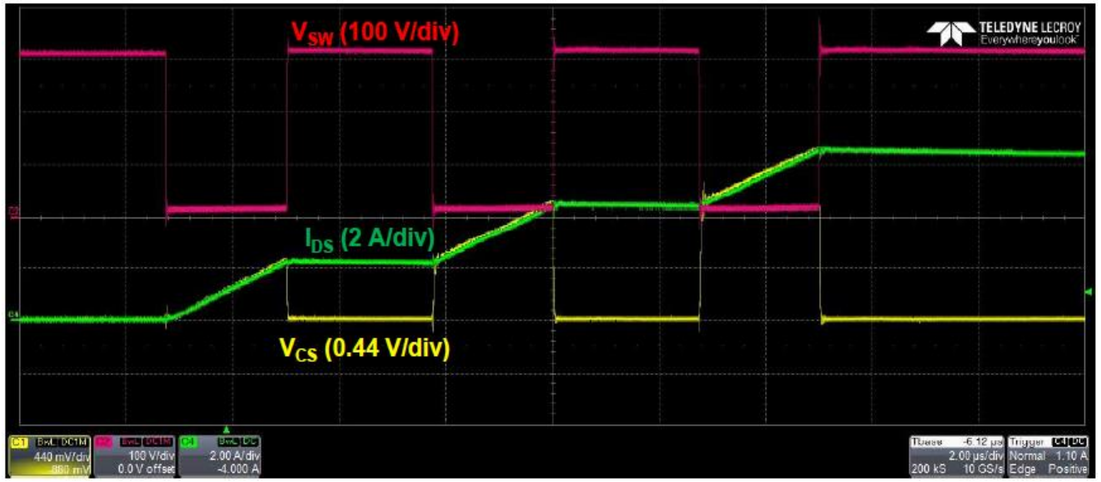
Lossless Current Sensing – Details



DCM Tracking
Example @ 192KHz



CCM Tracking
Example @ 200KHz



The Efficiency Benefit

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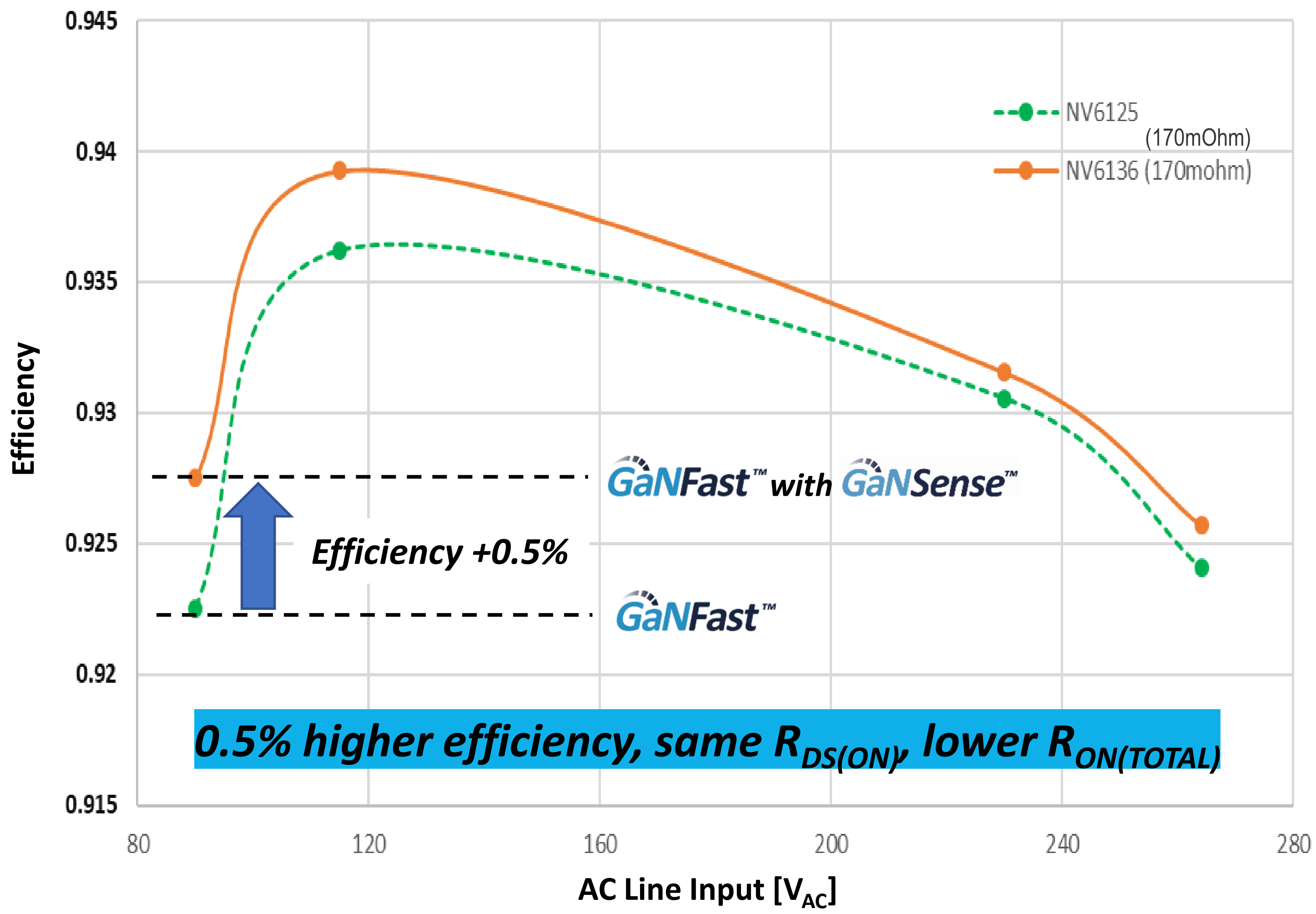
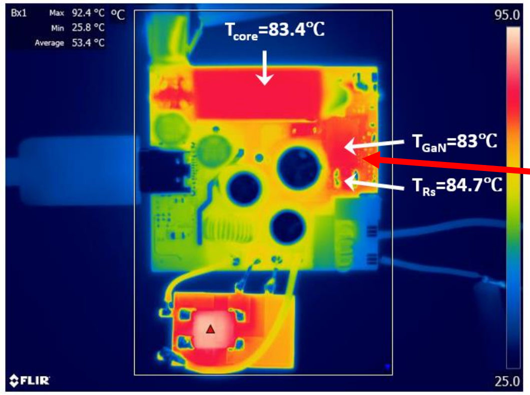
Efficiency (60W HFQR, 20V/3A)



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

GaNFast™

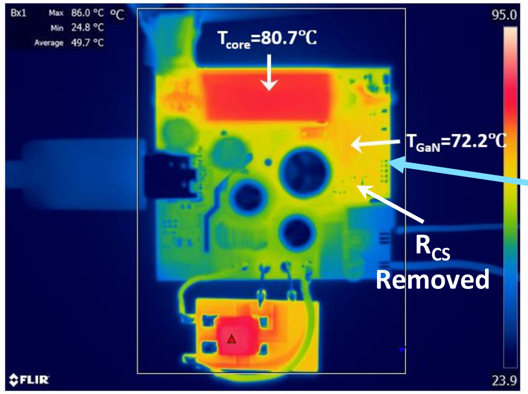


NV6125

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

R_{CS} HOT-SPOT = 85°C!

GaNFast™ with GaNSense™



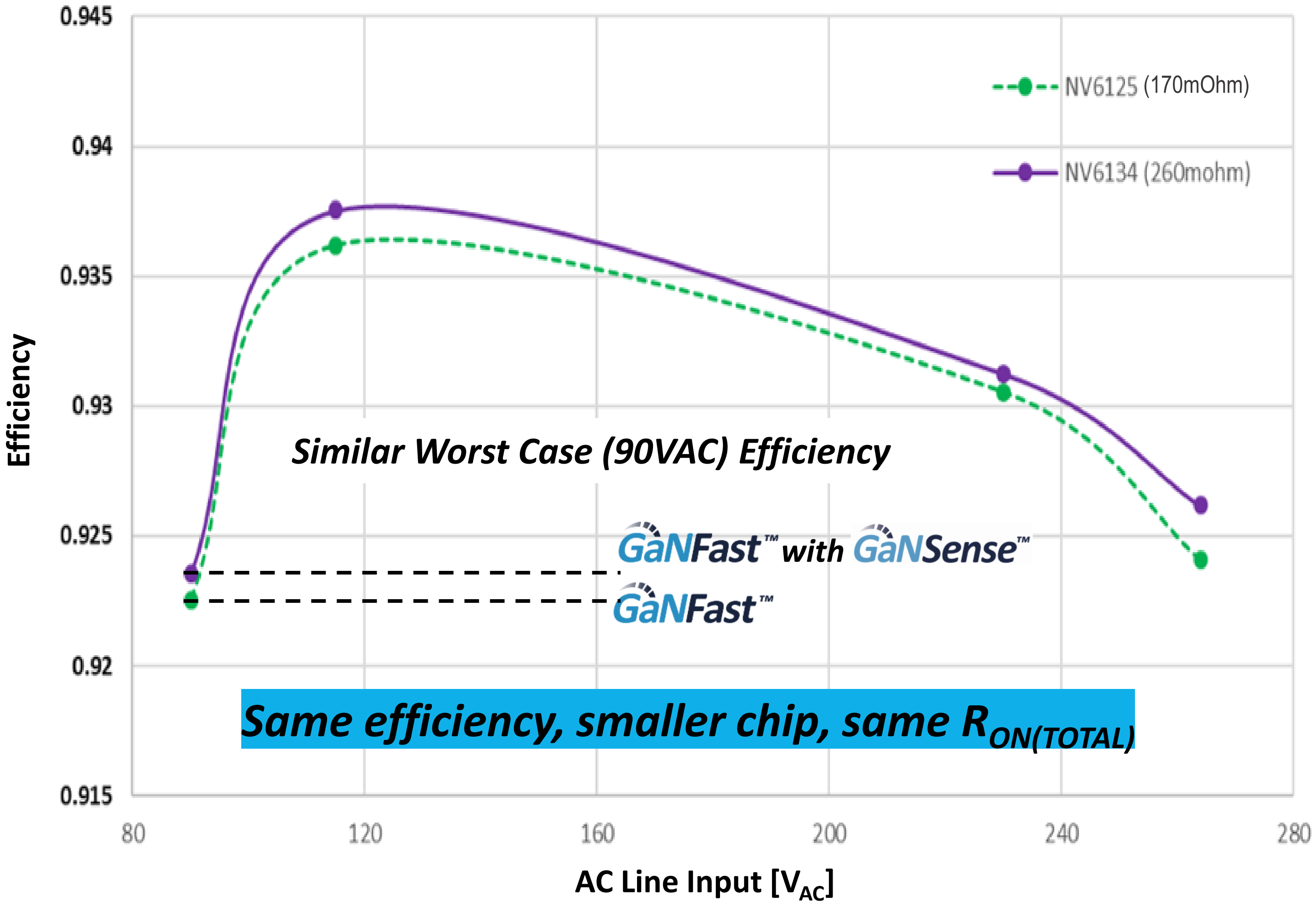
NV6136

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

NO HOT-SPOT
T_{GaN} 10°C Cooler

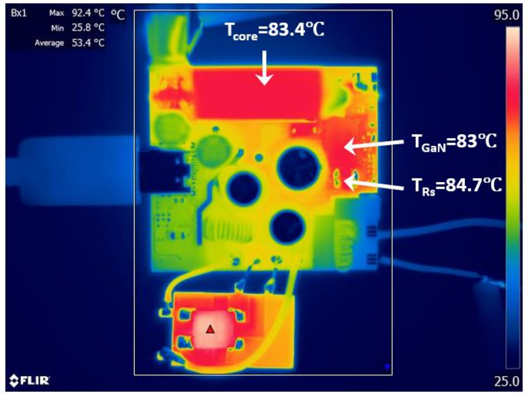
The Efficiency Benefit

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



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

GaNFast™

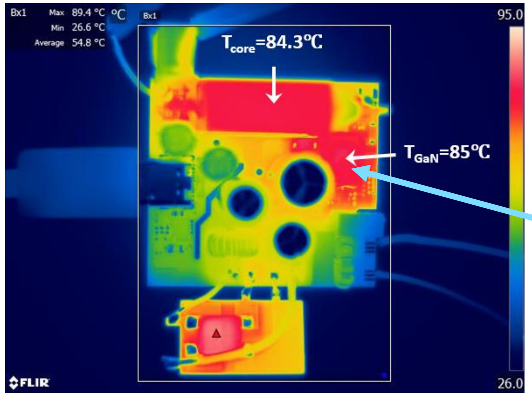


NV6125

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

T_{GAN} = 83°C

GaNFast™ with GaNSense™



NV6134

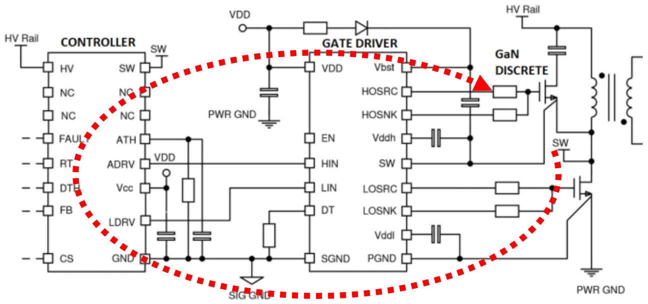
$R_{DS(ON)}$ = 260 mΩ
R_{CS} = 0 mΩ
$R_{ON(TOT)}$ = 260 mΩ

No R_{CS}
T_{GAN} = 85°C

Autonomous Over-Current Protection (OCP)

Navitas

Discrete GaN Solution

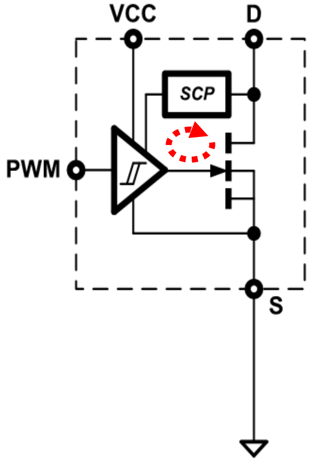


Uses QR controller OCP function

T_{OCP} = 180 ns

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

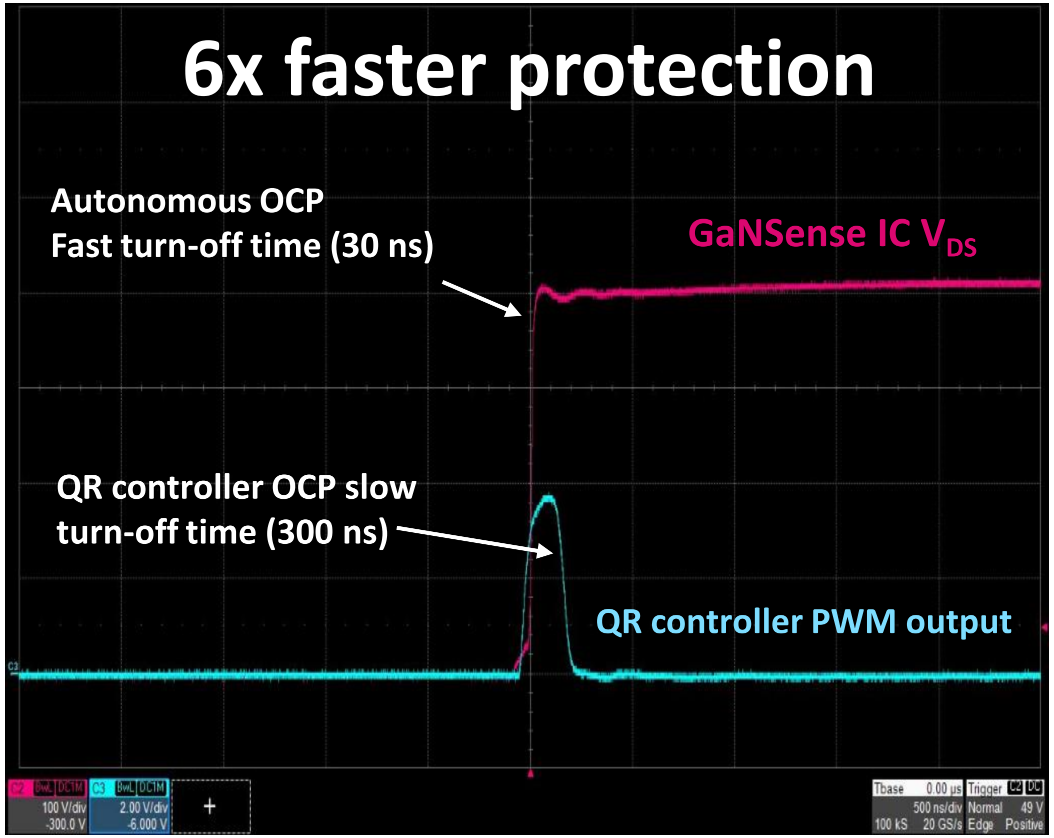
GaNFast™ with GaNSense™



Integrated SCP function

T_{OCP} = 30 ns

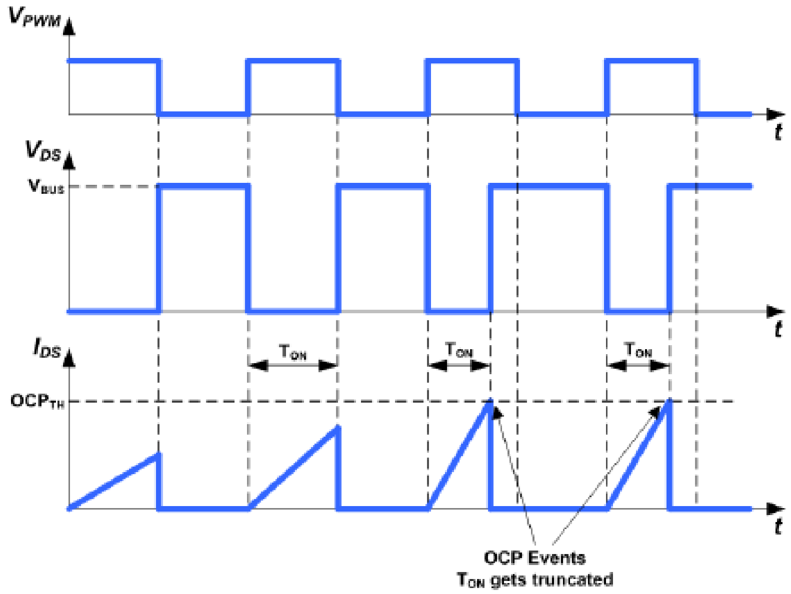
- *Autonomous OCP*
- *Fast-acting self-protection*
- *Cycle-by-cycle protection*
- *Excellent robustness*



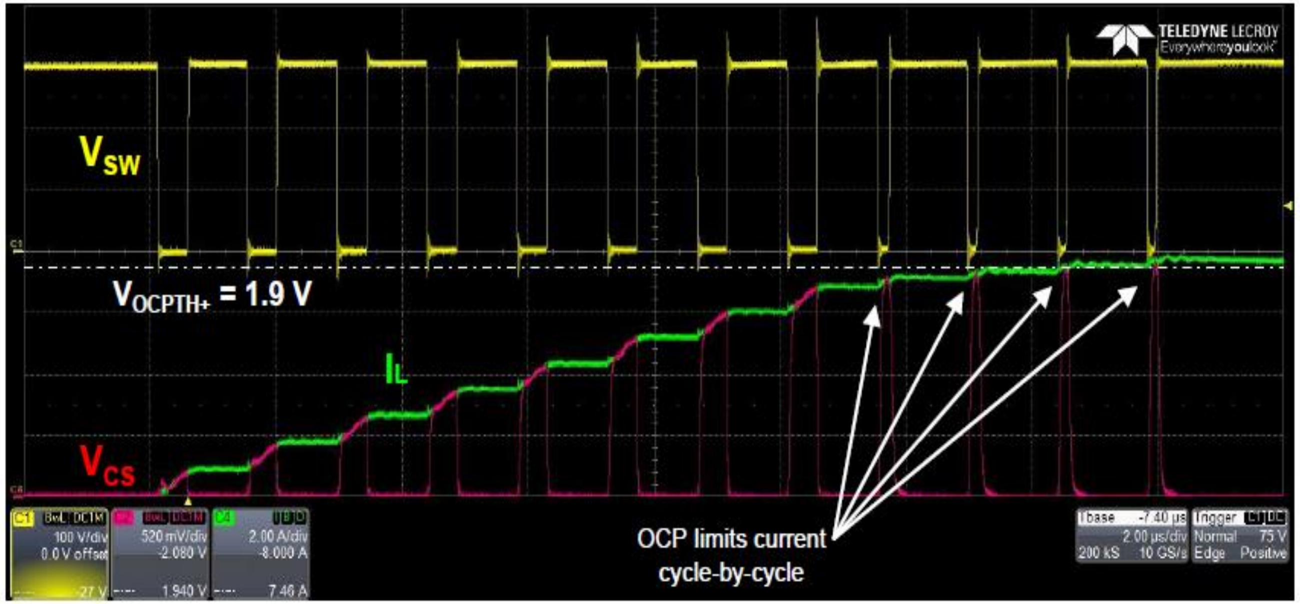
- *QR controller OCP = slow turn-off (180 ns)*
- *NV6136 OCP = fast turn-off (30 ns)*

Autonomous Over-Current Protection (OCP)

Navitas



Over Current Protection DCM Timing Diagram



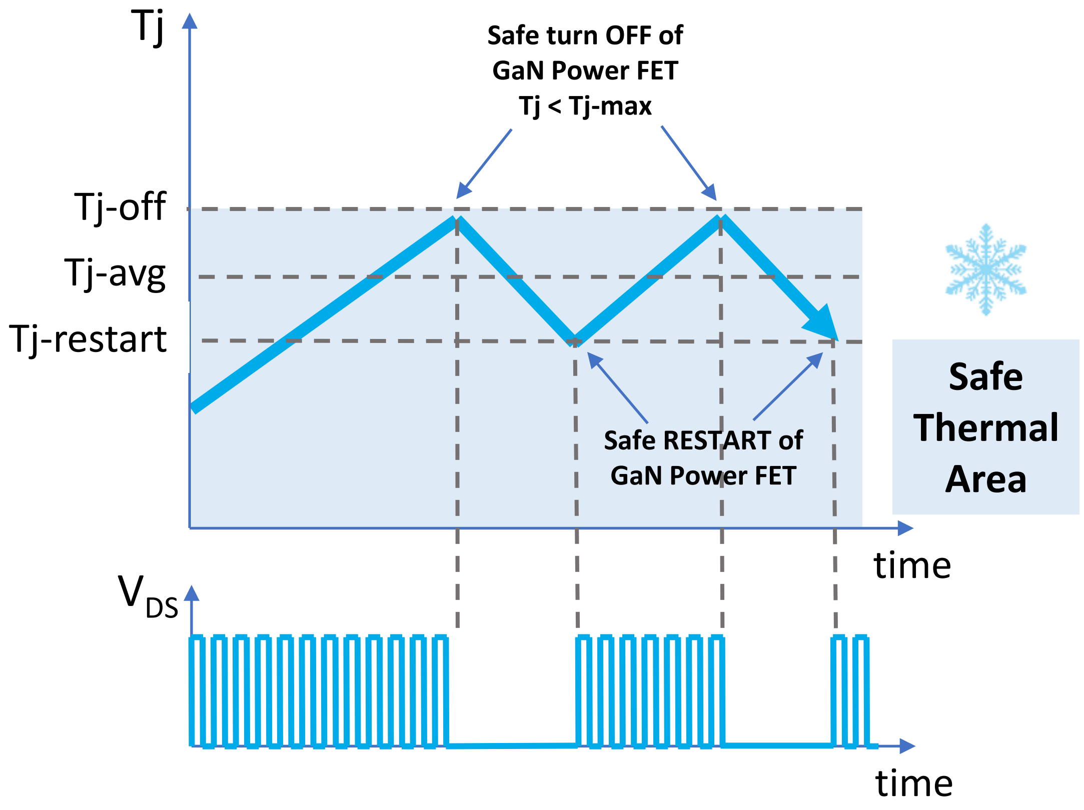
Cycle by cycle over current protection in CCM boost configuration

- On any given cycle, if the CS output voltage exceeds 1.9V, the internal gate driver will turn off the GaN IC and truncate the on-time.
  - **OCP response time 30ns!** Compare to ~200ns response if relying on most conventional controllers.
- The current at which the IC protects is dependent on the I_{DRAIN}→ I_{CS} ratio and the value of R_{SET}.
- Turn-on OCP blanking time prevents noise from triggering the fault and is optimized for GaN FET protection.
- This protection mechanism is designed to be accurate and user programmable via R_{SET}.

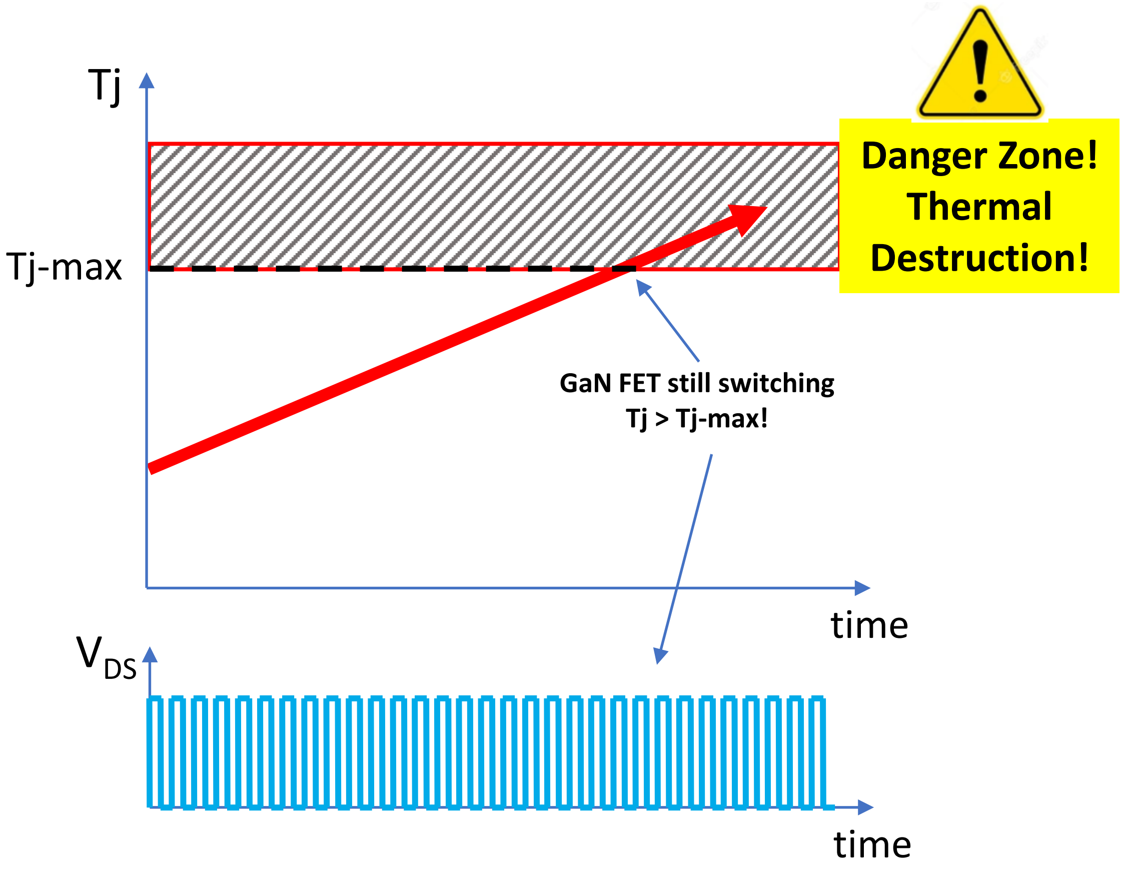
Over Temperature Protection

Navitas

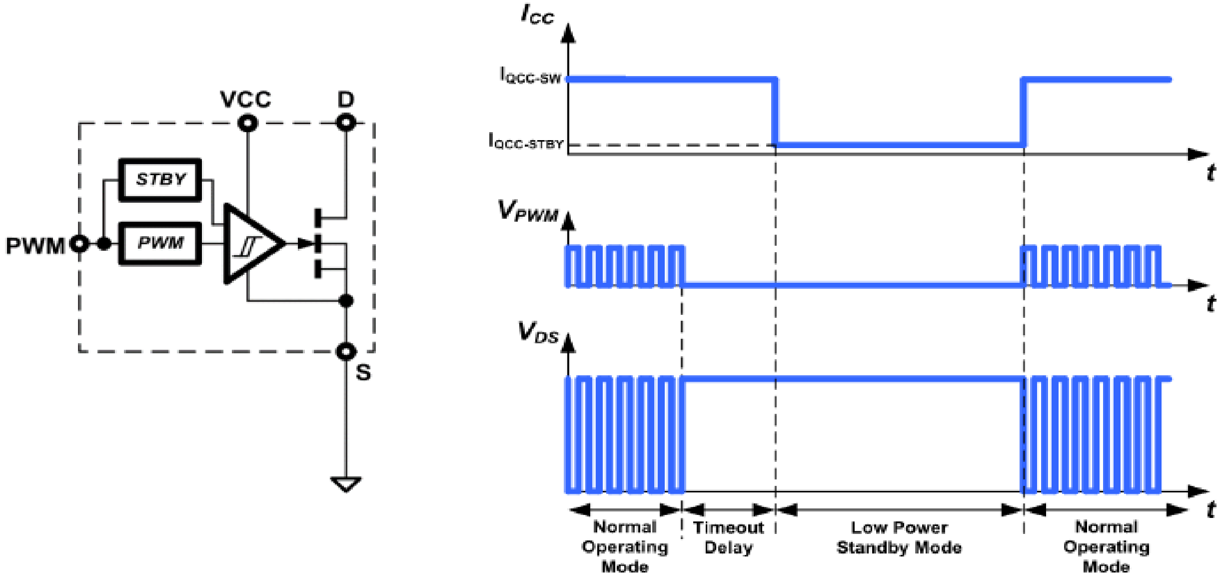
GaNSense IC w/OTP



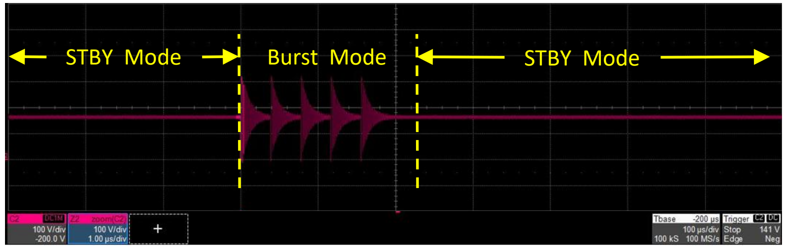
Unprotected GaN



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).

GaNSense Mass Production: 65W

Navitas

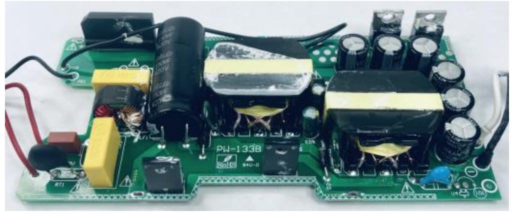
Lenovo YOGA

Charger Power, Output(s)	65W 2CA	65W 2C	
			
Powertrain	Discrete GaN	GaNFast IC with GaNSense	
Size (cc)	105	75	30% smaller
Power Density (W/cc)	0.6	0.9	50% higher
Efficiency (%)	89.15%	92.50%	3.4% higher
Loss (W)	7.1	4.9	30% energy savings
Drive, Protection Components	19	5	75% fewer
PCB Area (mm^2)	83	15	80% smaller
T_{CASE} max (°C)	85°C	<77°C	8°C cooler

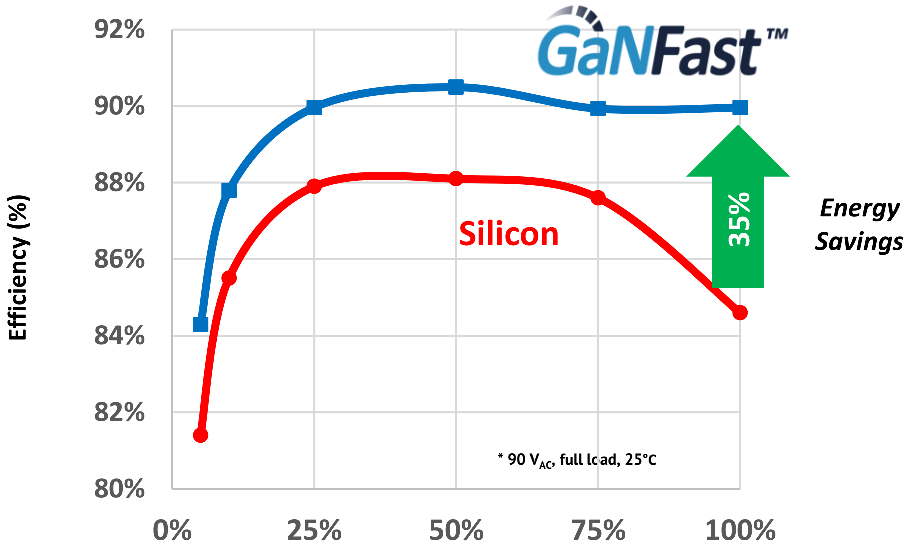
120W GaNFast with GaNSense

Navitas

Si 120W 19V



Asus 120W (PA-1121-28)
84.6%* peak
332 cc, 419 g
0.36 W/cc

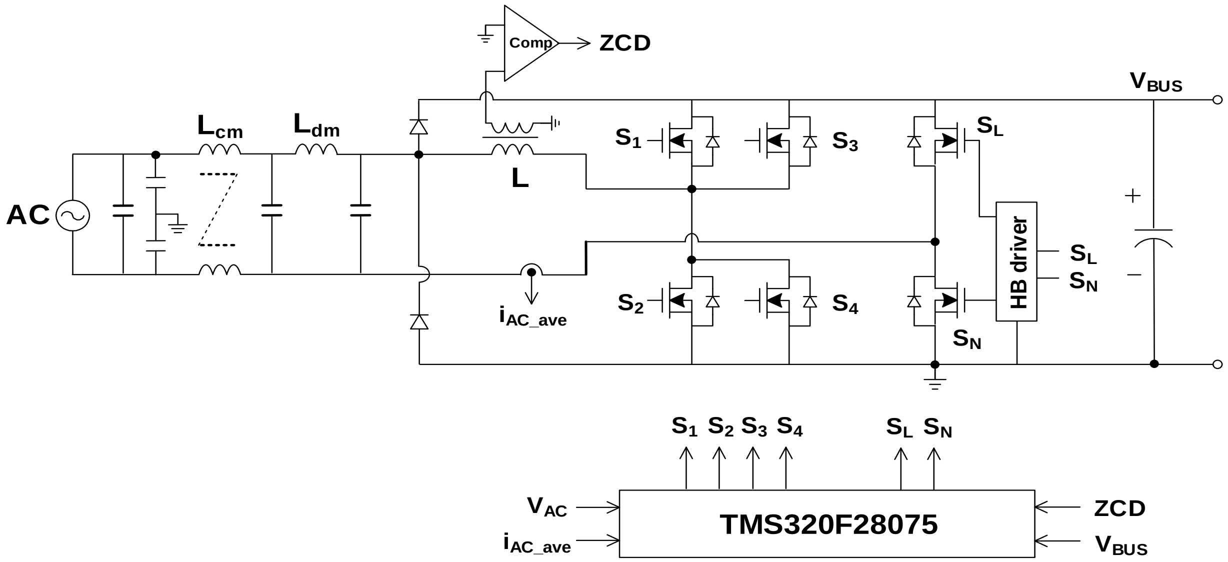


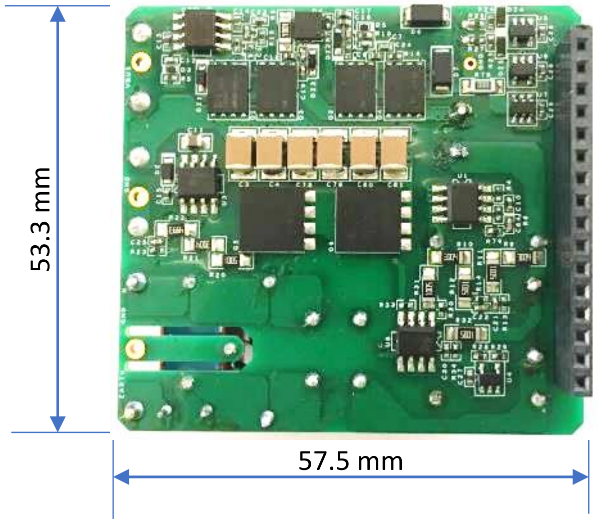
35% lower power losses
6% system efficiency improvement
~4x smaller system size

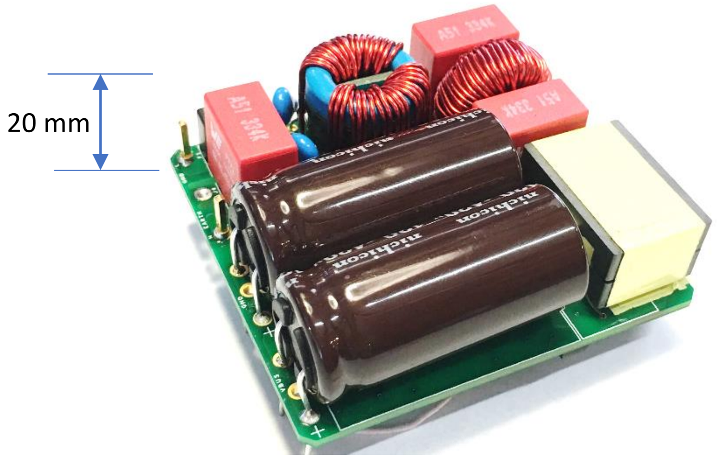
GaN 120W USB-C PD

Xiaomi 120W Note 11 Pro
90.5%* peak
87.5 cc, 147 g
1.37 W/cc

300W Totem-Pole PFC





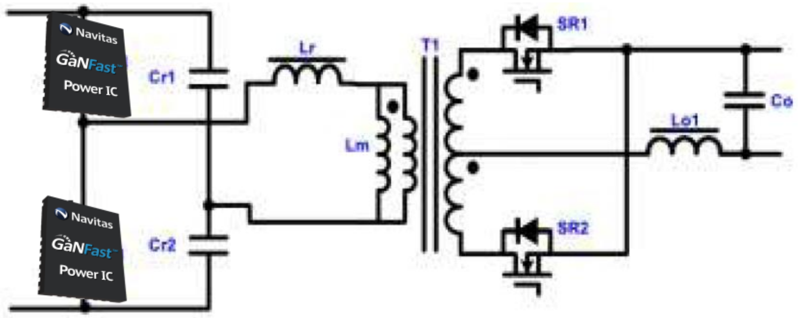


Input	Universal AC (85-265V_{AC}, 47-63Hz)
Output	400V (300W)
Fast FETs	NV6117 (110mΩ) GaN Power ICs
Slow FETs	Si Superjunction (62mΩ)
Freq	300-1,200 kHz
Size	53.3 x 57.5 x 20 mm = 62 cc uncased *(DSP controller board not included)*
Power Density	4.9 W/cc (80 W/in^3) uncased
Target Efficiency	98.5% @ 220V_{AC}, 98% @ 110V_{AC}, 97.5% at 90V_{AC}, full load

Dr. Weijing Du, Navitas

1kW HV DC-DC

- 97.8% Efficiency, 800kHz
- 400 VDC_{IN} , $48V_{OUT}$
- HB LLC

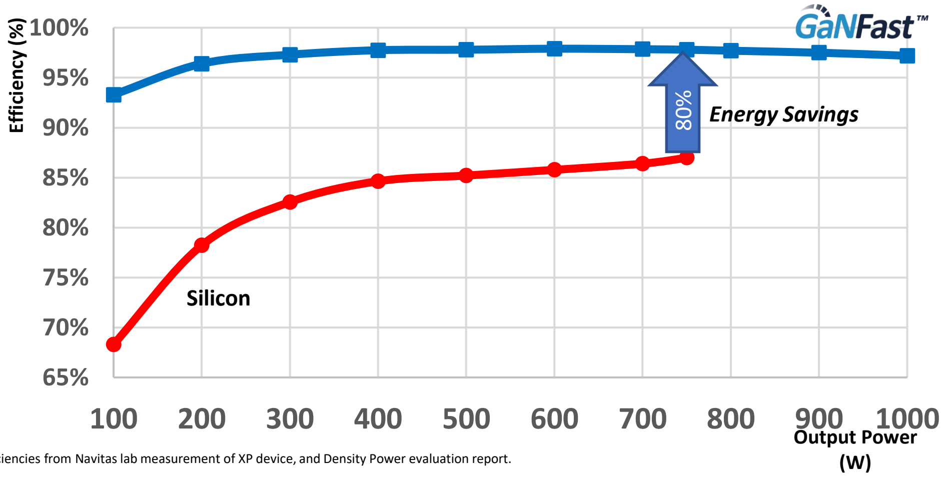


GaNFast™
(NV6128)

4x Smaller, 80% Energy Savings, 33% More Power

Silicon 750W
(XP QHL750300S48)
200 kHz, 92% peak
116.8 x 61 x 12.7 = 90 cc
8 W/cc

GaN 1 kW
(Density Power DQB1K0F380S48)
850 kHz, 97.7% peak
58.4 x 36.8 x 14.5 mm = 31 cc
32 W/cc

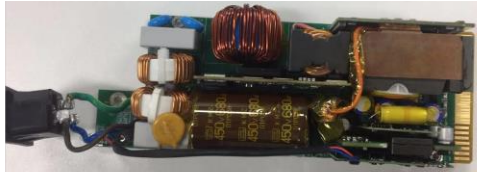


Efficiencies from Navitas lab measurement of XP device, and Density Power evaluation report.

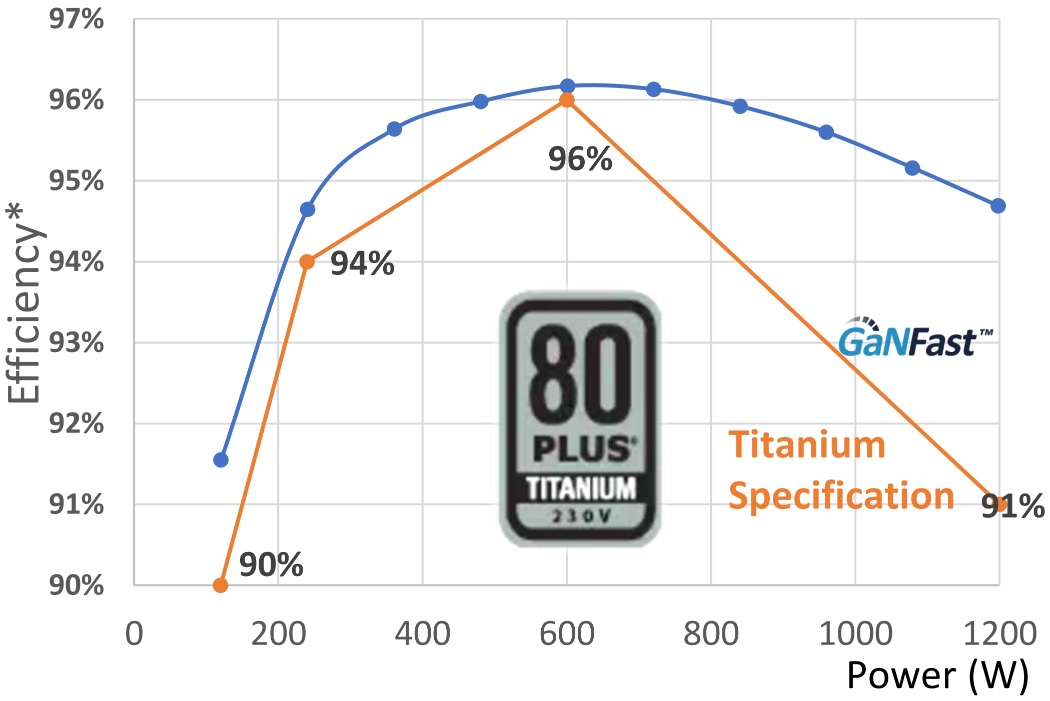
1.2kW CPRS

Navitas

- Designed by Navitas Data Center Design Center
- >96% Efficiency for Titanium grade
- Cased 185 x 73.5 x 39 mm (530 cc)
- Power Density: 2.6 W/cc



Exceeds EU 'Titanium' efficiency grade

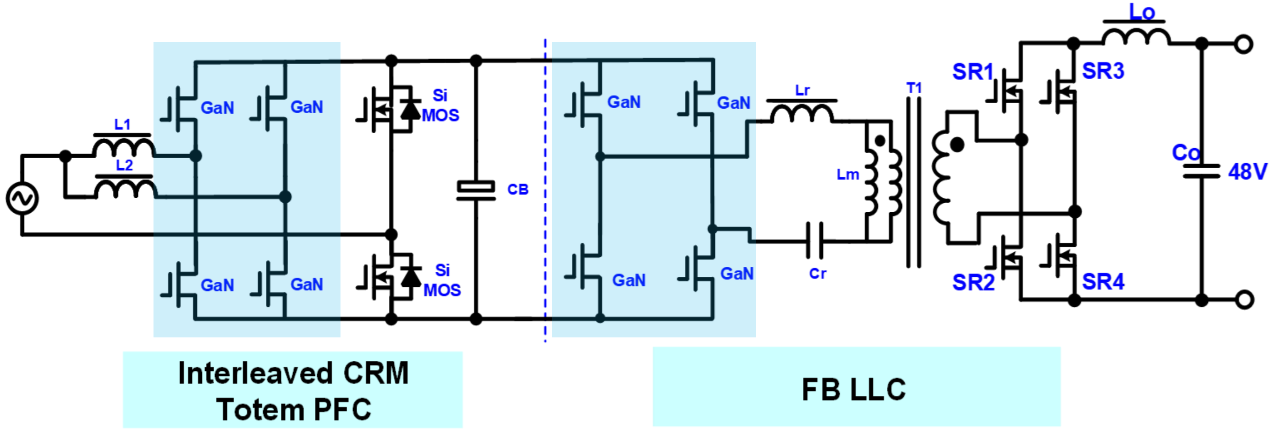


Exceeds extreme 'Titanium' grade efficiency, demanded by European Union's 'Directive 2009/125/EC, 2019 Annex', in force by January 1st, 2023. "Lower cost than silicon" – data center customer.

*** 230 V_{AC} @ 25°C, excludes fan**

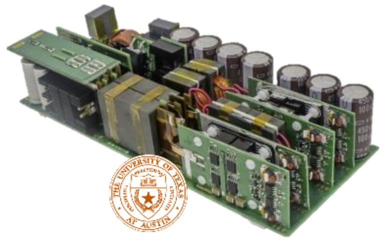
3.2kW Server Power

- GaNFast ICs for Totem-Pole PFC (MHz) + LLC (MHz)
- 98% Efficiency, 92W/in^3
- AC-54V, 48V$_{OUT}$
- 1U x 2U x 210 mm (800 cc)
- Power Density: 4.4 W/cc (73 W/in^3)

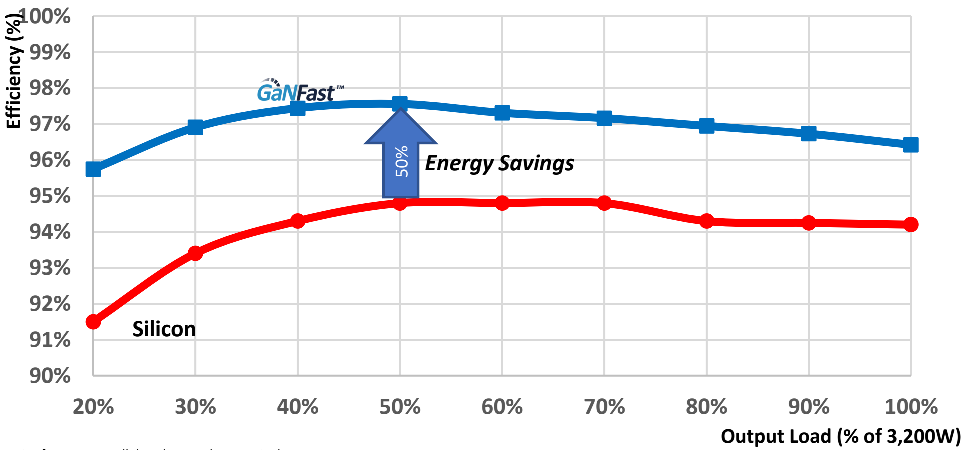


3.2 kW AC-54V converter; 650V GaNFast power ICs for MHz totem-pole PFC and MHz LLC primary with 100V GaN FETs for LLC secondary rectification.

2x Smaller, 50% Energy Savings



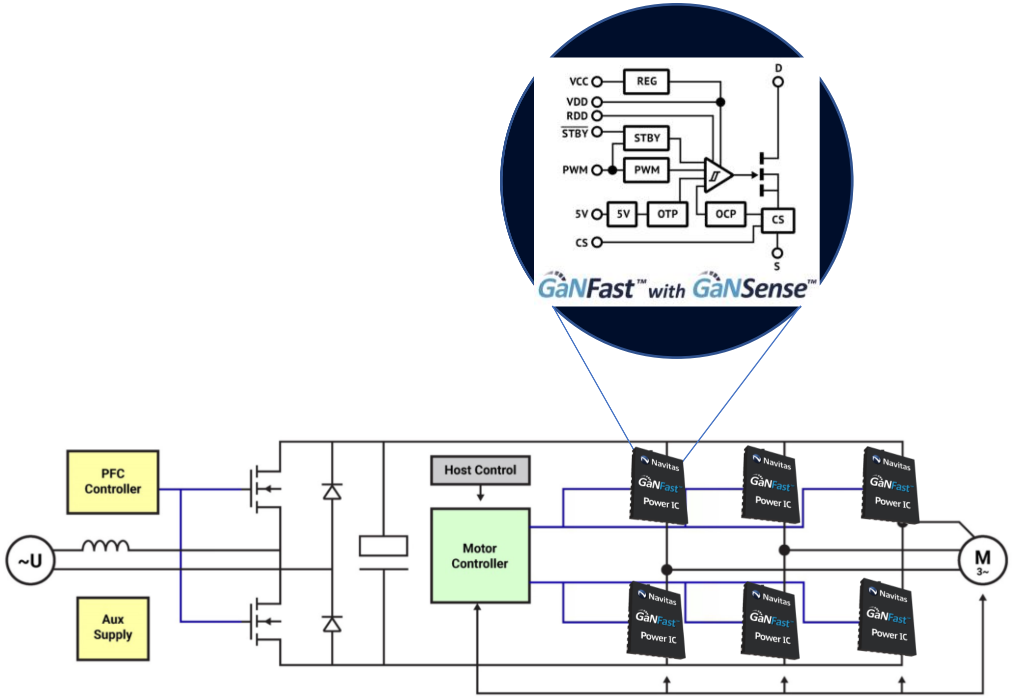
Silicon 3,200W	GaN 3,200W
(Meanwell DPU-3200-48)	(UT Austin)
47 kHz, 500 kHz, 94.8% pk	1 MHz, 97.7% pk
325 x 107 x 41 mm = 1,426 cc	210 x 81 x 43 mm = 731 cc
2.2 W/cc	4.4 W/cc



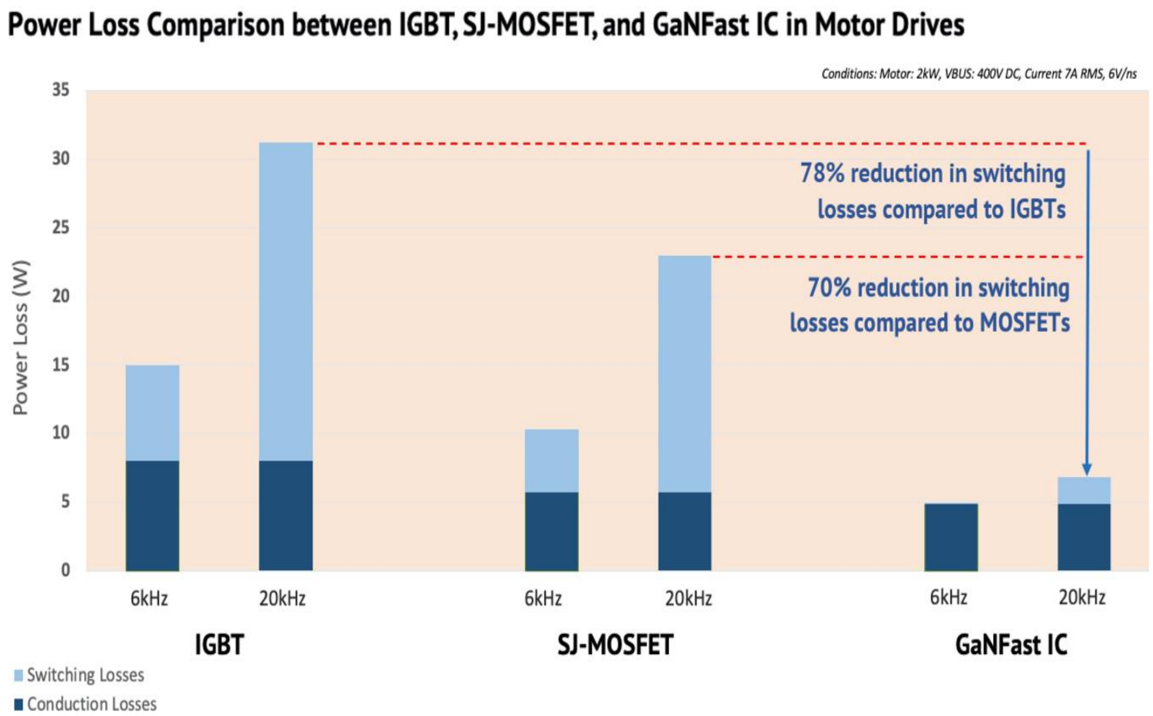
Efficiencies from Meanwell datasheet and UT Austin data

Industrial Motor Drive

- Navitas GaNFast ICs exhibit lower losses across all switching frequencies, but significantly as switching frequency increases

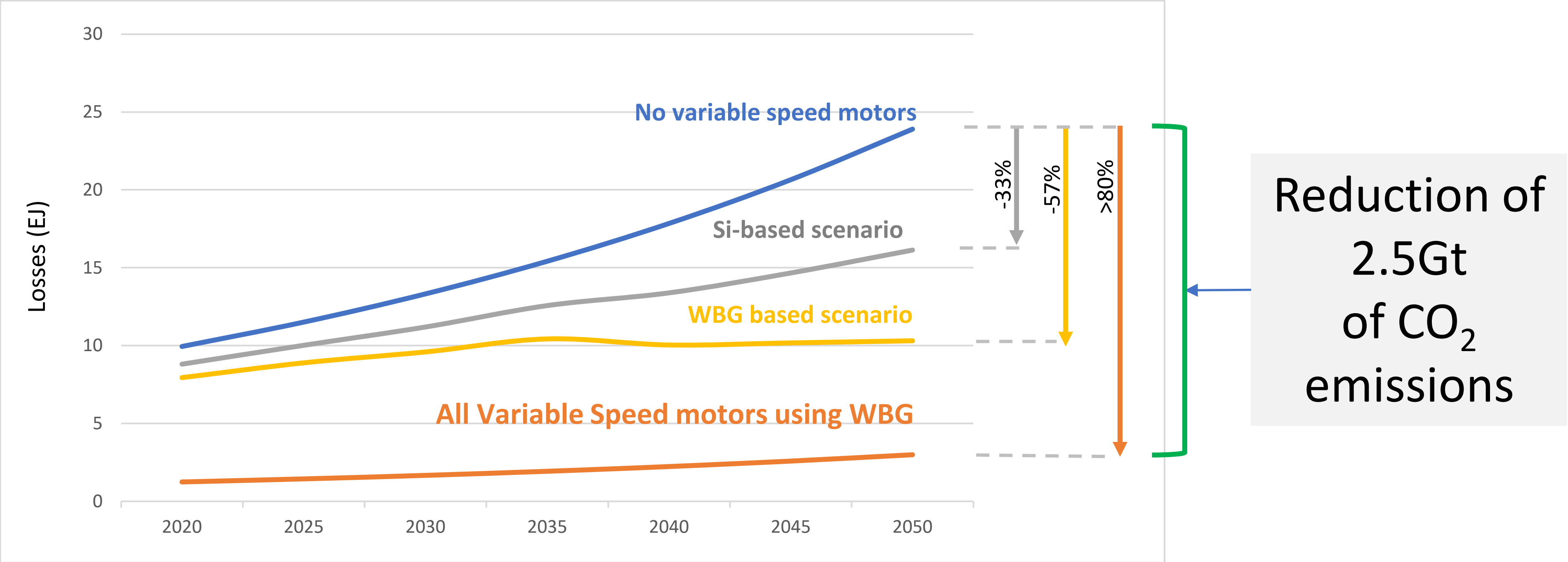


Typical Motor Drive (3-Phase) Schematic with GaNFast and GaNSense



Source: Navitas Semiconductor calculations

High Efficiency, Variable Speed Industrial Motors



(Image: ABB)

- Electric motors use ~70% of total industrial electricity consumption at ~60% efficiency
- WBG enables moving to modern, highly efficient motors, which can improve the total industrial electrical consumption efficiency to >90% and reducing the losses by >80%
- Higher power levels (20kW+) and voltages (690V and higher) enabled through SiC, whereas GaN is preferred for lower voltages

Summary

- GaN is the next generation power semiconductor that offers superior performance, whilst providing lower CO_2 footprint in device and system manufacturing
- GaN power devices require monolithic integration of driver and power stage to enable highest frequency, performance, and reliability
- Device structure, design and manufacturing processes are paramount to quality and reliability.
- Further integration of real-time autonomous sensing and protection delivers highest efficiency, performance, and reliability.

“Electrify Our World™”

Thank you