EPE '22
ECCE EUROPE

Advancing GaN Power ICs with Efficiency, Reliability & Autonomy

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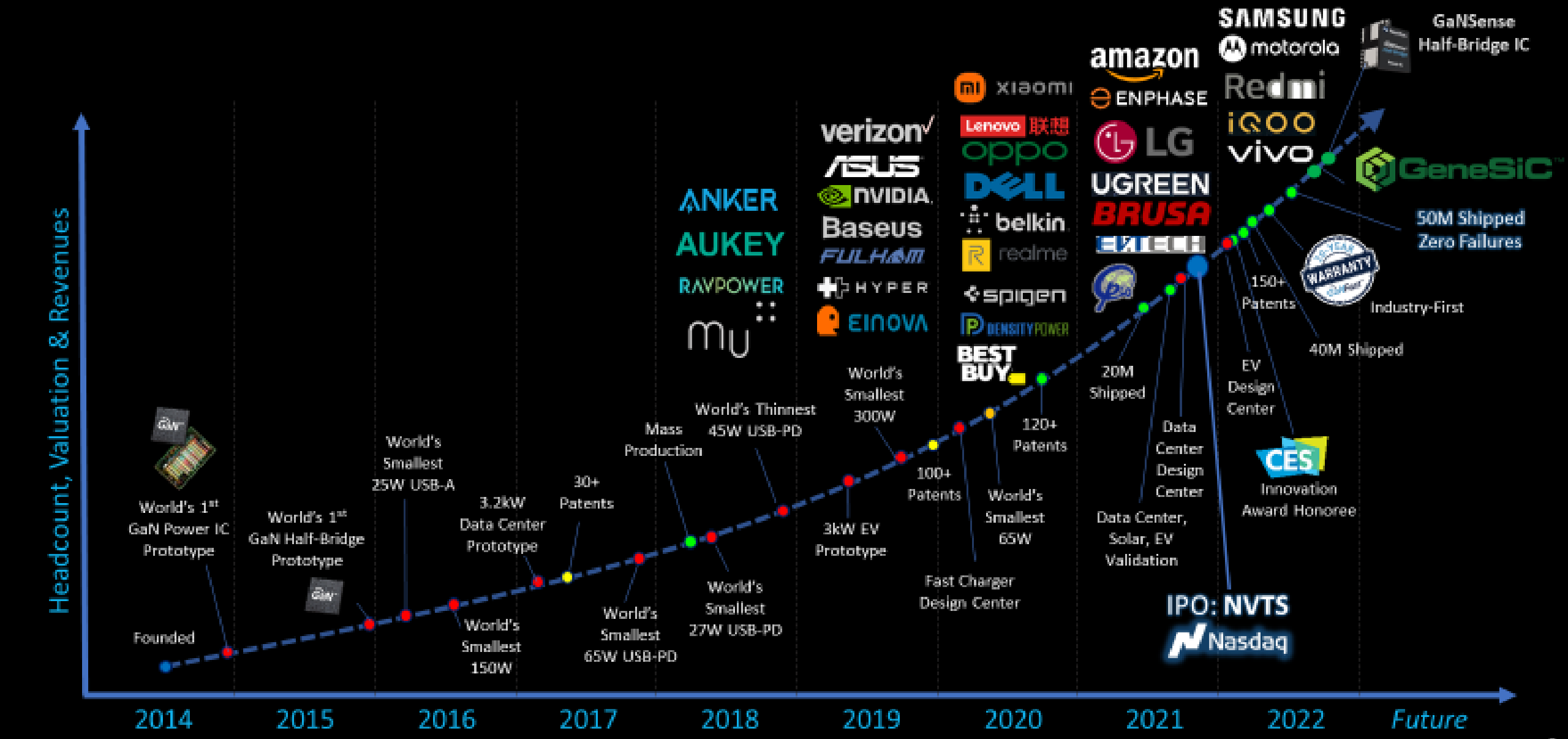
EPE'22 ECCE Europe-Conference, 7th September 2022

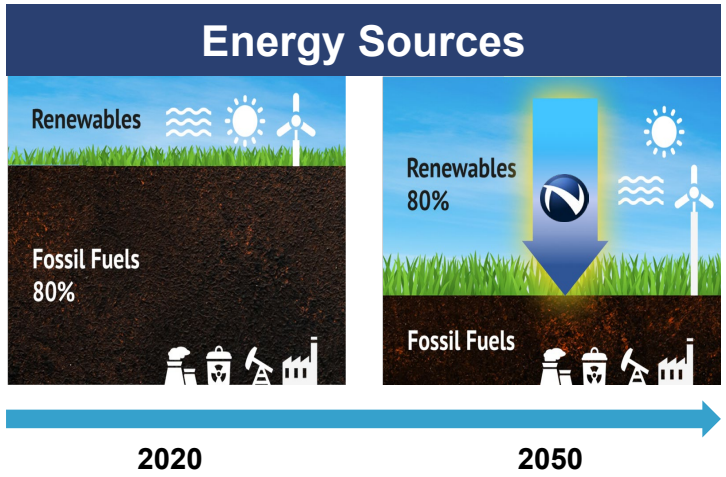
Navitas

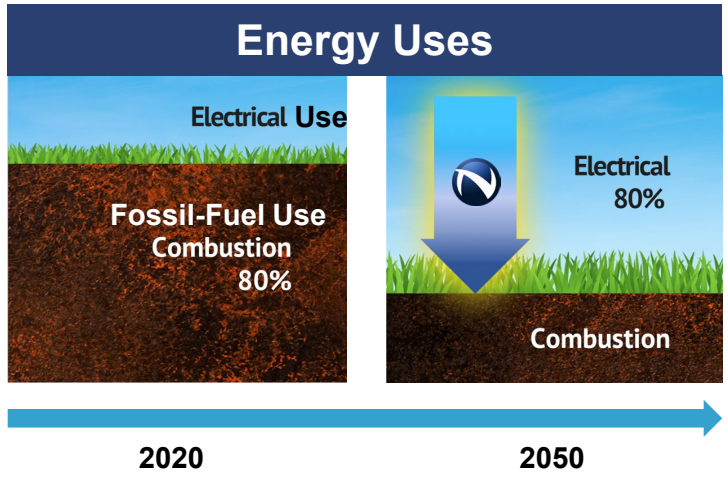
Energy • Efficiency • Sustainability

#1 in GaN, now the only pure-play WBG company

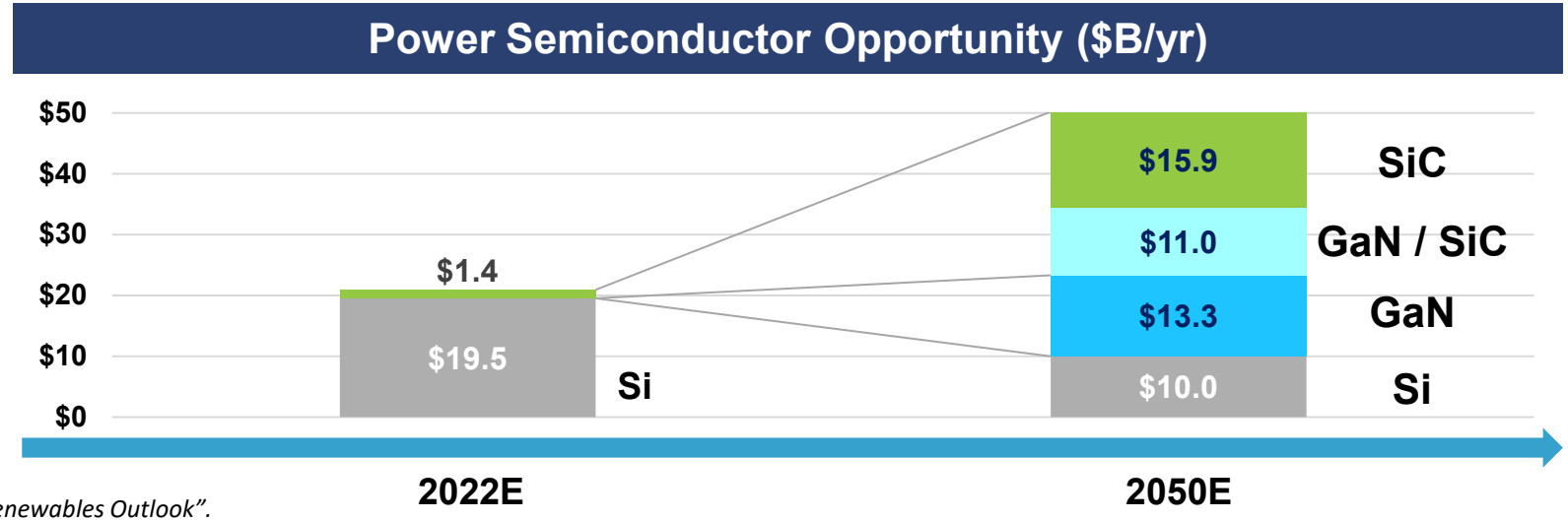


Energy sources and uses are being electrified…





…creating a $40B GaN + SiC opportunity by 2050



Fossil-fuel vs renewable ratios adapted from IRENA 2020 "Global Renewables Outlook".
Shift required to meet "Transforming Energy Scenario, 9.5 Gton target in 2050", per Paris Agreement's 1.5˚C rise.
Market opportunity $ from Yole Développement, 2020 and Navitas analysis.

GaN + SiC: The Future of Power Semis

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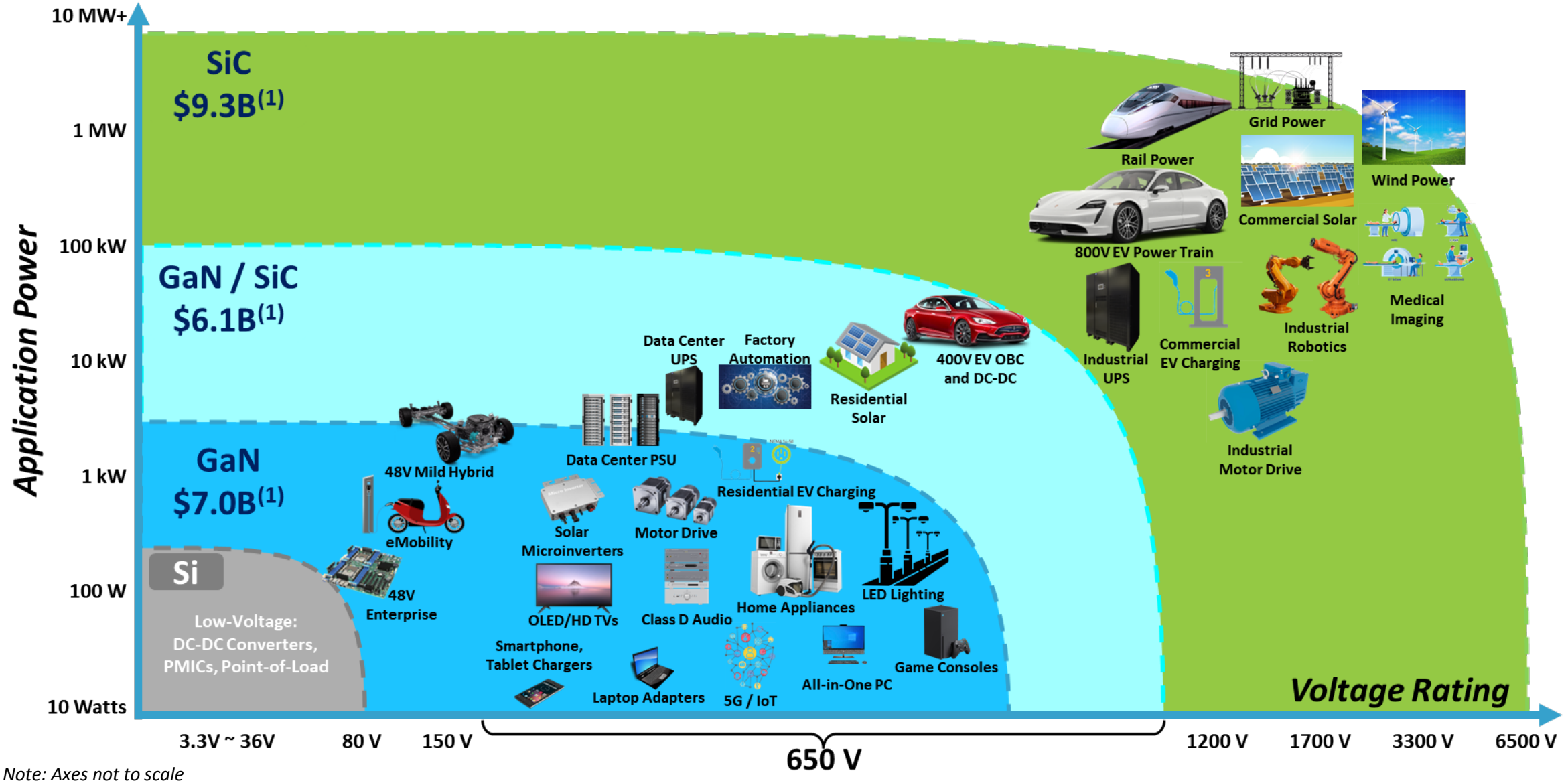


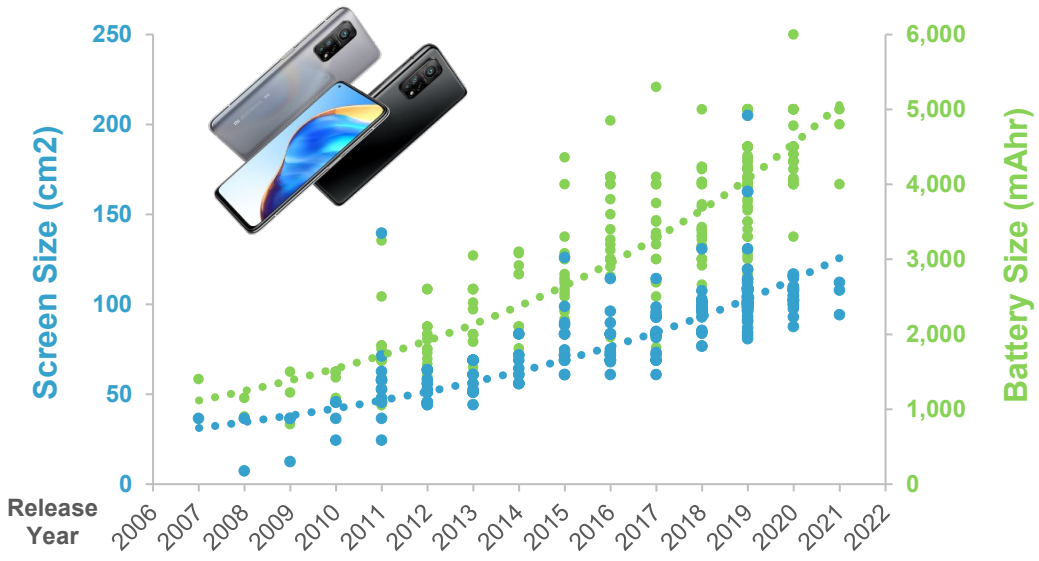
Note: Axes not to scale

Note (1): 2026E potential, Source: Yole, DNV, IRENA, Fraunhofer ISE, IHS, Cisco, Hyperscale, Peer annual reports, Wall Street research.

GaN is Positioned To Be The Future Of Mobile Charging

Larger Mobile Screens And Batteries Need More Power

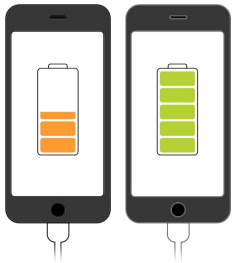
Screen Size and **Battery Size** Continue to Increase[1]



Over $2.5B GaN IC opportunity[3]

- 2.5Bu per year of mobile wall chargers shipped
  - Phone, tablet, laptop and after-market
- Over $1 of GaN content per charger and increasing over time

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



Mobile
Half the size and weight
of traditional chargers

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

65W Multi-Port GaN Wall Charger[2]

3 Silicon Chargers

1 GaN Charger

3x smaller, 3x lighter, and less expensive

Mobile is Moving to GaN Fast Chargers, Creating a Multi-Billion Dollar GaN IC Opportunity

1) Includes Huawei, Xiaomi, OPPO, OnePlus, RealMe, Samsung, Apple and Google.
2) Based on Navitas measurements of select GaN-based mobile wall chargers compared to Si-based chargers with similar output power.
3) Based on estimates from IDC PC Tracker, USB-C research, Yole Research and Navitas estimates.

The GaN Revolution

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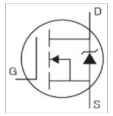
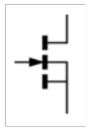
Silicon FET



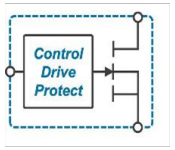
- Old, slow
- High Qg
- High Coss
- Fsw < 100kHz

Discrete GaN



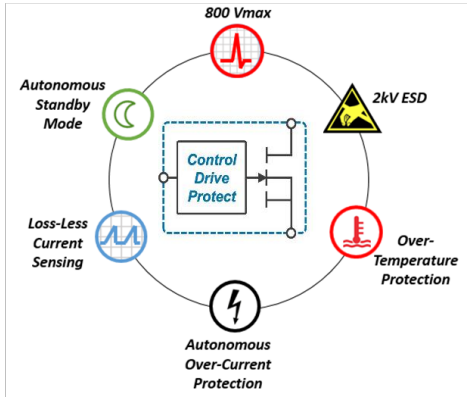
- Exposed gate
- External gate drive
- dV/dt sensitivity
- Layout sensitivity
- ESD sensitivity
- Unknown reliability
- Unknown robustness

GaNFast™



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

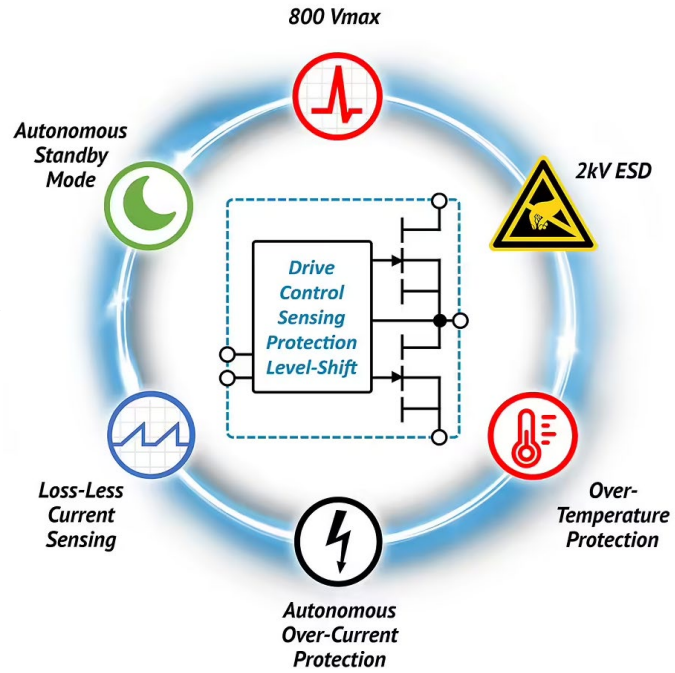
GaNSense™



GaNFast benefits plus:

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

GaNSense Half-Bridge



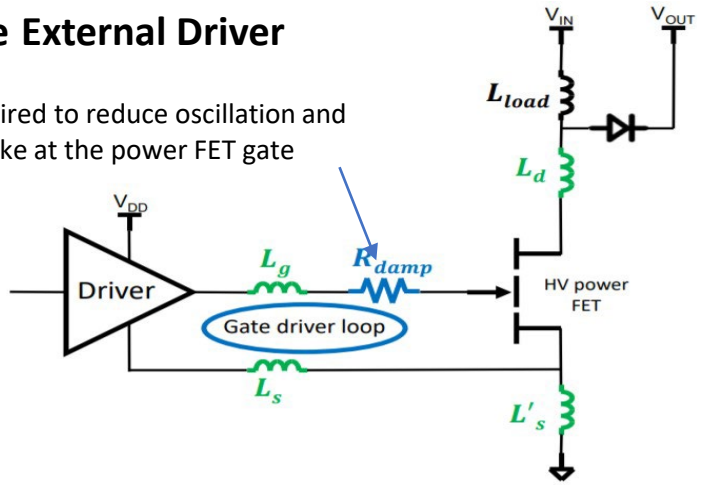
GaNSense Singles benefits plus:

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

GaN Integration for Efficiency, Speed & Stability

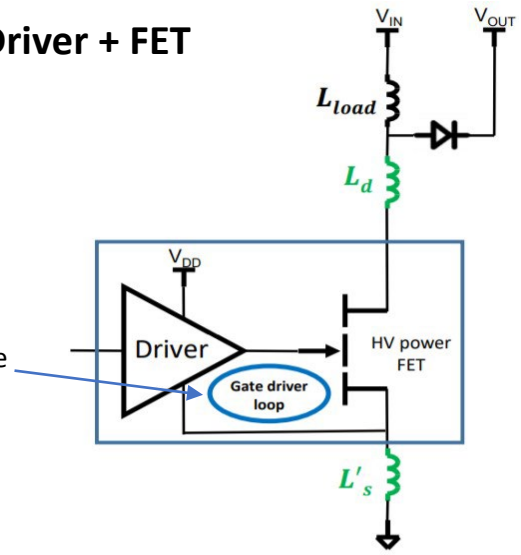
Discrete External Driver

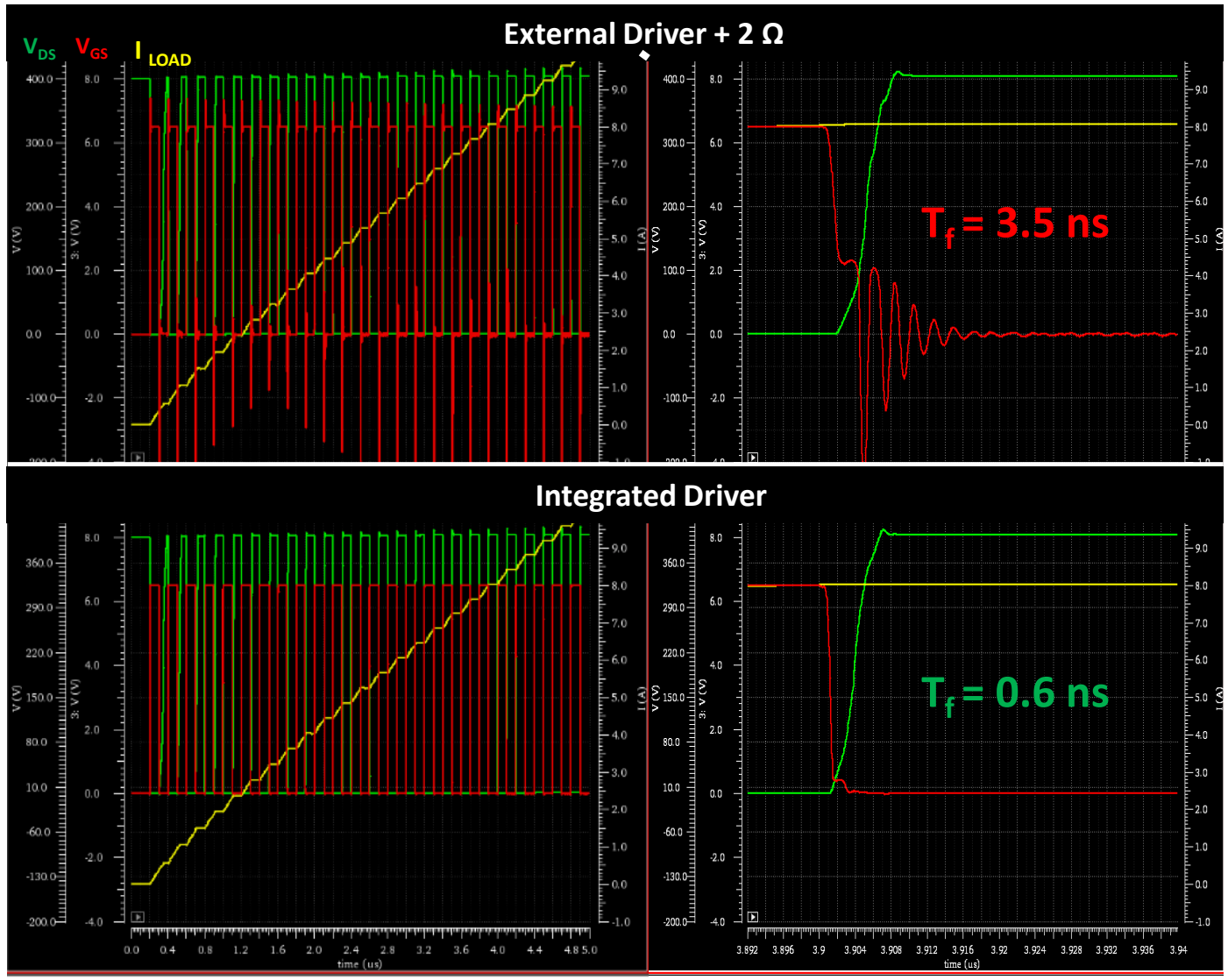
R_{DAMP} required to reduce oscillation and voltage spike at the power FET gate



Monolithic GaN Driver + FET

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





Ref: "Next-generation GaN Isolators / Level-Shifters for High Frequency, High Efficiency Power Conversion", APEC 2017 Industry Session, Oliver & Giandalia

GaN Integration Drives Performance

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Discrete GaN Half-Bridge

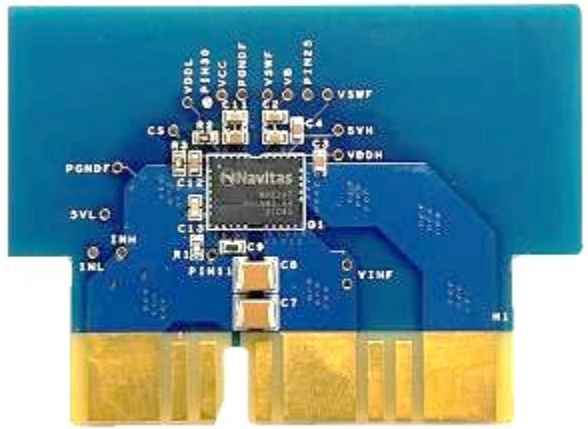
- × 33 components
- × 250 mm² footprint
- × External HB driver HVIC
- × External. HV bootstrap
- × 2x HV bypass diodes
- × 2x external gate drives
- × Exposed gates

61% fewer components

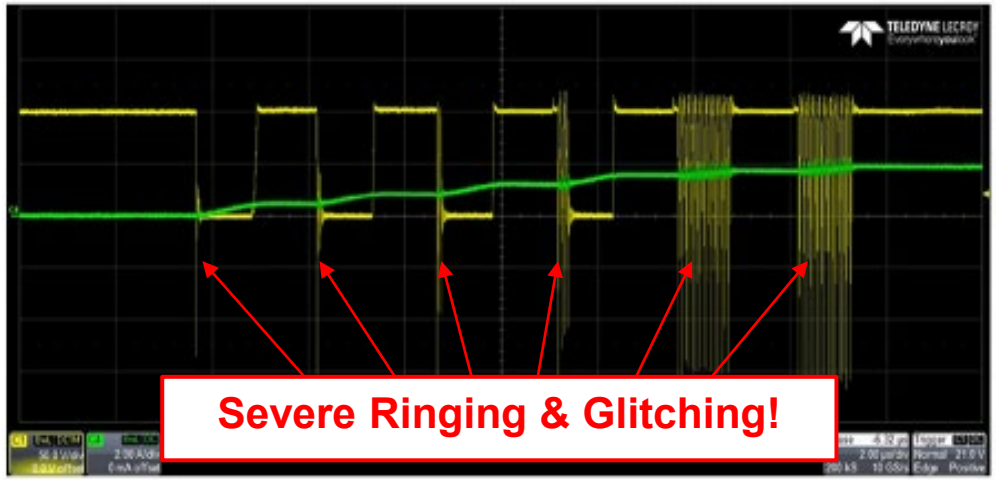
64% smaller footprint

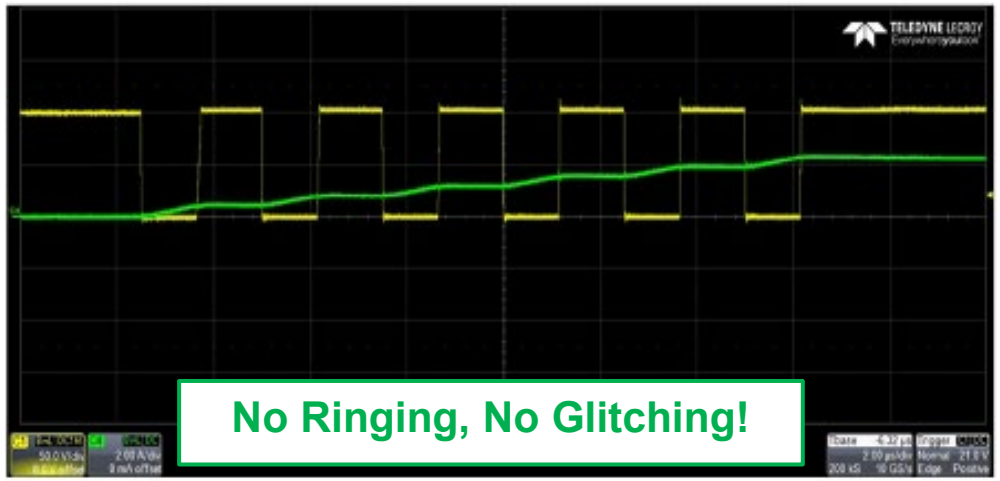
Complete integration

GaNSense Half-Bridge IC



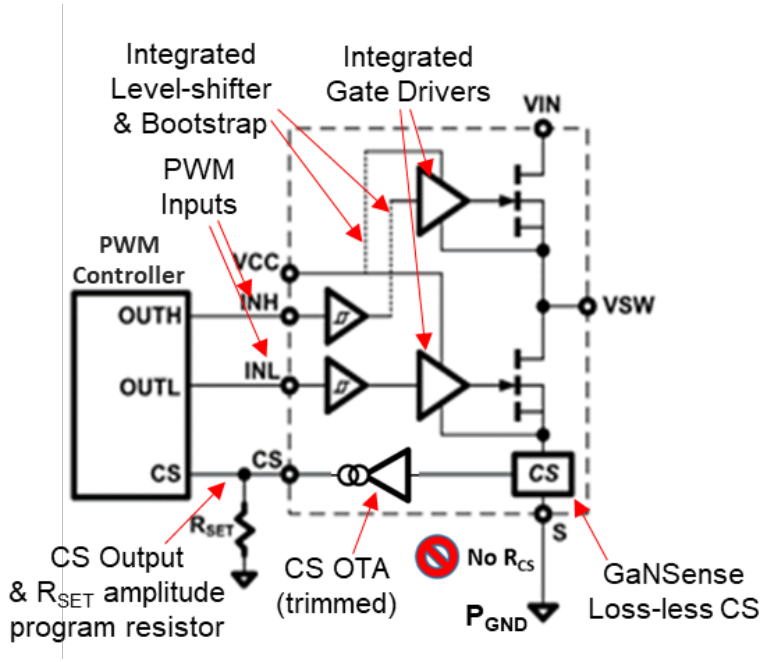
- ✓13 components
- ✓90 mm² footprint
- ✓Level shifters
- ✓Bootstrap
- ✓Gate drivers
- ✓No exposed gates



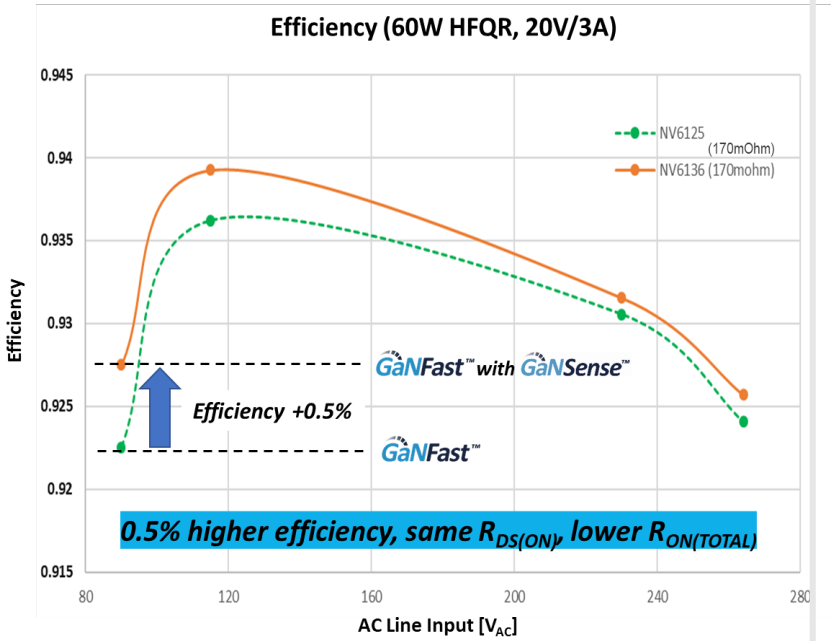


Integrated, Loss-less Current Sensing

Integrated, programmable loss-less current sensing

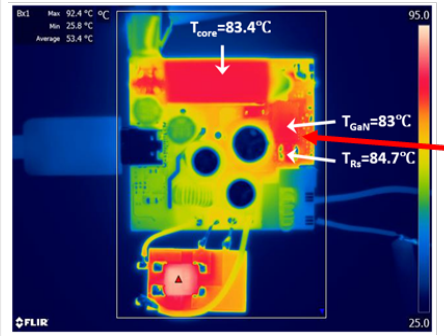


No R_{SENSE} = increased efficiency



No R_{SENSE} = no hot-spots or heat transfer

GaNFast™

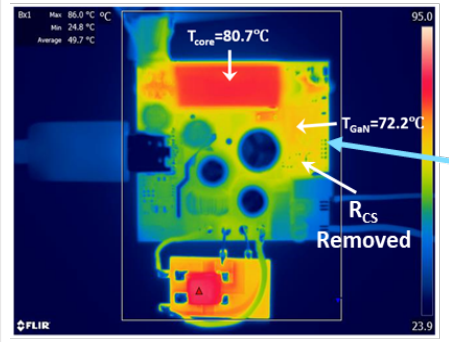


NV6125

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

R_{CS} HOT-SPOT = 85°C!

GaNSense™



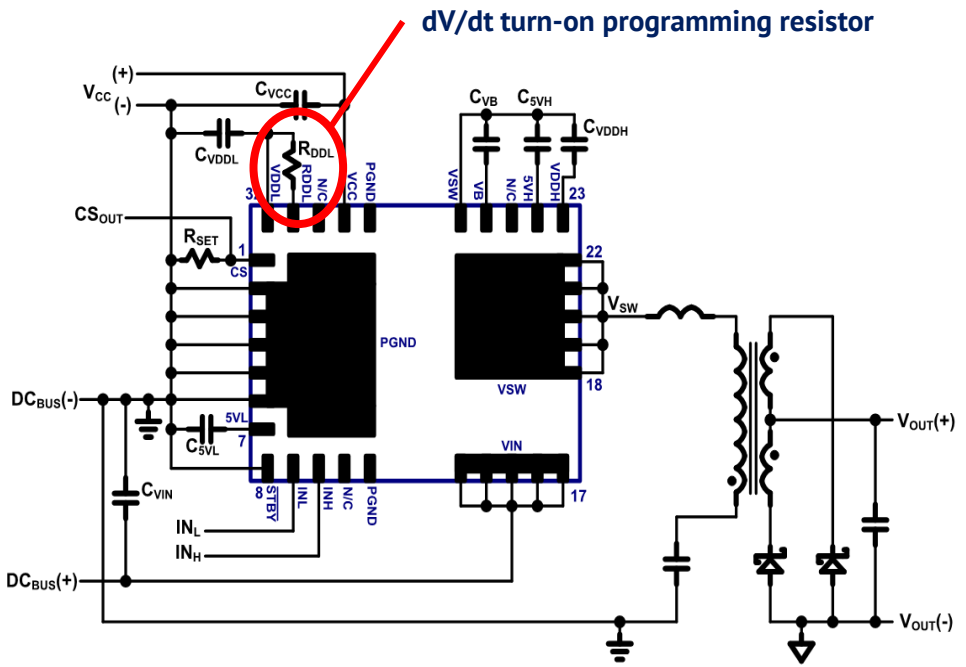
NV6136

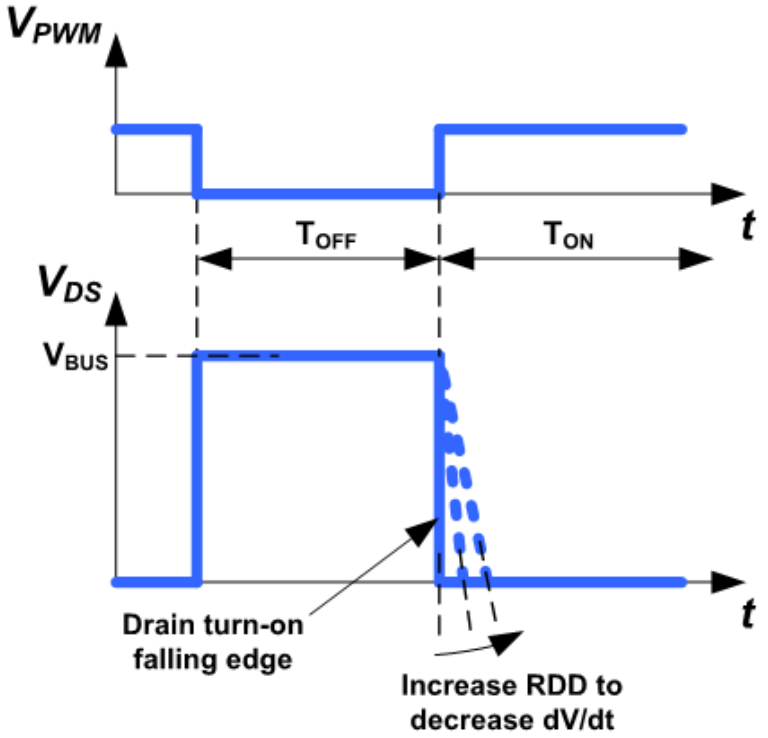
$R_{DS(ON)}$ = 170 mΩ
R_{CS} = 0 mΩ
$R_{ON(TOT)}$ = 170 mΩ

NO HOT-SPOT
T_{GaN} 10°C Cooler

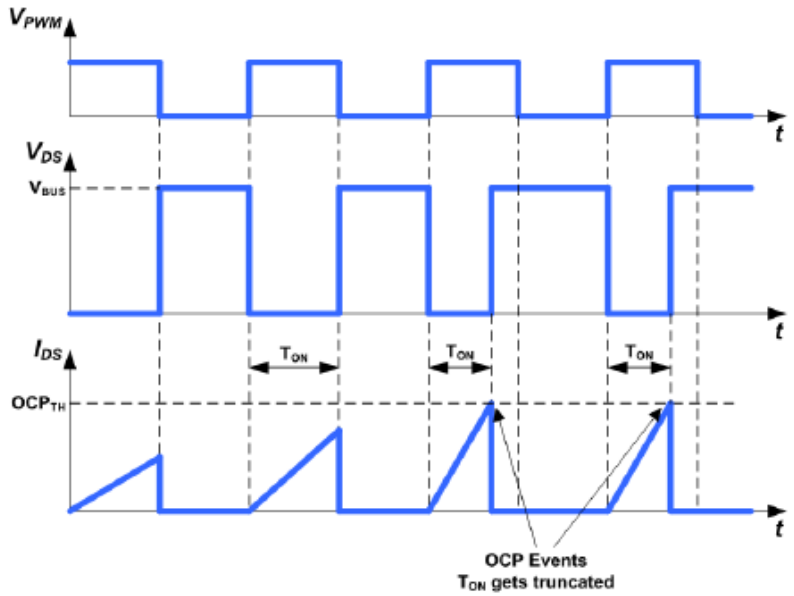
Programmable Turn-on dV/dt Control

- Limits the slew rate (dV/dt) of the drain of the power FET during turn-on
- First start-up pulses or during hard-switching conditions
- Reduce EMI or reduce circuit switching noise

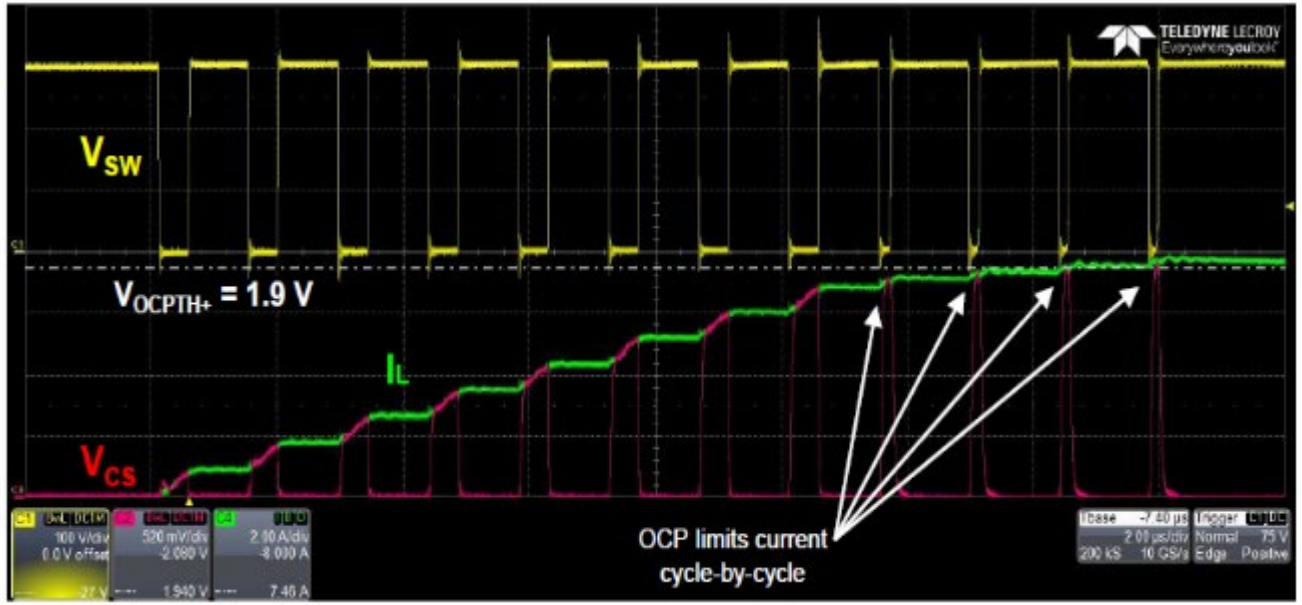




Cycle-by-Cycle Over-Current Protection (OCP)



Over-Current Protection DCM Timing Diagram

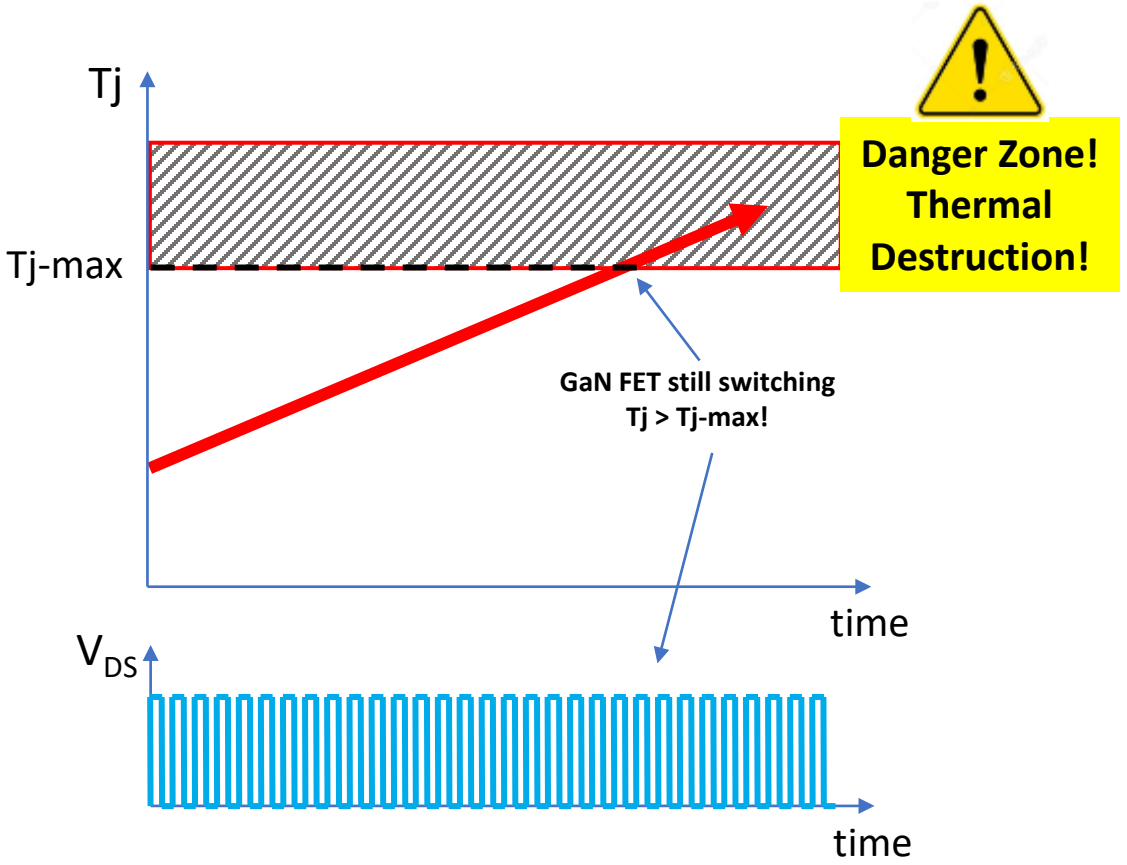


Cycle-by-cycle over current protection in CCM boost configuration

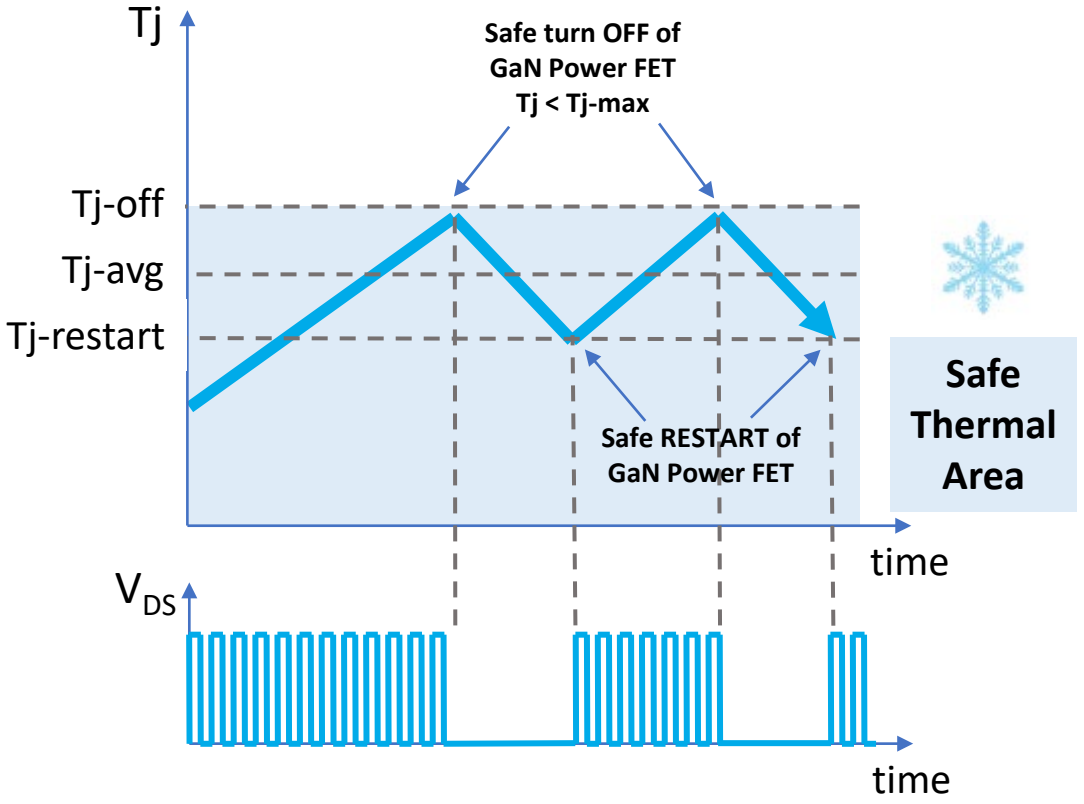
- If V_{CS} > 1.9V, internal gate driver will turn off the GaN IC, ending the on-time
  - **OCP response 'detect-to-protect' in 30 ns!** 6x faster than conventional controllers
- Accurate, user-programmable current set-point (based on I_{DRAIN}→ I_{CS} ratio, R_{SET})
- Turn-on OCP blanking time prevents noise from triggering the fault, is optimized for protection

Over-Temperature Protection (OTP)

Discrete GaN



GaNSense IC w/OTP



Soft Switching & GaN ICs = High Efficiency & Frequency

Primary Switch Power Loss using Silicon FETs:

$$P_{FET} = P_{COND} * k + P_{DIODE} + P_{T\text{-}ON} + P_{T\text{-}OFF} + P_{DR} + P_{QRR} + P_{QOSS}$$

- $R_{DS(ON)}$ loss
- Duty cycle loss
- Reverse conduction loss
- Switch-ON transition loss
- Switch-OFF transition loss
- Gate Drive loss
- Reverse recovery loss
- Output Capacitance loss

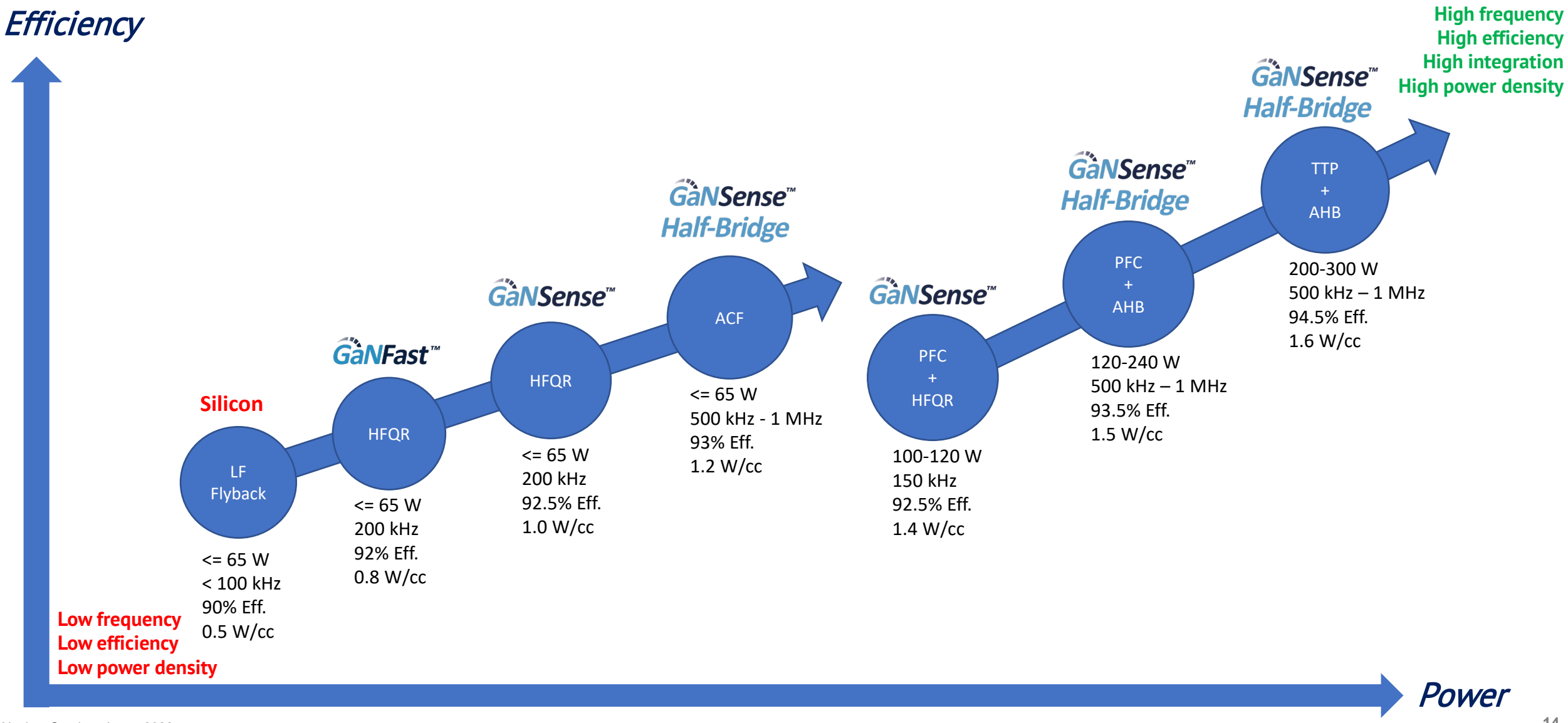
Primary Switch Power Loss using GaN Power ICs:

$$P_{FET} = P_{COND} * k + P_{DIODE} + P_{T\text{-}ON} + P_{T\text{-}OFF} + P_{DR} + P_{QRR} + P_{QOSS}$$

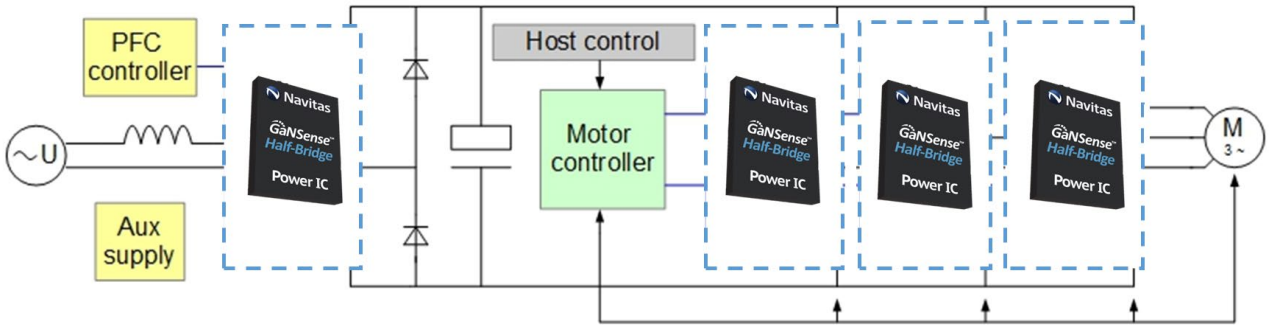
MINIMIZED MINIMIZED

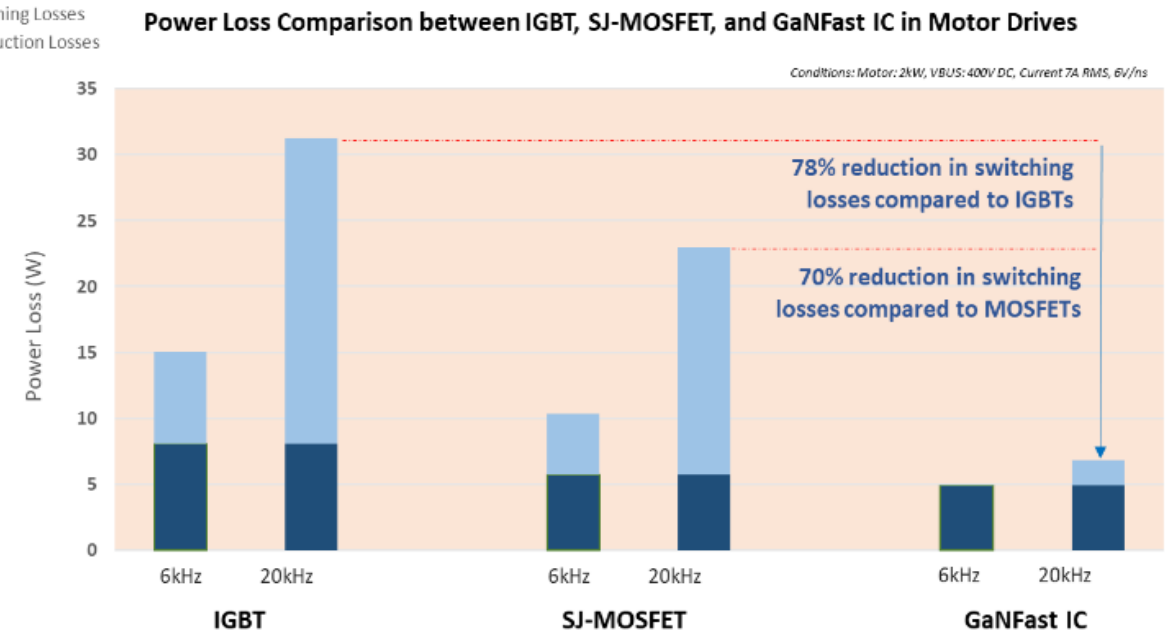
Soft-switching and GaN ICs **ELIMINATE** turn-on & reverse recovery losses & **MINIMIZE** drive, deadtime, and device charging losses

Enabling Next-Gen, High-Speed Topologies



GaNSense Half-Bridge ICs Enable Inverter Motor Integration





- **Motor Drive**: compact, high efficiency, reduced thermal management
- **TTP PFC**: highest efficiency, fewest components and smallest footprint
- **Aux Supply**: compact, efficient HFQR topology

- Significant reduction in cost, weight and size of thermal management (heatsink, fans, etc.)
- GaN Power ICs into a 2kW motor drive
  - Inverter efficiency increases 2.5% (96%→ 98.5%)
  - Total losses reduced 50% (15W→6.8W)

Ref: "Autonomous GaN Power ICs Deliver High-Performance, Reliable Motor Drives", white paper, Hesener, May 2022

Integrating drive, protection, and loss-less current sensing, provides compact, easy to design, robust systems

Navitas

Complete integration of Half-Bridge phase into a single IC provides the most compact, efficient, fastest-switching, reliable and simplest solution for a wide variety of motor applications, such as fans, pumps, blowers, and compressors

	Discrete IGBT (Baseline)	Discrete (SJ) MOSFET	Discrete SiC	IPM (Gate Driver + 6 Switches)	Discrete GaN (Standalone)	Discrete GaN (Cascode)	GaNFast™ with GaNSense™
Electrical Efficiency	0	+	++	0	+++	++	+++
System Size (e.g. heatsink)	0	0	+	+	++	++	+++
Number of Components	0	0	0	++	-	0	++
Design Effort and Time	0	0	0	++	-	0	+++
Inverter Robustness	0	0	-	+	-	-	++
Inverter Reliability	0	0	+	+	+	0	++
System Cost	0	0	+	+	++	+	+++

Summary

- Navitas' mission is to Electrify the World to create a more sustainable future.
- Next-gen WBG (GaN and SiC) offer superior performance, and significantly lower CO_2 footprint in device and system manufacturing.
- Monolithic integration of driver and power stages enabled GaNFast power ICs to establish new benchmarks in efficiency, density, and reliability and lead the GaN market.
- GaNSense technology delivers new capability to integrate many useful drive, sensing, protection and autonomous control features.
- Complete integration of GaNSense Half-Bridge with additional sensing, monitoring, and protection delivers exceptional and cost-effective performance in the major power converter and inverter applications.
- It is time for legacy silicon to step to the side, as wide band gap is ready to take over.

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CARBON NEUTRAL®

Company

Electrify Our World™

Navitas