Power Sources Manufacturers Association
The Multinational Power Electronics Association

Navitas

Let's go GaNFast™

Monolithic GaN Device Integration Drives Efficiency, Density and Reliability in Power Conversion

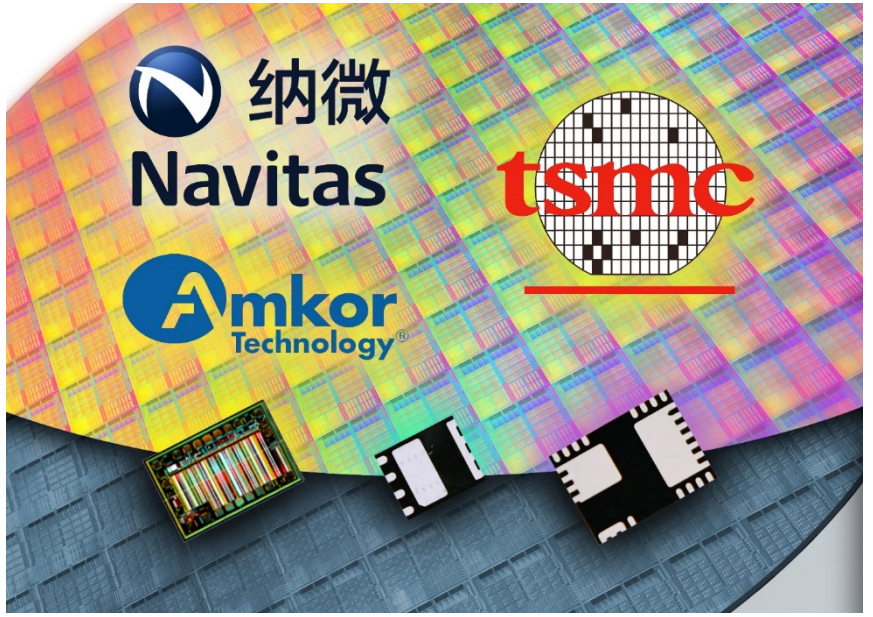
Dan Kinzer, CTO/COO dan.kinzer@navitasemi.com
& Stephen Oliver, VP Sales & Marketing stephen.oliver@navitassemi.com

August 16th 2018

Navitas Semiconductor Inc.

GaNFast™

- World's first & only GaN power IC company
- Mass production, qualified "Beyond JEDEC"
- Founder member JEDEC JC-70.1 GaN Reliability
- www.navitassemi.com



navitas

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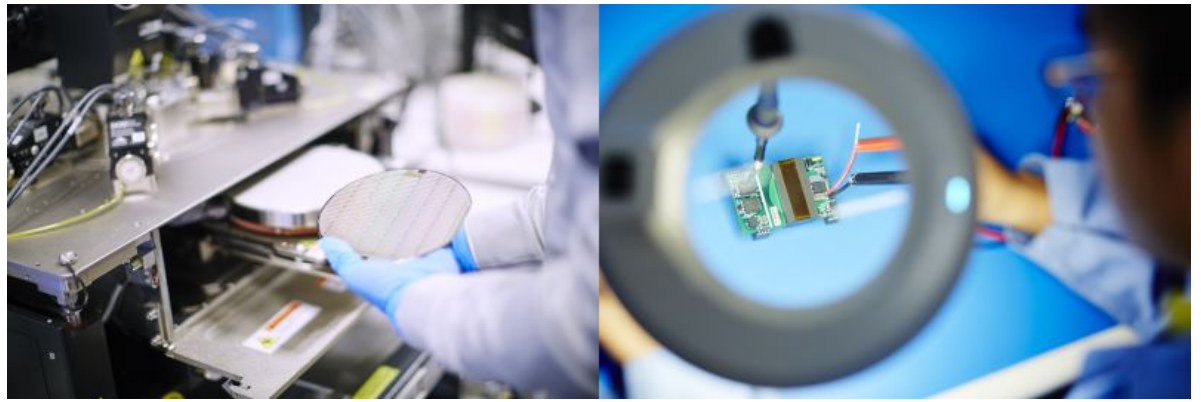
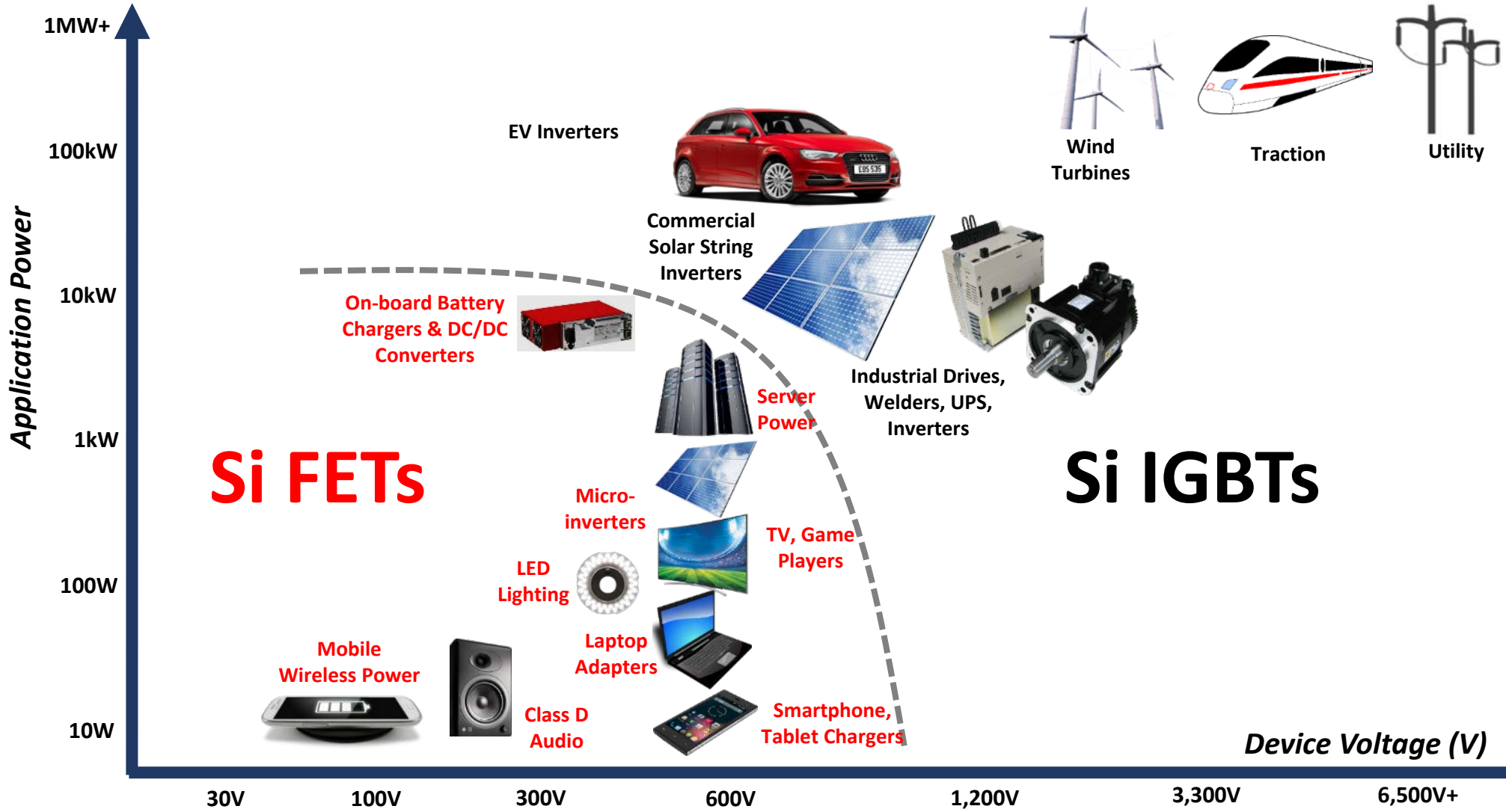


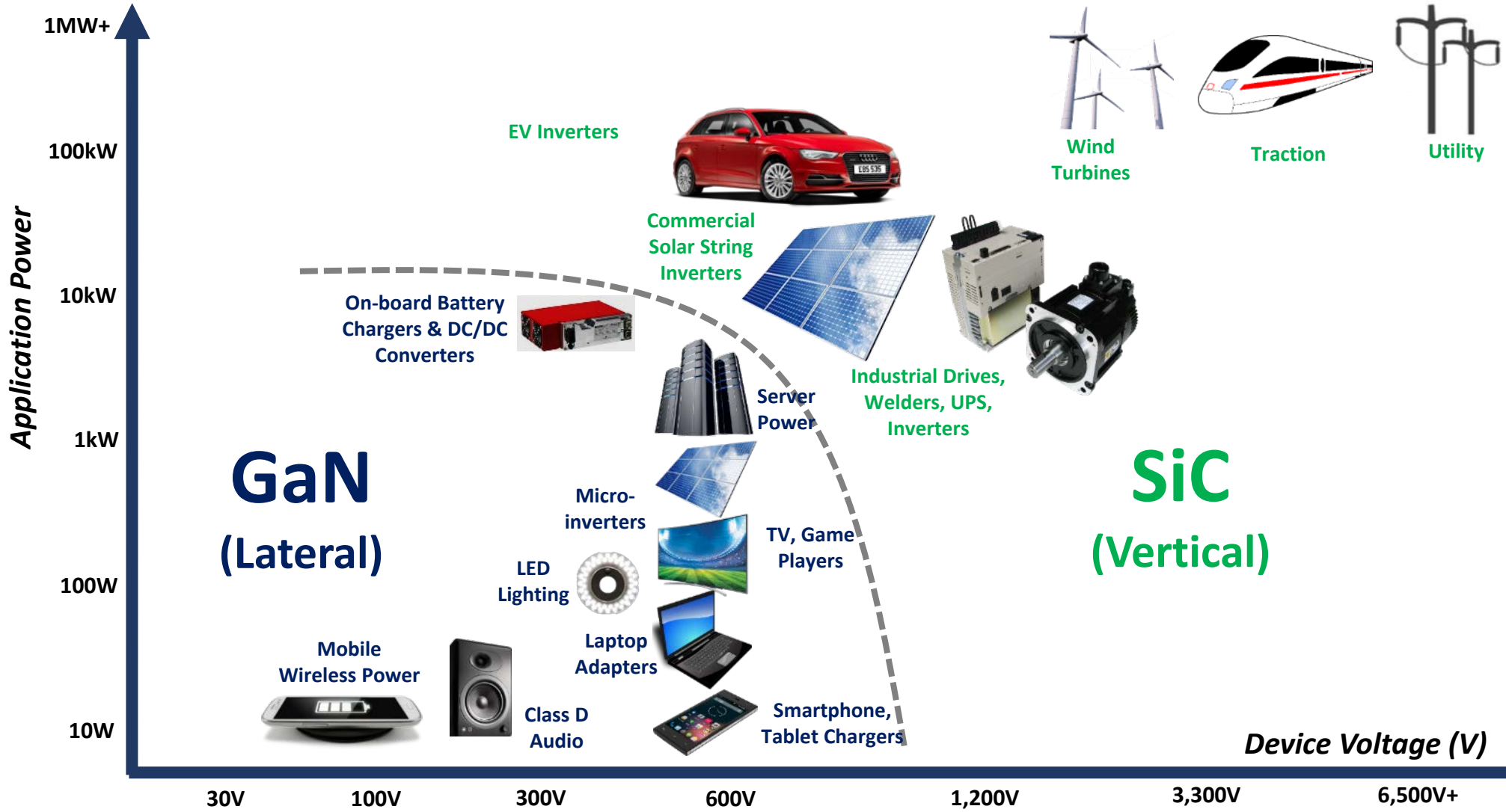
The Si Landscape

GaNFast™



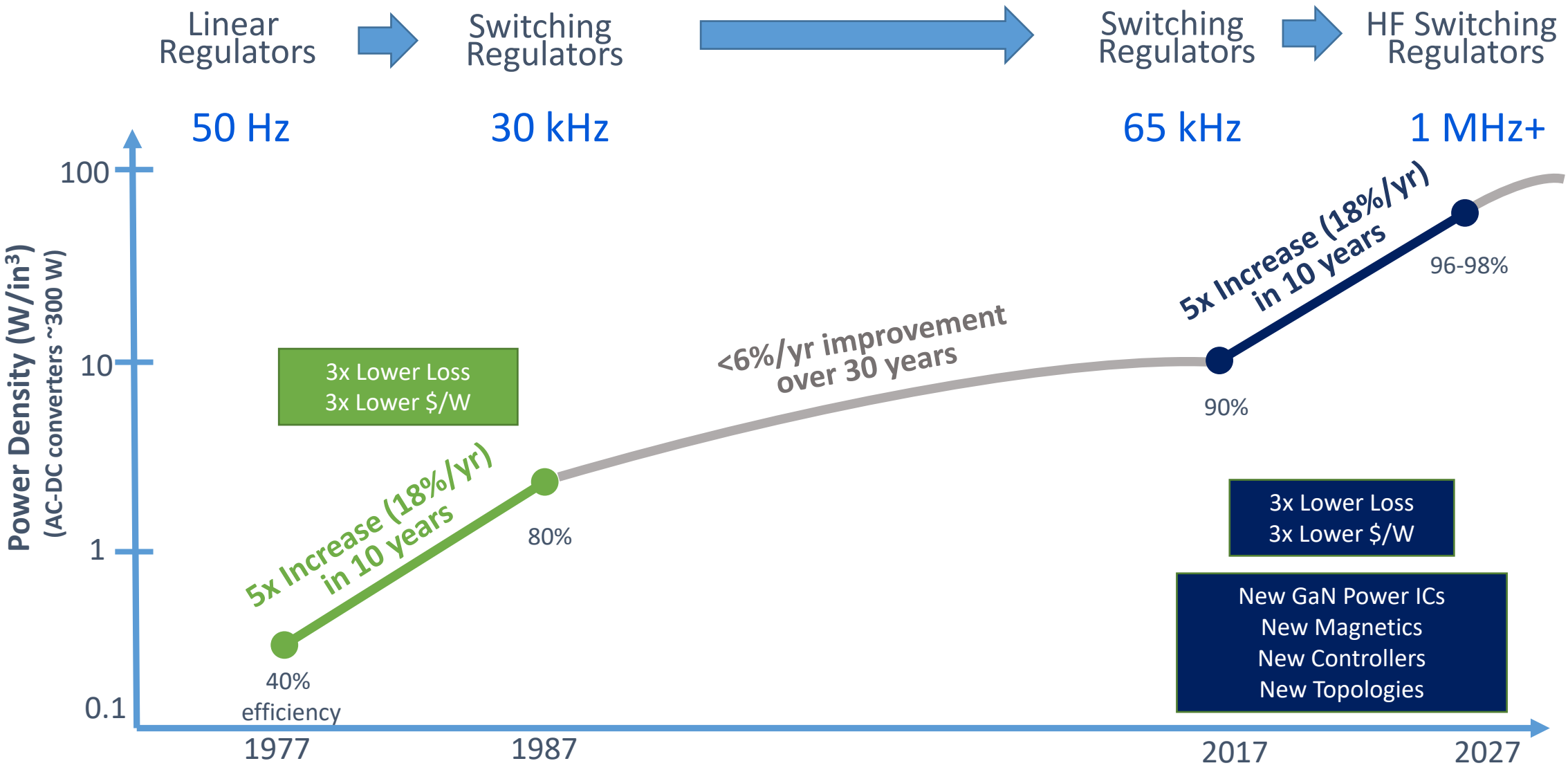
The GaN / SiC Landscape

GaNFast™



The Next Revolution in Power Systems

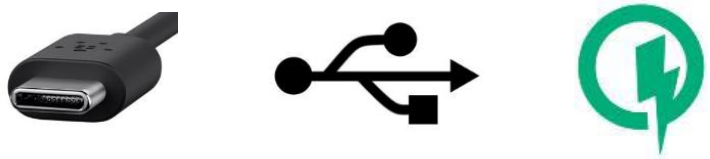
GaNFast™



Market Demands

- **Legislative**
  - US DoE VI, Euro CoC Tier 2

- **Features**
  - Type C, USB PD 3.0 / PPS / QC 4.0



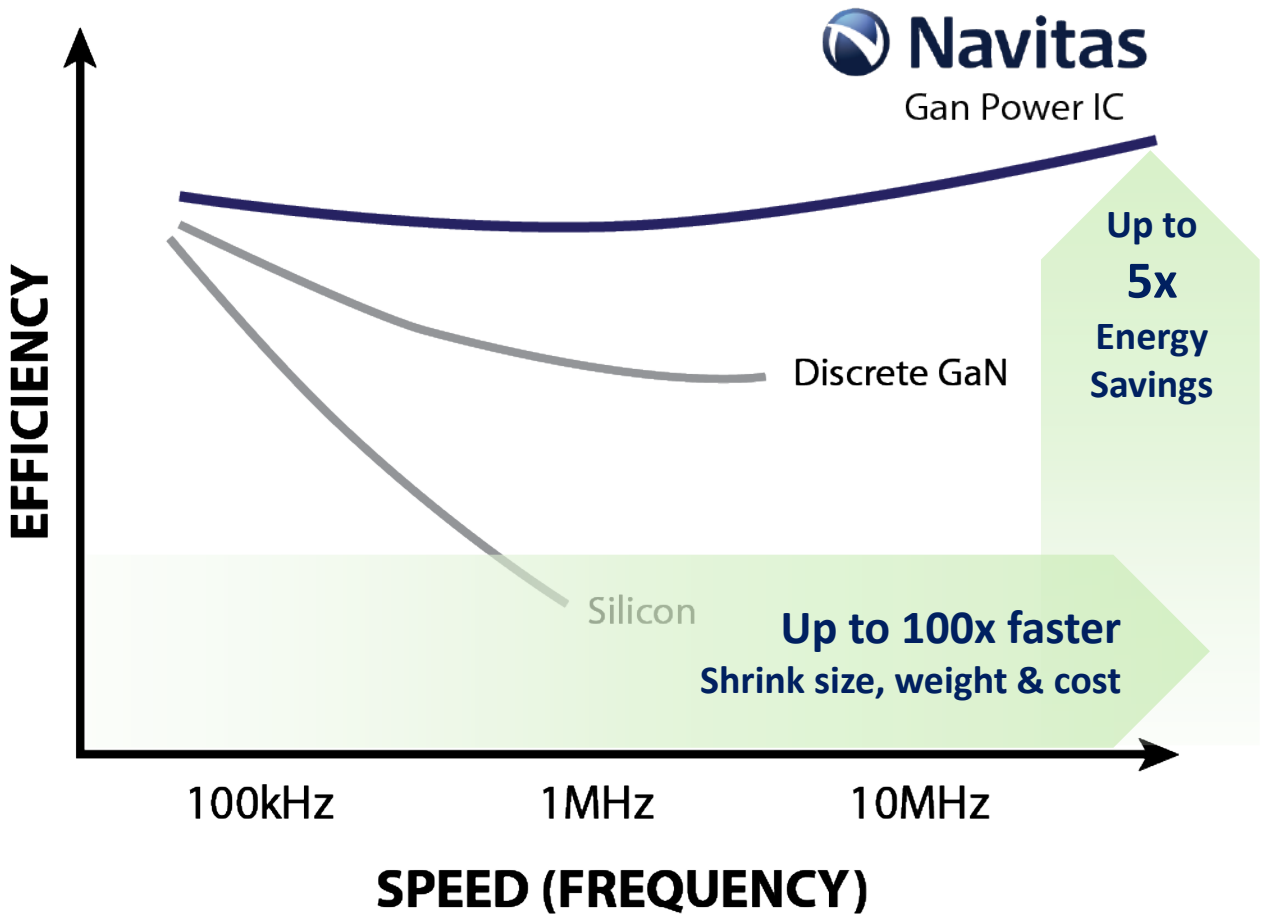
- **Performance**
  - Fast charging, size, weight, low profile

- **Cost**
  - Premium vs old, slow designs?

Speed & Efficiency are Key

GaNFast™

- **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**



High-Frequency Eco-System

GaNFast™

GaNFast power ICs plus…

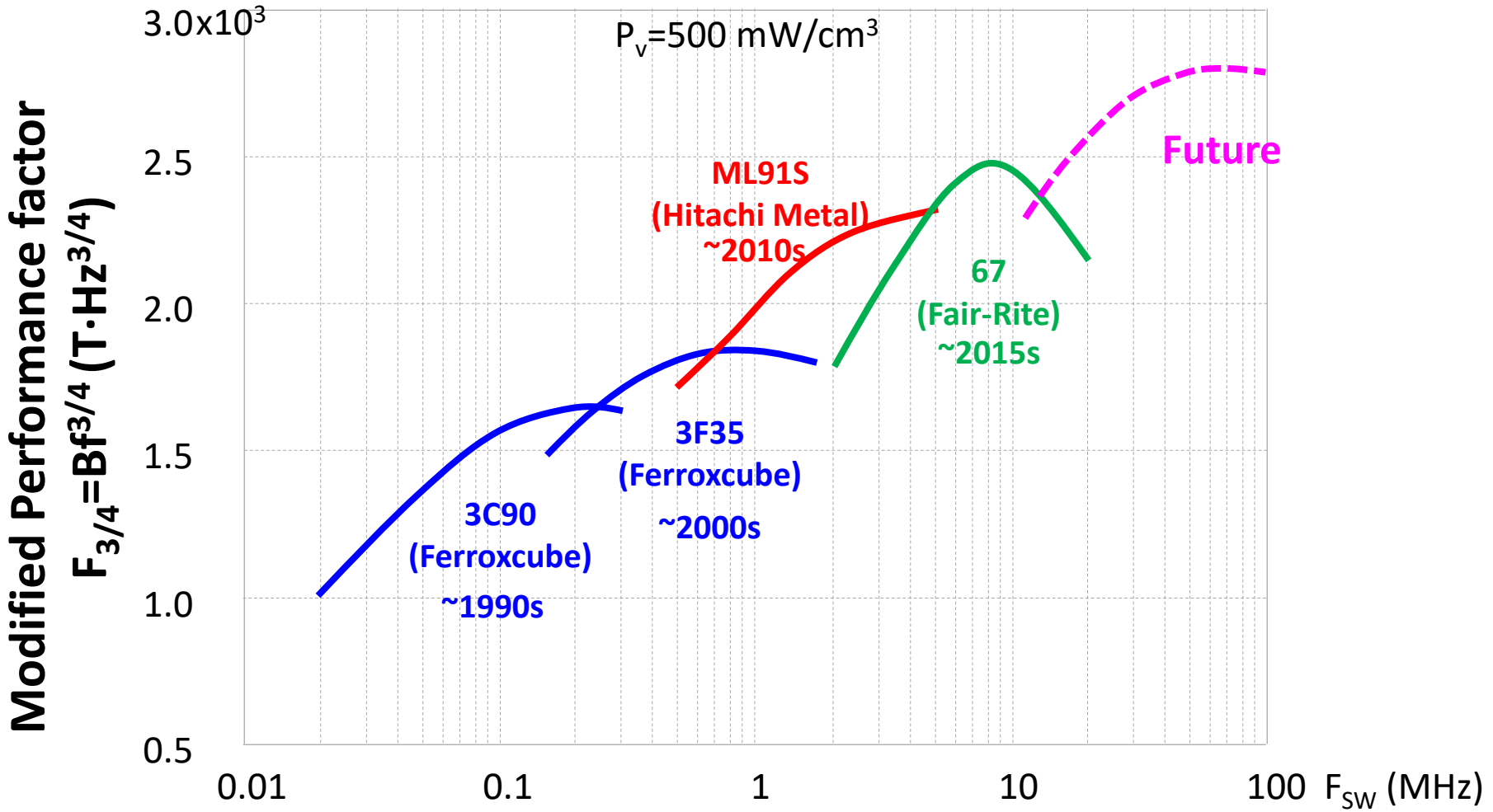
- HF Controllers

- HF Magnetics

- HF SR FETs

- HF Architectures

Magnetics: 10x Faster Every Decade

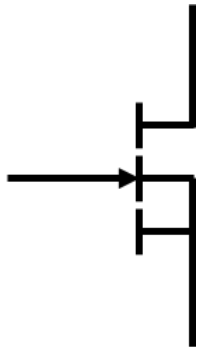


Y. Han, G. Cheung, A. Li, C. R. Sullivan and D. J. Perreault, "Evaluation of Magnetic Materials for Very High Frequency Power Applications," in *IEEE Transactions on Power Electronics*, vol. 27, no. 1, pp. 425-435, Jan. 2012.

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.

World's First GaNFast™ Power ICs

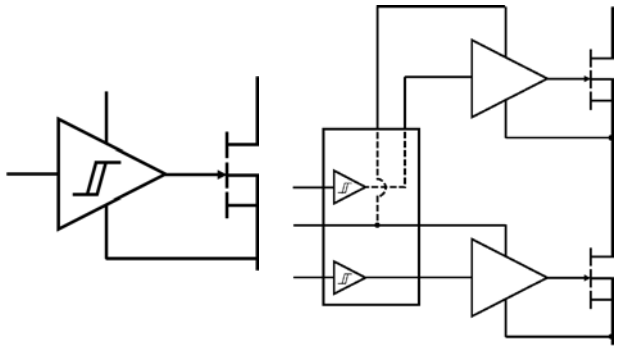
Fastest, most efficient GaN Power FETs



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

+

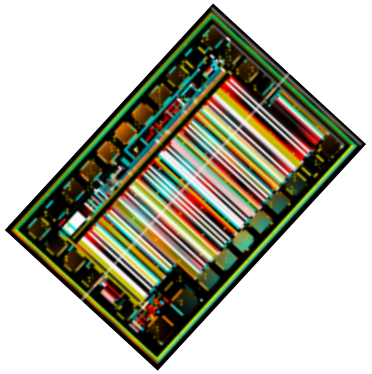
First & Fastest Integrated GaN Gate Drivers



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

=

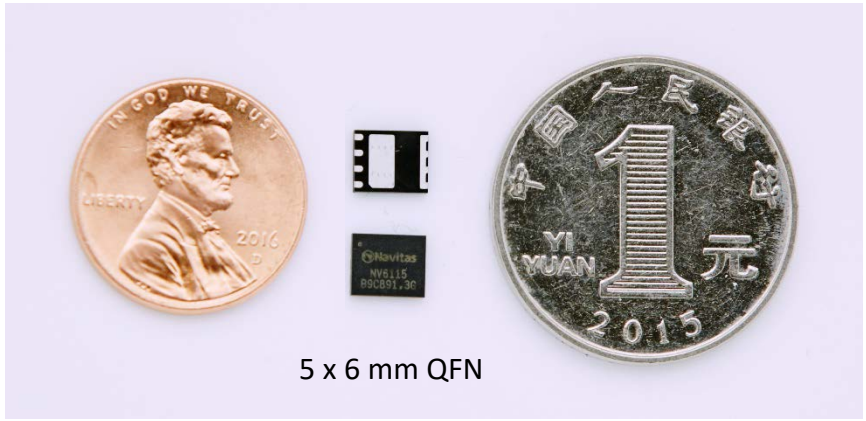
World's First GaNFast™ Power ICs

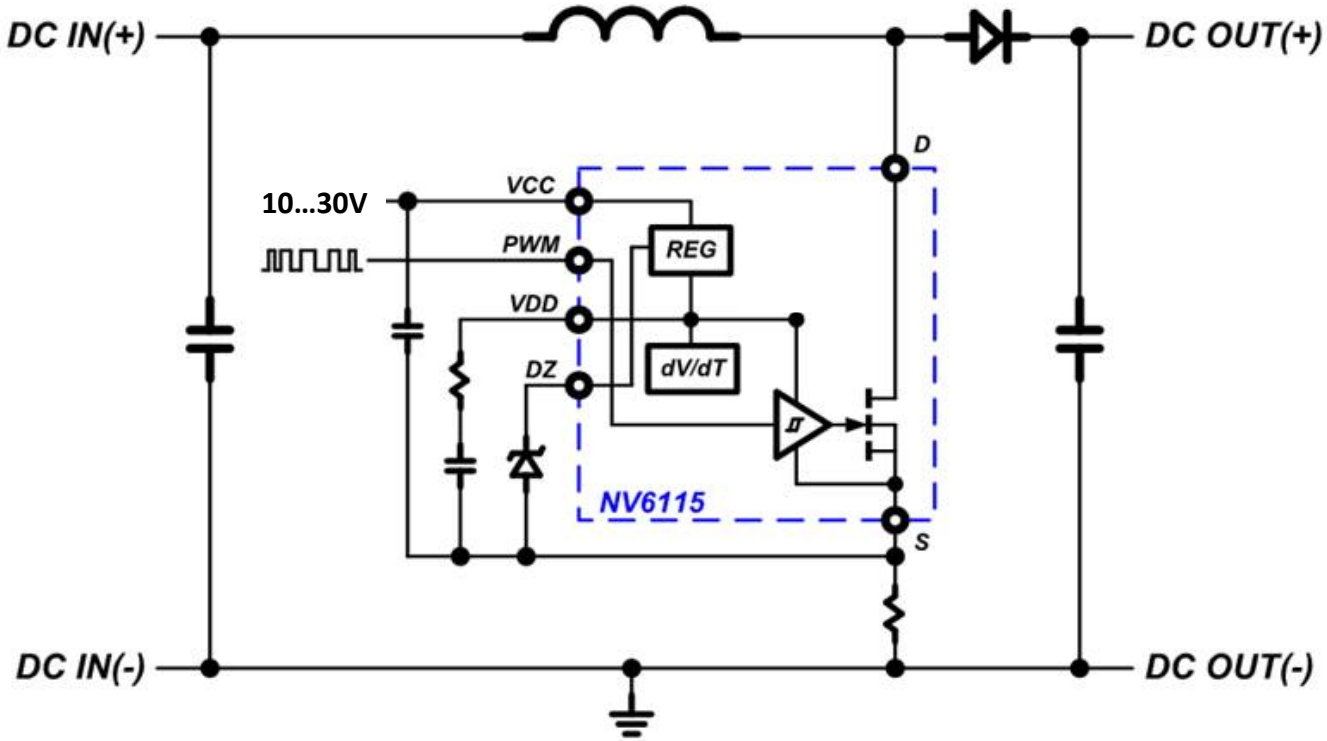


Up to 40MHz switching, 5x higher density & 20% lower system cost

Single GaNFast Power IC

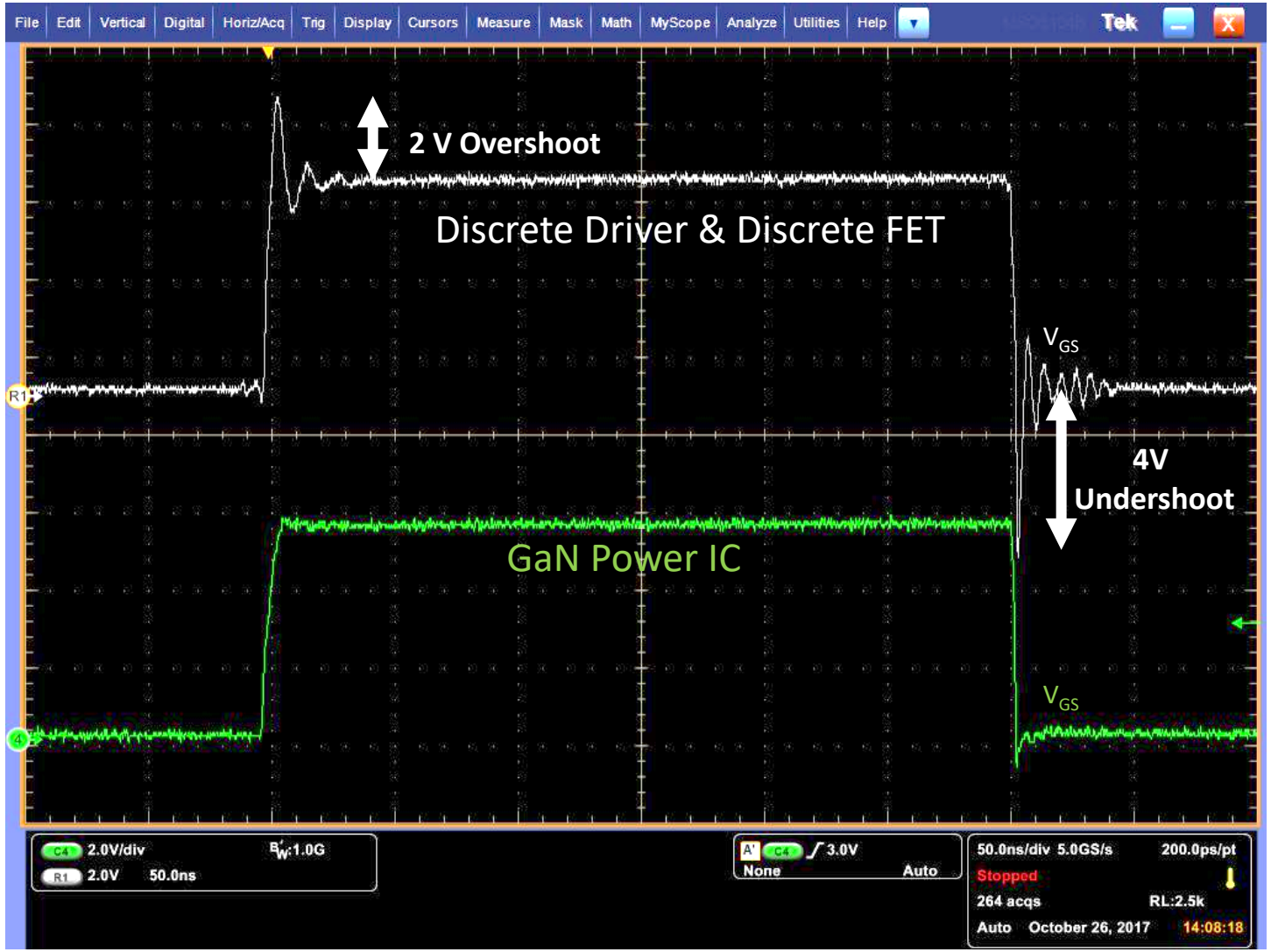
- Monolithic integration, 650V
  - GaN FET
  - GaN Driver
  - GaN Logic
- Mass production





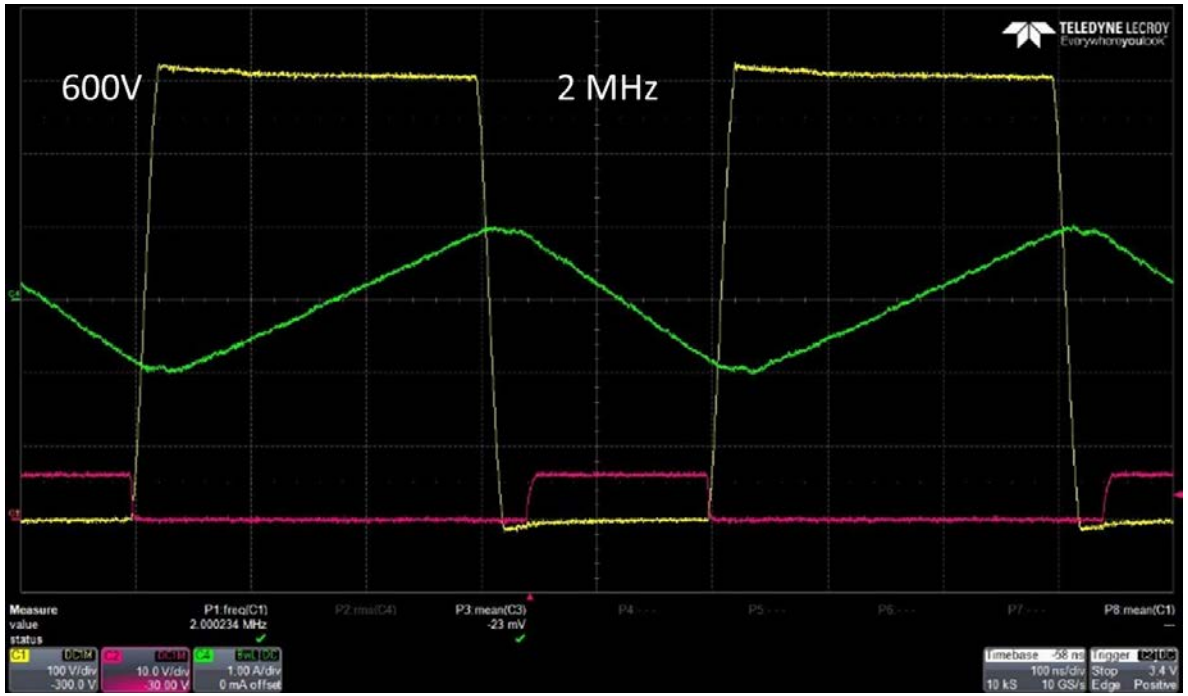
Clean, Controlled FET Gate

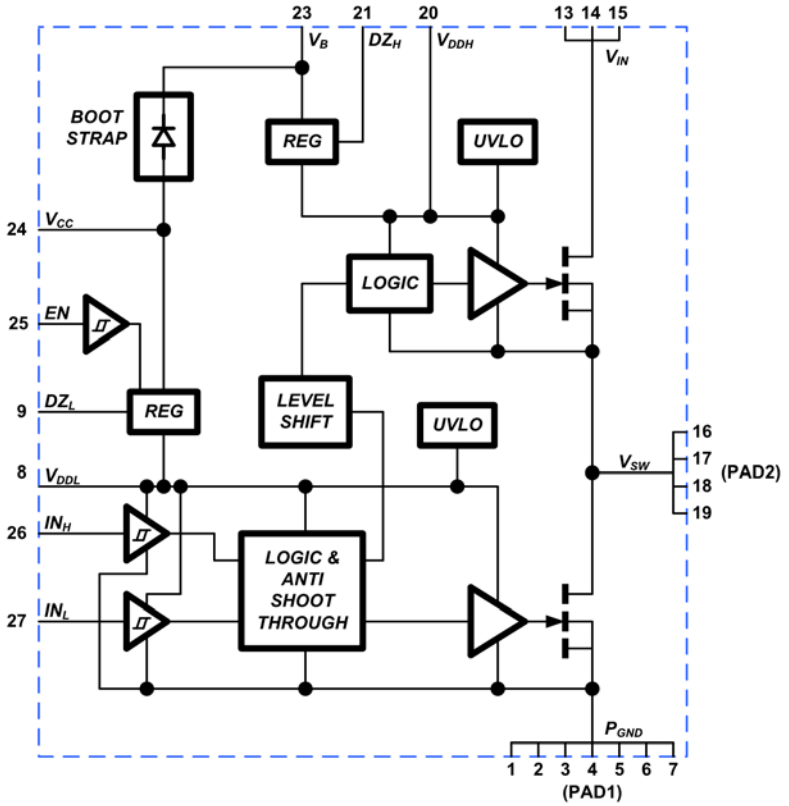
- **Discrete driver**
  - Gate-loop inductance creates overshoot (even with good layout)
  - Reliability concern
- **GaNFast Power IC**
  - No gate loop parasitic
  - Clean and fast gate signal
  - No CdV/dt turn-on
  - No IV crossover turn-off switching losses

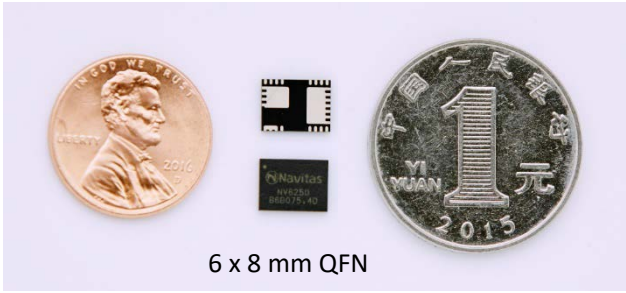


Half-Bridge GaNFast Power IC

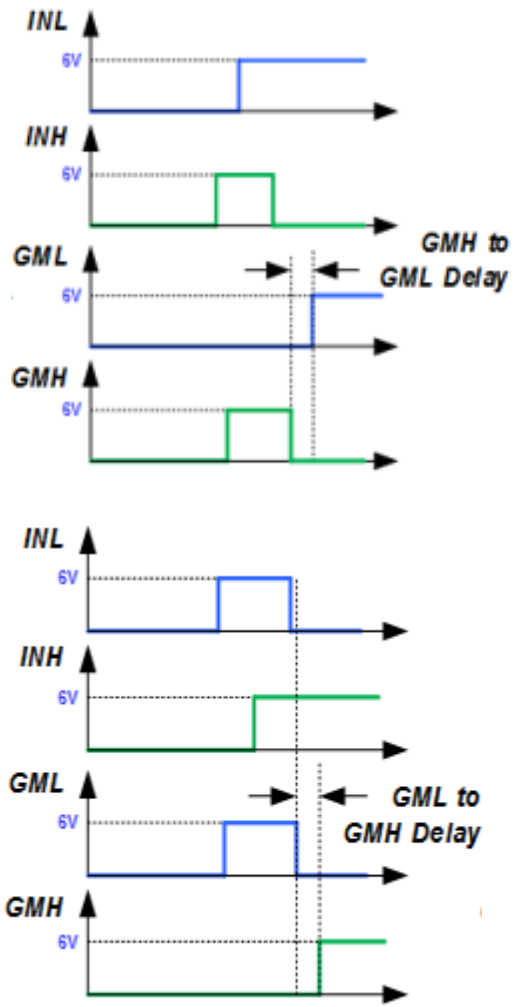
- Monolithic integration, 650V
  - 2x GaN FETs
  - 2x GaN drivers
  - GaN Logic (level-shift, bootstrap, UVLO, shoot-through, ESD)



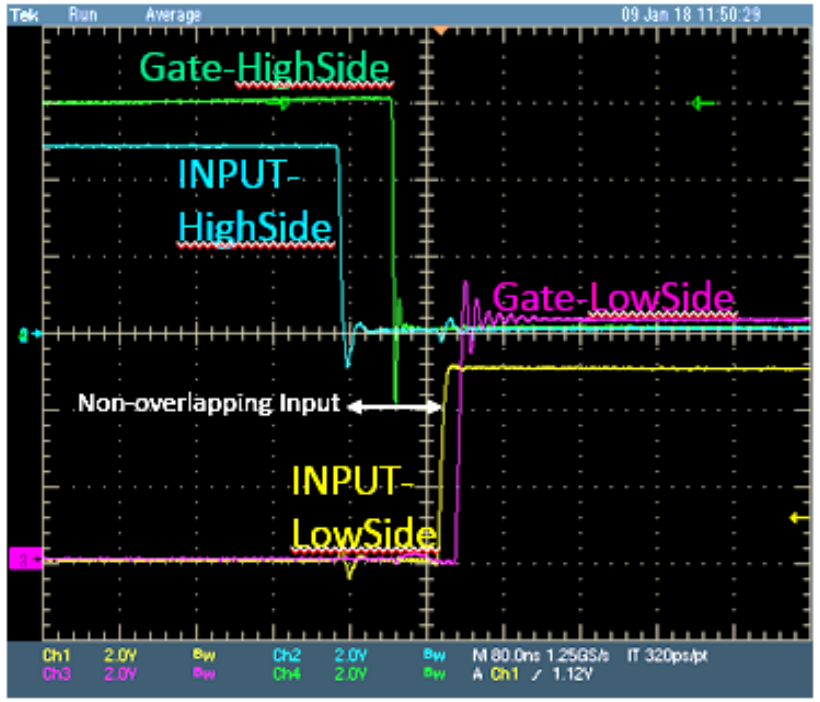




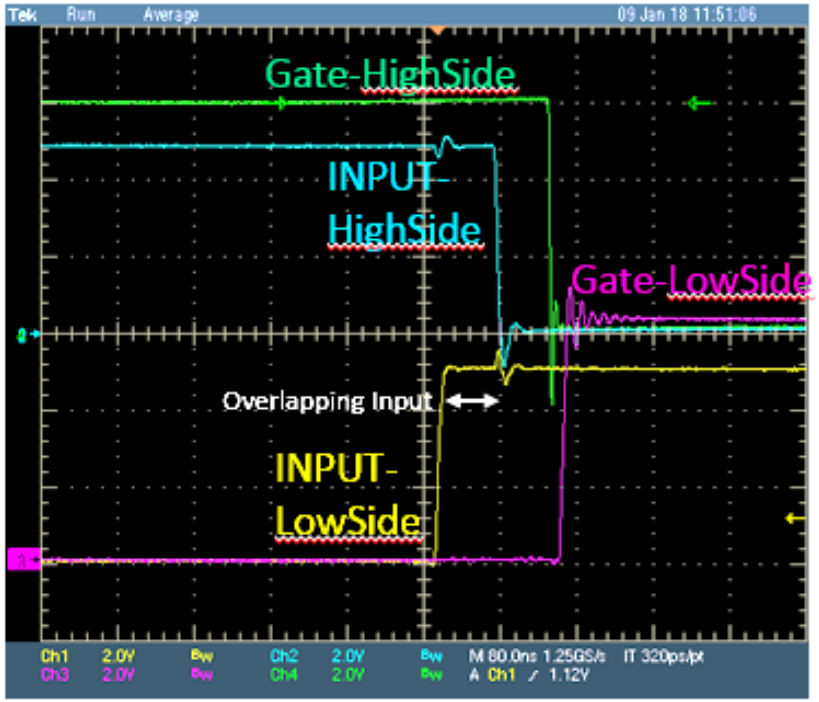
Robust GaNFast Half-Bridge



Non-Overlapping Logic Input
(Typical Operation)



Overlapping Logic Input
(GaNFast Power IC Protection)



5 V digital input, 6.2 V gate output, 80 ns/div

‘Beyond’ JEDEC Qualification

GaN-Based Qual Plan

	Reference	Test Conditions	Duration	Lots	S.S.
Package Stress	JESD22-A113 J-STD-020	Preconditioning (MSL1): Moisture Preconditioning + 3x reflow: HAST, UHAST, TC & PC	N/A	3	308
Package Stress	JESD22-A104	Temperature Cycle: -55°C / 150°C	1,000cy	3	77
Package Stress	JESD22-A122	Power Cycle: Delta Tj = 100°C	10,000cy	3	77
Package Stress	JESD22-A110	Highly Accelerated Stress Test: 130°C / 85%RH / 100V V_{DS}	96hrs	3	77
Die Stress	JESD22-A108	High Temperature Reverse Bias: 150°C / 520V V_{DS}	1,000hrs	3	77
Die Stress	JESD22-A108	High Temperature Gate Bias: 150°C / 6V V_{GS}	1,000hrs	3	77
Die Stress	JESD22-A108	High Temperature Operating Life	1,000hrs	3	77
Die Stress	JS-001-2014	Human Body Model ESD	N/A	1	3
Die Stress	JS-002-2014	Charged Device Model ESD	N/A	1	3

Lifetime Models
(HTOL, HTRB)

+

Failure Modes
Established

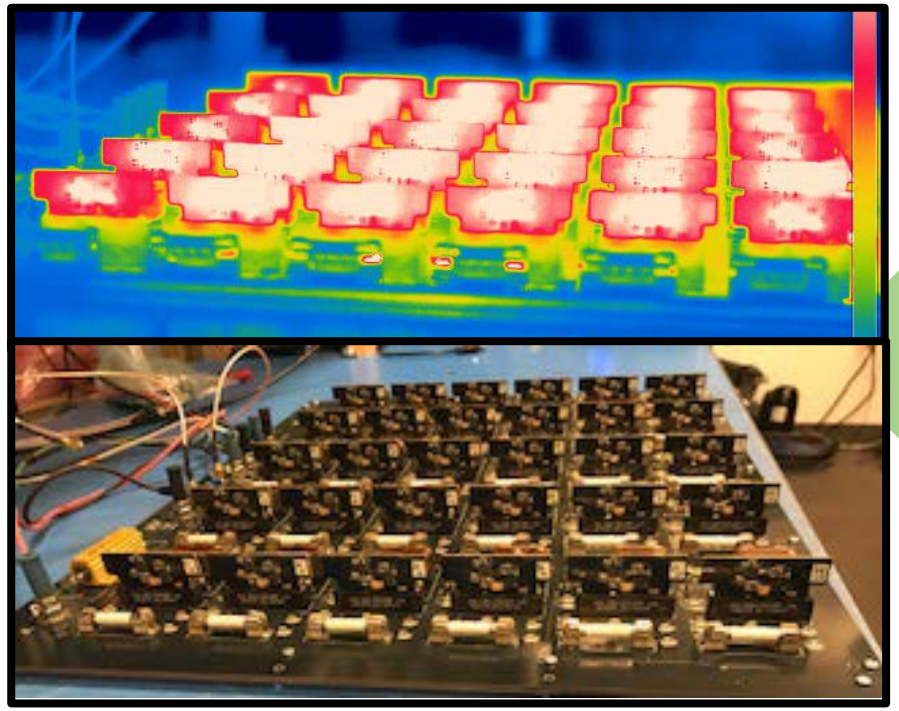
Application Specific HTOL Test Bench

ZVS HTOL at Statistical Sample Sizes

GaNFast™

- Matches all elements of application profile
  - FET & IC
- Many cells in parallel
  - Statistical sample sizes
- Low total power consumption
- Conditions changeable to develop lifetime and acceleration models

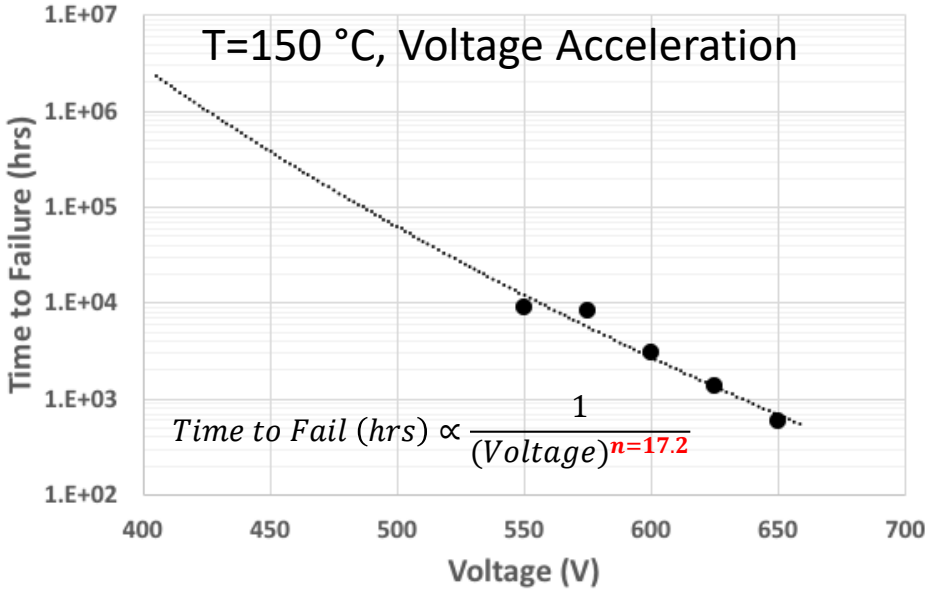
HTOL Mother Board

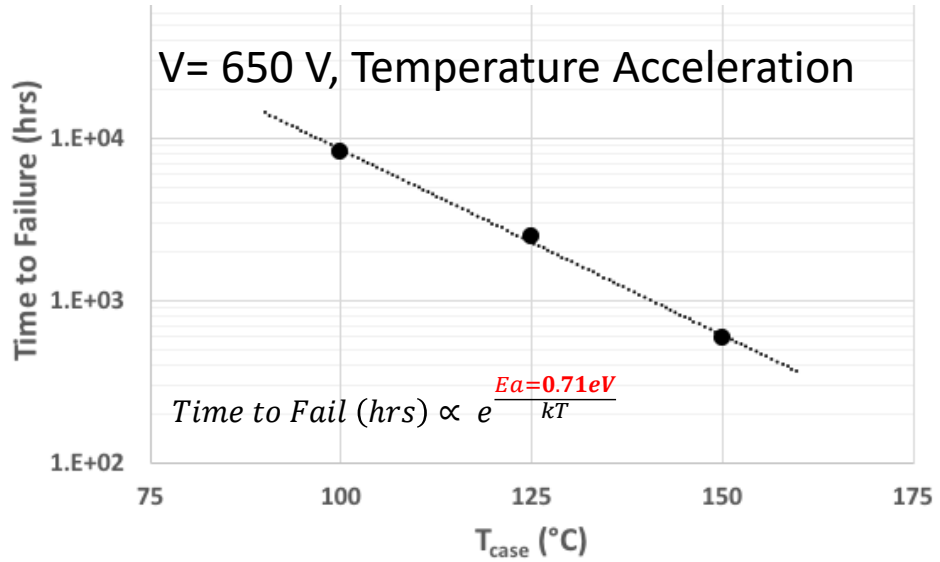


Qualification	3 Lots x 77
Lifetime Models	Voltage Current Frequency Temperature
Early Life Failure Rate	3 Lots x 1,000

HTOL-based Lifetime Model

Voltage/ Temperature	100	125	150
550			✓
575			✓
600			✓
625			✓
650	✓	✓	✓





Lifetime Estimation: ACF Charger

$$Temperature\ Acceleration\ Factor(AF_{temp}) = e^{\frac{E_a}{k}\times(\frac{1}{T_{application}}-\frac{1}{T_{reliability}})}$$
$$E_a = 0.71eV$$

$$Voltage\ Acceleration\ Factor(AF_{voltage}) = (\frac{V_{reliability}}{V_{application}})^n$$
$$n = 17.2$$

$$Total\ Acceleration\ Factor(AF_{Total}) = AF_{TEMP}\ x\ AF_{VOLTAGE}$$

$$Lifetime\ estimate\ in\ application = AF_{Total}\ x\ Time\ to\ failure\ in\ reliability\ (TTF_{reliability})$$

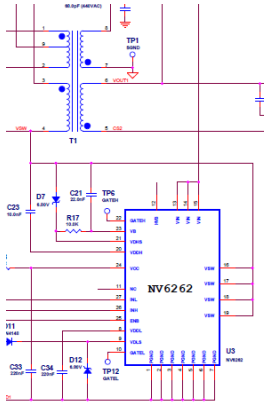
ACF Charger Full-Power Profile →

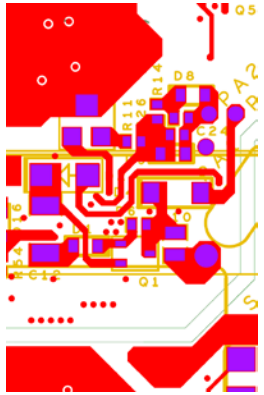
AC line Voltage (V)	Rectified AC voltage (V)	Reflected Voltage (V)	Switch Voltage (V)	Full power Temp (°C)
120	170	120	290	85
240	340	120	460	85

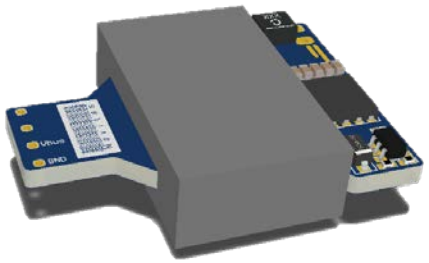
$$Lifetime = AF_{Total}\ x\ TTF_{reliability} = \mathbf{233\ years}\ @\ 240V\ AC\ input$$

Predicted lifetime in charger application (ACF) exceeds 10yr lifetime requirement

GaNFast Applications



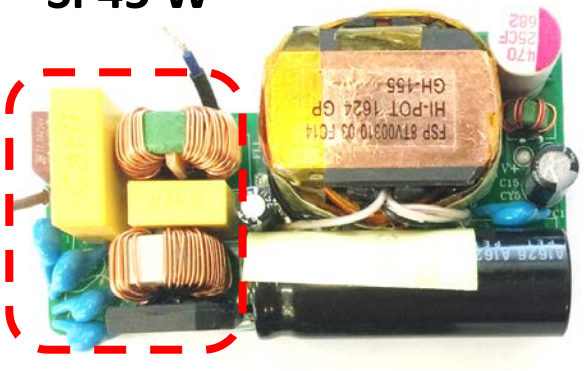




EMI? Si QR @65 kHz vs. GaN ACF @300 kHz

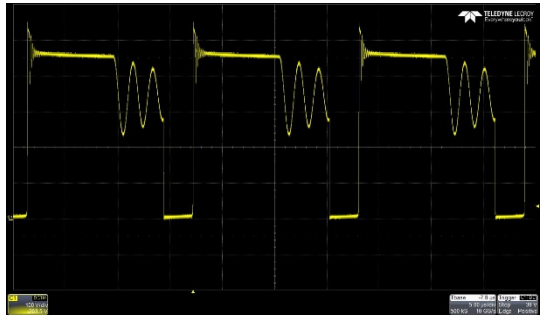
GaNFast™

Si 45 W

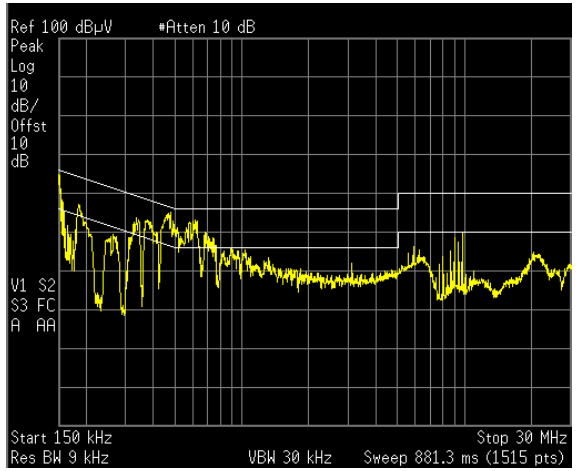


90V_{AC}

240V_{AC}

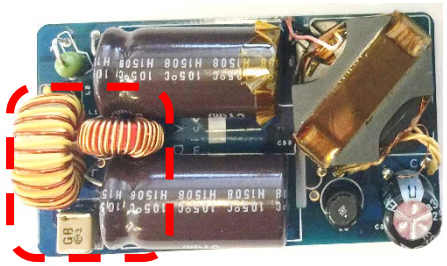


115V_{AC}

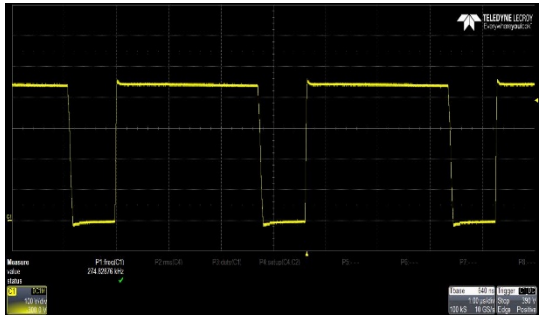


Si: Overshoot/ringing: Need low-frequency to pass EMI

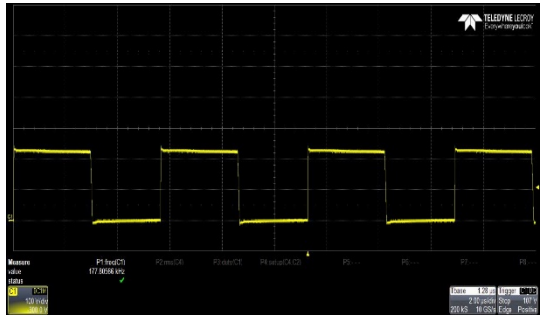
GaNFast 45 W



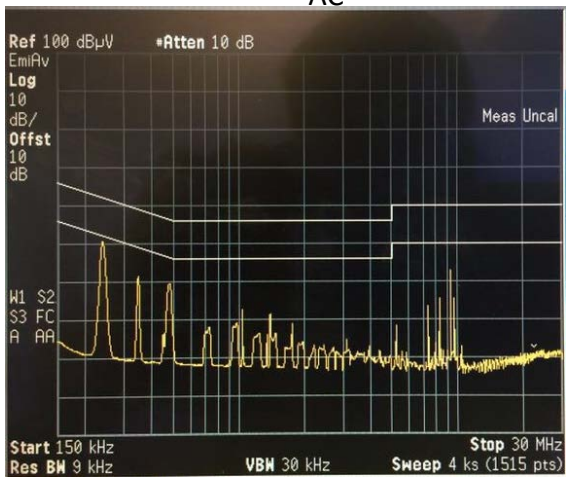
90V_{AC}



240V_{AC}



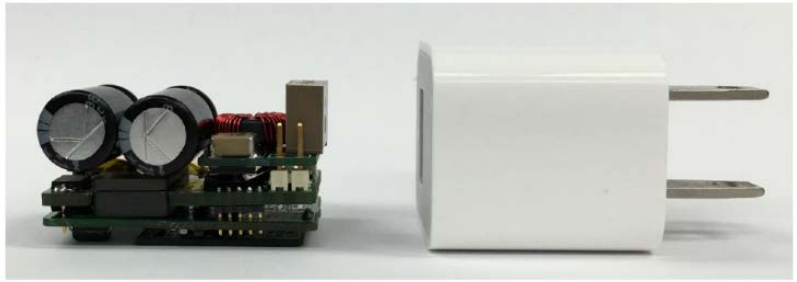
115V_{AC}



GaN: No overshoot/ringing: good EMI
Smaller, cheaper EMI filter

Quiet Power: GaNFast ACF at 1 MHz

- High frequency + Soft-switching + Pre-emptive EMI design

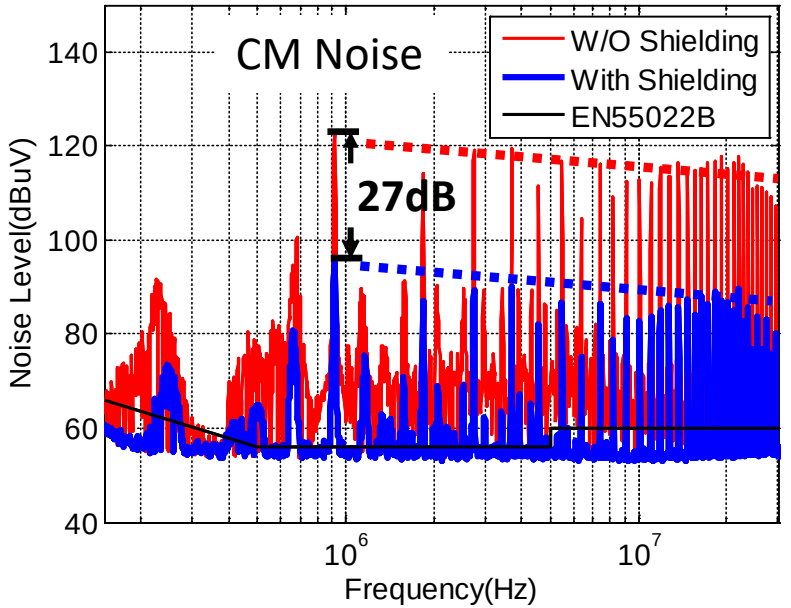


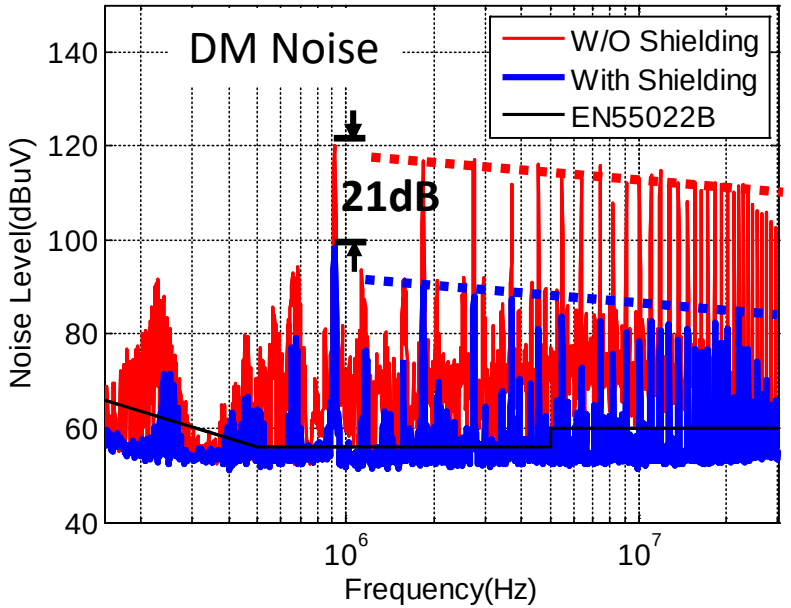
CPES Prototype 25W | iPhone charger 5W

Conducted EMI Analysis and Filter Design for MHz Active Clamp Flyback Front-end Converter

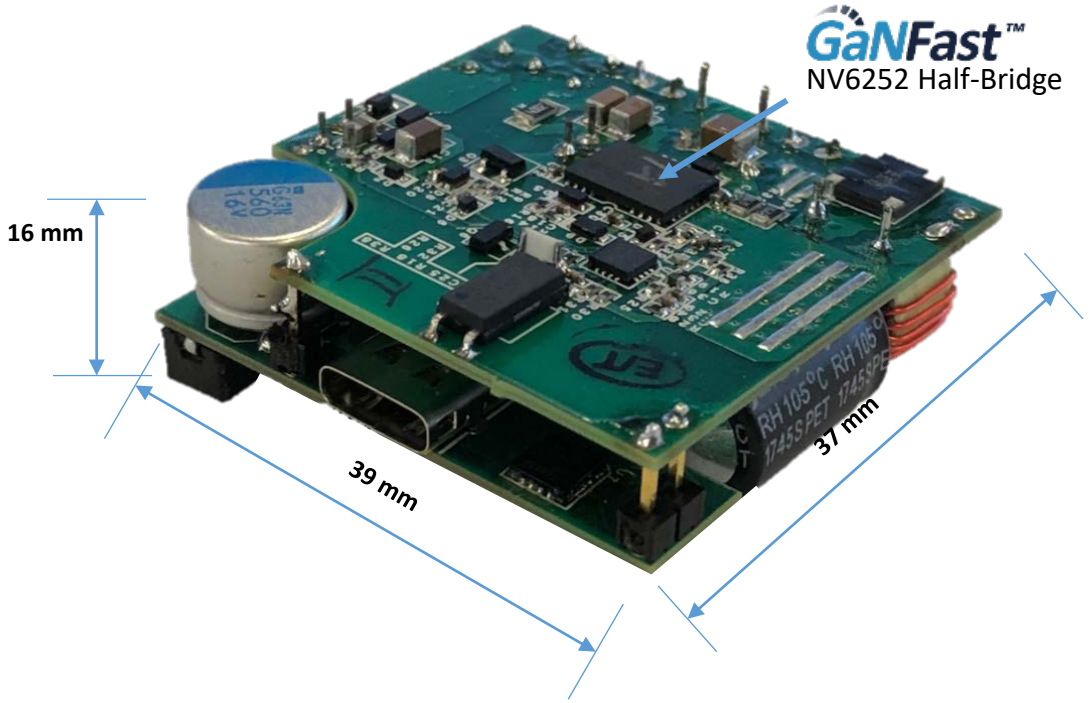
Xiucheng Huang, Junjie Feng, Fred C. Lee, Qiang Li, and Yuchen Yang
Center for Power Electronics Systems, the Bradley Department of Electrical and Computer Engineering
Virginia Polytechnic Institute and State University, Blacksburg, VA, 24061, USA

978-1-4673-9550-2/16/$31.00 ©2016 IEEE 1534





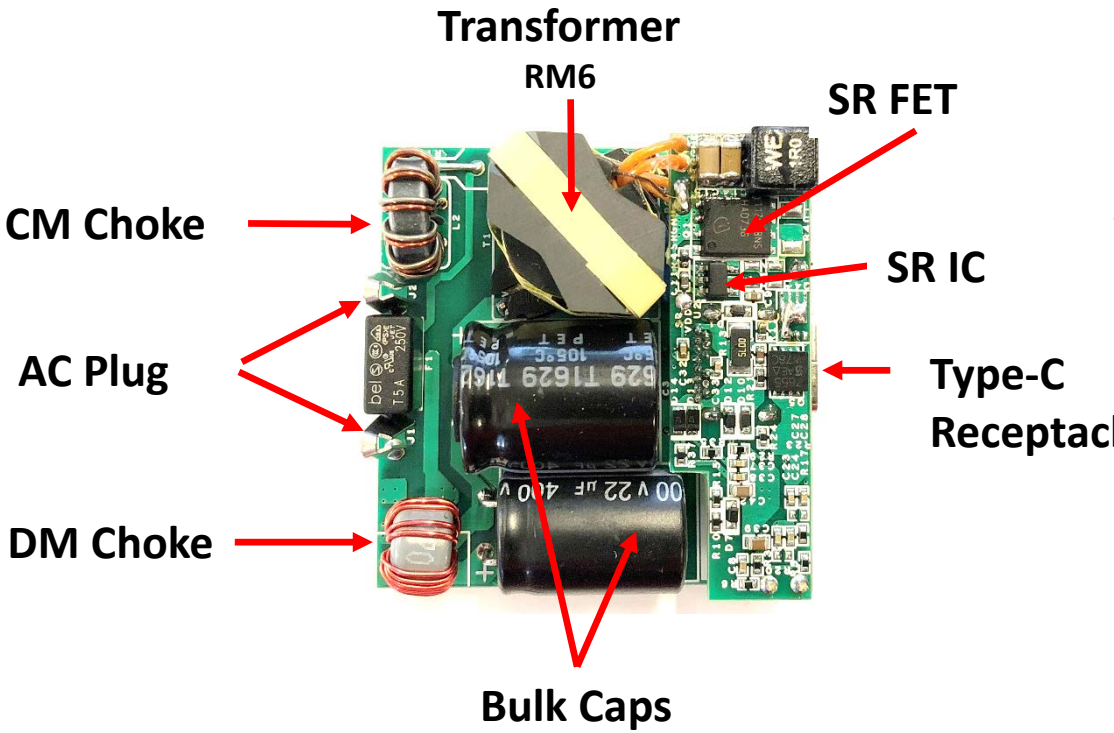
World's Smallest 27 W USB-PD

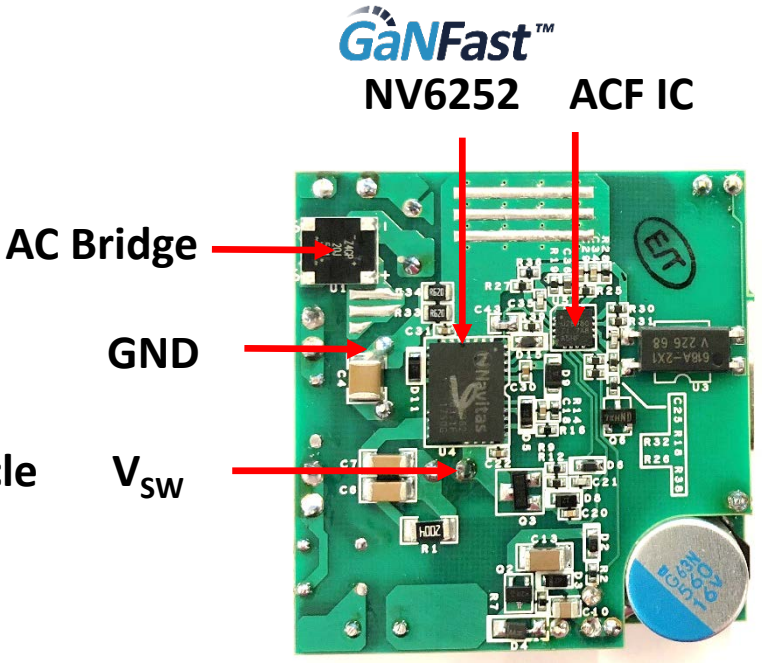


Power, Output	27 W USB-PD
Topology	ACF with UCC28780 and NV6252 GaNFast Power IC
Frequency	300 kHz
Size	23 cc (39 cc with case)
Density	1.2 W/cc (19 W/in^3) (0.7 W/cc (11 W/in^3) cased
Efficiency	>93% peak, 92.8% at 90 V_{AC}, full load DoE Level VI, Euro CoC (EuP) Tier 2

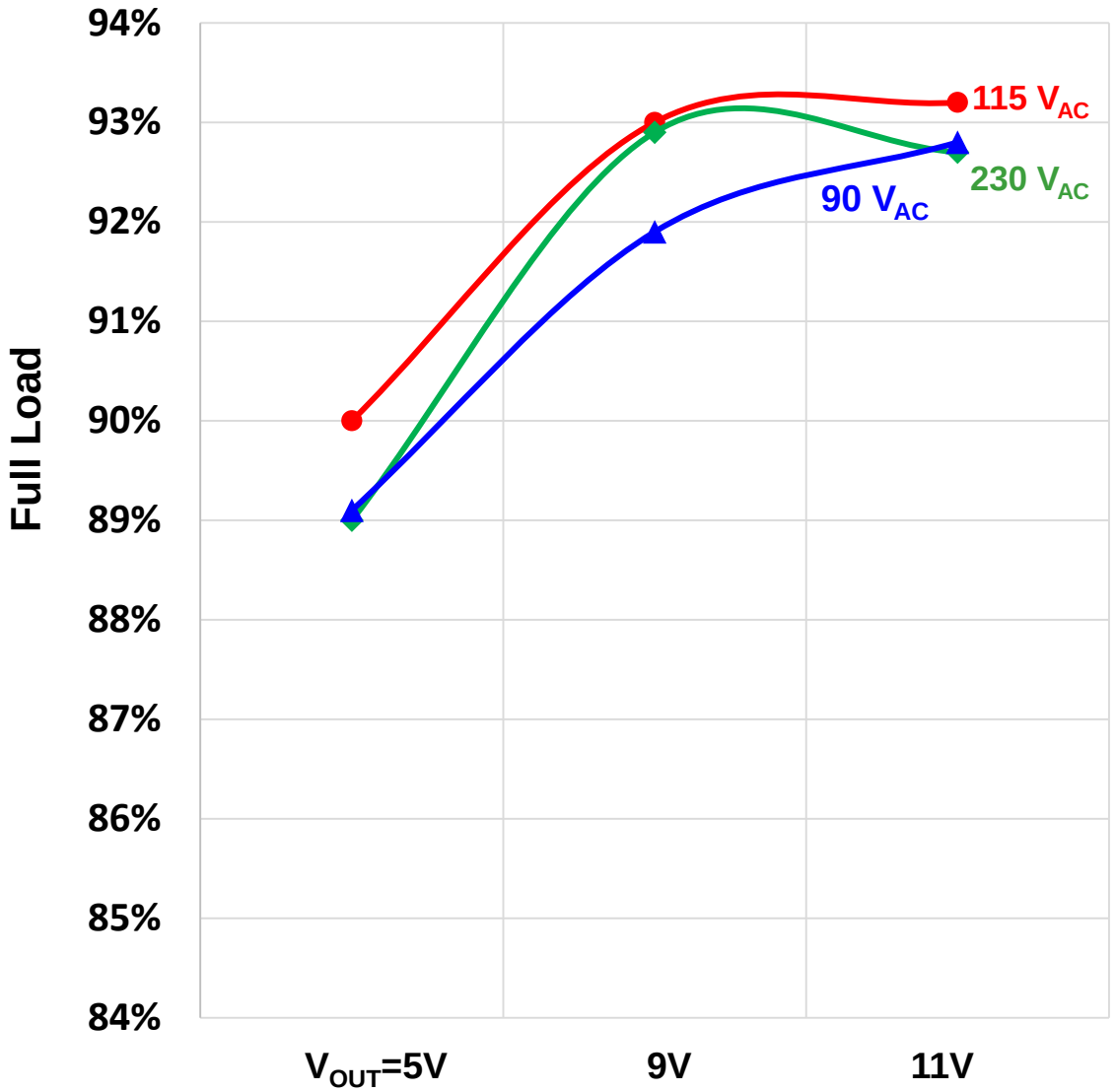
Available now

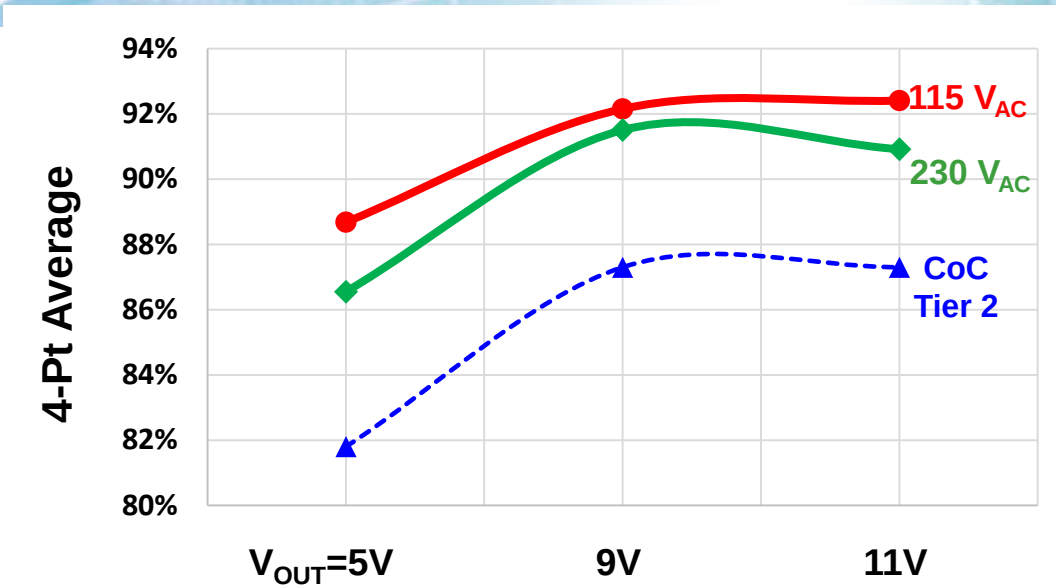
27 W Clean Design

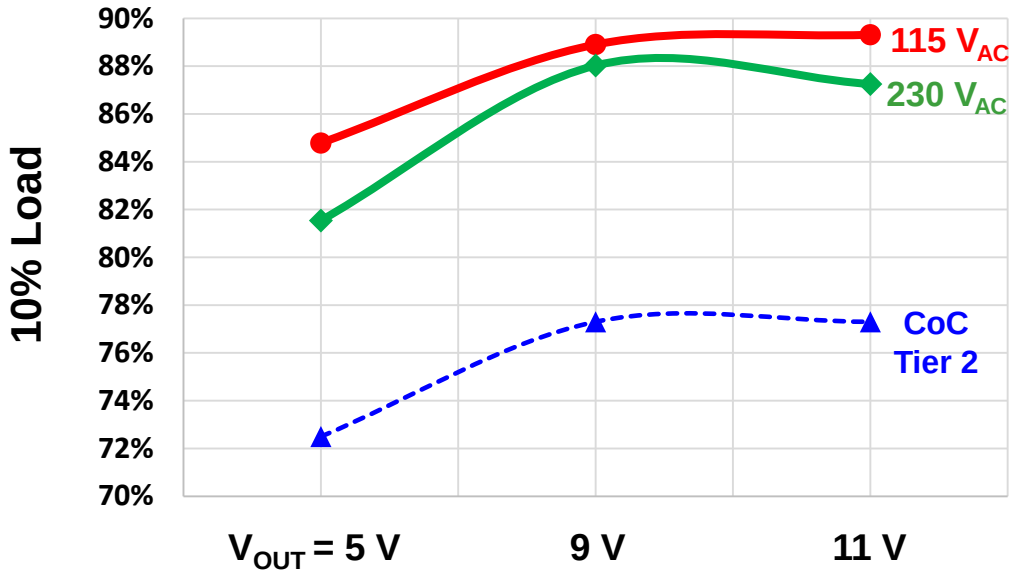




27 W High Efficiency



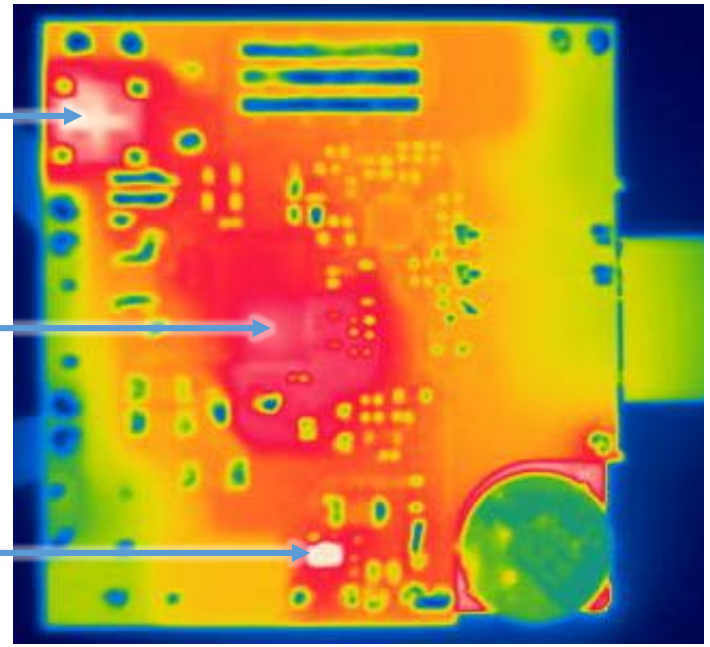




27 W Cool Operation

Top

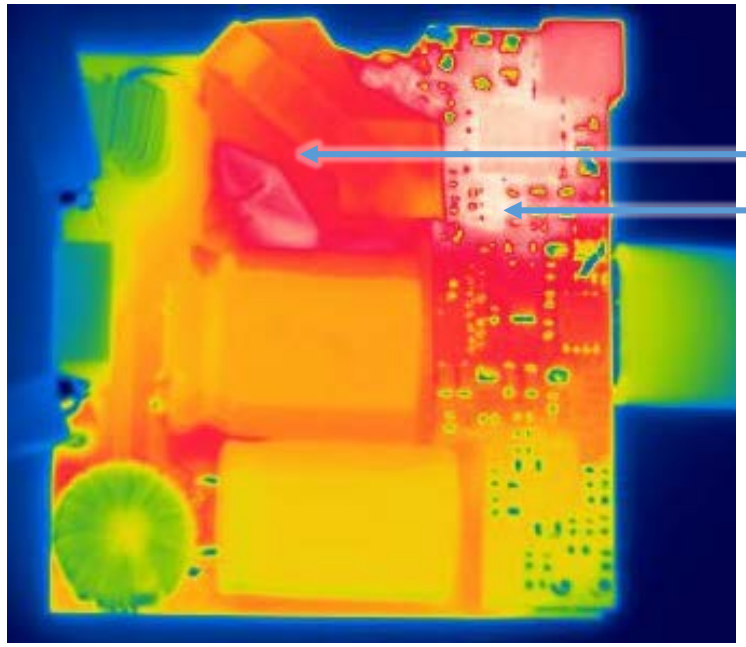
Bottom



AC Bridge 80°C

GaNFast
Half-Bridge 75°C

V_{CC} LDO 80°C



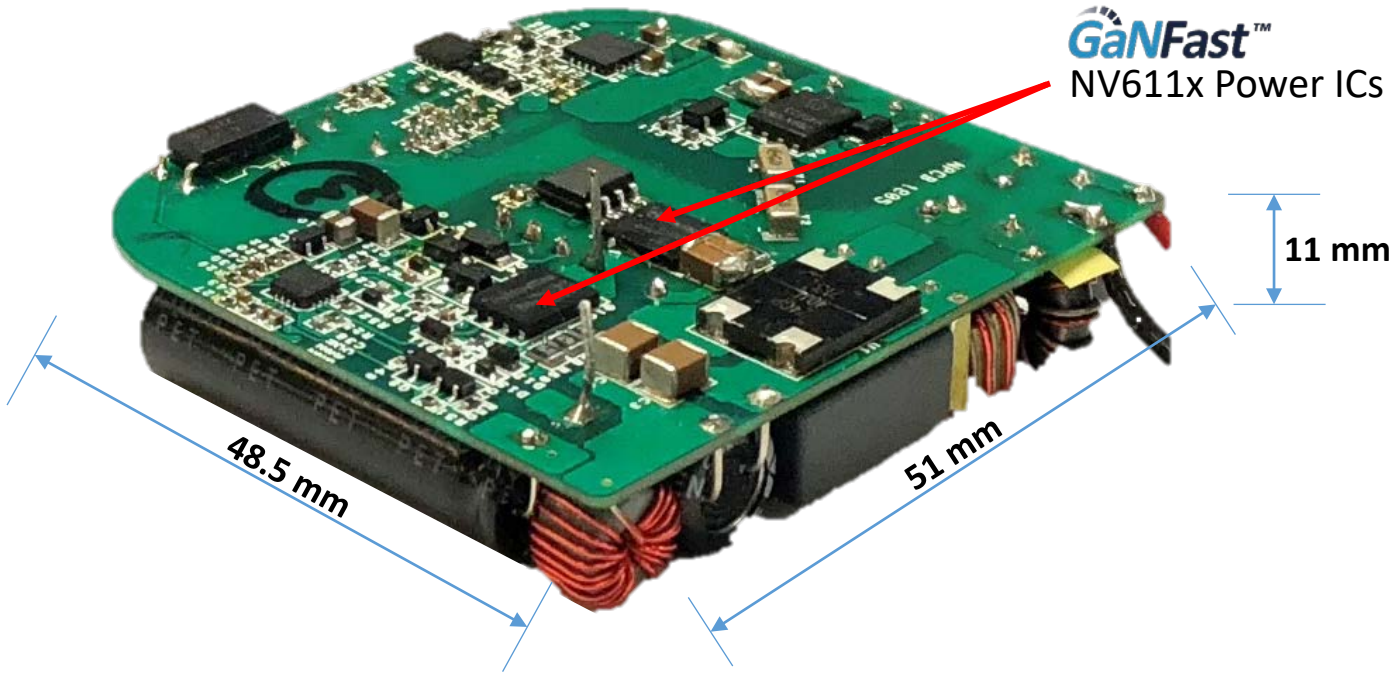
Transformer 75°C

SR IC 80°C

90 V_{AC}, 27 W, 25 °C, uncased, no airflow

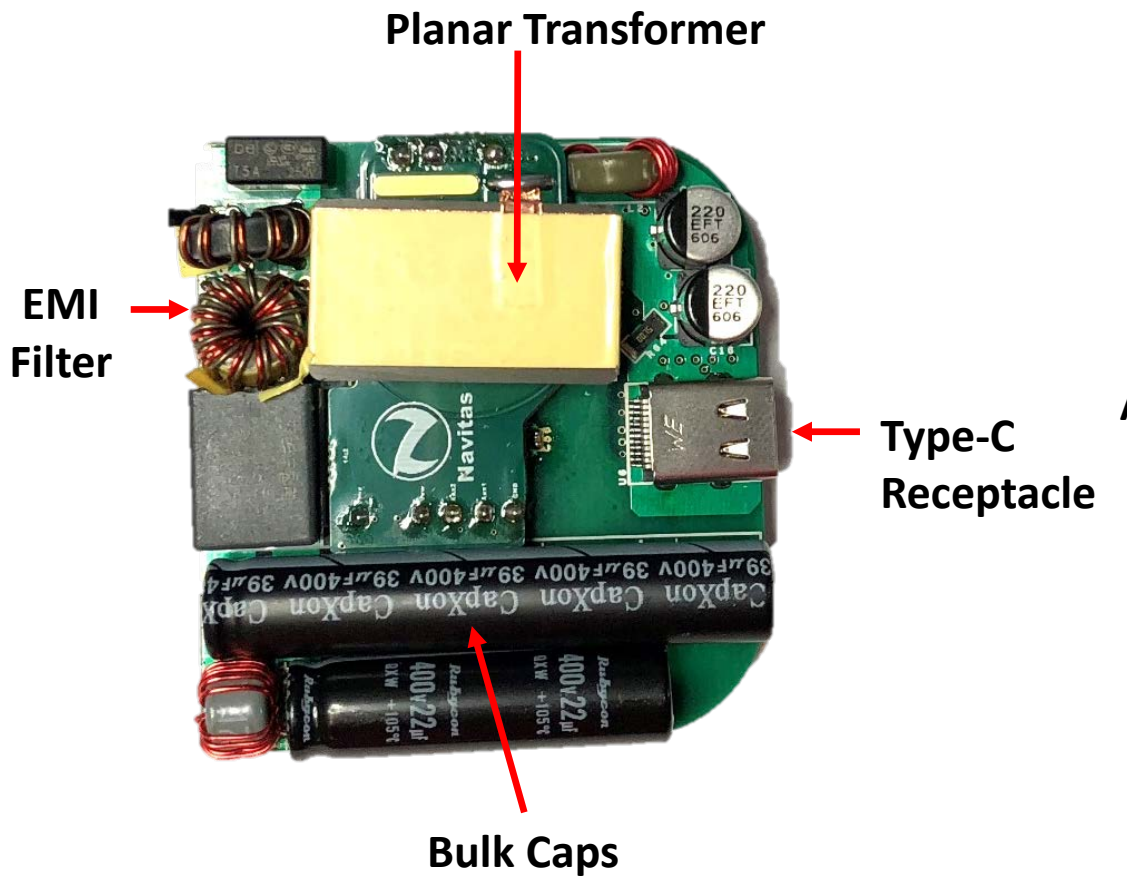

GaNFast™
GaN Power IC
Navitas
mu one

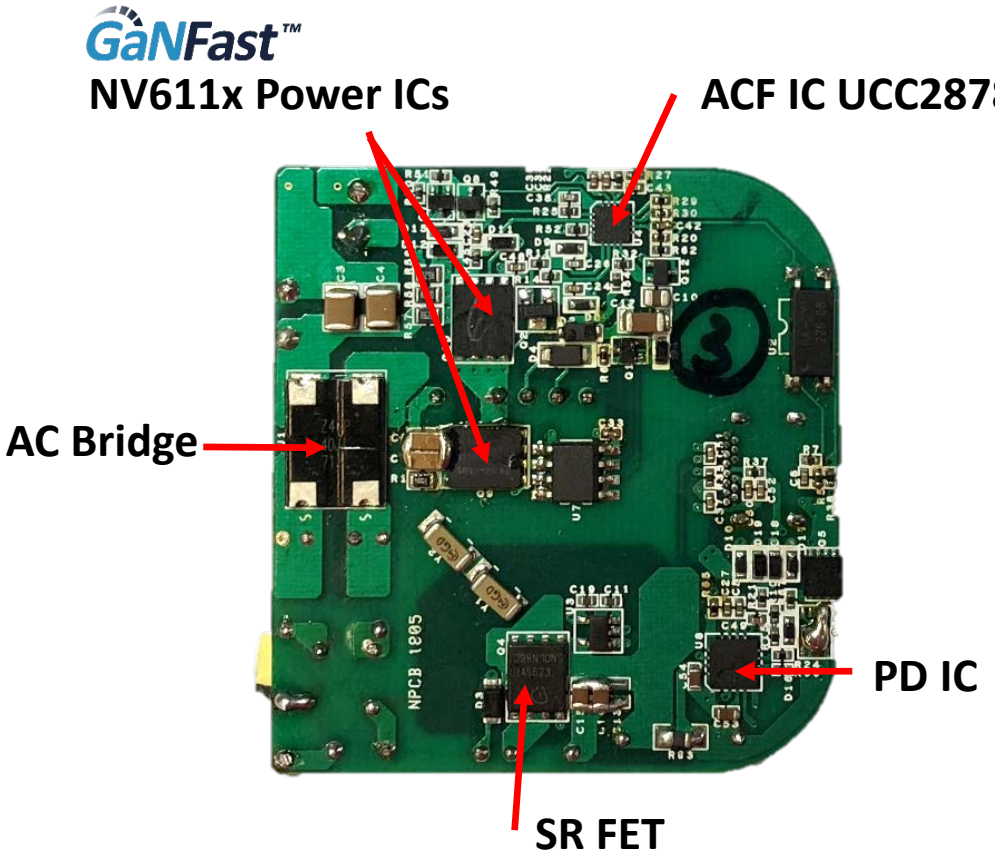
World's Thinnest Universal 45 W



- In mass production, see www.kickstarter.com , search "Mu One"
- Size : 29 cc (41 cc with case)
- Density : 1.7 W/cc (27 W/in^3), 1.1 W/cc (18 W/in^3) cased

45 W Mu One: Major Components





45 W Mu One: Cool Operation

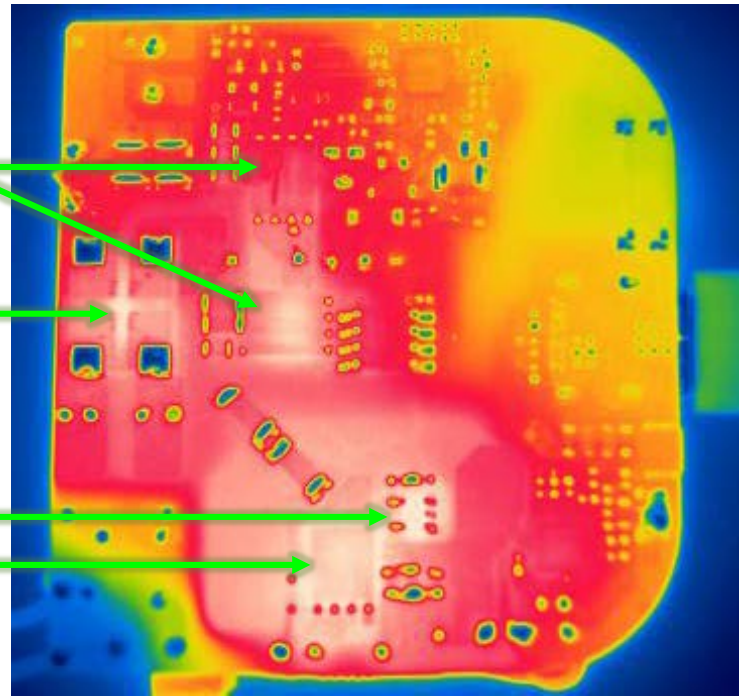
Top

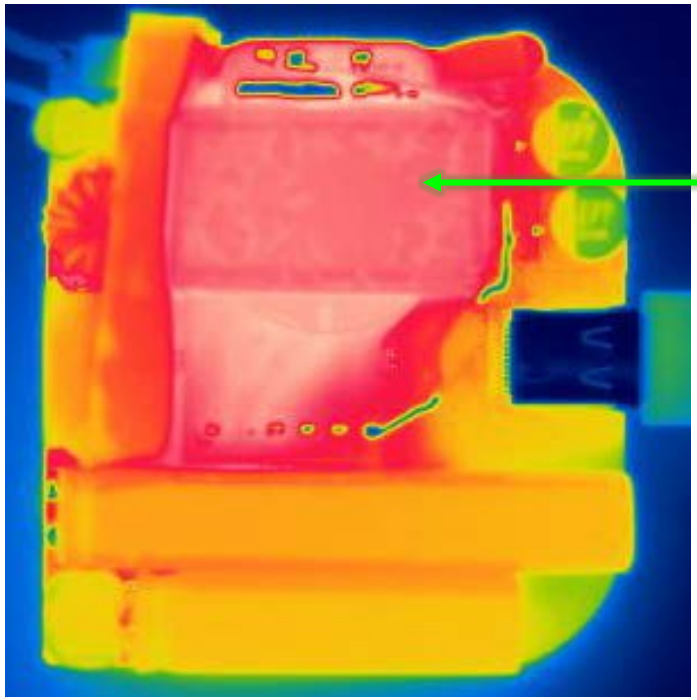
Bottom

GaNFast
Power IC 75°C, 80°C

AC Bridge 80°C

SR IC 85°C
SR FET 85°C

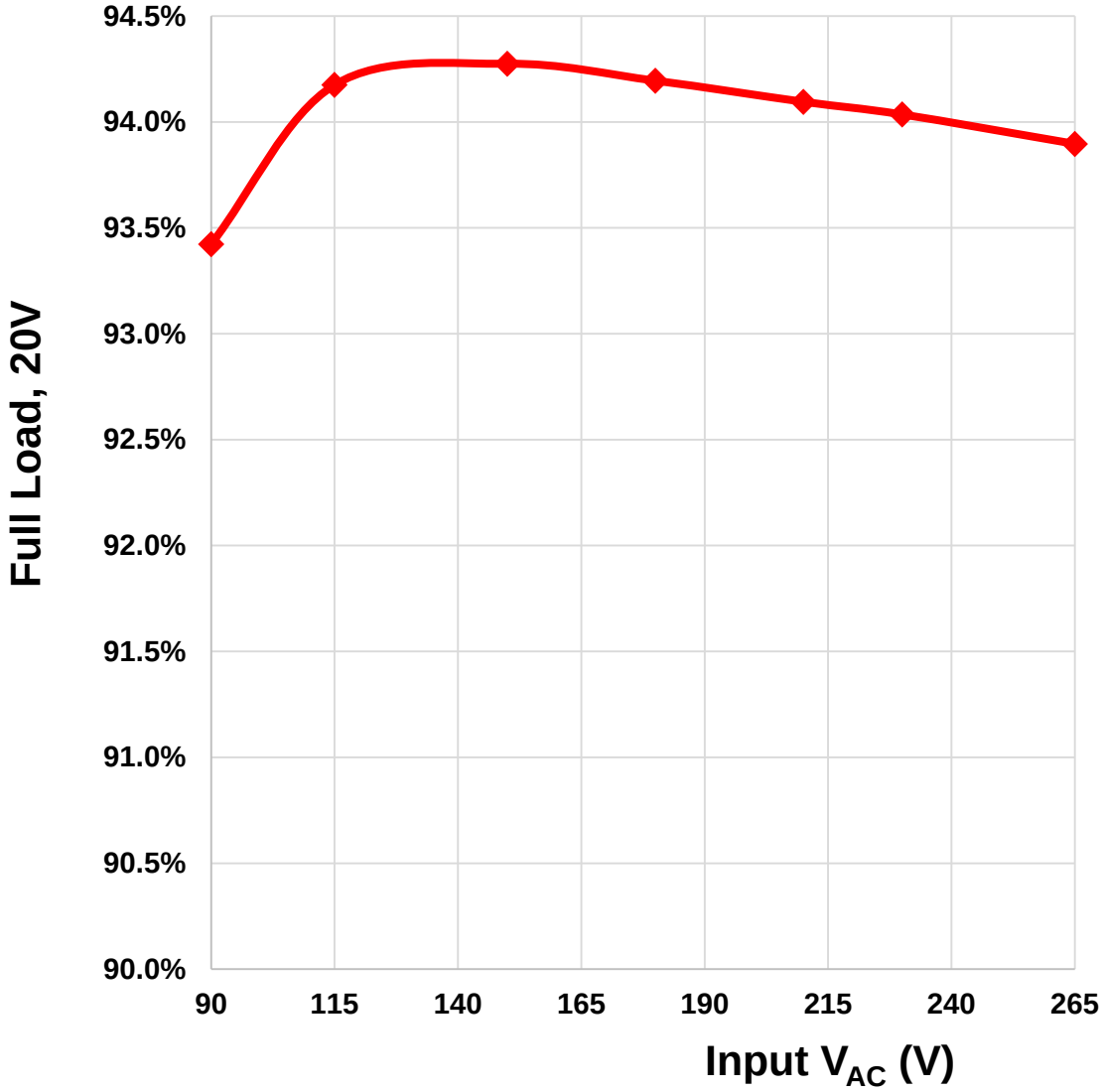


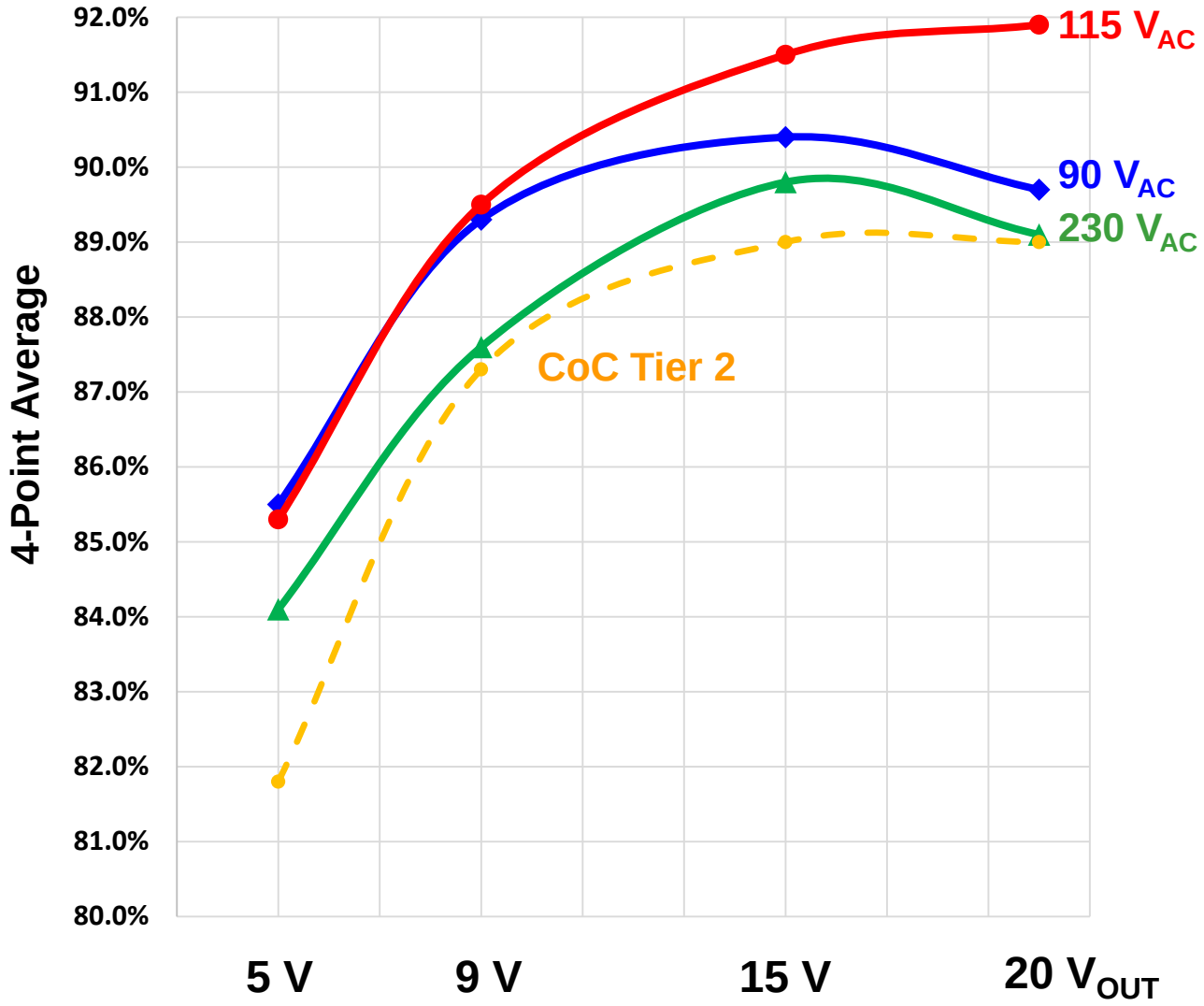


Transformer 80°C

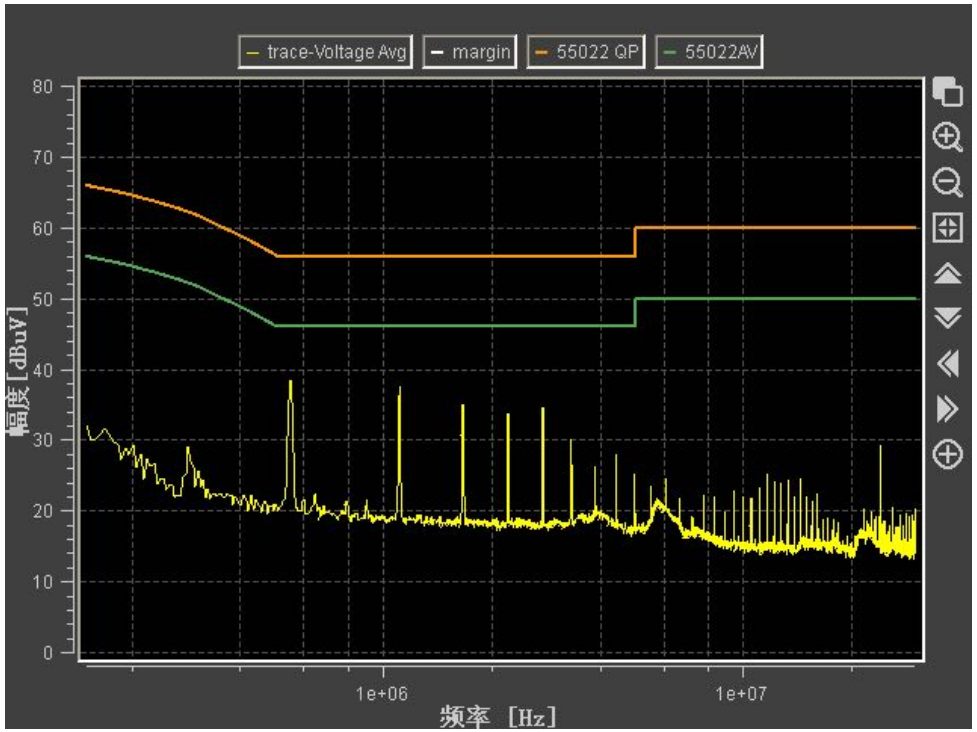
90 V_{AC}, 45 W, 25 °C, uncased, no airflow

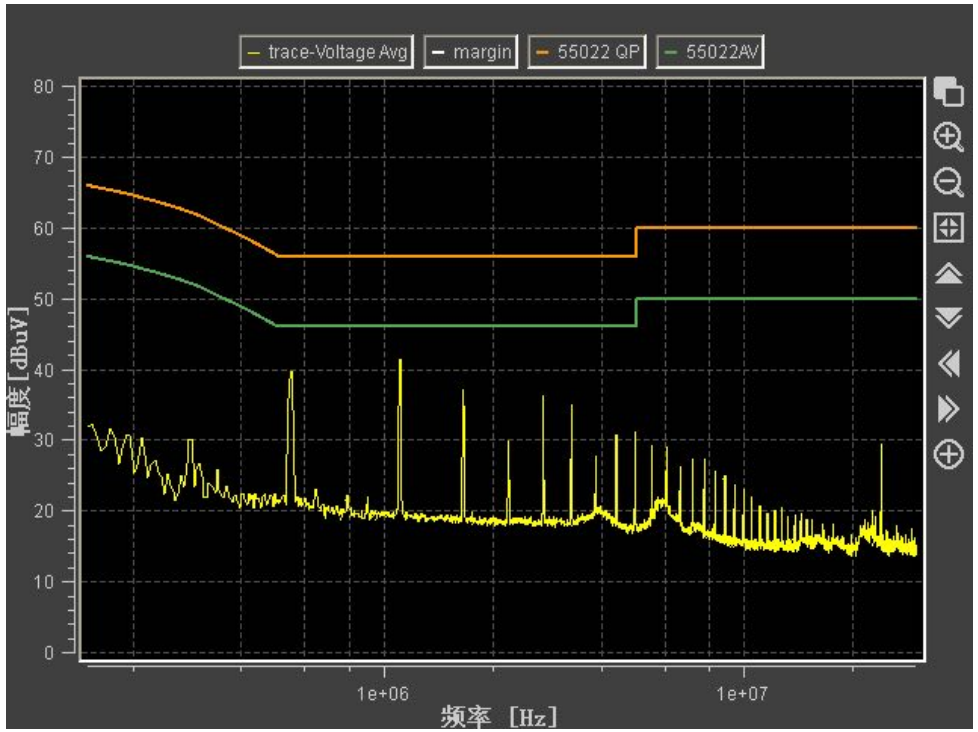
45 W Mu One: Efficiency



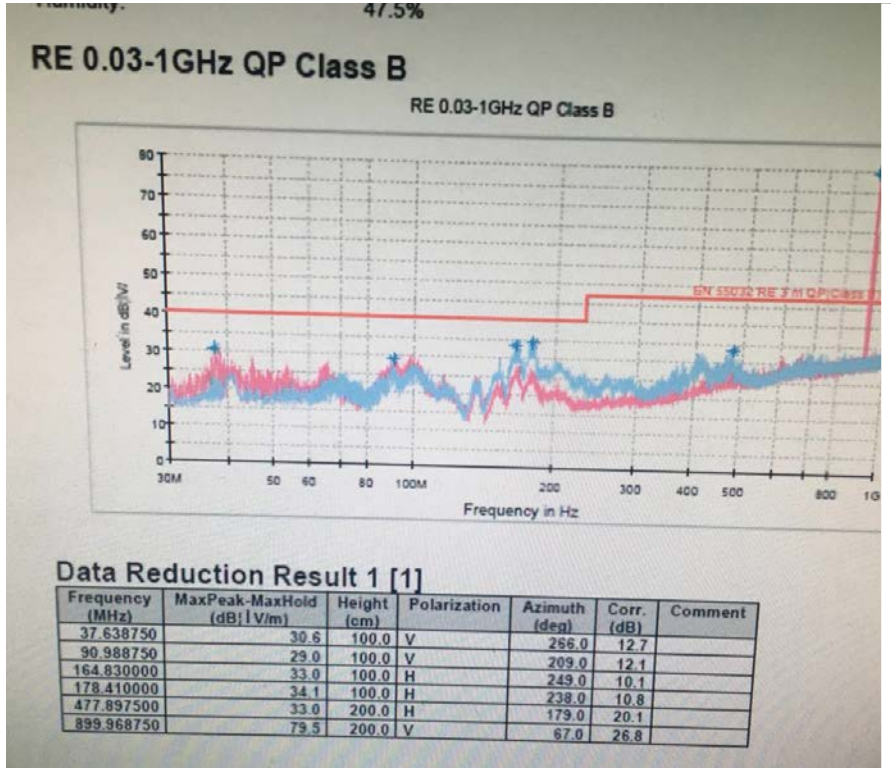


45W Mu One Conducted EMI



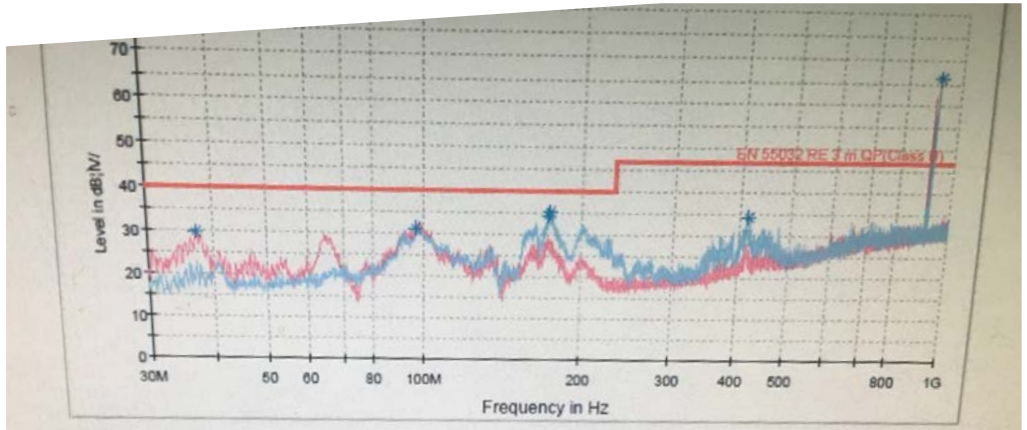


45W Mu One: Radiated EMI



Data Reduction Result 1 [1]

Frequency (MHz)	MaxPeak-MaxHold (dBµV/m)	Height (cm)	Polarization	Azimuth (deg)	Corr. (dB)	Comment
37.638750	30.6	100.0	V	266.0	12.7	
90.988750	29.0	100.0	V	209.0	12.1	
164.830000	33.0	100.0	H	249.0	10.1	
178.410000	34.1	100.0	H	238.0	10.8	
477.897500	33.0	200.0	H	179.0	20.1	
899.968750	79.5	200.0	V	67.0	26.8	

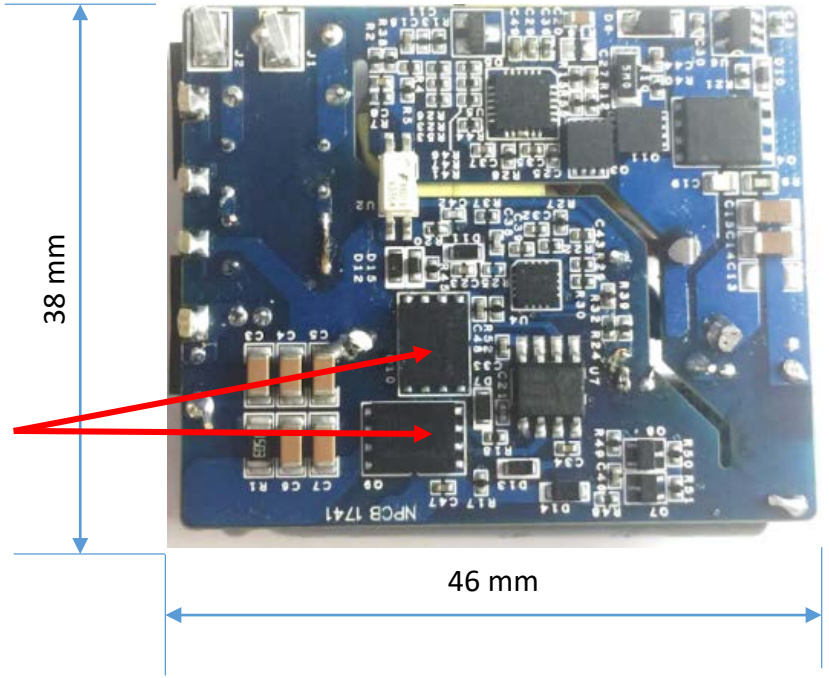


Data Reduction Result 1 [1]

Frequency (MHz)	MaxPeak-MaxHold (dBµV/m)	Height (cm)	Polarization	Azimuth (deg)	Corr. (dB)	Comment
37.032500	29.5	100.0	V	219.0	12.5	
96.323750	31.2	100.0	V	196.0	12.7	
171.862500	34.2	200.0	H	244.0	10.6	
173.681250	35.1	200.0	H	244.0	10.7	
415.211250	34.2	100.0	H	194.0	18.4	
911.972500	65.9	100.0	H	6.0	27.0	

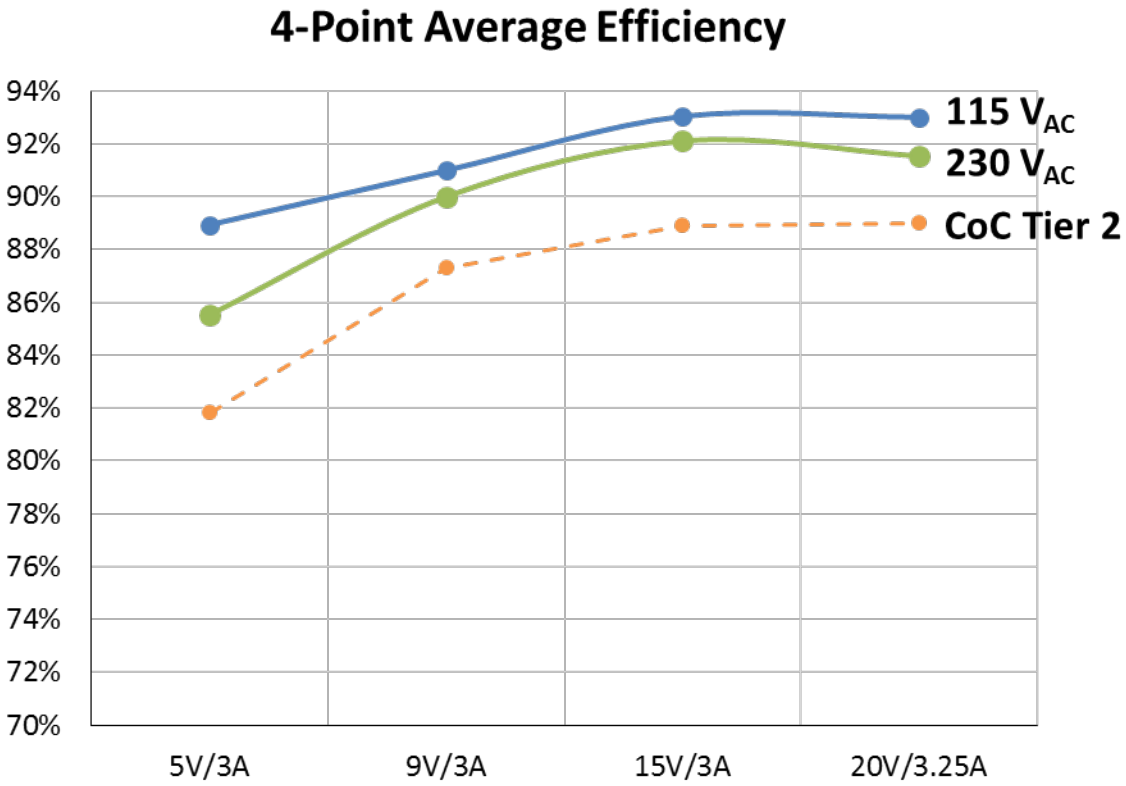
World's Smallest 65 W USB-PD Adapter

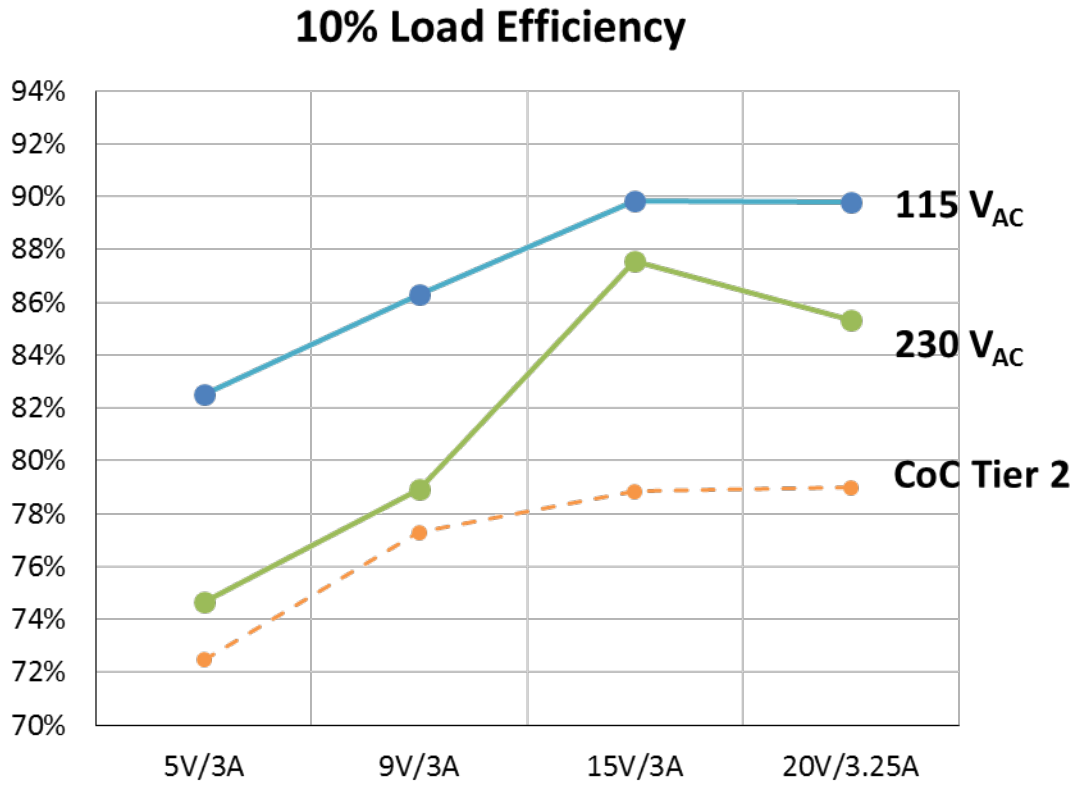
GaNFast™
Power ICs



Power, Output	65 W USB-PD
Topology	ACF with UCC28780 and NV6115, NV6117 GaNFast Power ICs
Frequency	300 kHz
Size	27 cc (45 cc with case)
Density	2.4 W/cc (39 W/in3) (1.5 W/cc (24 W/in3) cased
Efficiency	>93% peak, 92.8% at 90 V_{AC}, full load DoE Level VI, Euro CoC (EuP) Tier 2

Highest Efficiency

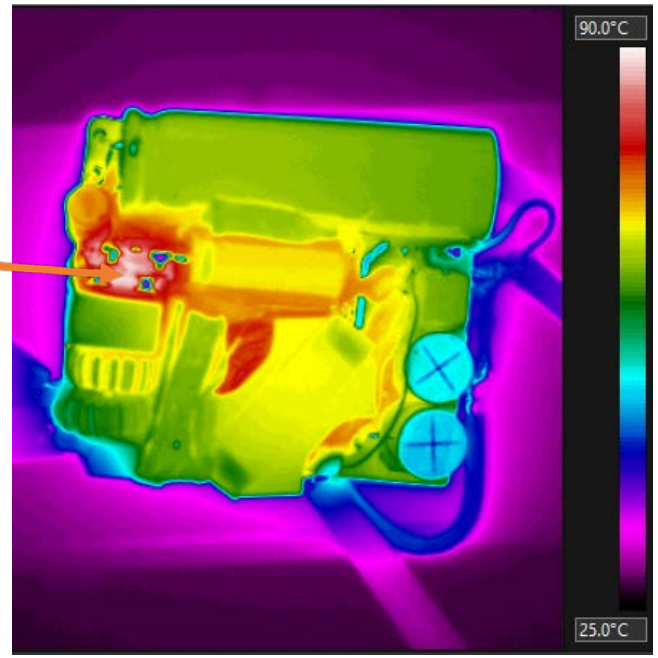


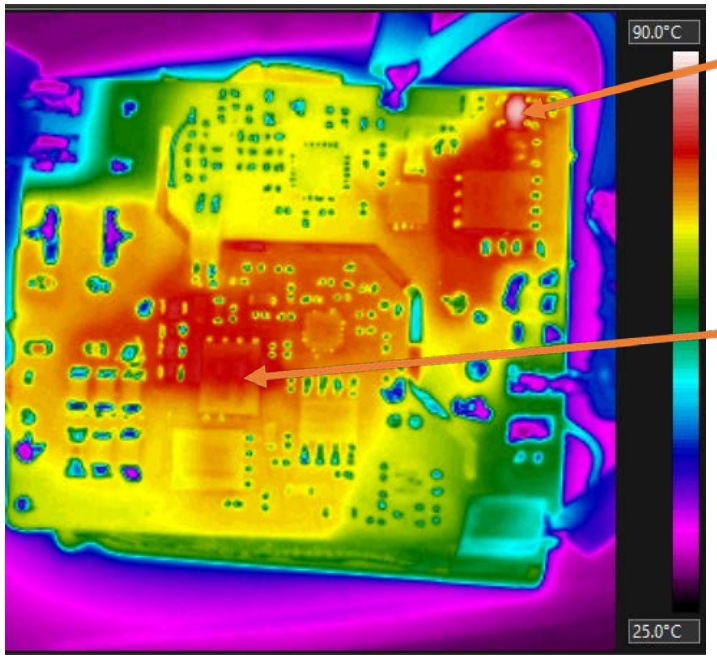


- Peak efficiency = 94.3% at 230 V_{AC}, full load (20V/3.25A)
- Lowest line efficiency = 93.4% at 90 V_{AC}, full load
- Standby: 25 mW at 115 V_{AC}, 40 mW at 230 V_{AC}
  - CoC Tier 2 spec is < 75mW, DoE Level VI spec <= 210 mW

Cool Performance

AC Rectifier
90 °C





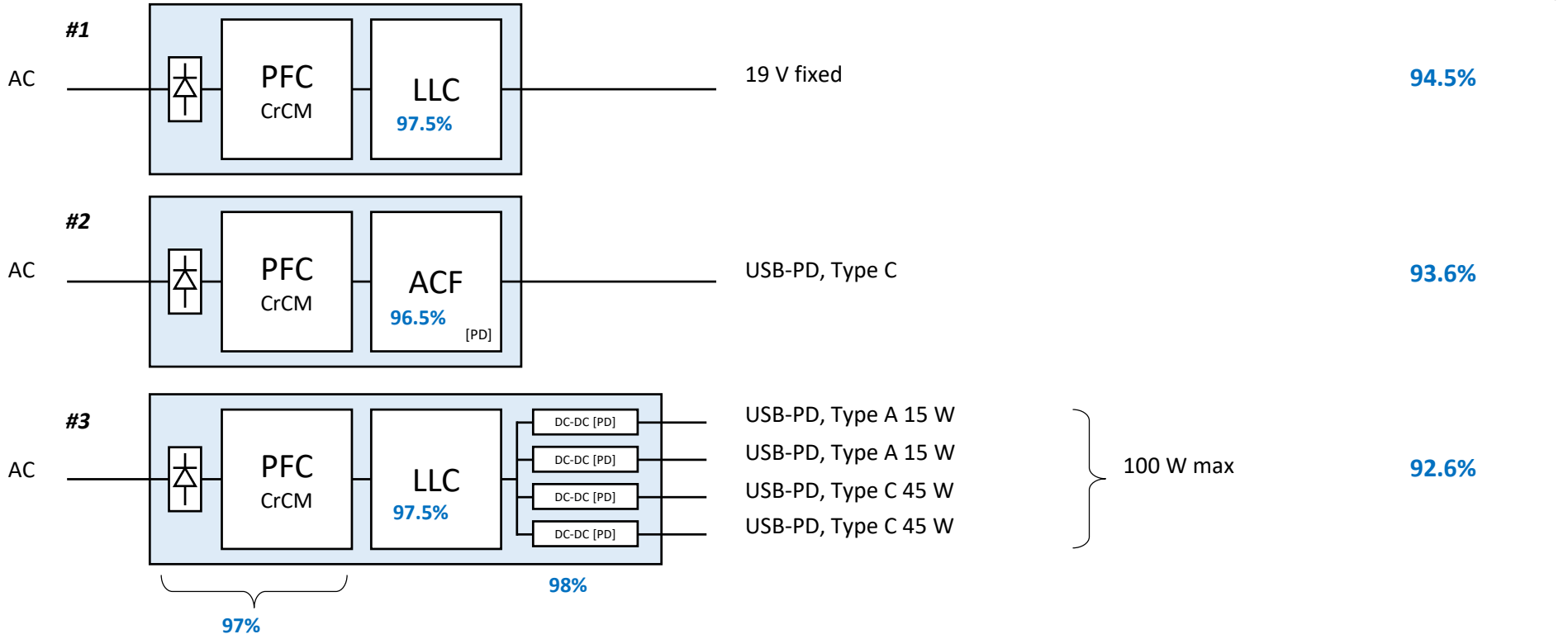
SR IC
82 °C

GaN IC
81 °C

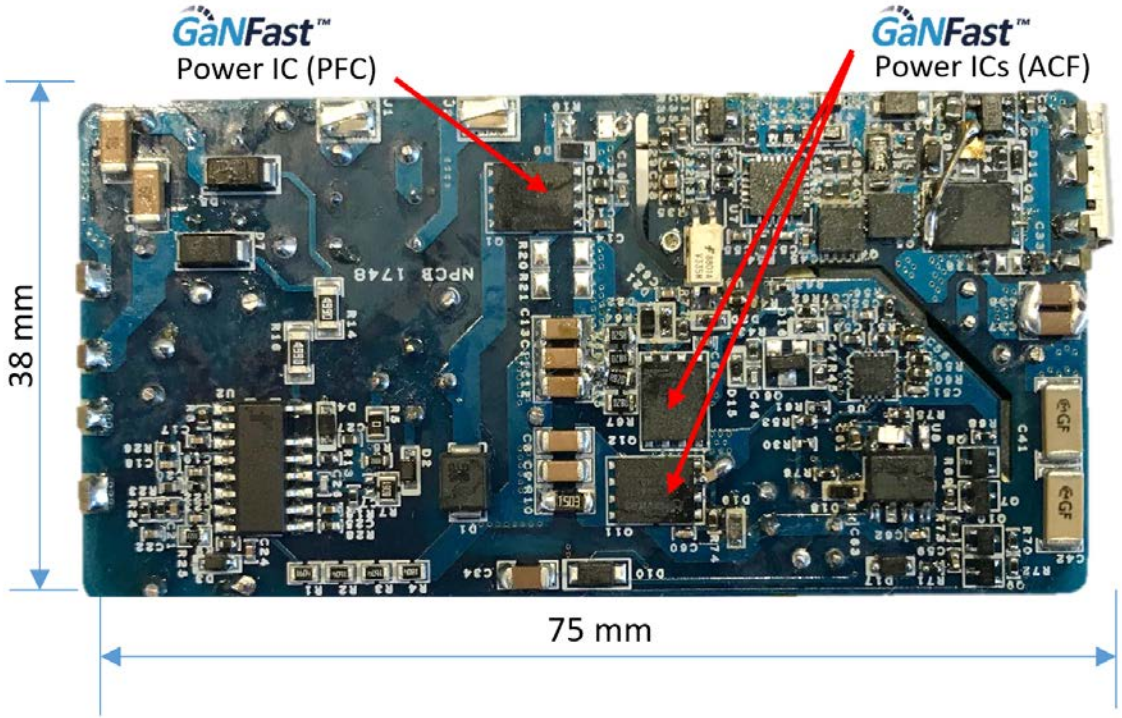
- Meets customer case specification of <=50°C
- Conditions: 115V_{AC}, 20V_{DC}, 65W, 25°C ambient, no airflow, no heatsink

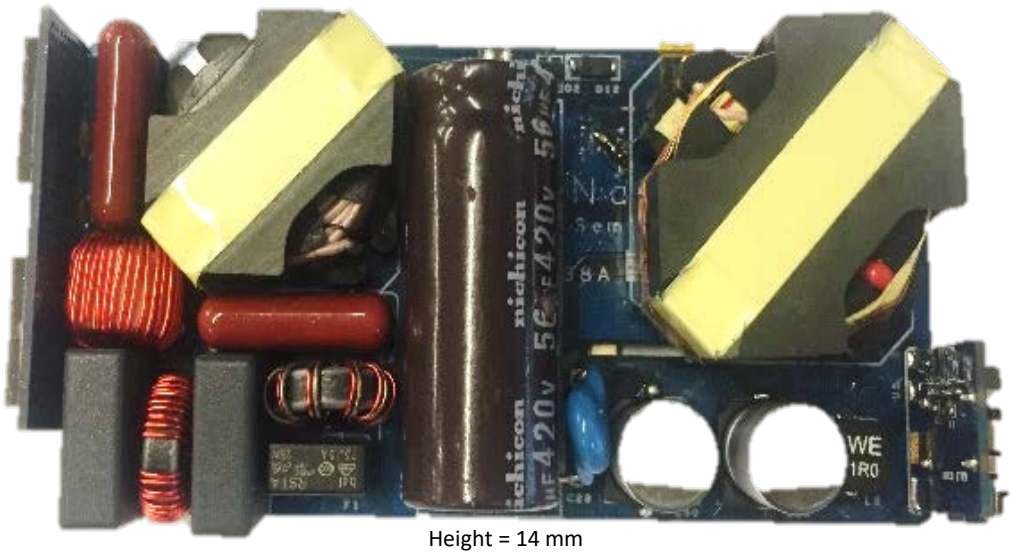
100W: Topology?

- Fixed or variable output?
  - LLC best for fixed output
  - ACF best for variable (PD) output



World's Smallest 100 W USB-PD





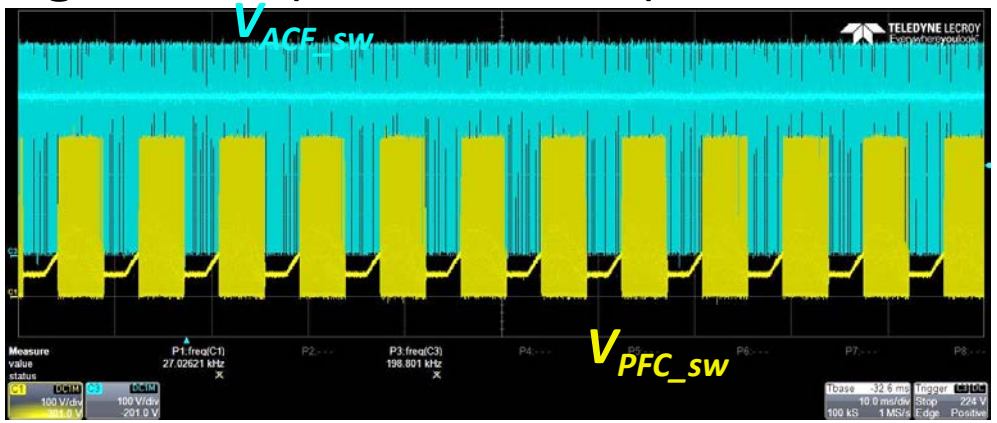
Height = 14 mm

Power, Output	100 W USB-PD
Topology	CrCM PFC with NCP1615 and NV6115 GaNFast Power IC ACF with UCC28780 and NV6115, NV6117 GaNFast Power ICs
Frequency	PFC min. 200 kHz, ACF 300 kHz
Size	40 cc (65 cc with case)
Density	2.5 W/cc (41 W/in^3) (1.5 W/cc (25 W/in^3) cased
Efficiency	>93.7% peak, 92.1% (target >93%) at 90 V_{AC}, full load, DoE Level VI, Euro CoC (EuP) Tier 2

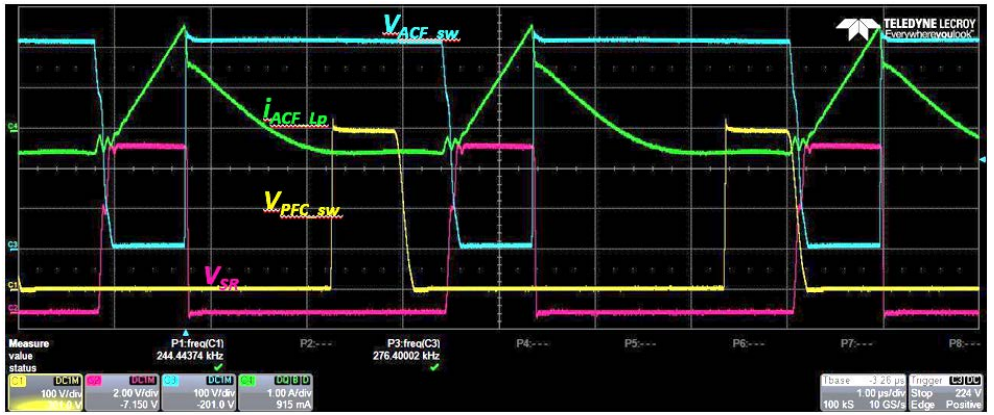
100 W USB-PD

Light Load (20 V, 500 mA)

10 ms/div



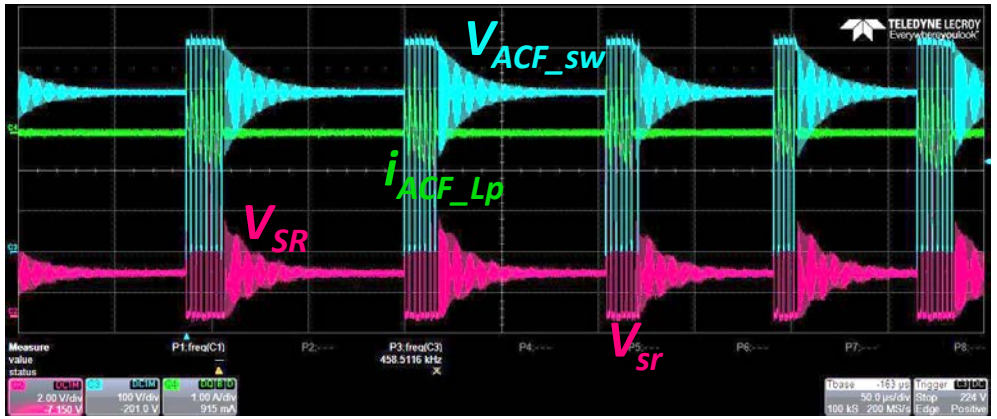
Heavy Load (20 V, 4.8 A)



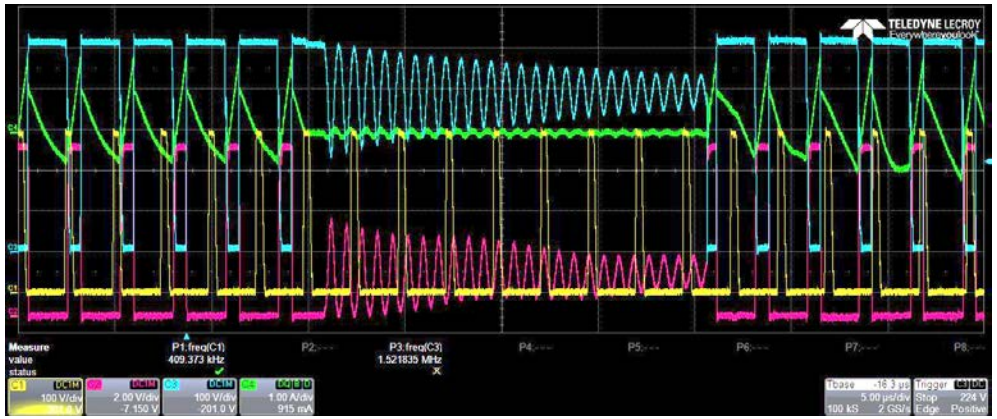
1 us/div

Light Load (20 V, 500 mA, zoom)

50 us/div

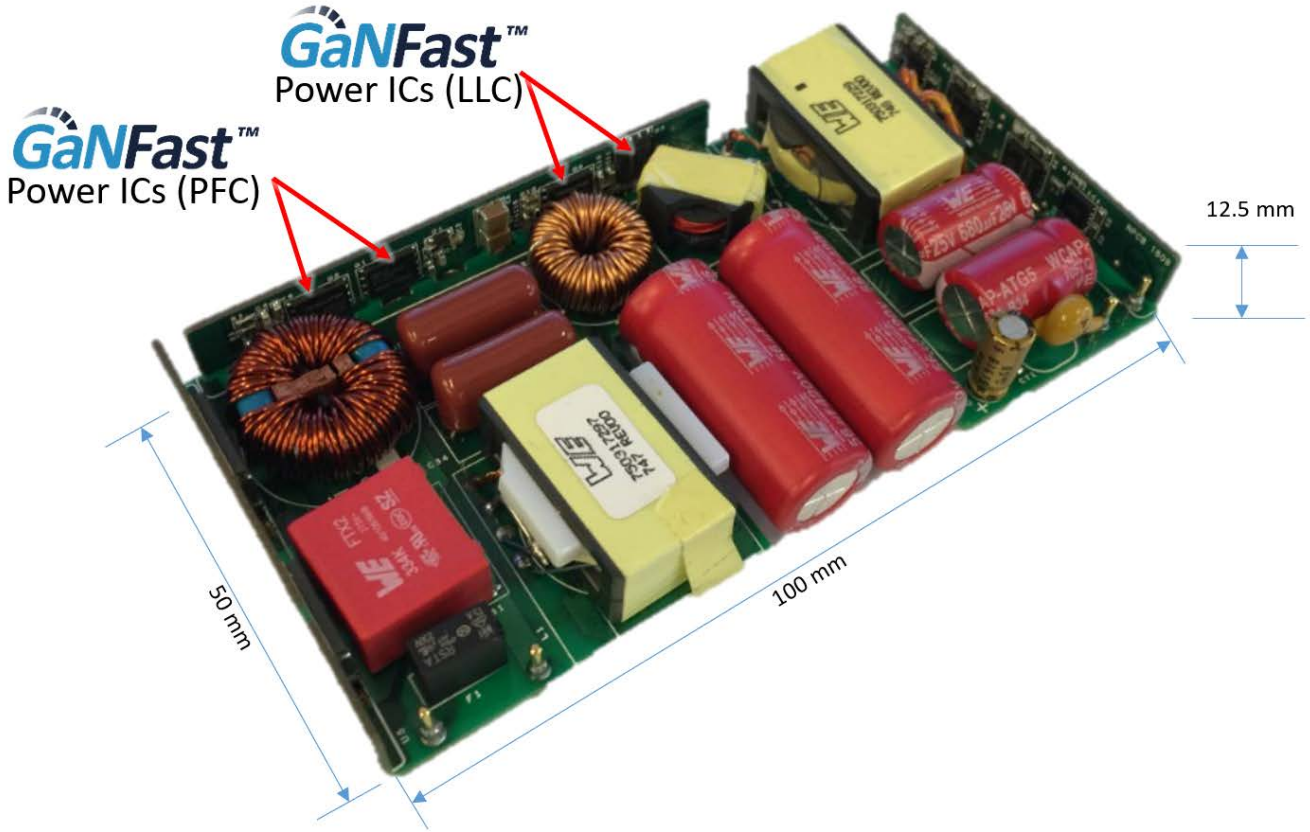


Half Load (20V, 2.5A)



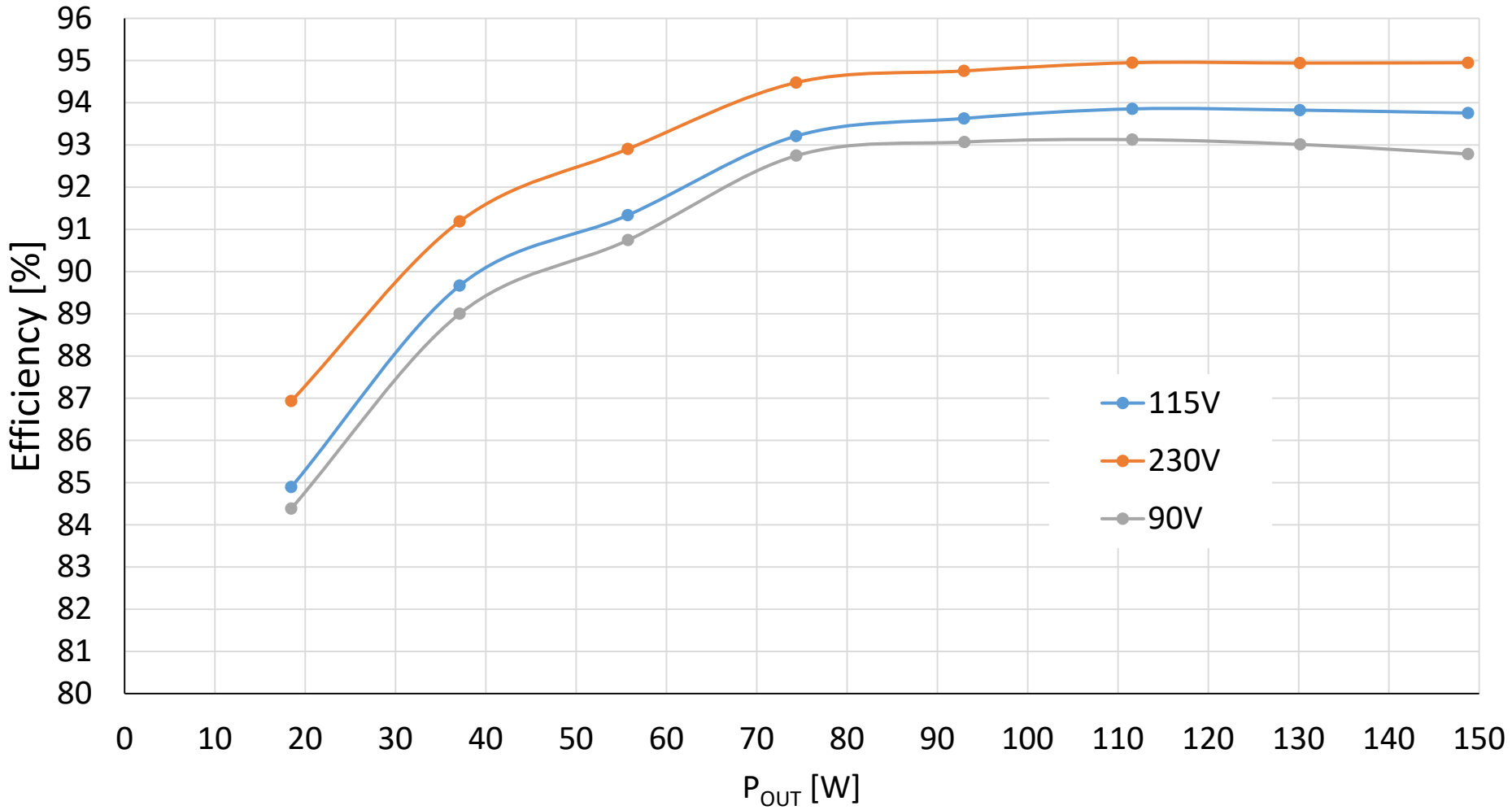
5 us/div

150 W, 19 V: 200/500 kHz

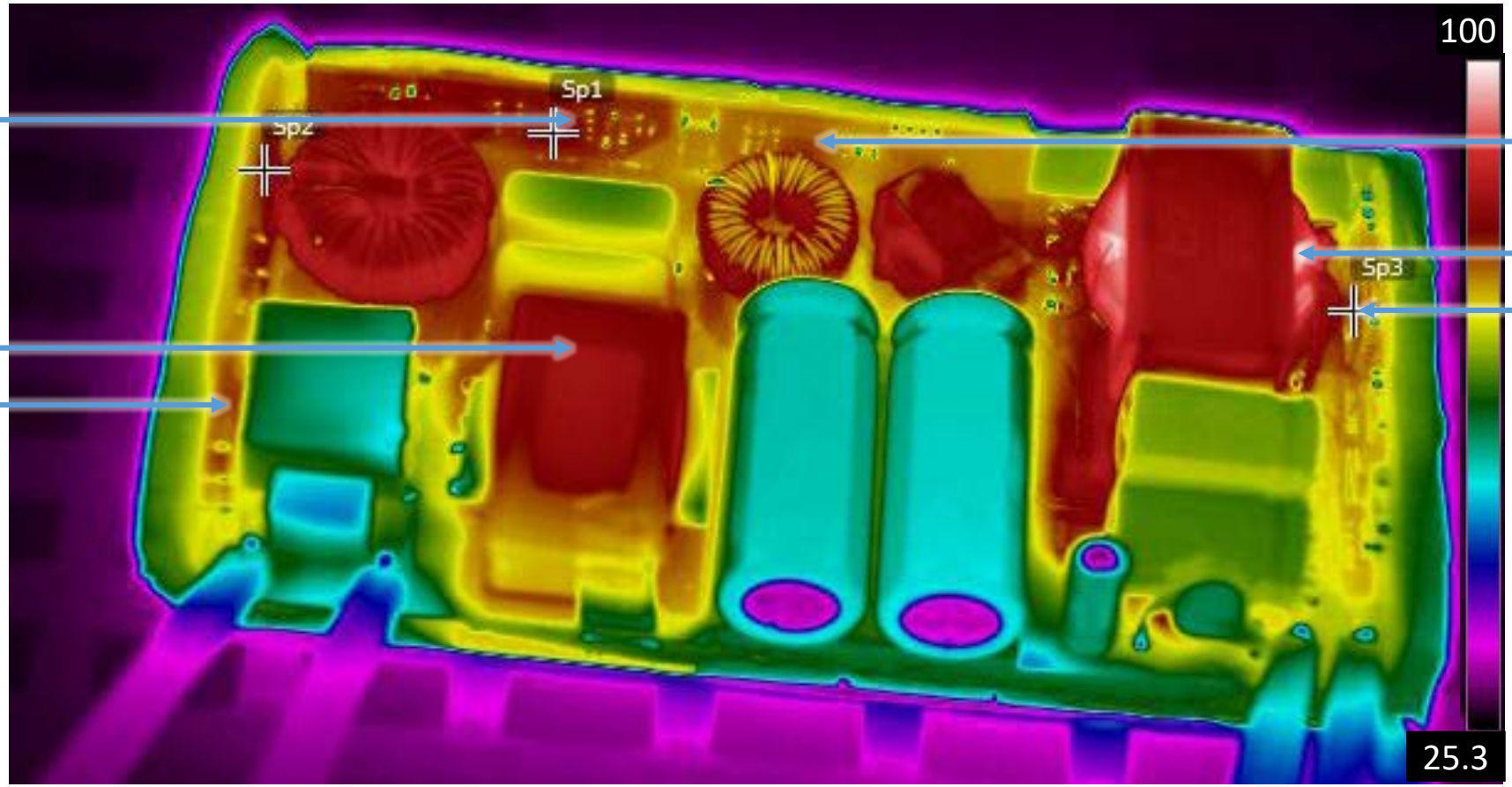


Power, Output	150 W, 19 V
Topology	CrCM PFC NCP1615 & LLC NCP13992AB with NV6115 GaNFast Power ICs
Frequency	PFC min. 200 kHz, LLC typ. 500 kHz
Size	63 cc (101 cc with case)
Density	2.4 W/cc (39 W/in^3) 1.5 W/cc (24 W/in^3) cased
Efficiency	95% peak, 93% at 90 V_{AC}, full load DoE Level VI, Euro CoC (EuP) Tier 2

150 W Highest Efficiency



150 W Cool Operation



PFC GaNFast 85°C

PFC Inductor 90°C

AC Bridge 85°C

LLC GaNFast 70°C

LLC Transformer 90°C

SR FETs 85°C

90 V_{AC}, 150 W, 25 °C, uncased, no airflow

Let's go GaNFast™