State-of-the-Art Mobile Charging: Topologies, Technologies and Performance

PSMA Industry Session IS05: Mobile Applications

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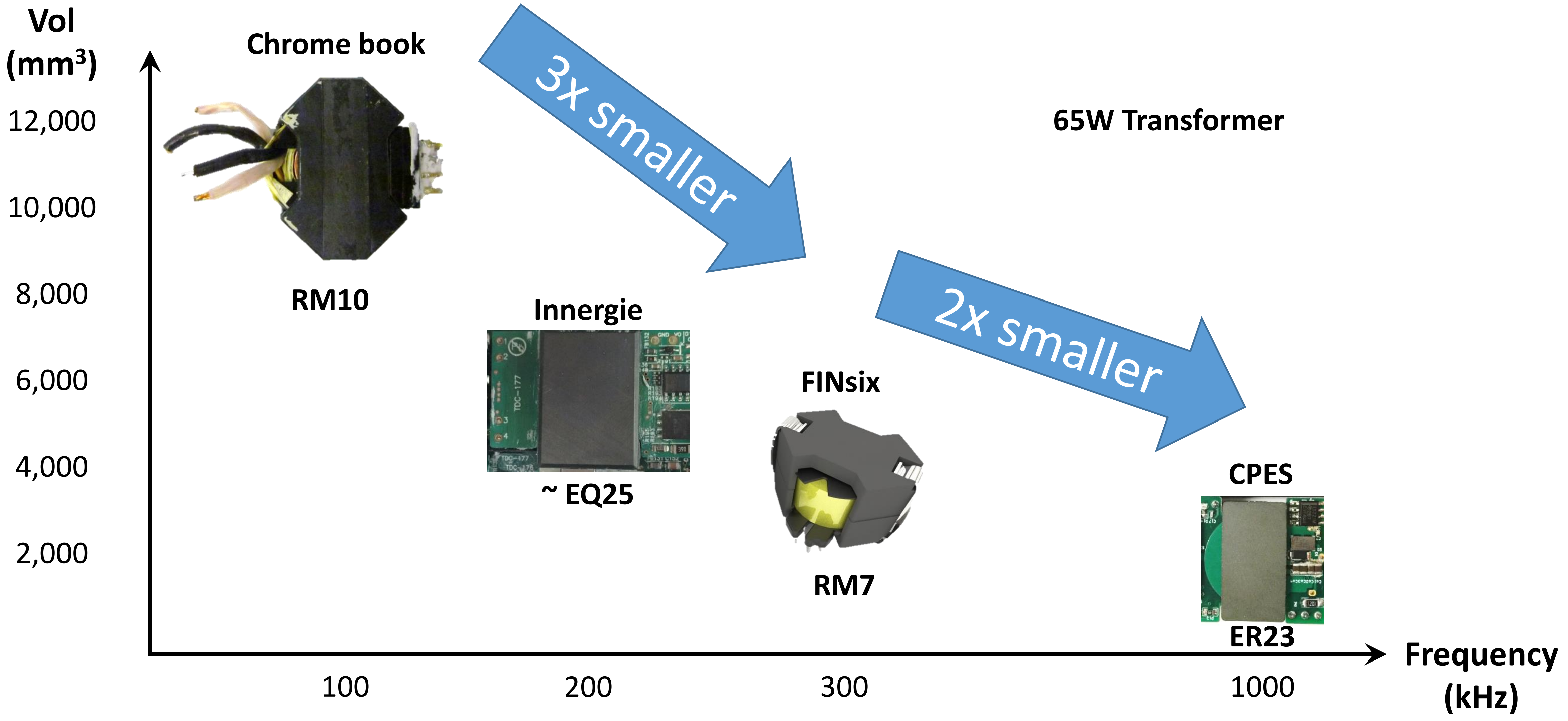
March 29th 2017

Getting to Fast…

- Topology / technique
  - Hard-switch → Soft switch (ZVS)
  - New technology enables new topologies to be commercially viable
- Switch technology
  - Si Bipolar → Si FET → Discrete / Cascoded GaN → GaN Power ICs
- Magnetic Materials
  - New compounds / alloys, optimized for high frequency

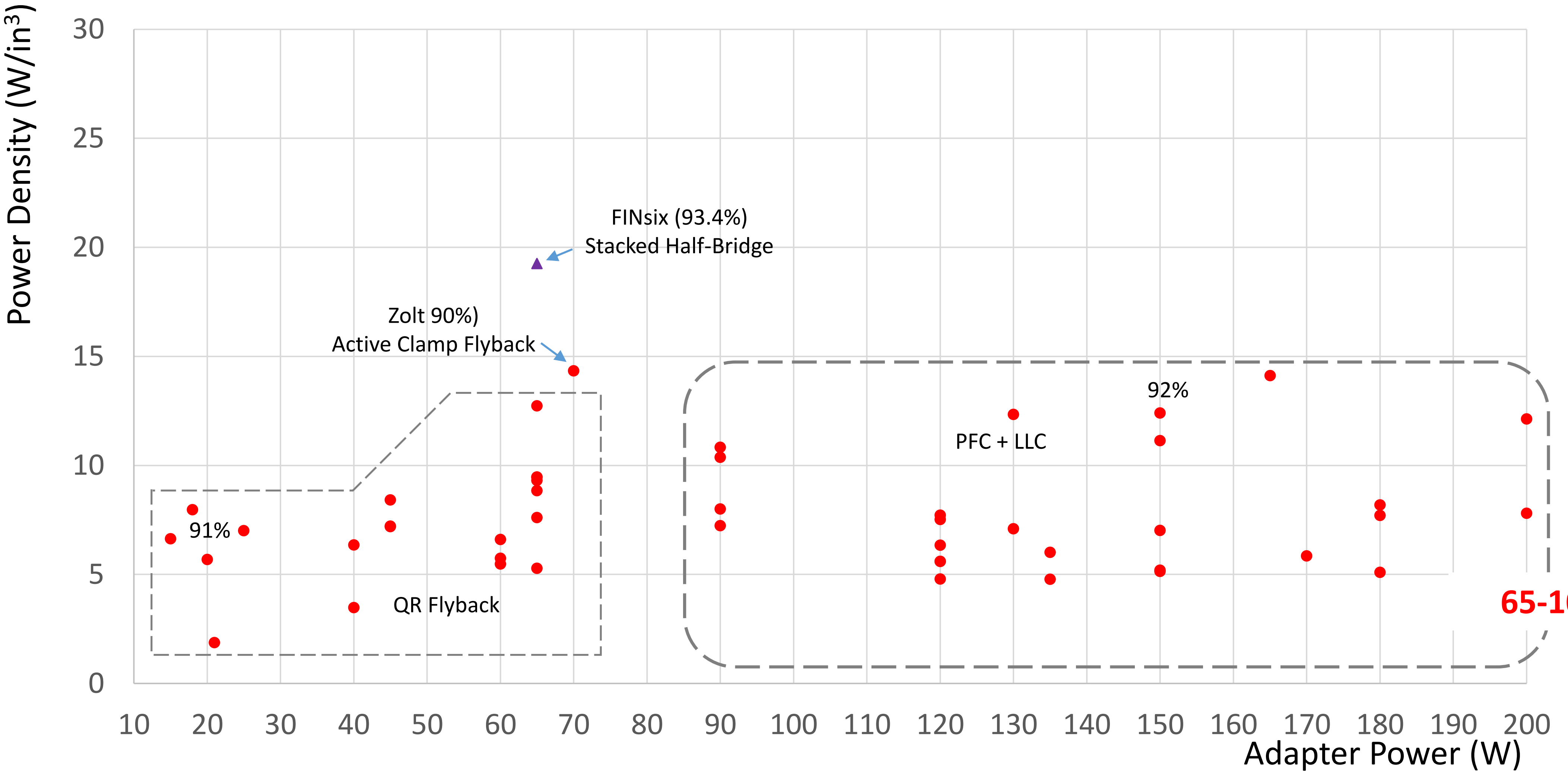
Fast → Small

Navitas



Adapter Density 2016:

Navitas

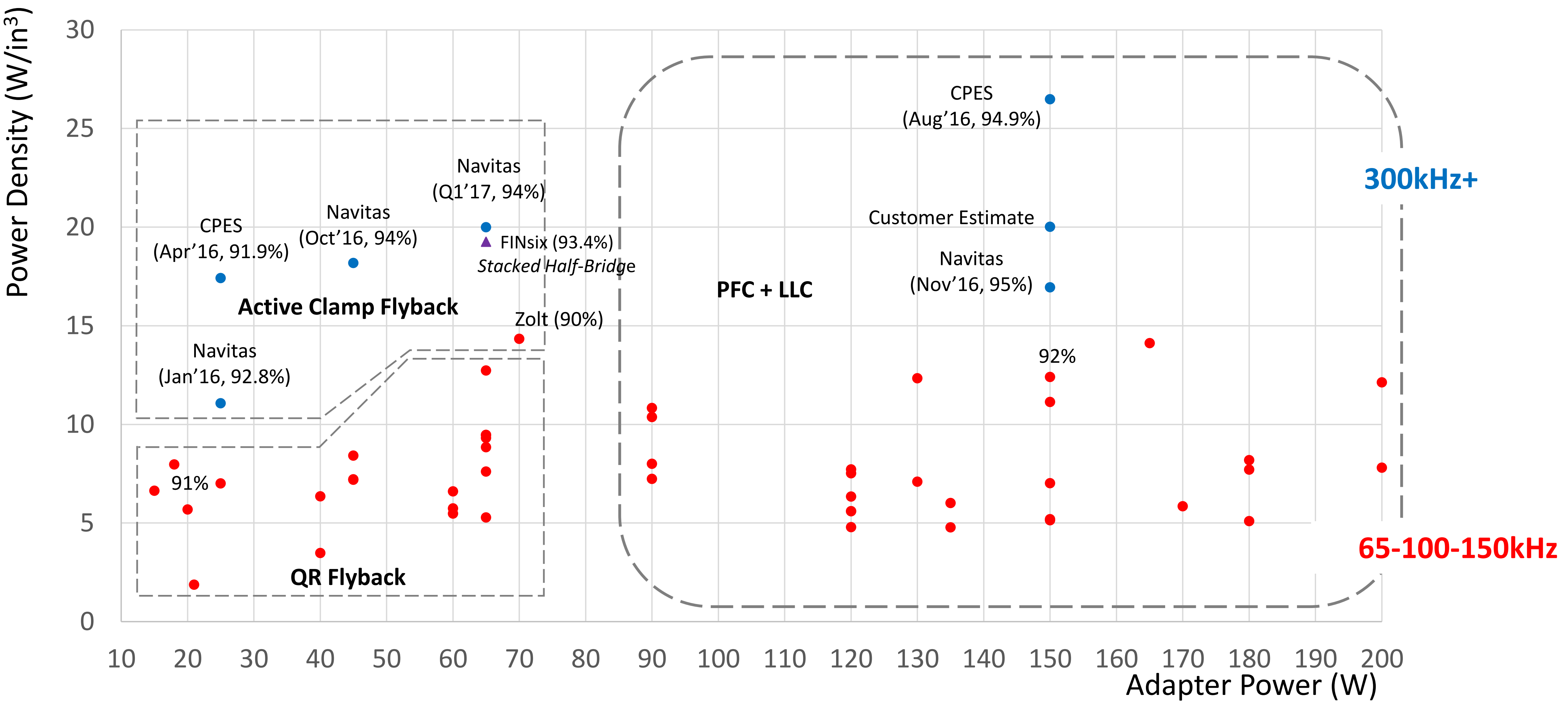


65-100-150kHz

Efficiency at full load, $120V_{AC}$

Adapter Density 2017:

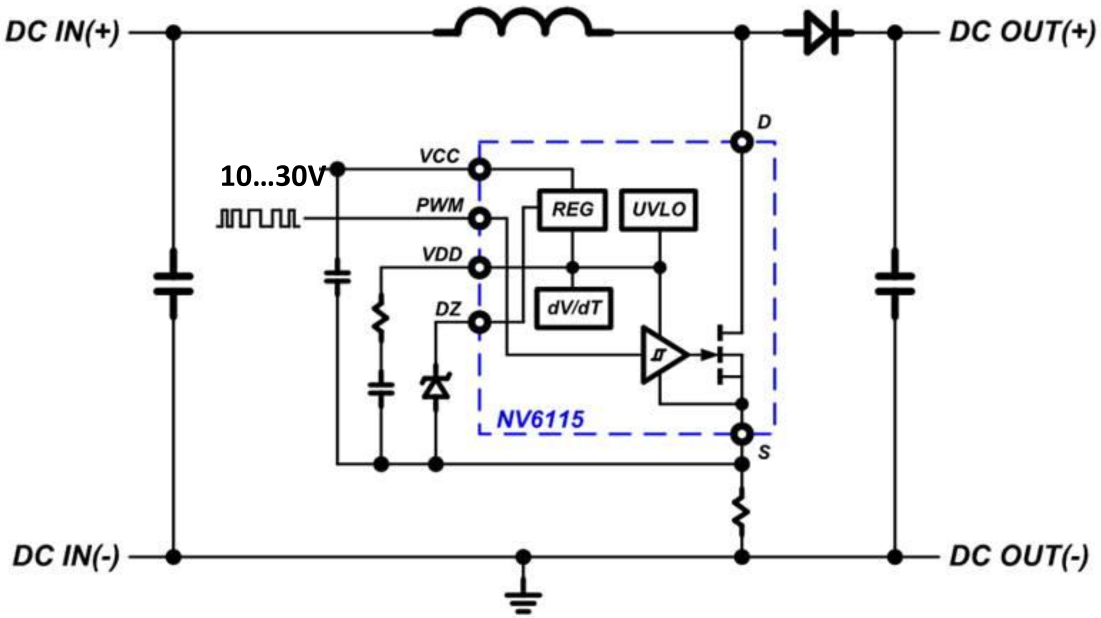
Frequency Drives Size

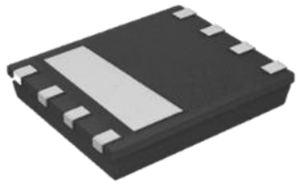


Efficiency at full load, 120V_{AC}

GaN Power IC: High-Speed FET, Driver & More

- Proprietary AllGaN™ technology
- **<u>Monolithic</u>** integration of GaN FET, GaN Driver, GaN Logic
- 650 V eMode
- 20x lower drive loss than silicon (<35 mW at 1 MHz)
- Driver impedance matched to power device
- Very fast (prop delay and turn-on/off of 10-20 ns)
- Zero inductance turn-off loop
- High dV/dt immunity (200 V/ns) with control
- Digital input
- Complete layout flexibility



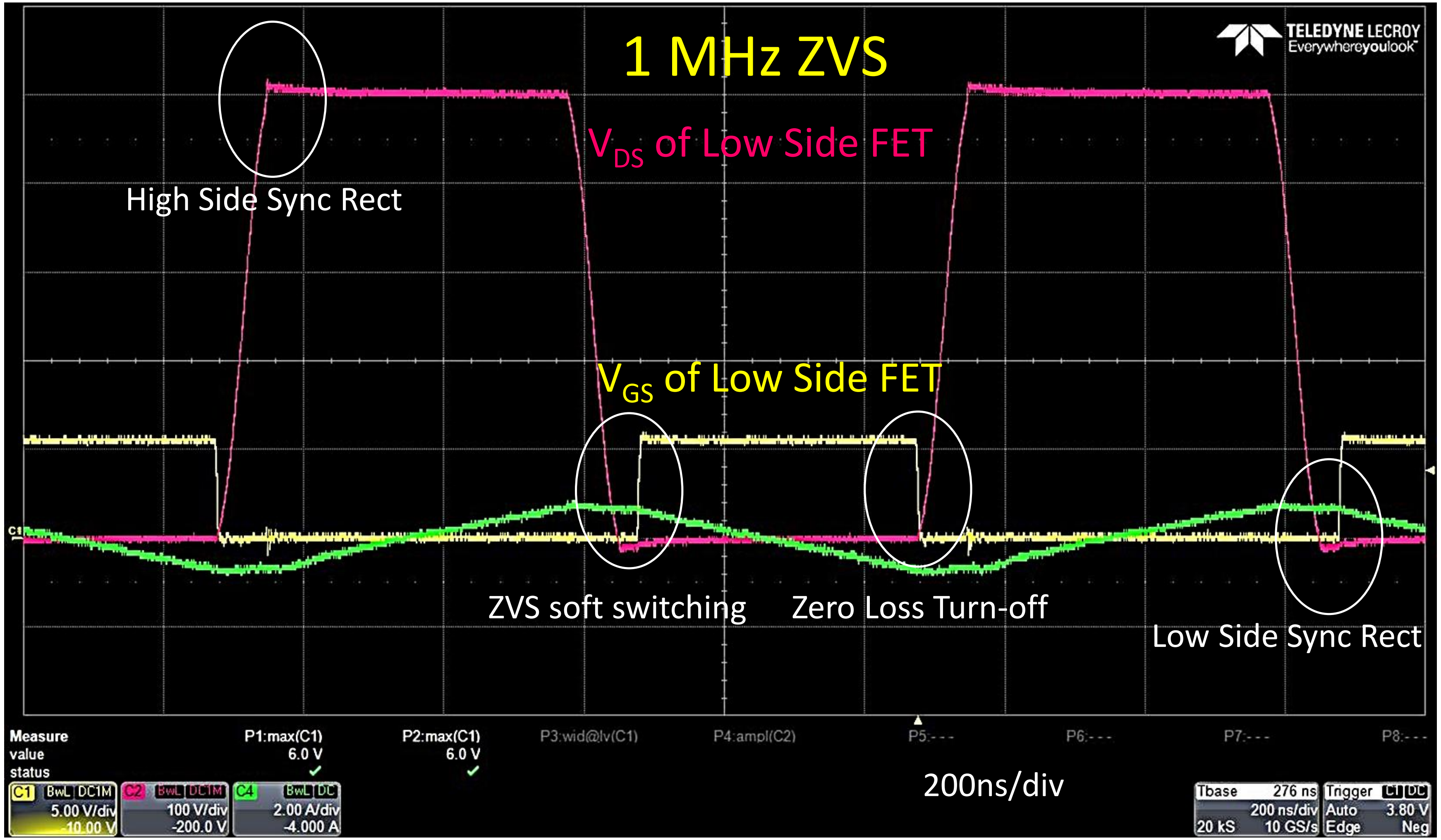


QFN 5x6mm

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

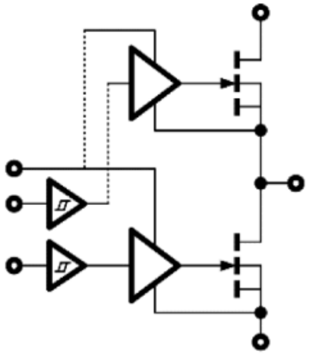
GaN Power IC – *Fast & Efficient*

- 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

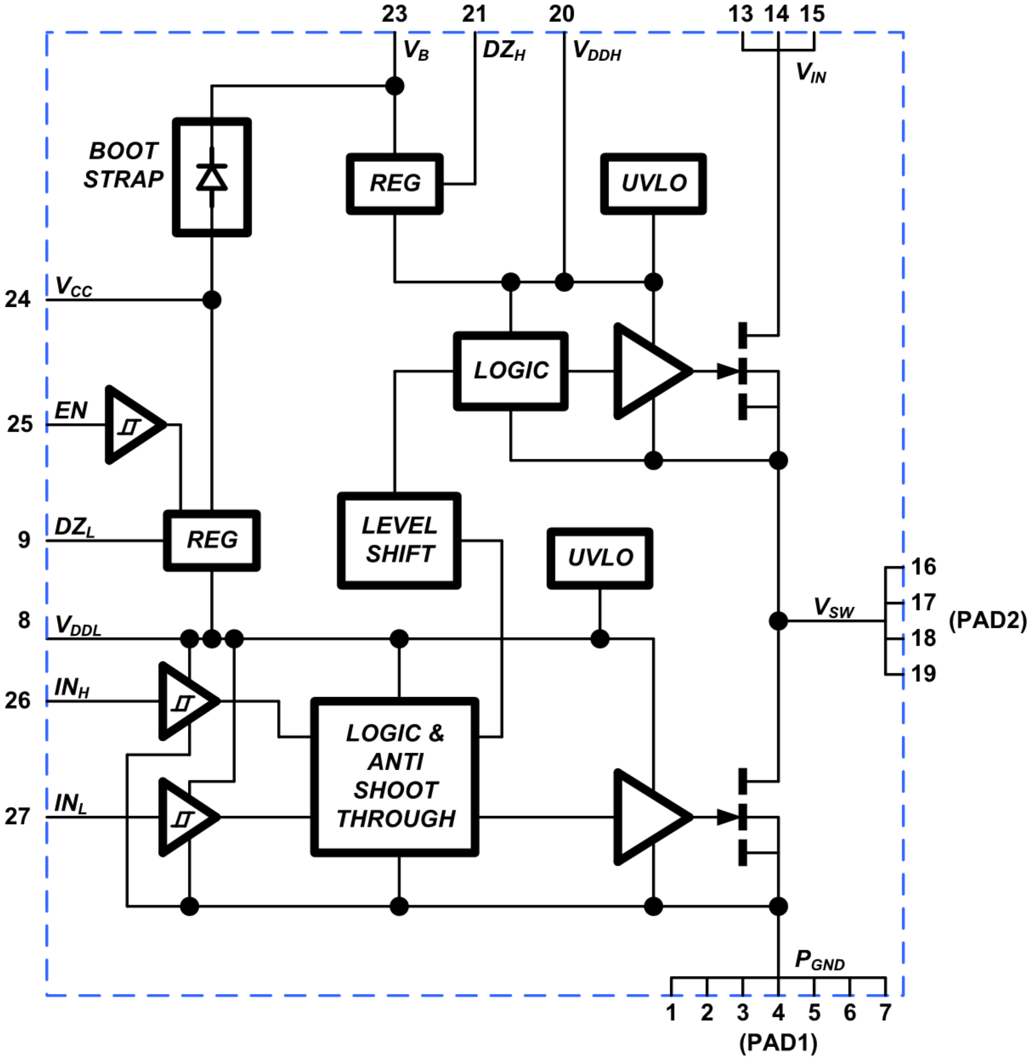


Half-Bridge iDrive GaN Power IC

PQFN 6x8 mm



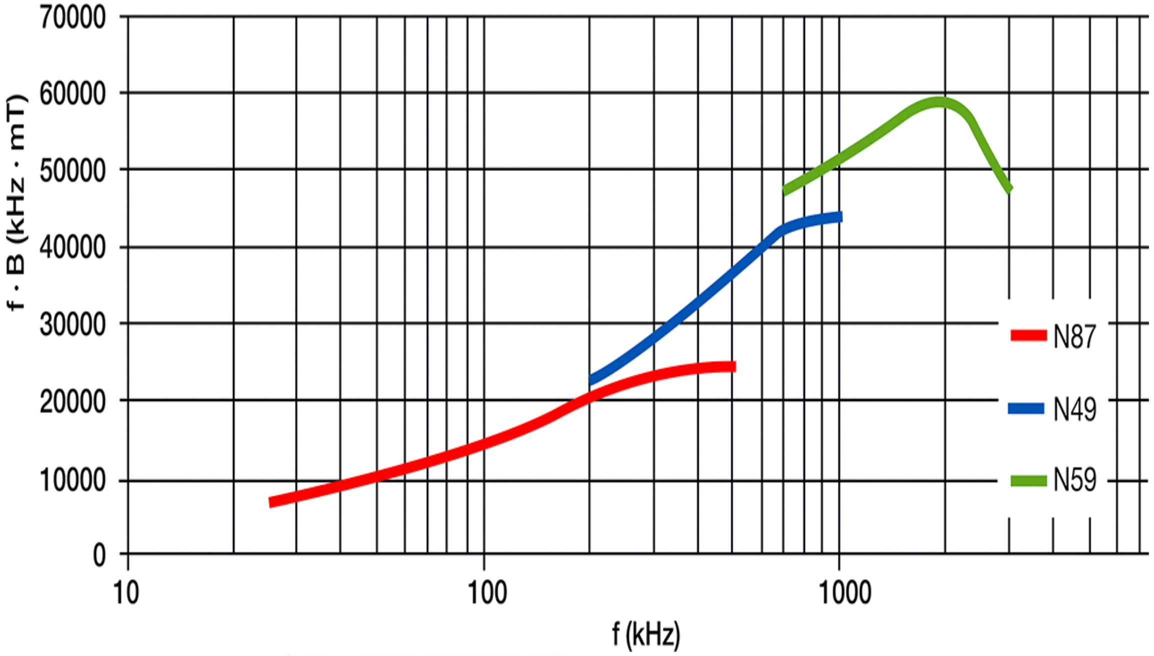
Simplified Schematic

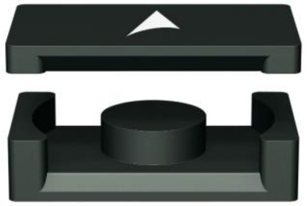


- Internal level-shift, bootstrap
- Range from (2x) 160-560 mOhm (650V)
- Single component
- Ground-referenced control
- Active Clamp Flyback, Half-Bridge, LLC, etc.

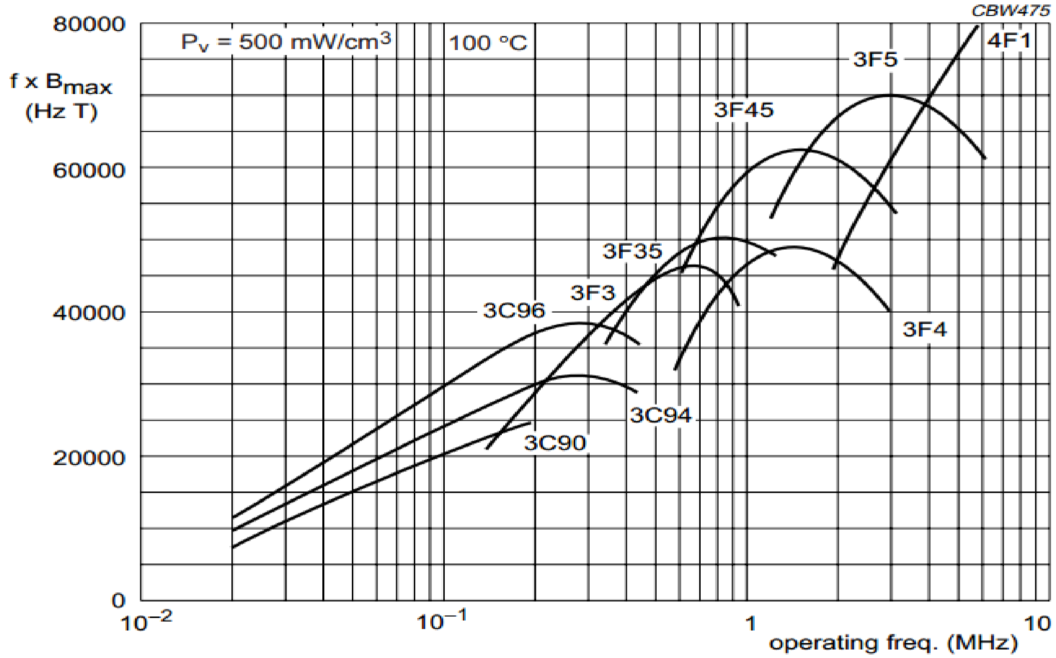
High Frequency Magnetics

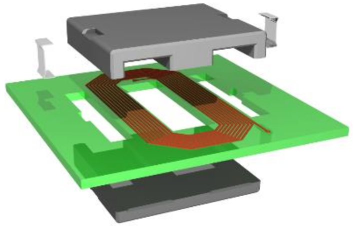
N59 optimized for 2MHz





3F & 4F up to 10MHz



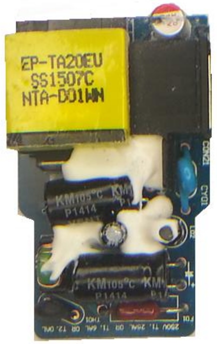


TDK/EPCOS N59/PC200 : https://en.tdk.eu/tdk-en/374108/tech-library/articles/products---technologies/products---technologies/low-losses-at-high-frequencies/1206400
Hitachi Metals ML91S : http://www.hitachi-metals.co.jp/e/press/news/2016/n0404.html
ACME P61 : http://www.acme-ferrite.com.tw/en/material.asp , http://www.acme-ferrite.com.tw/investor/m3.pdf

Fast Chargers … *going "GaN Fast"*

3x Fast Charging with 50% Energy Savings

Existing Si-based 15W



100 kHz
Up to 6.5 W/in^3
88%

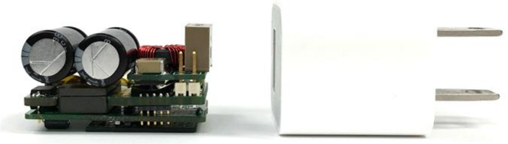
AllGaN™ 2016 25W

2x Faster Charging

300-500 kHz
11 W/in^3
>92%

AllGaN™ 2017 25W

3x Faster Charging



25W 5W

>1 MHz
17.5 W/in^3
>95%

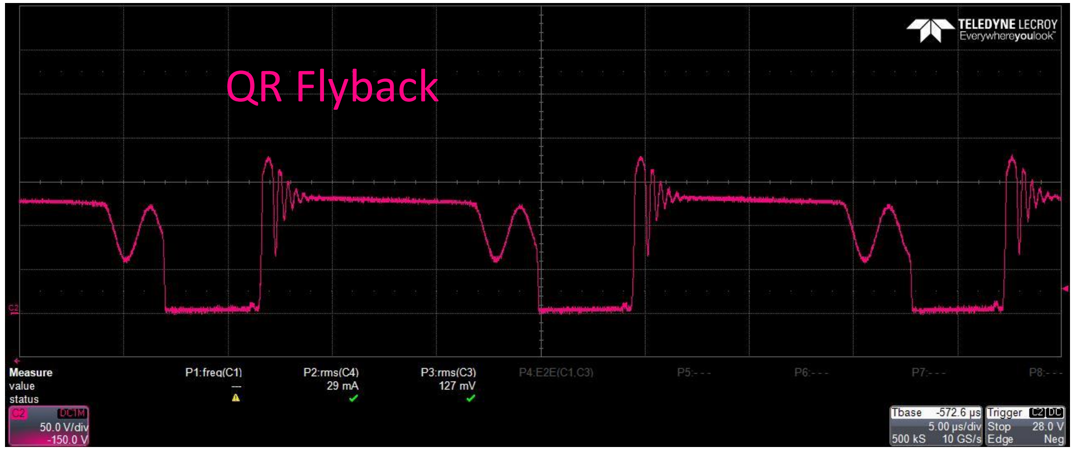
Smartphones & Tablets

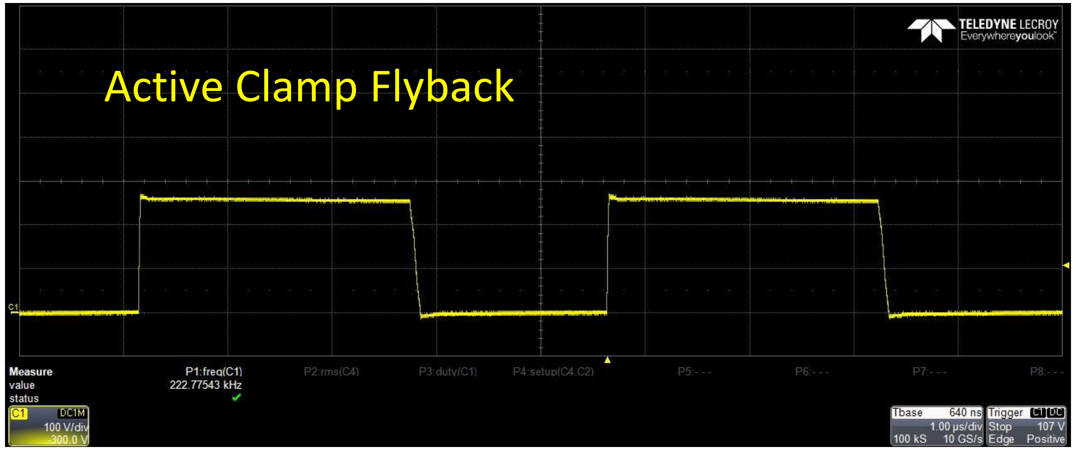
Fast-charging Drones

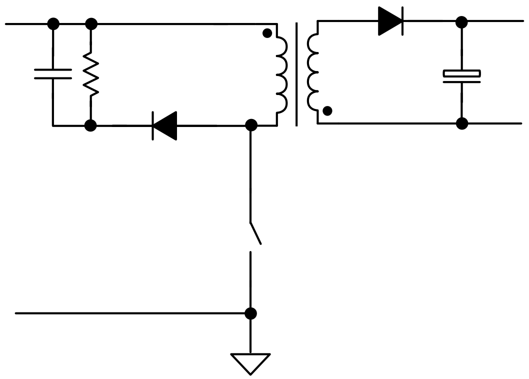
AR / VR & Wearables

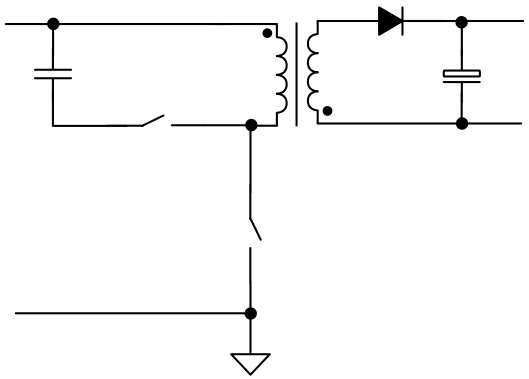
2016: Navitas; **2017**: Xiucheng Huang, "High Frequency GaN Characterization and Design Considerations," Ph.D Dissertation, Dept. Electr. Eng., Virginia Tech., Blacksburg, VA, USA, 2016.

Quasi-Resonant (QR) vs. Active Clamp Flyback (ACF)









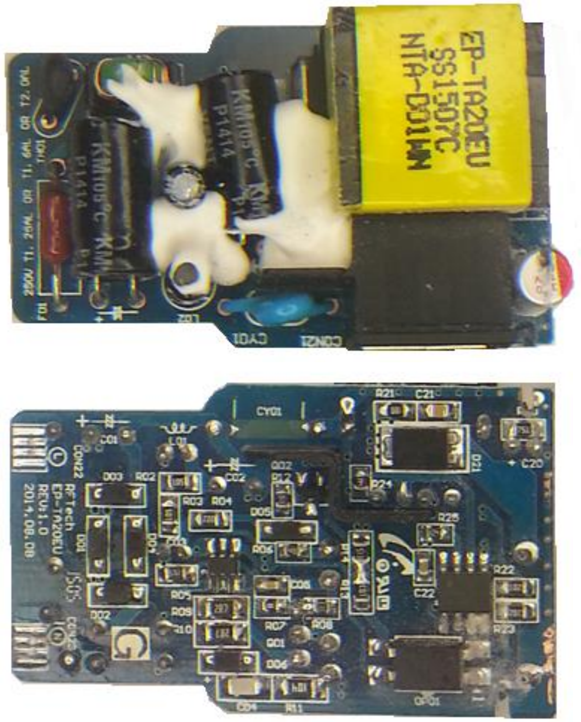
- High loss in RCD snubber circuit
- Partial hard switching at high line
- Losses increase with switching frequency

- No resistor needed in the snubber: no snubber loss
- Full range zero-voltage switching (ZVS): no switching loss
- ACF enables high switching frequency

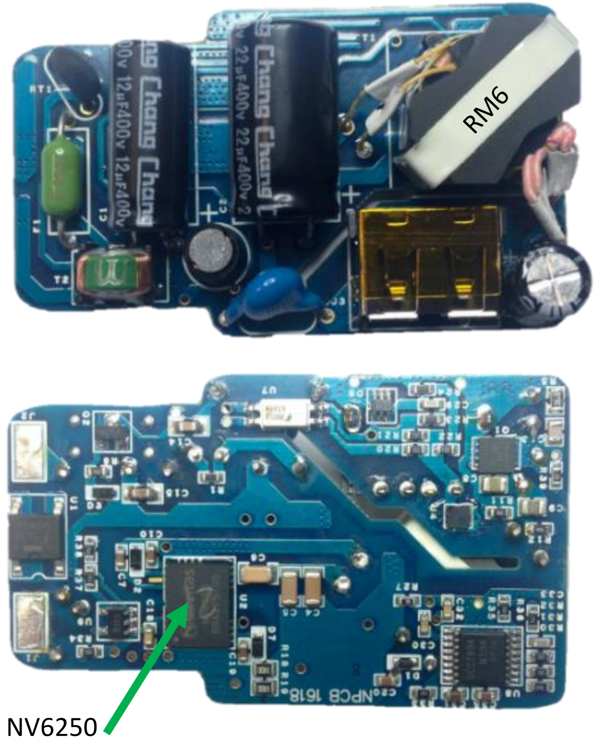
Navitas

25W ACF: 66% More Power

Original 15 W case

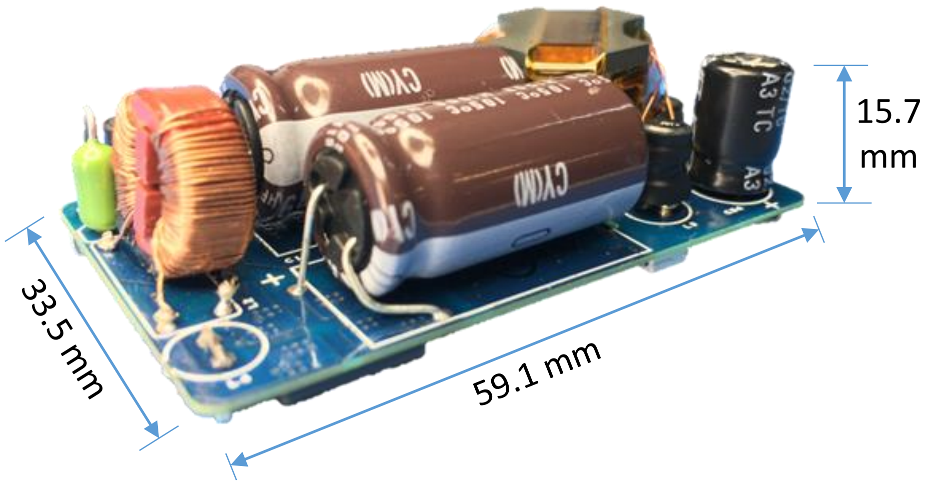


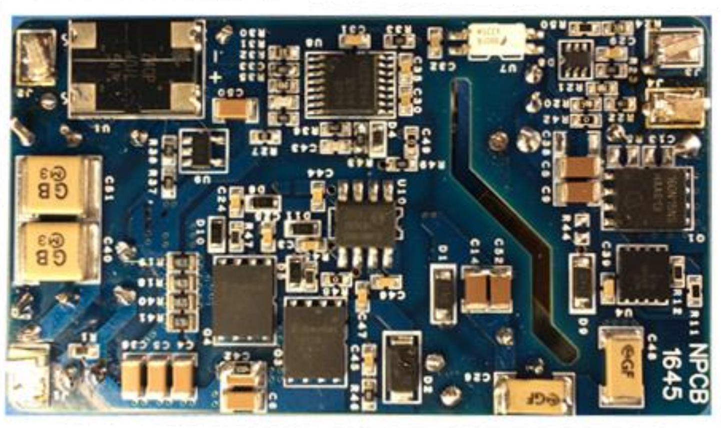
Original 15 W
Si-based QR Flyback
~100 kHz



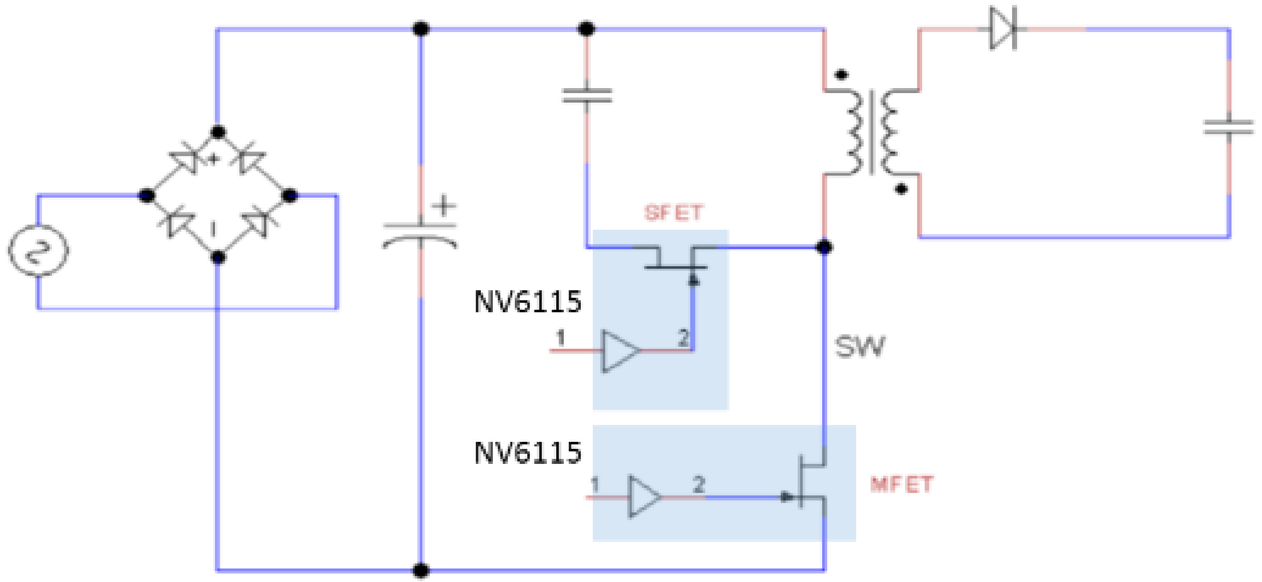
Upgraded 25 W
Half-Bridge GaN Power IC ACF
~400 kHz

45W ACF



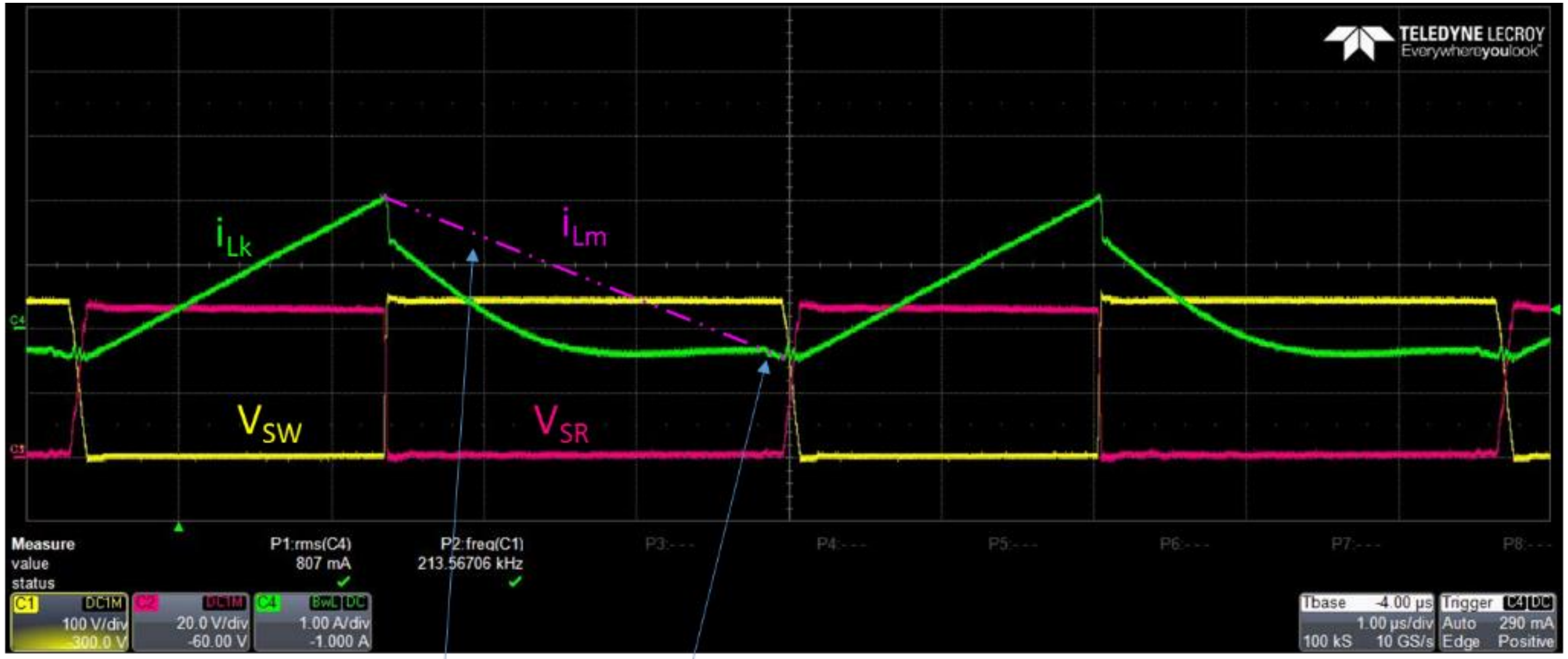


- 94.5% efficient at 220V (94.2% at 120V$_{AC}$, 93.1% at 90V$_{AC}$)
- 23.7 W/in^3 density (uncased)
- 15.7mm profile



For further details of ACF, please see APEC 2017 technical paper "Active Clamp Flyback Using GaN Power IC for Power Adapter Applications", Xue, Zhang

45W CrCM ACF Operation

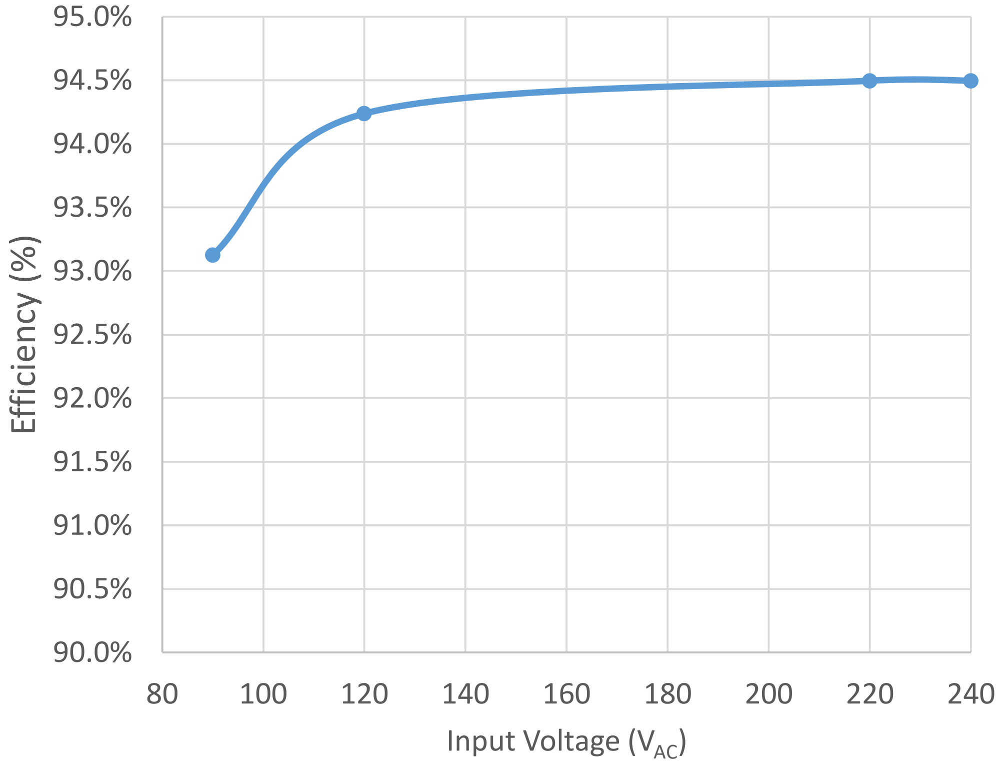


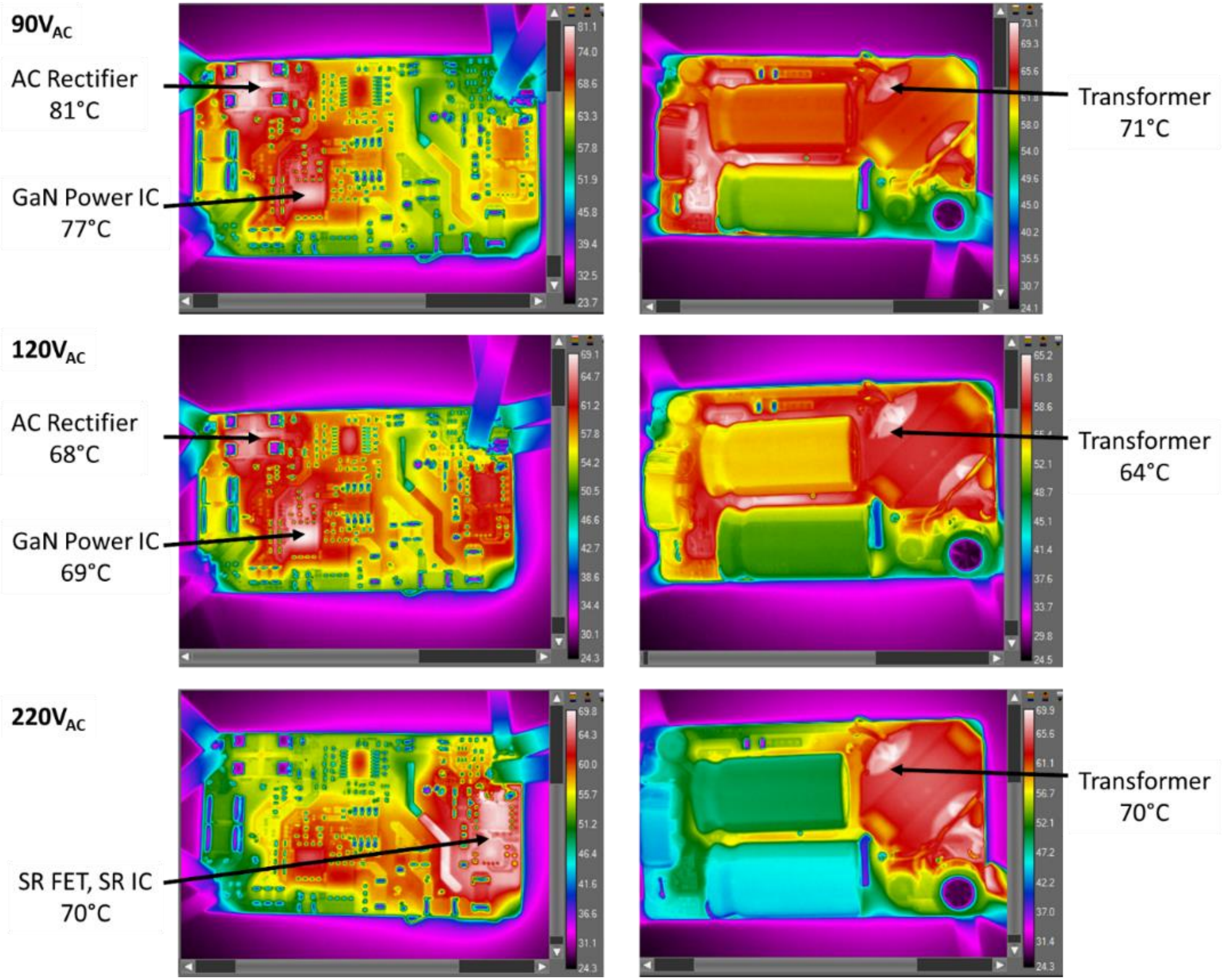
Magnetizing current (drawing)

Inductor current merges with magnetizing current, achieves SR ZCS turn-off

- Switch-node voltage (V_{SW}), SR FET voltage (V_{SR}), leakage current (i_{LK}) and magnetizing current (I_{Lm})
- $120V_{AC}$, 0.2A load, F_{SW} = 210kHz

45W ACF: High Efficiency, Cool Temperatures

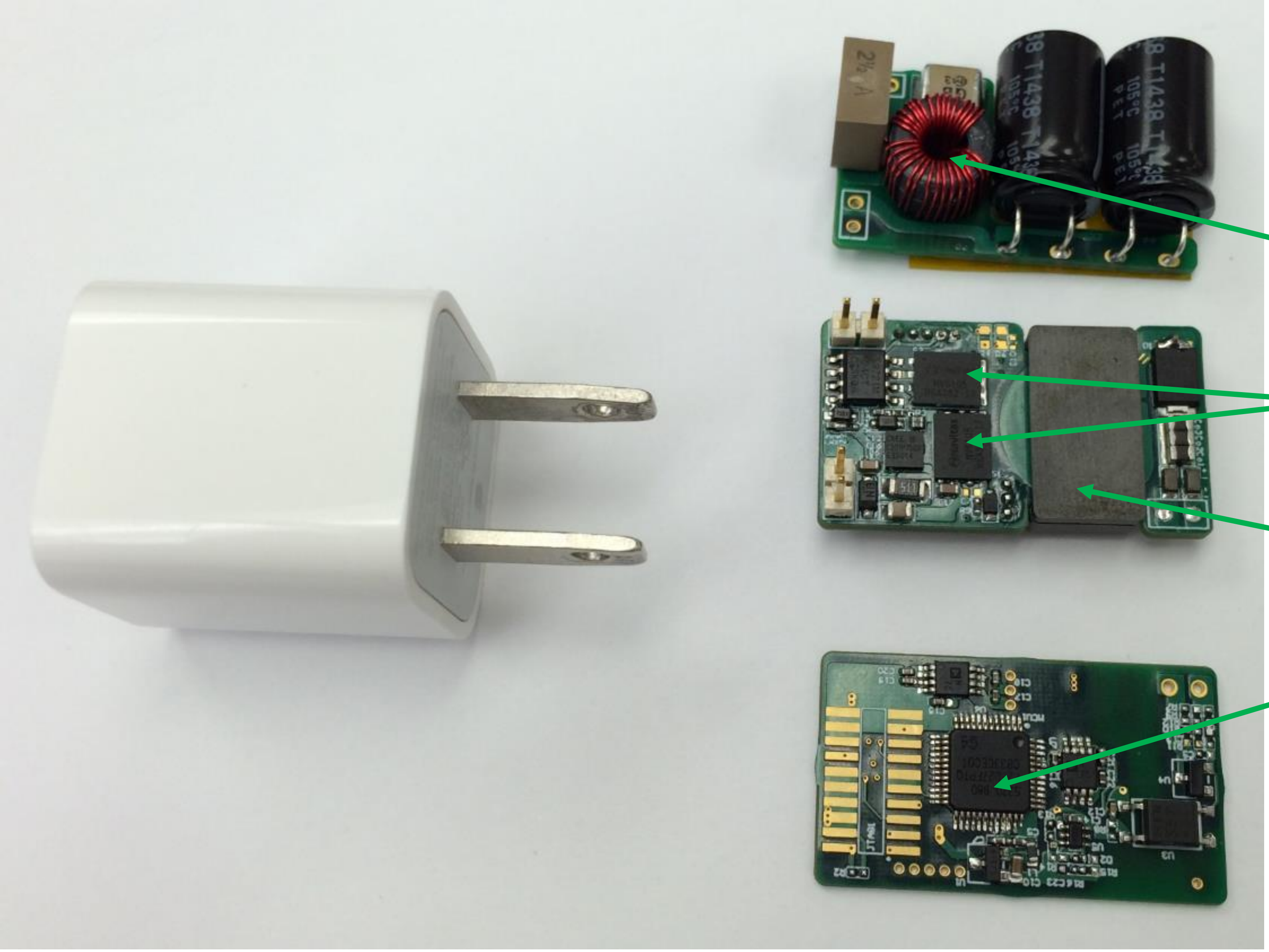




1 MHz, 25 W, 17 W/in3 (cased) ACF (CPES 2016)

Navitas

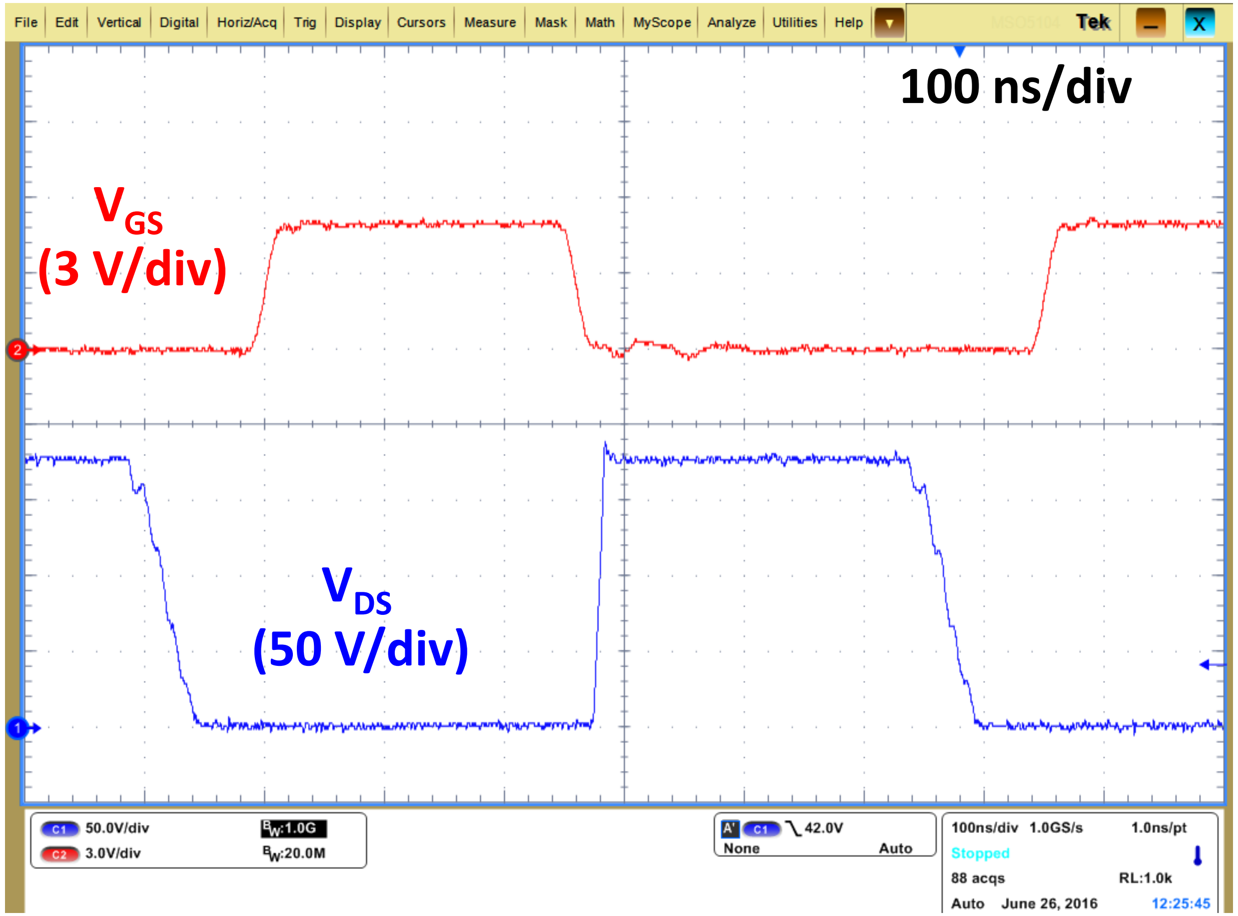
CPES
Center for Power Electronics Systems



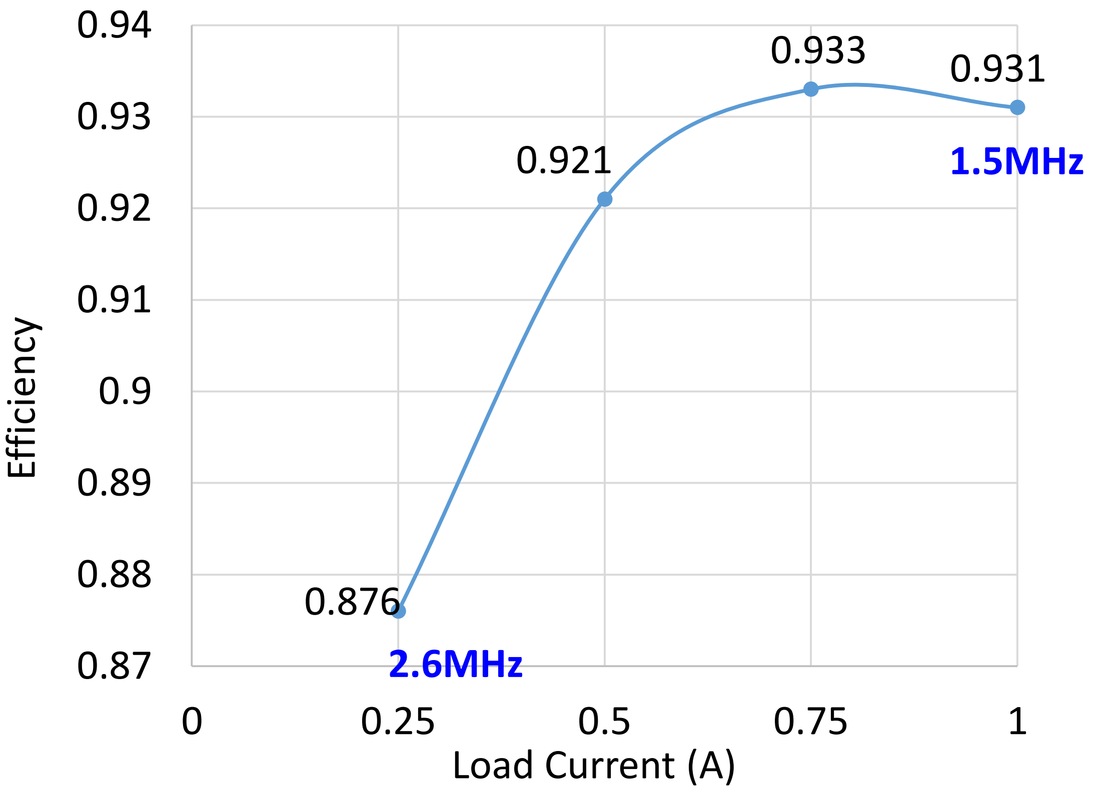
- Single-stage EMI
- Navitas GaN Power ICs
- Planar transformer
- DSP (for prototype)

MHz+ 25 W ACF

F_{SW}=1.5MHz



Efficiency vs. Load



** Exclude bridge and EMI filter loss*

GaN Power ICs enable Hi-Density Adapters

3x Higher Density with 50% Energy Savings

Existing Si-based
150W

100 kHz
5-10 W/in^3
88%

AllGaN™ 2016
150W

2x Higher Density

300-500 kHz
17 W/in^3
>93%

AllGaN™ 2017
150W

3x Higher Density

>1 MHz
26.5 W/in^3
>95%

Ultra-thin LED TV

All-in-One PCs

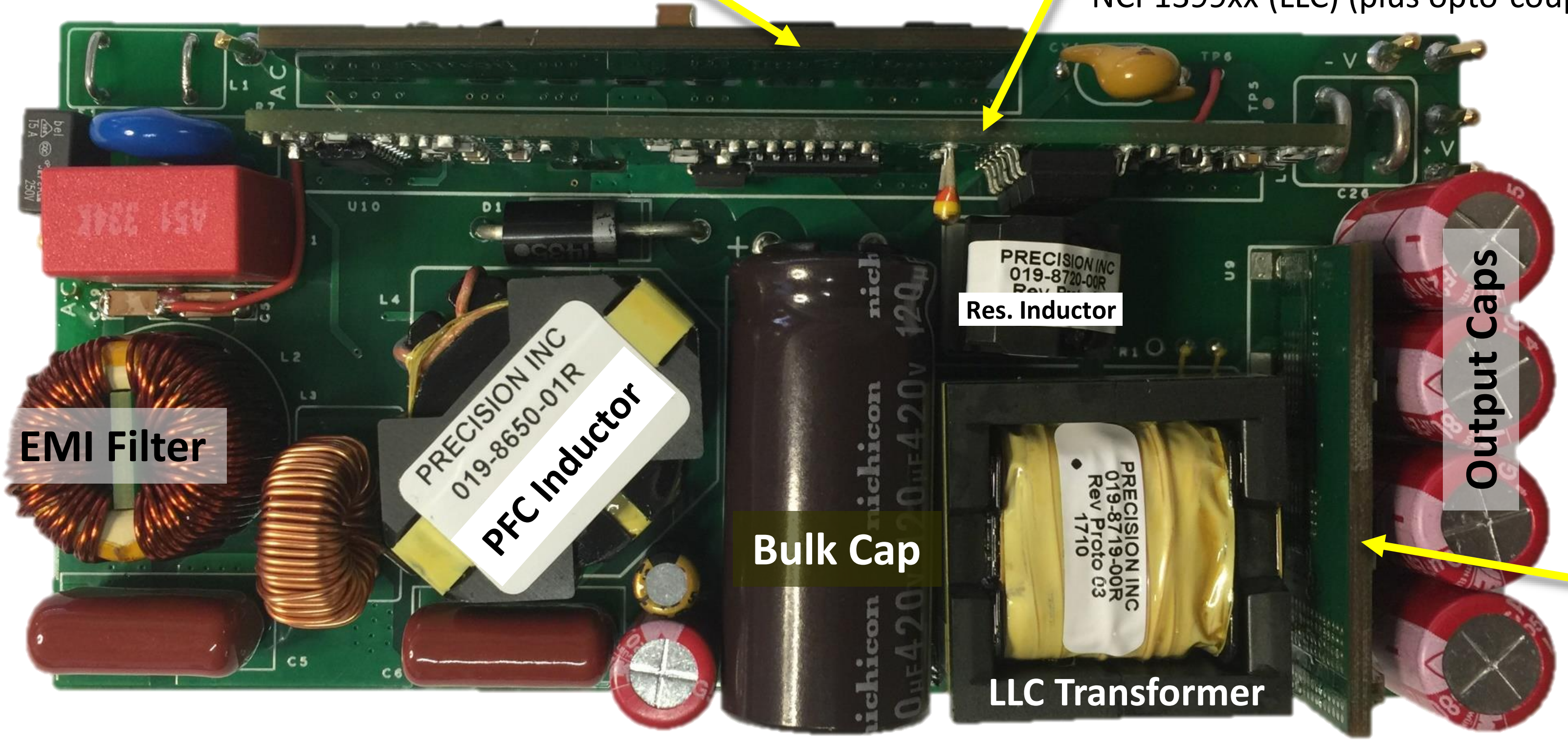
Next-Gen Gaming Consoles

2016: Navitas + On Semiconductor; **2017**: Xiucheng Huang, "High Frequency GaN Characterization and Design Considerations," Ph.D Dissertation, Dept. Electr. Eng., Virginia Tech., Blacksburg, VA, USA, 2016.

150W AC-19V

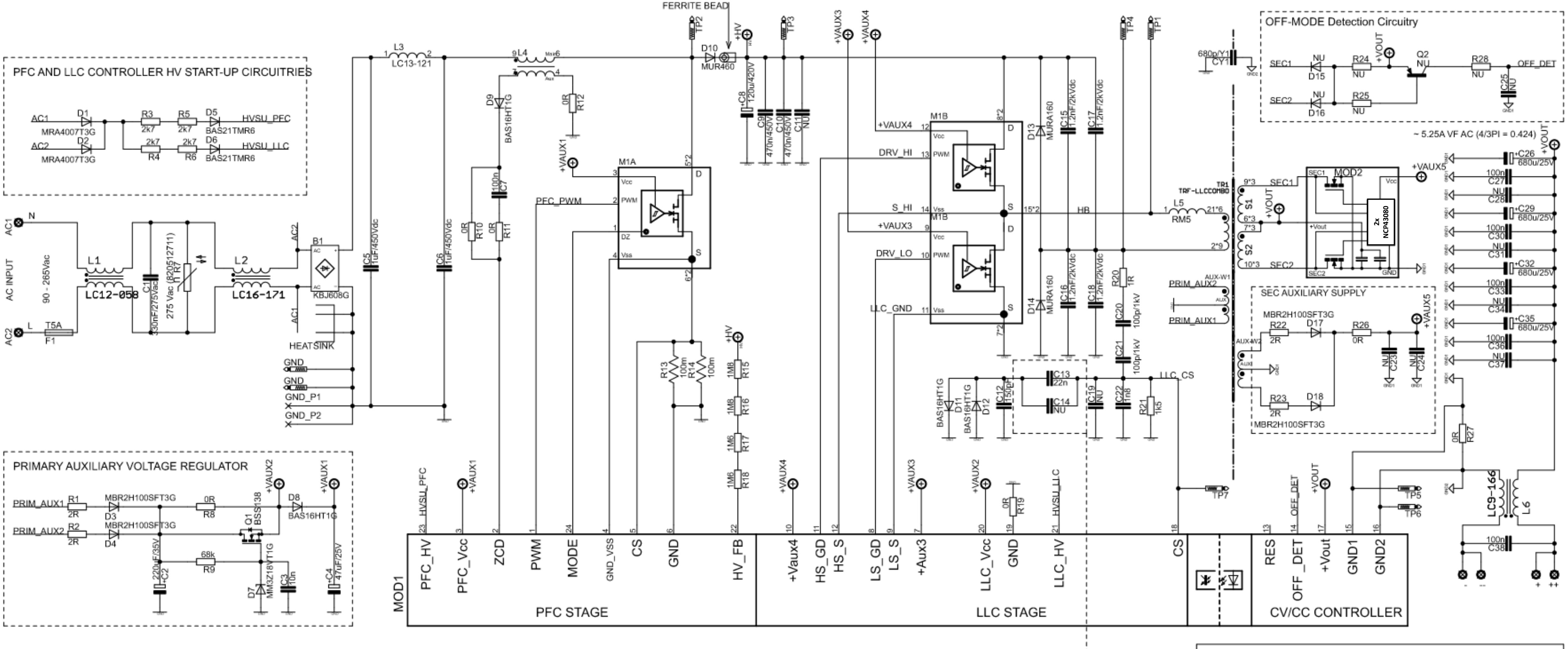
PFC + LLC Powertrain Daughtercard
NV6117 (PFC), 2x NV6115 (LLC)

PFC + LLC Control Daughtercard
NCP1615 (PFC)
NCP1399xx (LLC) (plus opto-couplers)



SR Daughtercard:
2x NCP43080
2x NVMFS5C628NL

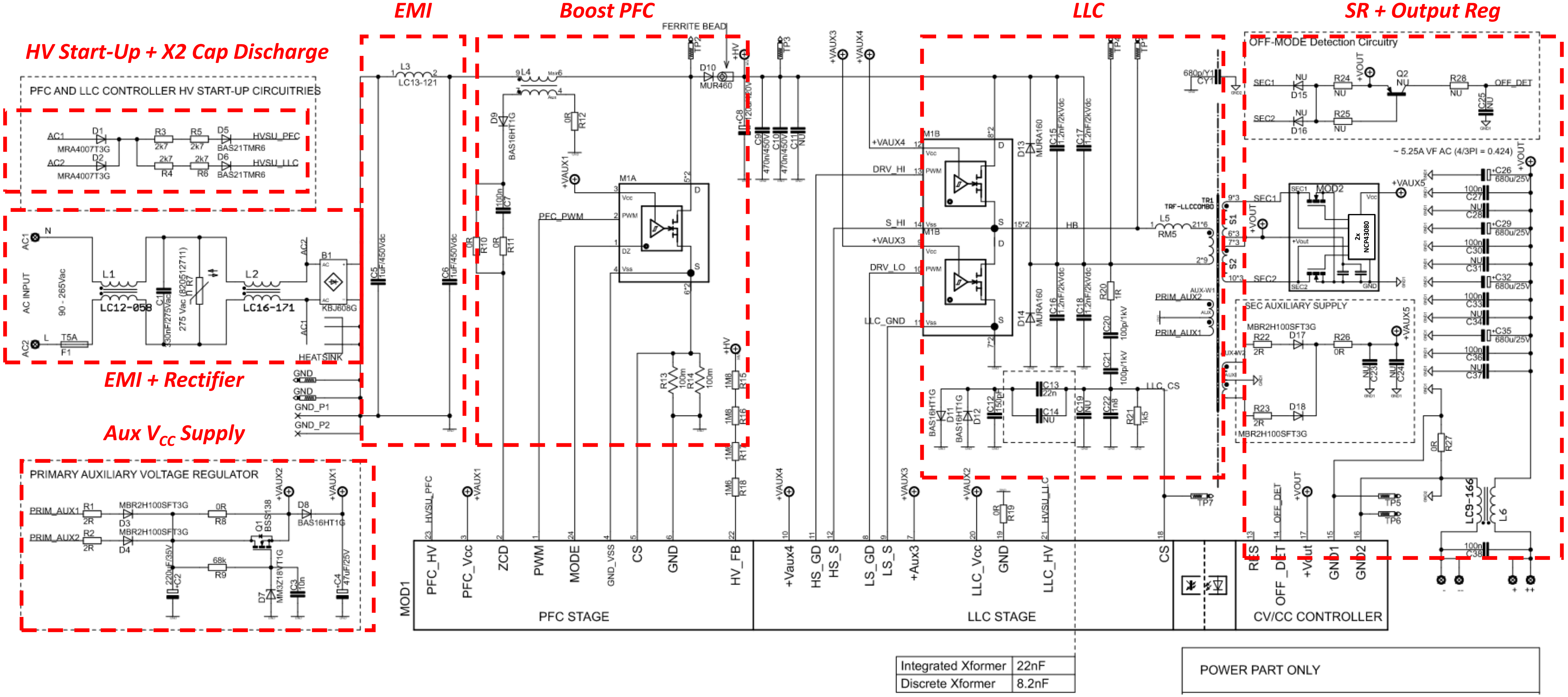
Schematics (Complete Board)



Integrated Xformer	22nF
Discrete Xformer	8.2nF

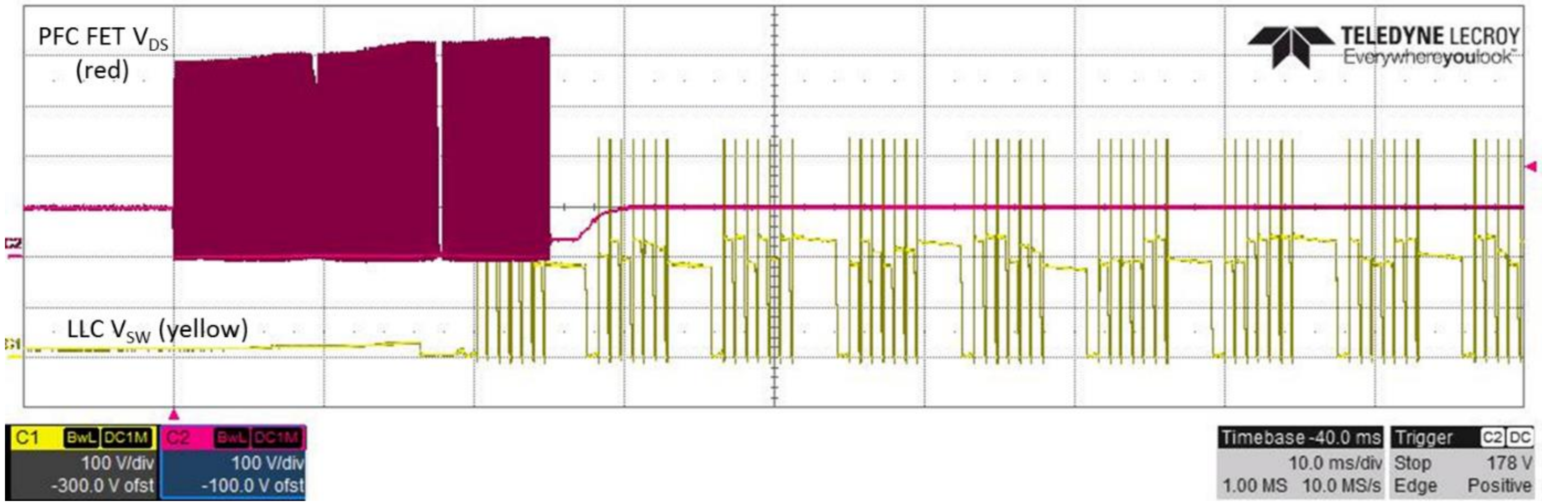
POWER PART ONLY

Schematics (Complete Board)

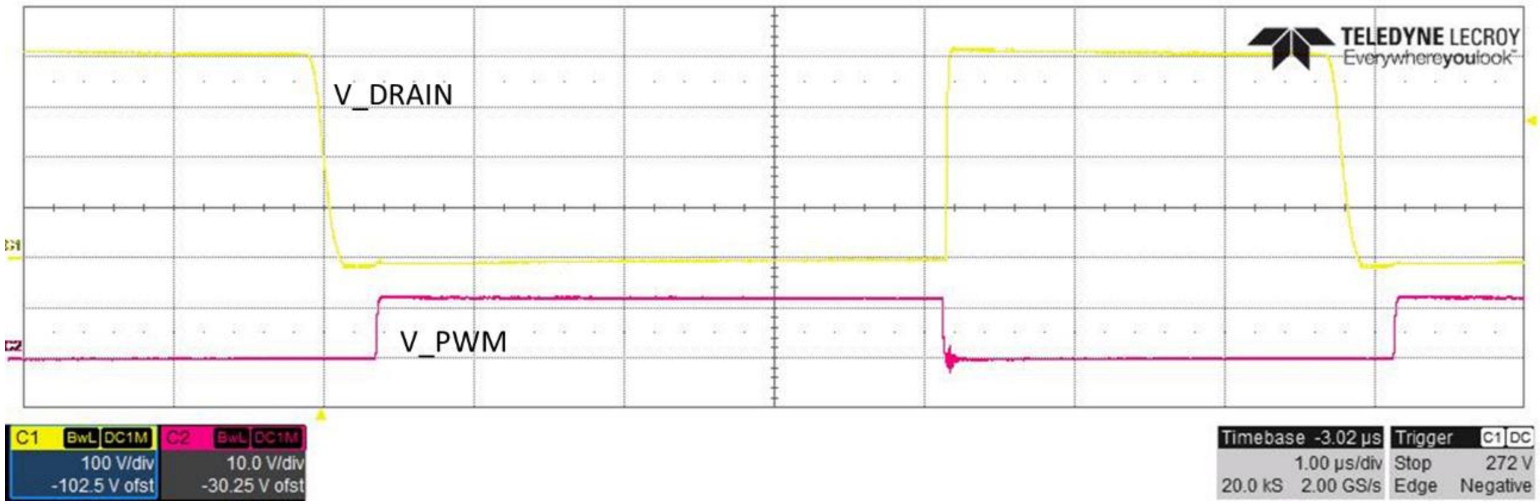


PFC Waveforms

PFC FET V_{DS}, LLC V_{SW} at start-up

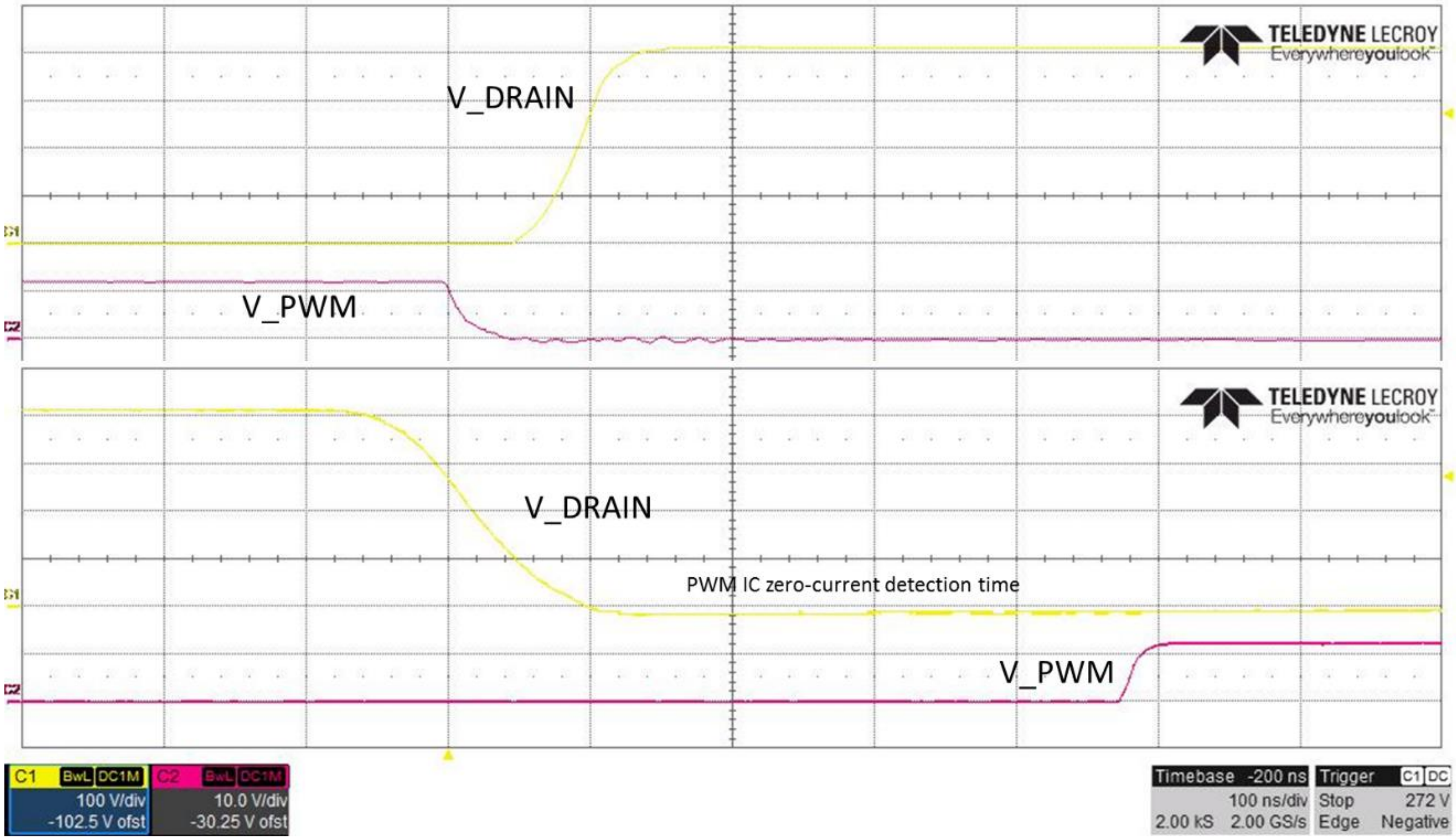


PFC switching (zoom), $220V_{AC}$, 150W

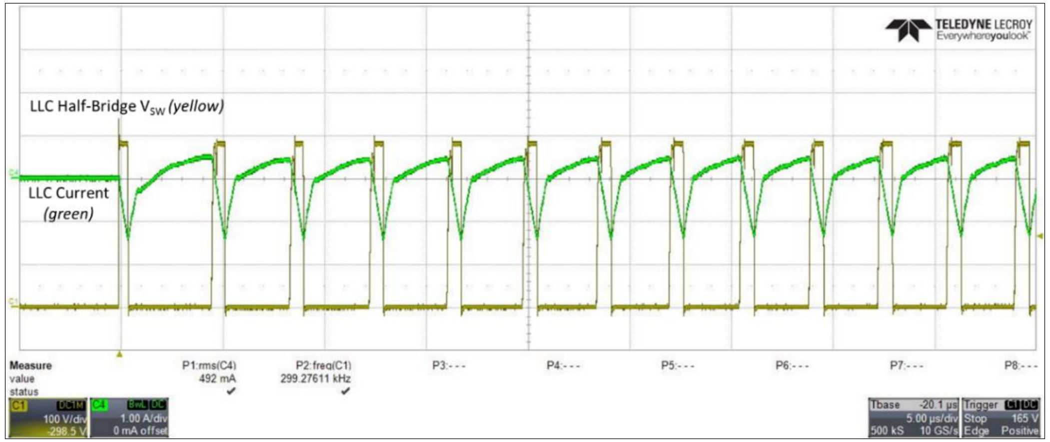


PFC Waveforms

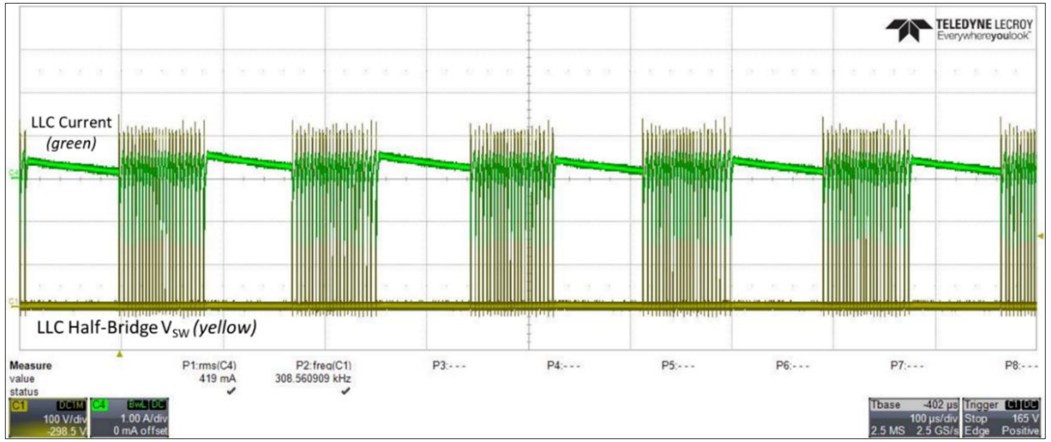
PFC switching (zoom), $220V_{AC}$, 150W



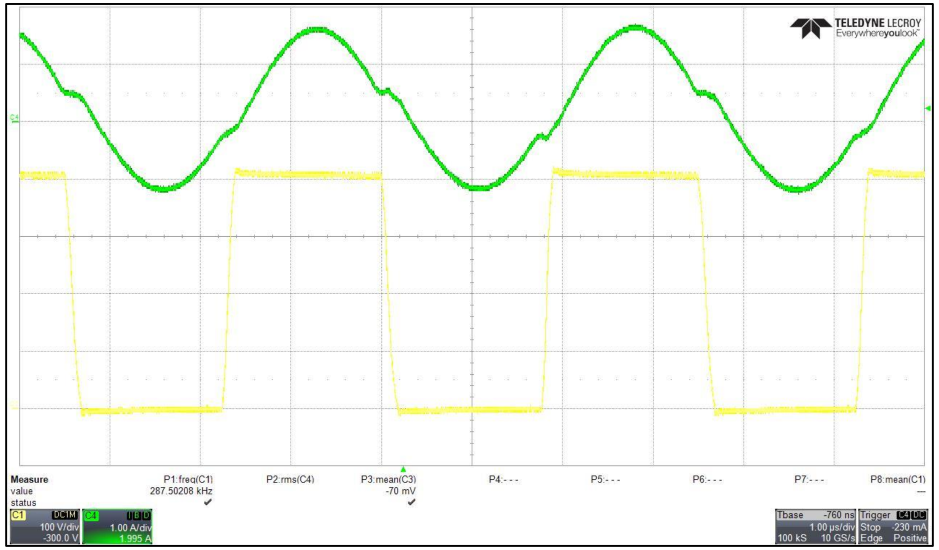
LLC Waveforms



LLC V_{SW}, open load, $19V_{OUT}$



LLC V_{SW}, skip-mode, $19V_{OUT,}$ 1A

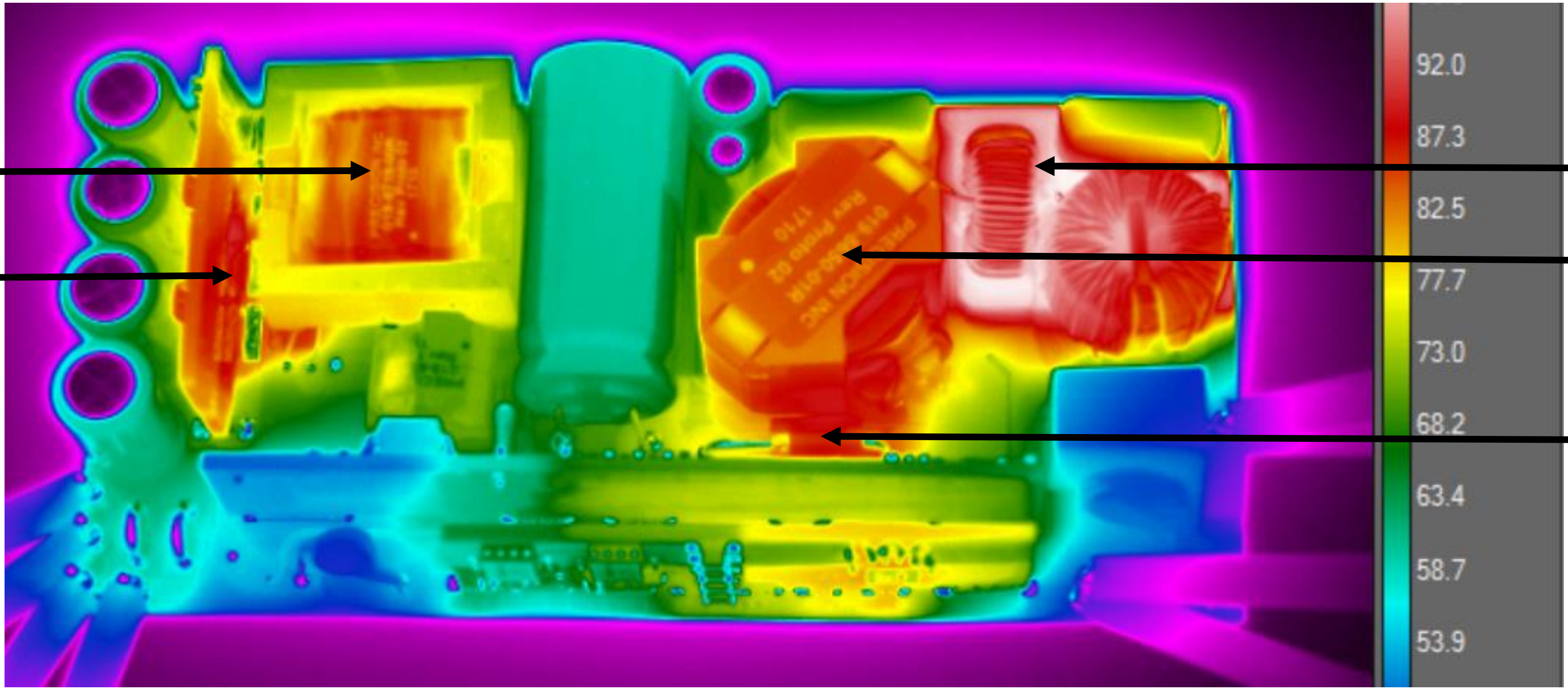


LLC V_{SW}, I_L, $19V_{OUT}$, 8A

150W: Running Cool

LLC Transf.
85°C

SR FETs
90°C



DM
Choke
90°C

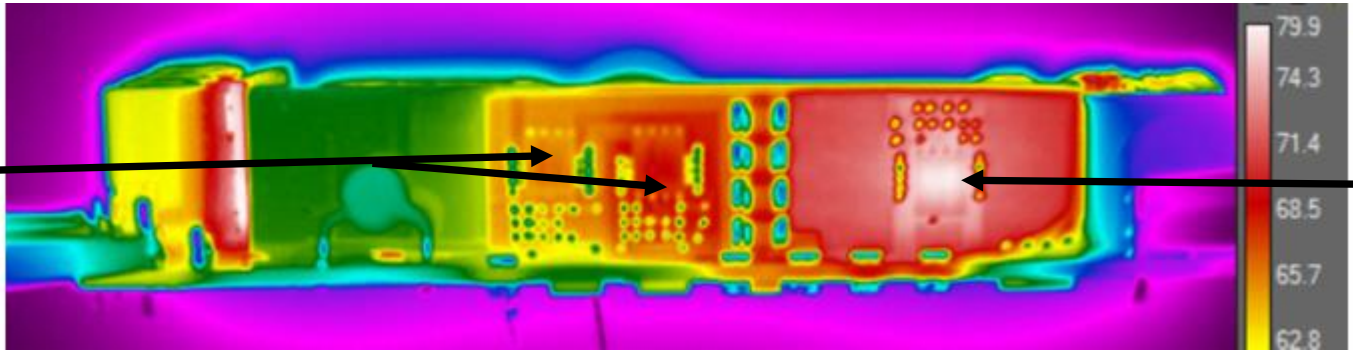
PFC
Inductor
85°C

PFC
diode
90°C

TOP VIEW

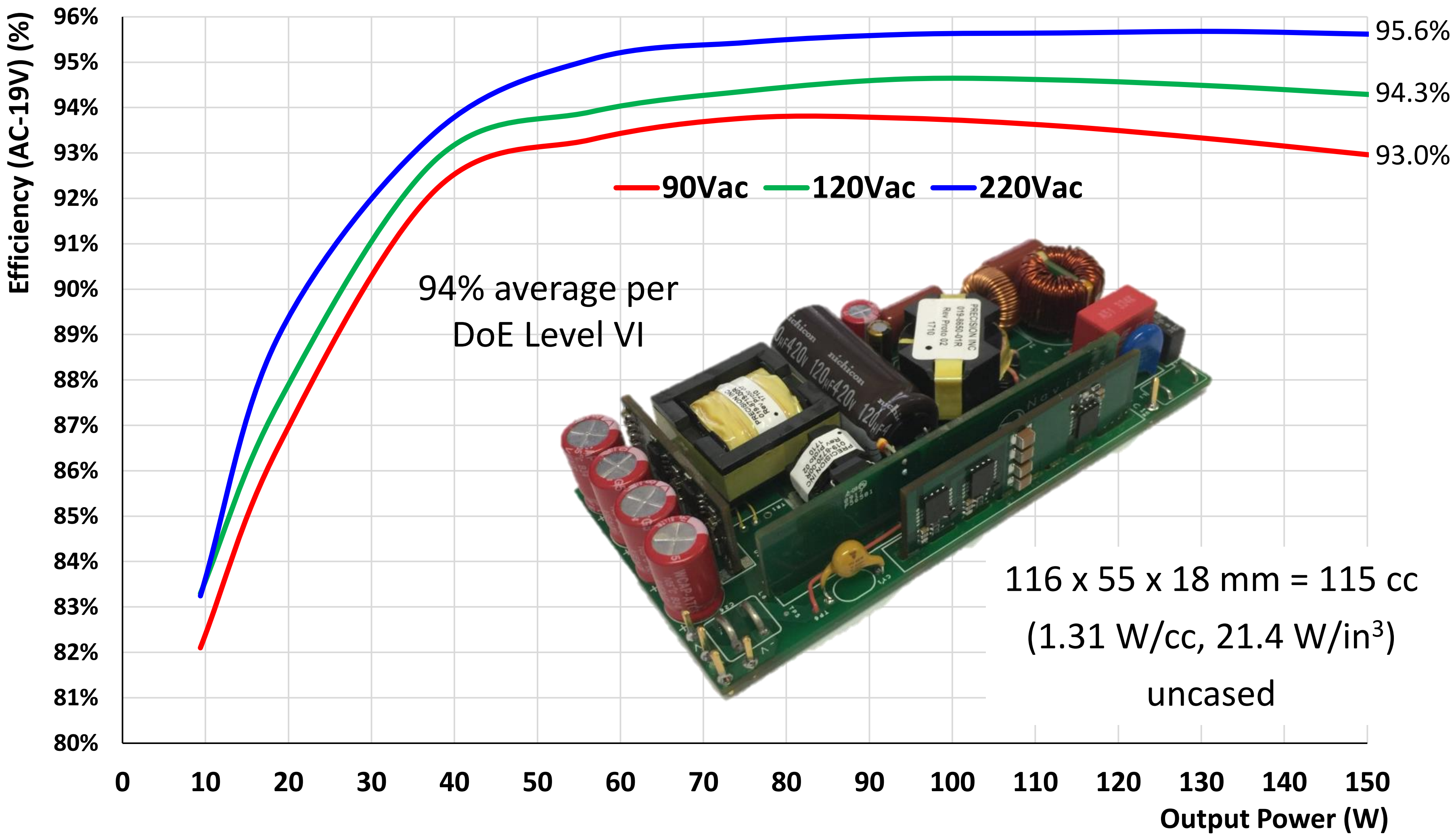
LLC Primary
(2x NV6115)
65°C

SIDE VIEW



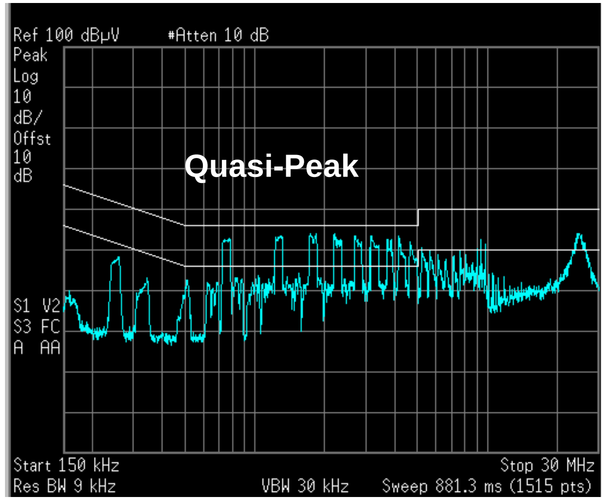
PFC Switch
(NV6117)
80°C

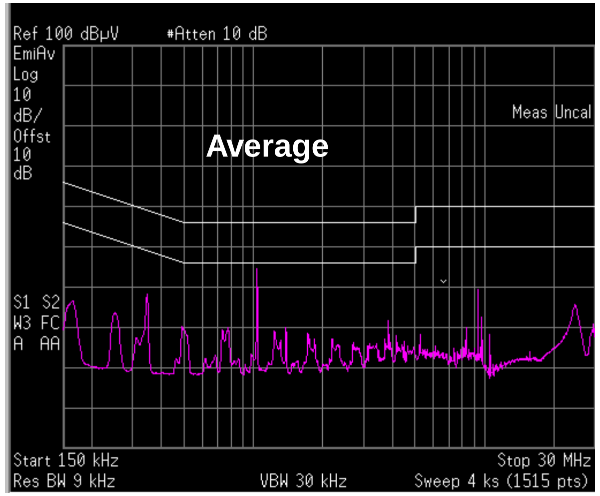
150W AC-19V, ~300 kHz



94% average per DoE Level VI

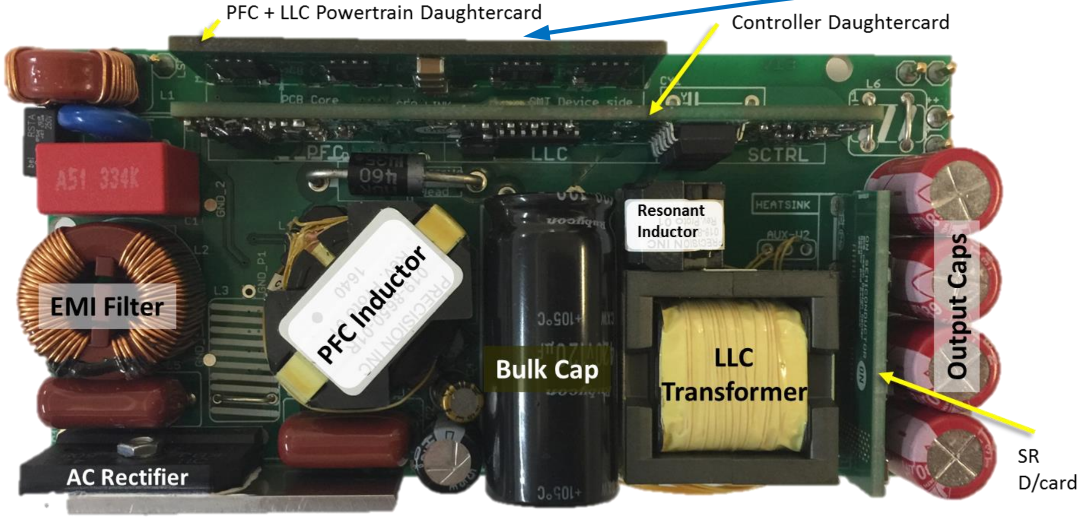
116 x 55 x 18 mm = 115 cc (1.31 W/cc, 21.4 W/in^3) uncased

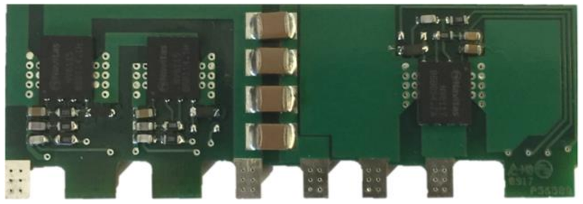




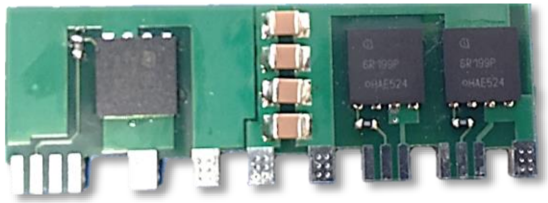
150W, 19V: GaN Power IC vs. Si

Part#	Technology	V	Pack	$R_{DS(ON)}$ (typ. mΩ)	Q_G (typ. nC)	$C_{OSS}(er)$ (typ. pF)	R x Q_G (mΩ.nC)	R x $C_{OSS}(er)$ (mΩ.pF)
STL34N65M5	Si FET	650	8x8	99	62.5	63	6,187	6,237
IPL60R199CP	Si FET	600	8x8	180	32	69	5,760	12,420
IPL60R299CP	Si FET	600	8x8	270	22	46	5,940	12,420
NV6115	GaN Power IC	650	5x6	160	2.5	30	400	4,800
NV6117	GaN Power IC	650	5x6	110	4	45	440	4,950
GaN Benefit							***14x***	***1.5-2.5x***





Navitas GaN Power ICs (5x6mm QFN)
PFC = 1x NV6117, LLC = 2x NV6115



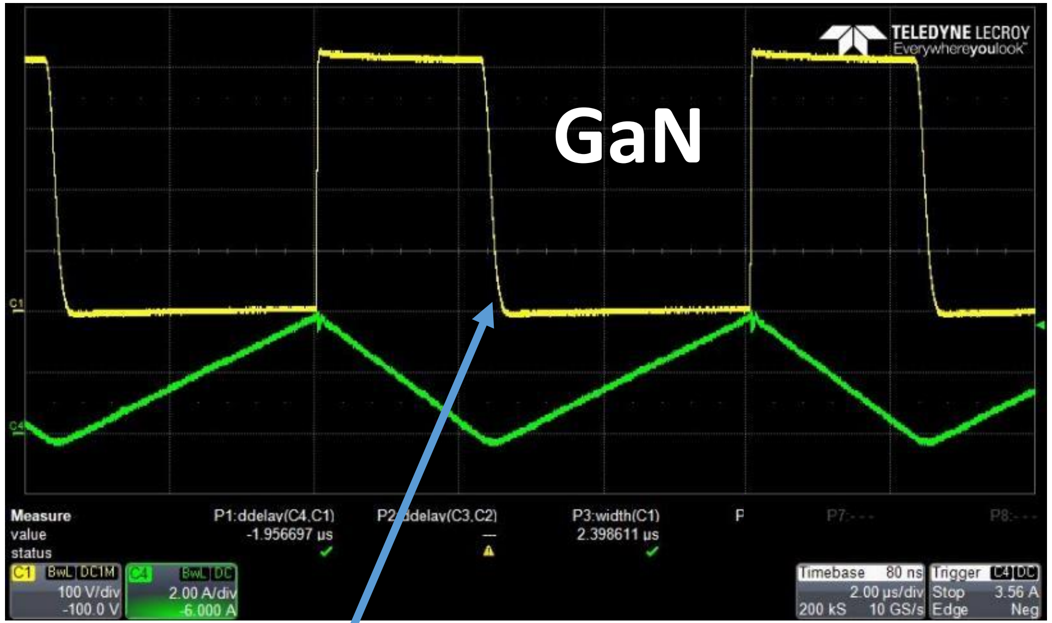
Si FETs (8x8mm QFN)
a) PFC = 1x IPL60R299CP, LLC = 2x IPL60R299CP
b) PFC = 1x IPL60R199CP, LLC = 2x IPL60R299CP

For further details of the 150 W, 21 W/in3 board, please see APEC 2017 Industry Session “State-of-the-Art Mobile Charging: Topologies, Technologies and Performance” (Mobile Applications)

Si Starts Hard Switching as Frequency Increases

120V$_{AC}$, Si CP partial hard-switching (~200kHz)

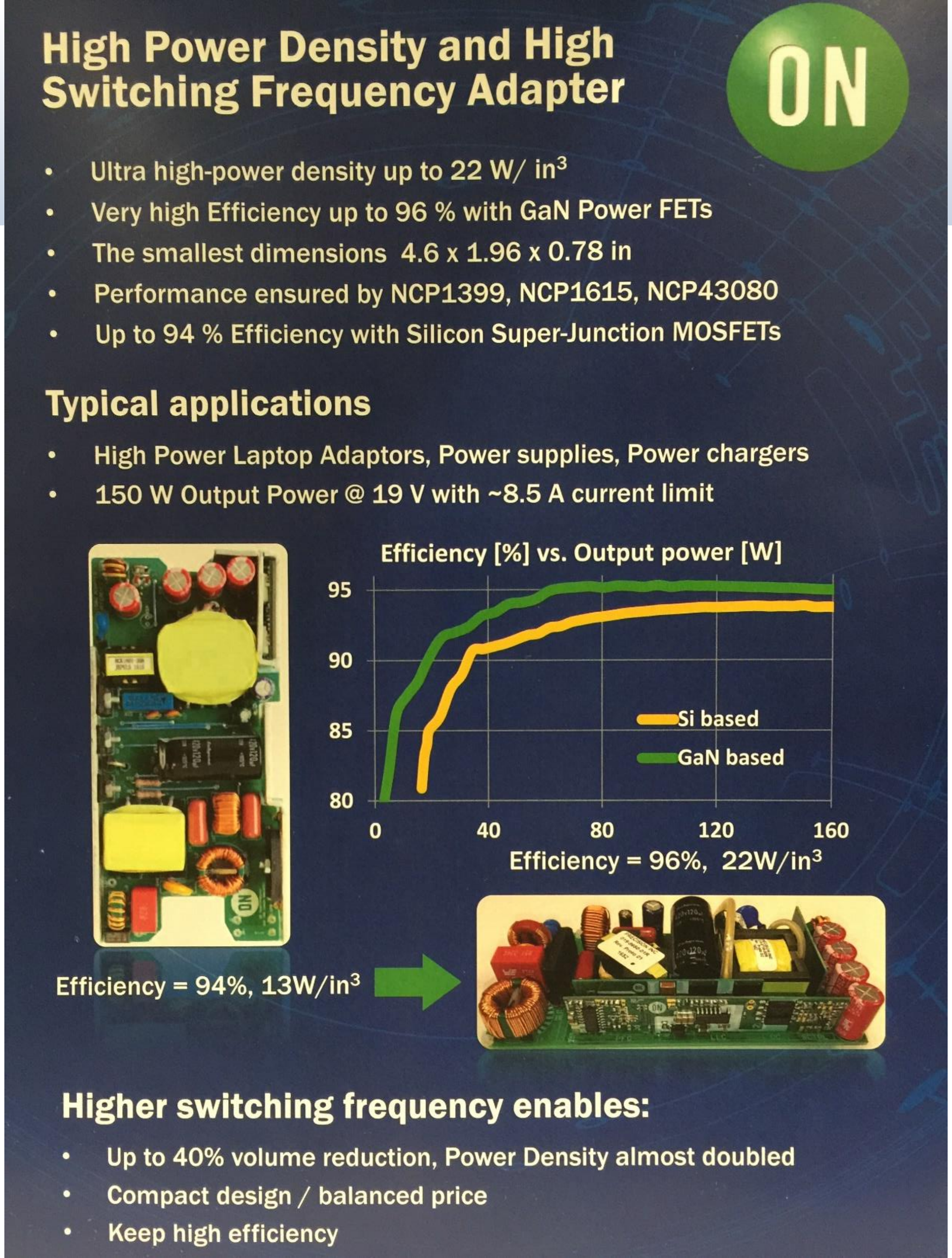
- Voltage spikes
- Partial hard-switching (loss)



120V$_{AC}$, GaN clean ZVS waveforms (~200kHz)

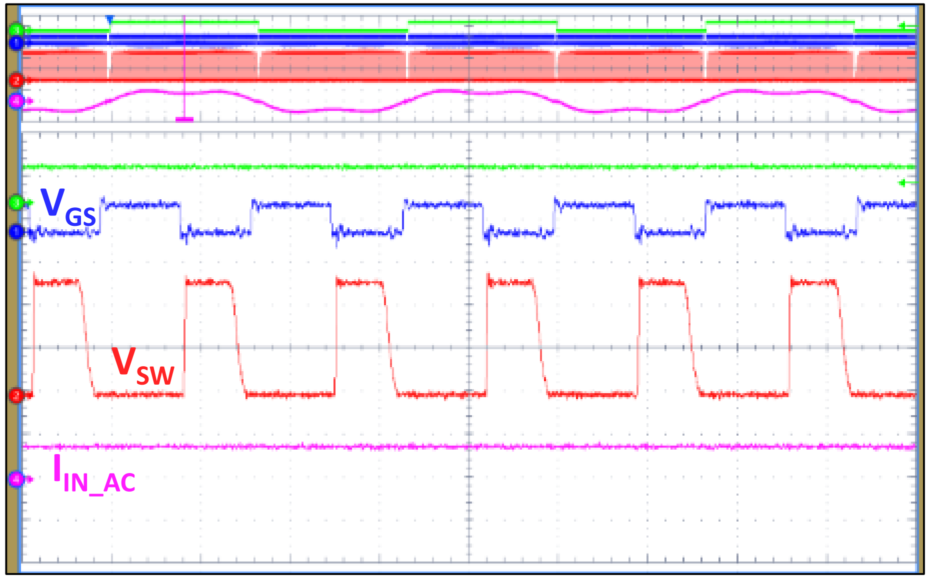
- No voltage spikes / overshoot
- Clean ZVS turn-on transition
- Minimize deadtime for low reverse conduction loss

GaN vs. Si

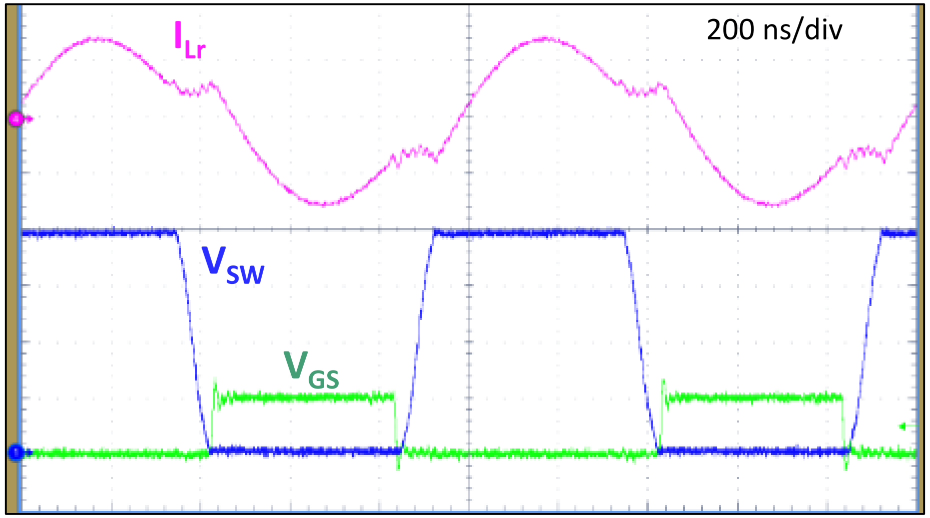

High Power Density and High Switching Frequency Adapter
ON
Ultra high-power density up to 22 W/ in3
Very high Efficiency up to 96 % with GaN Power FETs
The smallest dimensions 4.6 x 1.96 x 0.78 in
Performance ensured by NCP1399, NCP1615, NCP43080
Up to 94 % Efficiency with Silicon Super-Junction MOSFETs
Typical applications
High Power Laptop Adaptors, Power supplies, Power chargers
150 W Output Power @ 19 V with ~8.5 A current limit
Efficiency [%] vs. Output power [W]
95
90
85
80
0
40
80
120
160
Si based
GaN based
Efficiency = 96%, 22W/in3
Efficiency = 94%, 13W/in3
Higher switching frequency enables:
Up to 40% volume reduction, Power Density almost doubled
Compact design / balanced price
Keep high efficiency

MHz 150W Totem-pole + LLC (CPES 2016)

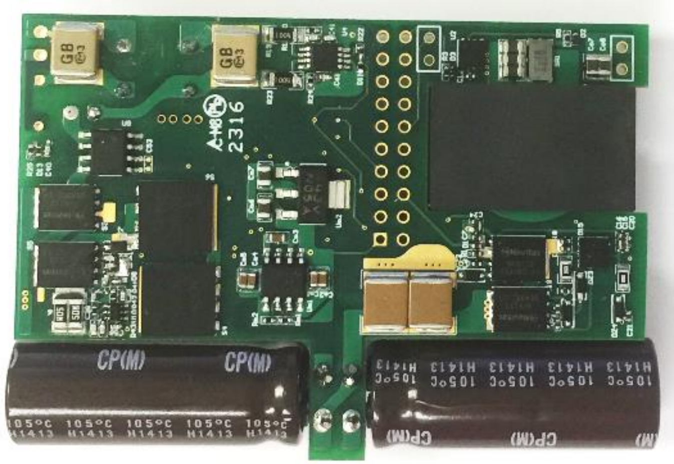
PFC

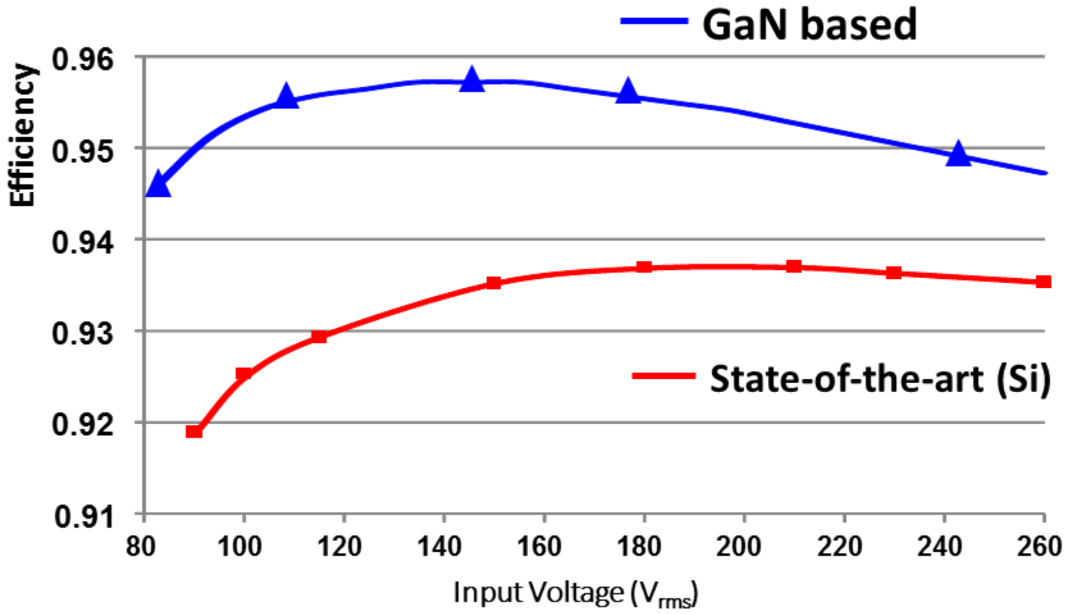


LLC



GaN-based
Power Density
= 35 W/in^3
(uncased)





Pop Quiz! How do we shrink our power supplies?

A. Select the right ZVS topology
B. Increase switching frequency
C. Select the right magnetic material
D. Select the right GaN Power IC
E. Increase efficiency
F. All of the above
G. None of the above…
…use hard-switching topologies and Silicon switching < 100kHz.