Navitas

Let's go GaNFast™

GaN Power IC Enable 4x Power Density 150W AC/DC Converter Design

IEEE PEAC 2018 Industry Session: "Power Devices and Applications" November 6th, 2018

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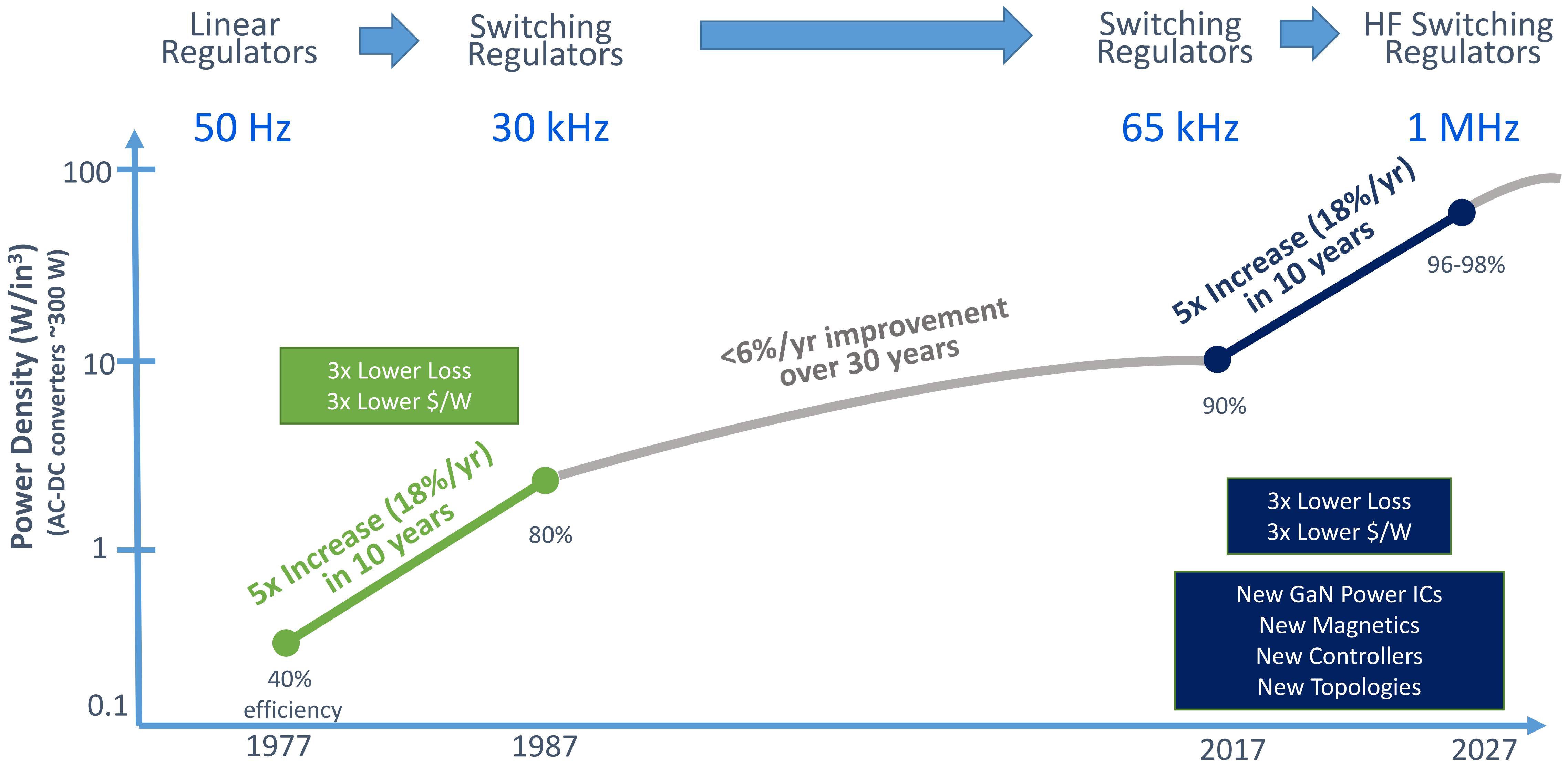
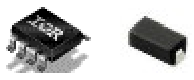
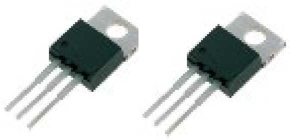
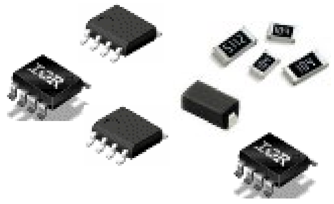
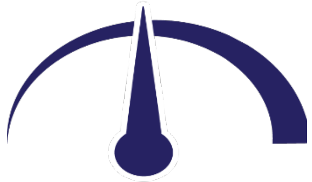
A Power Supply Revolution Once Again! GaNFast™



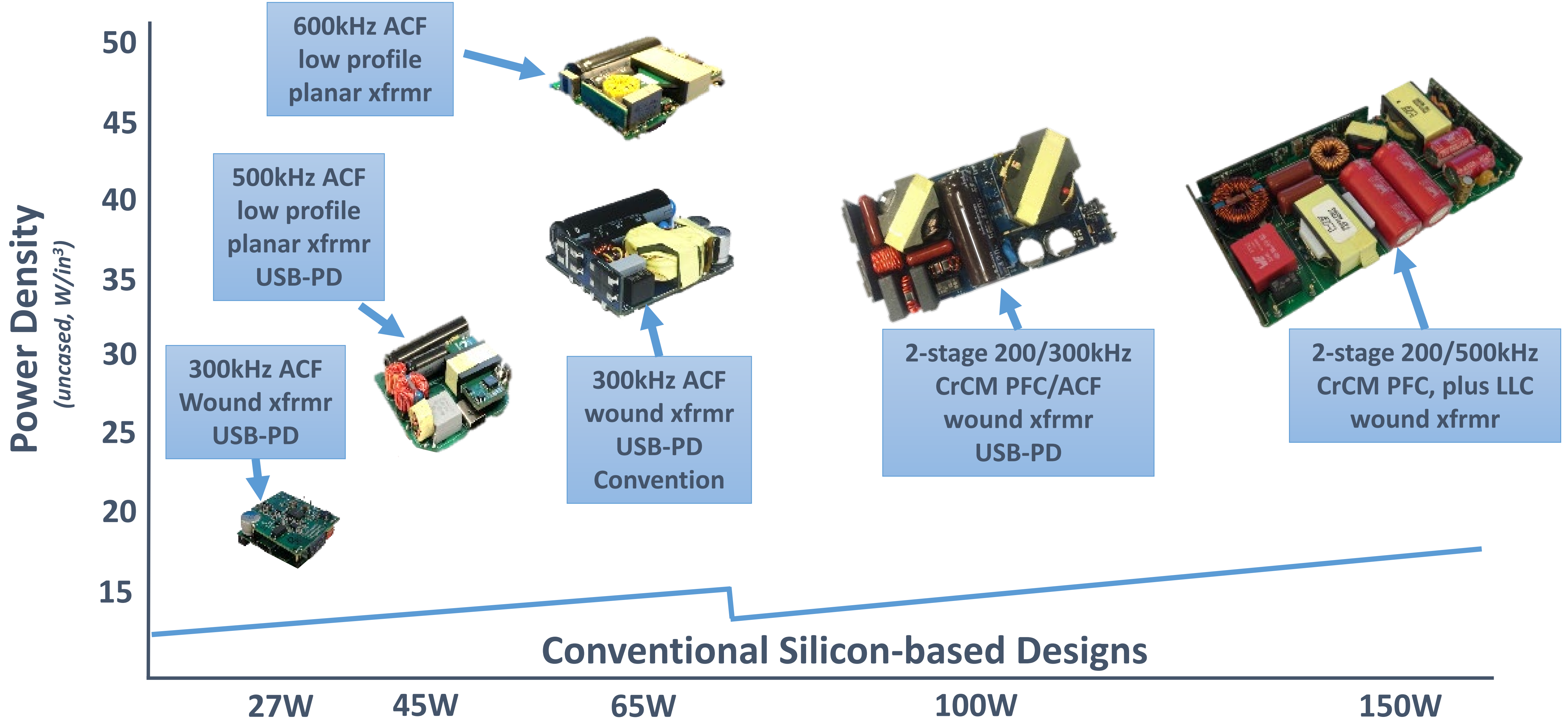
The Power of GaN Power ICs

... Unequaled Integration, Speed & Efficiency

GaNFast™

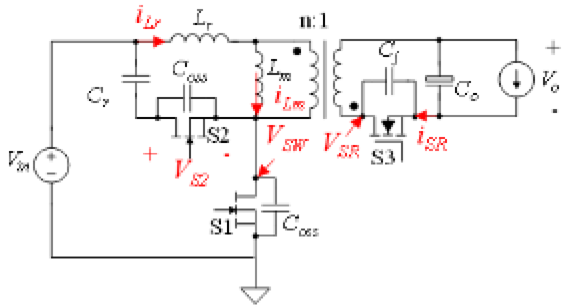
	Driver Circuits	Power Devices	Passive Components	Switching Frequency	Energy Efficiency
Silicon				 *<100kHz*	*85-90%*
Discrete GaN				 *300kHz*	*88-92%*
GaN Power ICs				 *>500kHz*	*90-95%*

The New World of GaNFast™ Adapters

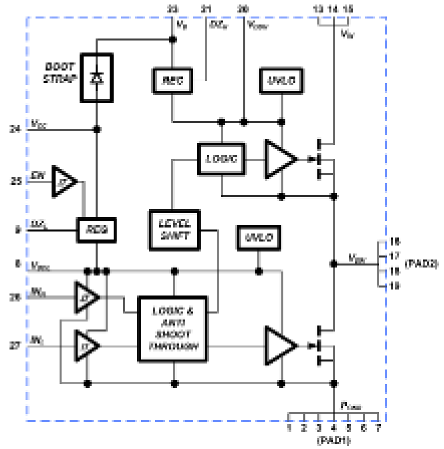


Key Elements For High-Density Adaptor

GaNFast™

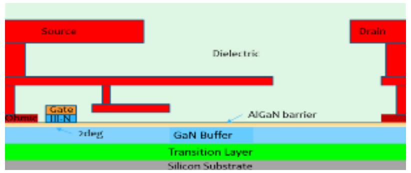


New Topologies



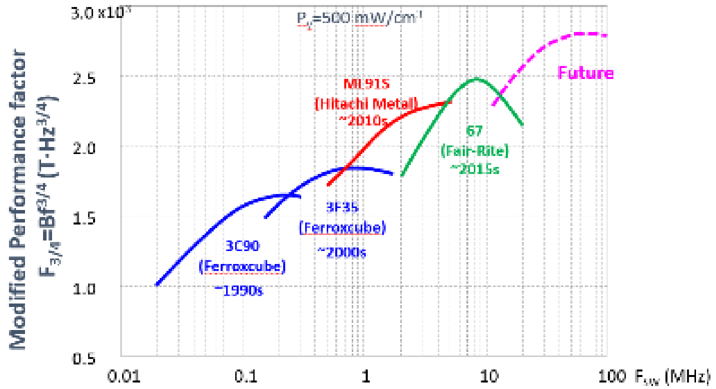
Higher Integration

GaN Device



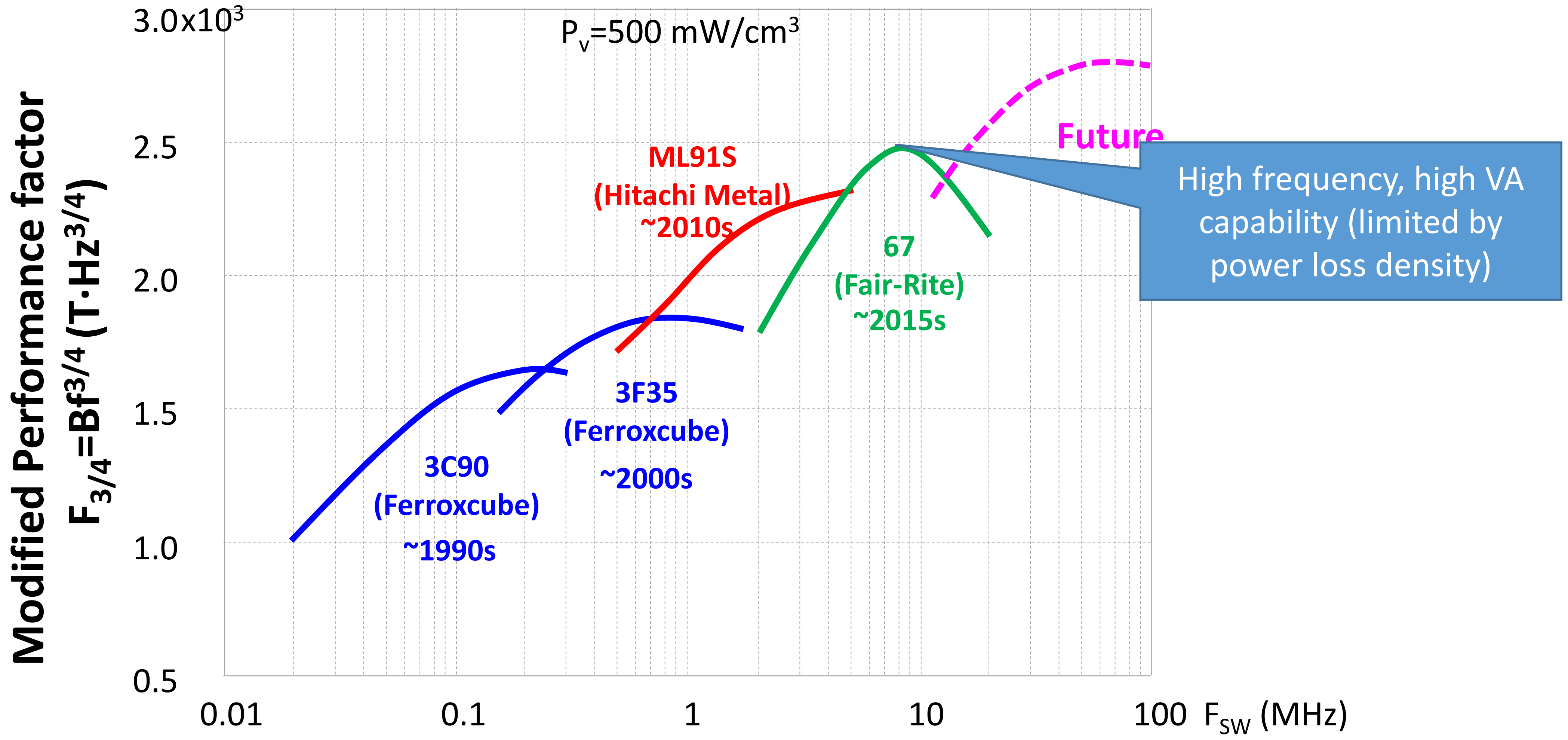
Hi-Frequency Controllers

Hi-Frequency Magnetic



>500Khz Controllers are ready!

Magnetics Frequencies – 10x Every Decade

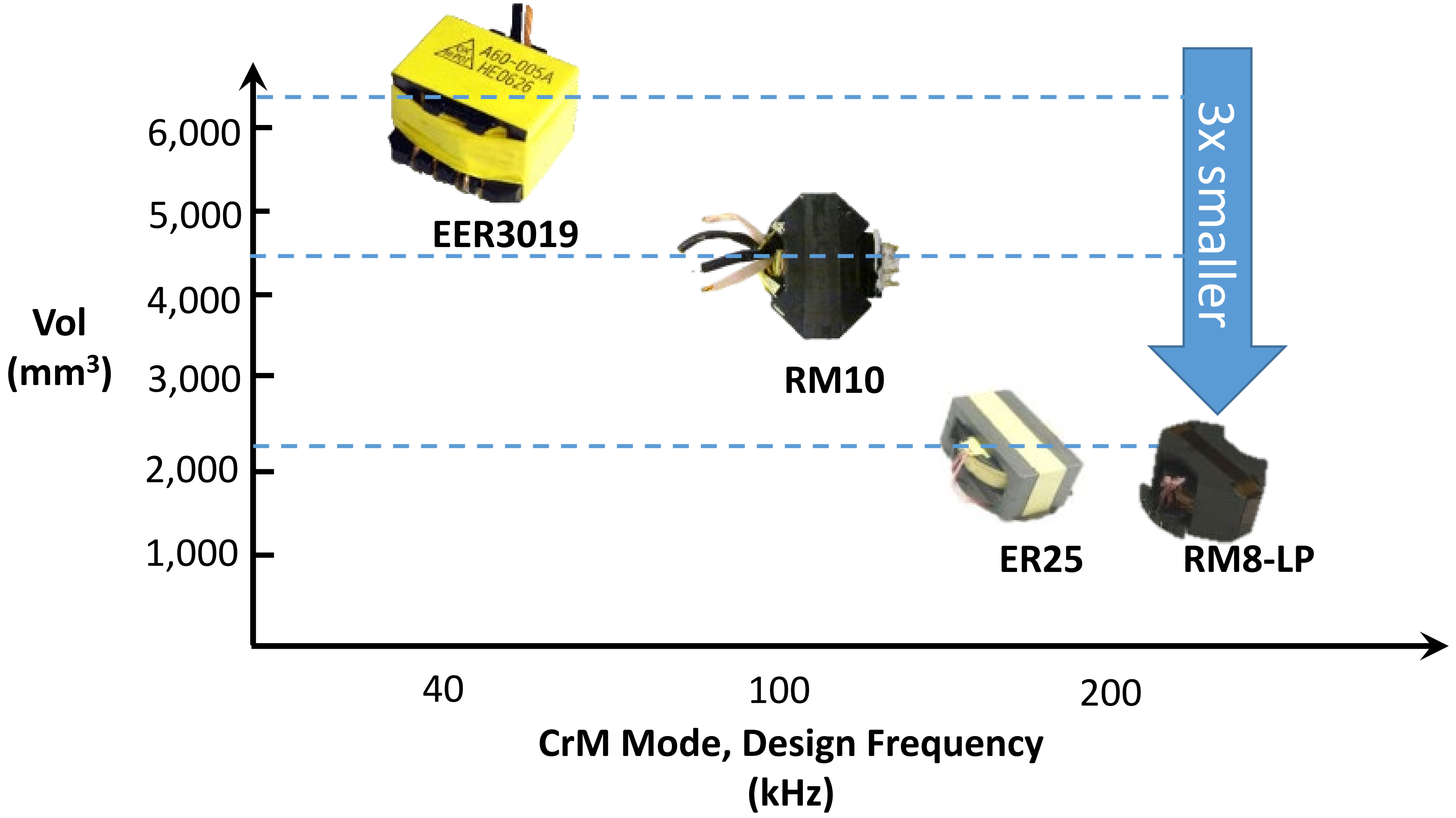


Y. Han, G. Cheung, A. Li, C. R. Sullivan and D. J. Perreault, "Evaluation of Magnetic Materials for Very High Frequency Power Applications," in *IEEE Transactions on Power Electronics*, vol. 27, no. 1, pp. 425-435, Jan. 2012.

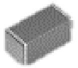
A. J. Hanson, J. A. Belk, S. Lim, C. R. Sullivan and D. J. Perreault, "Measurements and Performance Factor Comparisons of Magnetic Materials at High Frequency," in *IEEE Transactions on Power Electronics*, vol. 31, no. 11, pp. 7909-7925, Nov. 2016.

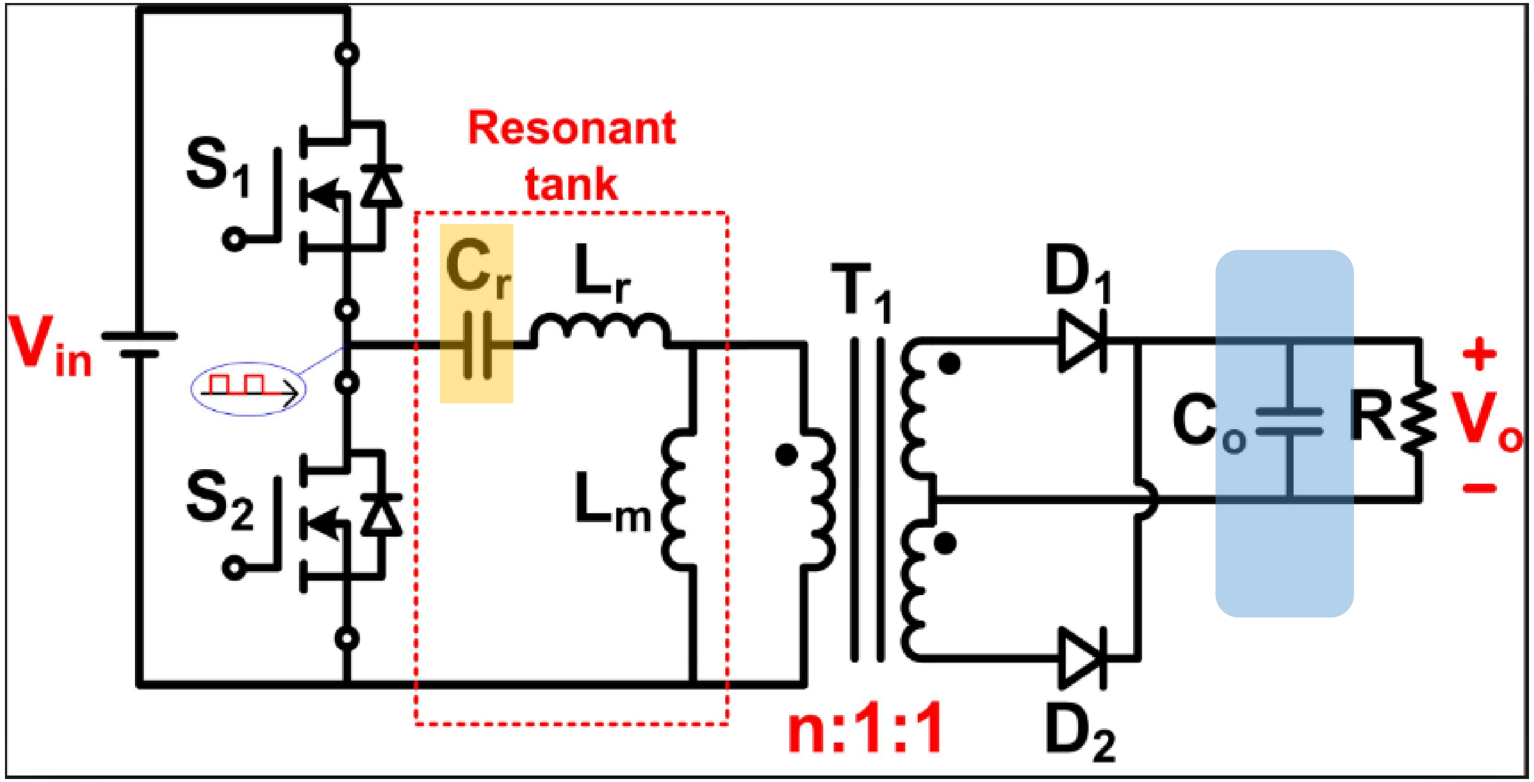
Speed Reduces Size: Magnetics

150W PFC Boost Inductor (Lm)



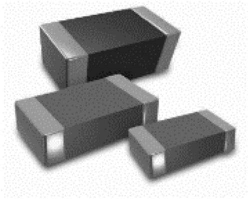
Speed Reduces Size: Capacitors





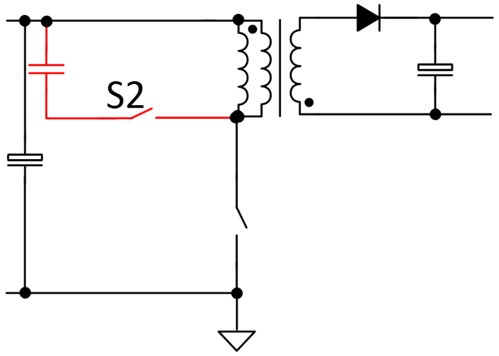
100kHz

500kHz



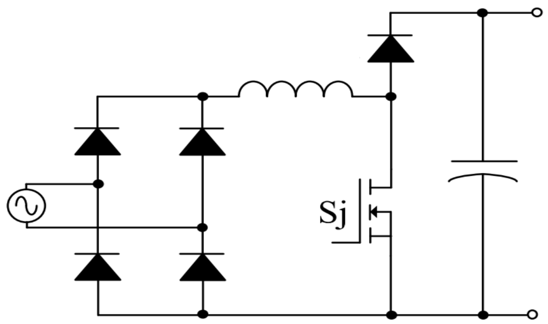
High Frequency Topologies

Active Clamp Flyback



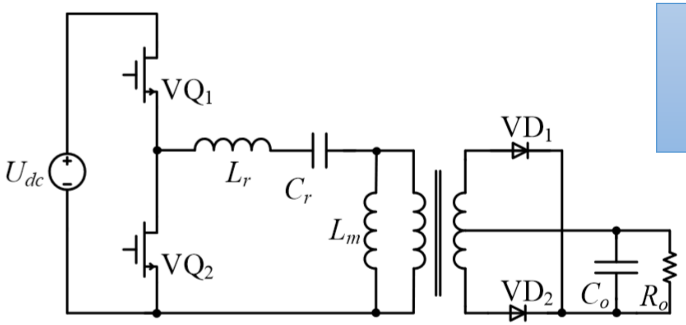
>1MHz(GaN)
Soft-switching

Bridge CrM Boost PFC



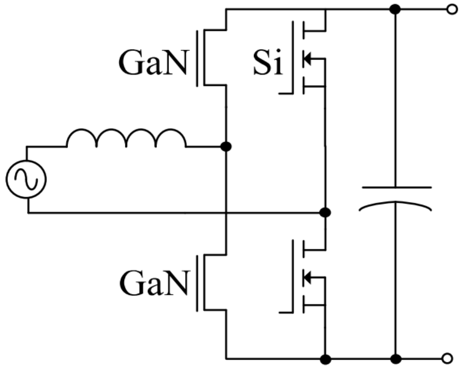
>200kHz
Quasi-Resonant

LLC



>1MHz(GaN)
Soft-switching

Bridgeless CrM Totem Pole PFC

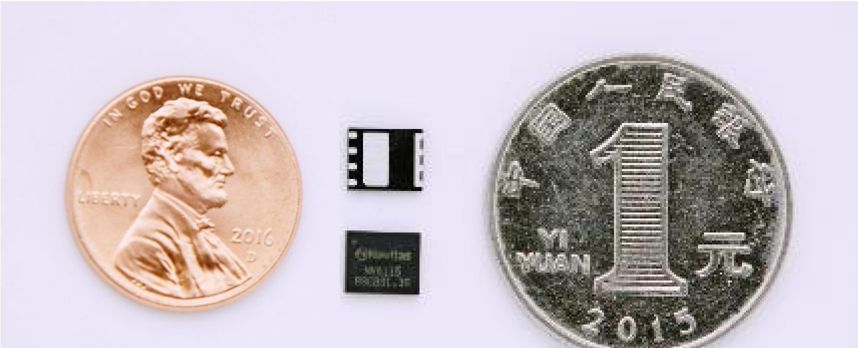


>1MHz(GaN) with
Soft-switching

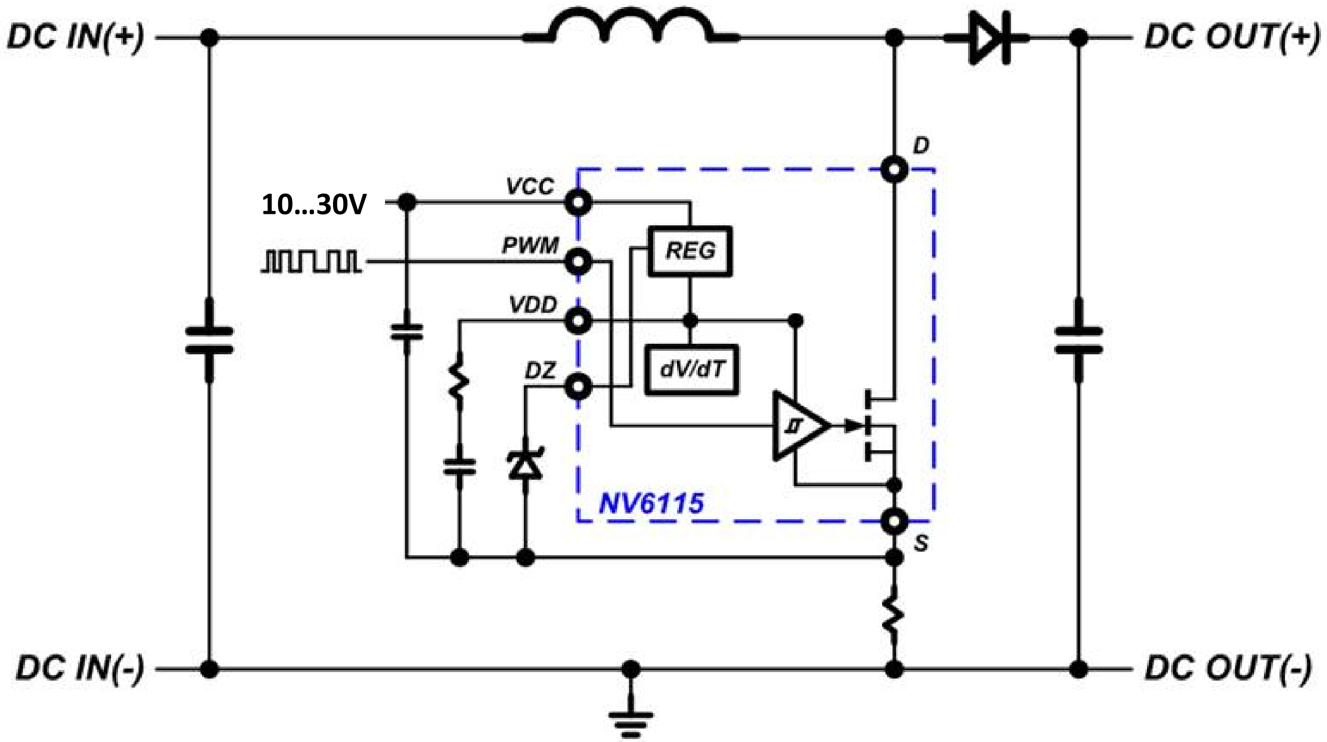
GaNFast™ Power IC

Monolithic integration at 650V

- GaN FET *(range 120-600 mΩ)*
- GaN Driver
- GaN Regulator
- dV/dt control
- Logic

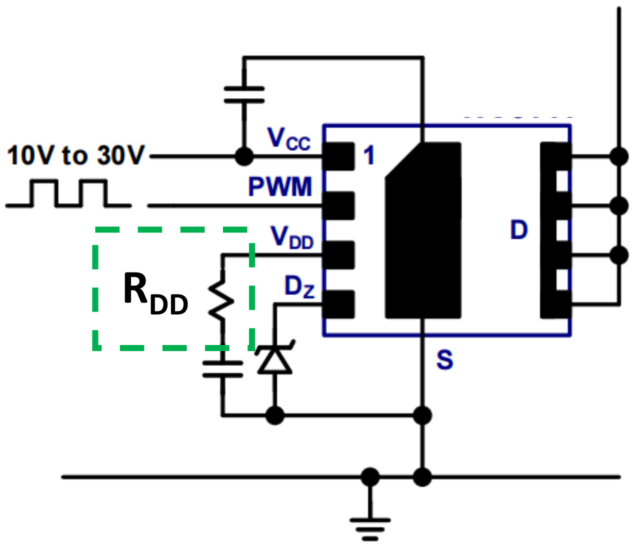


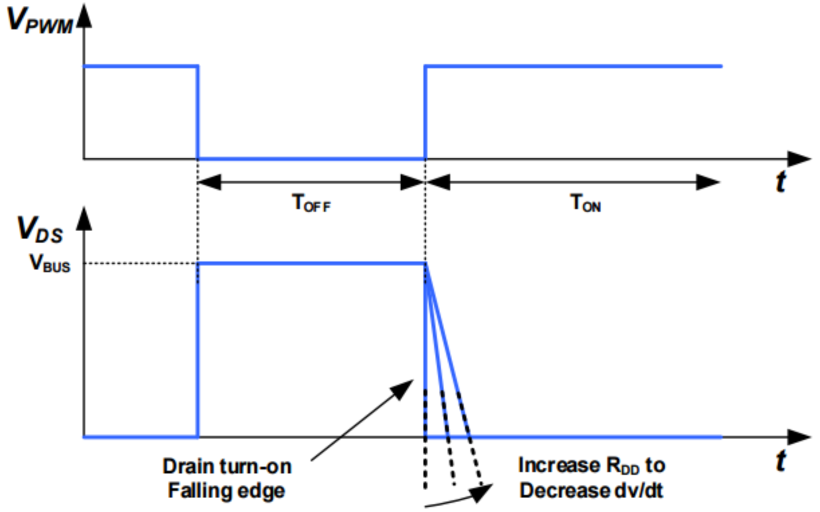
5 x 6 mm QFN

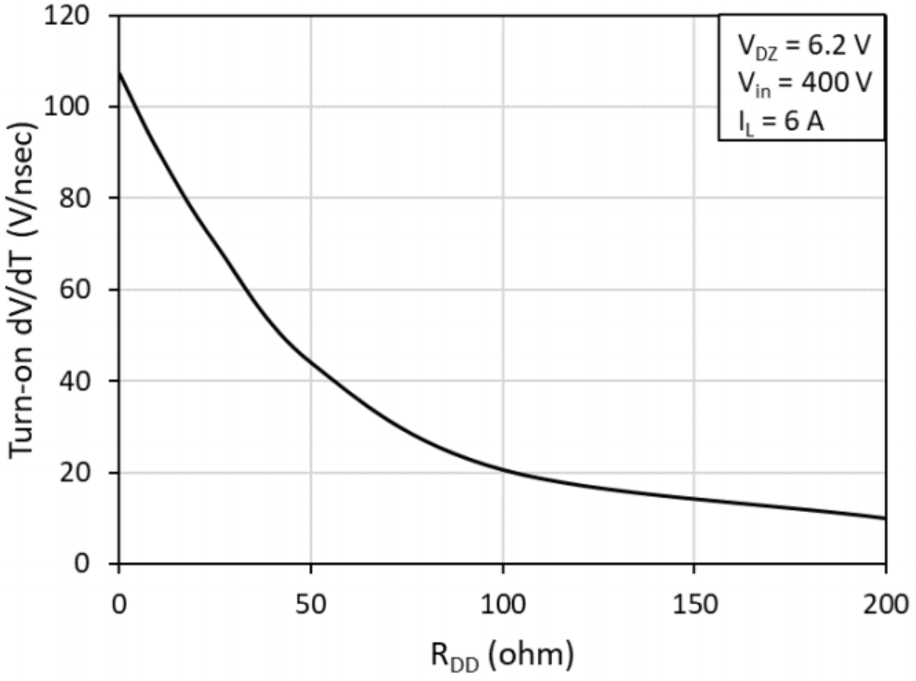


Voltage Slew-Rate Control… Easy EMI Tuning

GaNFast™







dV/dt controllable from 100 V/ns to 10 V/ns

Speed & Integration → Eliminate T_{off} Losses

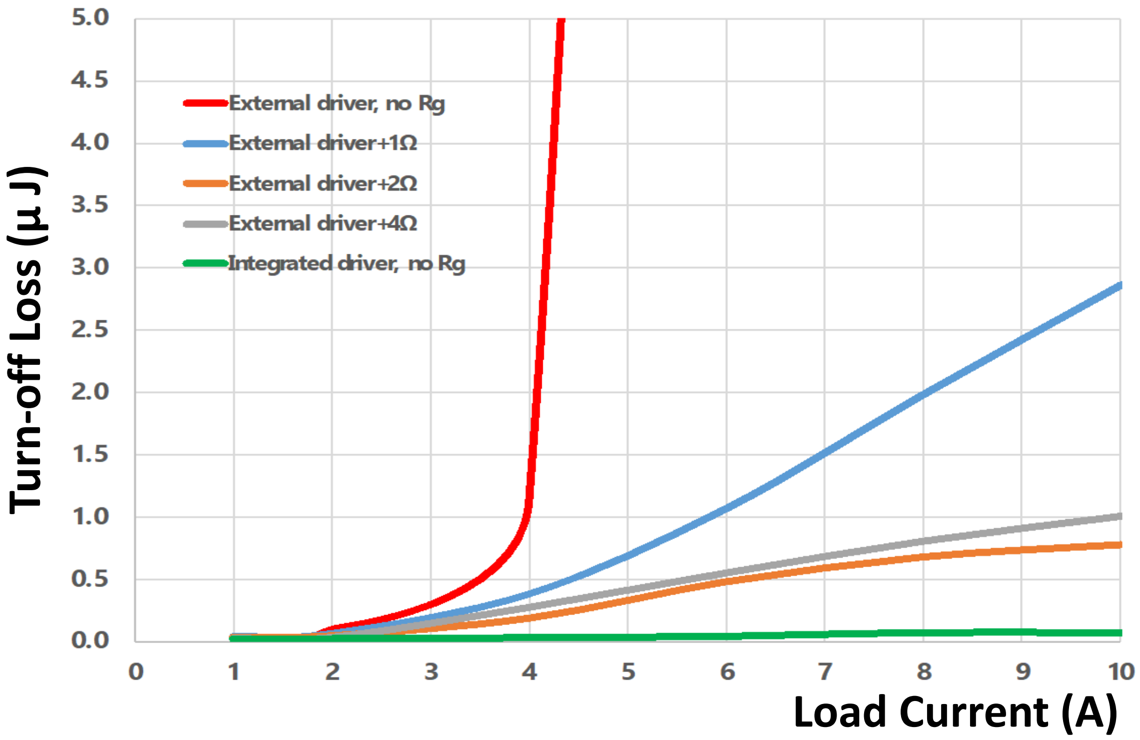
GaNFast™

External drivers

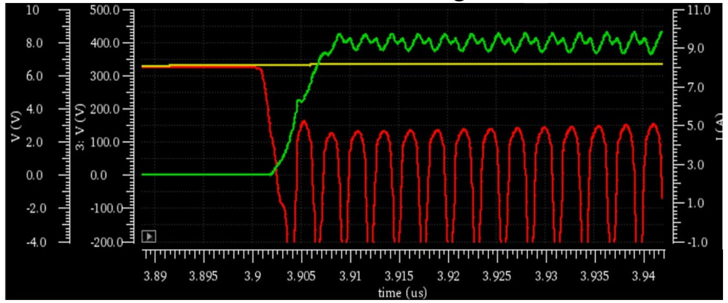
- Just 1-2 nH of gate loop inductance can cause unintended turn-on
- Gate resistors reduce spikes but create additional losses

Integrated GaN drivers (iDrive™)

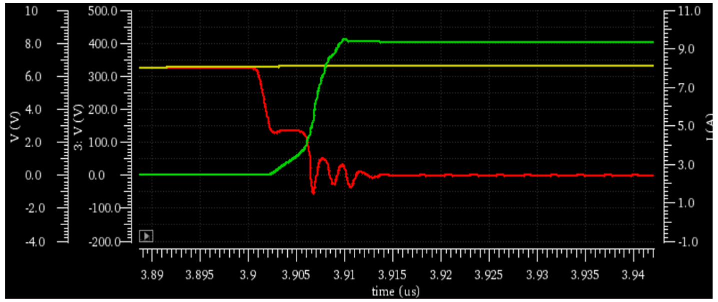
- Eliminate the problem
- Negligible turn-off losses
- Removes unintended turn-on due to high dV/dt



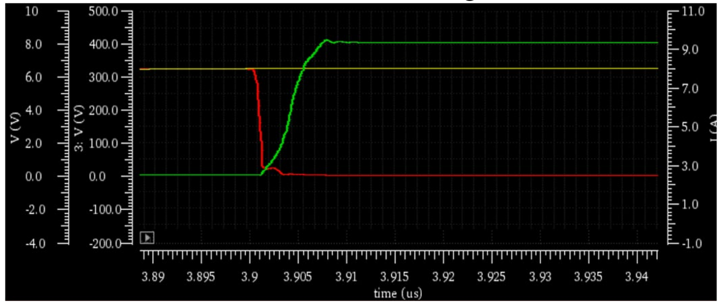
Discrete FET and drive, no R_G = out of control



Discrete FET and drive, with R_G = slow, lossy



Integrated FET and drive, no R_G = fast, efficient

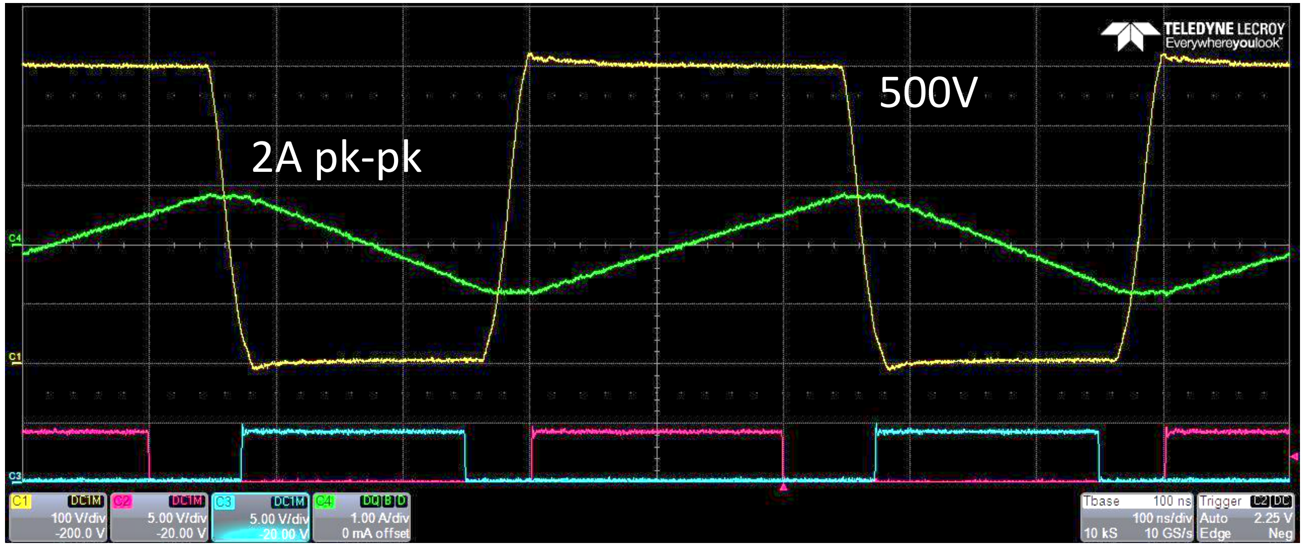


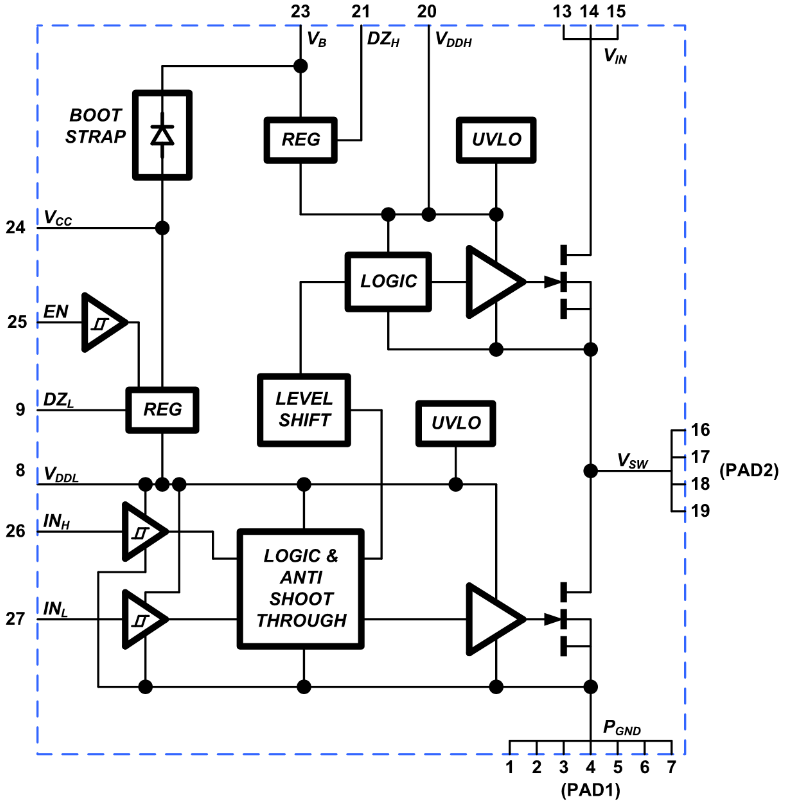
High Integration: Half-Bridge GaN Power IC

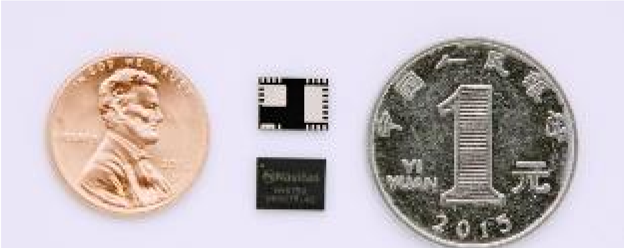
Monolithic integration at 650V

- 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…)

2 MHz soft-switching operation

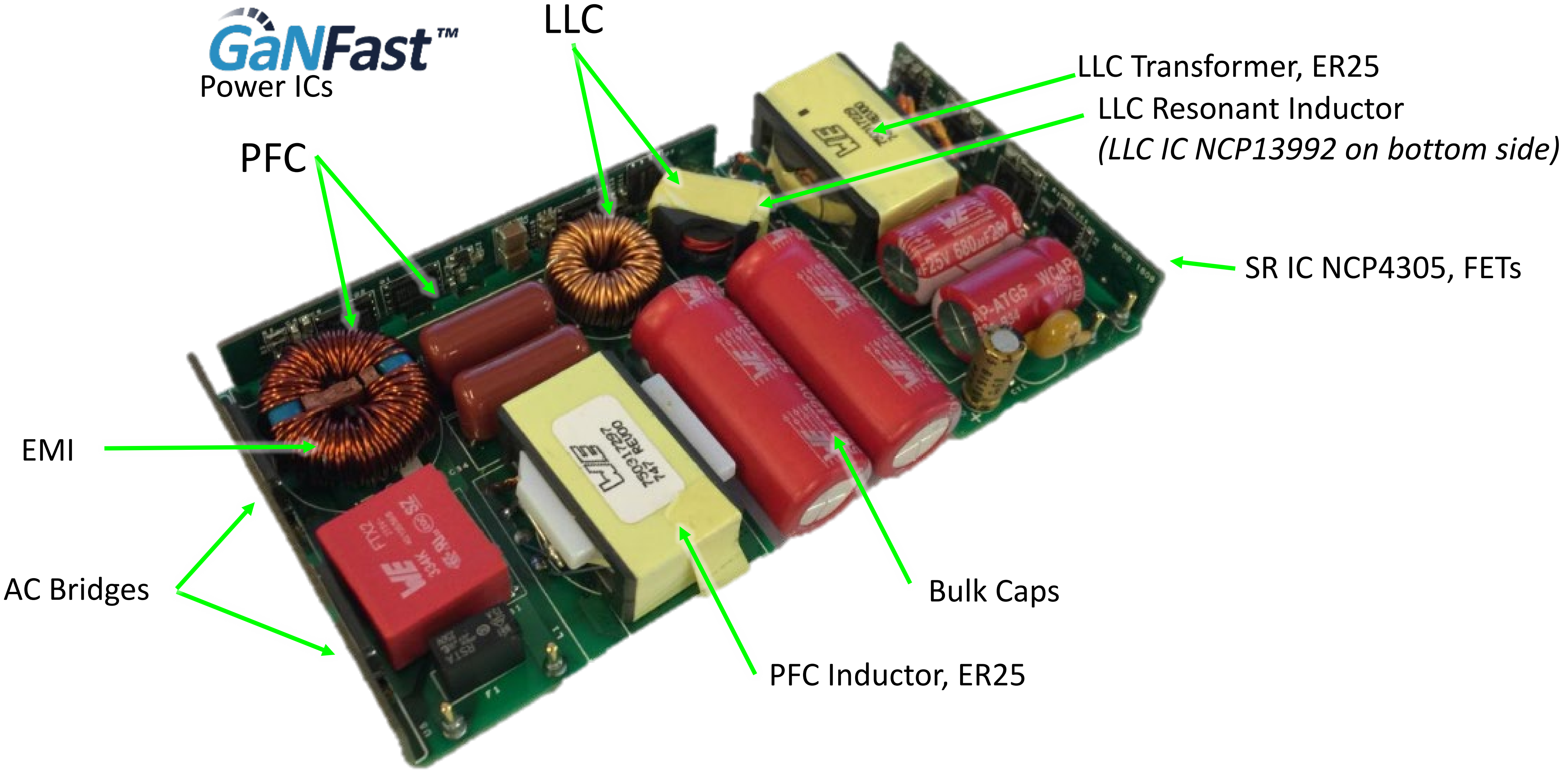




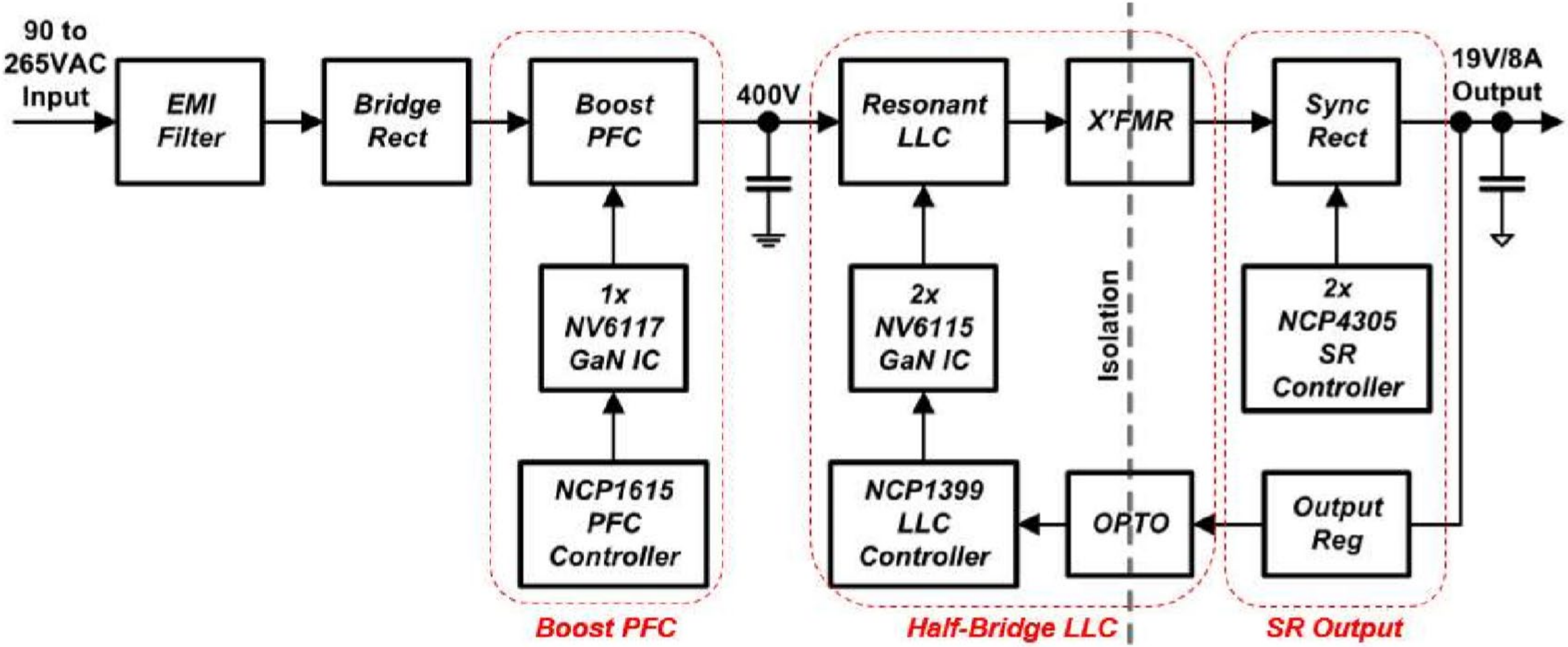


6 x 8 mm QFN

150W, 19V: PFC min 200 kHz, LLC 500 kHz



Block Diagram – 150W/19V



500kHz 150W/19V

GaNFast™

Ref.	Parameter		Value	Units
V_{IN}	Input Voltage		90-265 47-63	V_{AC} Hz
V_{OUT}	Output Voltage		19	V
I_{OUT}	Output Current (100% load)		8	A
I_{OUT_LIM}	Output Current Limitation (short-circuit or over-load)		9.5	
P_{OUT}	Output Power (max)		150	W
F_{SW}	Switching Frequency	PFC (120V, 100% load) PFC (220V, 100% load) LLC	200 100 500	kHz kHz kHz
η	Efficiency	230 V_{AC}, 150 W 115 V_{AC}, 150 W	94.9 93.8	% %
P_{STBY}	Standby Power Consumption	115 V_{AC}	< in progress	mW
		230 V_{AC}	< in progress	mW
PF	Power Factor		0.95	
	Board Dimensions		100 x 50 x 12.5	mm
	Board Volume (uncased)		62.5	cc
	Power Density (uncased)		39.3 2.4	W/in^3 W/cc

PFC Stage

Switching Waveforms: CrCM PFC Boost Stage

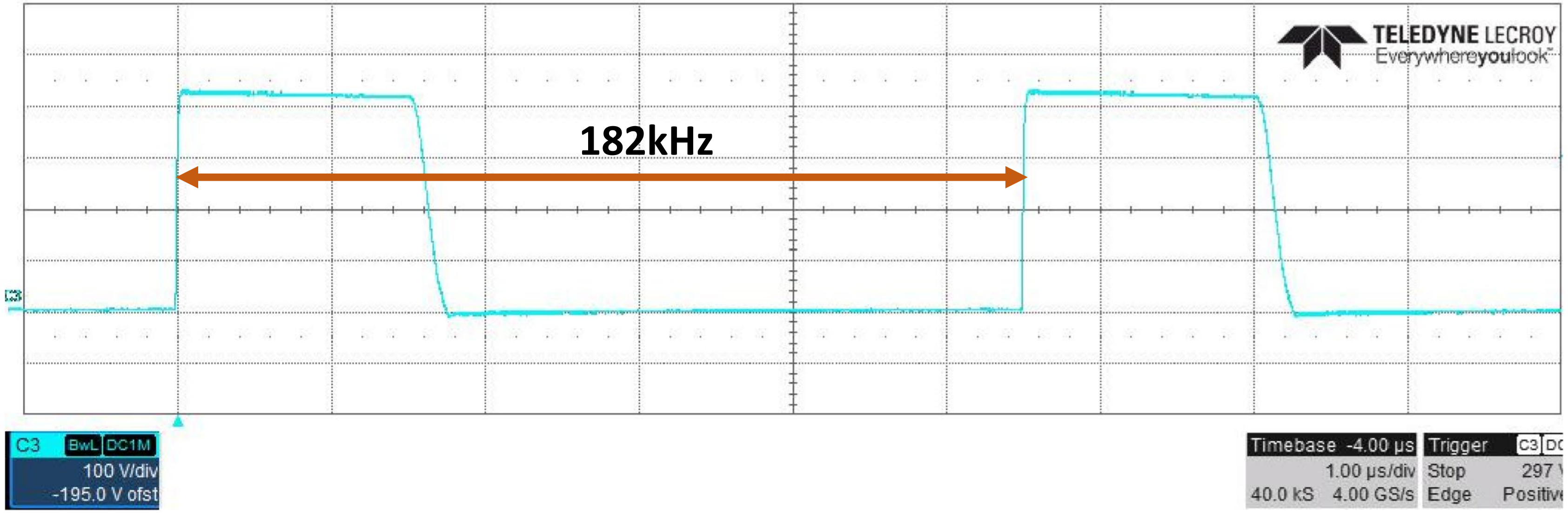
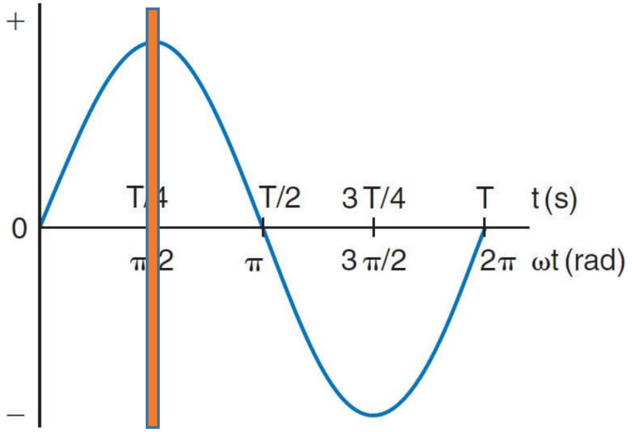


Fig. 8a: CrCM PFC Boost 90 V_{IN}, 400 V_{OUT}, 150 W, 182 kHz (peak of AC line)



LLC Stage

GaNFast™

Switching Waveforms: DC-DC (LLC) Stage

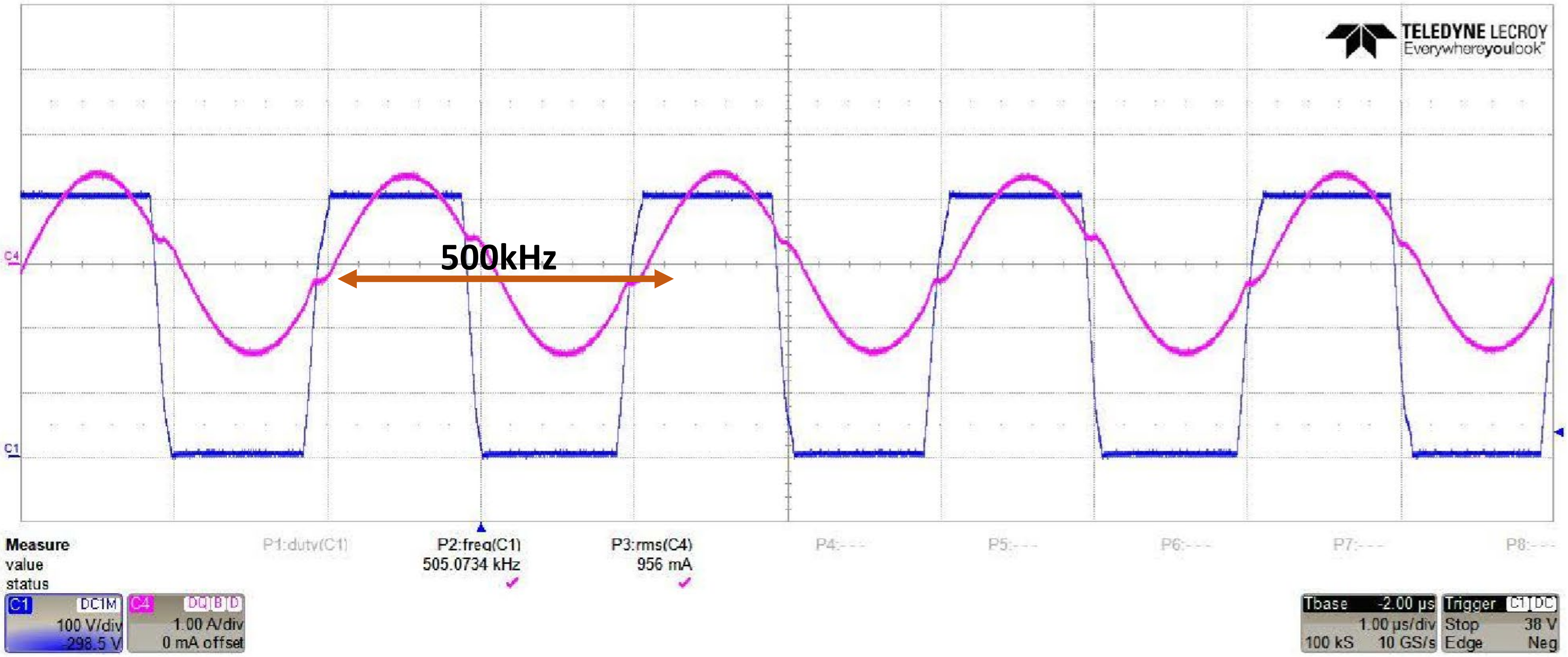
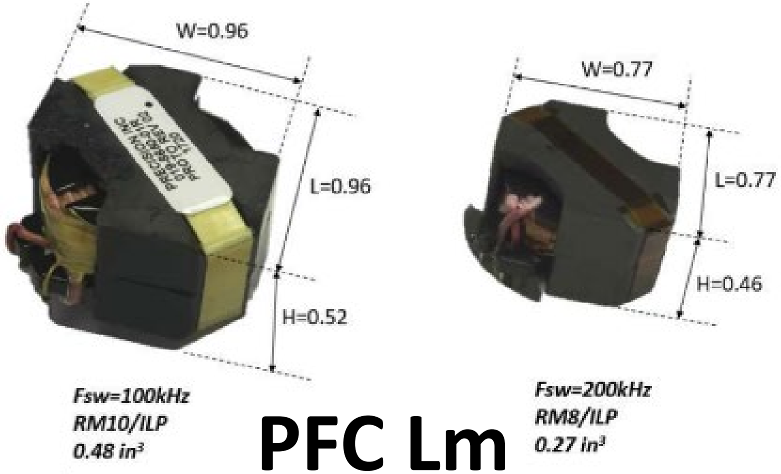
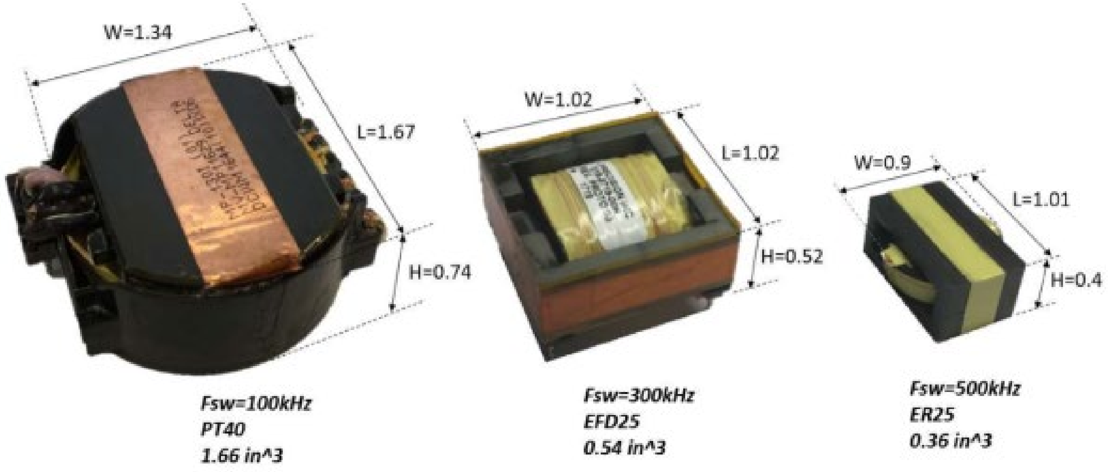


Fig. 9a: LLC V_{SW}, I_L, 19 V_{OUT}, 8 A

Reduced Magnetics Size @ 500kHz



PFC Lm



LLC Lm

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

Fsw↑→ Lm↓→ Size↓

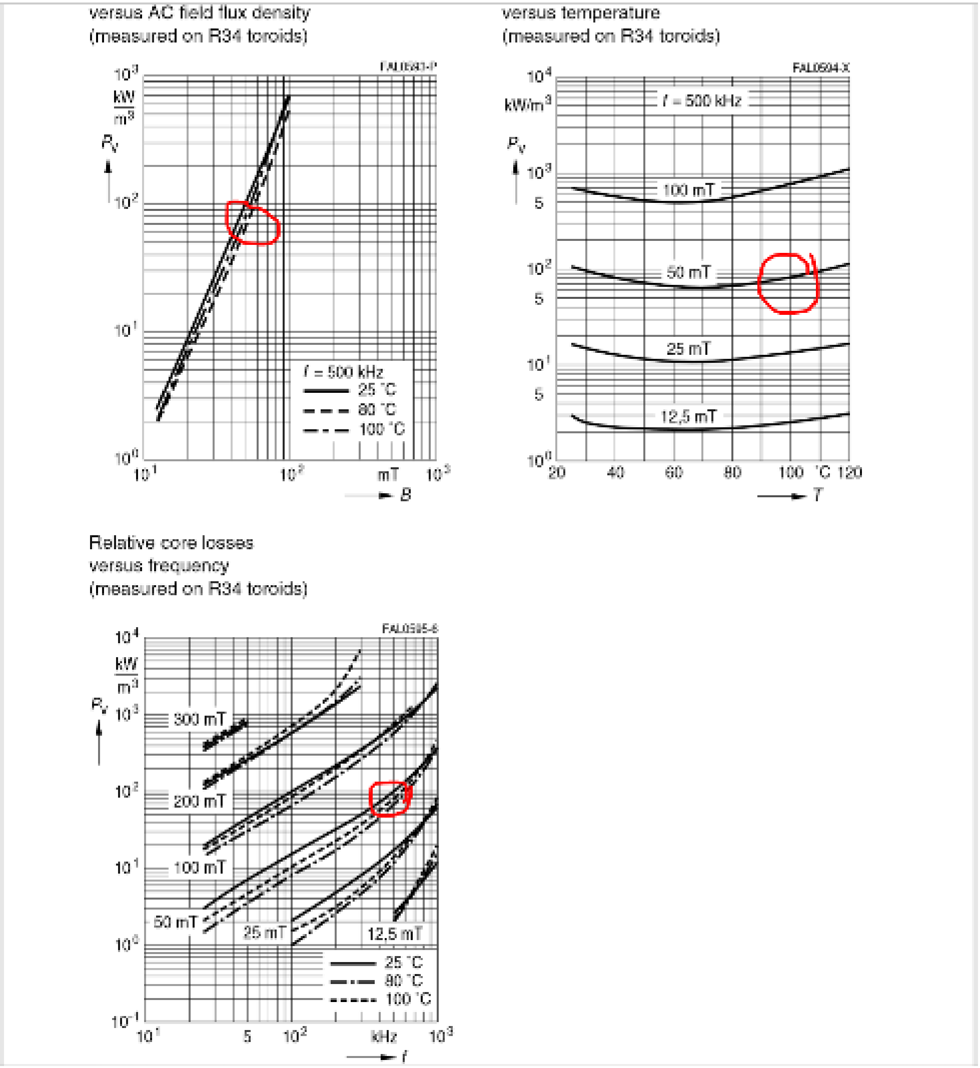
Fsw↑→ Lr, Cr↓→Lm↓→Size↓

GaN → Coss↓ ↗

TDK N49 Core Material (500kHz)

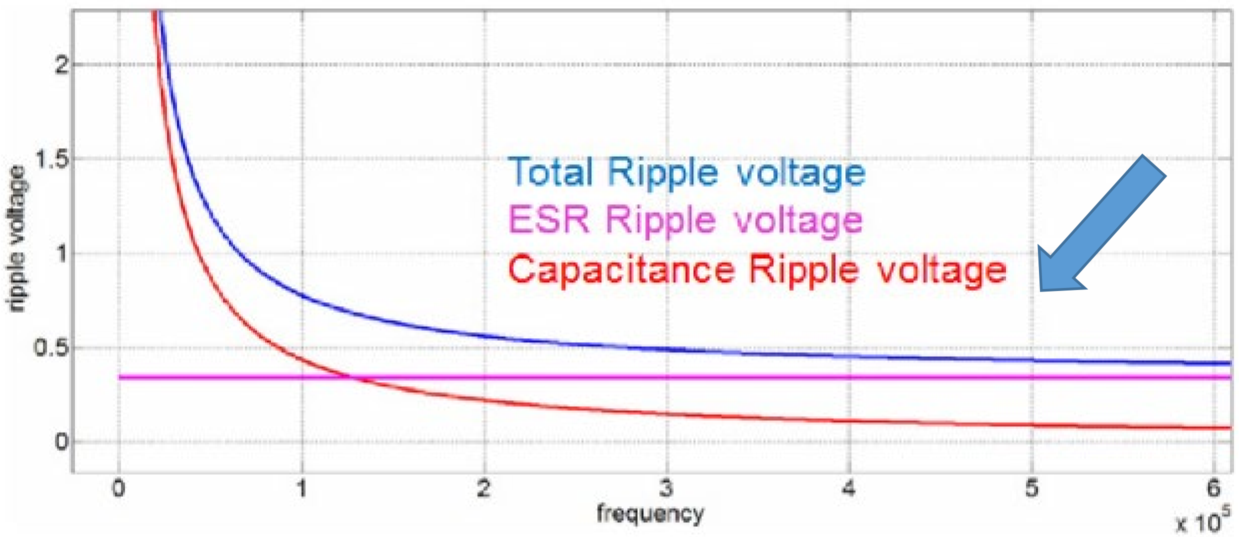
Material properties

	Symbol	Unit	
Preferred application			Power transformers
Material			N49
Base material			MnZn
	Symbol	Unit	
Initial permeability (T = 25 °C)	μ_i		1500 ±25%
Flux density (H = 1200 A/m, f = 10 kHz)	B_S (25 °C) B_S (100 °C)	mT mT	490 400
Coercive field strength (f = 10 kHz)	H_c (25 °C) H_c (100 °C)	A/m A/m	38 33
Optimum frequency range		kHz	300 … 1000
Hysteresis material constant	η_B	10^{-6}/mT	<0.4
Curie temperature	T_C	°C	>240
Mean value of α_F at 25 … 55 °C		10^{-6}/K	—
Density (typical values)		kg/m³	4750
Relative core losses (typical values)	P_V		
25 kHz, 200 mT, 100 °C		kW/m³	—
100 kHz, 200 mT, 100 °C		kW/m³	—
300 kHz, 100 mT, 100 °C		kW/m³	330
500 kHz, 50 mT, 100 °C		kW/m³	80
1 MHz, 50 mT, 100 °C		kW/m³	475
Resistivity	ρ	Ωm	17
Core shapes			RM, EFD, ELP, Toroid, EQ, ER



Reduced Output Cap @ 500kHz

Ripple voltage vs Switching Frequency



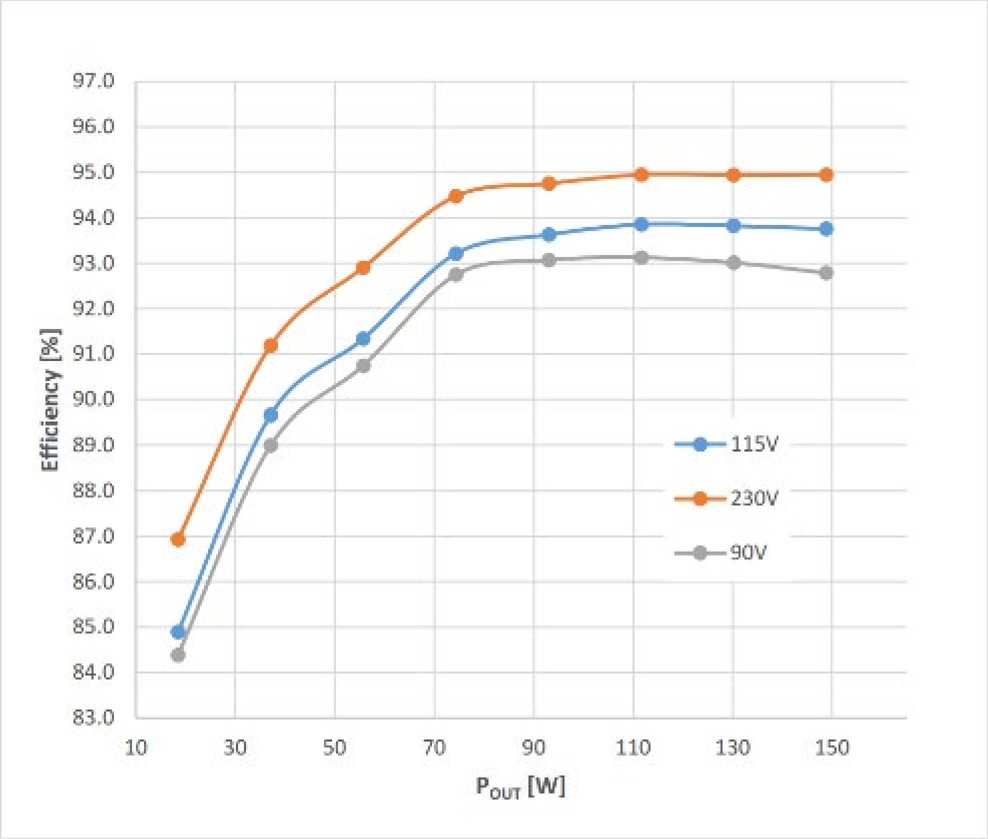
- Output ripple = ESR ripple (Io, ESR) + Cap ripple (Co, Io, fsw dependent)
- ESR is dominant factor for output ripple at high fsw
- Small output cap is used for high fsw

"Design Considerations of Resonant Network and Transformer Magnetics for High Frequency LLC Resonant Converter", J Electr Eng Technol. 2016; 11(2): 383-392

93% Efficiency @ 90VAC, Full Load

GaNFast™

Efficiency vs Load & AC line voltage

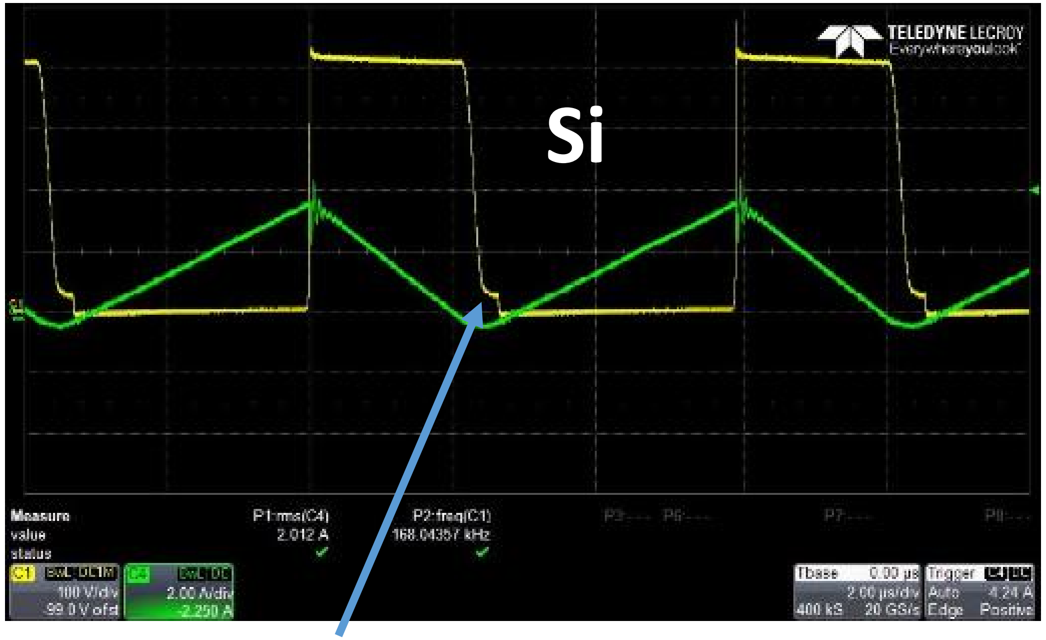


No heatsink, no airflow, room ambient

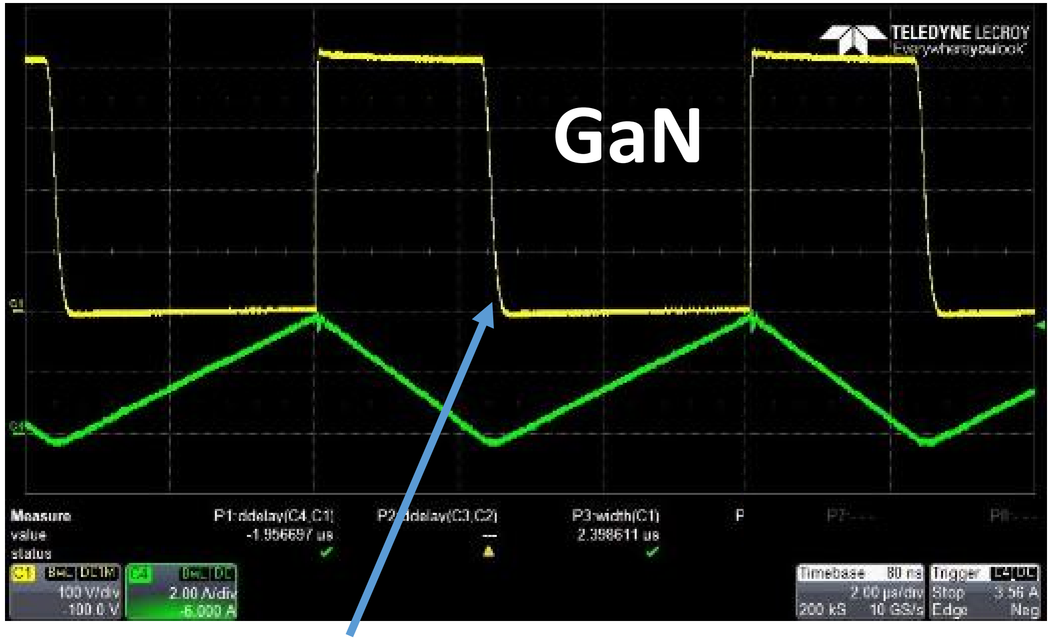
Power Loss Estimate by Component

	90V	90V	115V	115V	230V	230V
Summary	***Ploss***	***%***	***Ploss***	***%***	***Ploss***	***%***
Diode Bridge	3.6	31.0	2.8	28.5	1.4	20.1
EMI Filter	0.5	4.3	0.3	3.1	0.1	1.1
Boost Switch	0.9	8.3	0.6	6.0	0.1	1.0
Boost Diode	1.8	15.5	1.4	14.3	0.7	10.0
Boost Inductor (1x)	0.75	6.5	0.8	7.7	0.8	10.8
Half Bridge FETs	0.2	1.5	0.2	1.7	0.2	2.4
LLC Transformer (1x)	1.2	10.5	1.2	12.4	1.2	17.5
Resonant Inductor	0.7	6.1	0.7	7.2	0.7	10.1
SR FETs (2x)	1.1	9.6	1.1	11.3	1.1	15.9
SR gate charge (2x)	0.2	1.7	0.2	2.1	0.2	2.9
Output Caps	0.4	3.3	0.4	3.8	0.4	5.4
Boost Sense Resistors	0.2	1.7	0.2	2.0	0.2	2.8
	90V		**115V**		**220V**	
Total Ploss	11.47	W	9.75	W	6.93	W
Efficiency	93.3	%	94.3	%	95.8	%

GaN Increases Efficiency



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



120V_{AC}, GaN clean ZVS waveforms (~200kHz)

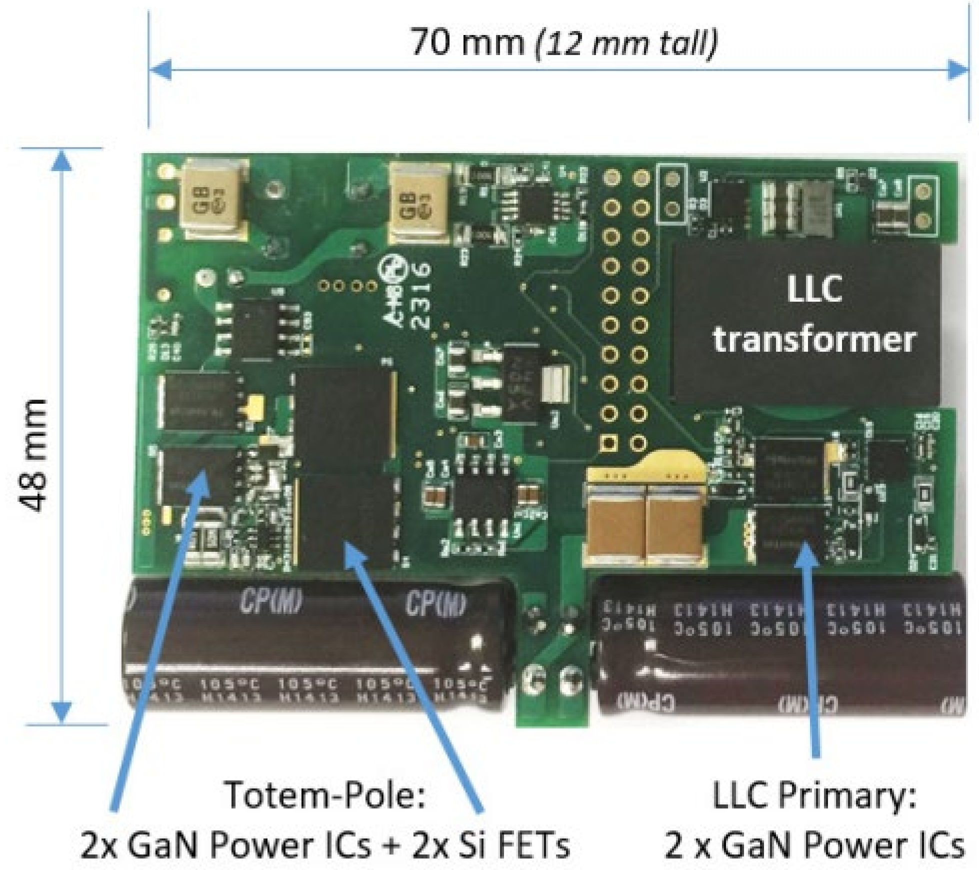
- Si C_{OSS} is 50x-100x worse than GaN at V_{DS} < 30V
- High loss due to large stored charge while hard-switching

- Turn-off losses low due to integrated drive
- Near loss-less ZVS turn-on transition
- Minimize deadtime for low reverse conduction loss
- No voltage spikes / overshoot

93% Efficiency @ 90VAC, Full Load

ITEM	Existing Silicon 140W Design	GaNFast 150W Design (NEV031)
Picture		
Spec	140W (19V / 7.37A)	150W(19V/7.9A)
Power Device	Si	Navitas GaNFast IC
PCB Size	60 x 149.5 x 31	50 x 100 x 12.5
Case Size	68 x 156 x 39 (414cc)	126cc (estimated)
Efficiency	89%	93%
PWM frequency	PFC= 40kHz, LLC= 85kHz	PFC= 200kHz, LLC = 500kHz

Next Generation 1MHz 150W NB Adaptor



150 W, 1 MHz Design

Topology: Totem-Pole PFC + LLC at 1 MHz
Power Device: GaNFast power ICs
Efficiency: >95% peak efficiency at full load

Let's go GaNFast™