Navitas

Power Accelerated

GaN Power IC Enable Next Generation Power Adaptor Design

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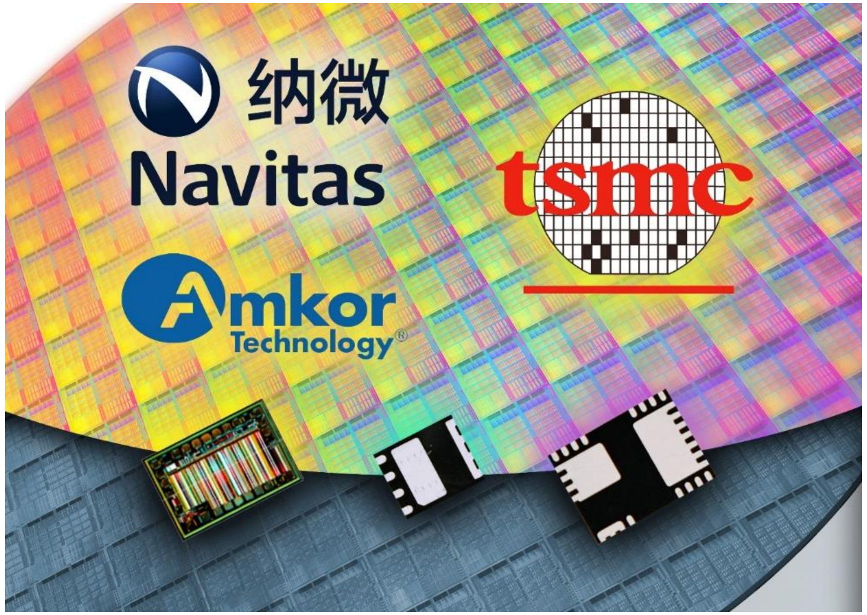
2018前瞻電源設計與功率元件技術論壇 Jan -30th

Navitas Semiconductor Inc.

- World's first & only GaN power IC company
- Founded January 2014
- HQ in El Segundo, CA, USA
- World-class team
- World-class manufacturing partners
- www.navitassemi.com



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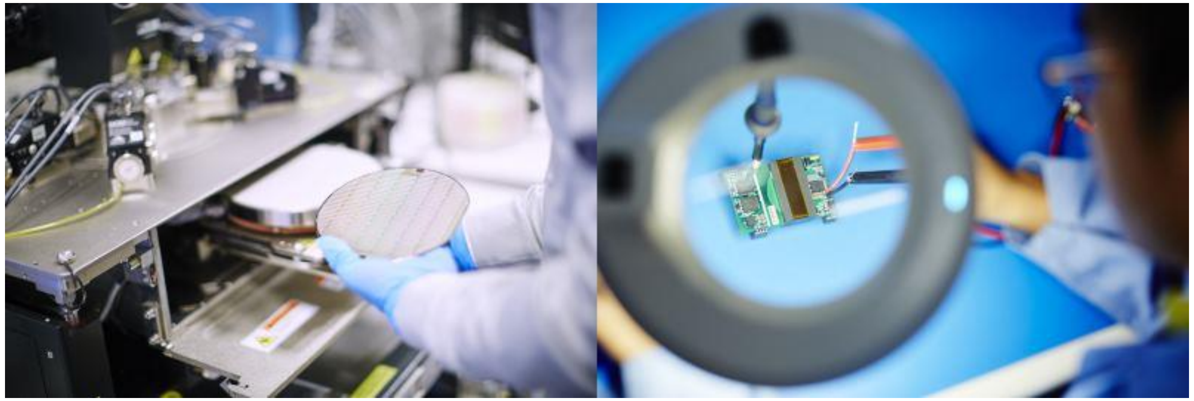
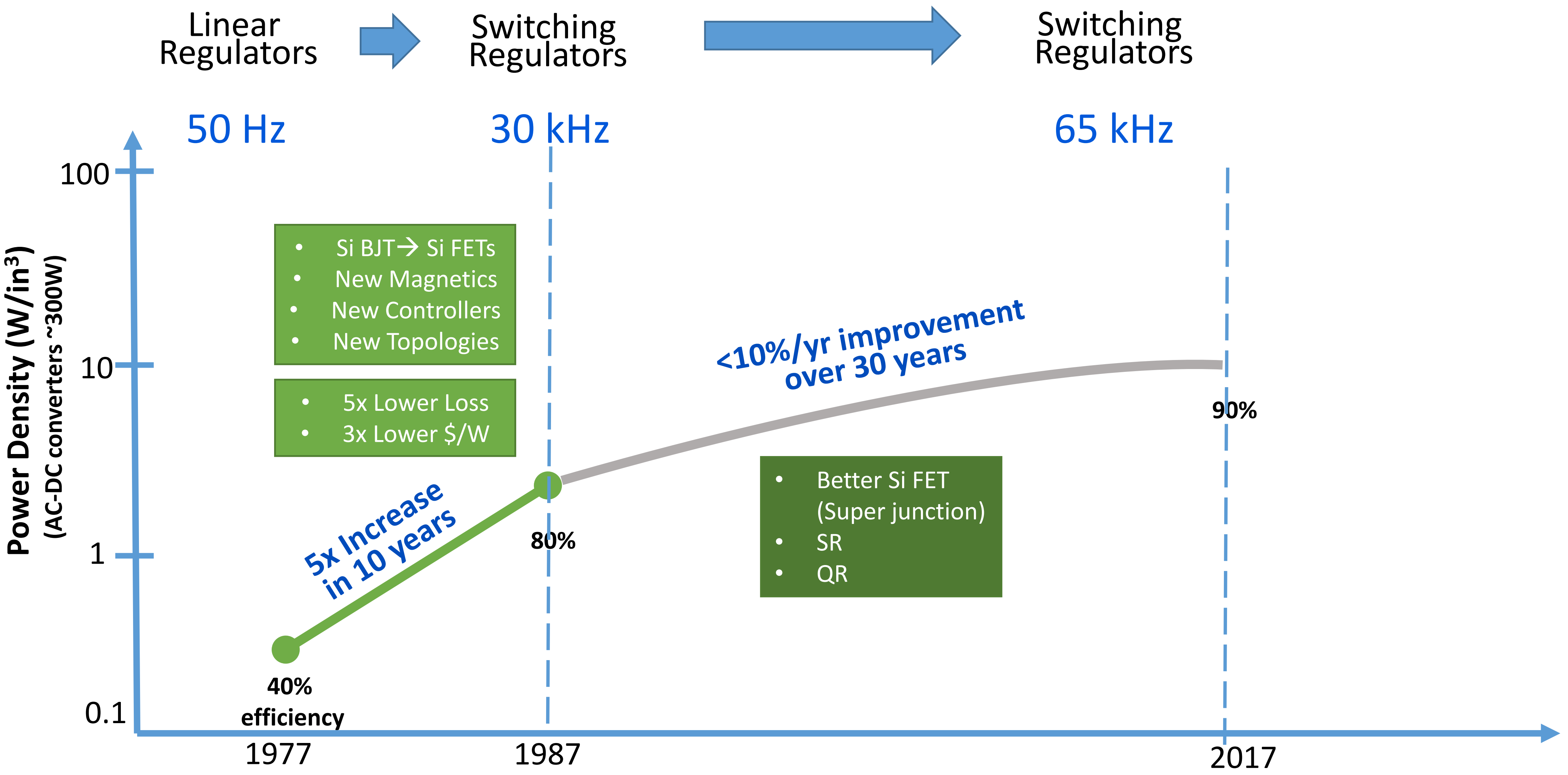
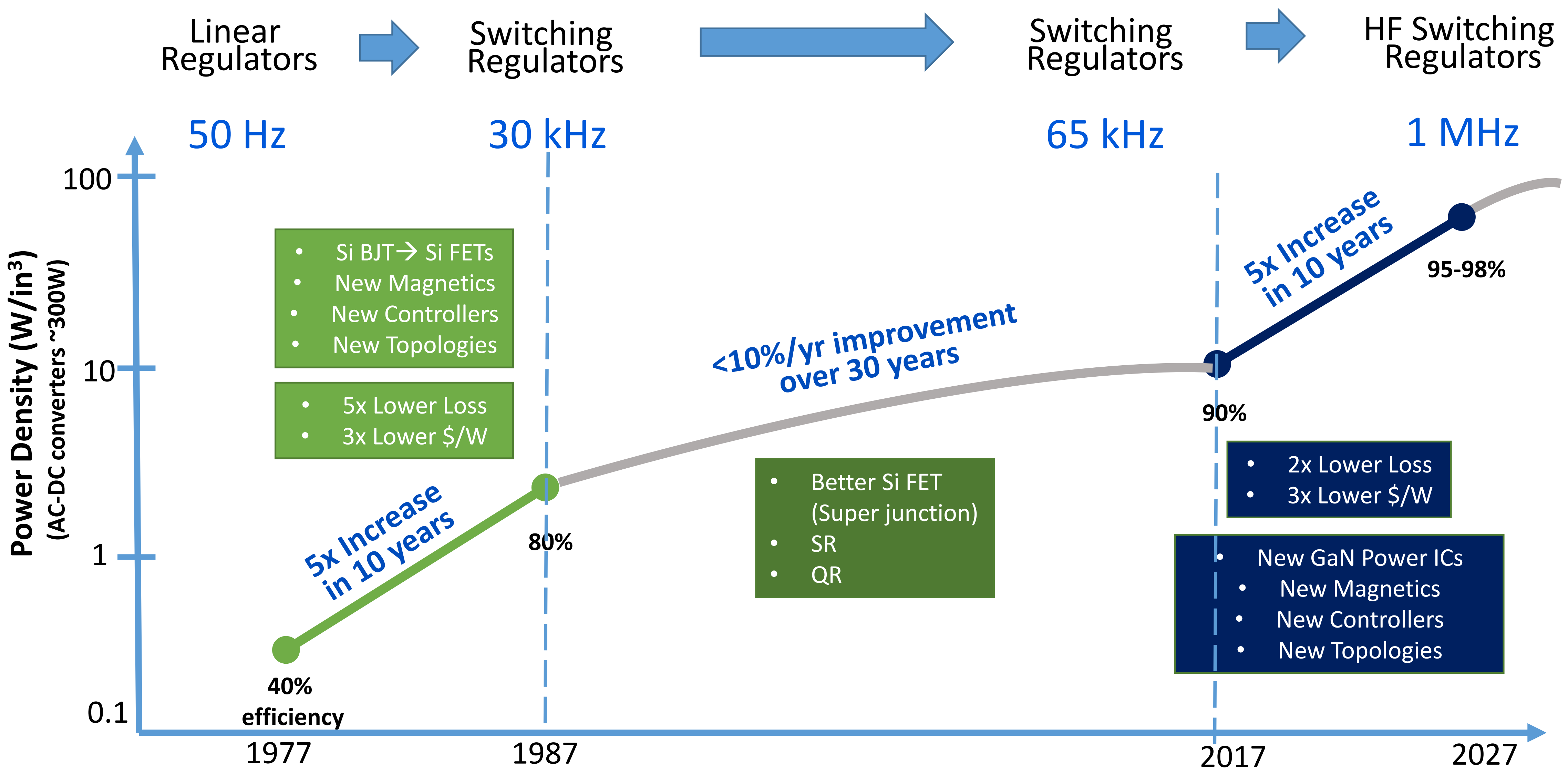


The First Revolution in Power Electronics

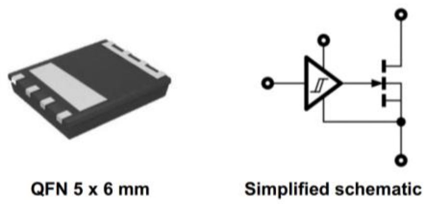


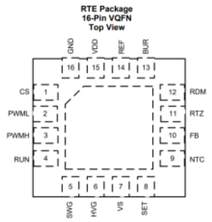
Today's Power Revolution



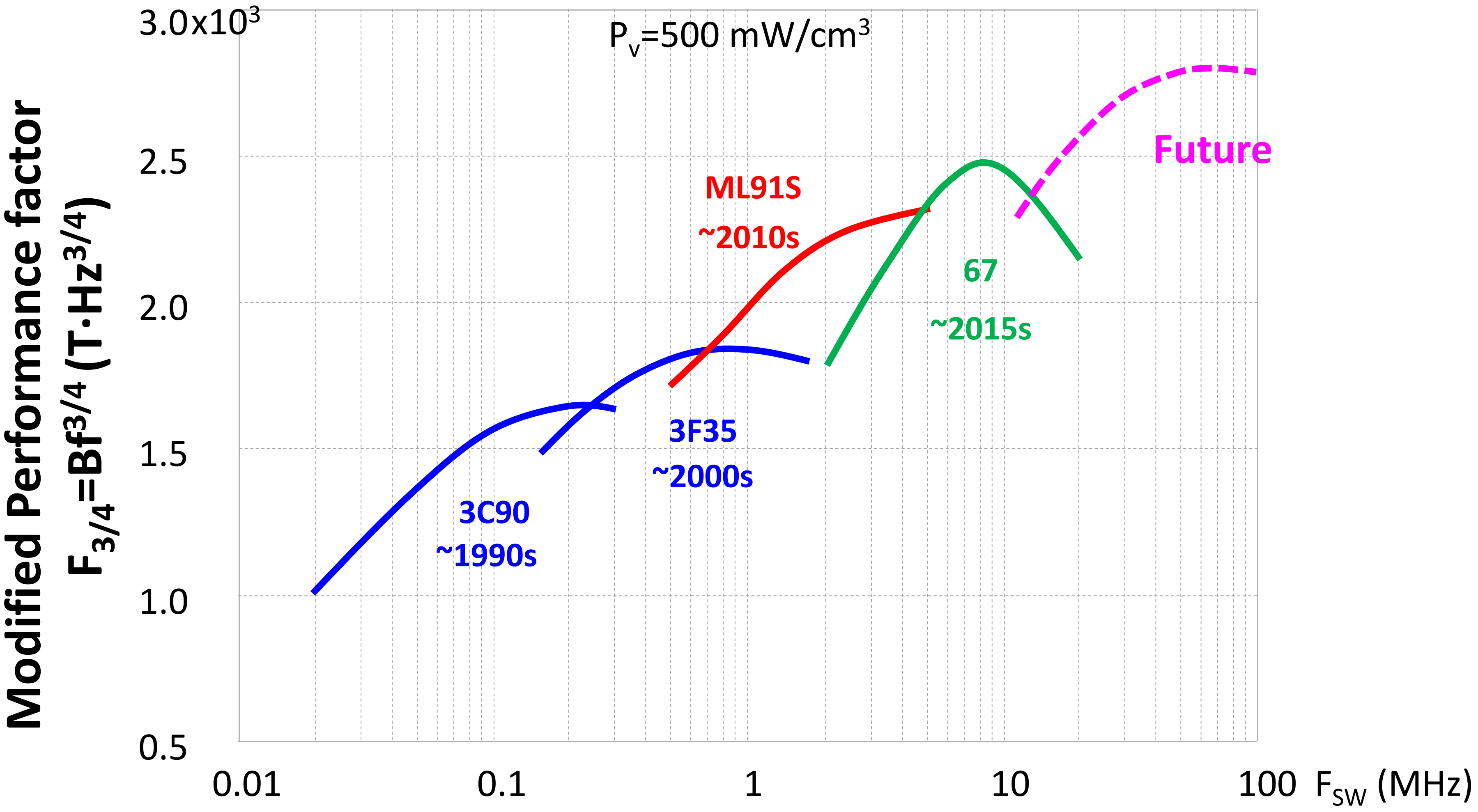
Key Factors for Next Generation Power Adaptor

- **HF Power Switch**
  - GaN Power IC, GaN FET, SiC FET
- **HF Magnetics**
  - 300kHZ~2MHz
- **HF Controllers**
  - ASIC ACF (up to 2MHz)
  - ASIC TP PFC (up to 2MHz)
  - ASIC LLC (up to 2MHz)





HF Magnetics



Y. Han, G. Cheung, A. Li, C. R. Sullivan and D. J. Perreault, "Evaluation of Magnetic Materials for Very High Frequency Power Applications," in *IEEE Transactions on Power Electronics*, vol. 27, no. 1, pp. 425-435, Jan. 2012.

A. J. Hanson, J. A. Belk, S. Lim, C. R. Sullivan and D. J. Perreault, "Measurements and Performance Factor Comparisons of Magnetic Materials at High Frequency," in *IEEE Transactions on Power Electronics*, vol. 31, no. 11, pp. 7909-7925, Nov. 2016.

HF Power Switch: Navitas GaN Power IC

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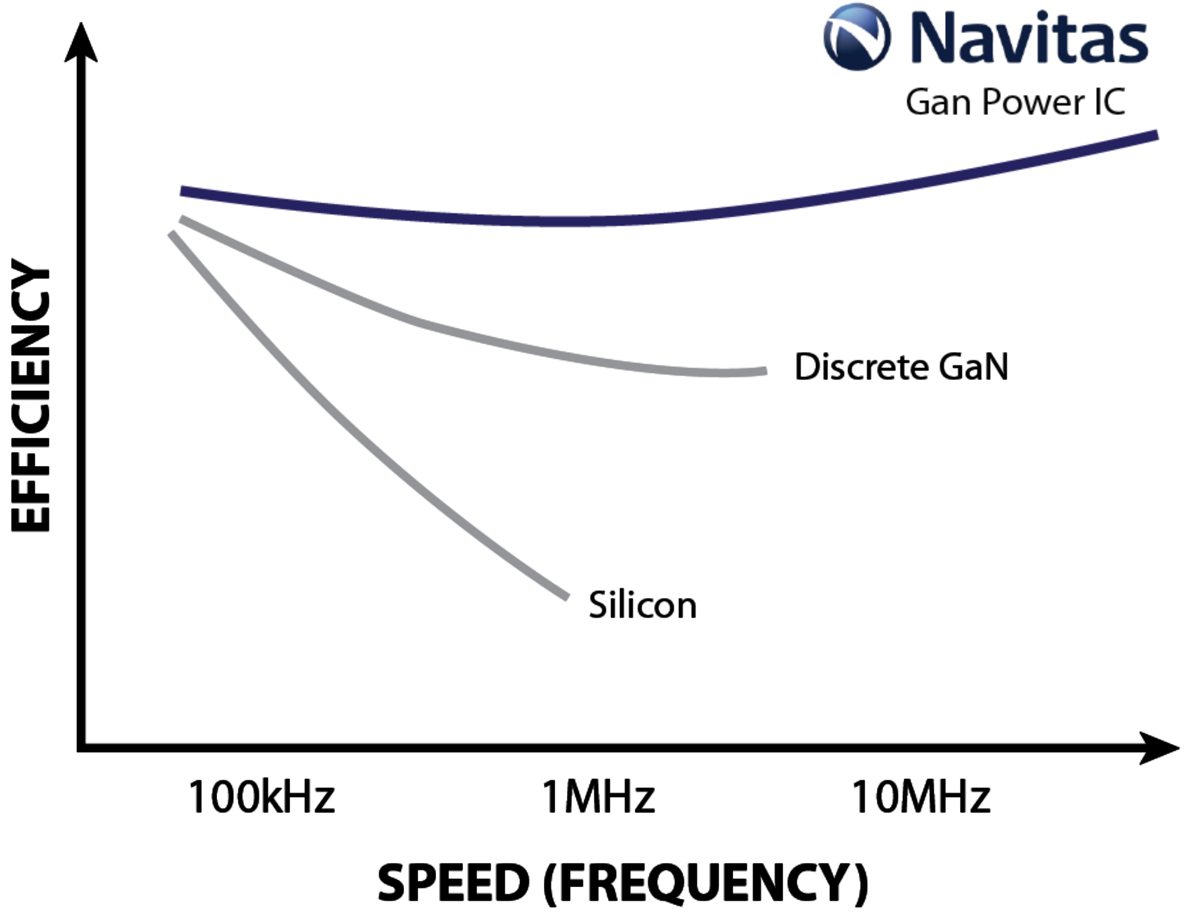
- **Speed** enables ***small size***, ***low-cost*** and ***faster charging***
- **Efficiency** enables ***energy savings***
- With Silicon or Discrete GaN power devices, you can get one ***or*** the other
- With GaN power ICs, you get ***both at the same time***, unequaled **Speed & Efficiency**



Hard-Switch → Soft-Switch with eMode GaN

Primary Switch Power Loss:

开关频率有关损耗

Minimized　Reduced

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

eMode GaN 消除的损耗

- k-factor　>1 due to increased circulating current, duty cycle loss(deadtime)
- $P_{T\text{-}On}$　= 0 (soft-switch)
- P_{DR}　↓ 10X (GaN P_{DR} negligible up to 2Mhz)
- P_{QRR}　= 0 （NO Reverse recovery）
- P_{DIODE}　↓ 2X (reverse conduction loss reduced due to short deadtime)
- P_{Qoss}　↓ 10X (GaN Coss charging/discharging loss negligible up to 2Mhz)
- $P_{T\text{-}OFF}$　= Reduced (limited by I-V crossover loss due to drive loop impedance)

Hard-Switch → Soft-Switch with Navitas GaN Power IC

Primary Switch Power Loss:

Minimized Reduced

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

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- $P_{T\text{-}OFF}$ = 0 (Due to driver Integration, No gate loop impedance)

Ideal Switching = No Switching Loss @ High F_{SW}

Navitas GaN ICs provide Ideal Switching

How?

HF Power Switch: World's First AllGaN™ Power ICs

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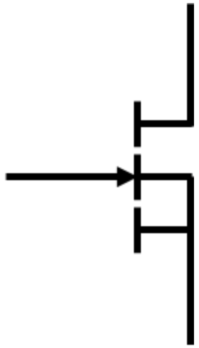
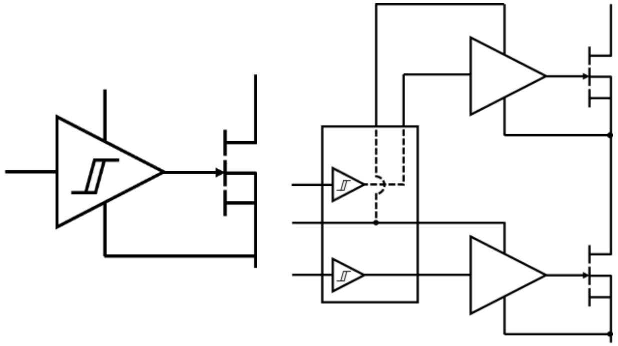
Fastest, Most Efficient GaN Power FETs



>20x faster than silicon
>5x faster than cascoded GaN
Proprietary design

iDrive First & Fastest Integrated GaN Gate Drivers



>3x faster than any other gate driver
Proprietary design
30+ patents granted/applied

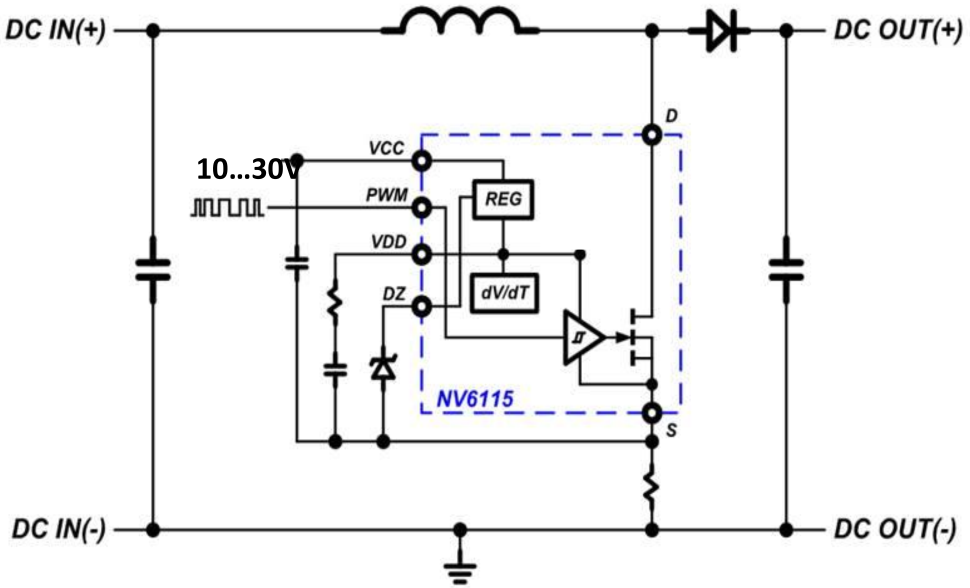
World's First AllGaN™ Power IC

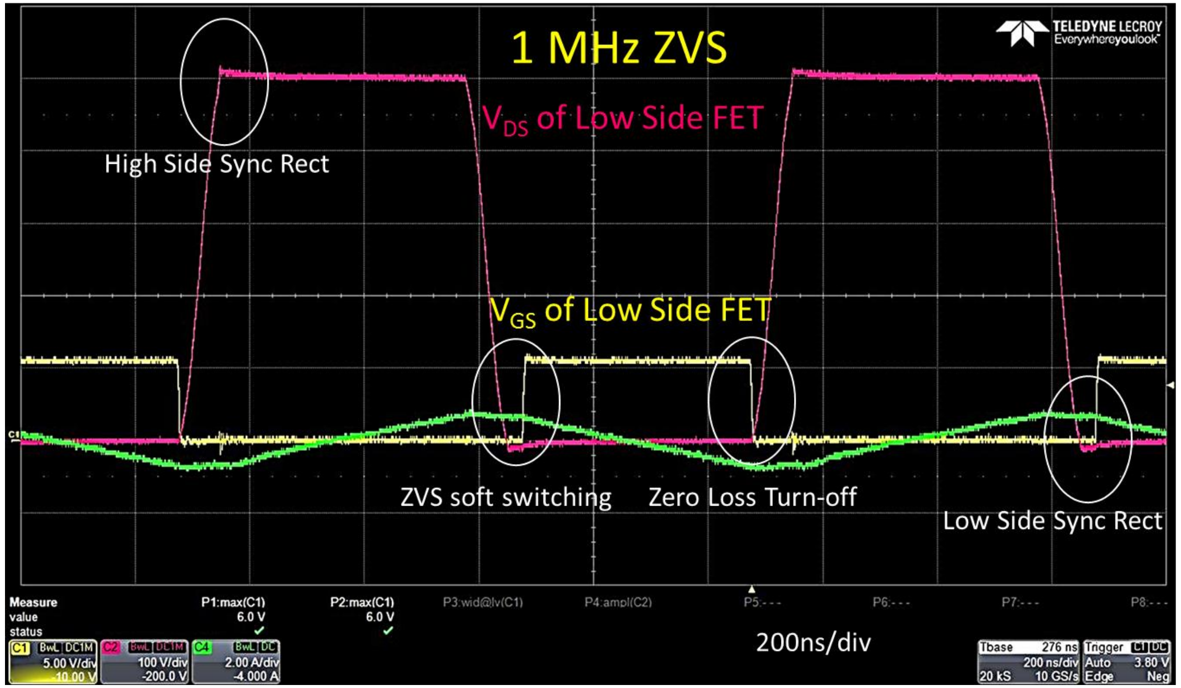
Up to 40MHz switching, 5x higher density & 20% lower system cost

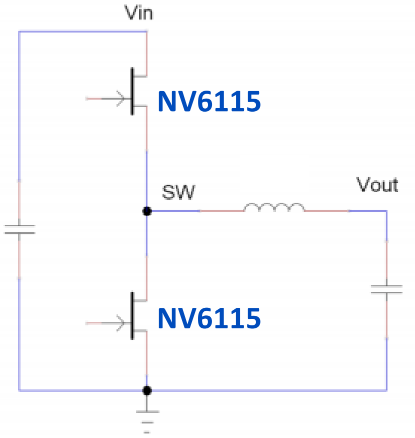
AllGaN™: Monolithic GaN Power IC

- Monolithic integration at 650 V
  - GaN FET *(range 110-560 mΩ)*
  - GaN Driver (iDrive™)
  - GaN Logic
- "Digital In, Power Out"

NV6115 PFC Boost 应用线路







5 x 6 mm QFN

Integrated Drive→ Simple & Robust

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Wide-range V_{CC} (10-30 V)

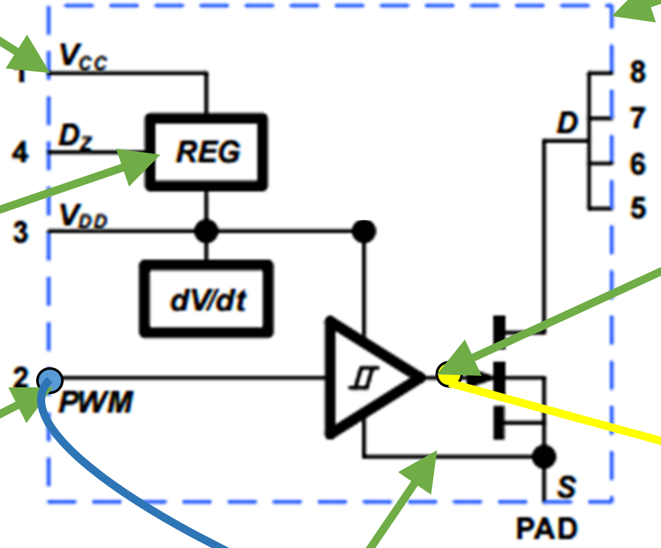
Total layout flexibility & simplicity

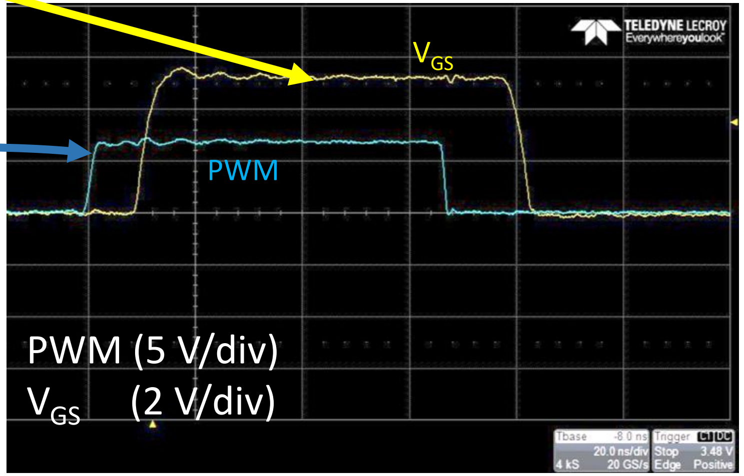
Gate protected from external noise

Regulator ensures V_{GS} within SOA

PWM hysteresis for noise immunity

No inductance or ringing in gate loop

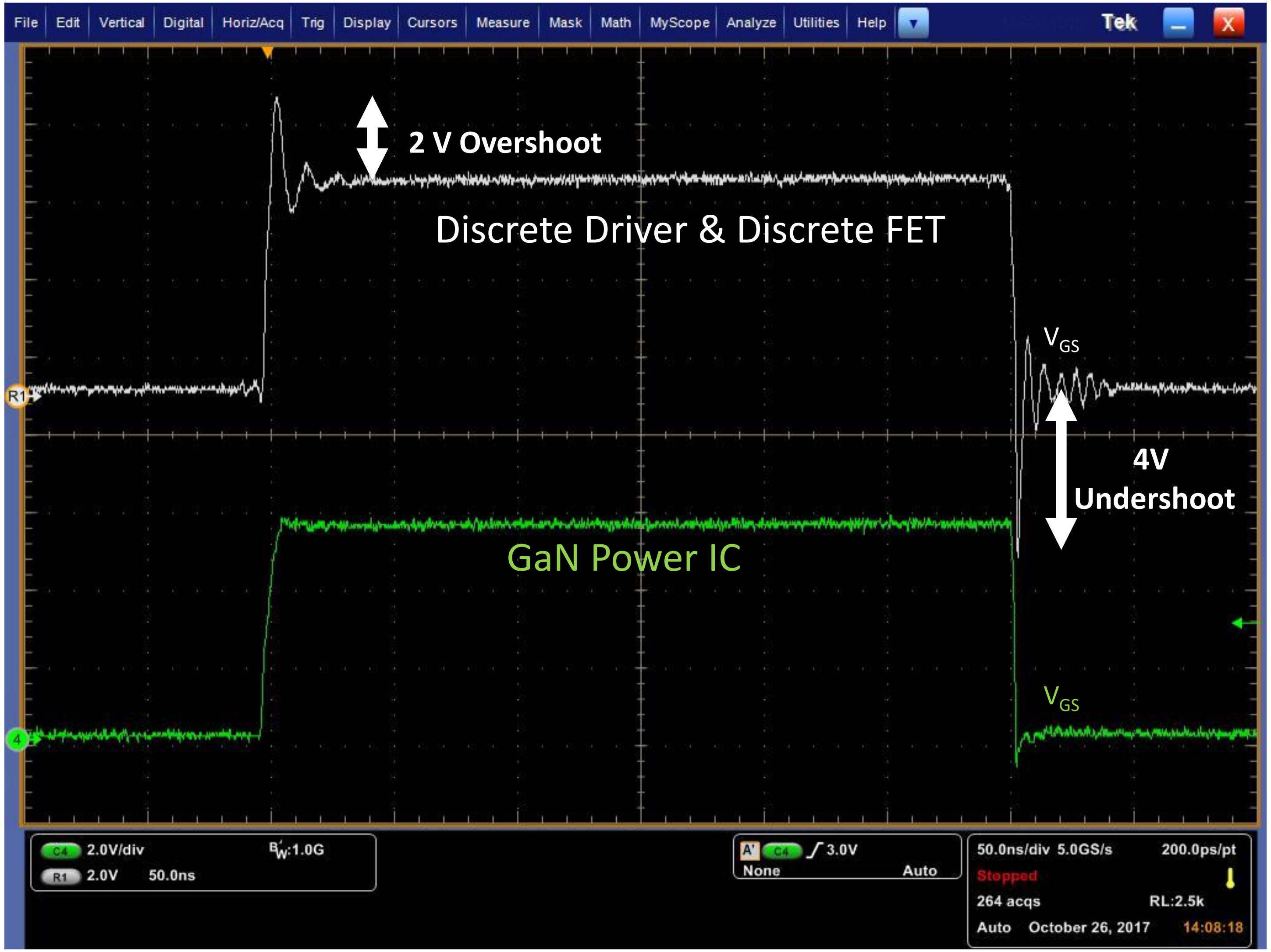




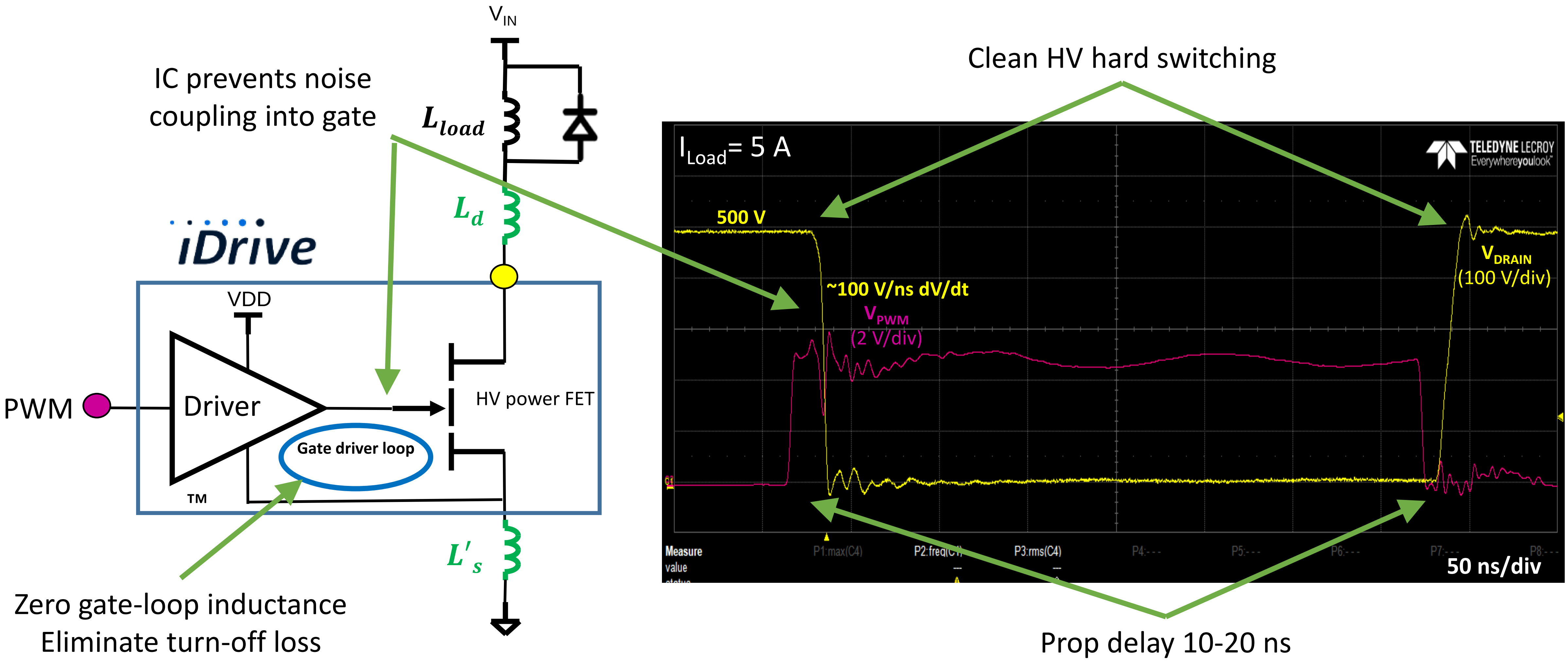
Clean, Controlled FET Gate

- **Discrete driver**
  - Gate loop inductance creates overshoot (even with good layout)
  - Reliability concern

- **iDrive™ GaN Power IC**
  - No gate loop parasitic
  - Clean and fast gate signal



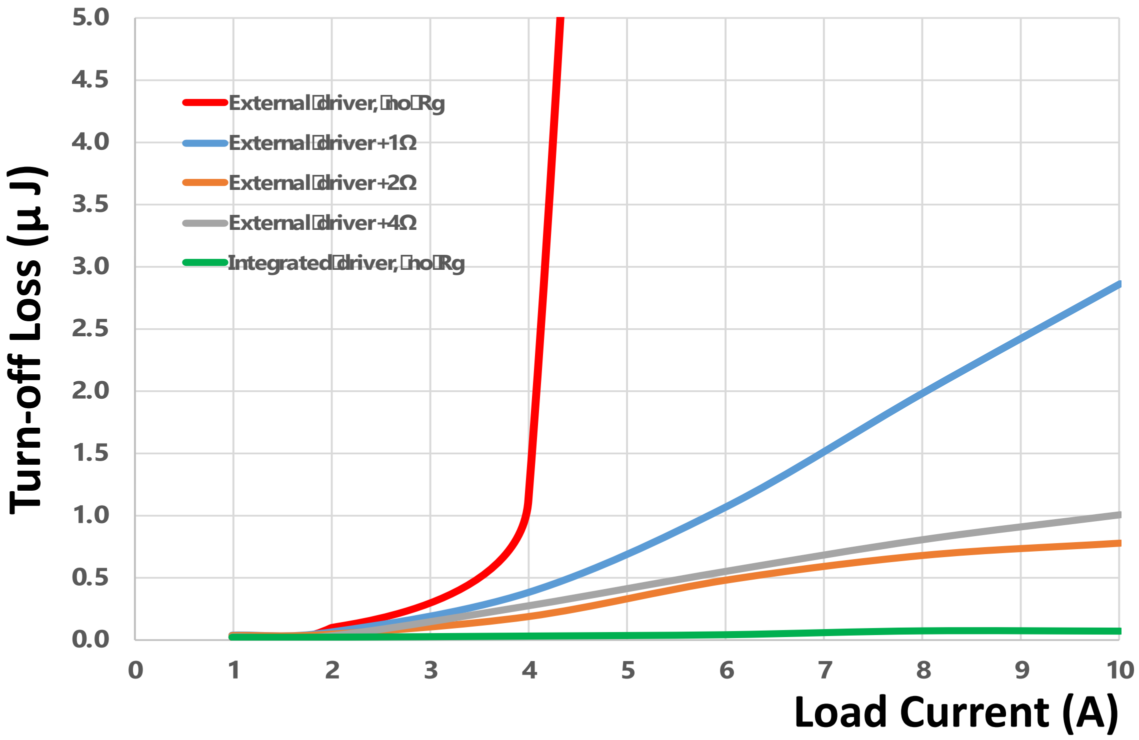
Fast & Clean Hard Switching



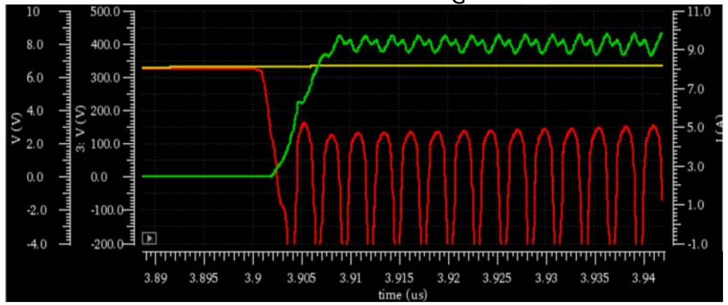
Speed & Integration → Eliminate Turn-off Losses

Navitas

- **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 (iDrive™)**
  - Eliminate the problem
  - Negligible turn-off losses
  - Removes unintended dV/dt turn-on



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

Hard-Switch → Soft-Switch with Navitas GaN Power IC

Primary Switch Power Loss:

Minimized Reduced

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

- k-factor >1 due to increased circulating current, duty cycle loss(deadtime)
- $P_{T\text{-}On}$ = 0 (soft-switch)
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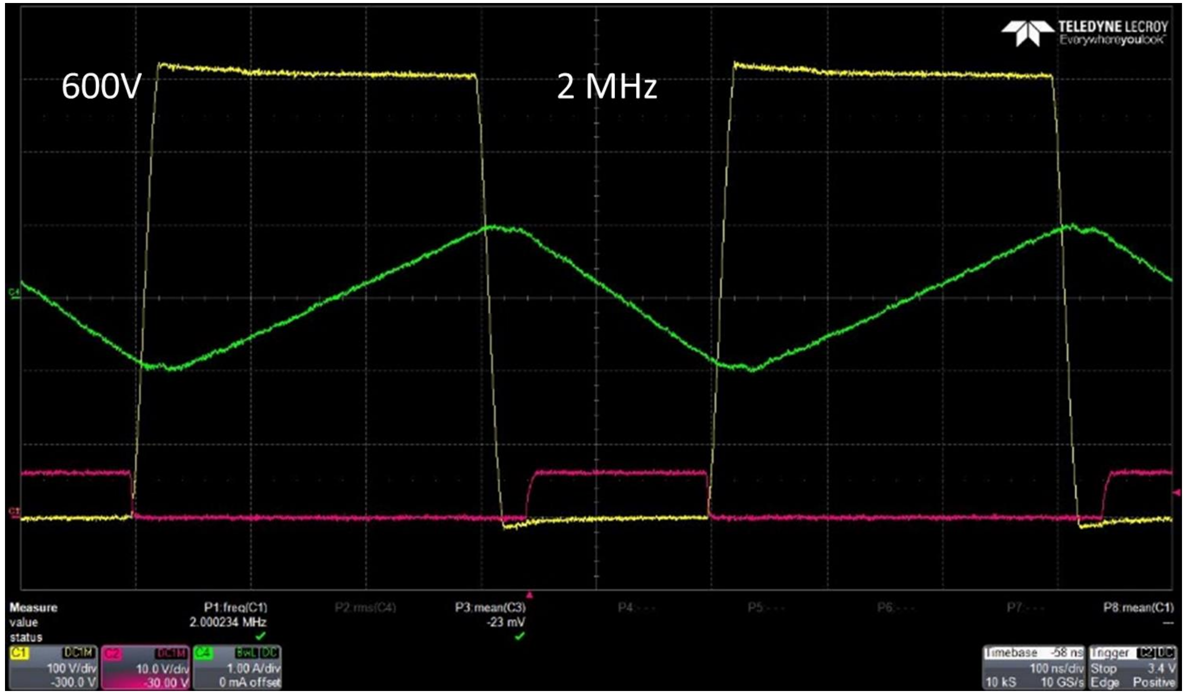
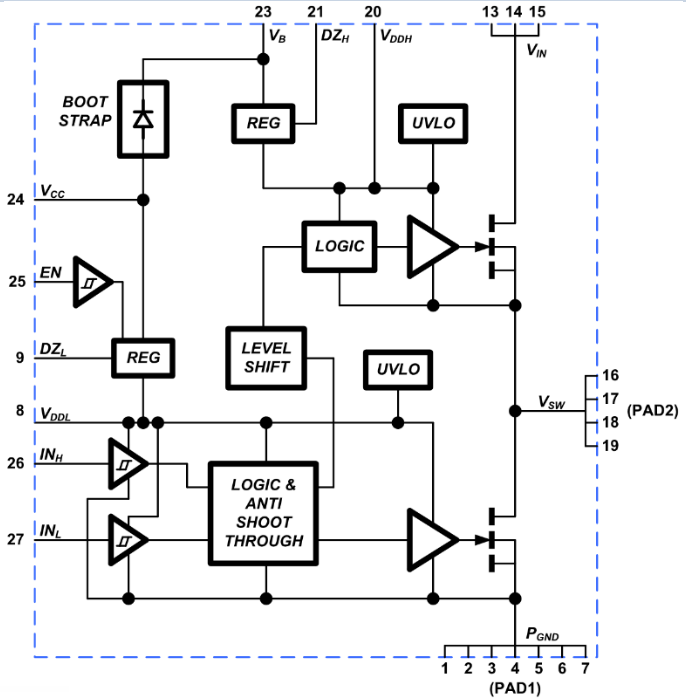
- P_{DIODE} ↓ 2X (reverse conduction loss reduced due to short deadtime)
- P_{Qoss} ↓ 10X (GaN Coss charging/discharging loss negligible up to 2Mhz)
- $P_{T\text{-}OFF}$ = 0 (Due to driver Integration, No gate loop impedance)

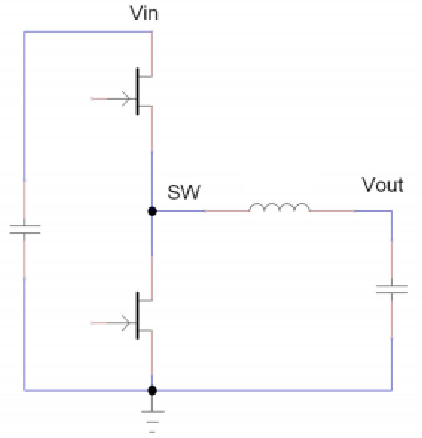
High Power Density = More Integration

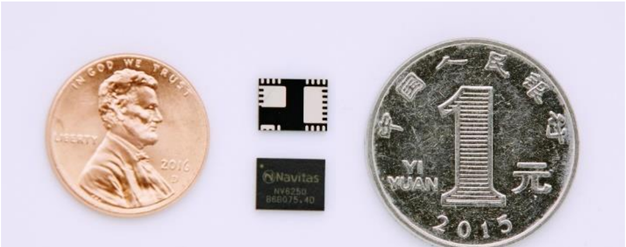
AllGaN™ Half-Bridge GaN Power IC

- Monolithic integration at 650V
  - 2x GaN FETs *(110-560 mΩ)*
  - 2x GaN drivers (iDrive™)
  - GaN Logic (level-shift, bootstrap, UVLO, shoot-through, ESD)
- "Digital In, Power Out"



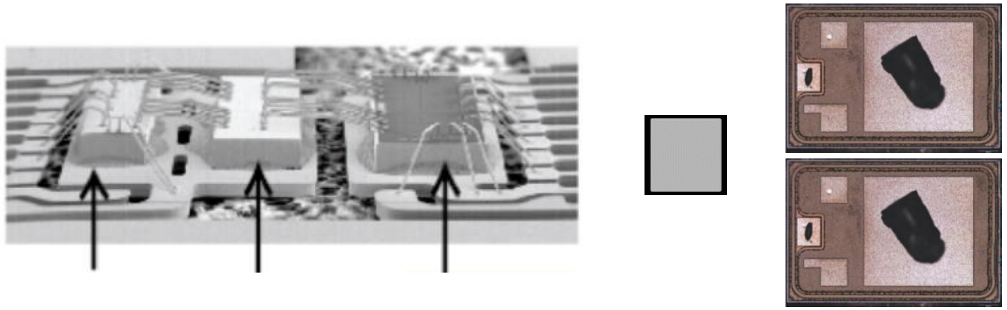






6 x 8 mm QFN

GaN Level-Shift: Low Loss, High-Frequency



Disparate Technologies

Hybrid isolator, discrete driver, discrete power, bootstrap diode

Monolithic Platform

Lateral GaN-on-Si, Half-Bridge GaN Power IC

High Power Loss

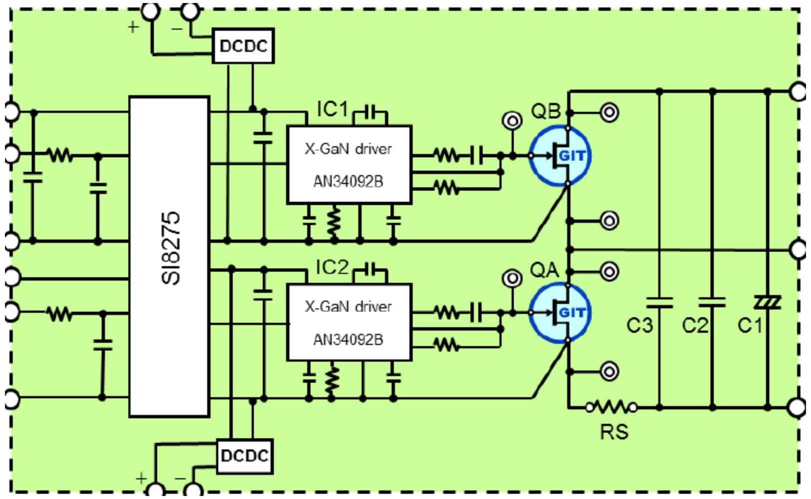
- Driver loss, R_G loss
- Bootstrap diode Q_{RR}, V_F
- Pulsed high current level shifter power (?)

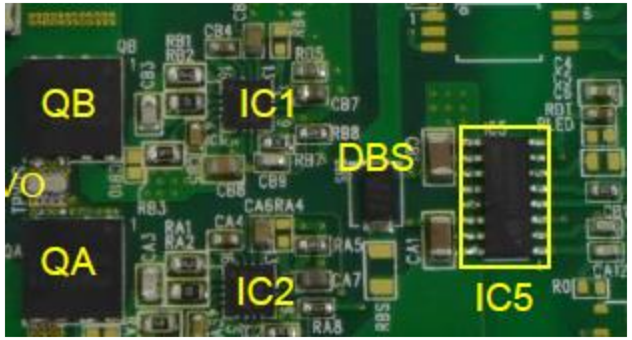
Low Power Loss

- No gate driver loop parasitics, matched driver-FET capability, negligible loss vs. frequency
- Zero Q_{RR} ,low V_{DS} in synchronous charging
- Very fast, low-power loss, MHz+

Complex Design → Easy-to-Use

Half-Bridge *Discrete* GaN

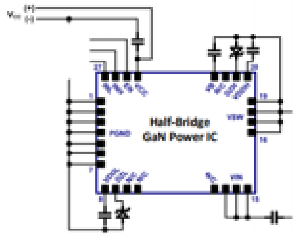




PCB Area: 24 x 42 ~ 1,000 mm^2

- ✓ 20x smaller PCB area
- ✓ Lower cost
- ✓ Robust & protected
- ✓ Simple
- ✓ Easy layout

Half-Bridge GaN *Power IC*

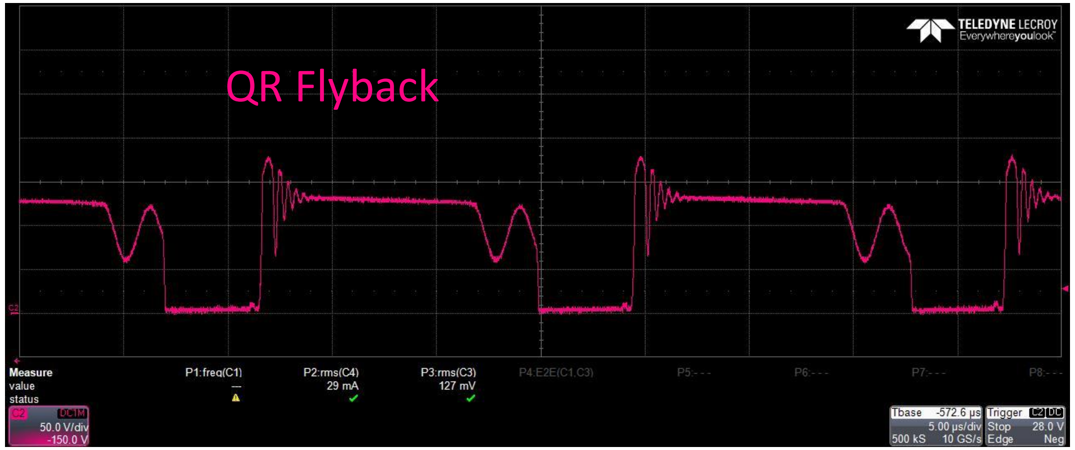


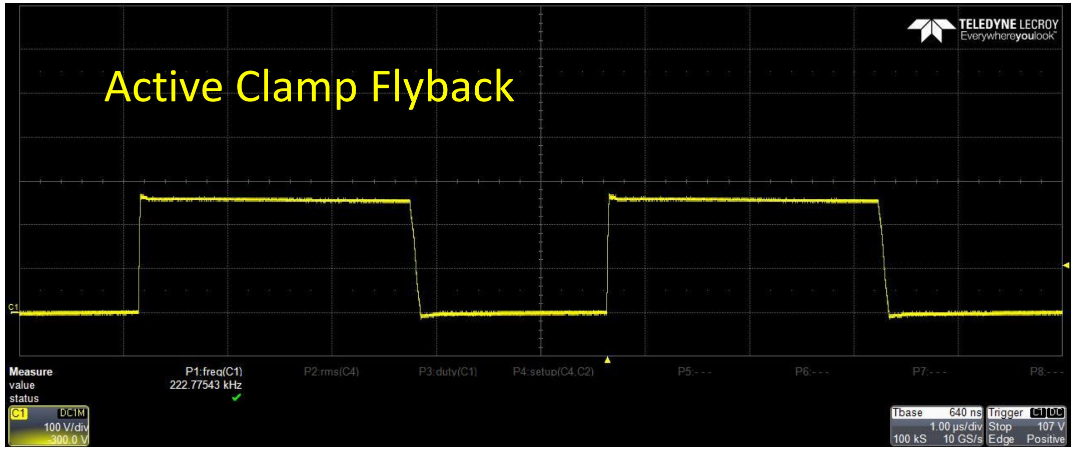
PCB Area: 6 x 8 = 48 mm^2

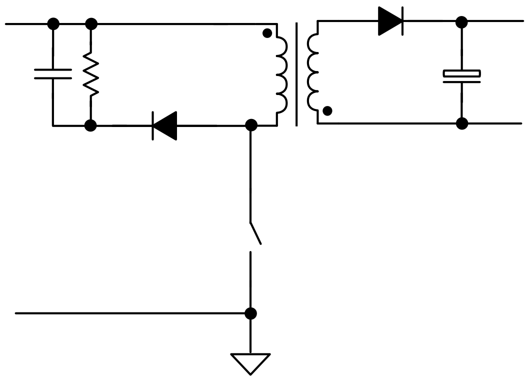
HF Topology for Low Power Adaptor(<75W)

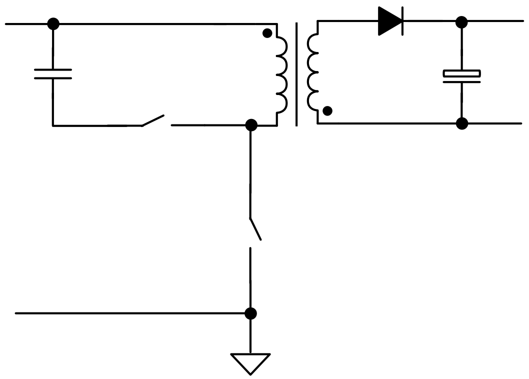
Active Clamp Flyback

QR vs ACF





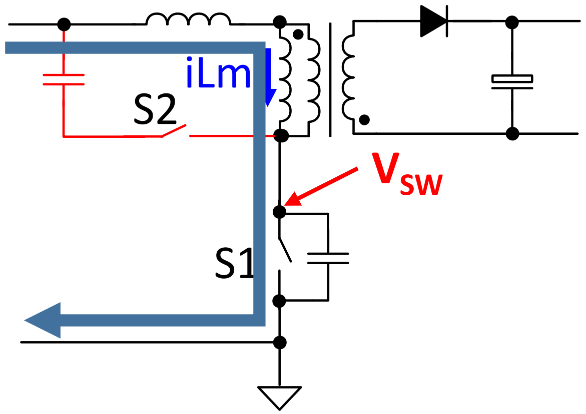


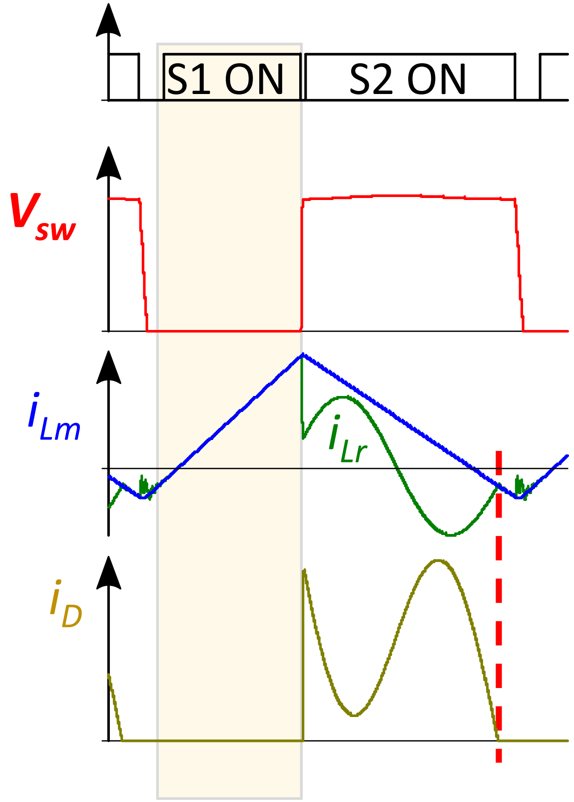


- RCD loss(leakage loss)
- Hard switching loss(high Line)
- Switching loss increases with high fsw

- No RCD loss(leakage loss)
- ZVS over all AC line, all load conditions
- ZCS achieved
- ACF operates at > 1MHz

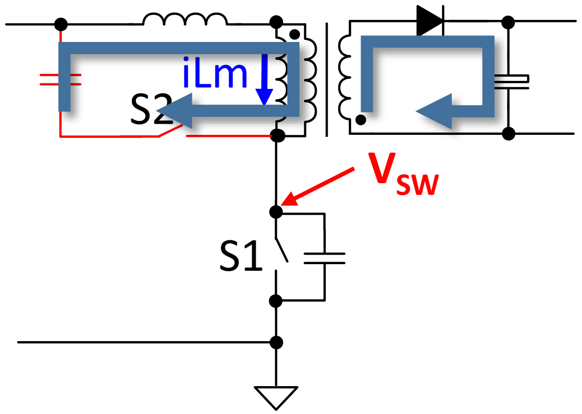
ACF Operation (S1 ON)

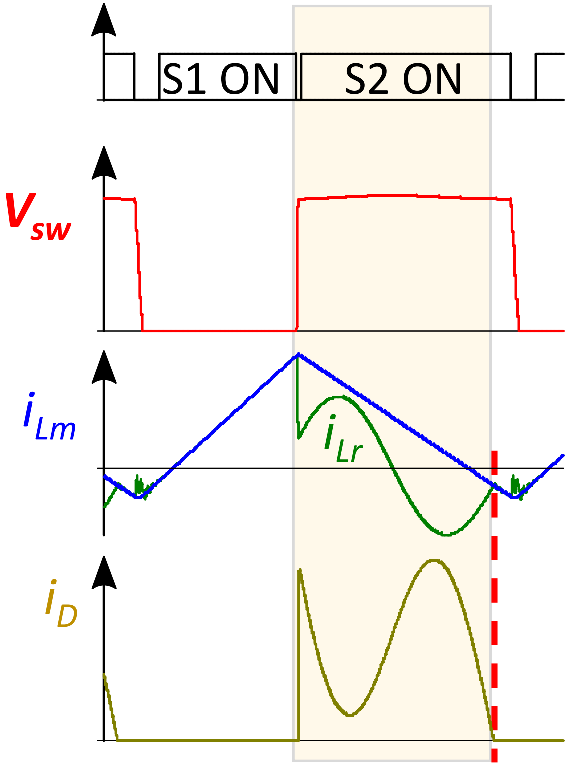




- S1 ON, linearly charging L_m, like a QR flyback

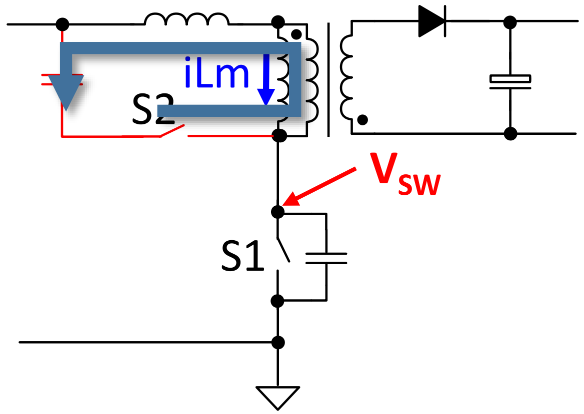
ACF Operation (S2 ON, S1 OFF)

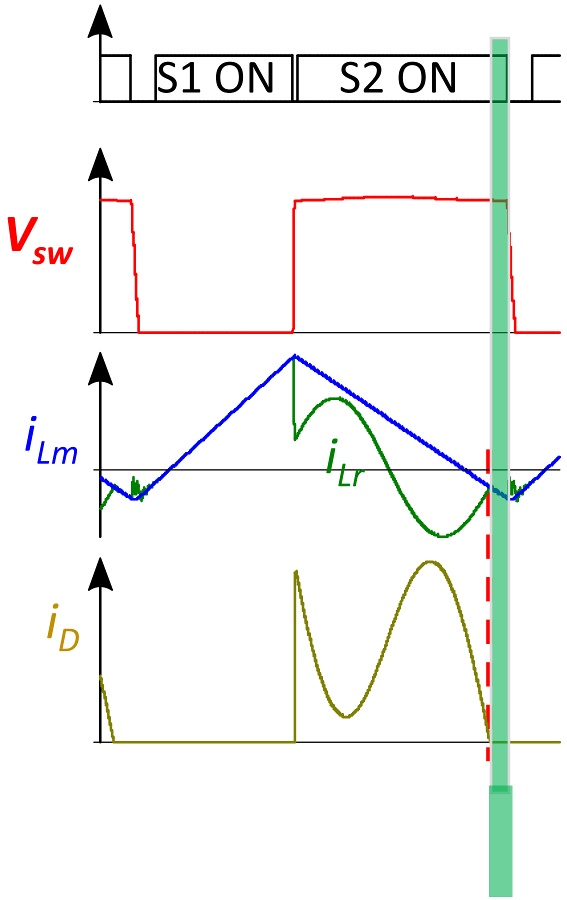




- S2 ON with ZVS, effective clamping since current can go both direction, no overshoot
- Leakage resonates with clamping capacitor
- Rectifier diode conducts and delivers power
- Interval ends when rectifier current drops to zero

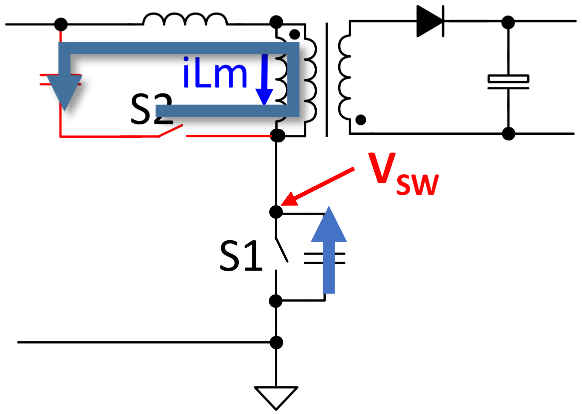
ACF Operation (Building Negative Lm)

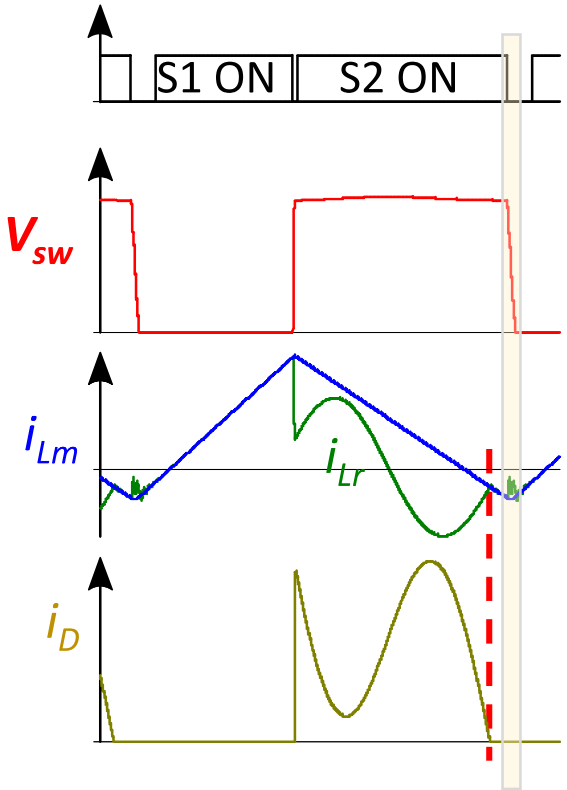




- S2 current equals to magnetizing current
- **Magnetizing current becomes negative**

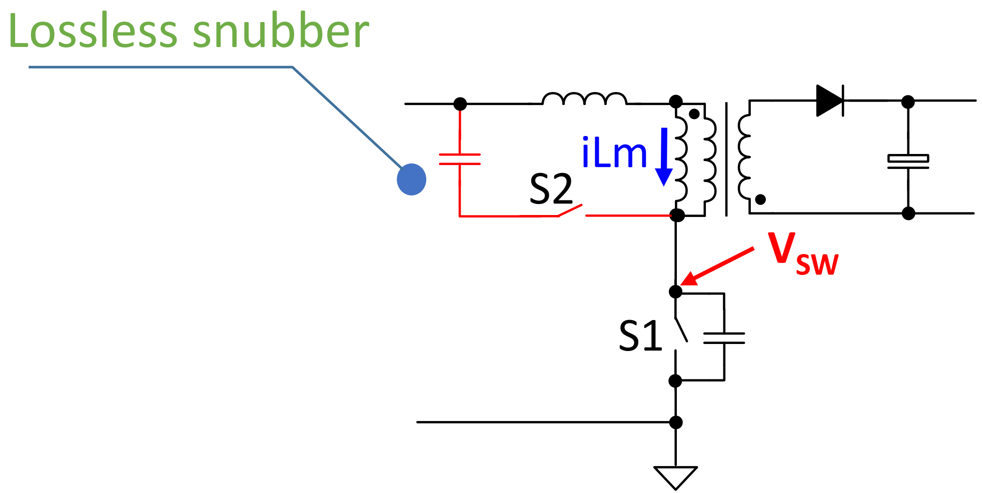
ACF Operation (S1 ZVS Transition)

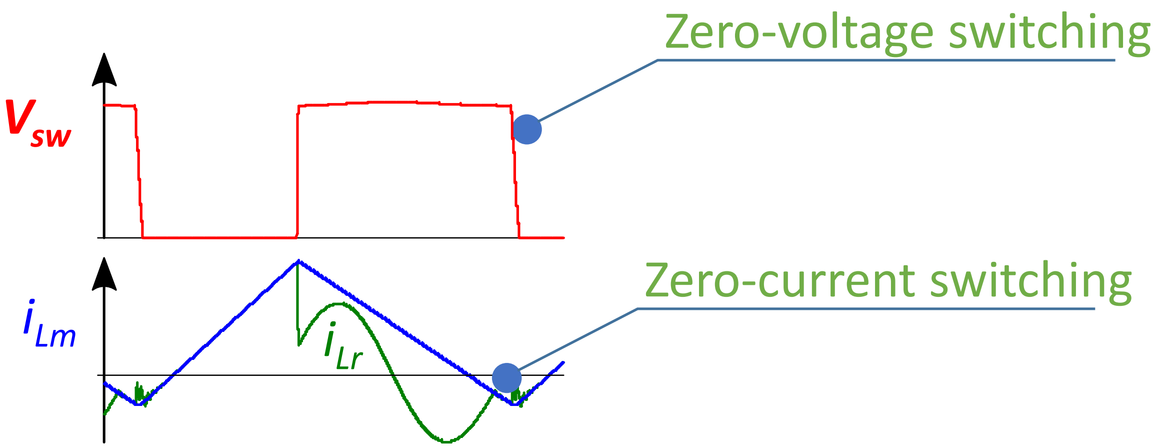




- Negative iL_m discharge S1 C_{OSS}
- S1 can be turned on later in ZVS

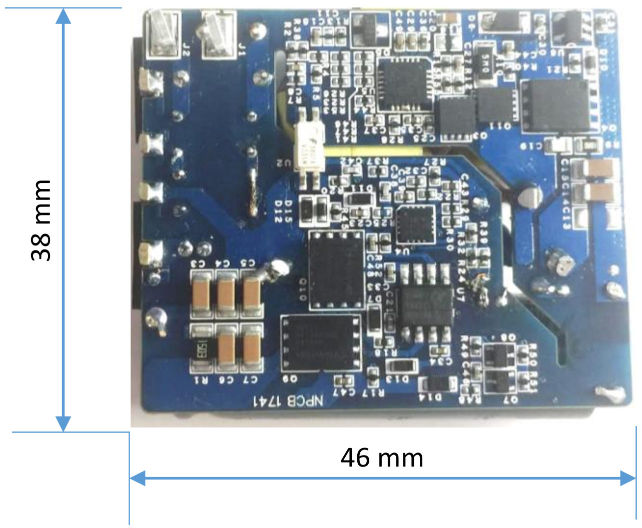
ACF Enables ZVS and High Frequency Switching

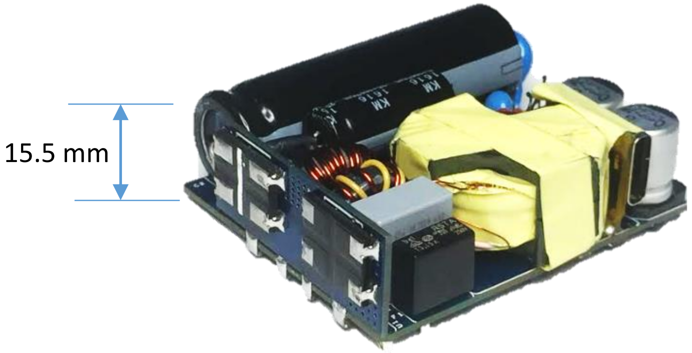




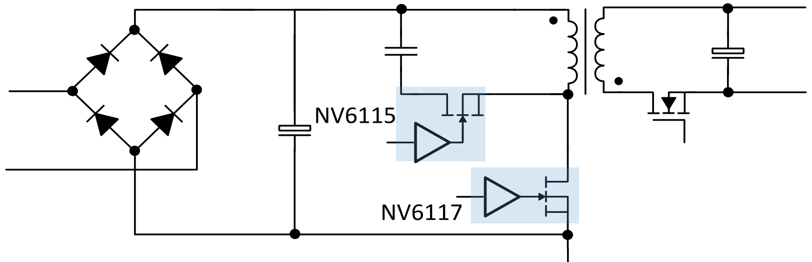
- No snubber losses, all leakage energy is recovered
- **ZVS turn-on over entire operation range**
- **ZCS turn-off for output rectifier**
- Clean waveforms reduce EMI
- Enable small adapter design with high frequency switching

65W USB-PD ACF: *World's Smallest Adapter*



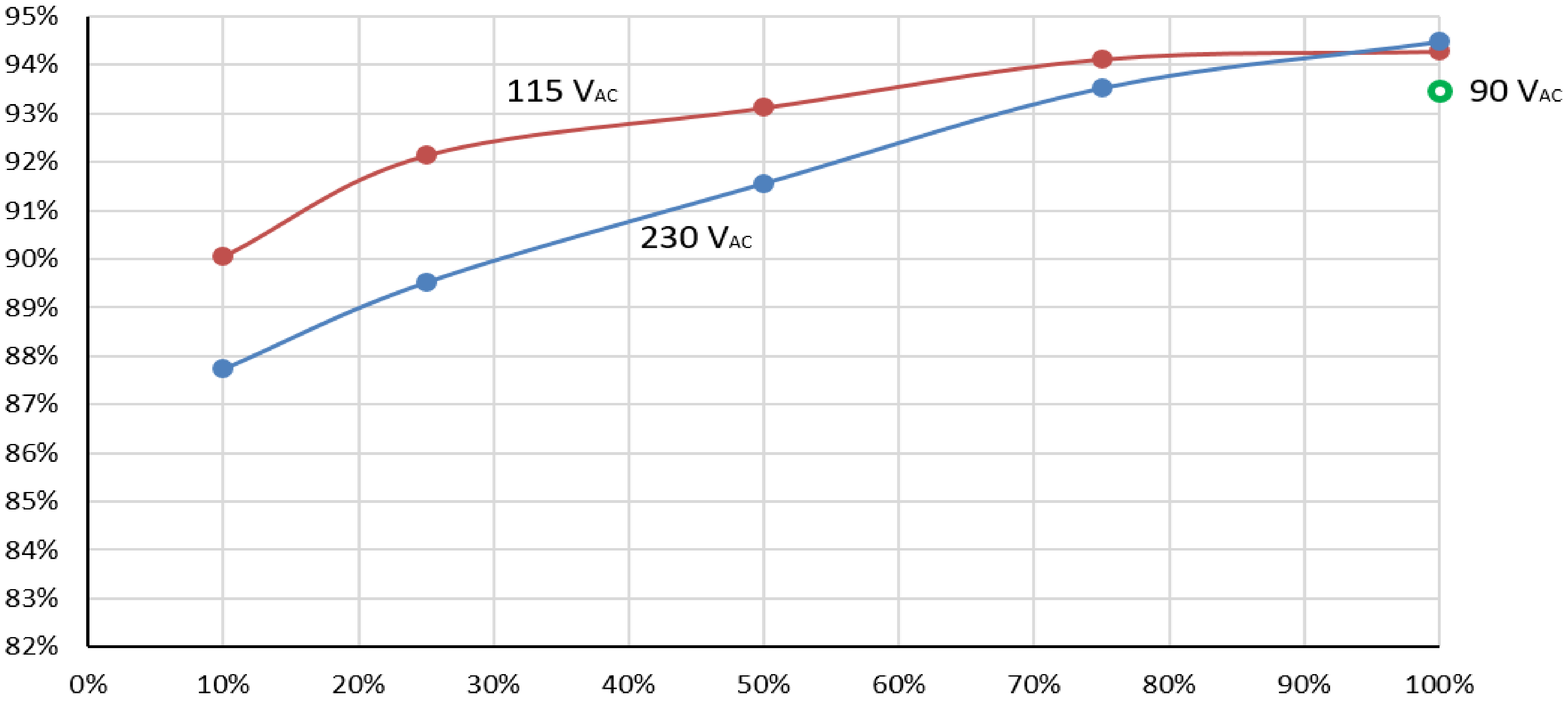


- Input : Universal AC (85-265V_{AC}, 47-63Hz)
- Output : USB-PD (5-20V) (65W)
- Frequency : 300~400kHz(Full Load)
- **Primary FET : NV6115 (160 mΩ) + NV6117 (110 mΩ) GaN Power ICs**
- **Controller(ACF) : UCC28780**
- **Magnetic Core : N49**
- Size : 38 x 46 x 15.5 mm = 27 cc uncased
  43 x 51 x 20.5 mm = 45 cc with 2.5 mm case
- **Efficiency : 93.4% at 90 V_{AC}, Full Load**
- **Power Density : 2.4 W/cc (39 W/in^3) uncased**
  1.5 W/cc (24 W/in^3) cased
- Construction : 4-layer, 2-oz Cu PCB, SMT powertrain
  "No heatsink" design



65W USB-PD ACF

Efficiency at 20 V_{OUT} (25°C, no airflow)



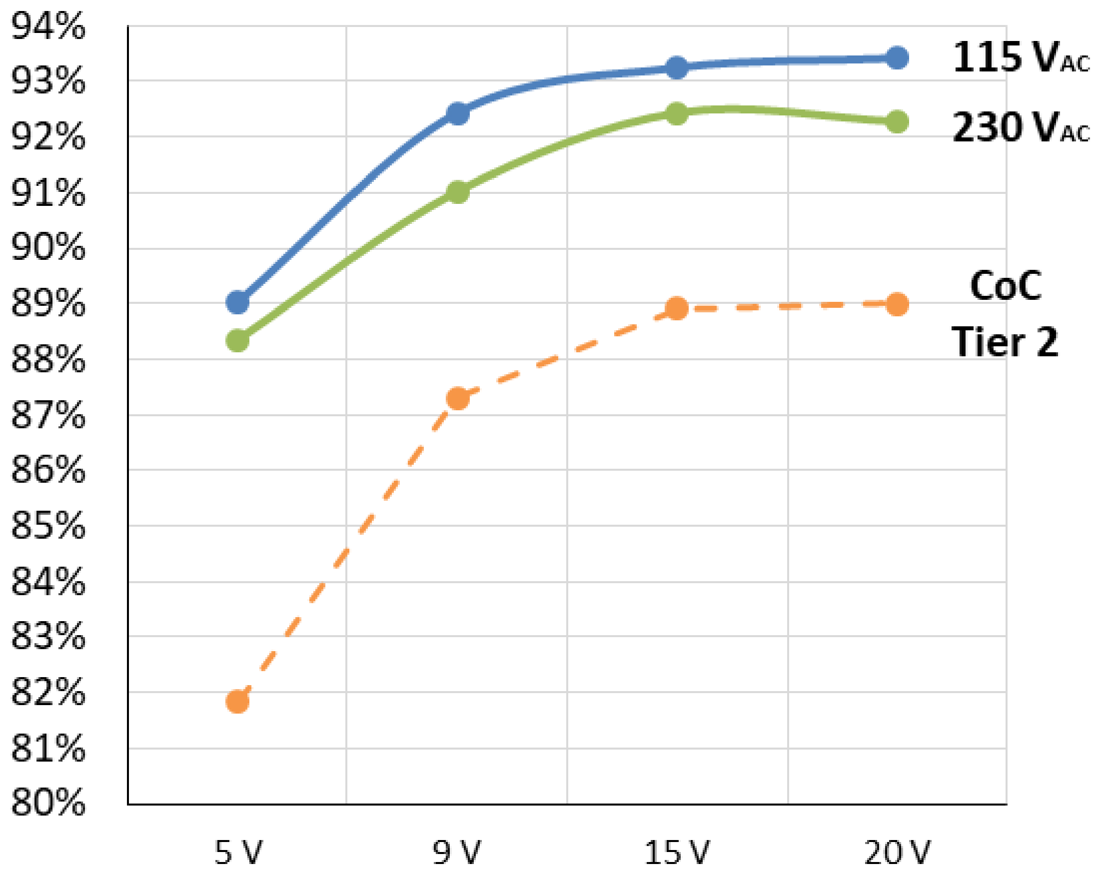
Efficiency measured at PCB

65W USB-PD ACF

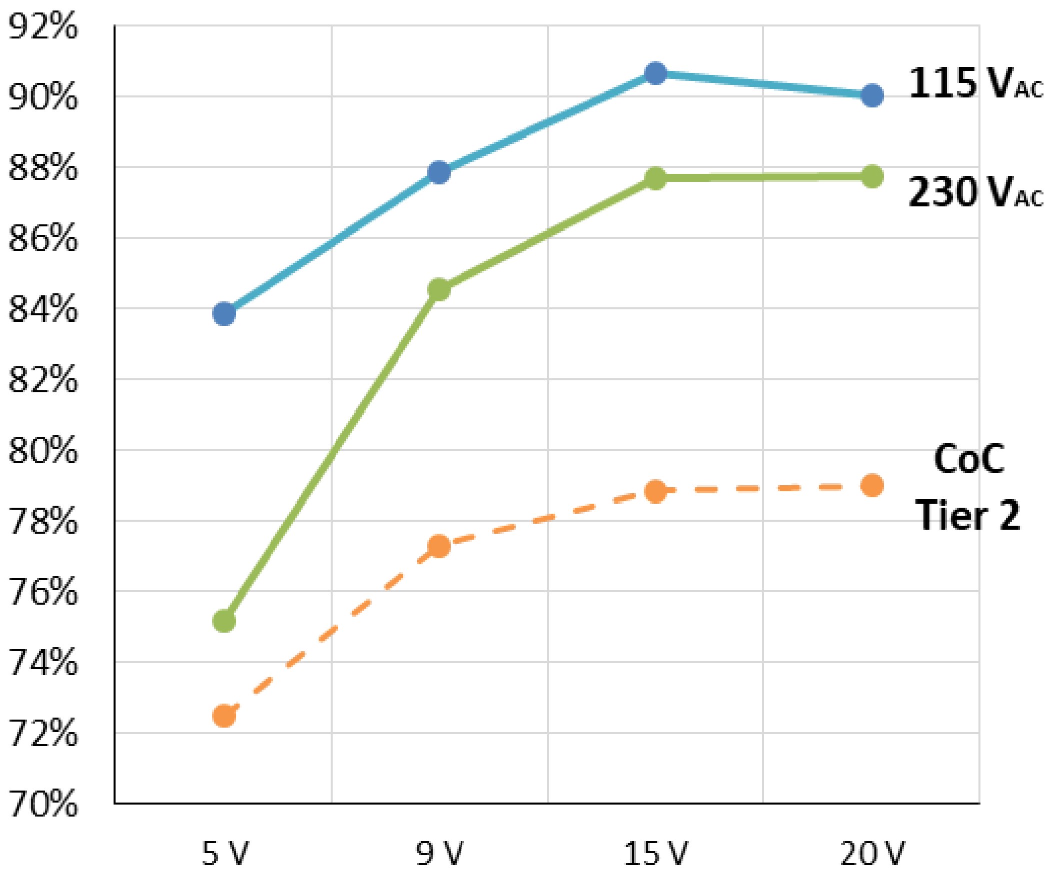
Efficiency (25°C, no airflow)

Controller(ACF) : UCC28780

4-point Average Efficiency



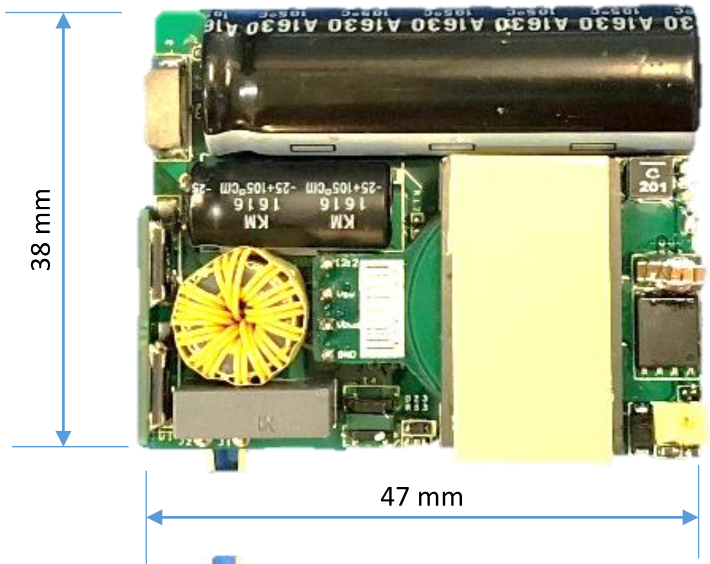
10% Load Efficiency

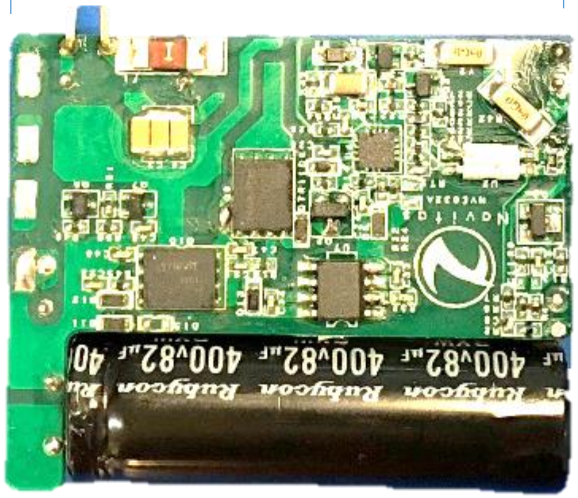


- Standby: 25 mW at 115 V_{AC}, 40 mW at 230 V_{AC} (CoC Tier 2 spec is < 75mW, DoE Level VI spec <= 210 mW)

Efficiency measured at PCB

600kHz 65W Planar Prototype



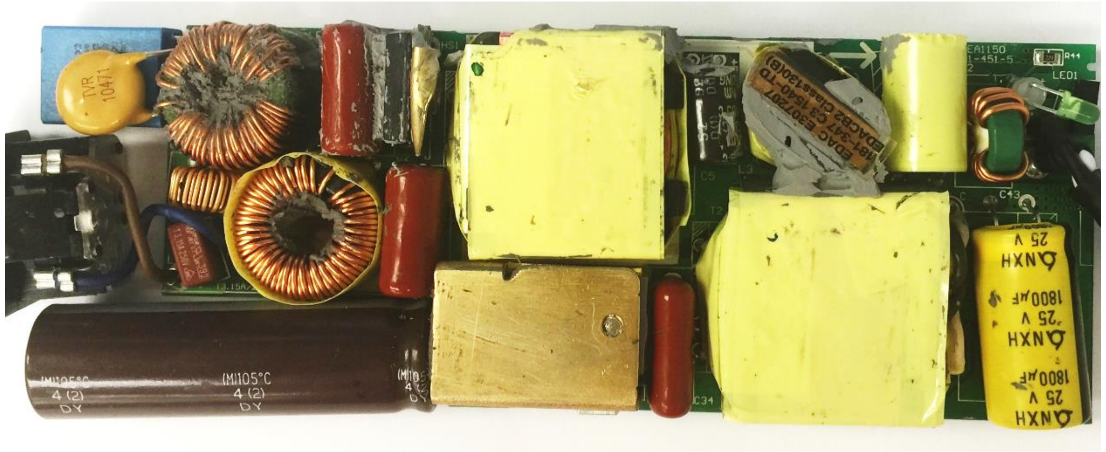


- Input : Universal AC (85-265V_{AC}, 47-63Hz)
- Output : Fixed 20 V (65W)
- **Powertrain : NV6115 (160 mΩ) + NV6117 (110 mΩ) GaN Power ICs**
- **Control : ACF = TI UCC28780**
- **Frequency : 500-600 kHz**
- Size : 38 x 47 x 12.5 mm = 22 cc uncased
  43 x 52 x 17.5 mm = 39 cc with 2.5 mm case
- Power Density : 2.9 W/cc (47 W/in^3) uncased
  1.7 W/cc (27 W/in^3) cased
- Construction : 4-layer, 2-oz Cu PCB, SMT powertrain
  “No heatsink” design

In progress, available Q2’18

1MHz 150 W

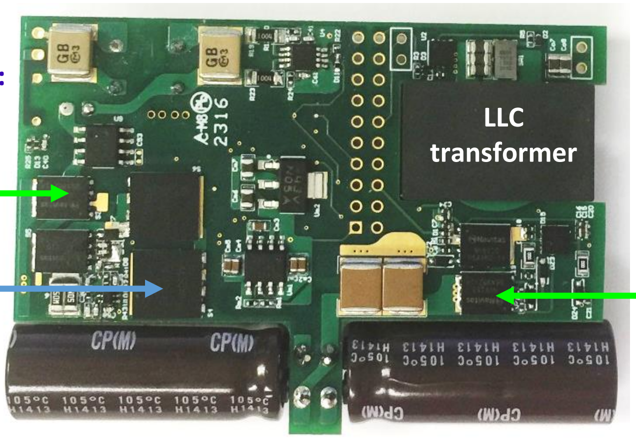
State-of-the-art Si 12W/in^3



1MHz GaN 35W/in^3

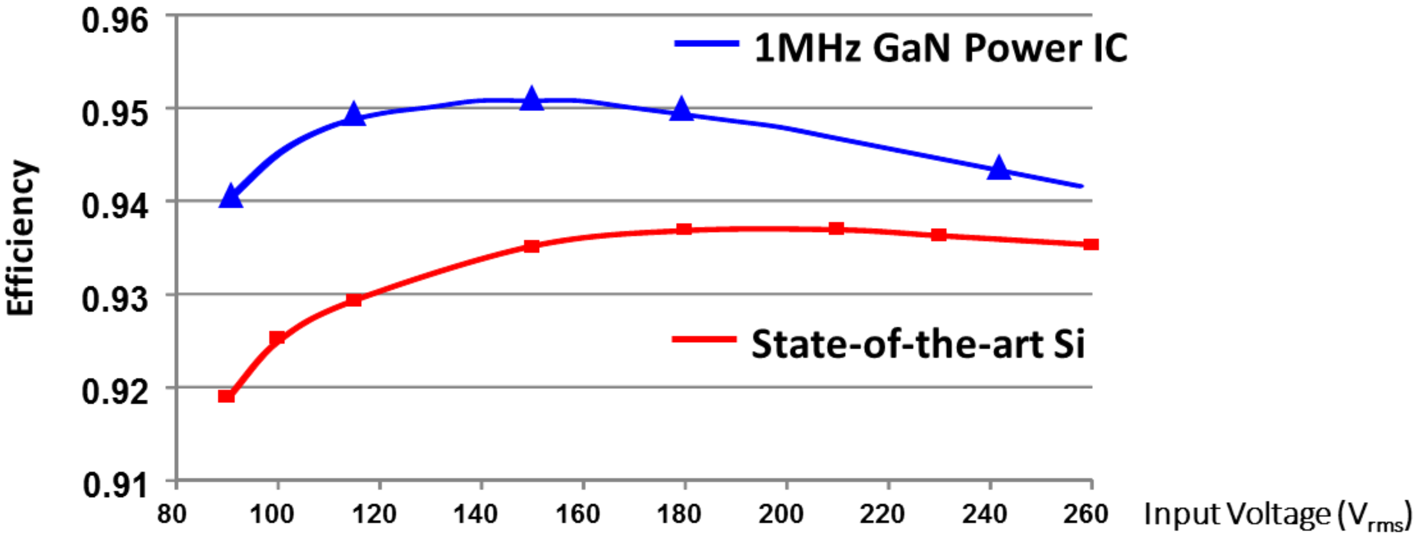
Totem-Pole: 2 x Navitas Power ICs

2 x Si FETs

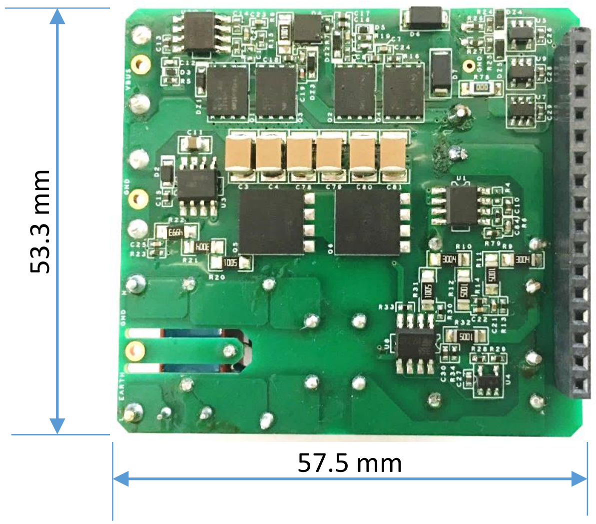


LLC Primary 2 x GaN Power ICs

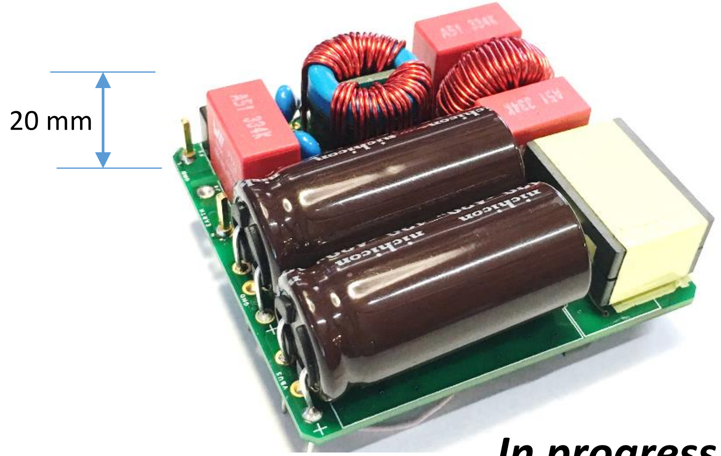
Microcontroller not shown

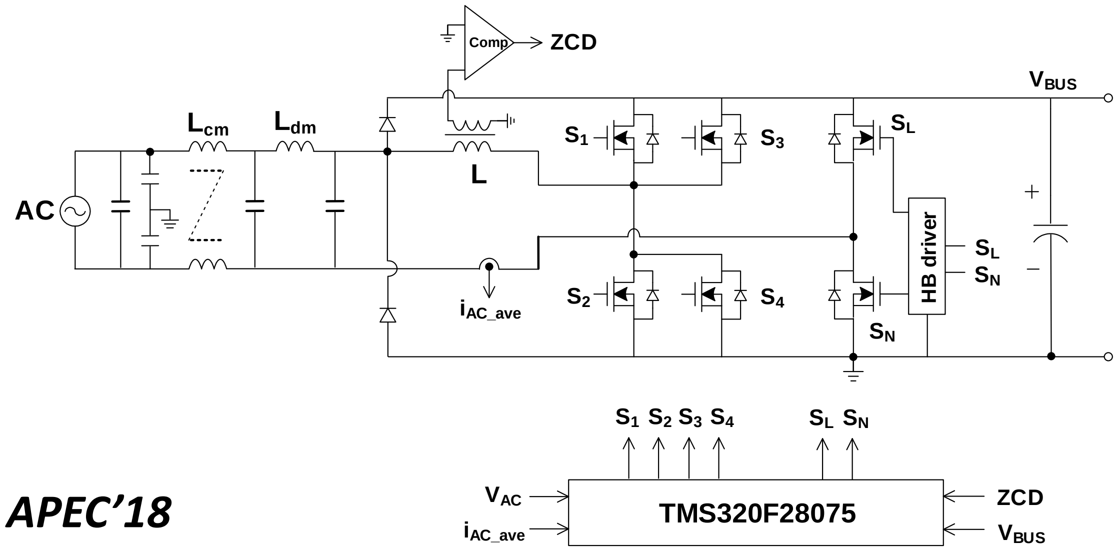


1.2 MHz, 300W Totem-Pole PFC (Preliminary)



- Input : Universal AC (85-265V_{AC}, 47-63Hz)
- Output : 400V (300W)
- Fast FETs : NV6117 (110mΩ) GaN Power ICs
- Slow (AC) FETs : Si Superjunction (62mΩ)
- Frequency : 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





In progress, report available APEC'18

Summary

- **Navitas GaN Power IC**

  Enable
  - Market adoption of HF magnetics
  - ACF topology adoption in low power application
  - HF ASIC for ACF, TP-PFC, LLC, SR invention
  &
  Next Generation High Power Density Adaptor


GaN
GaN Power ICs: Integration Drives Performance
纳微 Navitas
65W USB-PD