Power Sources Manufacturers Association
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APEC 2017

Navitas

Power Accelerated

# Next-generation GaN Isolators / Level-Shifters for High Frequency, High Efficiency Power Conversion

PSMA Industry Session, Isolation Barrier Technologies for Power Electronics

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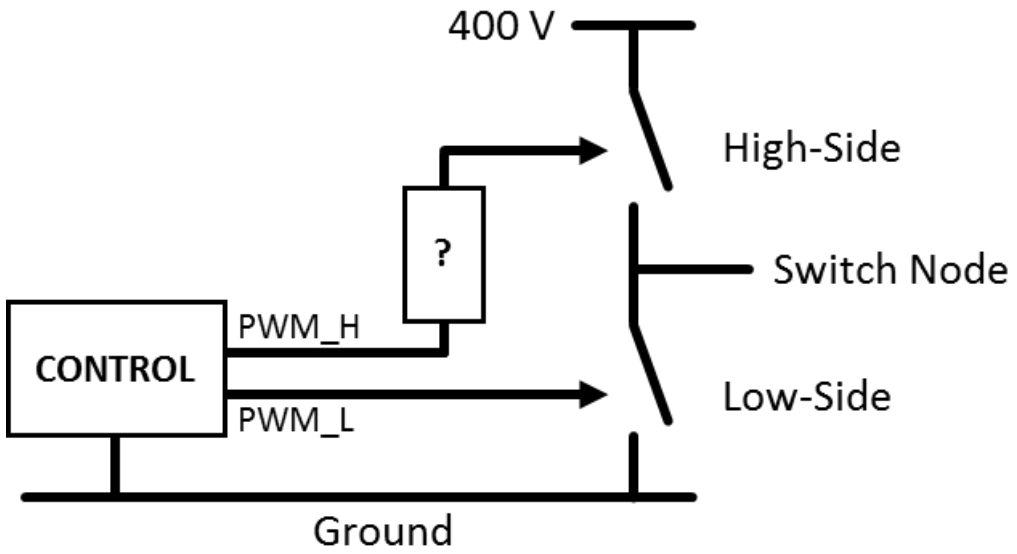
APEC, March 30th 2017

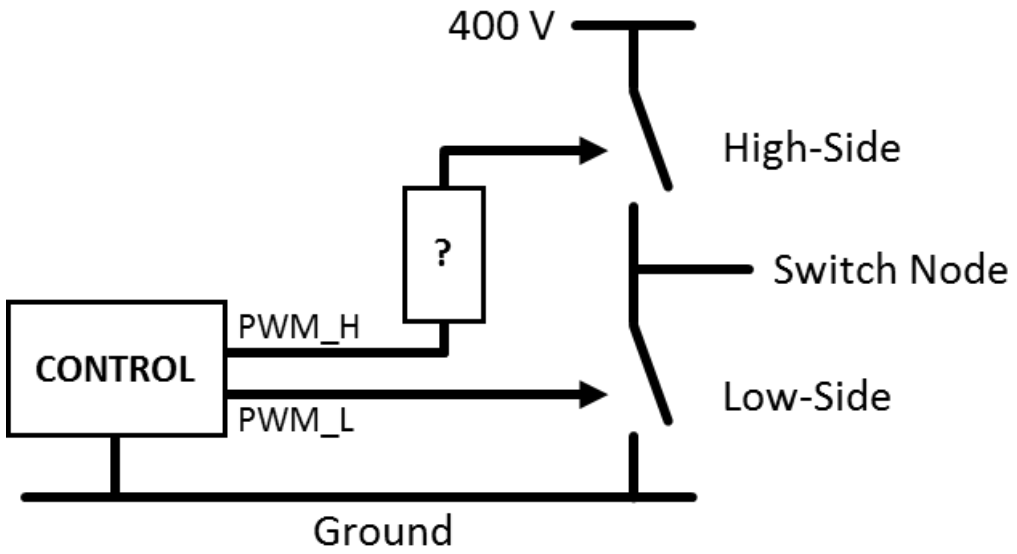
# Scope: The Half-Bridge Challenge

- Half-Bridge Topologies:
  - Active Clamp Flyback (25-65W)
  - LLC (90-400W+)
- Switching Frequency 100 kHz – 1 MHz+
- Functional (not galvanic) isolation (650 V)
- Function (uni-directional)
  - High-side Power
  - High-side Signal
- Normalized to 160 mΩ, 2.5 nC $Q_G$, eMode GaN FETs
  - Focus on driver, level-shifter influence



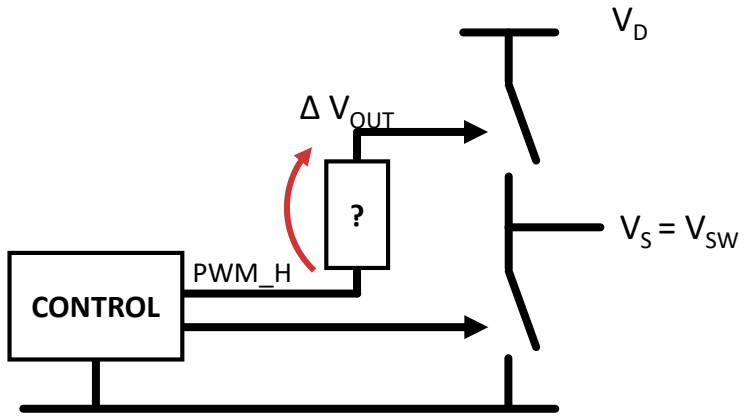
# Level-Shift Performance → System Size, Cost

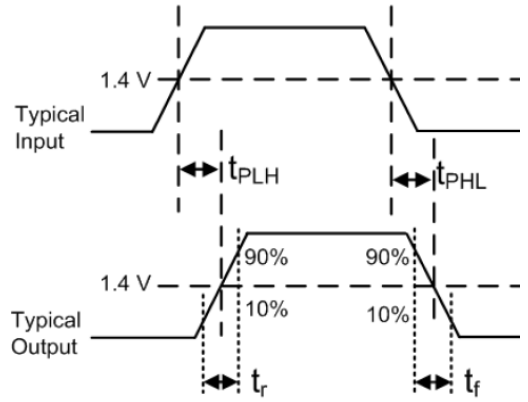
- Efficiency
  - Level-shift (driver) loss
  - Propagation delay loss
- Speed
  - Propagation delay
  - Switching frequency
- Noise
  - Common Mode Transient Immunity (CMTI) (dV/dt)
- Features
  - Protection (shoot-through, ESD, UVLO, etc.)
  - Programmability
- Cost
  - Integration, component count, magnetics size



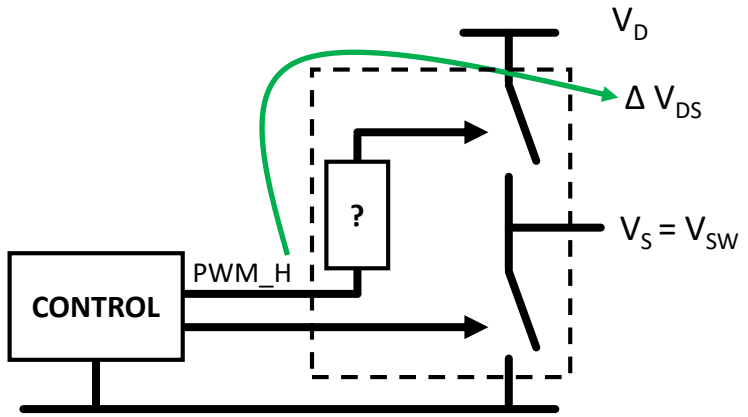
# A Note on Prop Delay

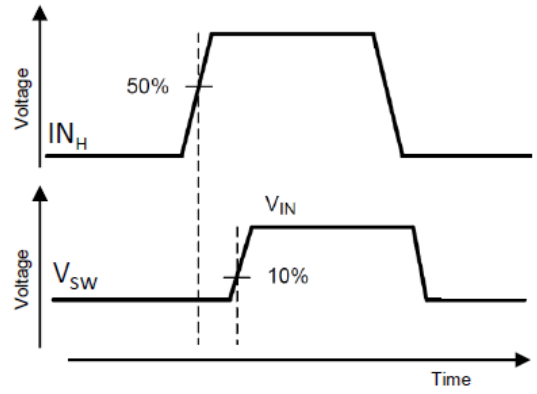
- Traditional ‘discrete’ level-shifter
  - Measured from the incoming PWM_H signal to a 10% change in the level-shifter’s own output
  - No account for FET speed, $R_G$, $Z_G$, etc.



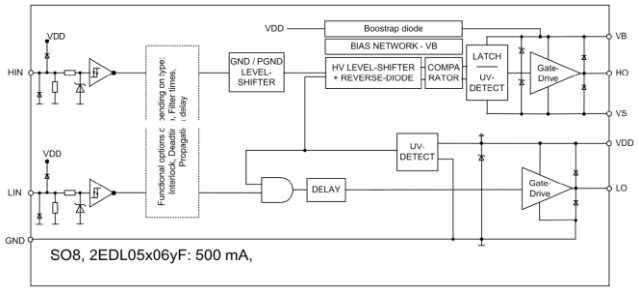
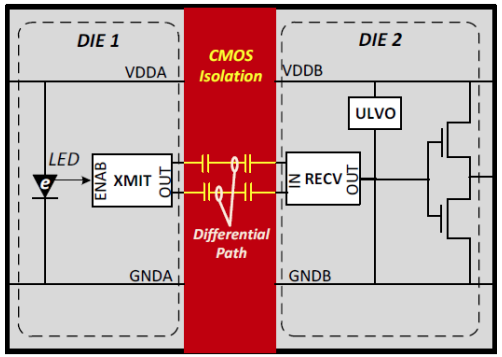
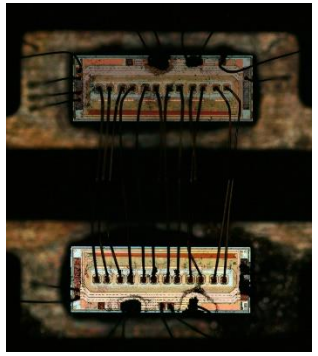
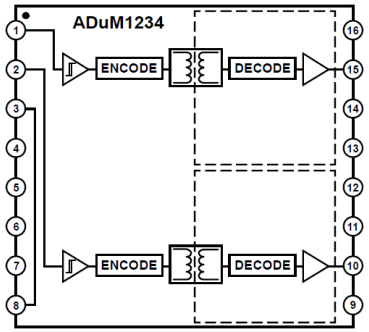
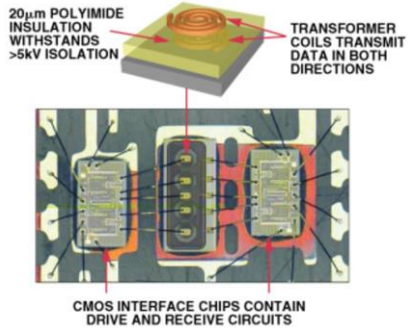
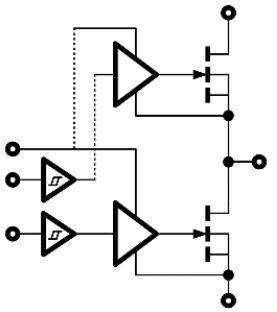
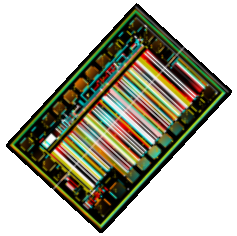




- Integrated GaN Power IC
  - Measured from PWM_H signal to a 10% change in high-side FET $V_{DS}$
  - Complete accountability



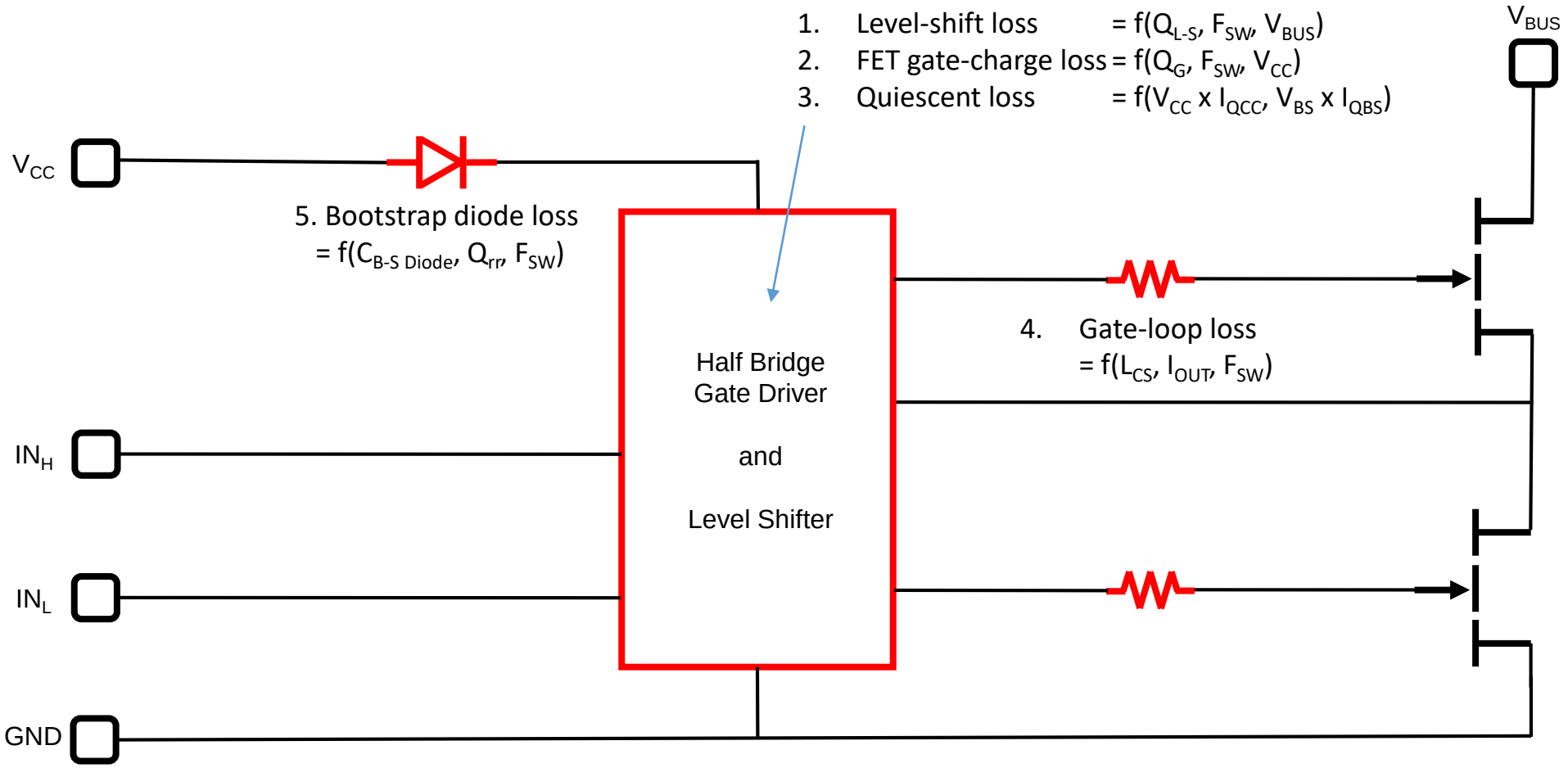



# High-Frequency Level-Shift Candidates

| Silicon-On-Insulator (SOI)<br>e.g. IR2113, UCC21521 | Capacitive-Coupled<br>e.g. Si8610 |
|---|---|
|  |   |
| **Inductive-Coupled**<br>**e.g. ADuM1234, ADuM3223, BM60210FV-C, 2ED020I06** | **GaN Power IC**<br>**e.g. NV62xx** |
|   |   |

*Representative images, not to scale*

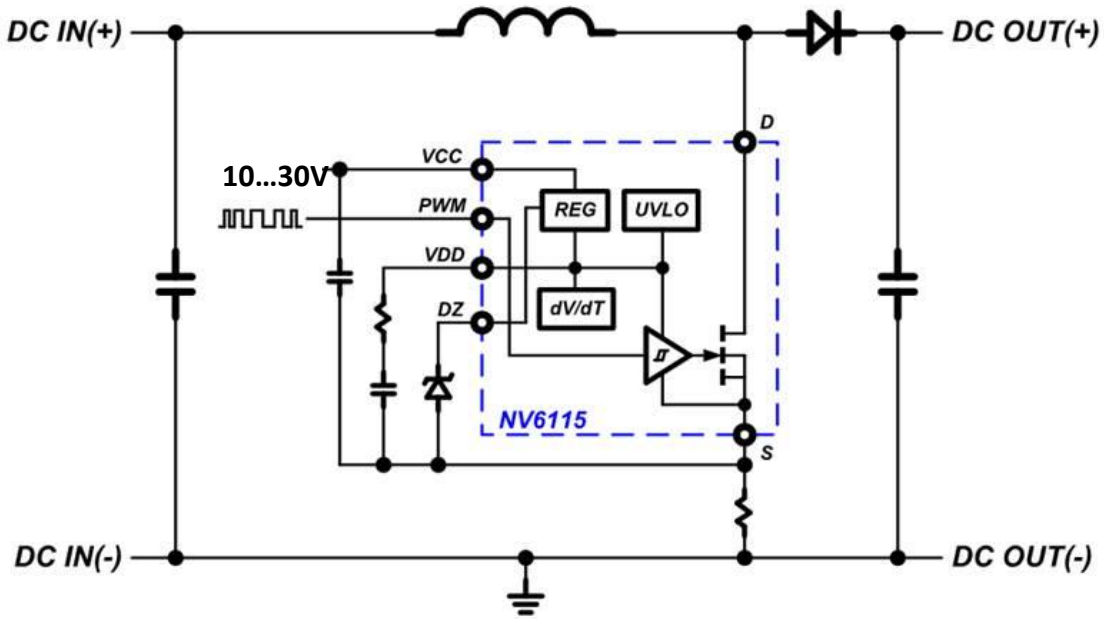
# Discrete Half-Bridge Drive: 5 Losses

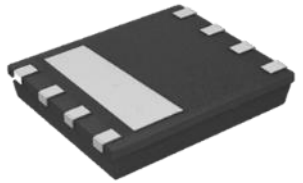


# Start with the single GaN Power IC

- Proprietary AllGaN™ technology
- Monolithic integration
- 650 V, eMode, GaN FET, GaN driver, GaN logic
- Very fast (prop delay and turn-on/off of 10-20 ns)
- High dV/dt immunity (200 V/ns) with control

- Digital in, power out…



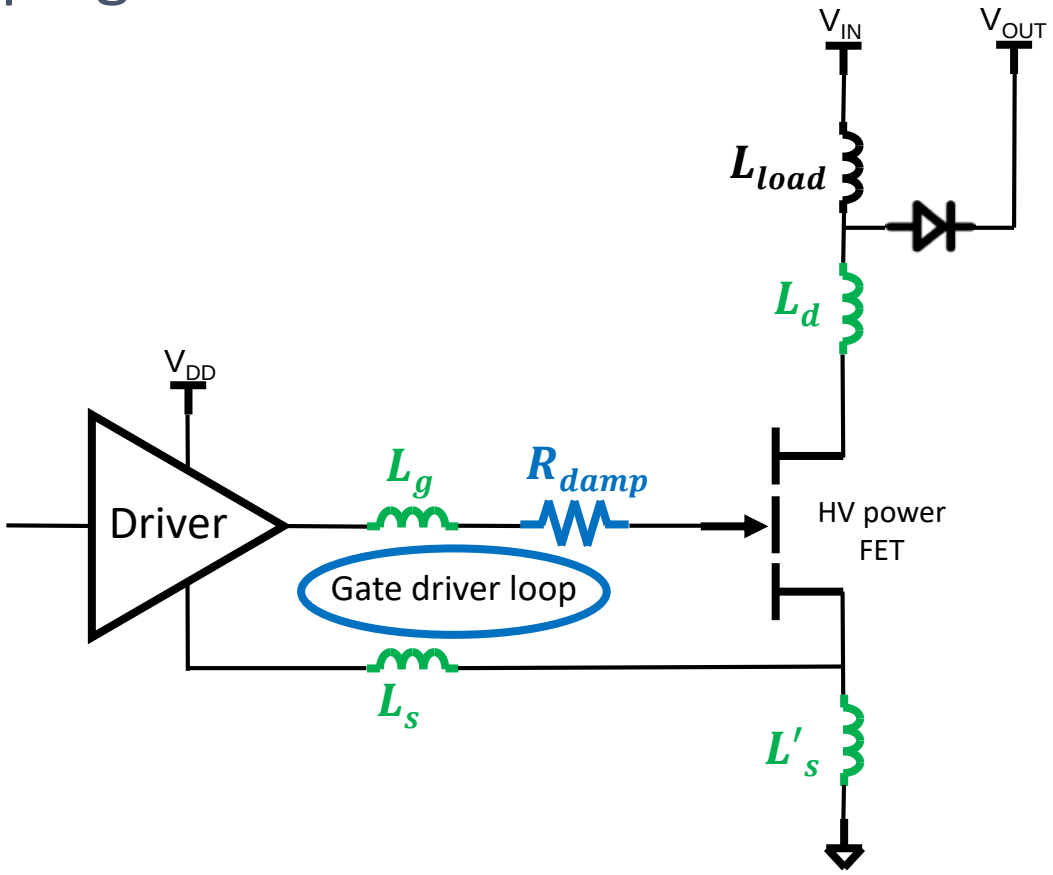



**QFN 5x6mm**

D. Kinzer, S. Oliver "Monolithic HV GaN Power ICs" in *IEEE PELS Power Electronics Magazine*, vol. 3, no. 3, pp. 14-21, September 2016

# Gate-Loop Loss = fn($L_{CS}$, $I_{OUT}$, $F_{SW}$)

- Common source inductance loss
- Damping resistor needed to reduce oscillation, voltage spike at the FET gate




$$R_{damp} \geq \sqrt{\frac{4(Lg + Ls)}{C_{gs}}}$$

| $L_g$+$L_s$ [nH] | $R_{damp}$ [Ω] |
|---|---|
| 0 | 0 |
| 1 | 2.83 |
| 2 | 4 |
| 3 | 4.9 |
| 4 | 5.66 |

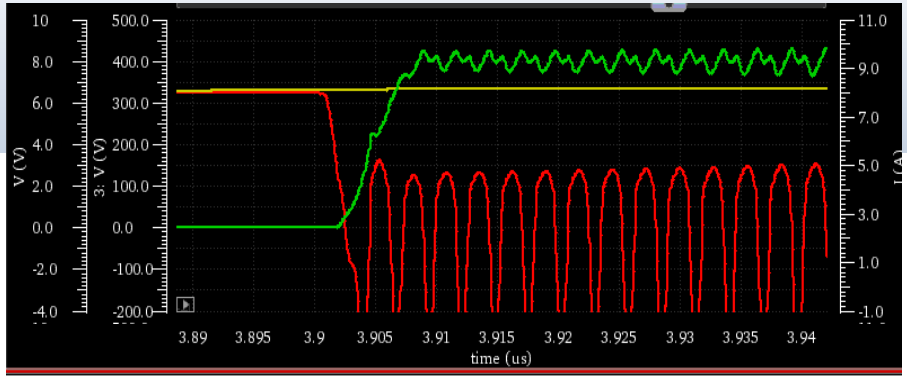
Cgs = 500pF

# Integration is Key

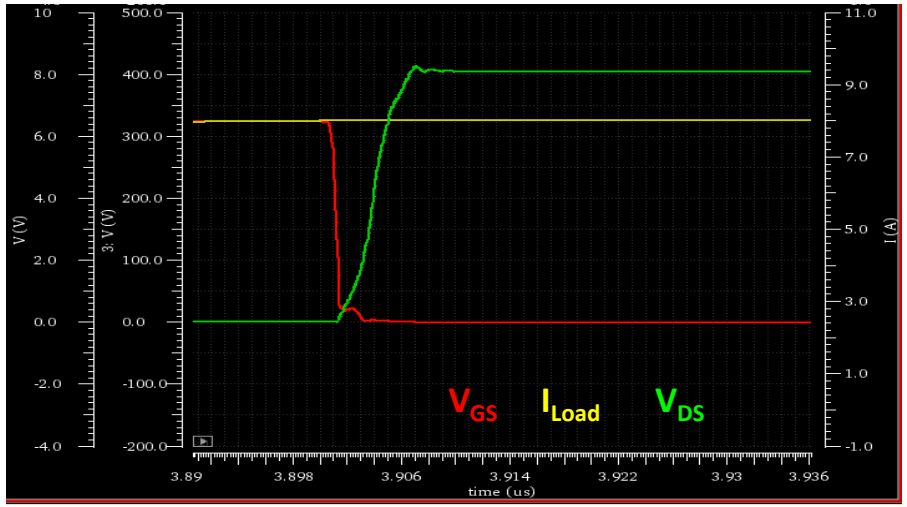
1. External driver: Oscillation

2. External driver + $R_G$: In control
   Slow
   Lossy

3. Integrated driver: In control
   10x faster
   Zero loss







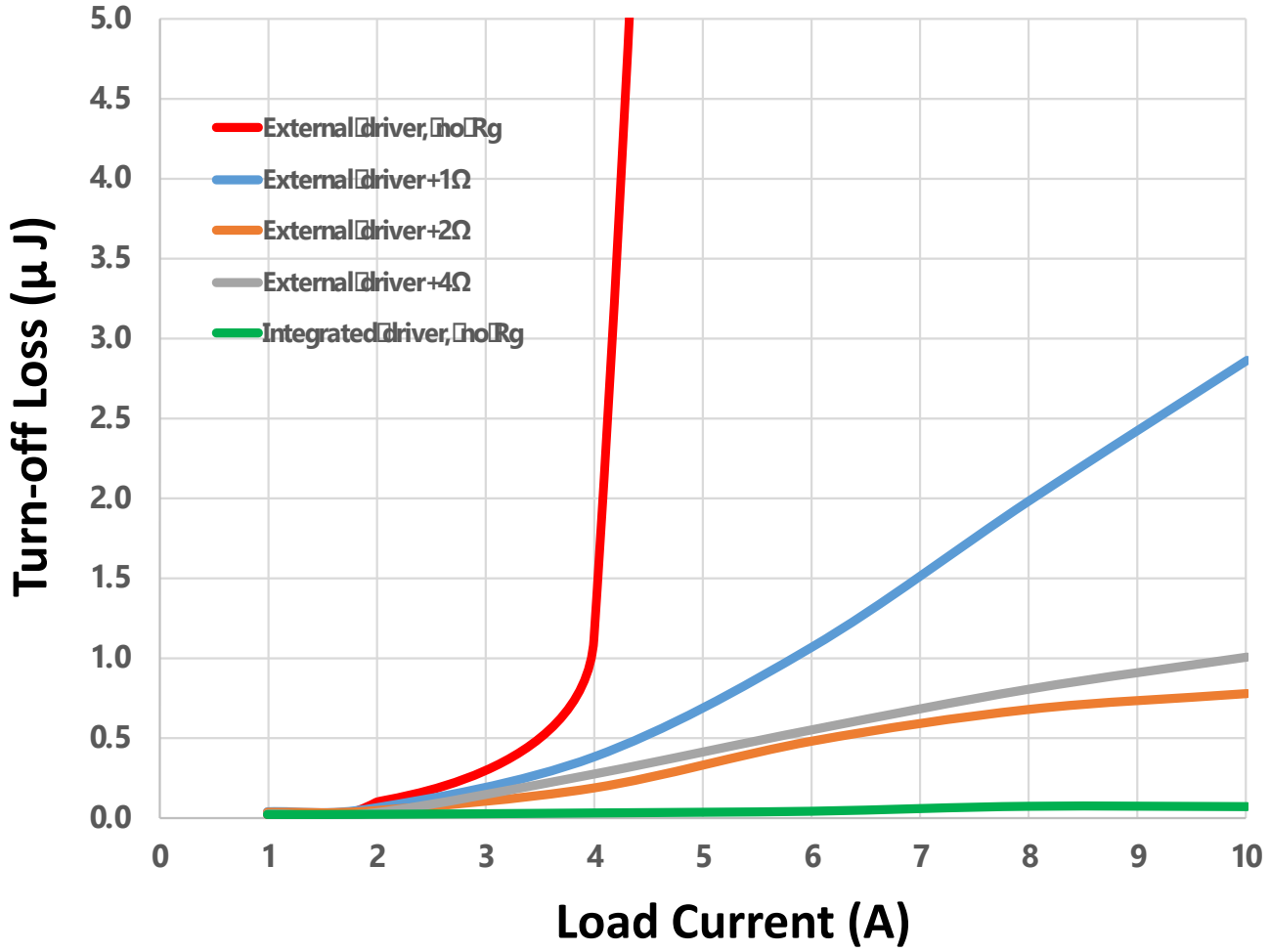
# Speed & Integration → Eliminate Turn-off Losses

## External drivers

- Significant turn-off losses
- Just 1-2 nH of gate loop inductance can cause voltage spikes that create unintended turn-on of the GaN FET
- Adding a gate resistor reduces spikes but slows down the circuit creating additional losses

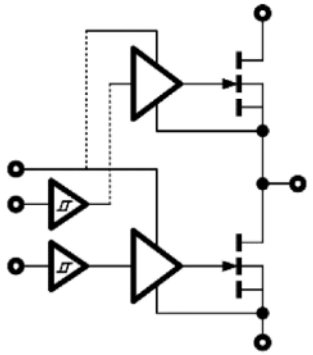
## Integrated GaN drivers (iDrive™)

- Eliminate the problem
- Negligible turn-off losses



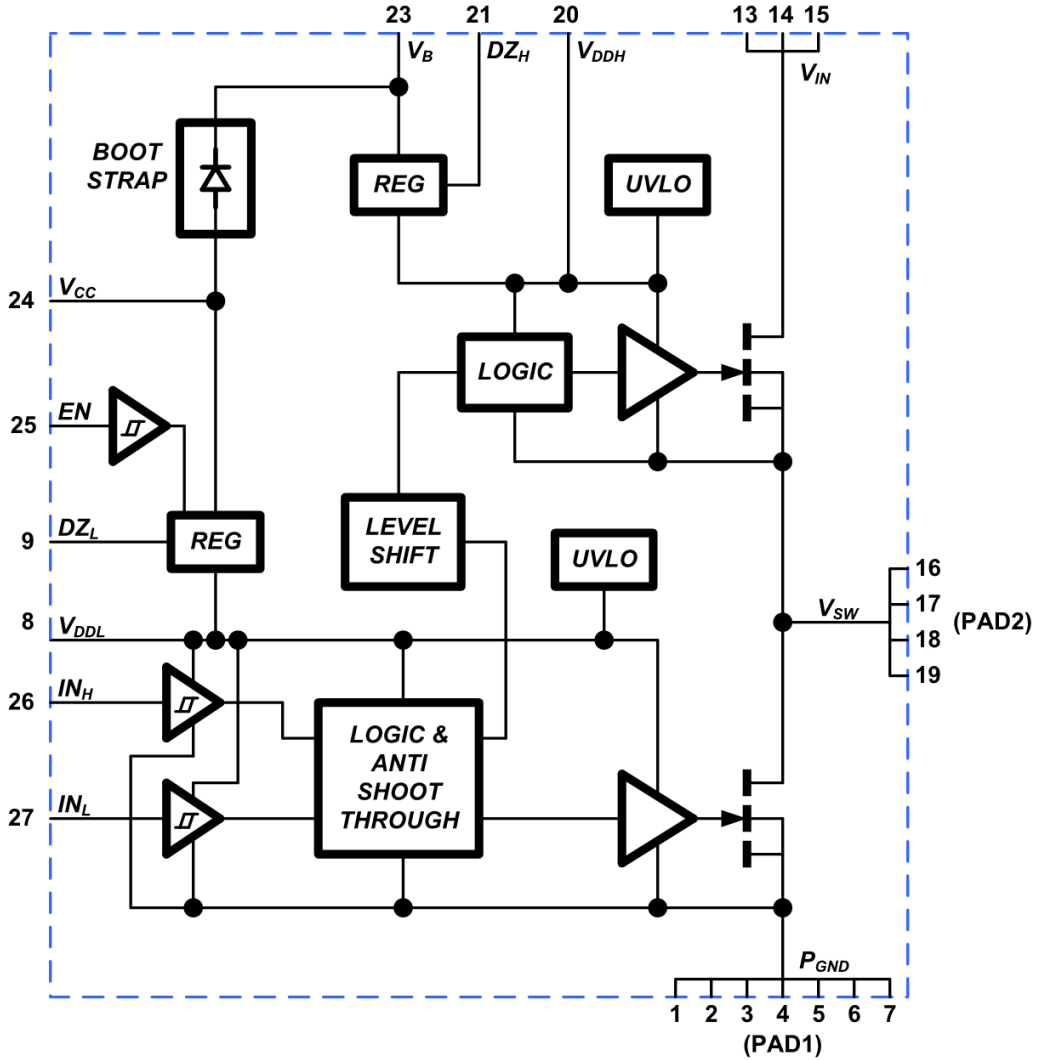
# Half-Bridge iDrive GaN Power IC


PQFN 6x8 mm

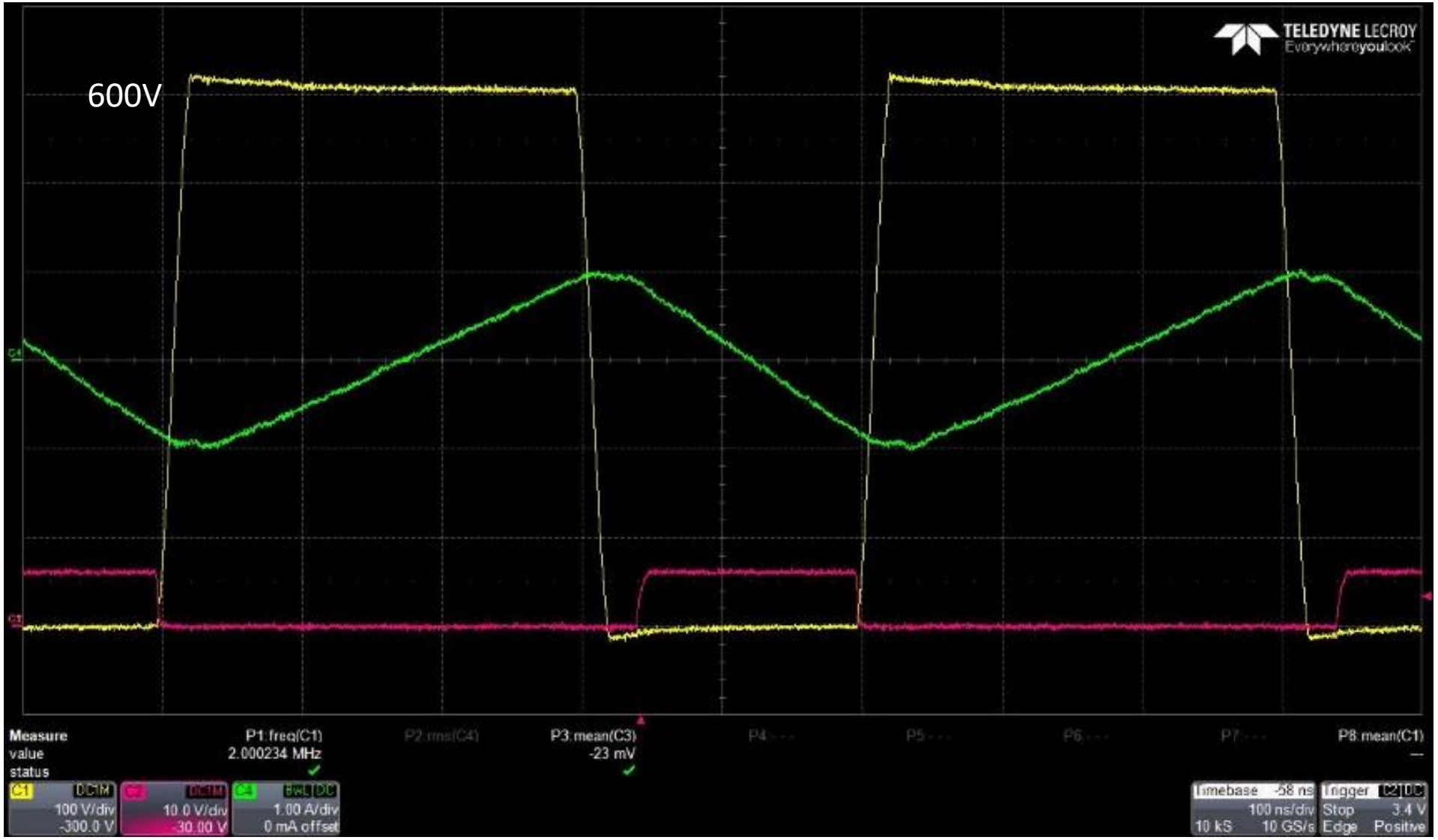


Simplified Schematic

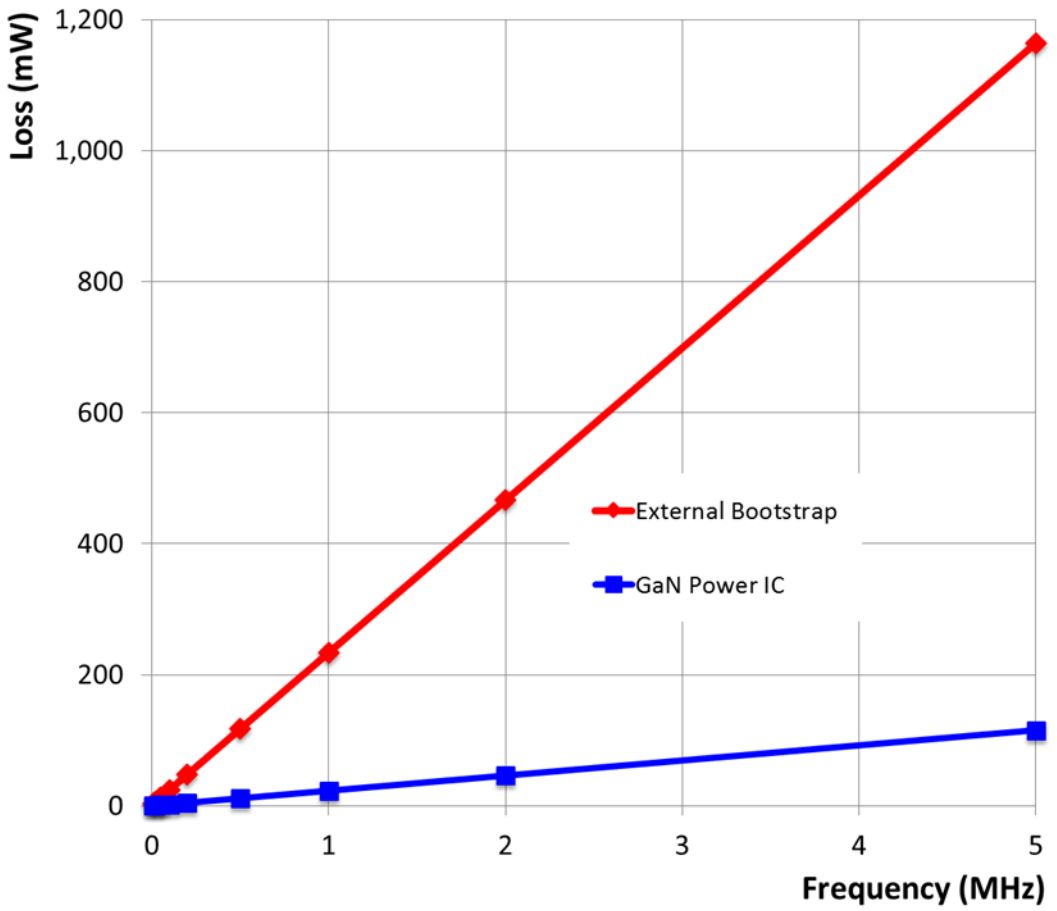
- Proprietary AllGaN™ technology
- Monolithic integration of 650V eMode GaN FET, driver, logic
- Internal level-shift, bootstrap
- Ground-referenced, digital input
- High dV/dt immunity (200 V/ns)
- Zero inductance turn-off loops
- Very fast (prop delay and turn-on/off of 20-40 ns)
- ESD, UVLO, shoot-through protection
- Flexible topologies: Active Clamp Flyback, Half-Bridge, LLC, etc.



# Half-Bridge GaN Power IC at 2 MHz

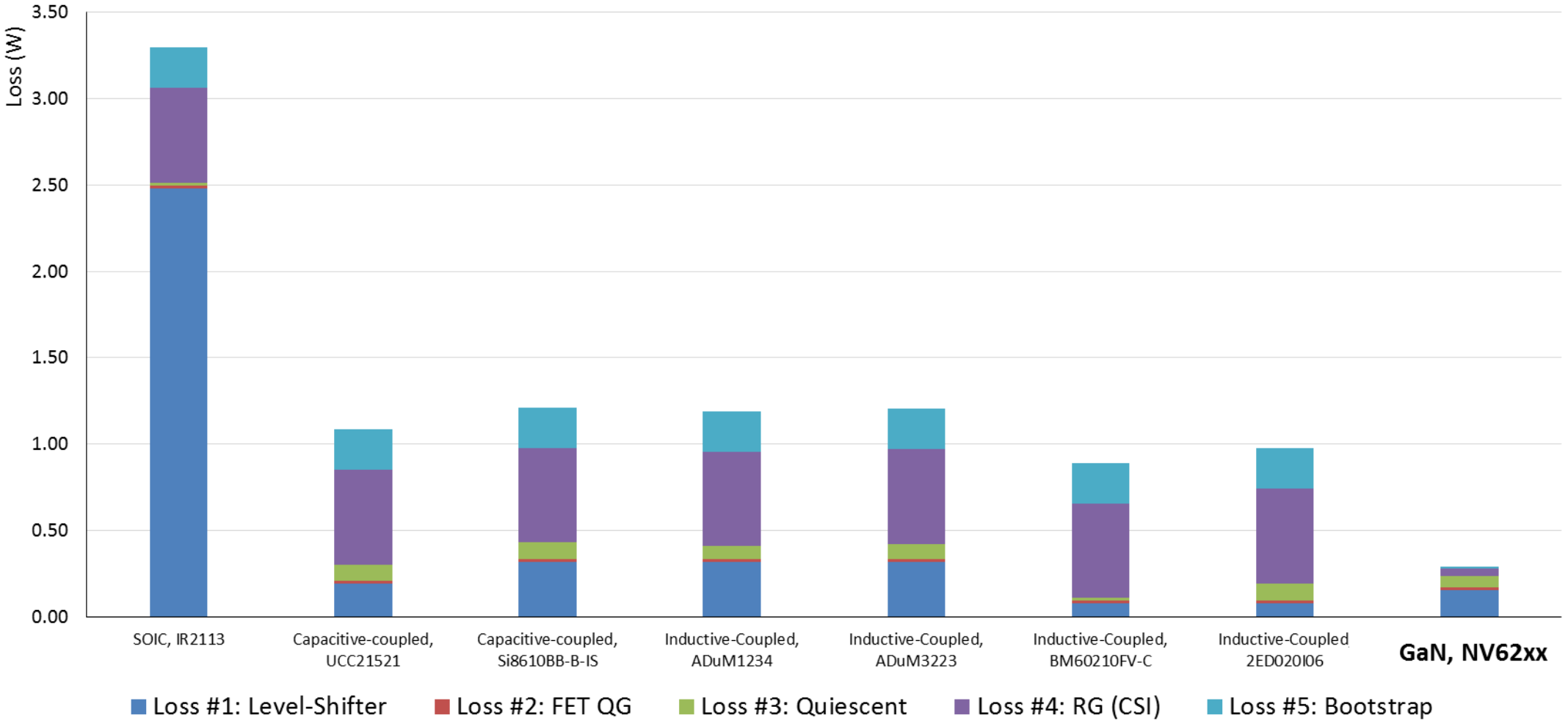


# Bootstrap Diode Loss = fn($C_{B\text{-}S\ Diode}$, $Q_{rr}$, $F_{SW}$)




- External diode ES1J (600 V, 1 A, $V_F$ = 1.7V at 1 A, SMA)

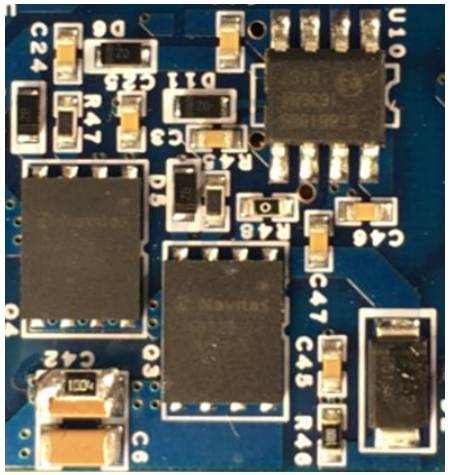
# 3x Lower Level-Shift Total Loss at 1 MHz



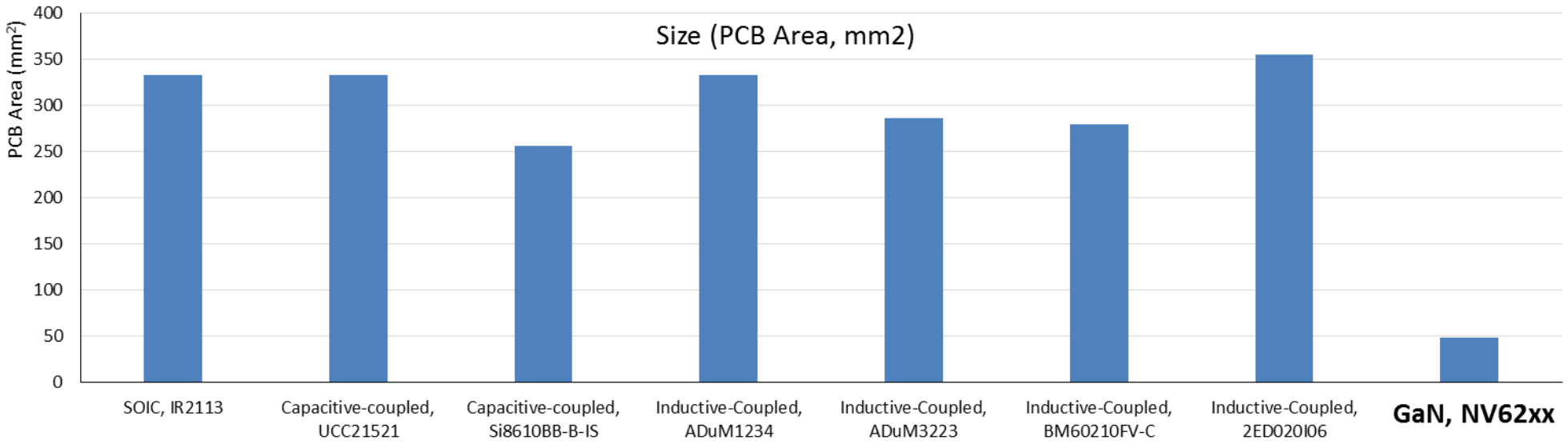

FET-specific loss (e.g. $I^2R$) common across all options, not included

# 5x Smaller, Easier

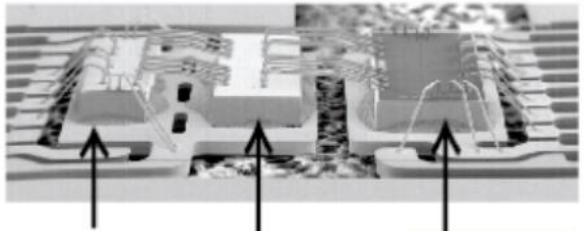
Si8610 + 2x FETs + Bootstrap + Rs, Cs




NV62xx



# High-Frequency Half-Bridge Integration

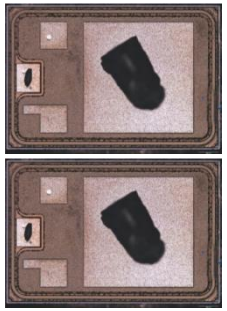


I/F Chip Si CMOS

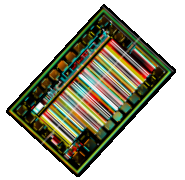
On-chip Transformer $SiO_2$ / Polyimide

Gate Driver Chip Si CMOS

Bootstrap Diode Si / SiC



Half-Bridge FETs Si



AllGaN™ Technology
Lateral 650V GaN-on-Si


Disparate technologies:
Hybrid isolator / driver with discrete powertrain

Homogeneous platform:
Lateral GaN-on-Si, NV6250 Half-Bridge GaN Power IC

**3** Losses
*(FET-size, $I^2R$ independent)*

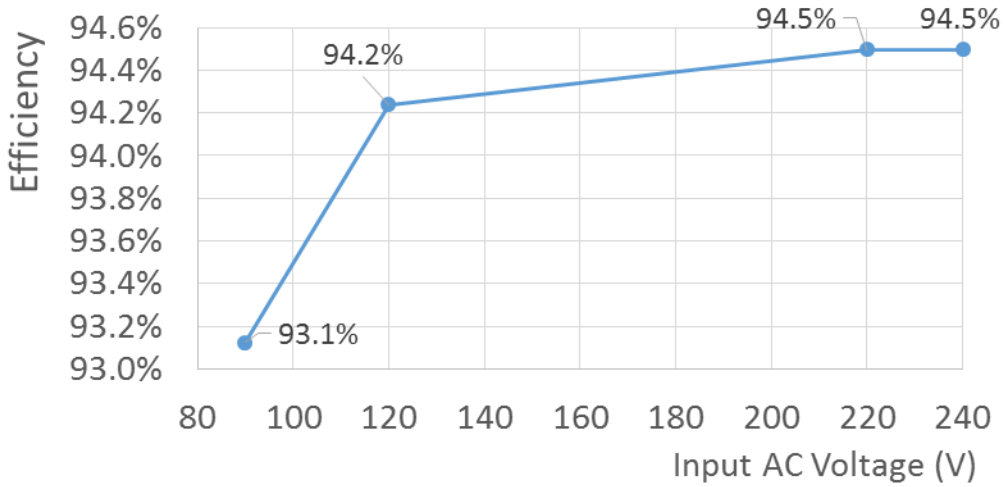
1) Driver loss, $R_G$ loss
2) Bootstrap supply
3) Level shifter

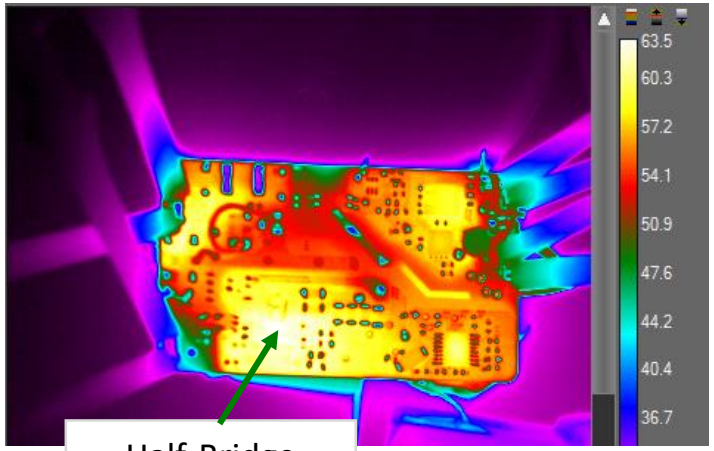
**Zero** Losses
*(FET-size, $I^2R$ independent)*

1) No gate driver loop parasitics, matched driver-FET capability, negligible loss vs frequency
2) Low equivalent $V_F$ , zero $Q_{rr}$
3) Extremely fast, low-power level shifter, multi-MHz operation, short propagation delay

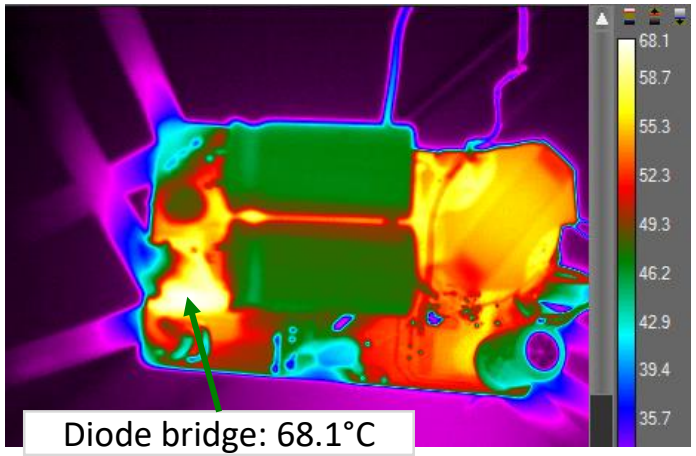
# 45W Adapter – 25 W/in³

59.1 x 33.5 x 15.7 mm



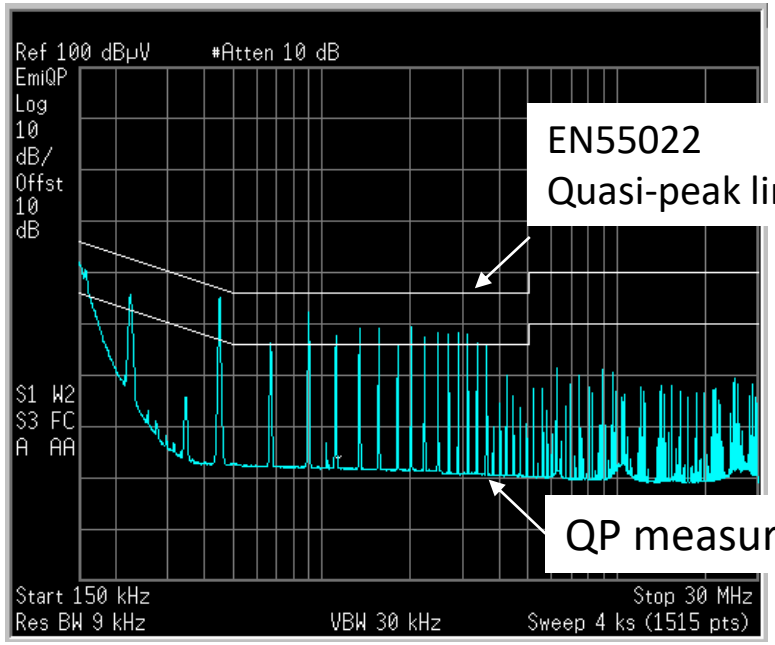




Half-Bridge
GaN IC: 63.5°C




Diode bridge: 68.1°C

45W, 90$V_{AC}$, no airflow, room ambient




EN55022
Quasi-peak limit

QP measure


# Next-generation GaN Isolators / Level-Shifters for High Frequency, High Efficiency Power Conversion

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Additional APEC references:

Paper ID#1104, State-of-the-Art Mobile Charging: Topologies, Technologies and Performance, Tom Ribarich and Stephen Oliver (Navitas)
Paper ID#2158, Active Clamp Flyback Using GaN Power IC for Power Adapter Applications, Lingxiao Xue and Jason Zhang (Navitas)
Paper ID#1159, GaN Power ICs at 1 MHz+: Topologies, Technologies and Performance, Dan Kinzer (Navitas)
Paper ID#1117, Next-Generation GaN Isolators for High Frequency, High Efficiency Power Conversion, Stephen Oliver, Marco Giandalia (Navitas)