PWR SOC 18

**Integrated Power Conversion and Power Management**

*next generation technology for emerging business opportunities, October 17, 18, 19, 2018, Hsinchu, Taiwan*

*new technologies* *new applications* *new markets*

# Navitas

# GaNFast™ PwRSoCs


*Dan Kinzer, CTO & COO, Navitas Semiconductor*

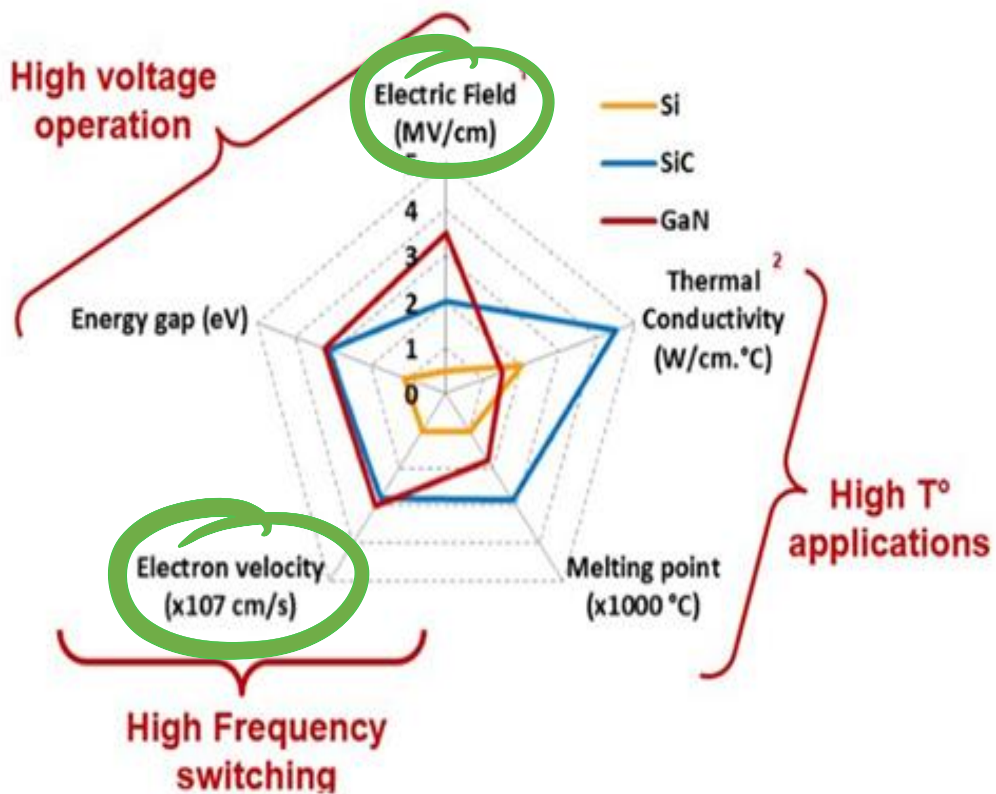

*PWRSOC18 Session 5, Hsinchu, Taiwan*

*October 18, 2018*

# Performance Limits of Power Semi Materials

GaNFast™

## Important Material Attributes

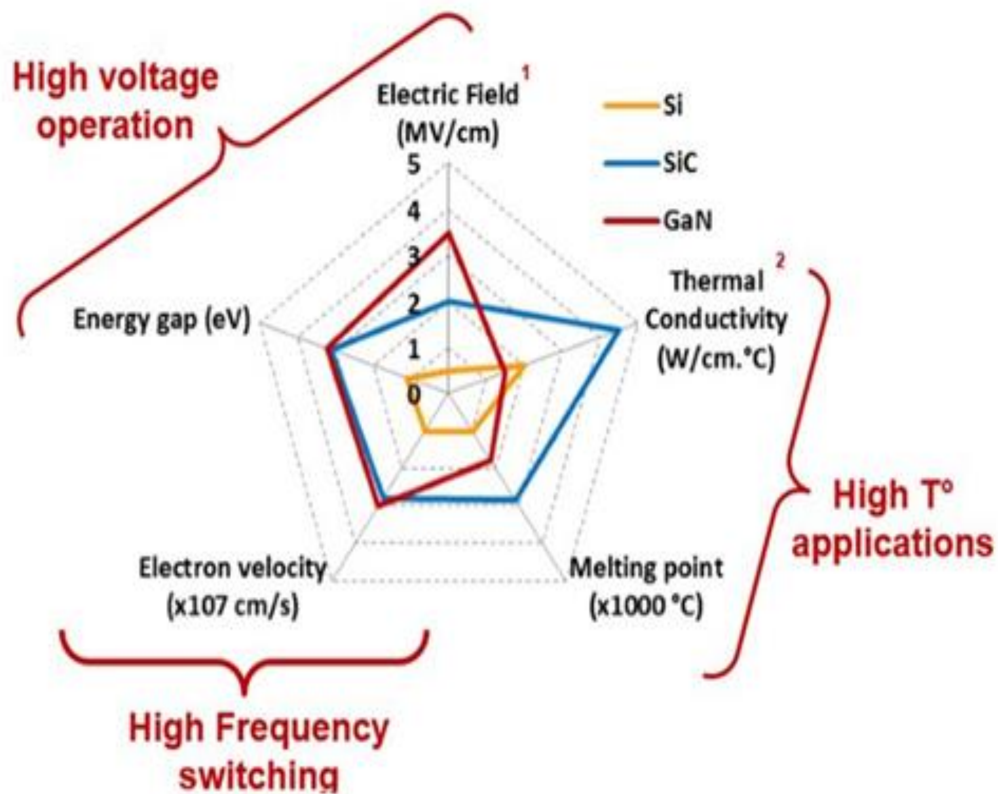



## Theoretical 1-D $R_{DS(ON)}$ / $BV_{DSS}$ for Vertical Devices

T = 300 K
Si limit
SiC limit
GaN limit
Diamond limit
$R_{DS(ON)}$ (mΩ-cm²)
$10^{8}$
$10^{6}$
$10^{4}$
$10^{2}$
$10^{0}$
$10^{-2}$
$10^{-4}$
$10^{2}$
$10^{3}$
$10^{4}$
$10^{5}$
Maximum Voltage (V)

# Performance Limits of Power Semi Materials

## Important Material Attributes




## Theoretical 1-D $R_{DS(ON)}$ / $BV_{DSS}$ for Vertical Devices

$T$ = 300 K

Si limit

SiC limit

GaN limit

Diamond limit

Vertical Si Current Performance

Lateral GaN Current Performance

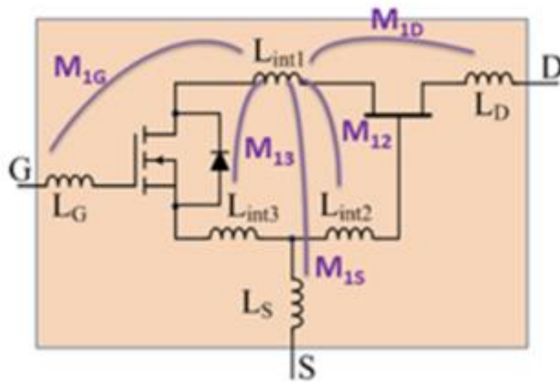
Lateral GaN 2-D Limit
(with 400 ohm-sq 2-DEG)
2.5 MV/cm, 3.5 MV/cm
***Almost matches Diamond!***

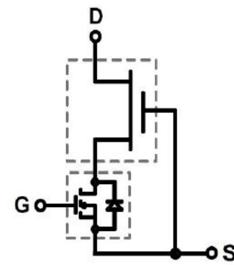
$R_{DS(ON)}$ (mΩ-cm$^2$): $10^{8}$, $10^{6}$, $10^{4}$, $10^{2}$, $10^{0}$, $10^{-2}$, $10^{-4}$

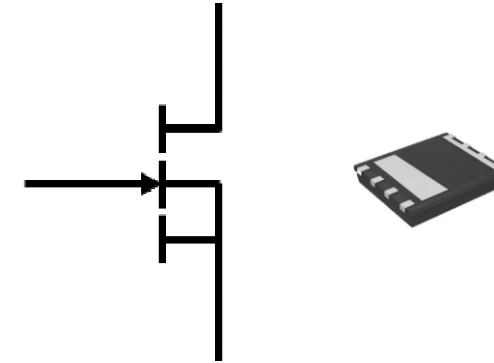
Maximum Voltage (V): $10^{2}$, $10^{3}$, $10^{4}$, $10^{5}$

# Two approaches: dMode and eMode GaN

GaNFast™





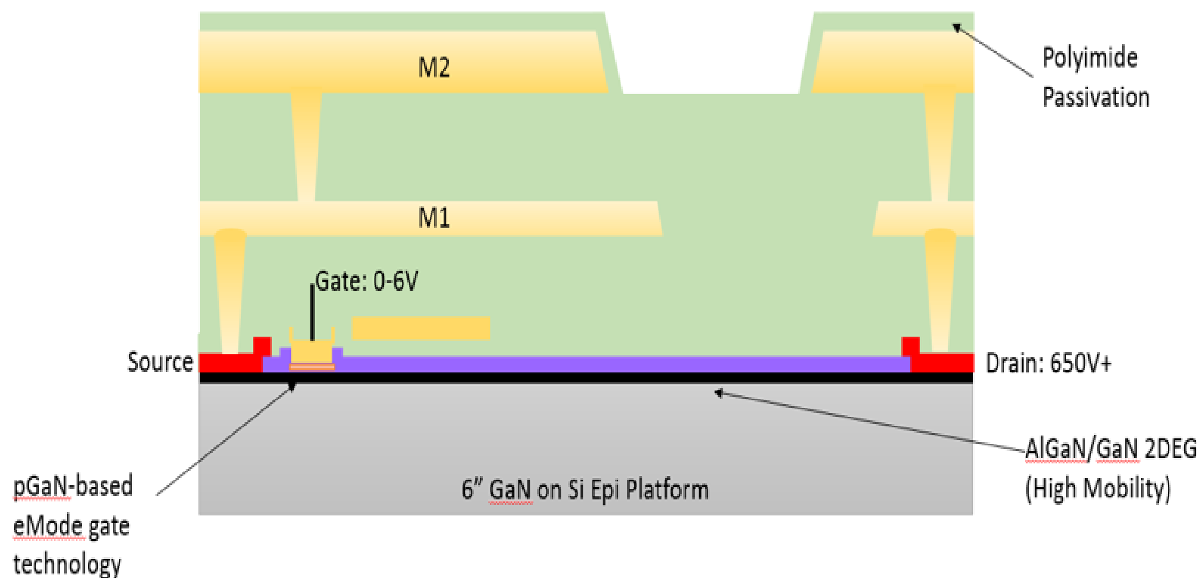
## Cascode GaN + Silicon Switch

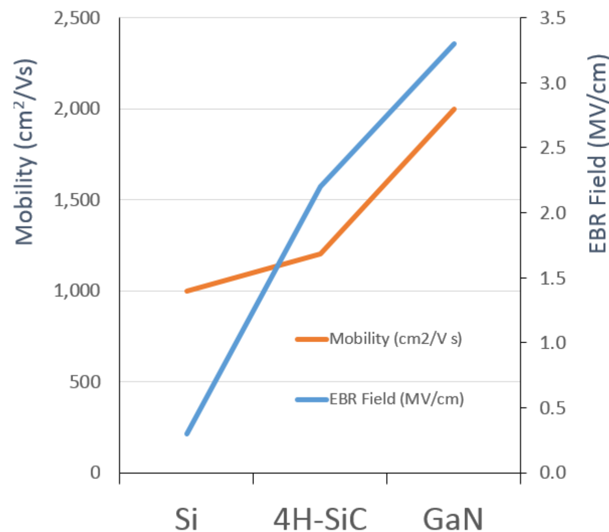
- Standard silicon FET gate
- Traditional packages
- Large package inductance
- Prone to oscillation
- No dV/dt control
- Complicated multi-die package

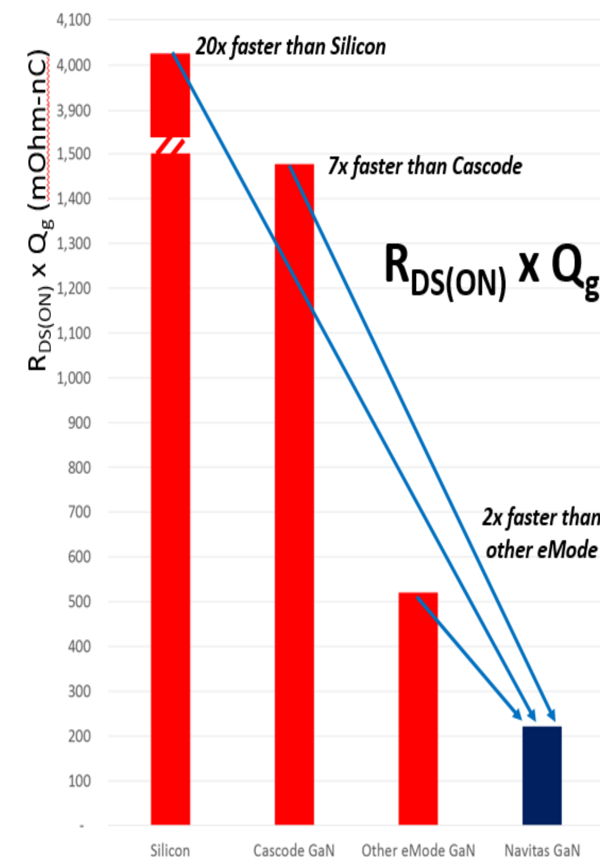
## eMode AllGaN™ Switch

- Extremely low gate charge
- No reverse recovery loss
- Easy to package
- Low package inductance
- Controlled dV/dt
- Careful gate voltage control

# 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
- Processed in established CMOS line → High yield, high capacity
- Multiple metal technology using standard CMOS processing equipment

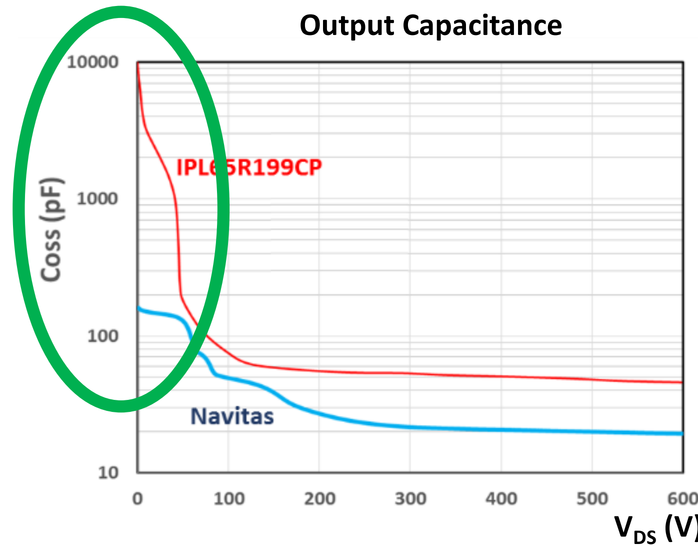
# GaN vs Silicon Output AC Characteristics

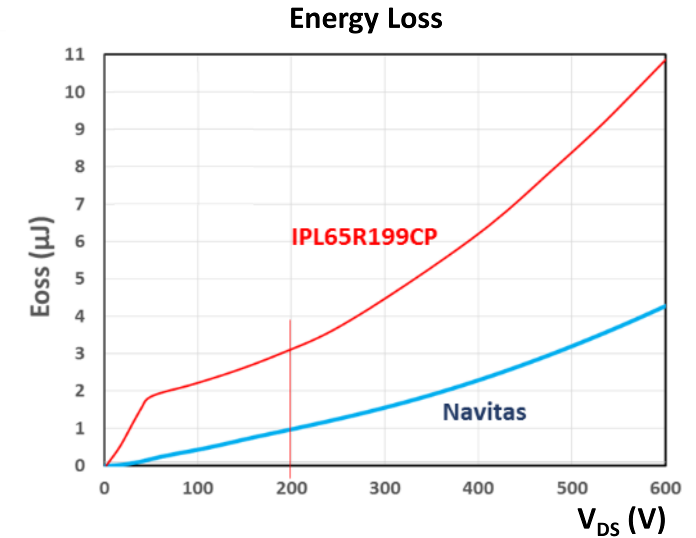
## Why is Silicon so High Loss?

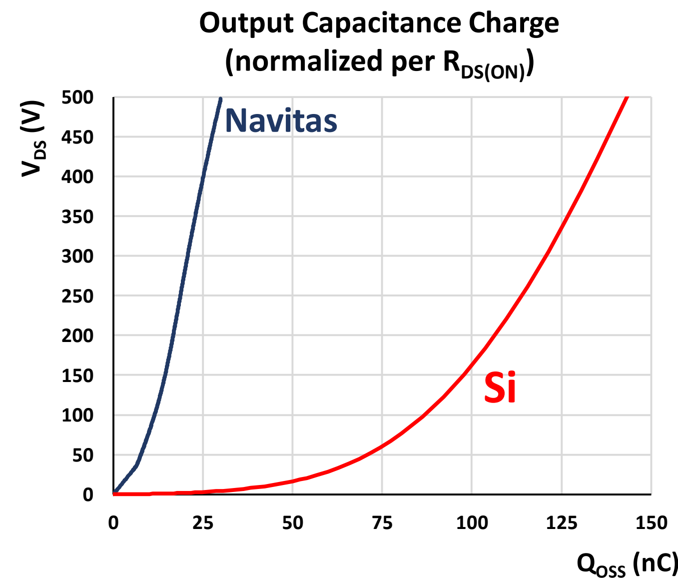
- Hard switching loss:
  $P_{LOSS} = E_{OSS}(V_{DS}) * F_{SW}$
- $C_{OSS}$ → Delay (limits $F_{SW}$)
- Too slow → partial ZVS → **$E_{OSS}$ loss**

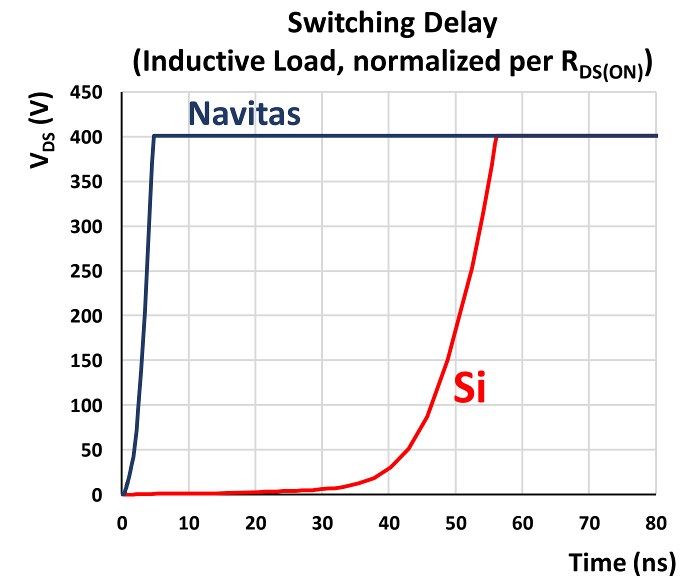
- Si $C_{OSS}$ is 50x-100x higher than GaN at $V_{DS}$ < 30V
- Si $P_{LOSS}$ is 3x higher than GaN at 200V (partial ZVS)
- Big effect at full or light load condition

Further information: "$C_{OSS}$ Hysteresis in Advanced Superjunction MOSFETs", Harrison, APEC 2016



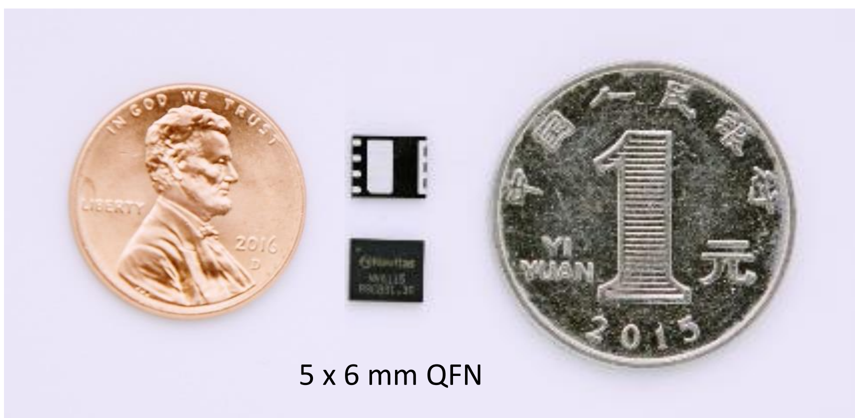



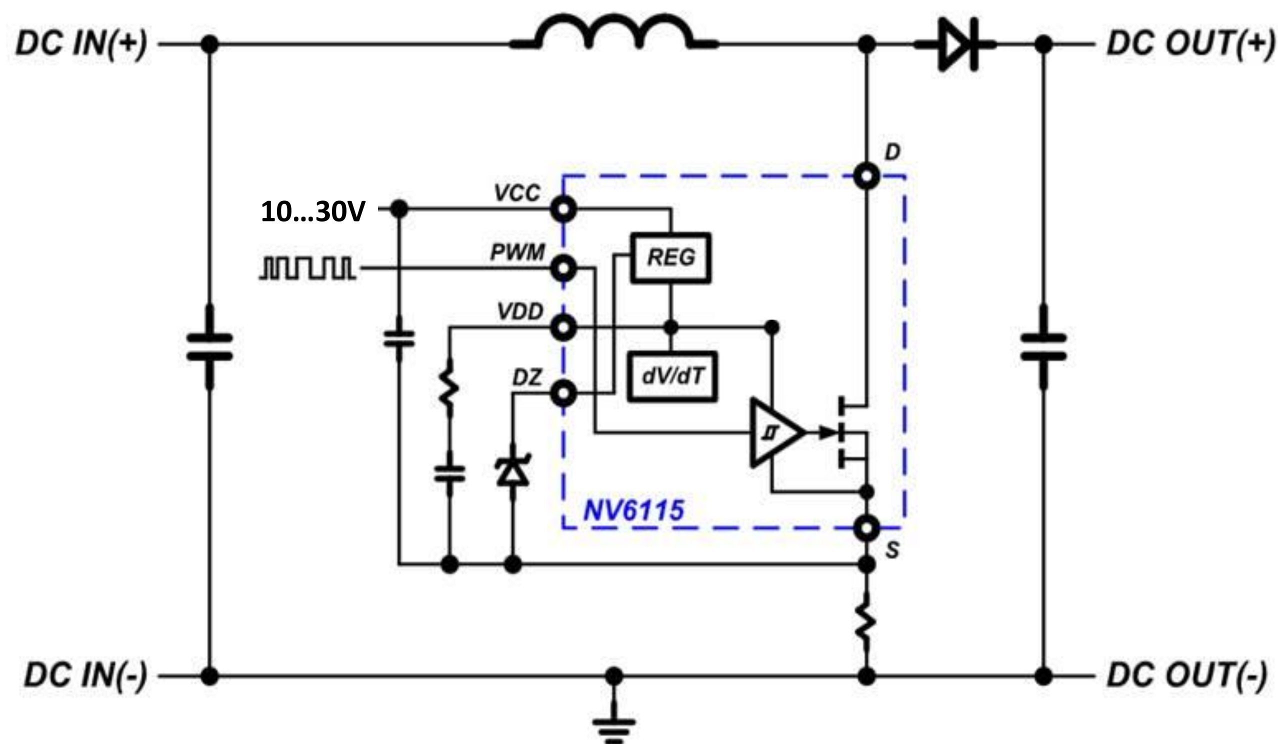
# Single Switch GaN Power IC

GaNFast™

## Monolithic integration at 650V

- GaN FET *(range 120-300 mΩ)*
- GaN gate driver (fast, no overshoot)
- Wide input voltage range (10-30V)
- GaN regulator (well controlled gate voltage)
- dV/dt control (programmable 10-100V/nsec)
- Hysteretic input, ESD, fault protection
- Fast and controlled start-up



# Integration Eliminates Turn-off Losses

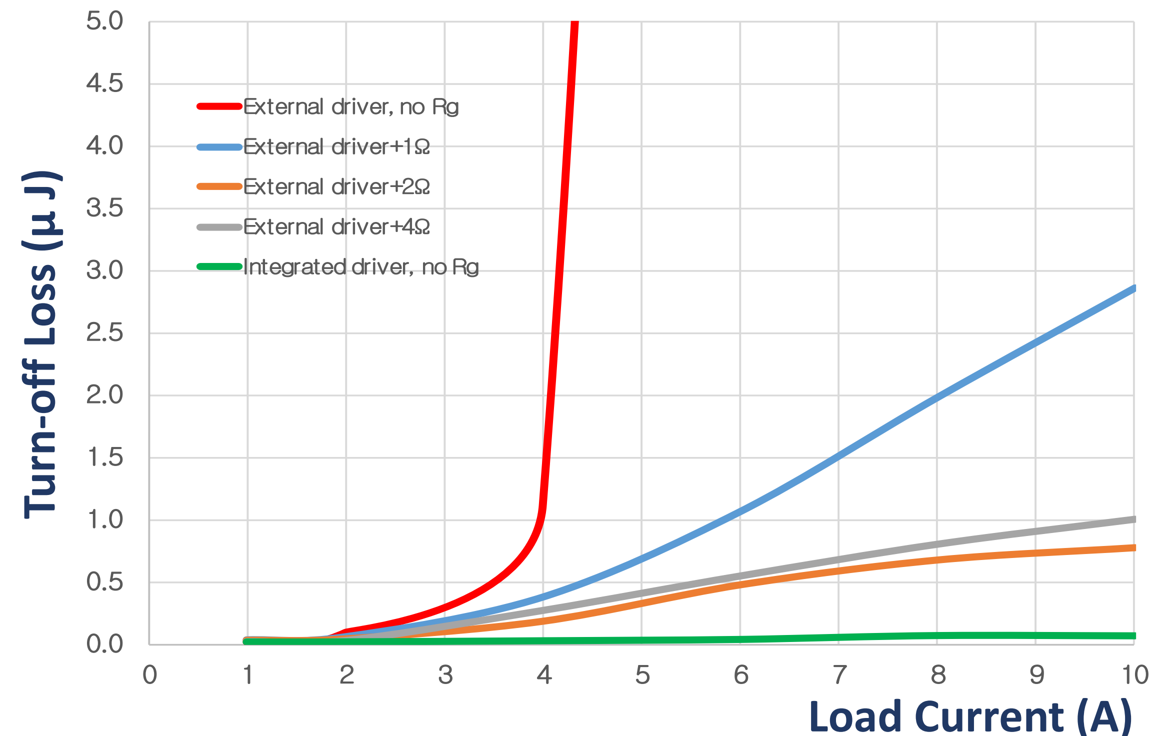
GaNFast™

## External drivers

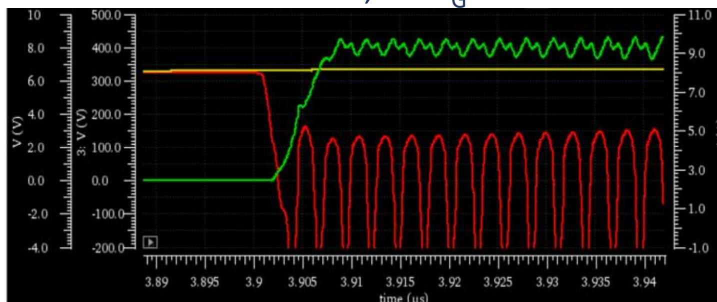
- Just 1-2 nH of gate loop inductance can cause unintended turn-on
- Gate resistors reduce spikes but create additional losses

## Integrated GaN drivers

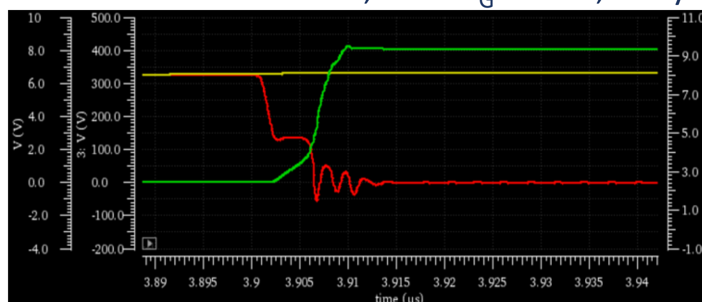
- Eliminate the problem
- Negligible turn-off losses
- Removes unintended turn-on due to high dV/dt




Discrete FET and drive, no $R_G$ = out of control



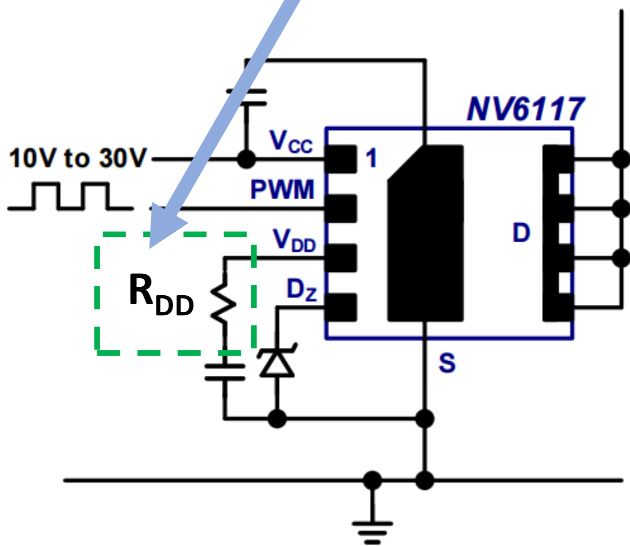
Discrete FET and drive, with $R_G$ = slow, lossy

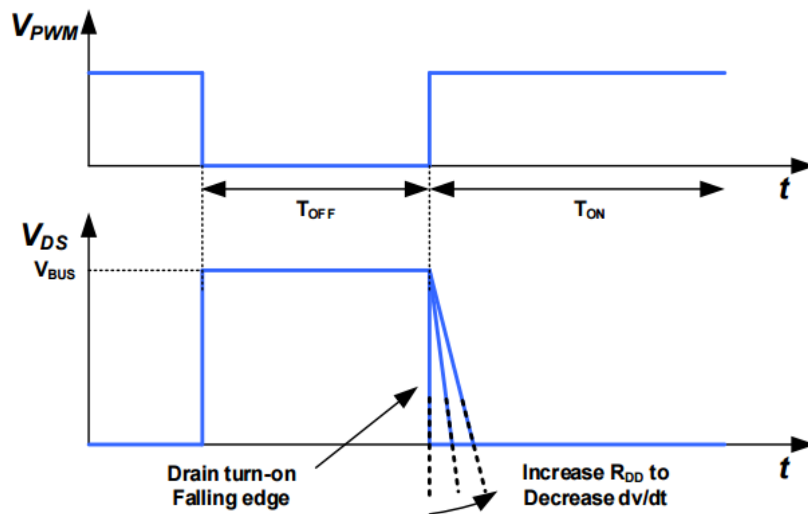


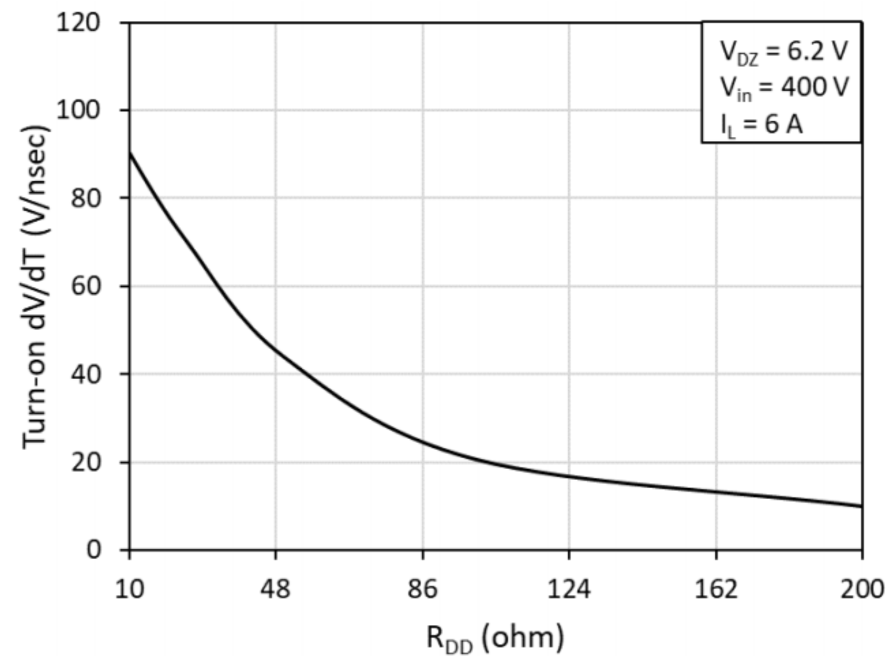
Integrated FET and drive, no $R_G$ = fast, efficient

# Voltage Slew-Rate Control … Easy EMI Tuning

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



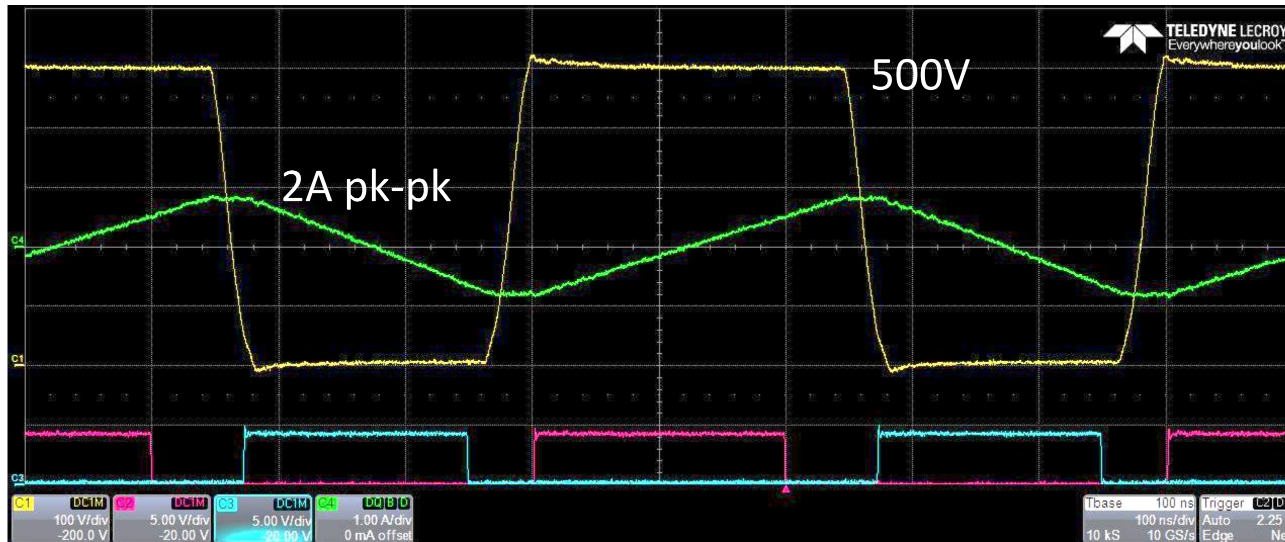



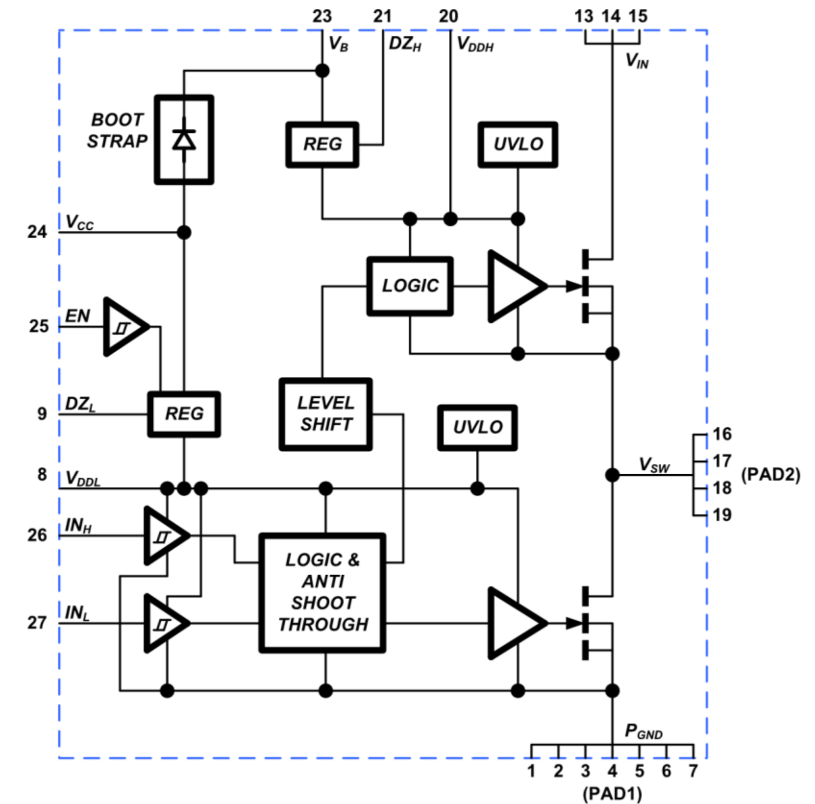



# High Integration: Half-Bridge GaN Power IC

GaNFast™

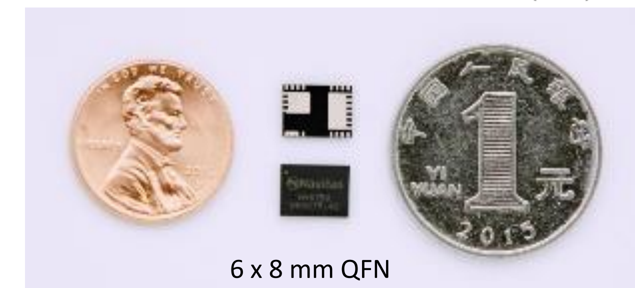
## 2 MHz Soft-Switching Operation




## Monolithic integration at 650V

- 2x 650V eMode GaN FETs *(a/symmetrical range 120-600 mΩ)*
- 2x 6V GaN gate drivers
- 2x 30V to 6V GaN regulators and UVLO circuits
- 650V GaN level-shifters and bootstrap drivers
- GaN Logic (shoot-through protection, fault mgmt, ESD, etc…)



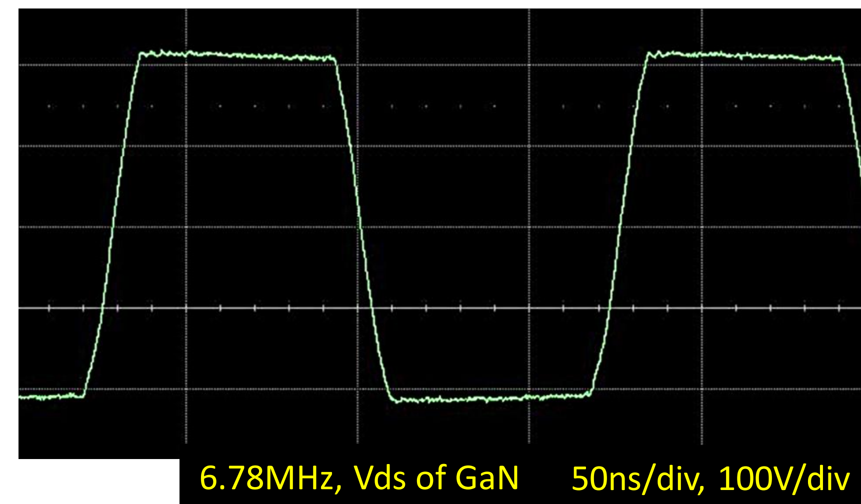
6 x 8 mm QFN

# Navitas 650V GaN Half-Bridge at 6.78MHz

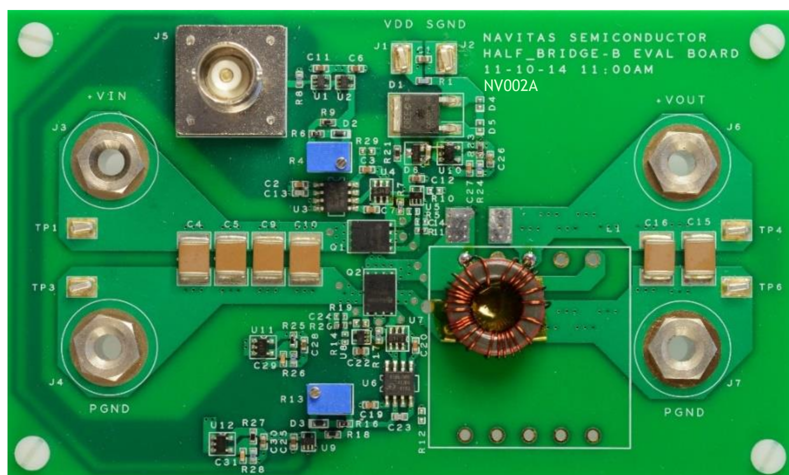
GaNFast™

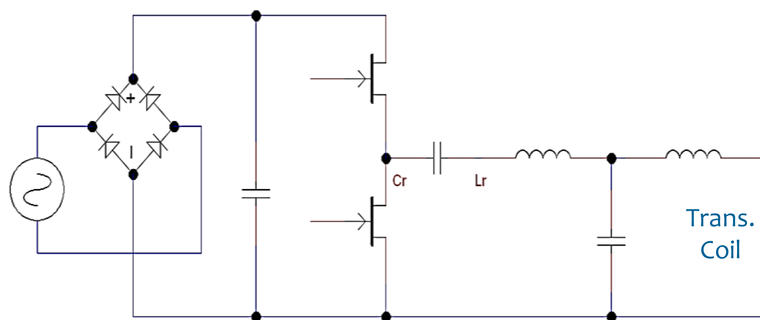
## Single-Stage AirFuel Wireless Power Transmitter

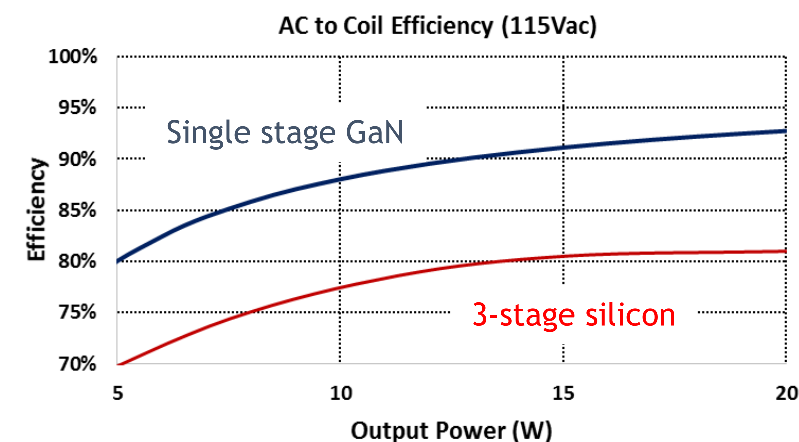
- **GaN Single Stage has <u>10% higher efficiency</u> AC input to RF output**
- ZVS half-bridge with 2x NV6115 (650V, 500mOhm, 5x6 PQFN)
- Clean ZVS switching at 400V and 6.78MHz
- Si is limited to ~400kHz, due 10x higher RxQ, poor body diode



6.78MHz, Vds of GaN 50ns/div, 100V/div



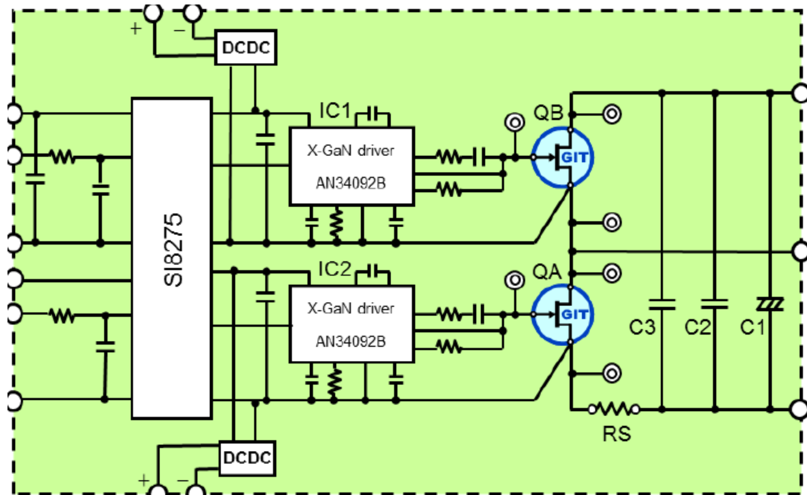



# Complex Design → *Made Simple*

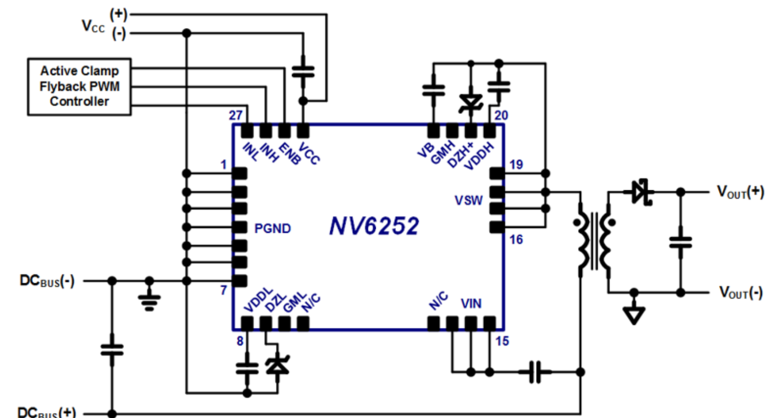
GaNFast™

## Half-Bridge *Discrete* GaN



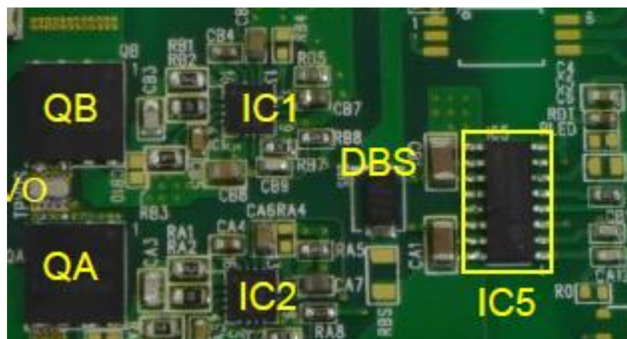

- 20x smaller PCB area
- 40+ fewer components
- Lower cost
- Robust & protected
- Simple
- Easy layout

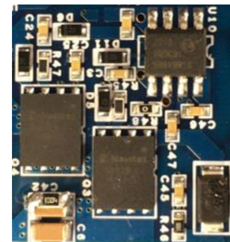
## Half-Bridge GaN *Power IC*




## Half-Bridge using 2x Single GaN *Power ICs*

+ isolator and bootstrap diode





PCB Area: 24 x 42 ~ 1,000 $mm^2$

PCB Area: 18 x 20 = 360 $mm^2$

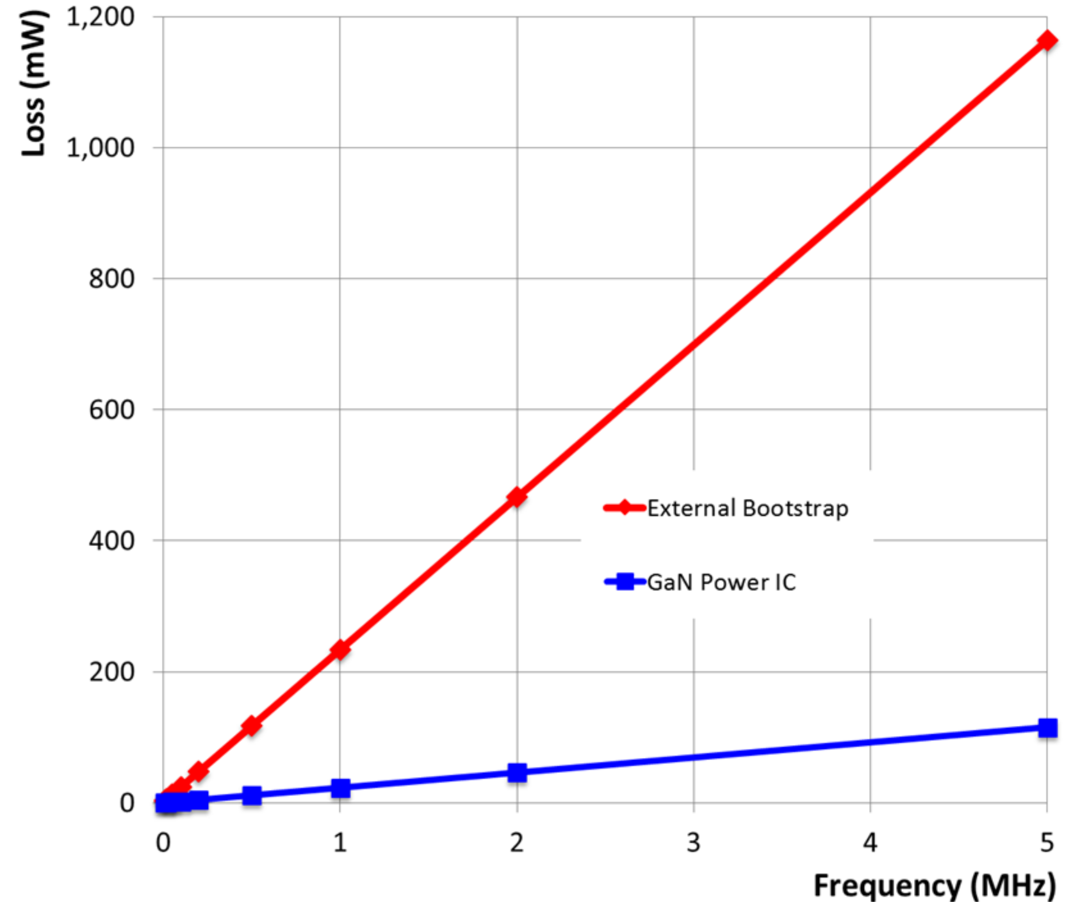
PCB Area: 6 x 8 = 48 $mm^2$

# Integration Eliminates Lossy Bootstrap Diode

GaNFast™

## Bootstrap Diode Integration Benefits:

- Avoids risk of dV/dt induced diode failure
- Eliminates diode recovery 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



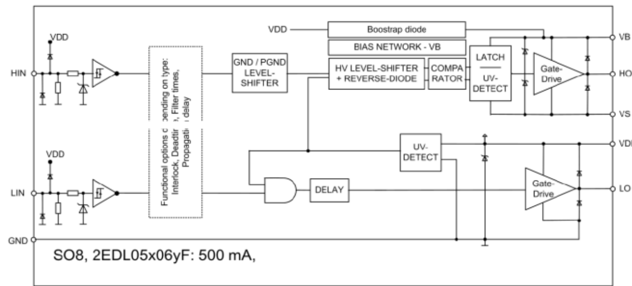

**Bootstrap Diode Loss = f($C_{diode}$, $I_r$, $Q_{rr}$, $F_{sw}$)**

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

# High-Frequency Level-Shift Candidates

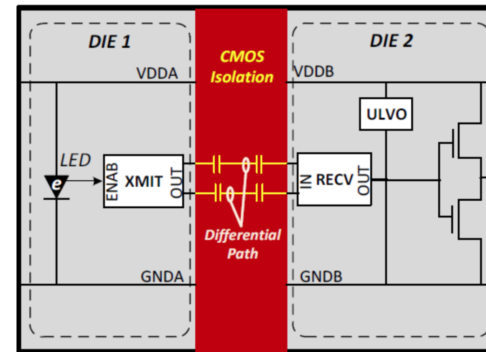
## Silicon-On-Insulator (SOI)

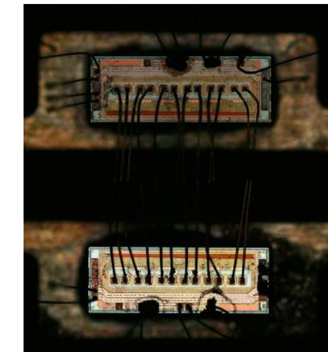
e.g. IR2113, UCC21521




## Capacitive-Coupled

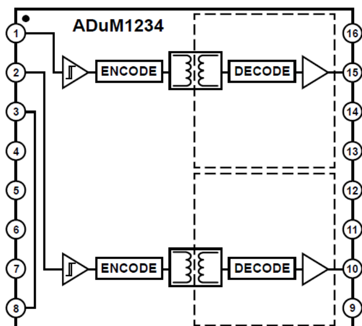
e.g. Si8610

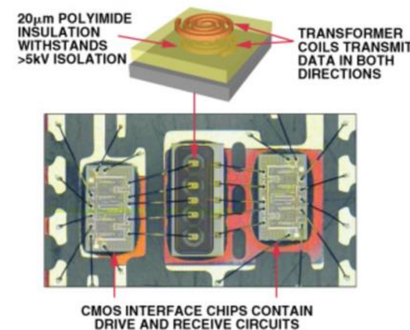


## Inductive-Coupled

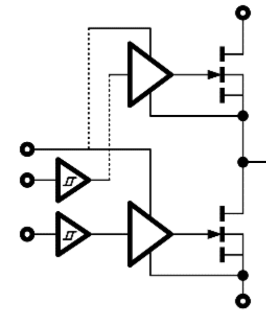
e.g. ADuM1234, ADuM3223, BM60210FV-C, 2ED020I06

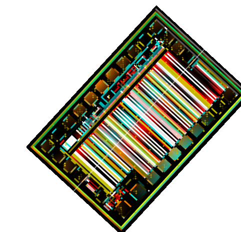



## GaN Power IC

e.g. NV62xx





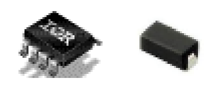
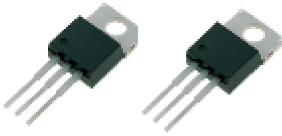
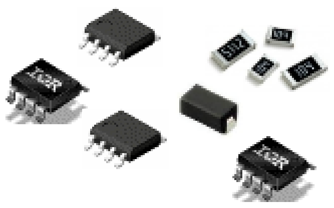
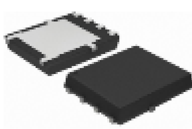
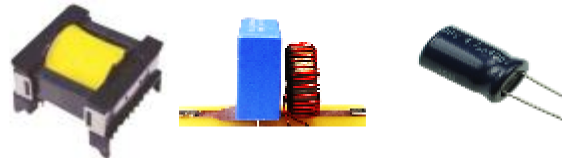
*Representative images, not to scale*

# 3x Lower Drive + Level Shift Loss, 1 MHz

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

# The Power of GaN Power ICs

GaNFast™

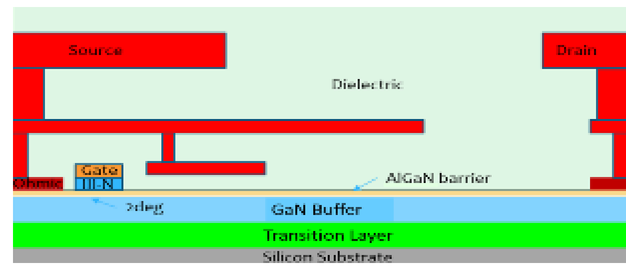
| | Driver Circuits | Power Devices | Passive Components | Switching Frequency | Energy Efficiency |
|---|---|---|---|---|---|
| *Silicon* |  |  | | *<100kHz* | *85-90%* |
| *Discrete GaN* |  |  |  | *300kHz* | *88-92%* |
| *GaN Power ICs* | | | | *>500kHz* | *90-95%* |

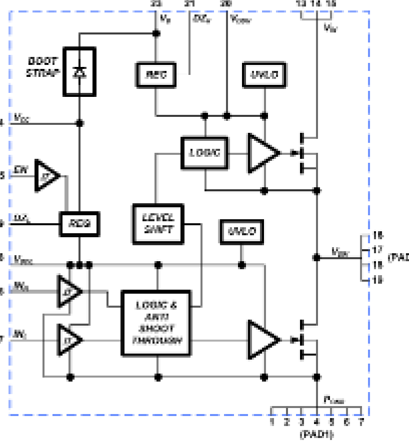
# Key Elements For New Adaptors

GaNFast™

## High Power Density Adaptors Needs

- GaN Power Device
- Higher Integration
- Advanced Magnetics
- High Frequency Controllers
- Soft Switching Topologies



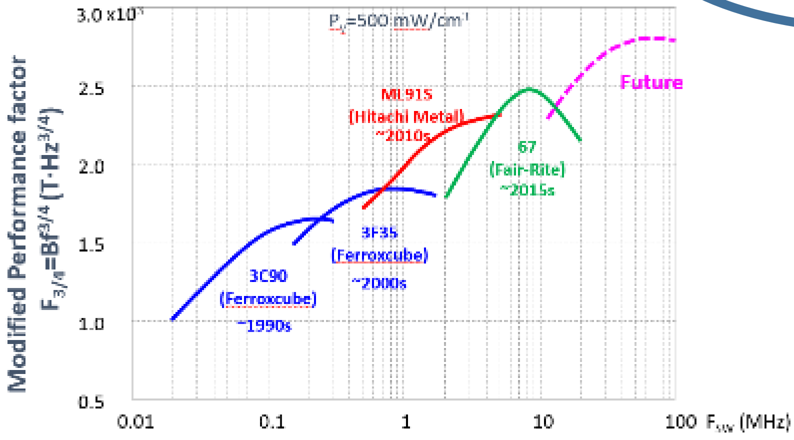

*Higher Integration*

*GaN Power Device*

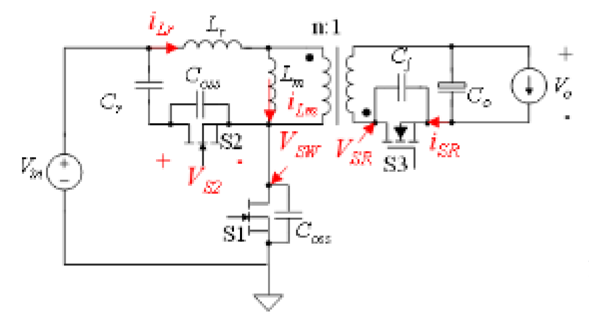
*New Magnetics*

*New Control IC*

*New Topology*

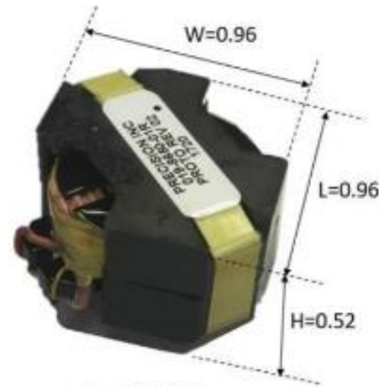



**>500Khz Controllers are ready!**

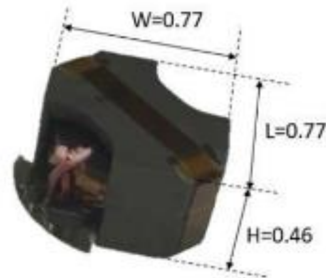


# Reduced Magnetics Size @ 500kHz

GaNFast™

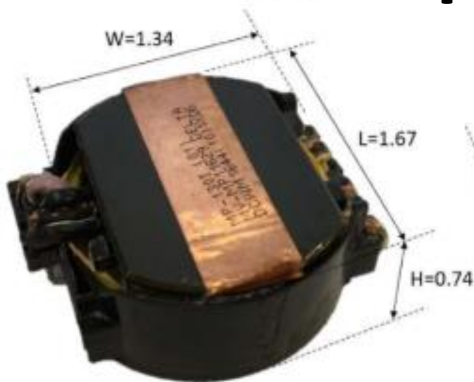



*Fsw=100kHz*
*RM10/ILP*
*0.48 in³*

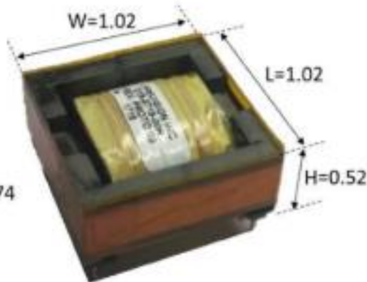



*Fsw=200kHz*
*RM8/ILP*
*0.27 in³*

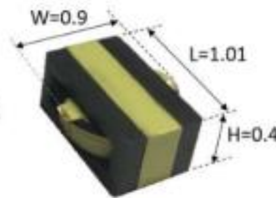
**PFC Lm**




*Fsw=100kHz*
*PT40*
*1.66 in^3*




*Fsw=300kHz*
*EFD25*
*0.54 in^3*



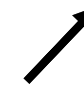

*Fsw=500kHz*
*ER25*
*0.36 in^3*

**LLC Lm**

$$L = \frac{V_{irms}^2 \cdot (V_O - \sqrt{2} \cdot V_{irms})}{2 \cdot f_{sw\,(min)} \cdot P_i \cdot V_O}$$

**Fsw↑→ Lm↓→ Size↓**

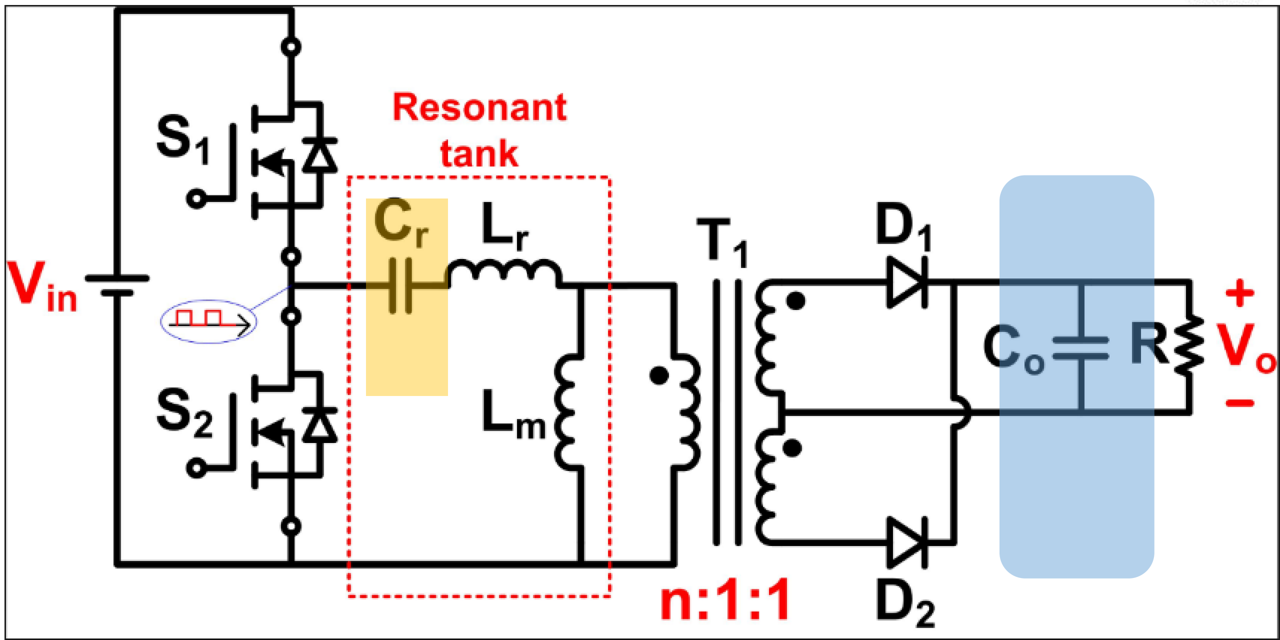
**Fsw↑→ Lr, Cr↓→Lm↓→Size↓**



**GaN → Coss↓**

# Frequency Reduces Capacitor Size

GaNFast™




Output Ripple = ESR Ripple + Cap Ripple

ESR is dominant factor at high fsw

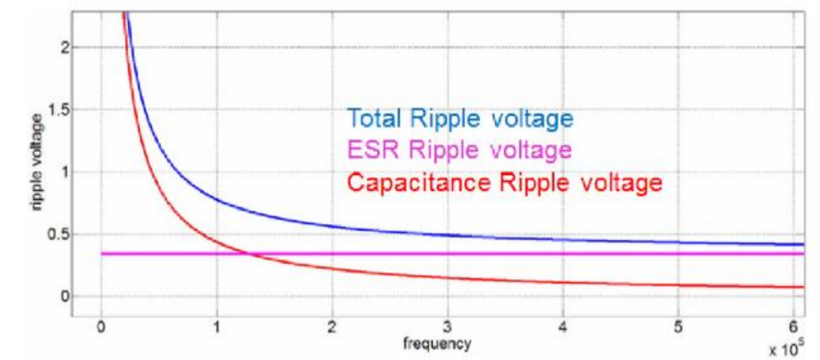



**Fig. 4.** Ripple voltage variation according to the switching frequency

"Design Considerations of Resonant Network and Transformer Magnetics for High Frequency LLC Resonant Converter",

J Electr Eng Technol.2016; 11(2): 383-392

# LLC 500kHz: Clean & Low Loss with GaN ICs

GaNFast™

## Switching Waveforms: DC-DC (LLC) Stage

TELEDYNE LECROY
Everywhereyoulook™

500kHz

C4
C1

| Measure | P1:duty(C1) | P2:freq(C1) | P3:rms(C4) | P4:--- | P5:--- | P6:--- | P7:--- | P8:--- |
|---|---|---|---|---|---|---|---|---|
| value | | 505.0734 kHz | 956 mA | | | | | |
| status | | ✓ | ✓ | | | | | |

C1 DC1M 100 V/div -298.5 V
C4 DC B D 1.00 A/div 0 mA offset

Tbase -2.00 µs 1.00 µs/div 100 kS 10 GS/s
Trigger C1 DC Stop 38 V Edge Neg

# 40W/in3, 95% efficient, 150W, 19V Adaptor

LLC (500kHz)

GaNFast™
Power ICs

CrM Boost PFC (200+kHz)

LLC Transformer, ER25

LLC Resonant Inductor
*(LLC IC on bottom side)*

SR IC, FETs

EMI

AC Bridges

Bulk Caps

PFC Inductor, ER25

# GaN Efficiency Outperforms Silicon

25%
+4.5%

50%
+3.5%

75%
+2.5%

100%
+2%

0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.9
0.89
0.88
0.87
0.86
0.85
0.84
0.83
0.82
0.81
0.8

0 20 40 60 80 100 120 140 160

Navitas GaN IC
Si MOSFET

90Vac 120Vac 220Vac

GaNFast™

# Let's go GaNFast™