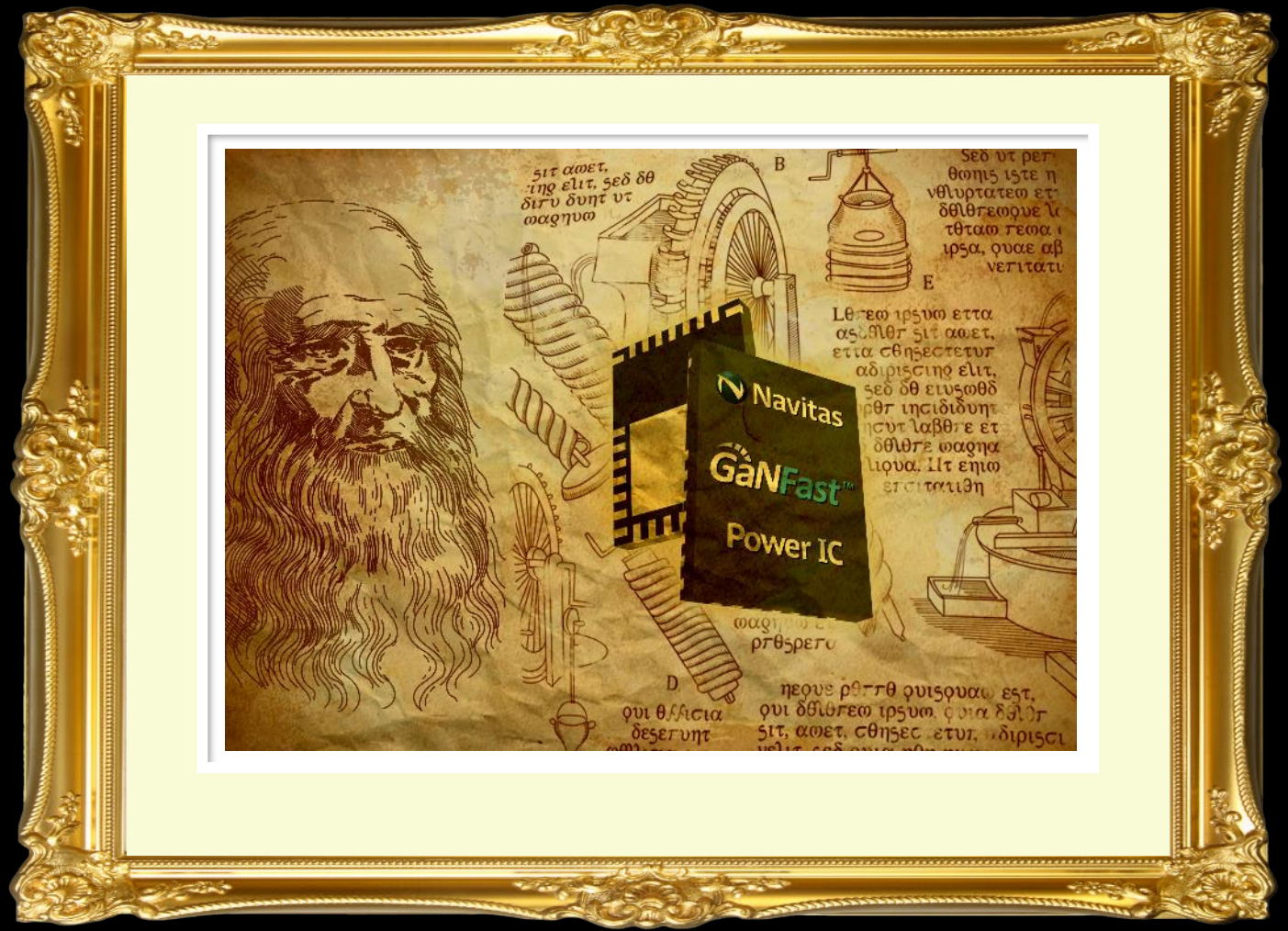
electronica China
慕尼黑上海电子展

Navitas



The Future of Power: High-Frequency Systems Enabled by GaN

April 2021



Dong Lin, Sr. Director, Applications, dong.lin@navitassemi.com
Stephen Oliver, VP Corp. Mktg. & IR, stephen.oliver@navitassemi.com



World's first and only GaN power IC company
Over 18Mu shipped and zero failures

- **Energy** to revolutionize power electronics
- **Energy** to accelerate change
- **Energy** to make a sustainable difference for our world



GaN is a high-speed semiconductor that switches up to 100x faster than Si and enables more efficient, smaller, lighter, cooler and lower cost systems; delivering 30-40% in energy savings.



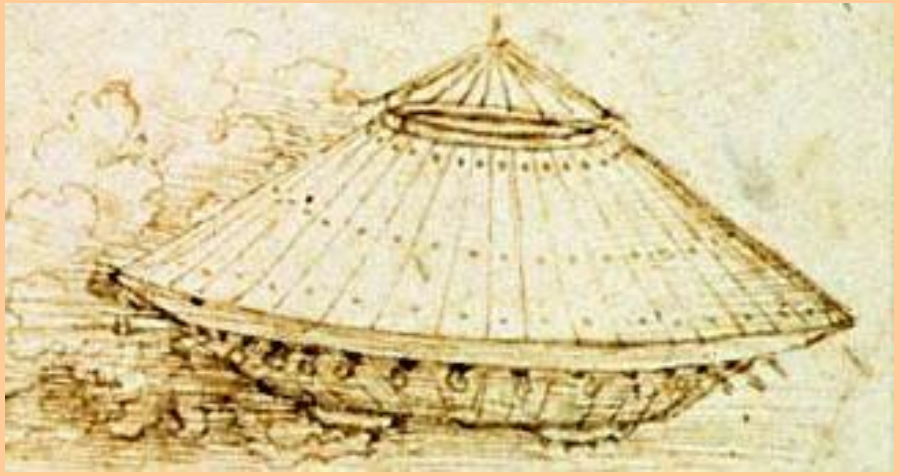
Leonardo da Vinci
1452-1519

Frustrated Genius:

Strong ideas…







…weak tools







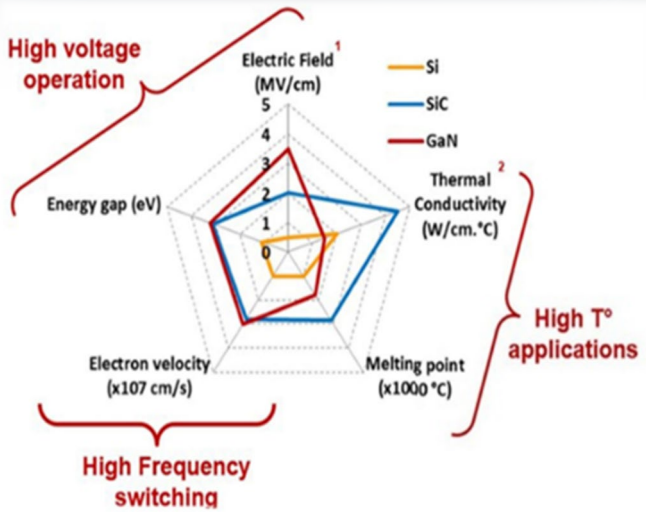
The Enabling Force



Power GaN Technologies

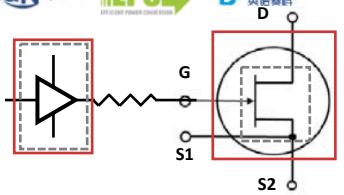


High Performance Semiconductor



eMode FET
(normally off)

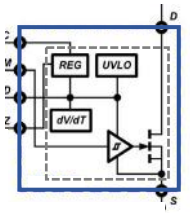
Panasonic infineon GaN Systems EPC Innoscience



GaN Discrete
Complex gate drive

Integration

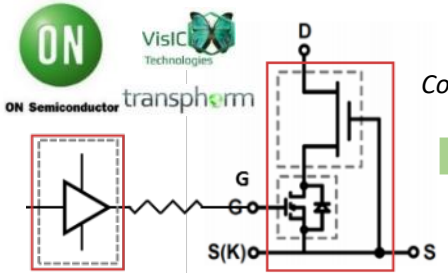
Navitas



GaN Power IC
GaN Power (FET),
Drive, Control, Protection
120+ Patents

dMode FET
(normally on)

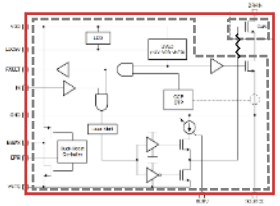
ON Semiconductor VisIC Technologies transphorm



Extra Si FET in
'cascode' configuration

Co-pack

Texas Instruments power integrations

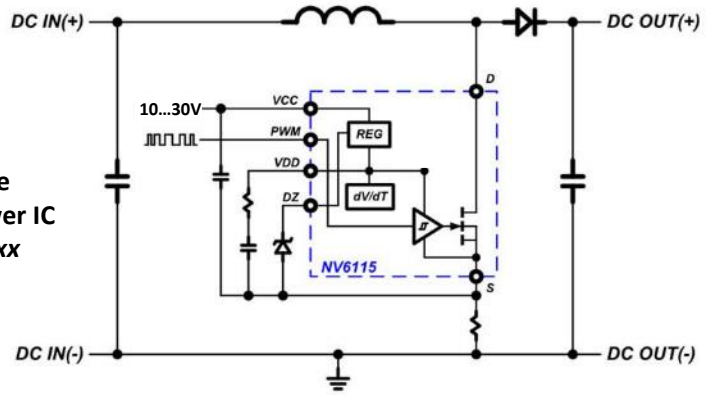


Si controller/driver
+ Si FET cascode
+ GaN dMode FET

GaNFast™ Power ICs: Single, Half-Bridge

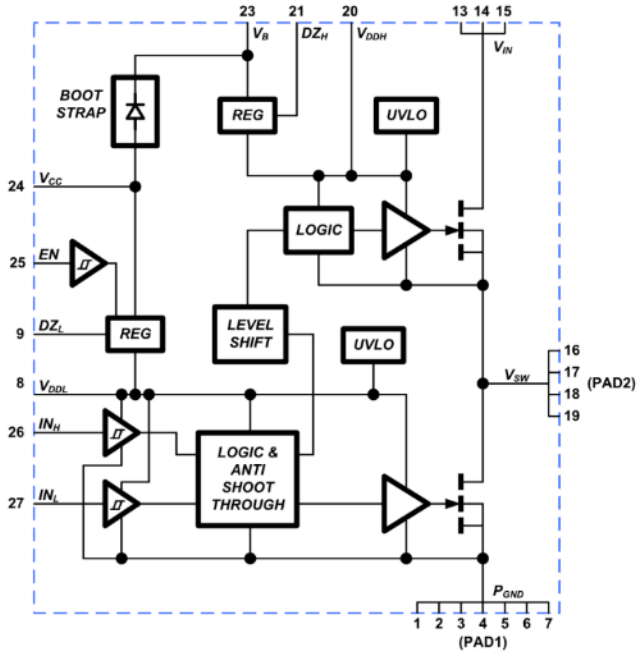
Navitas

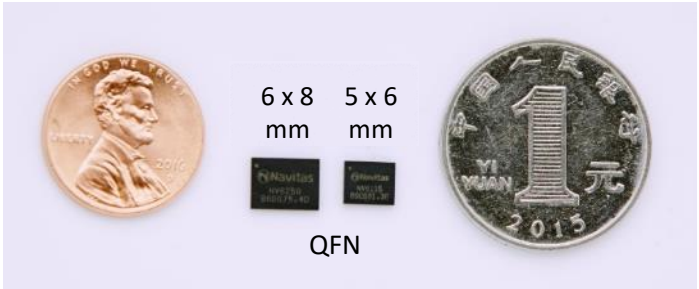
Single
GaN Power IC
NV61xx

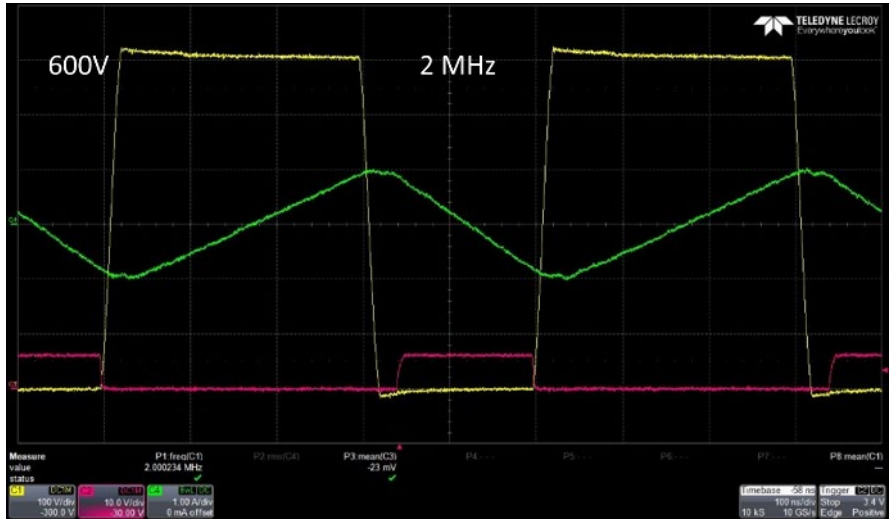


- Monolithic integration, 650 V / 800 V, 2 MHz
  - GaN Power FET(s) + Driver + Control + Protection
  - Features: on-board regulators, hysteretic input, level-shift, bootstrap, dV/dt control, UVLO, shoot-through & ESD protection
- "Digital In, Power Out"

Half-Bridge
GaN Power IC
NV62xx







2MHz, 0-600V Half-Bridge

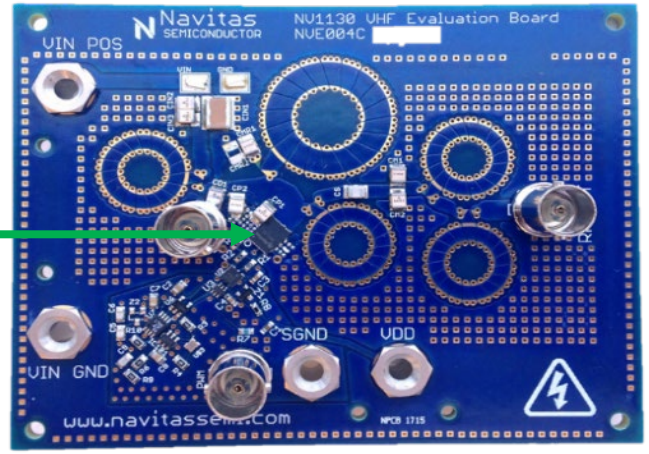
2x Energy Savings at 27-40 MHz

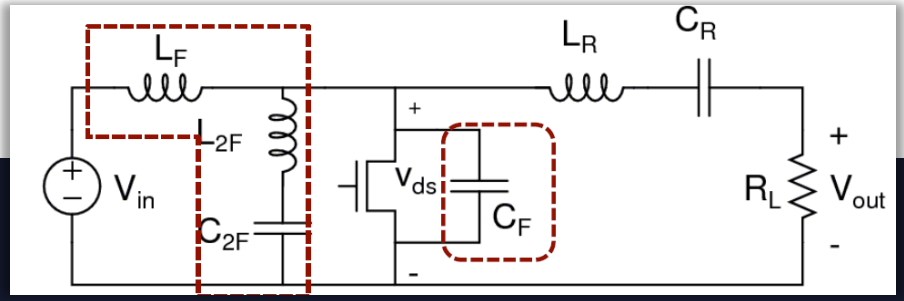
Navitas
Stanford University

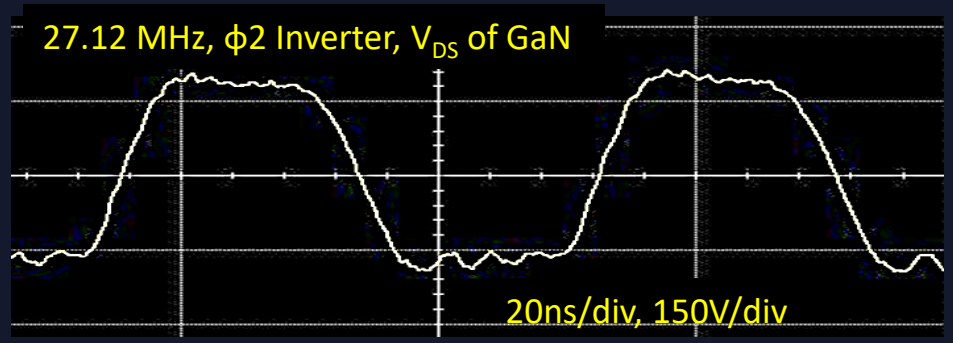
Class Phi-2 DC/AC converter

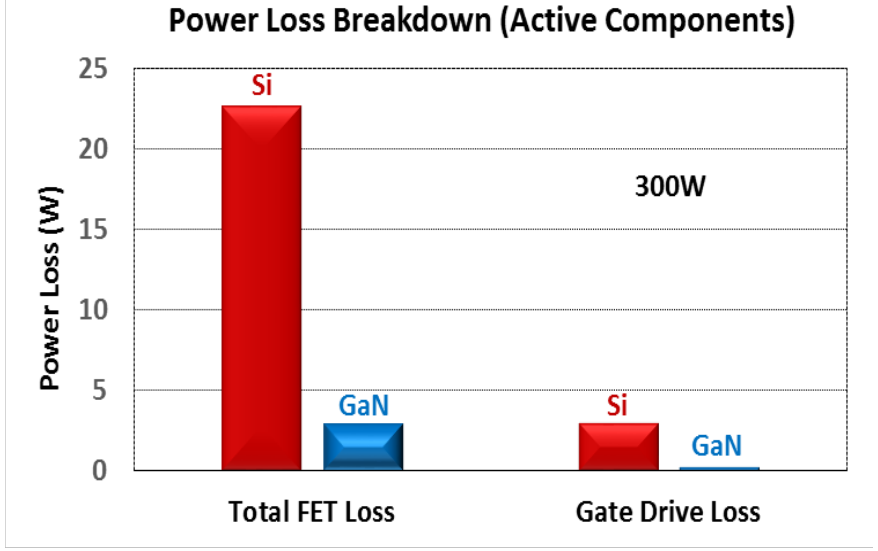
- 50% less loss than RF Si
- 16x smaller package
- Air-core inductors
- Minimal FET loss
- Negligible gate drive loss

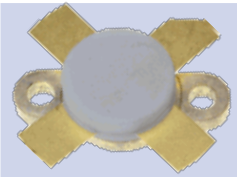
GaNFast™









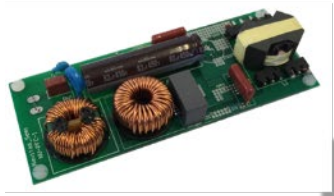
Technology	V	Pack (mm)		F_{SW} (MHz)	Eff. (%)	Power (W)
RF Si (ARF521) Microsemi POWER PRODUCTS GROUP	500	M174 22x22		27.12	91%	150
eMode GaN Navitas	650	QFN 5x6		27.12	96%	150
				40.00	93%	115

Hot Silicon, Cool GaN

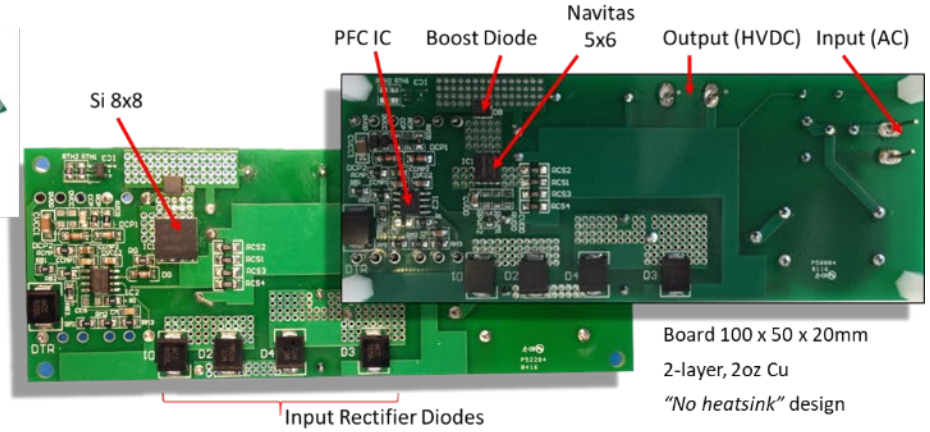
	Pack	$R_{DS(ON)}$ mΩ	Q_G nC	C_{OSS}(er) pF	C_{OSS}(tr) pF	R*Q_G mΩ.nC	R*C_{OSS}(tr) mΩ.pF	R*C_{OSS}(er) mΩ.pF
Navitas GaN	5x6	160	2.5	30	50	400	8,000	4,800
IPL65R199CP	8x8	180	32	69	180	5,760	32,400	12,400
IPL60R130C7	8x8	115	35	53	579	4,025	66,600	6,100
GaN Benefits	**>50%**	**n/a**	**>10x**	**>2x**	**>10x**	**>10x**	**>7x**	**>2.5x**

Navitas

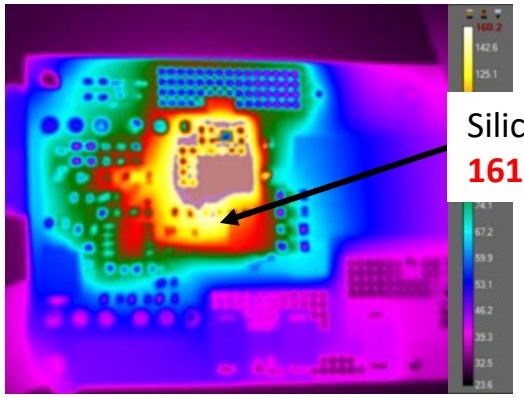
CrCM PFC test board



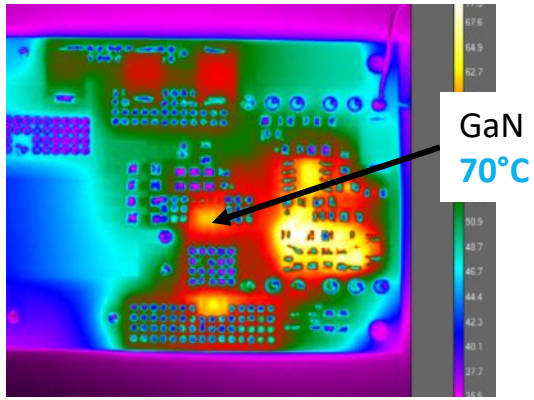
AC to 400 V_{DC}, 150 W
120V = 167-230 kHz
220V = 230-500 kHz
265V = 1 MHz
(control IC limit)



Board 100 x 50 x 20mm
2-layer, 2oz Cu
"No heatsink" design



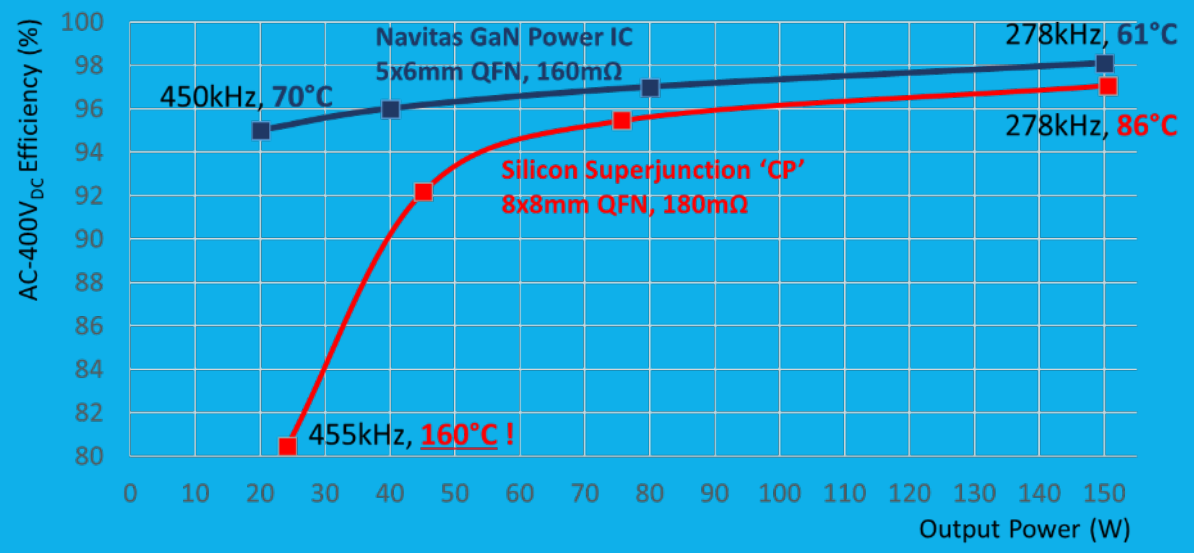
220V_{AC}, 455 kHz, 25W



220V_{AC}, 450 kHz, 20W

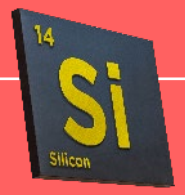
GaN is the cool winner at high frequency

(50x-100x lower C_{OSS} than Si @ V_{DS} < 30V, reduces switching loss by 3x)



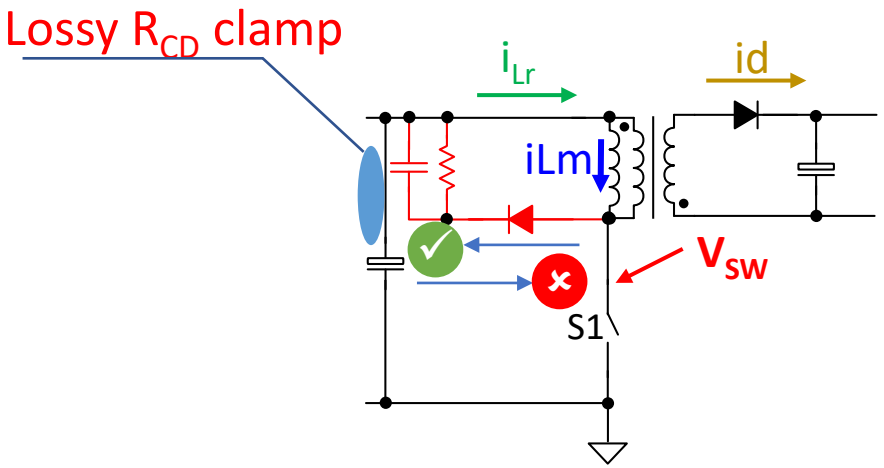
The evolution of Flyback Frequency

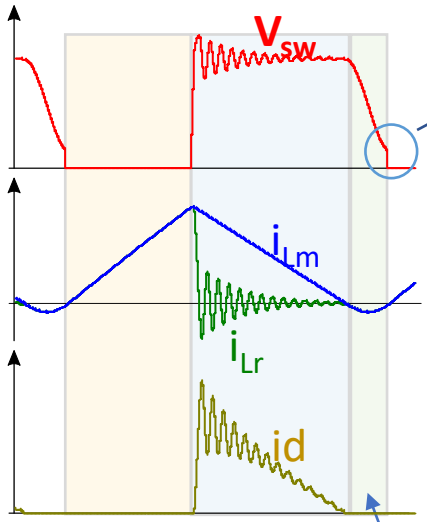
	1970	1988	1996	2016	2018	2020
Topology	Flyback	Resonant Flyback	Active-Clamp Flyback (ACF)			Pulsed ACF (P-ACF)
	T. Godawski, Zenith	Prof. Fred Lee, VPEC	R. Watson, VPEC	Dr. X. Huang, CPES	GaNSemi	Powerland
Technology / Frequency						
University		1 MHz	100KHz	1 MHz	1 MHz+	1 MHz+
Industry	10 kHz	30-50 kHz	50 kHz	100 kHz	500 kHz	500 kHz





QR Flyback Losses



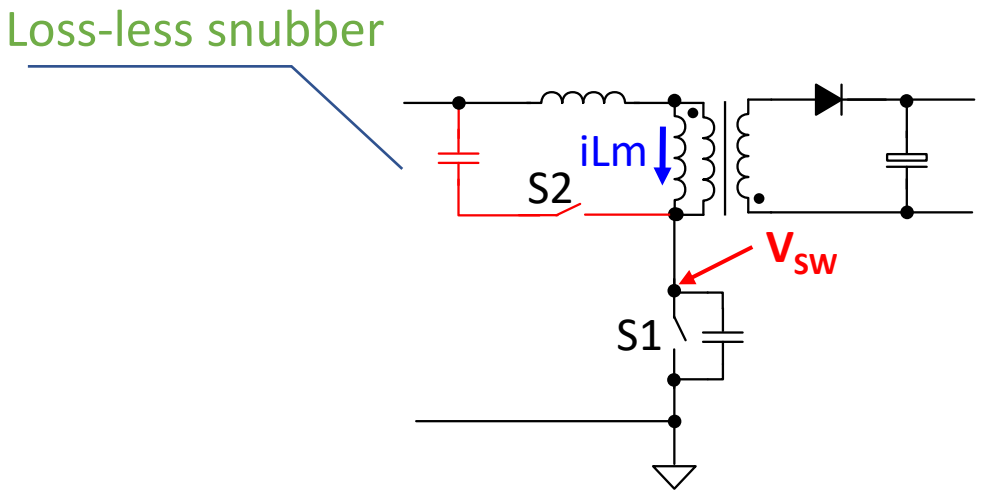


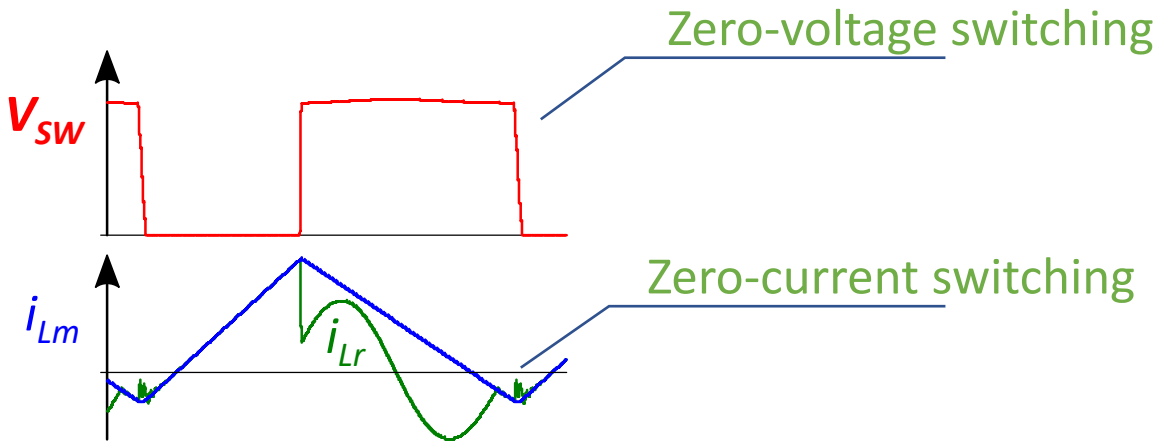
Lossy hard switching

S1 ON S1 OFF Resonant for valley switching

- Quasi-Resonant (QR) Flyback
  - Frequency-dependent ***losses***
    - Leakage inductance
    - Snubber/clamp
    - Partial hard-switching at high line
    - Slow turn-on to minimize EMI
  - Difficult to improve efficiency at high frequency

ACF Enables ZVS and High Frequency





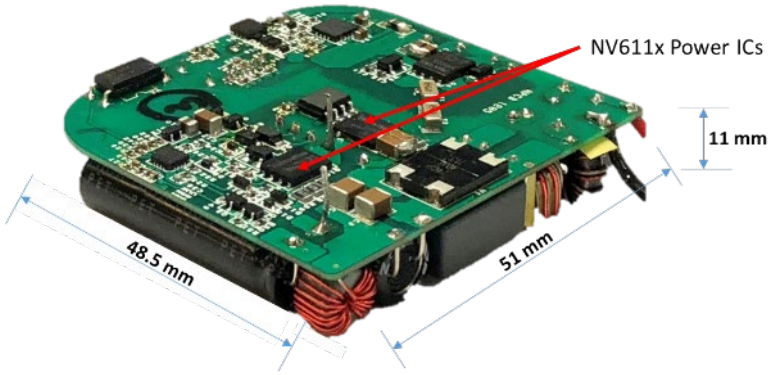
- Active-Clamp Flyback (ACF)
  - No snubber losses, all leakage energy is recovered
  - ZVS soft switching over entire operation range
  - ZCS soft turn-off for output rectifier
  - Clean waveforms reduce EMI
  - Enable small adapter design with high-frequency switching

Mass Production: ACF

Navitas

2018

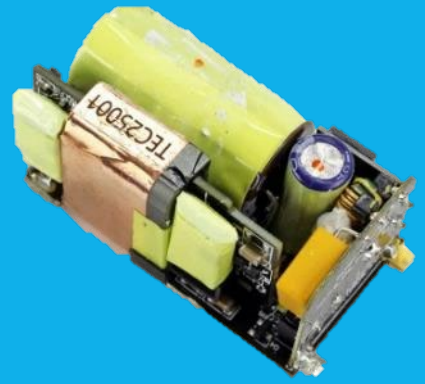




World's Thinnest 45W
45W, 41 cc, 1.1 W/cc

2019

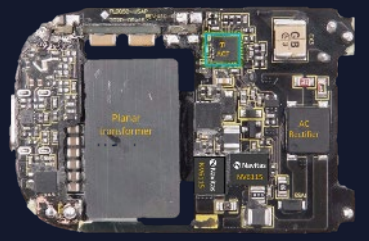




World's Smallest 65W
65W, 53 cc, 1.2 W/cc

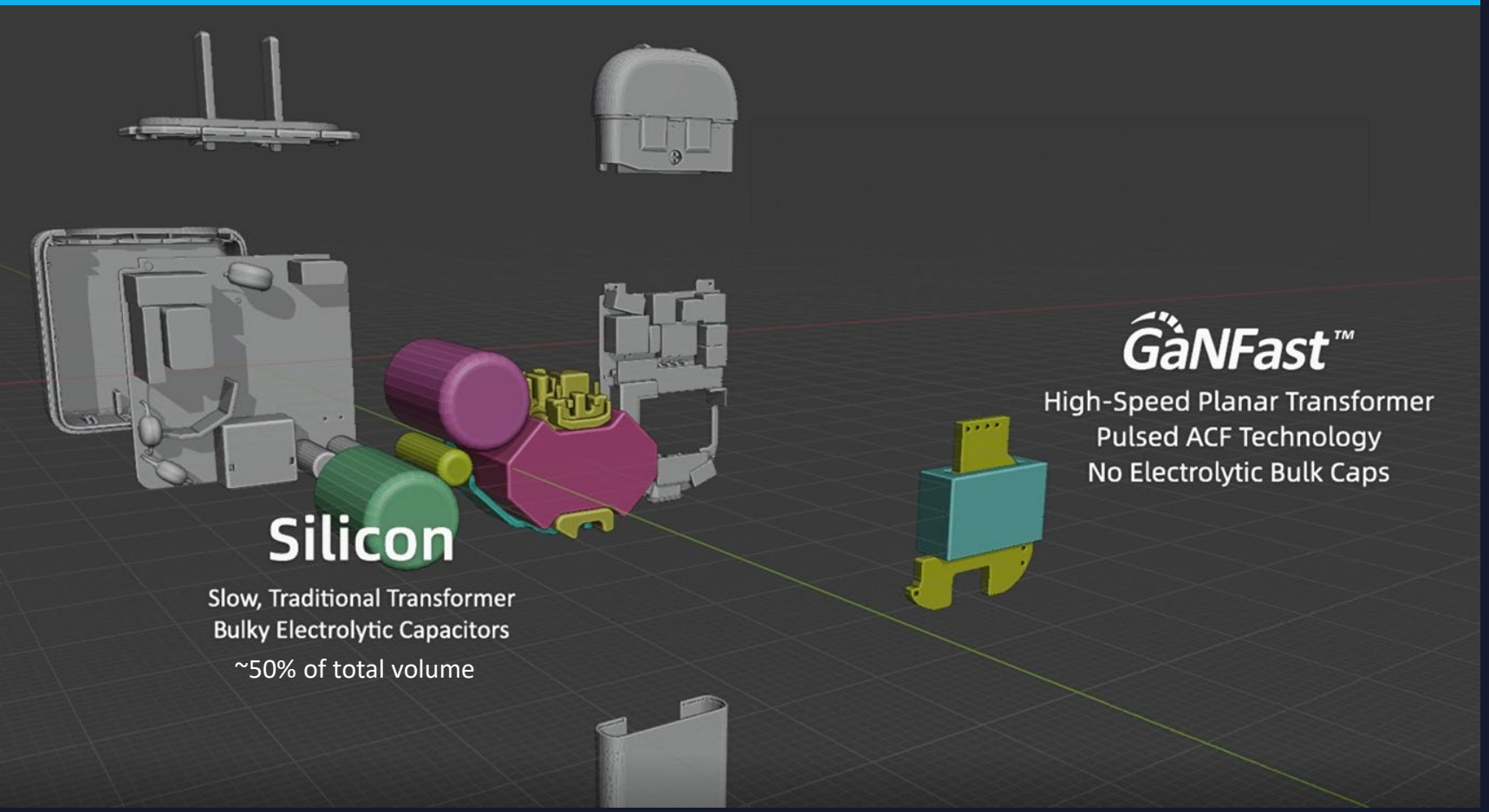
2020





'Pulsed-ACF'
World's Thinnest 50W
50W, 34 cc, 1.5 W/cc

No Cap, Thin Transformer



- 60% thinner/smaller transformer
- 80% smaller output caps
- No electrolytic bulk cap
- Easier EMI
  - 10x increased frequency
  - Planar shield layer
  - More consistent parameters

Pulsed-ACF

- Topology:
  - Rectified AC 100Hz feeds directly into high-frequency ACF
  - ACF maintains 100 Hz smooth pulse output to charge the phone's battery, even if input voltage range is wide
  - Stability, and accurate current and voltage monitor critical
  - Eliminates electrolytic bulk capacitor
  - OPPO-proprietary 'direct-charge' means during each pulse gap, polarization effect in the phone battery is eliminated, reducing wear-out mechanisms and extending battery life

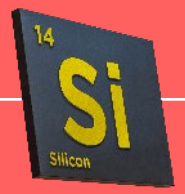


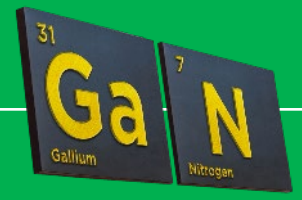


- Powertrain:
  - 2x Navitas NV6115 (170mOhm GaNFast power ICs)
  - Low RDS(ON to minimize 'on-state' losses
  - Minimal COSS for best 'switching' performance
- Control:
  - TI UCC28782 ACF + On Semi NCP51530
  - High-speed, soft-switching (~500 kHz)

The evolution of Front-End Frequency

	1977	2008	2010	2016	2018	2021
Topology	AC Bridge + CCM Boost	Bridge-less Boost (CCM)	Bridge-less Totem-Pole (CCM)	Bridge-less Totem-Pole (CrCM)		
		Huber, Jan, Jovanovic, Delta	B. Su, Zhejiang University	Dr. X. Huang, CPES	A. Huang, UT Austin (3.2kW) W. Du, Navitas (300W)	On Semiconductor Navitas
Technology / Frequency						
University		110 kHz	100 kHz	0.6-2 MHz	0.5-1 MHz	1 MHz+
Industry	(passive)	50 kHz	50 kHz		50-100 kHz / CCM	400 kHz (ASIC)



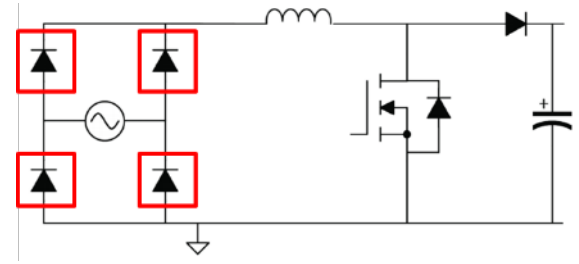


Rectifier on Fire!

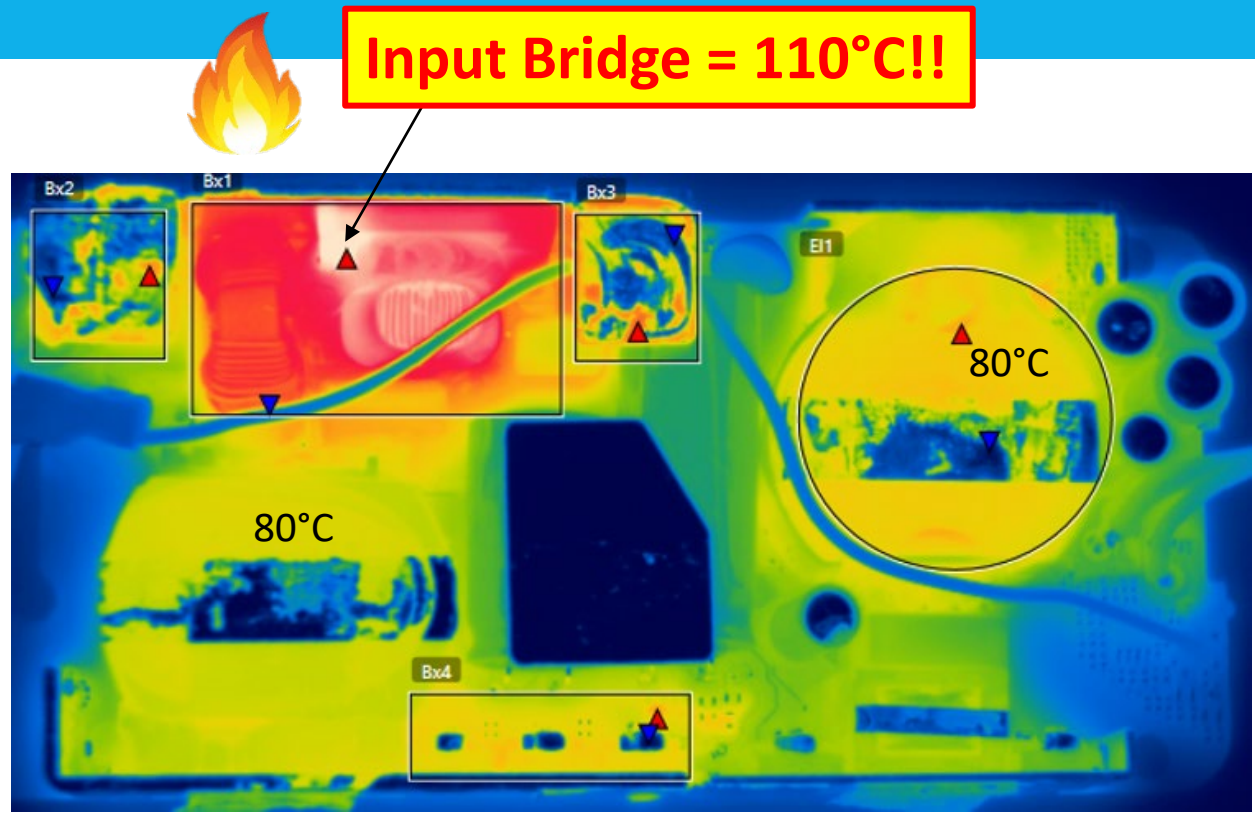
Navitas

Output:	20 V, 14 A, 280 W
Size:	179 x 85 x 36 mm = 542 cc (cased)
P. Density:	0.52 W/cc
Efficiency:	93.3% (@ 90 V_{AC}, 280 W)





Traditional AC-rectifier + Boost PFC



$$P_{LOSS\text{-}BRIDGE} = 2 \times V_F \times I_{RMS}$$

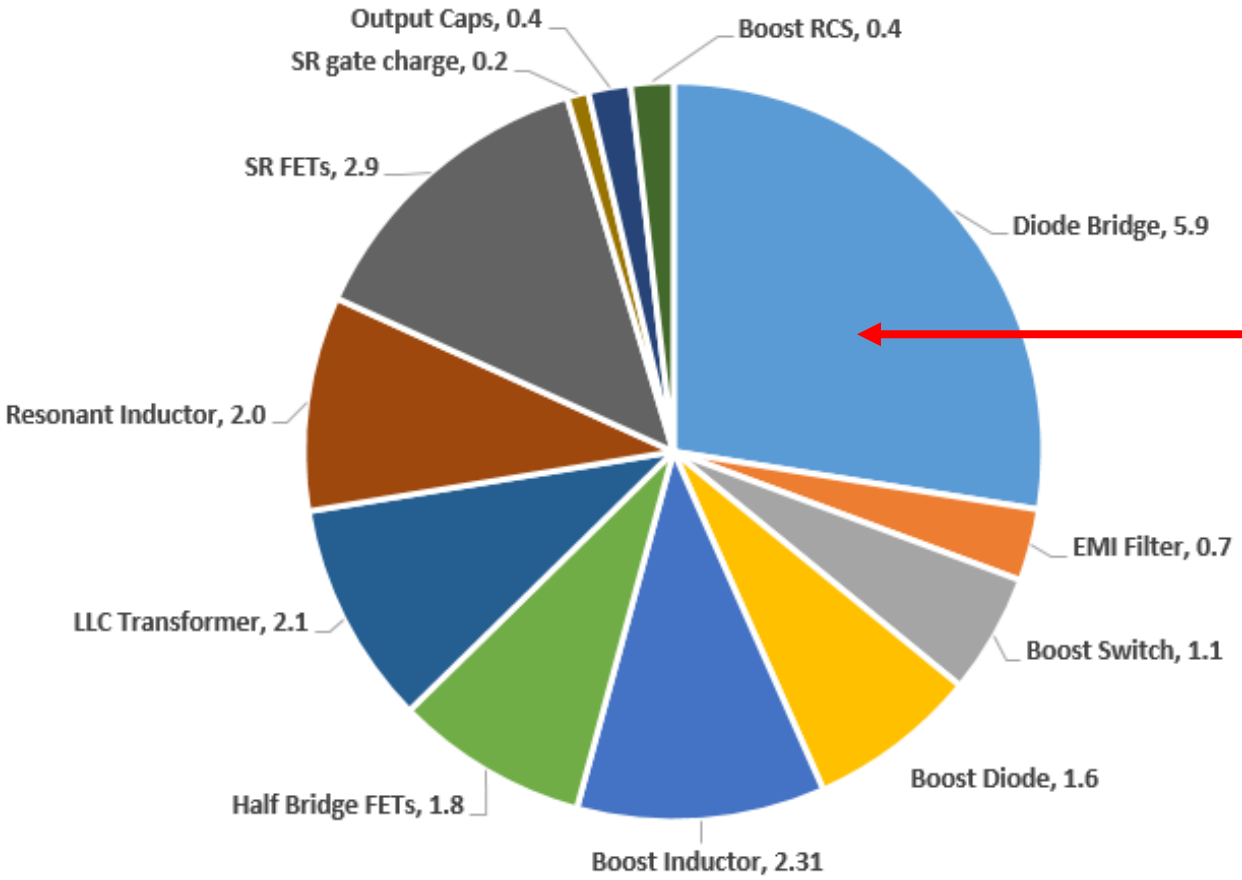
$$P_{LOSS\text{-}BRIDGE}\ (300W, 90V_{AC}) = 6W$$

2x Diodes Always Conducting!

(PCB in free air, T_{AMB} = 25°C, V_{IN}=90 V_{AC}, 100% load)

Navitas Company Confidential, Under NDA

Remove The Bridge!

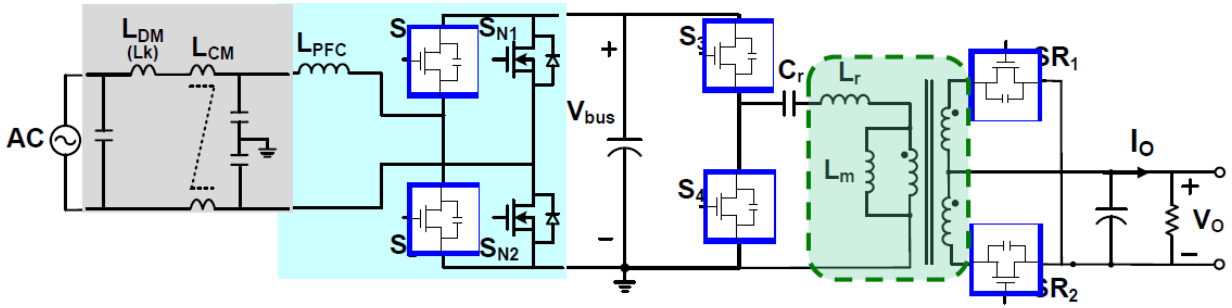


$P_{LOSS\text{-}BRIDGE}$ > 25% of P_{TOTAL}

(@ 90 V_{AC} , 300 W)

2016: 1MHz CrCM Totem-Pole

Key Features of Proposed two-stage Adapter



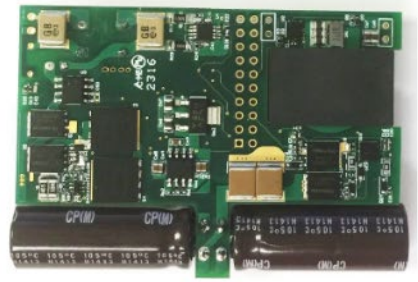
1. MHz CRM Totem-pole + MHz LLC DCX
2. Magnetic of LLC integrated into PCB
3. EMI shielding
4. Harmonic injection to reduce bulk cap
5. One-stage EMI filter

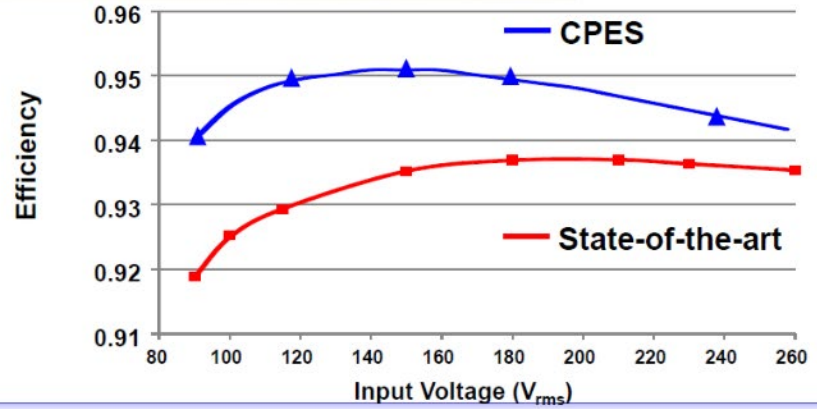
150W Prototype

State-of-the-art 150W (12W/in^3)

CPES 2-stage 150W (35W/in^3)

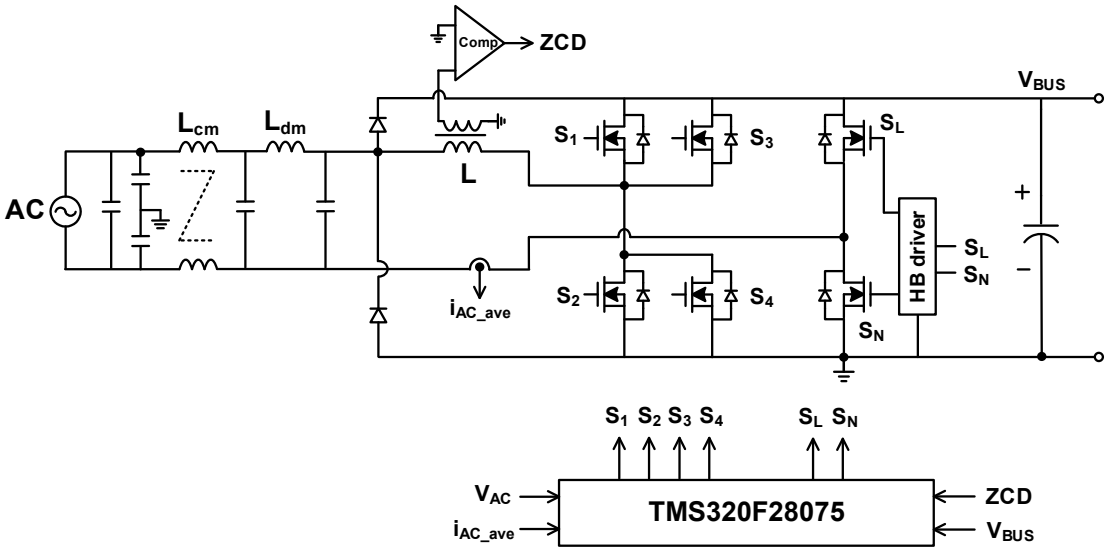


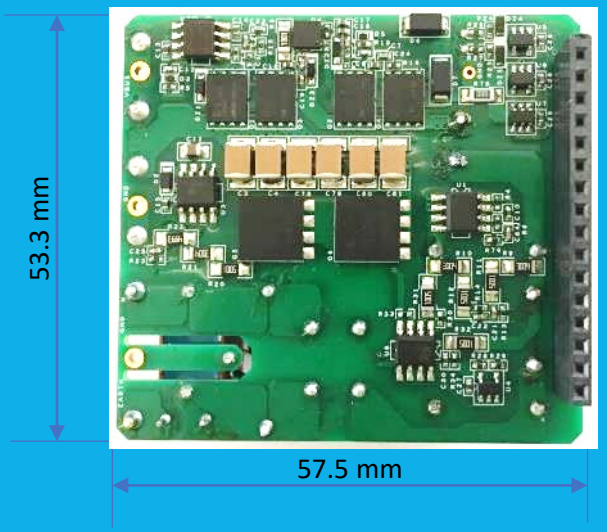




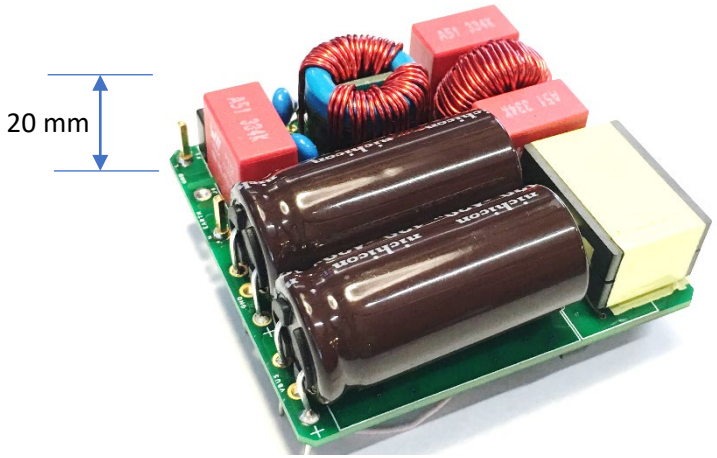
- Powertrain: GaNFast NV6105
- Control TI DSP C2000

300W Totem-Pole PFC





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

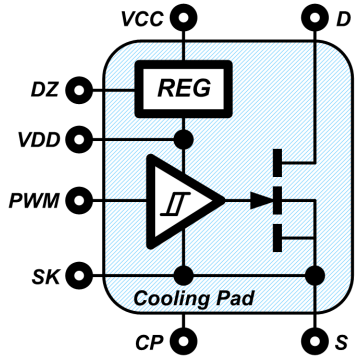


NV6128: 70mΩ GaNFast Power IC

Features

- ***Integrated gate drive***
- ***Integrated gate drive regulator***
- *70 mΩ eMode GaN FET*
- *Wide V_{CC} range (10 to 30 V)*
- *Programmable turn-on dV/dt*
- *Source Kelvin GND*
- *2 kV ESD (HBM)*
- *800 V transient*
- *650 V continuous*
- *Q_{rr} = Zero (0)*

Simplified Schematic



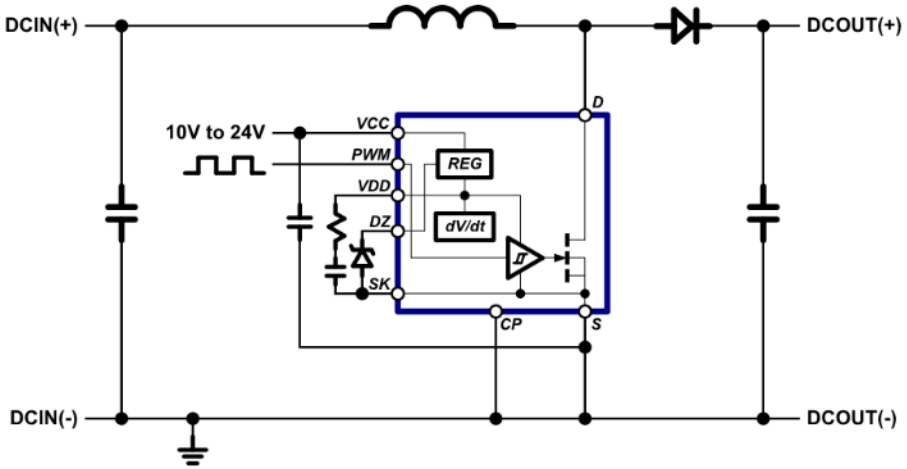
Package



6x8 mm PQFN

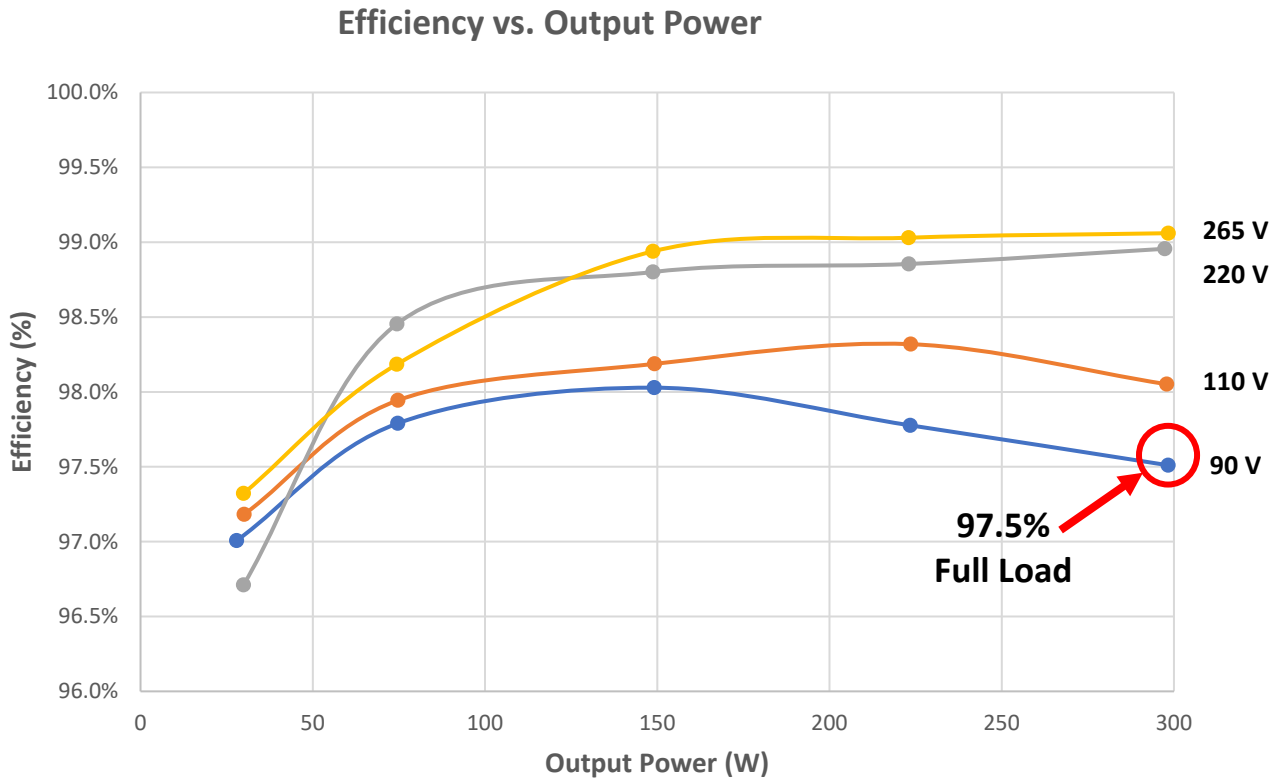
Large Cooling Pad

Typical Application Schematic (Boost PFC)

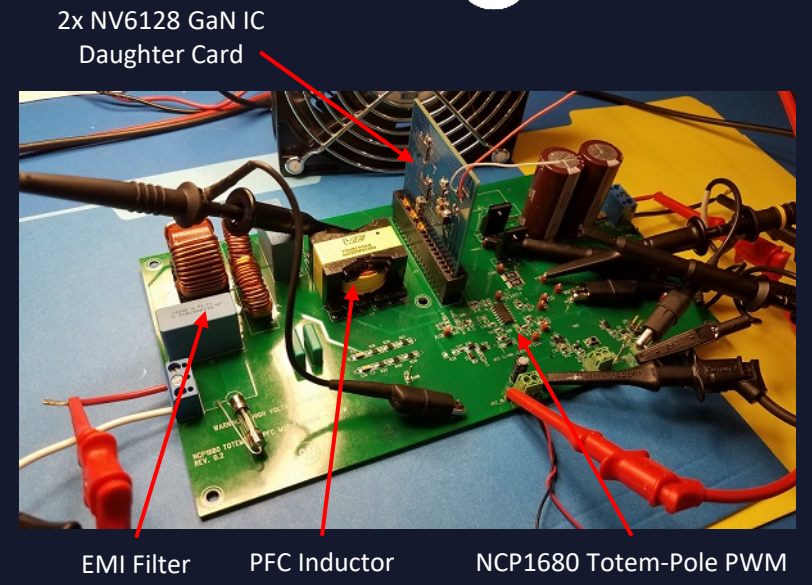


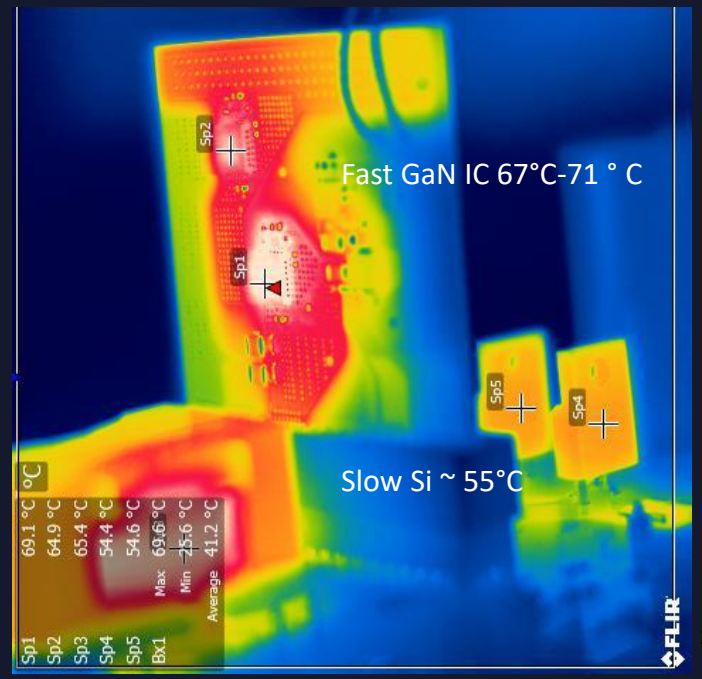
High Efficiency, Cool Operation

- Bridge + Boost PFC = 96%
- CrCM Totem-Pole PFC = 97.5%
- Totem-pole = +1.5% !

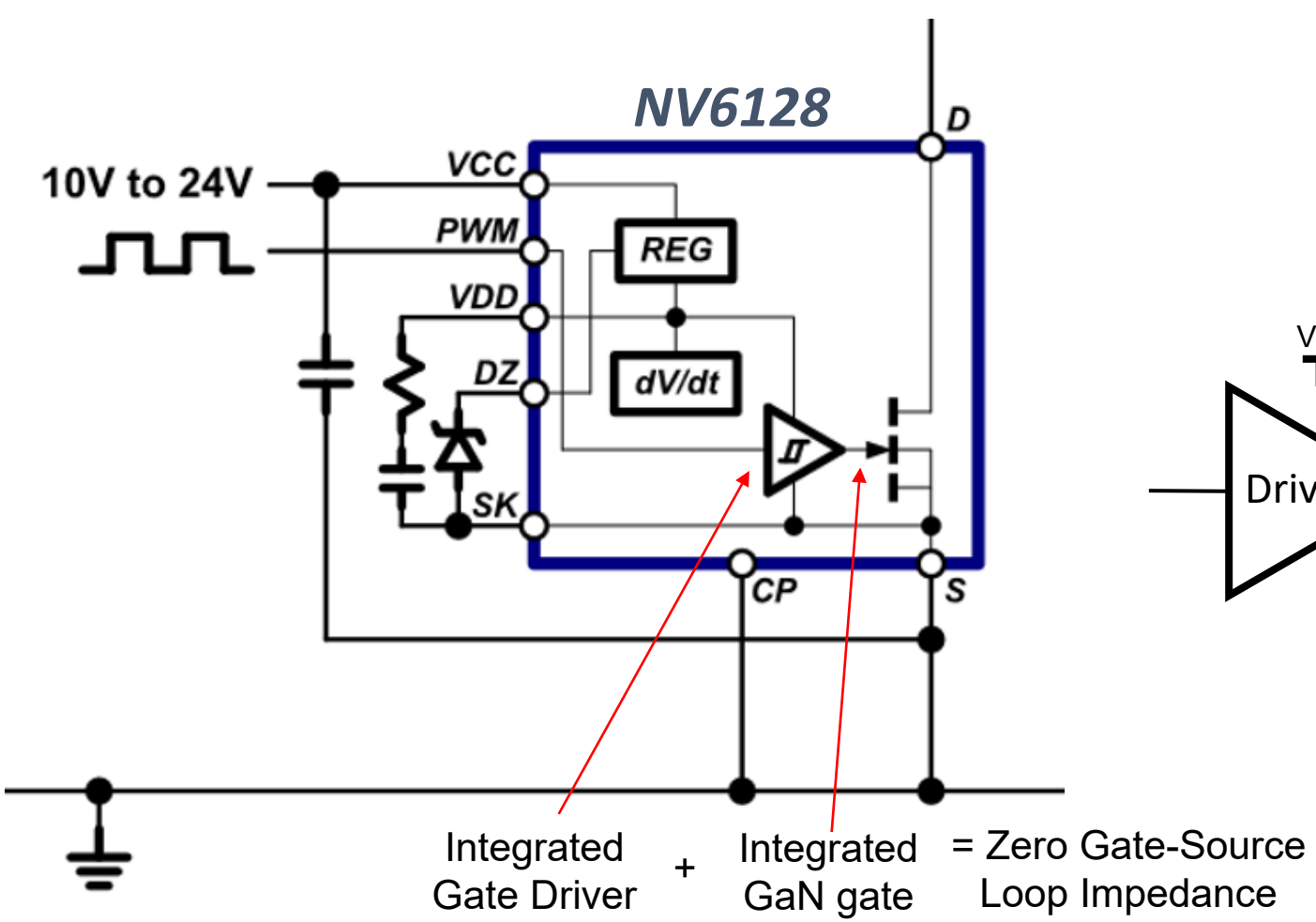


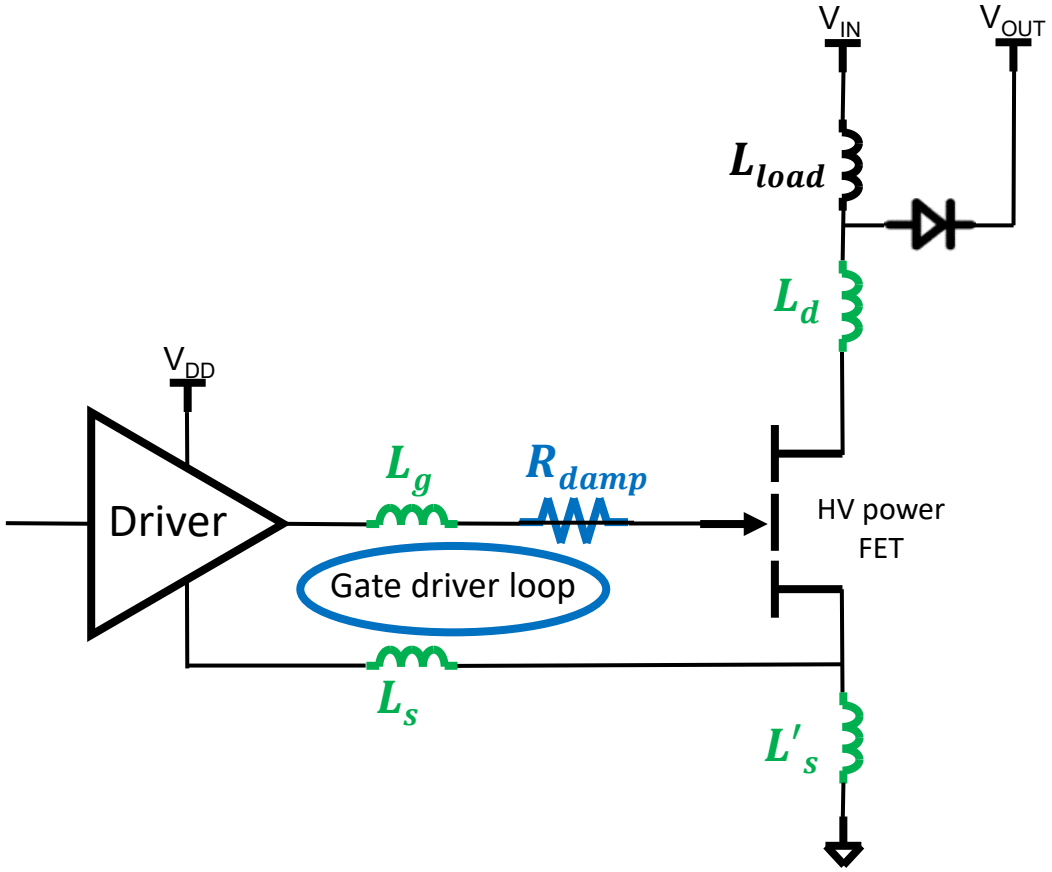
Navitas





Integration Drives Performance





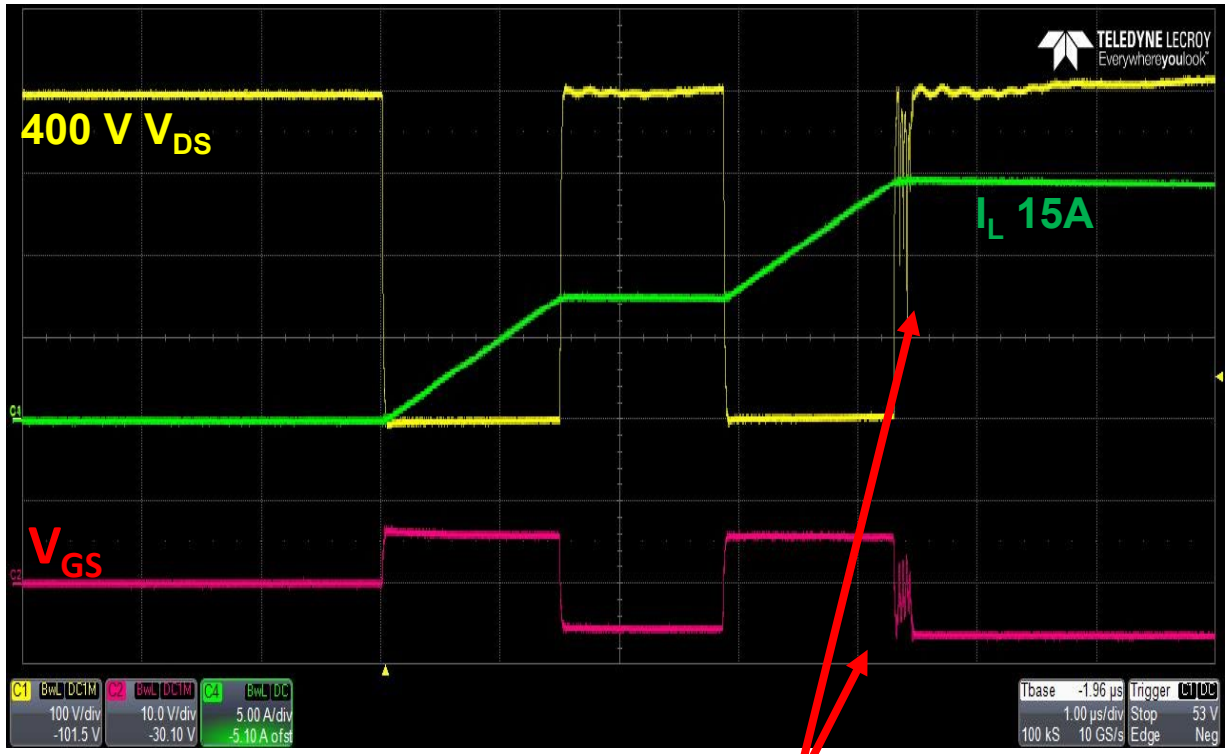
Integrated Gate Driver + Integrated GaN gate = Zero Gate-Source Loop Impedance

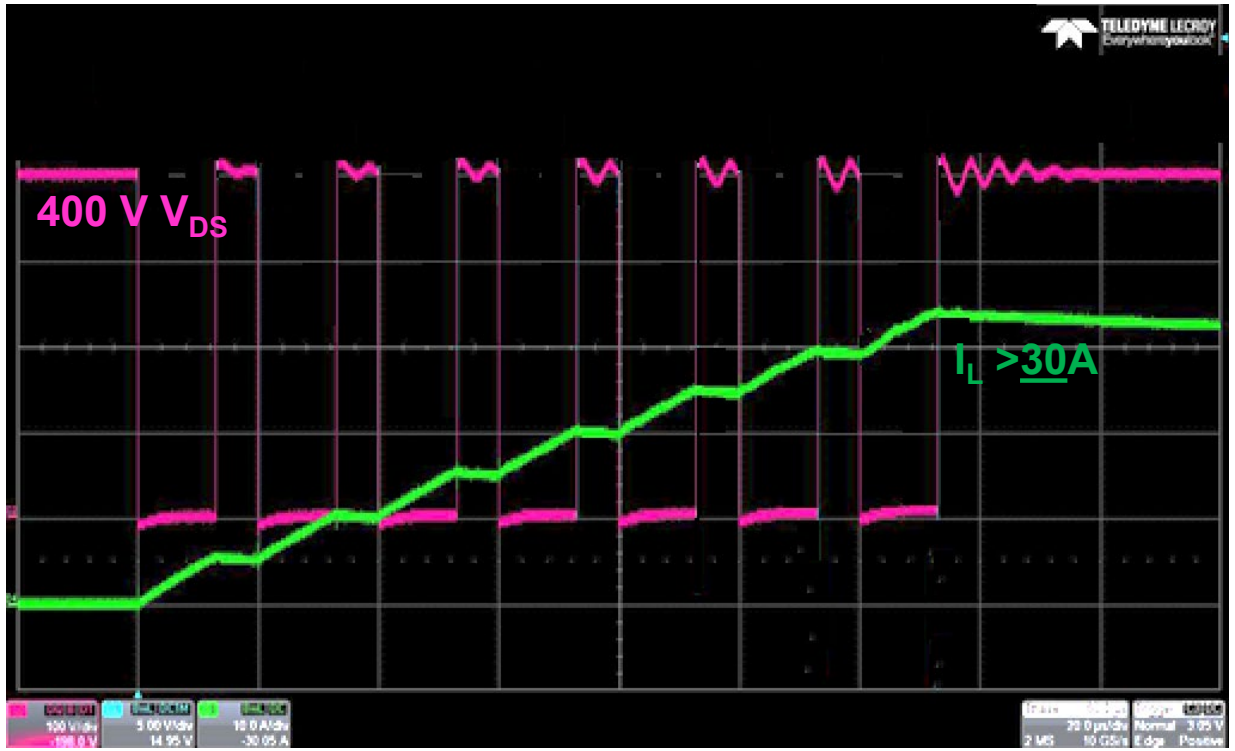
Only GaNFast is Fast… and Safe

Double-Pulsed Test (Sync Boost Circuit)

Navitas

Discrete GaN → **GaN Power IC**





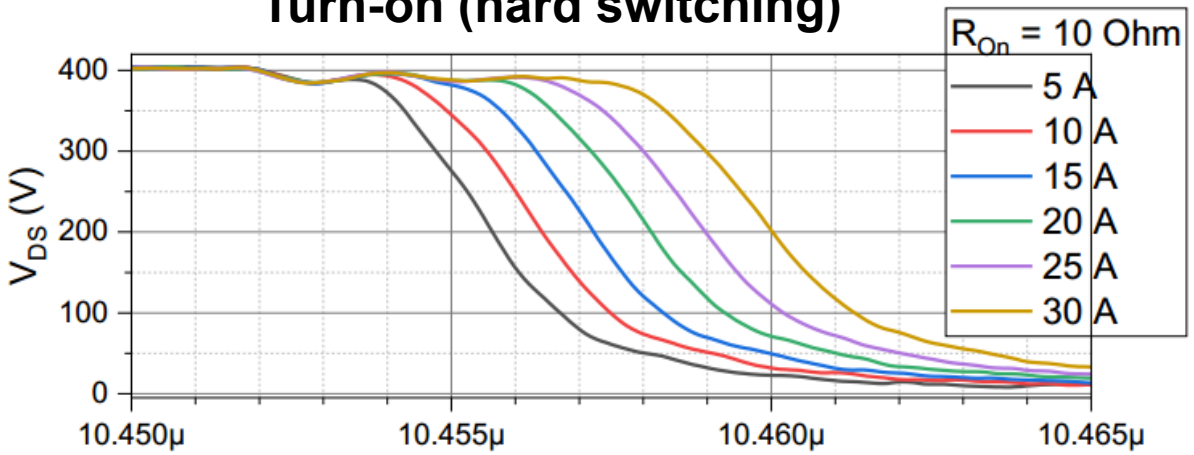
- Exposed gate
- Faulty switching
- Dangerous ringing & glitching!

- Integrated gate
- Clean switching
- Safe, smooth performance

“Best GaN We Tested!”

Navitas

Turn-on (hard switching)



Partner Feedback:

“Protected gate removes external parts without restricting switching speeds”

“Minimal ringing optimizes EMI”

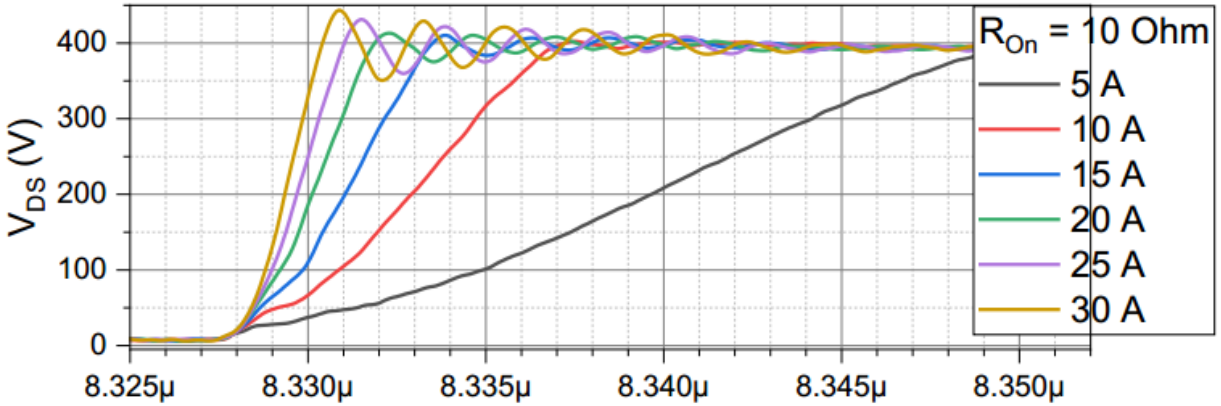
“No gate-loop risks”

“Fast and very clean switching”

“Easy to control slew rates”

“Integrated gate allows fast switching” (dV/dt > 200 V/ns, di/dt >10 A/ns)

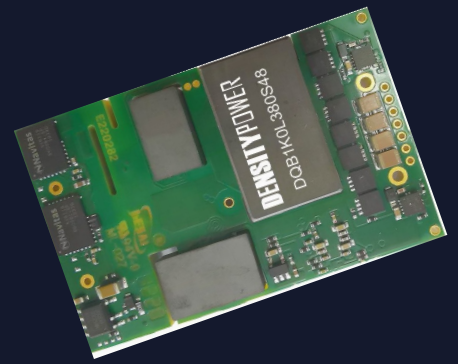
Turn-off (hard slewing)

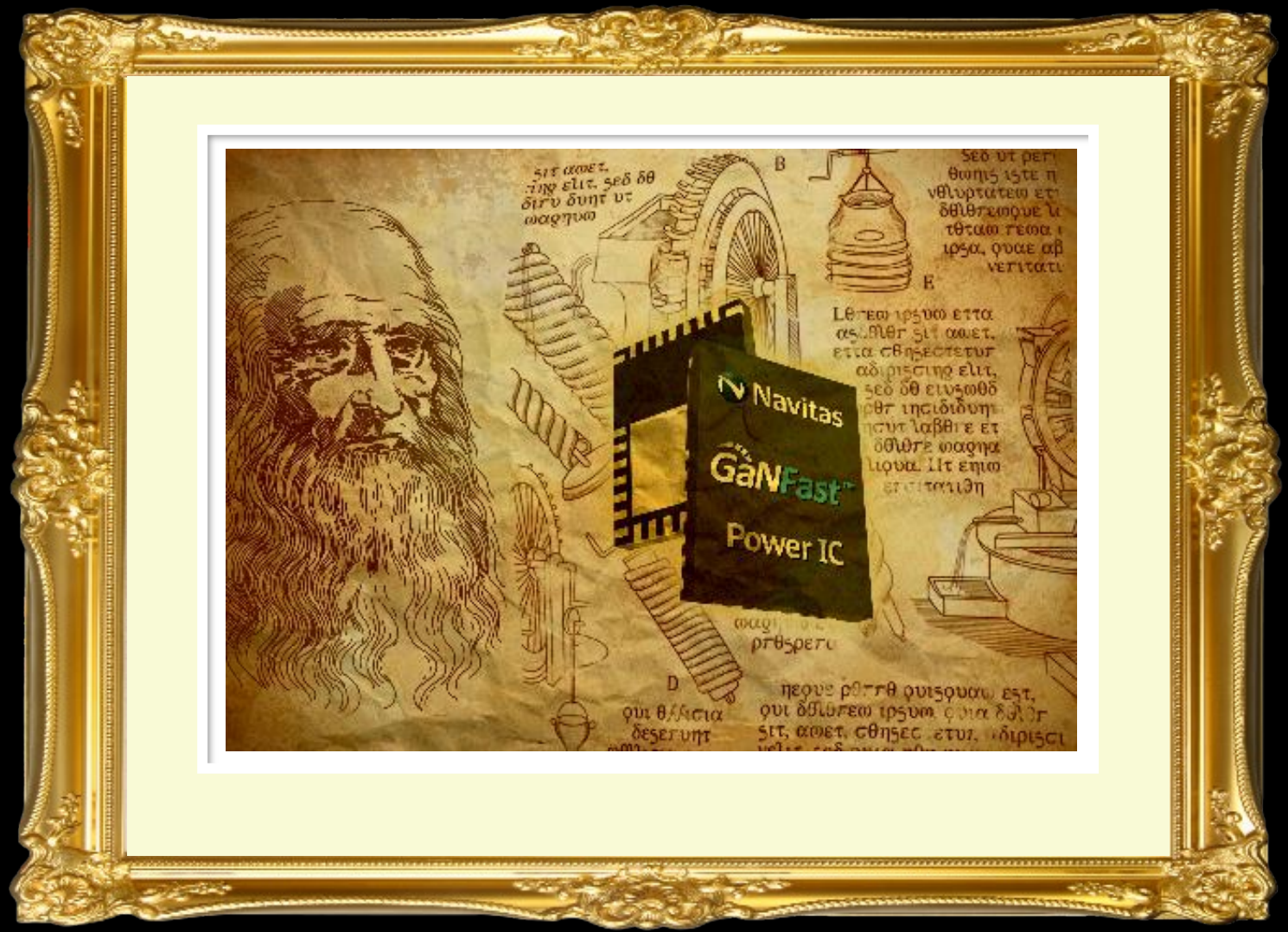


High-Frequency HVDC

Quarter (¼) Brick, 400 V_{IN}

Navitas

2015 Si	2020 GaN	2021 GaN
150 W	300 W	1,000 W
	2x Power	***6x Power***
		
	DENSITYPOWER	DENSITYPOWER
Best-in-class Si	GaNFast Power ICs	GaNFast Power ICs
90-92%	92.5-94.5%	97.0-97.7%
	400 kHz	850 kHz



Let's go GaNFast™

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