The eGaN® FET Journey Continues

EPC
EFFICIENT POWER CONVERSION

Advances in Gallium Nitride Technology

November, 2018

Steve Colino

Agenda

- Technology Update
- Packaging
- Designs Design Examples
- Integration
- Roadmap

What Do Energy Savings Buy You?

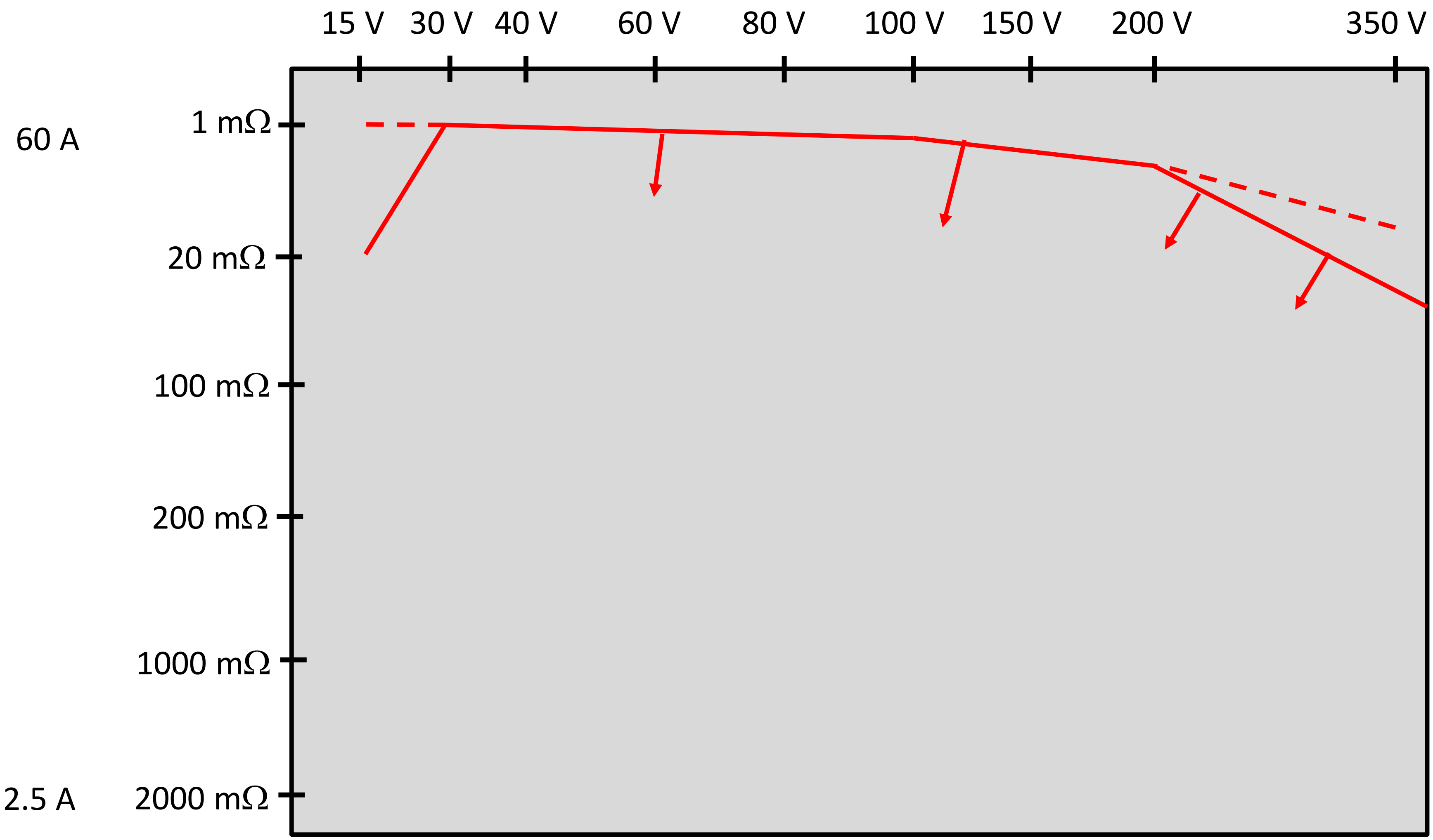
- 500 W at 24/7 is 4,400 kWH per year
- Average cost for industrial energy in the US is $0.0735/kWH
- $322 per year
- $3.22 savings per year for each 1% efficiency gain
- A 25 year live saves $805.00 per 1% efficiency gain
- China
  - 0.81 RMB/kWH = $0.12/kWH
  - $52.6 per year
  - A 25 year live saves $1315.00 per 1% efficiency gain

Why GaN?

- When compared with MOSFETs of the same V_{DS} capability and $R_{DS(on)}$, GaN FETs are:
  - Smaller
  - Lower Q_G, Q_{GS}, Q_{GD}
  - Lower Q_{OSS}, zero Q_{RR}
  - Lower L and L_{CS}
- With each new generation
  - Technology difference increases
  - Price difference decreases
- GaN allows smaller, lighter, more efficient solutions
- GaN allows new innovation
- GaN Progress is accelerating

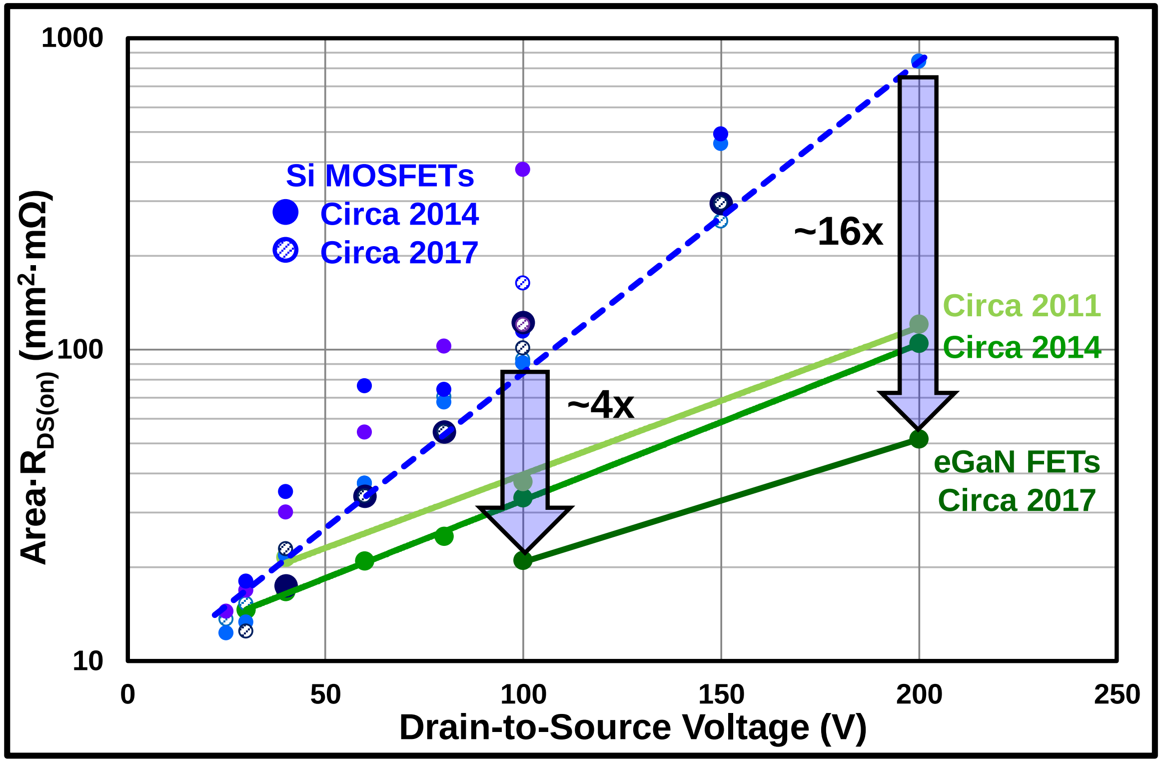
eGaN FET Technology Update

eGaN FET Range



eGaN Size vs MOSFET

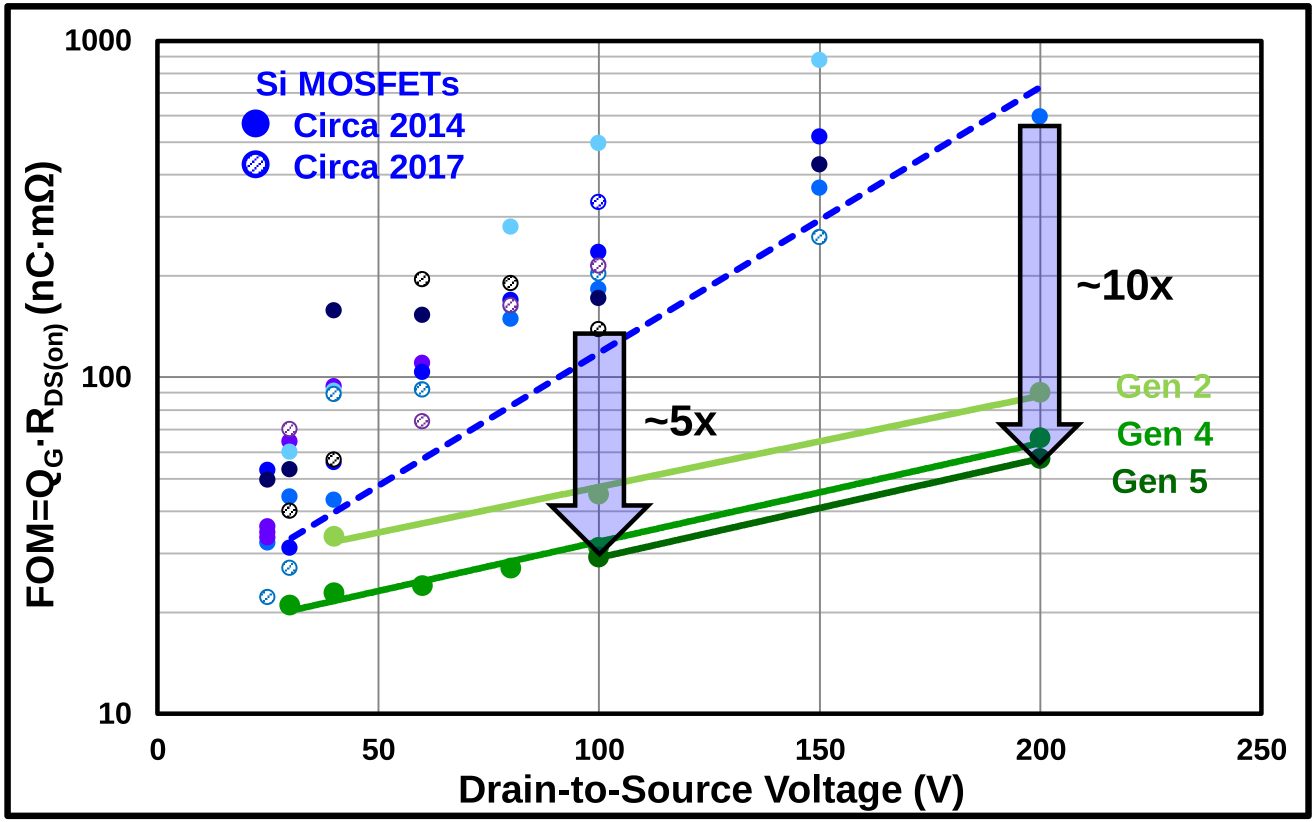
EPC Gen 4 and Gen 5 are much smaller than the best MOSFETs



Actual Product Resistance

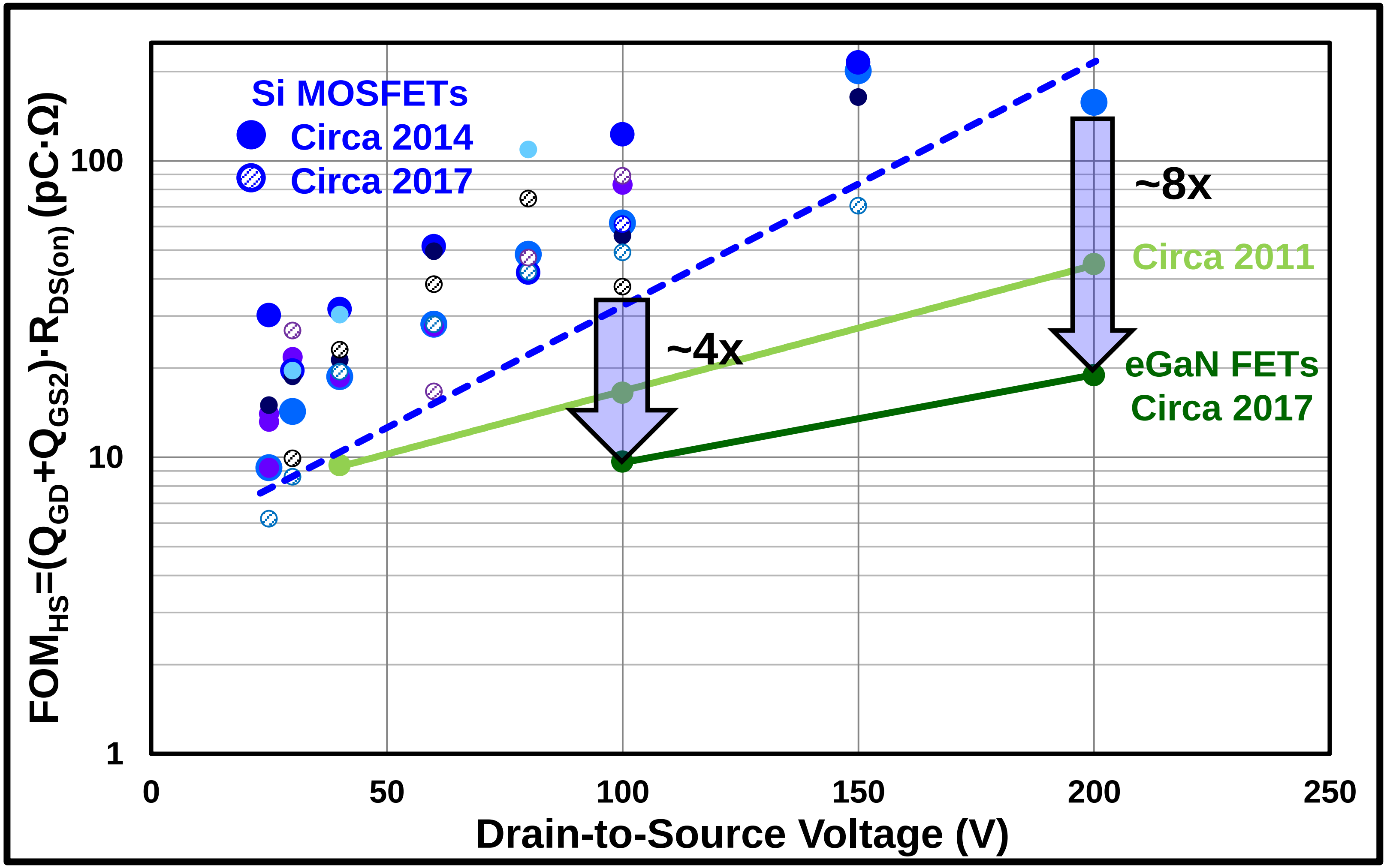
eGaN Performance Vs MOSFET

EPC Gen 4 and Gen 5 Have Best-in-Class Hard Switching Performance



V_{DS}=0.5·V_{DSS}, I_{DS}=20 A

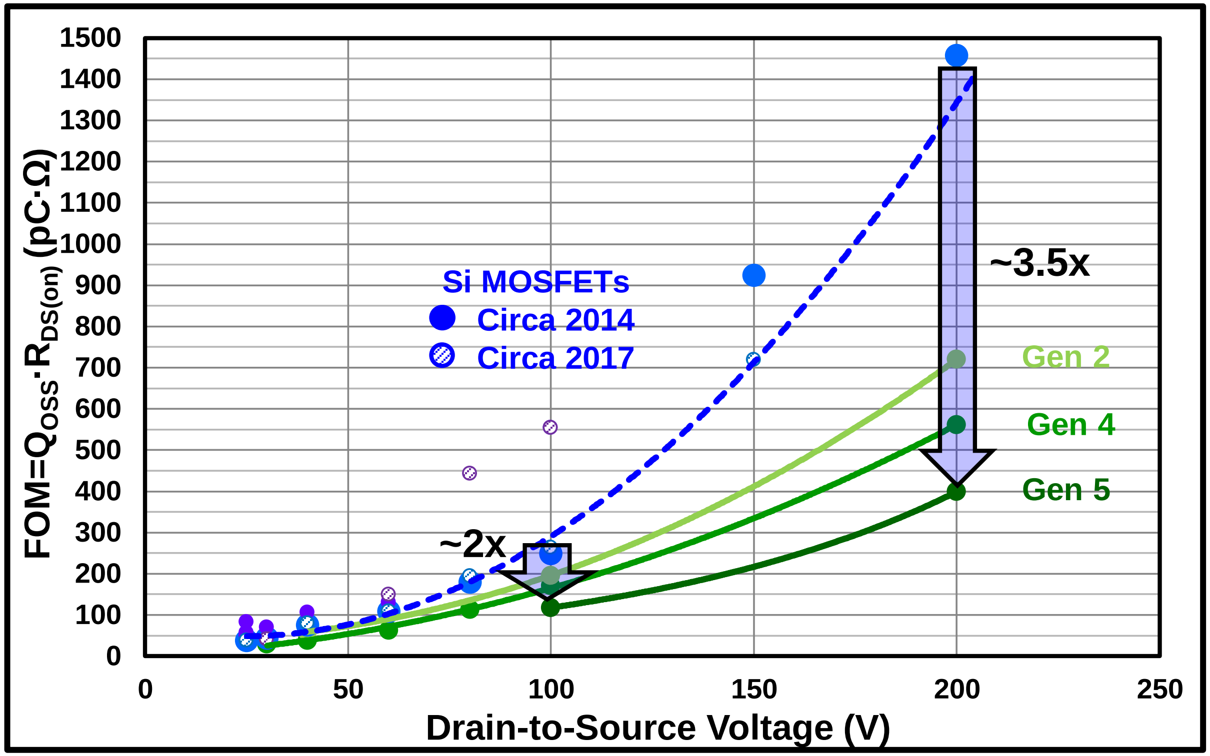
eGaN Performance Vs MOSFET



$V_{DS}=0.5\cdot V_{DSS}$, $I_{DS}=20$ A

eGaN FET Performance Vs MOSFET

EPC Gen 4 and Gen 5 Have Best-in-Class Soft Switching Performance



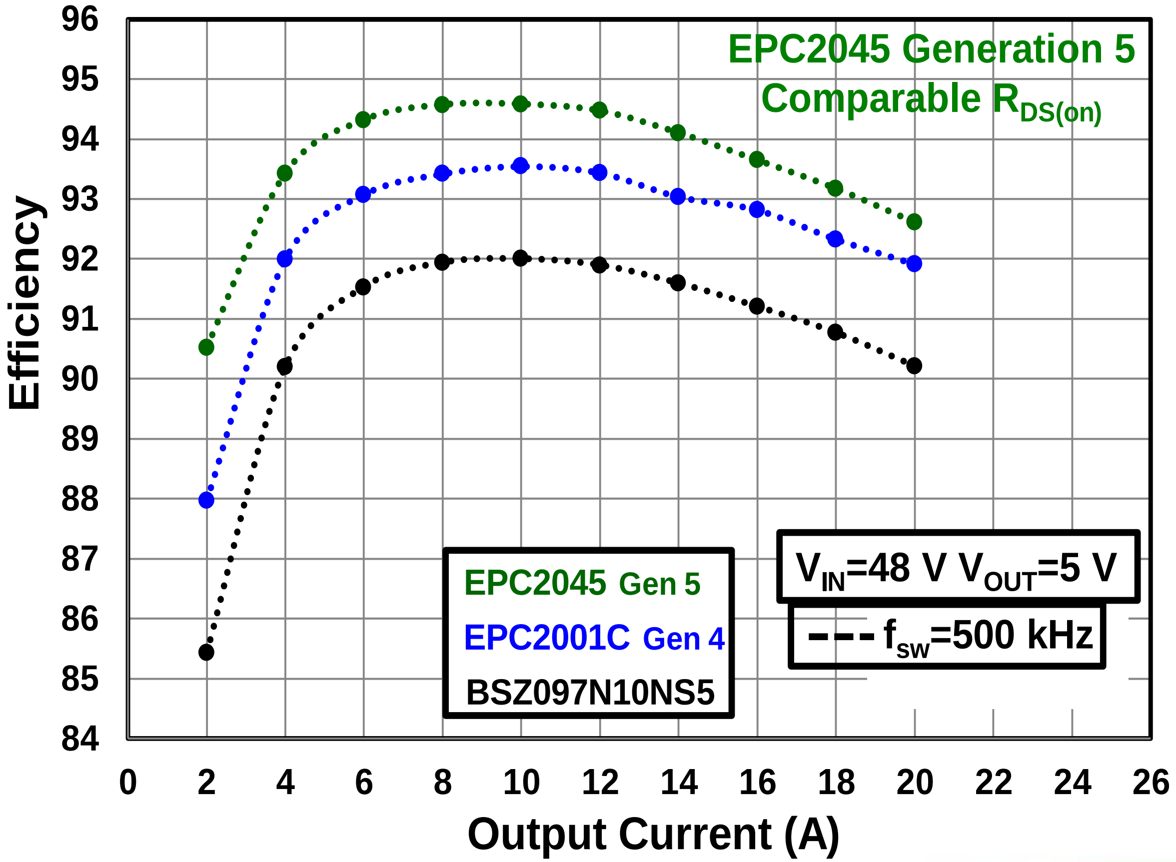
V_{DS}=0.5·V_{DSS}

100 V – Technology Comparisons

	$R_{DS(on)}$	$Q_{OSS}+Q_{RR}$	$R_{DS(on)}$ x $(Q_{OSS} + Q_{RR})$	Q_{GD}	$R_{DS(on)}$ x Q_{GD}	Area
EPC2045	5.6 typ 7 max	21	118	1.1	6.2	3.75
EPC2053	3.2 typ 4 max	43	138	1.5	4.8	7
GS61008P	7 typ 9.5 max	21.3	149	1.5	10.5	34.7
BSC040N10NS5	3.4 typ 4 max	149	507	12	40.8	33.2

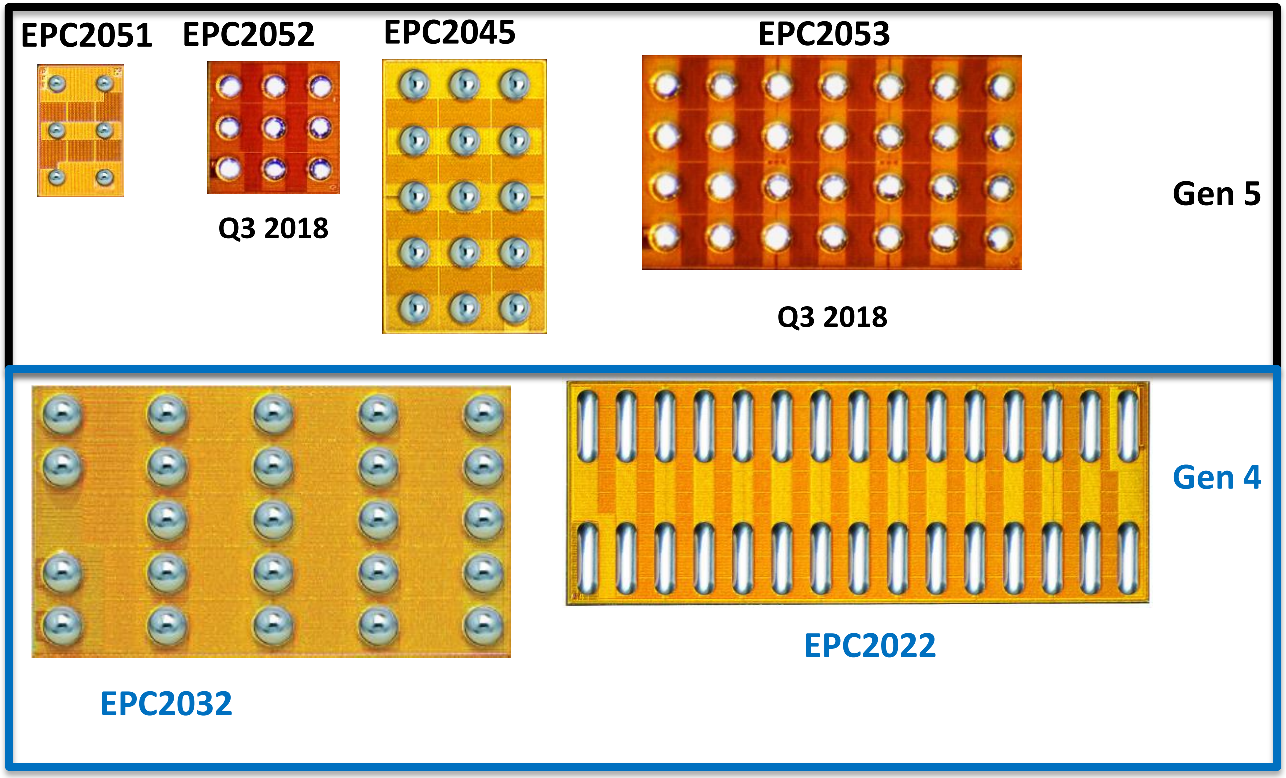
100 V: Gen4 vs Gen 5 Family
Buck Converter Efficiency Comparison

Gen 5 Devices have higher performance and are about half the size of Gen 4. Both Gen 5 and Gen 4 are far superior to the best available MOSFET.



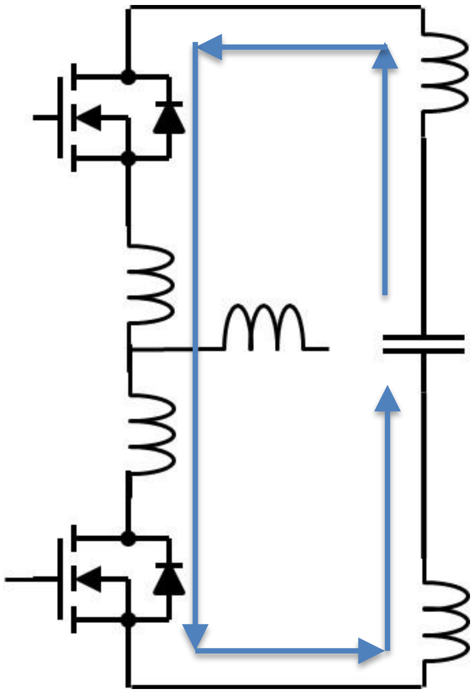
eGaN FET Packaging

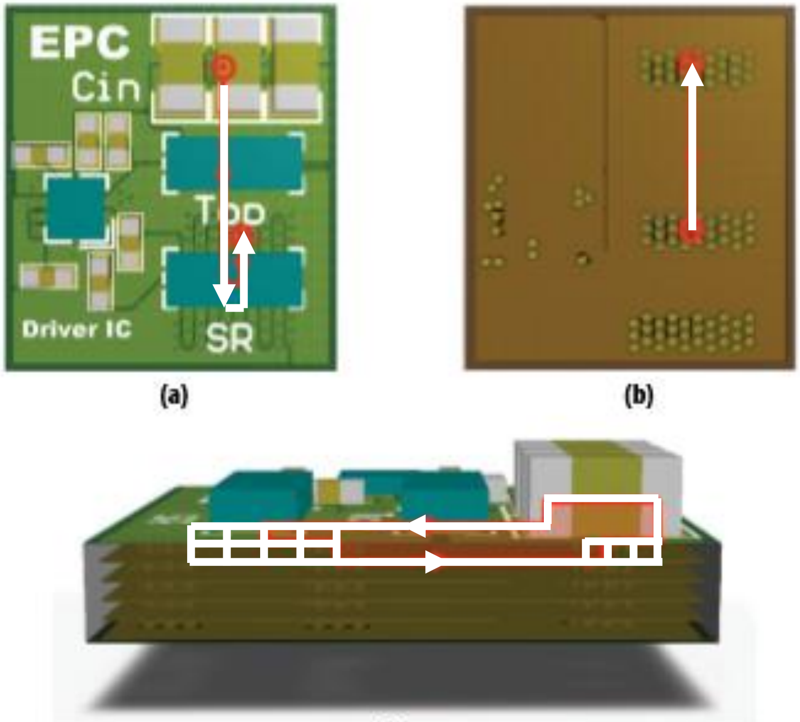
Wafer Level Packaging (100 V)



- Absolute minimum lead resistance and inductance
- Minimum footprint on PCB
- Dual sided cooling (pulls heat out of the board)
- RoHS 6 of 6 and MSL 1

Low Inductance Package

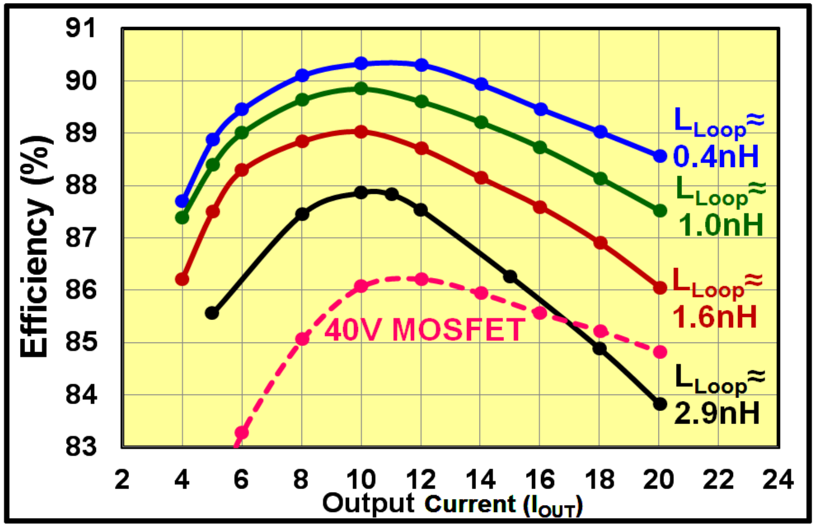




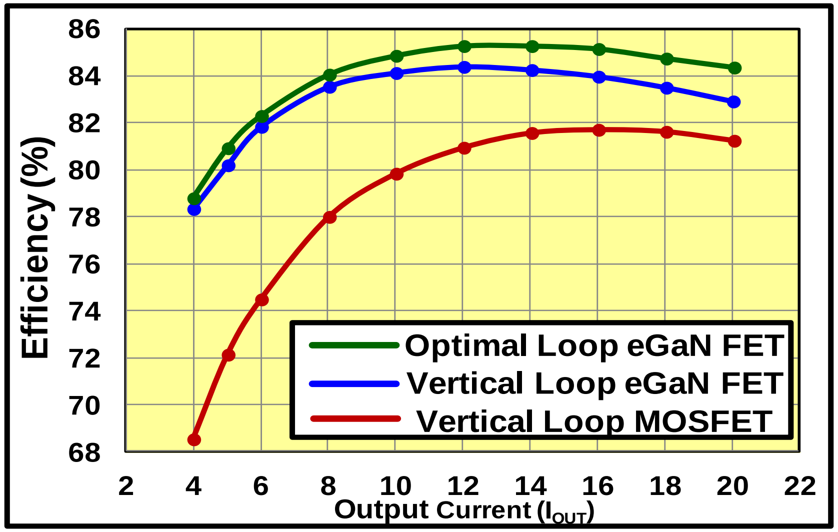
(a)
(b)
(c)

- Low inductance layout of the high frequency loop reduces ringing and increases efficiency

Layout Comparison Efficiency Results



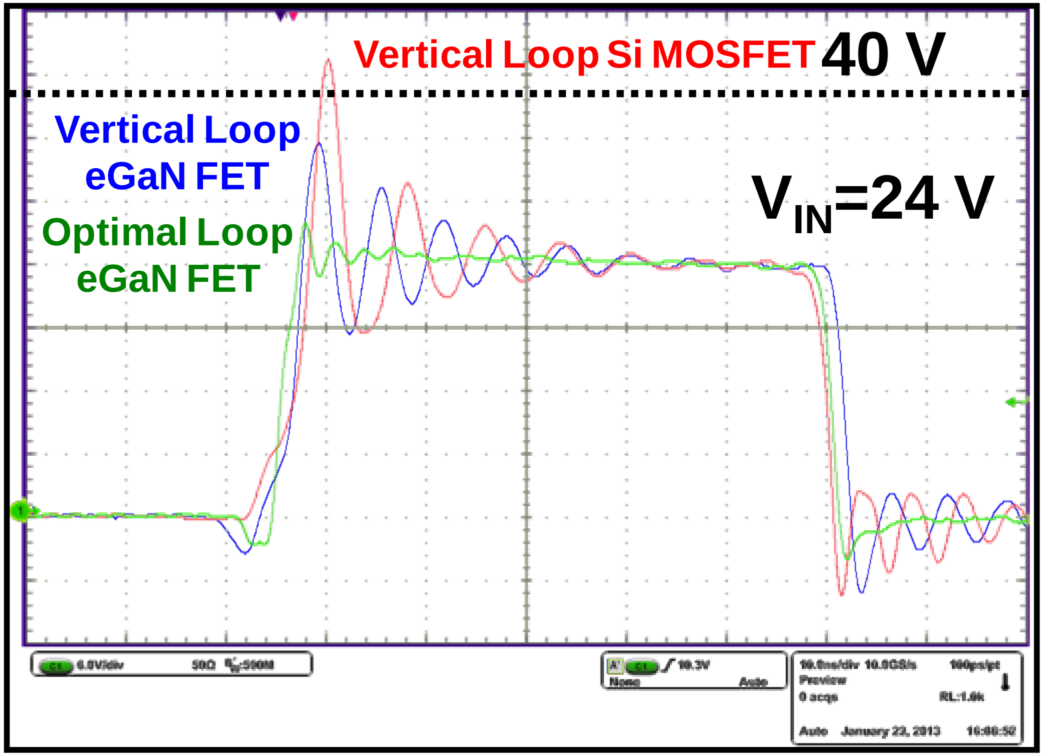
12 V to 1.2 V, 1 MHz



24 V to 1.2 V, 1 MHz

- Package inductance of MOSFETs dominates both common source inductance and high frequency loop inductance losses
- eGaN FET wafer level LGA packages have ultra-low inductance and allow ultra-low high frequency loop inductance

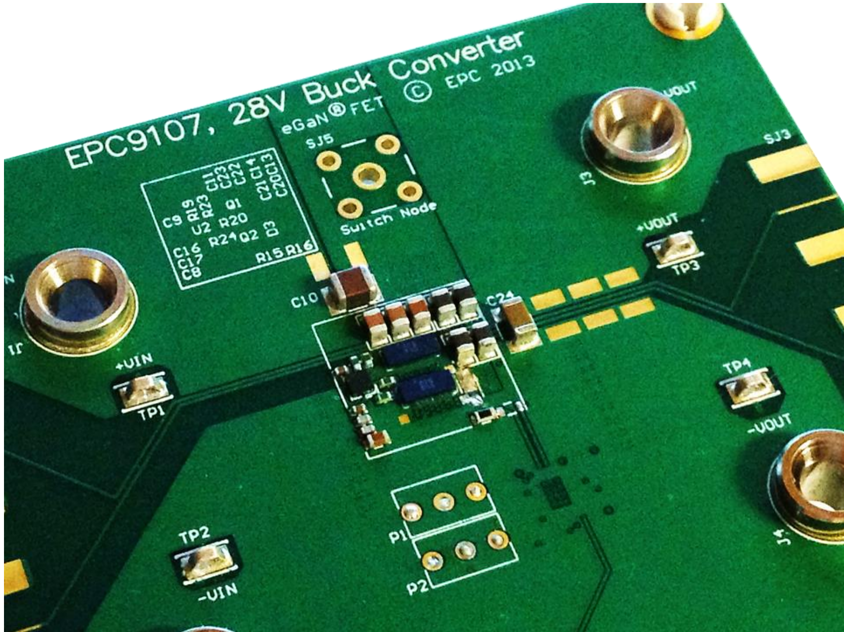
Switchnode Peak and Ringing

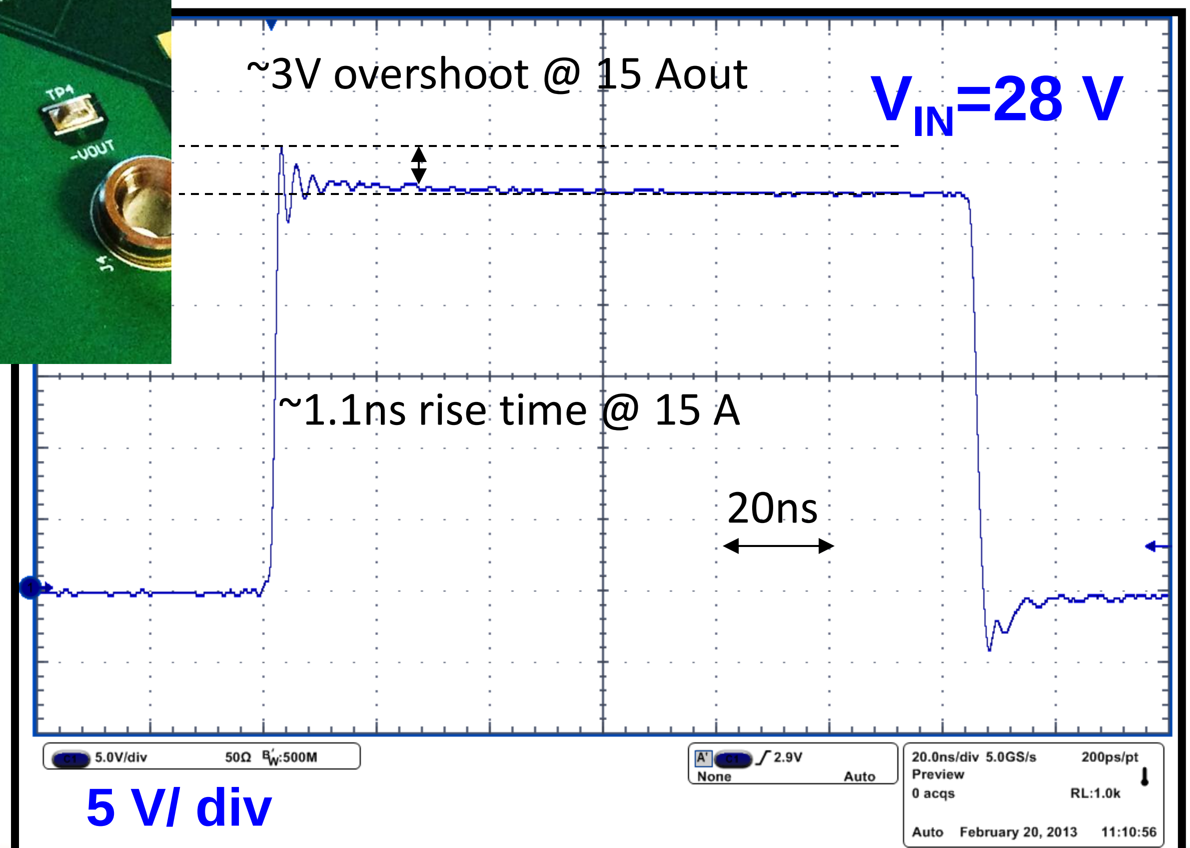


- Low inductance high frequency loop reduces peak voltage and ringing
  - Lower voltage device for same application can further increase efficiency
- Reduced ringing eases design for EMI

Ultra-Fast Switching

V_{IN}=12-28 V V_{OUT}=3.3 V
I_{OUT}=15 A F_S=1 MHz
2 x EPC2015





Switching Node Voltage

V_{IN}=28 V I_{OUT}=15 A

Little ringing for low EMI

Integrated Half-Bridge

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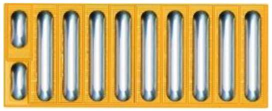
Generation 2/4 Discrete HB



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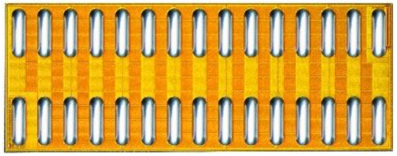
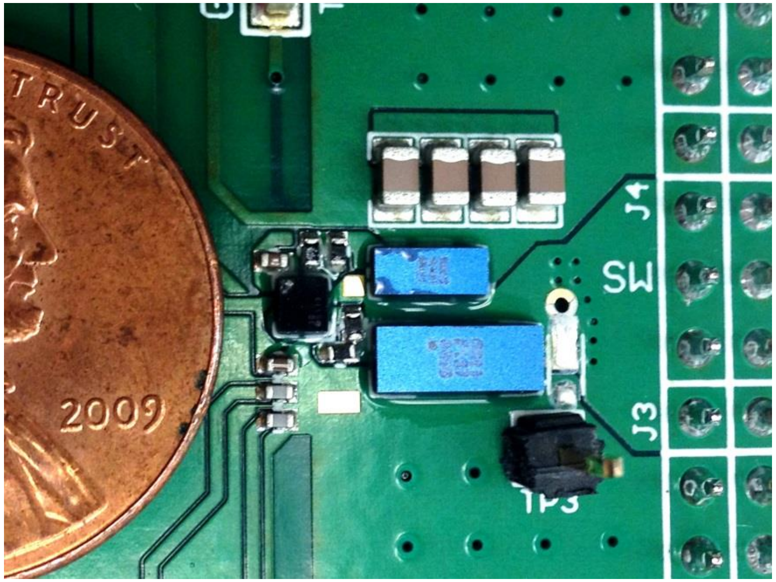
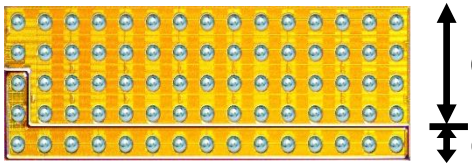


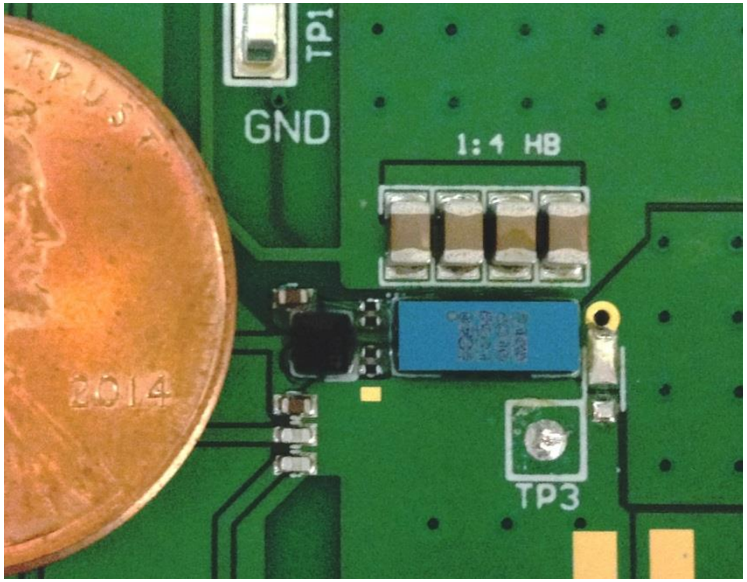
Top Switch (Q1) Bottom Switch (Q2)



Generation 4 Monolithic 1:4 HB

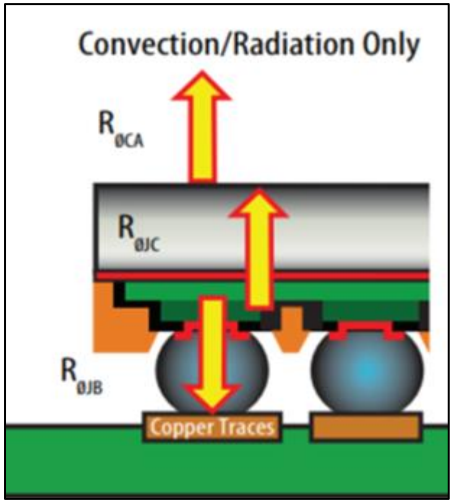


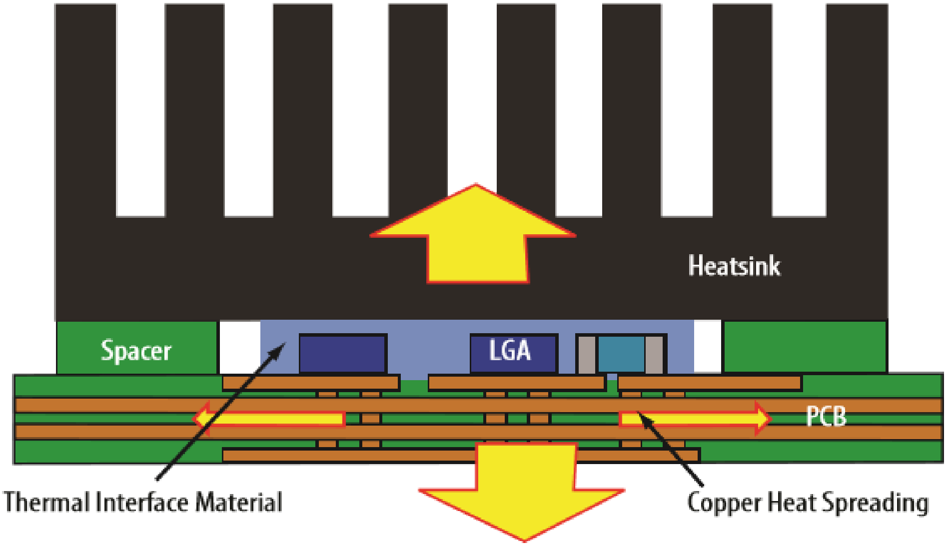
33 % die size reduction



Dual Side Cooling or Power Overlay

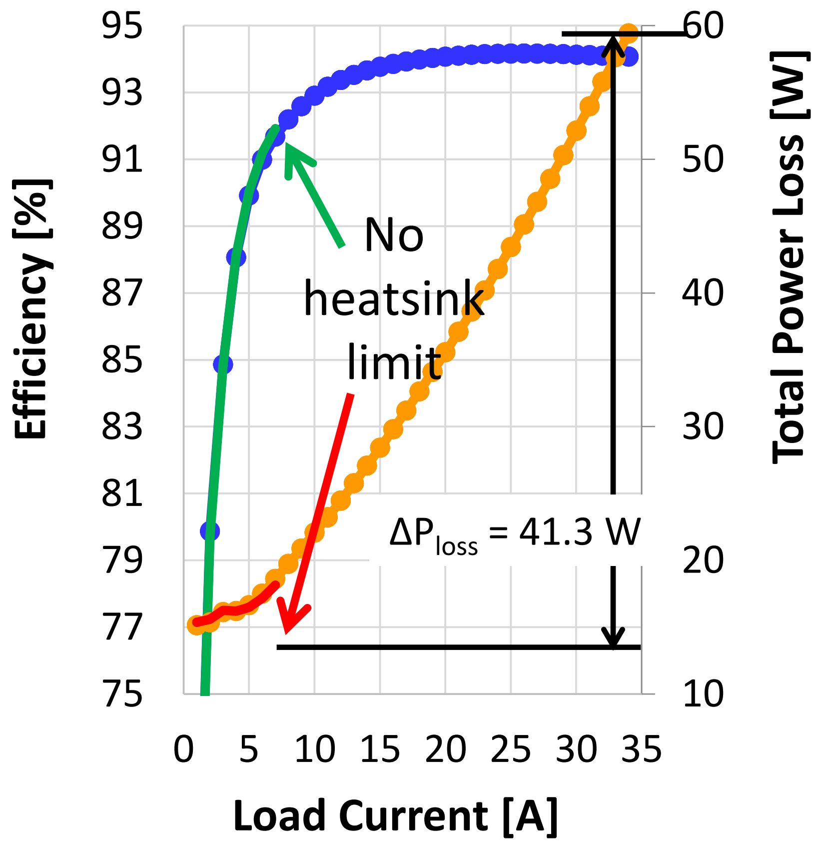
eGaN FETs conducts heat to the top through Silicon substrate





Part number	Vds	Rdson	Id-A	Qg nC	Qrr	Rthjc	Rthjb	Rthja	Size mm	Area	Package
	Volts	mohm	A	NC	nC	deg C/W	deg C/W	deg C/W	L x W	Sq. mm	
BSC030N08NS5	80	3	100	61	94	20	0.9	50	5 x 6	30	PQFN56
EPC2021	80	2.5	90	15	**0**	**0.4**	1.1	42	6.05 x 2.3	**13.92**	LGA

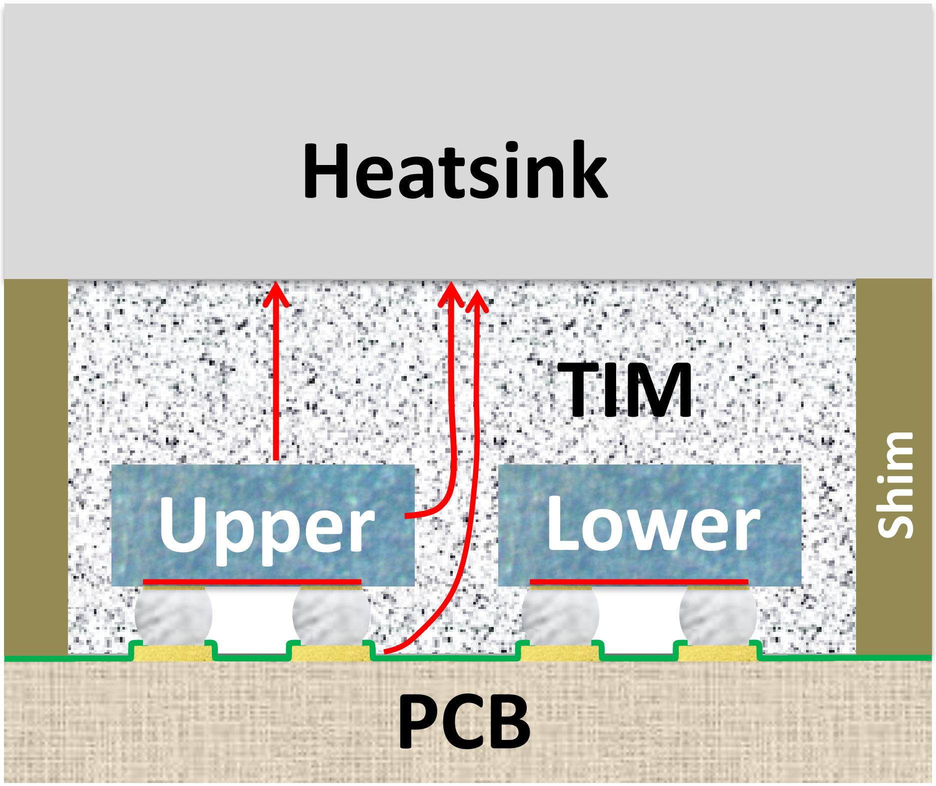
eGaN FET Thermal Application



140 V to 28 V @ 250 kHz

Bergquist: GF3500S35-00-60-50CC

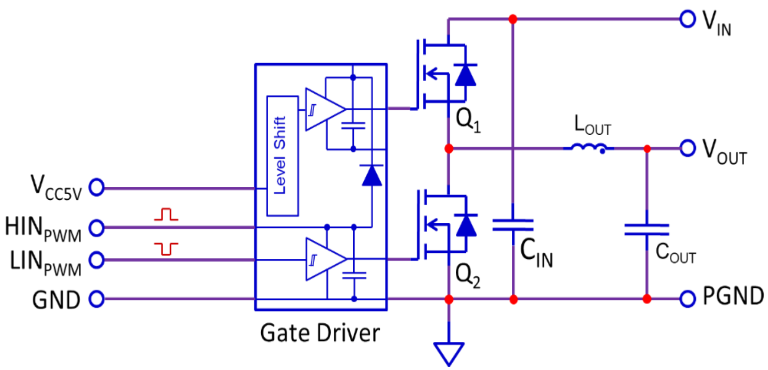
Thermal Resistivity = 200 °C·mm²/W
0.3 °C·in²/W

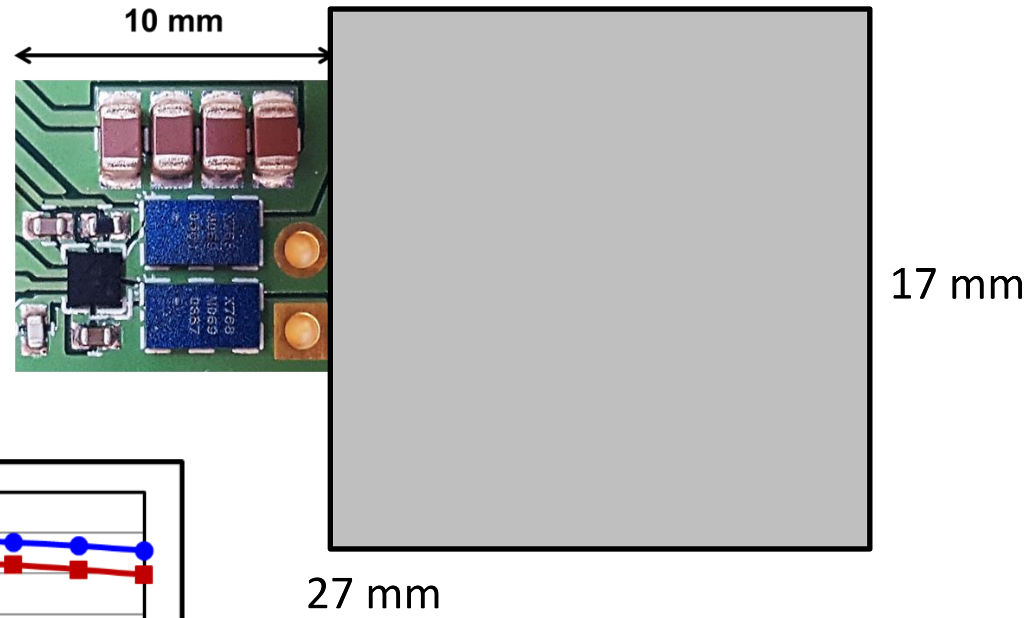


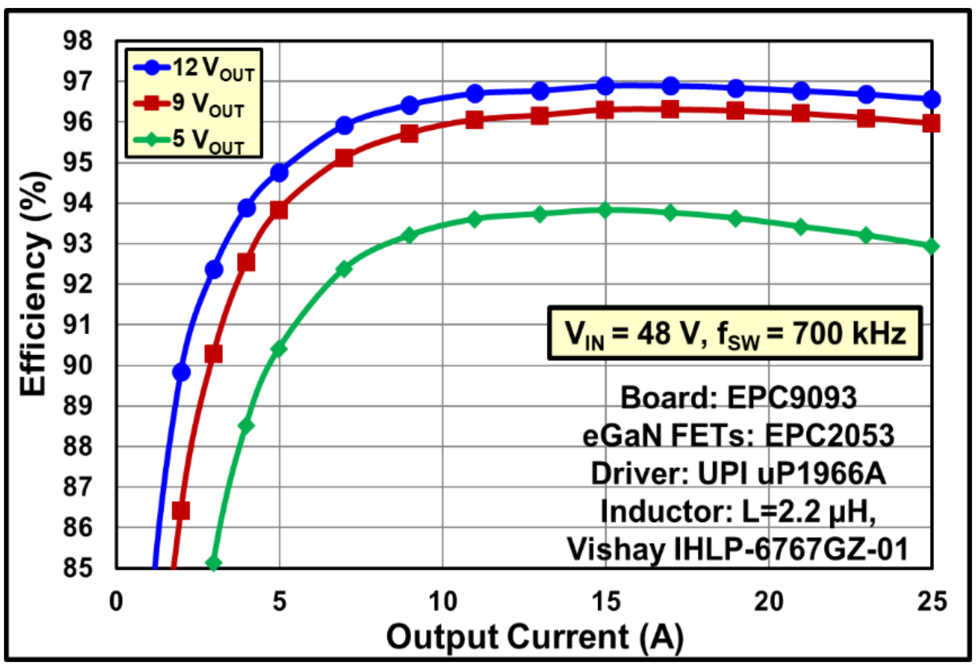
Simple to implement, low cost

Design Examples

48 V to 12 V Buck Converter



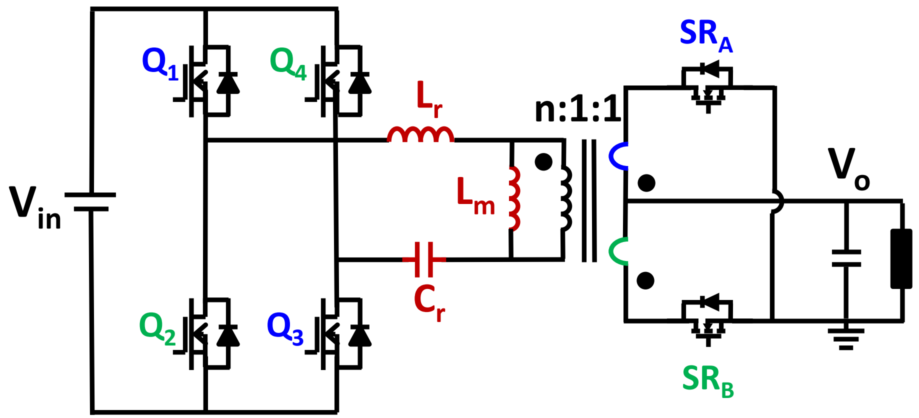




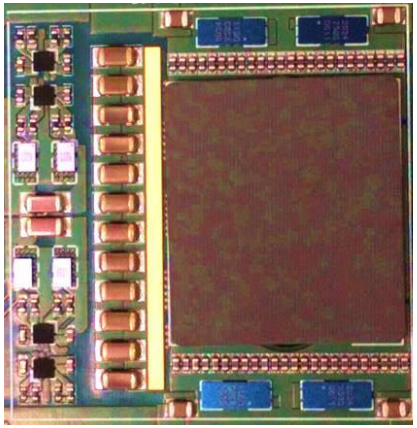
GaN enables efficient 48 V input Buck Converters

Buck converters are small and inexpensive

54 V DCX

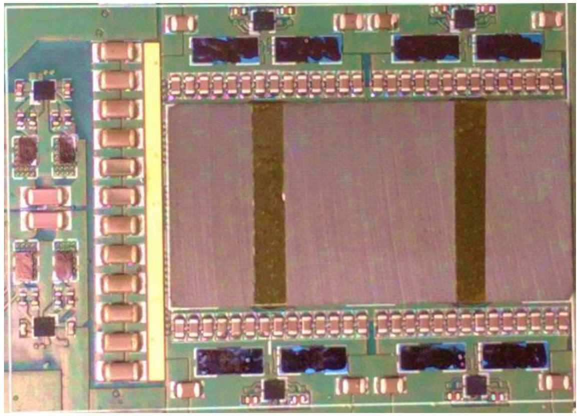


- 1 MHz Switching frequency
- Integrated Matrix Transformer
- Unregulated



4:1

36 mm x 37 mm

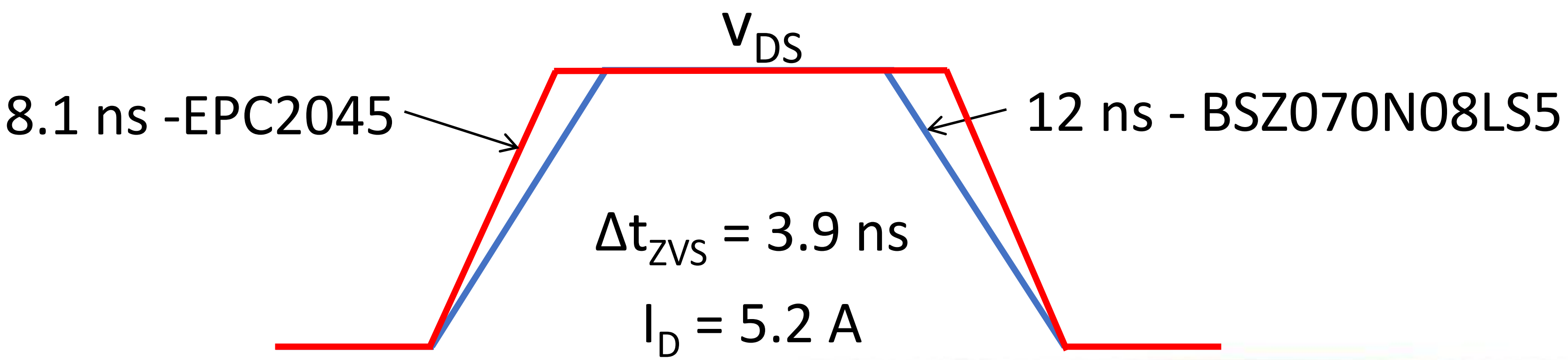


8:1

51 mm x 37 mm

Effect of lower Q_{OSS}

- Faster ZVS transition time for same current
  - Lower energy for LLC resonant tank
  - Lower ripple current in transformer
  - eGaN FET = higher effective duty cycle
    - **Lower RMS current for lower I^2R losses**
- Lower ZCS losses (when it occurs)

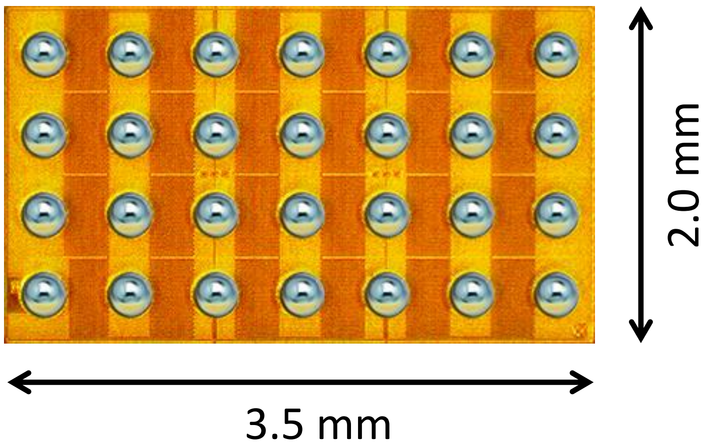


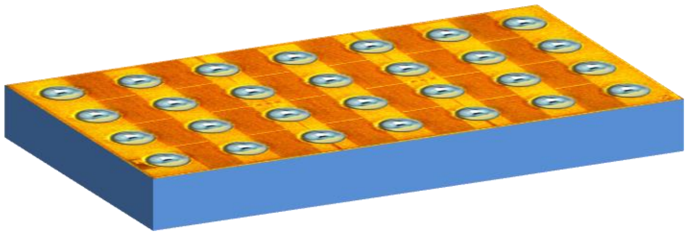
900 W

48 V to 12 V

eGaN FET for 900 W

EPC2053





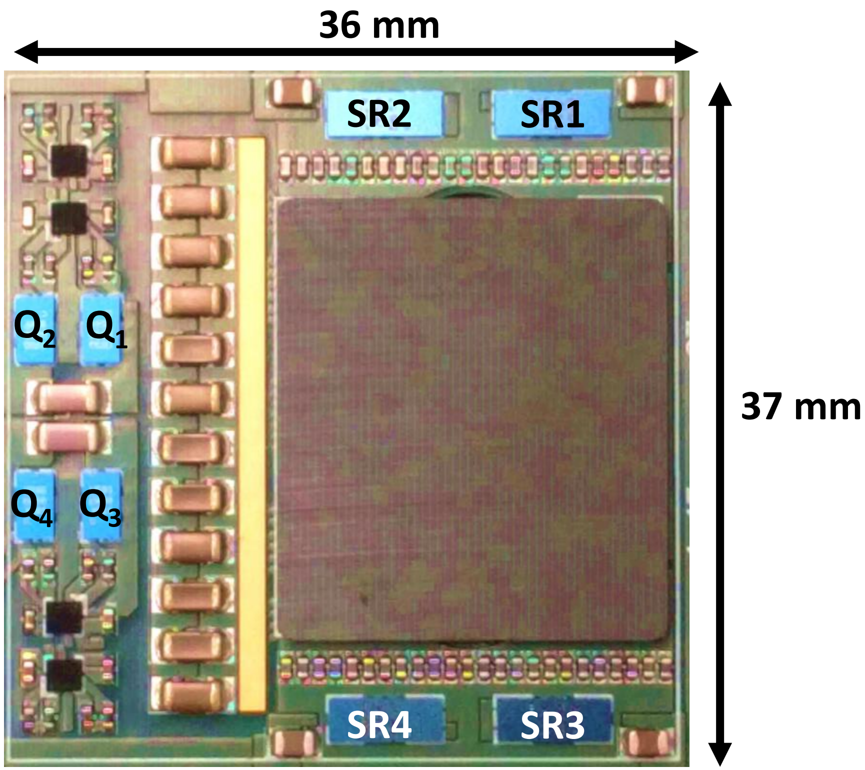
100 V Gen5

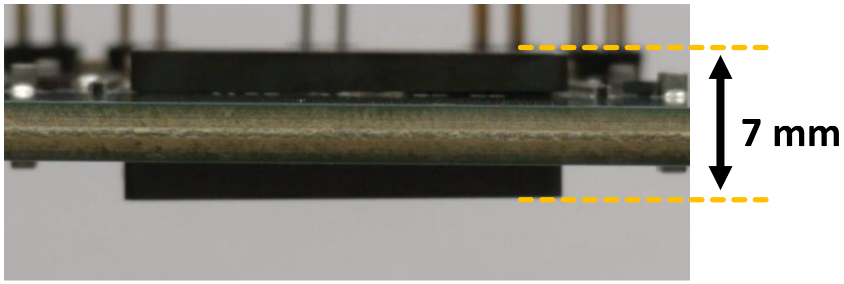
4* mΩ at V_{GS} = 5 V

7 mm^2

*Max. Value, T_J = 25°C

48/12V GaN – DCX Module#1





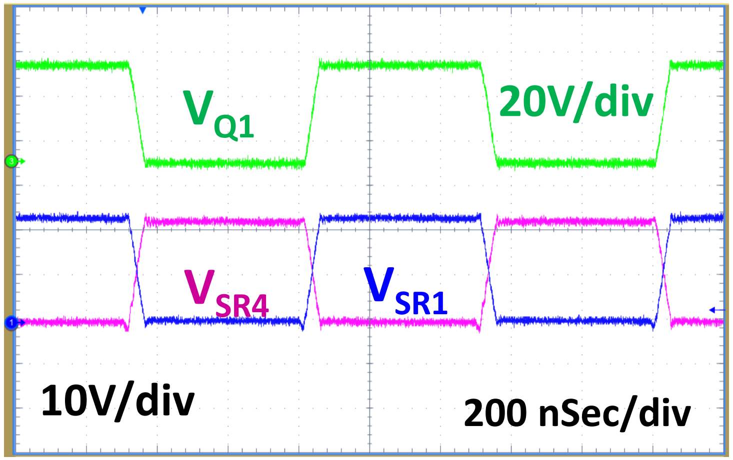
EPC9983A-V1

Q1 – Q4	EPC2053
SR1-SR4	EPC2024
V_{in}	48V – (40-60V)
V_o	12V – (10-15V)
P_{omax}	900W
F_s	1MHz
L_m	2.2 uH
C_r	19*0.22 uF = 4.2 uF
PCB Layers	14

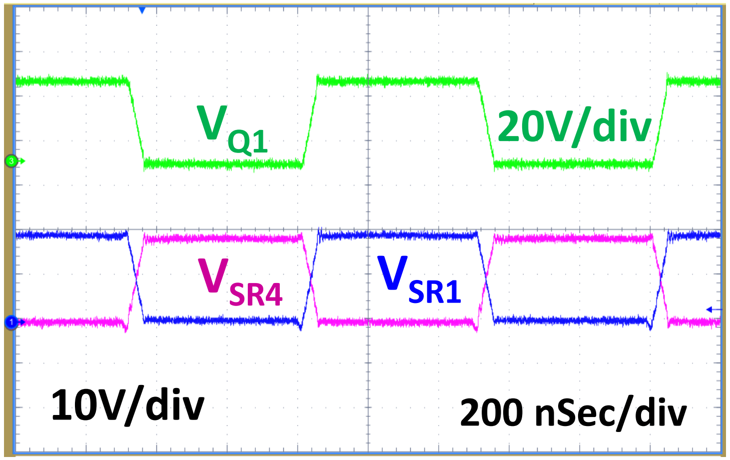
Power Density 1500 W/in^3 - 450 W/in^2

Full Load Operating Waveforms

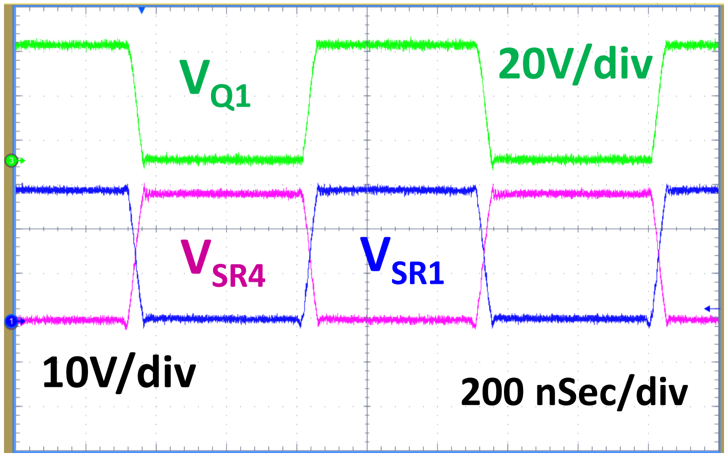
48 V to 12 V – 75 A



40 V to 10 V – 70 A

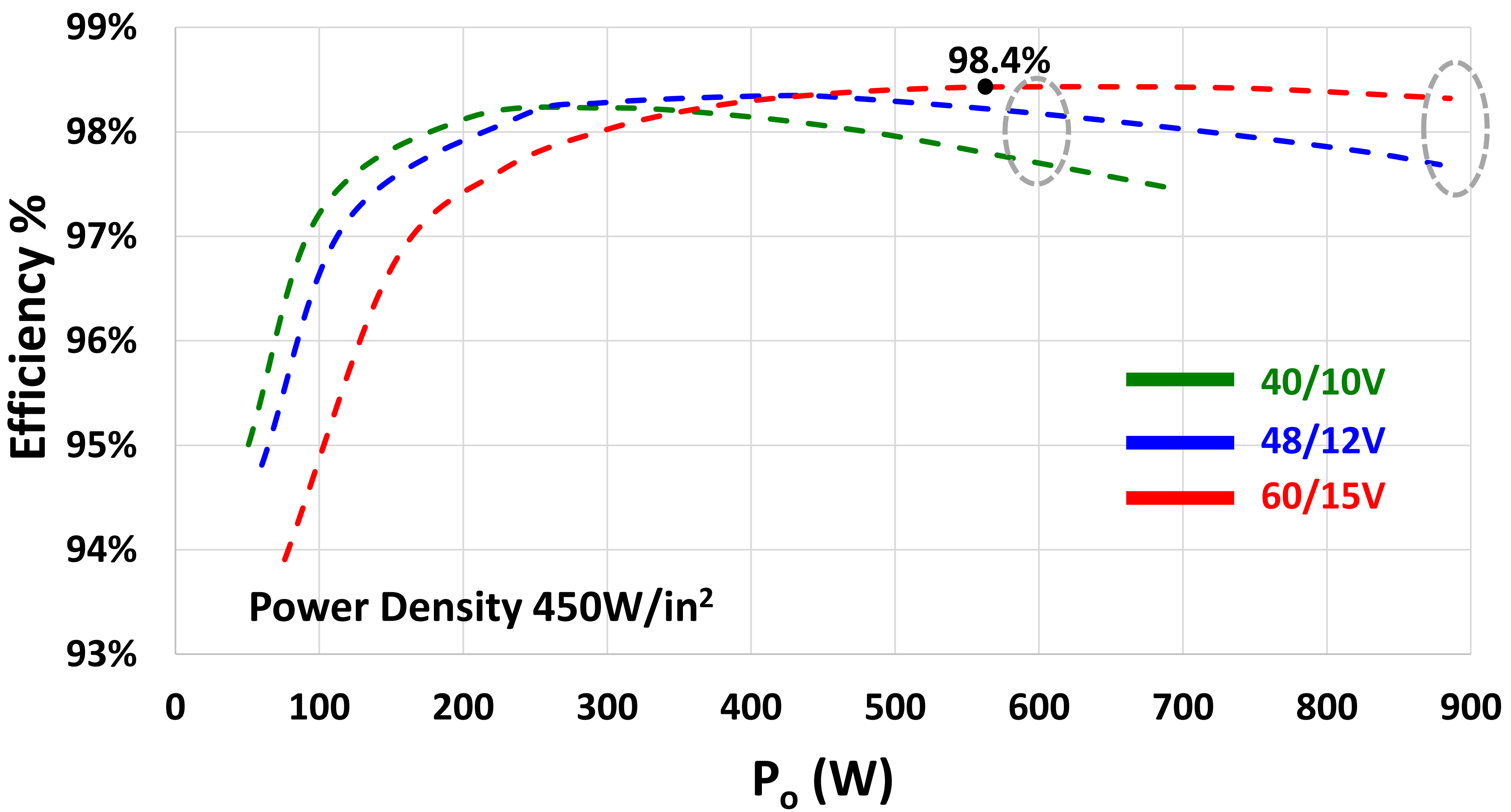


60 V to 15 V – 60 A



- **ZVS Operation at all conditions**
- **No overshoot on both primary and secondary devices**

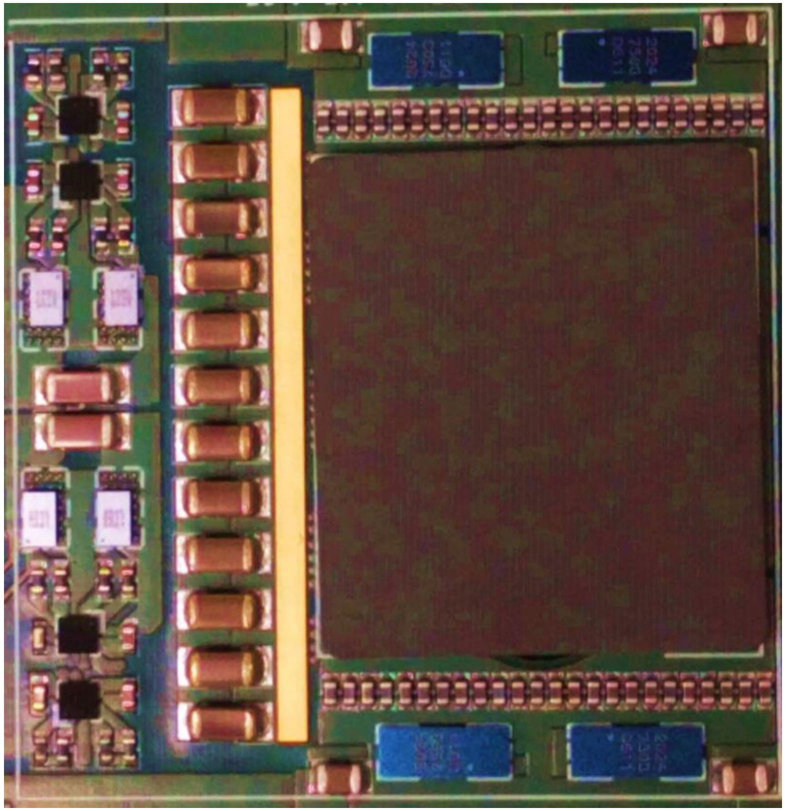
Efficiency V_{in} = 40 V - 60 V

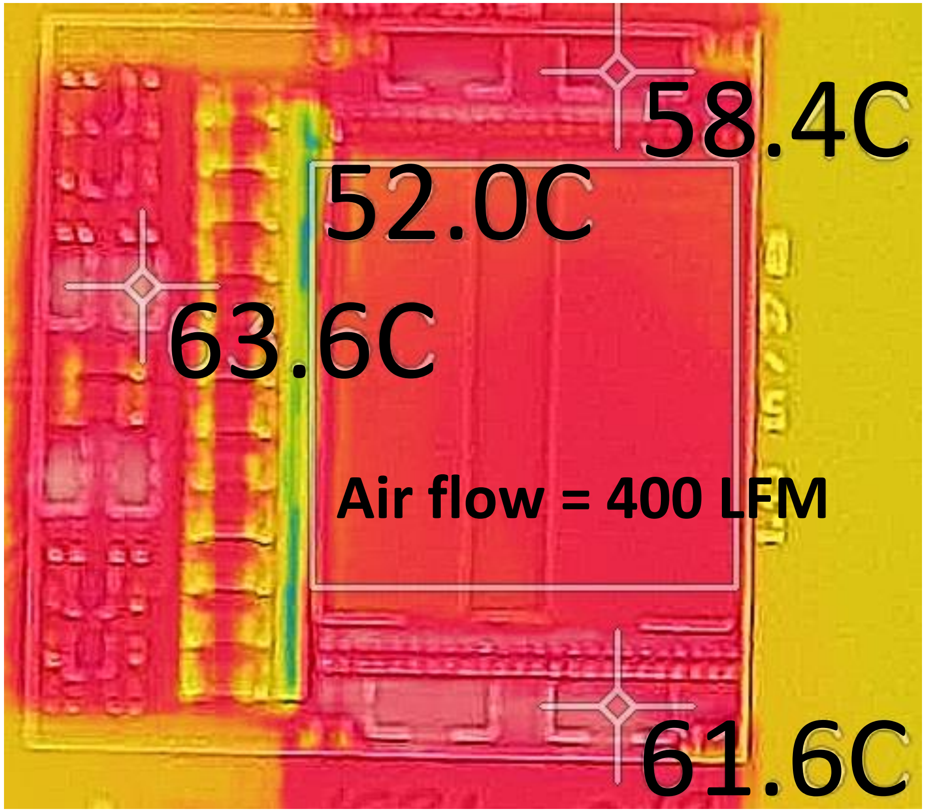


Power Supply limited at V_{in} = 40 V

Thermal Performance

V_{in}= 54 V, V_{out} = 13.5 V, P_{out} = 900 W, I_{out} = 70A, T_{amb} = 25°C





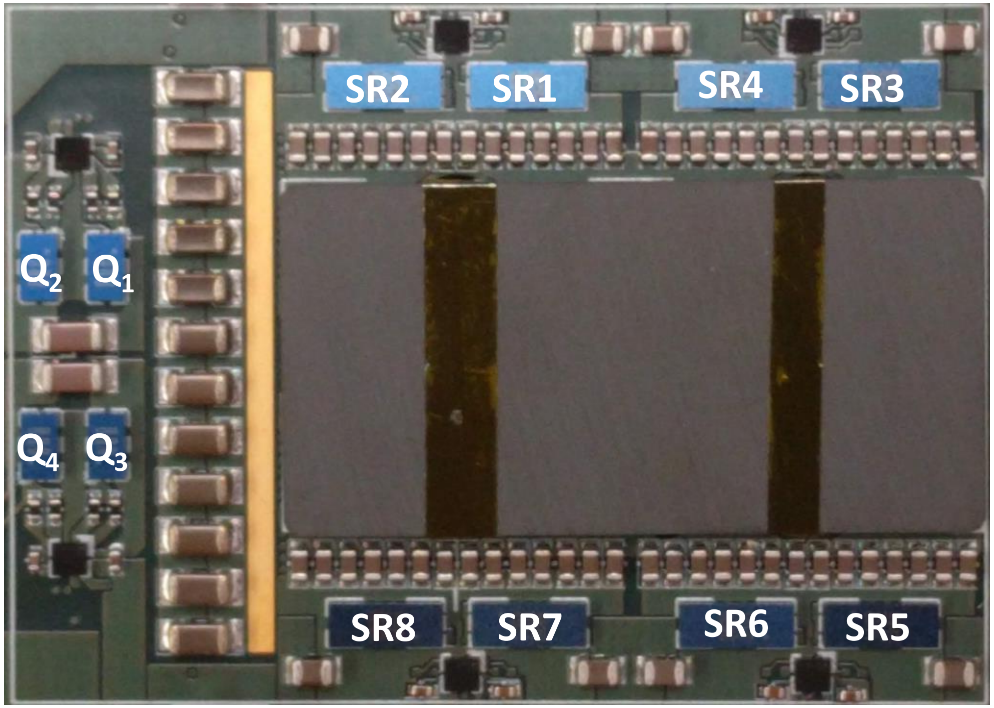
Excellent Current Sharing for Synchronous Rectifiers

900 W

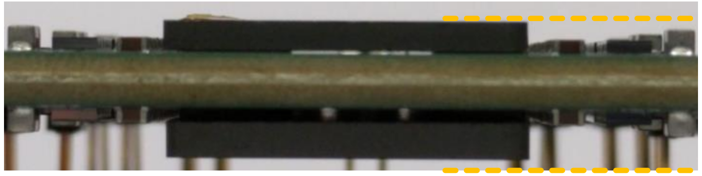
48 V to 6 V

48/6V GaN – DCX Module#1

51 mm



37 mm



6.9 mm

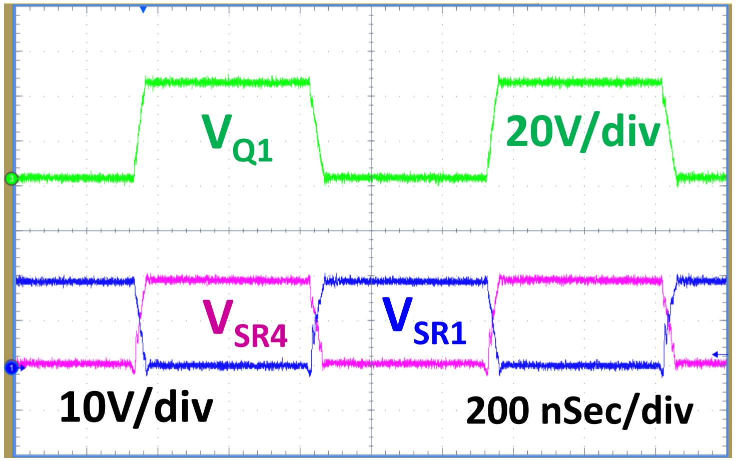
EPC9983B-V1

Q1 – Q4	EPC2053
SR1-SR8	EPC2023
V_{in}	48V – (40-60V)
V_o	6V – (5-7.5V)
P_{omax}	900W
F_s	1MHz
L_m	2.2 uH
C_r	16*0.22 uF = 3.52uF
Board SN	1831-033
PCB Layers	14

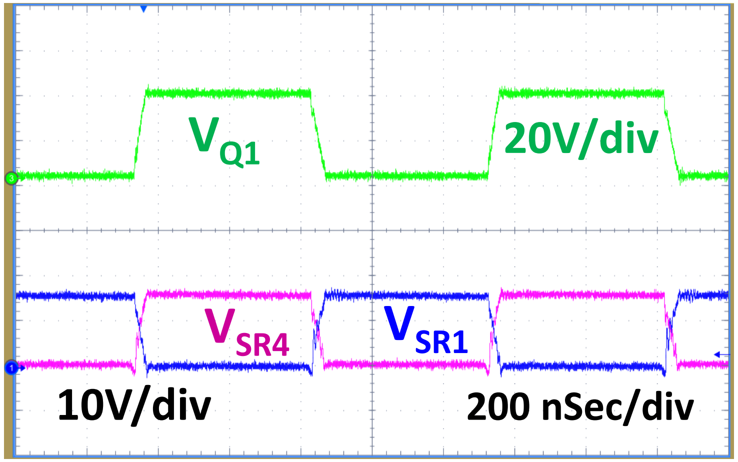
Power Density 1200 W/in^3 - 330 W/in^2

Full Load Waveforms

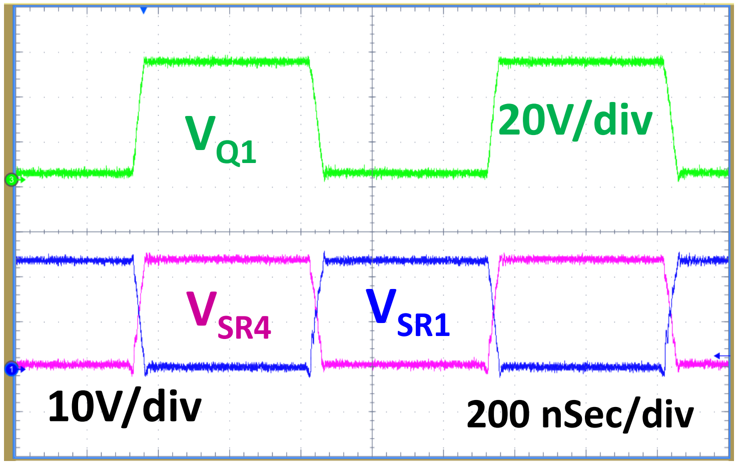
48 V to 6 V – 150 A



40 V to 5 V – 150 A

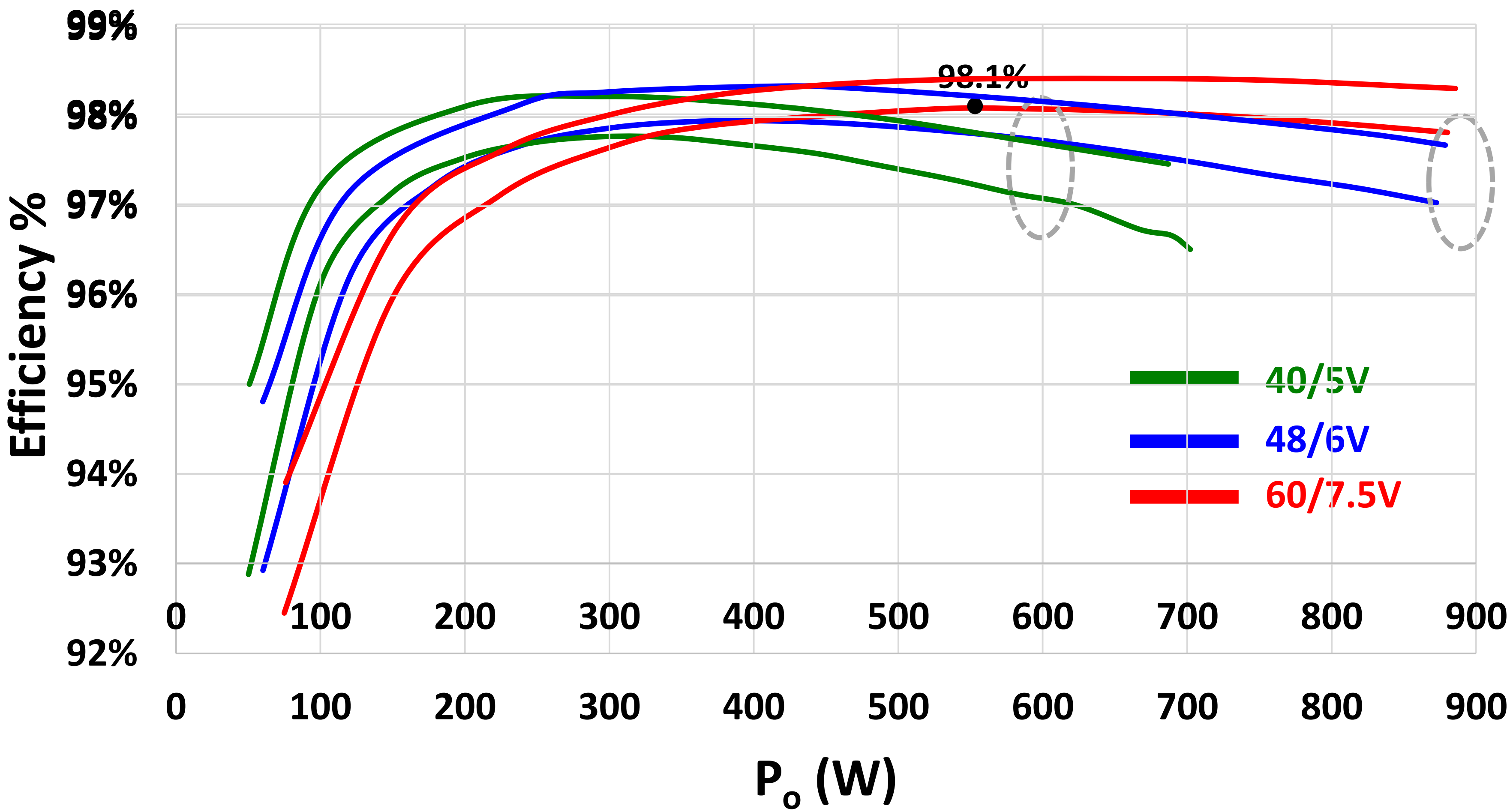


60 V to 7.5 V – 120 A



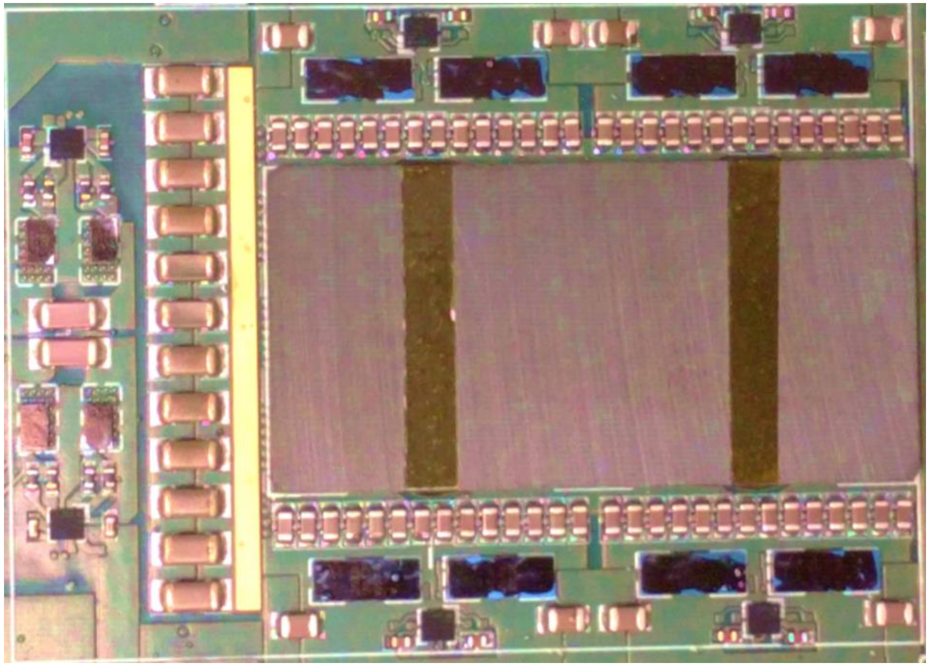
- ZVS Operation at all conditions
- No overshoot on both primary and secondary devices

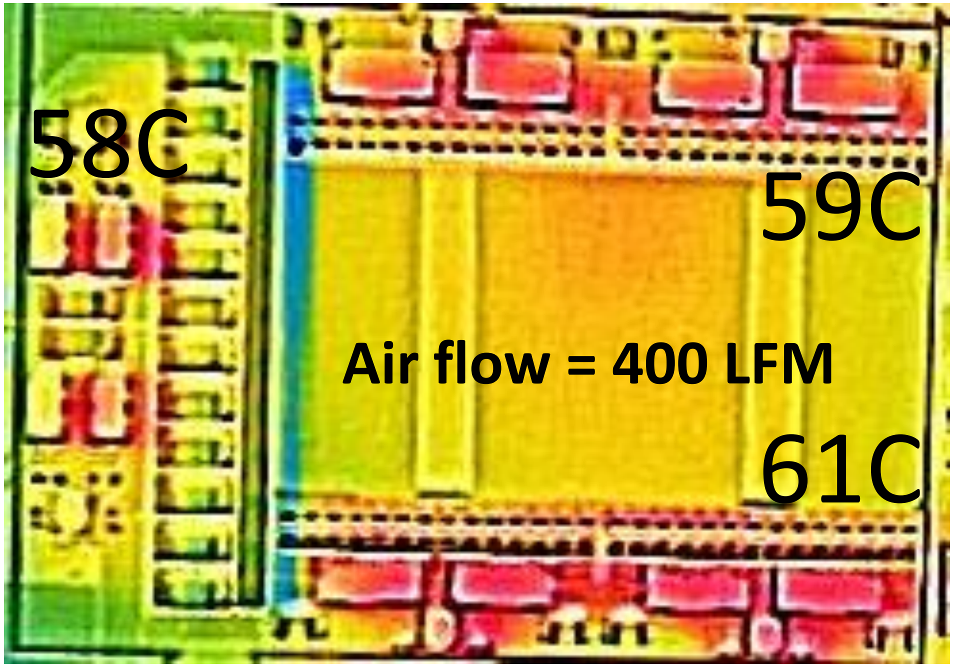
12 V_{out} vs 6 V_{Out}



Thermal Performance

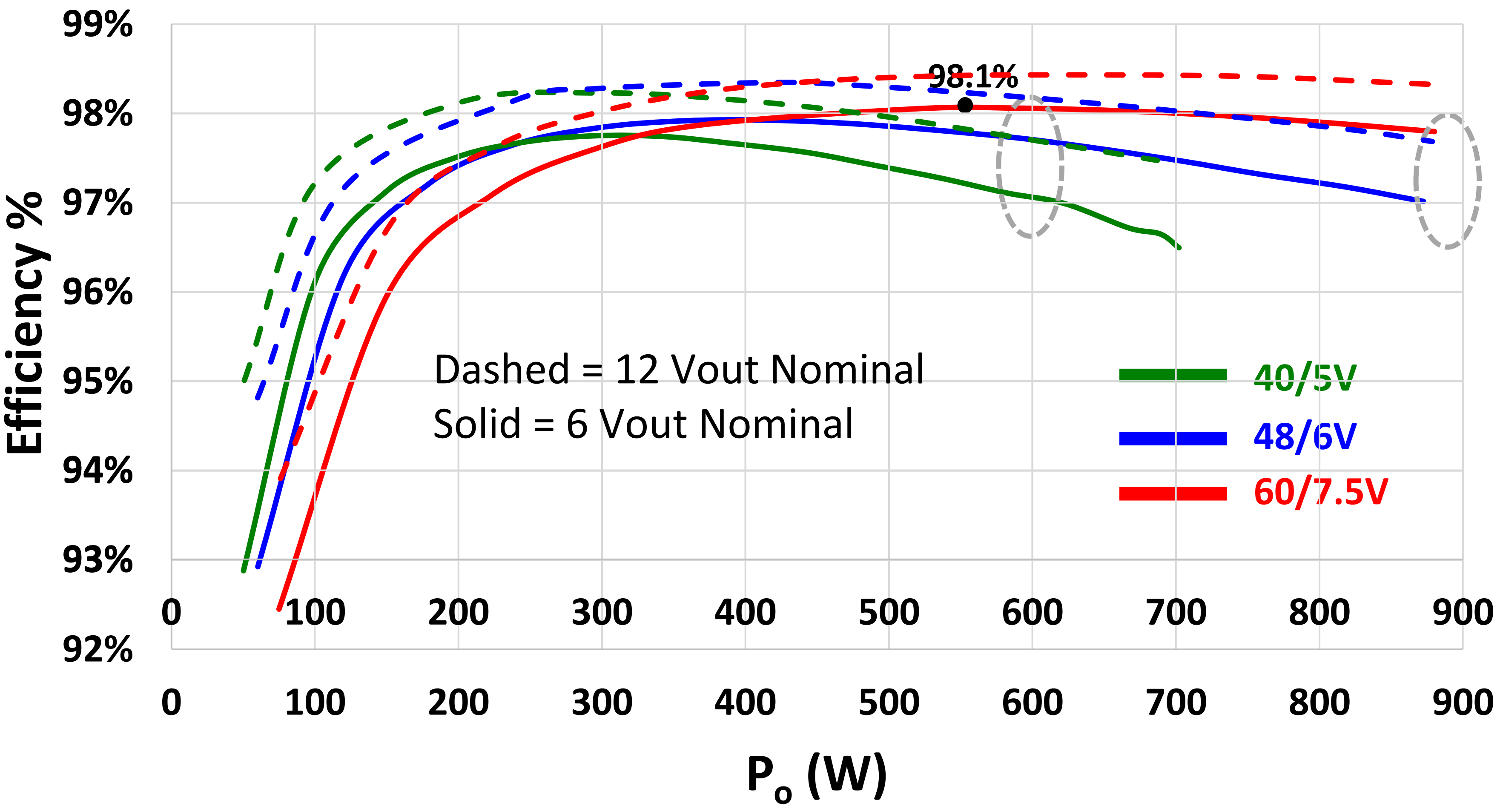
V_{in}= 54 V, V_{out} = 6.75 V, P_{out} = 900 W, I_{out} = 130 A, T_{amb} = 25°C



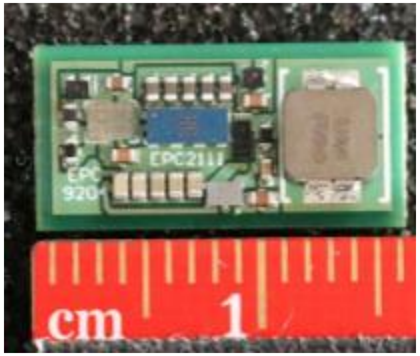


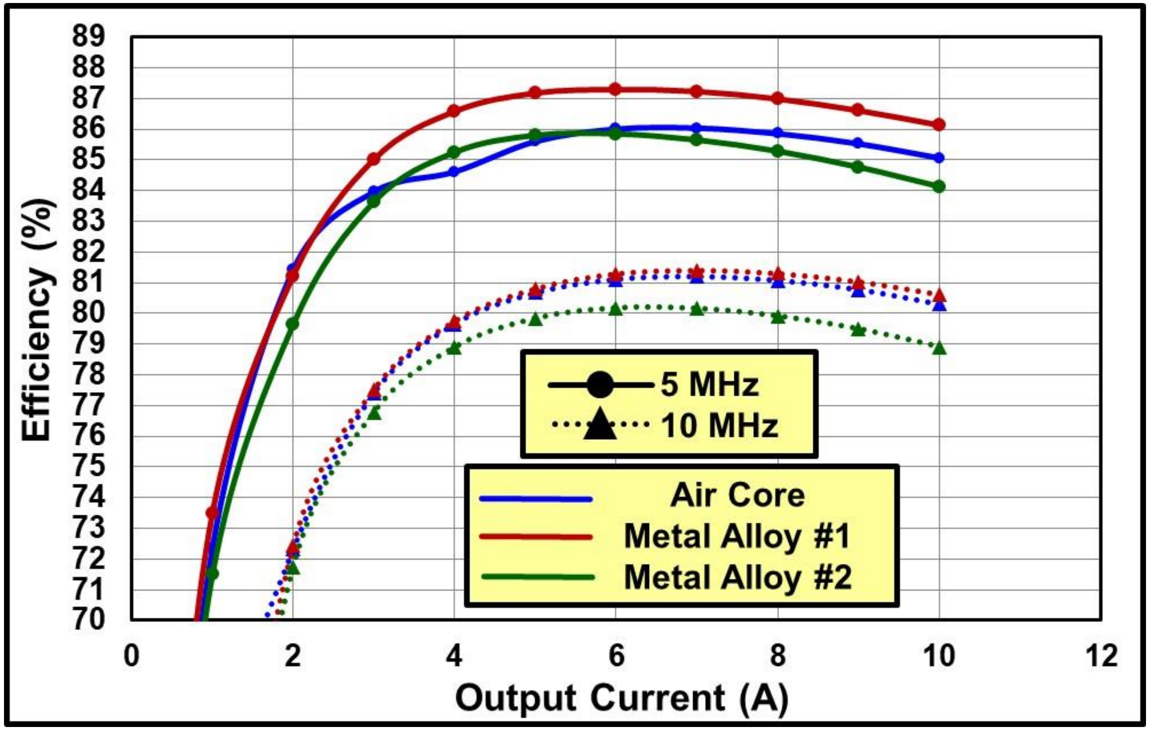
Excellent Current Sharing for Synchronous Rectifiers

12 V_{out} vs 6 V_{Out}



12 V to Load



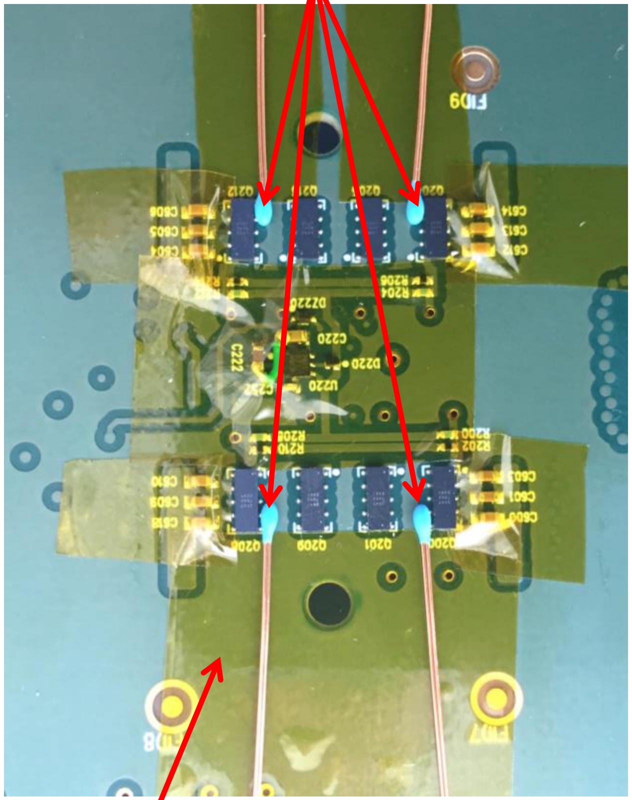


- **Uses EPC2111 half bridge IC and Psemi PE29102 gate driver**

Heatsink Installation Details

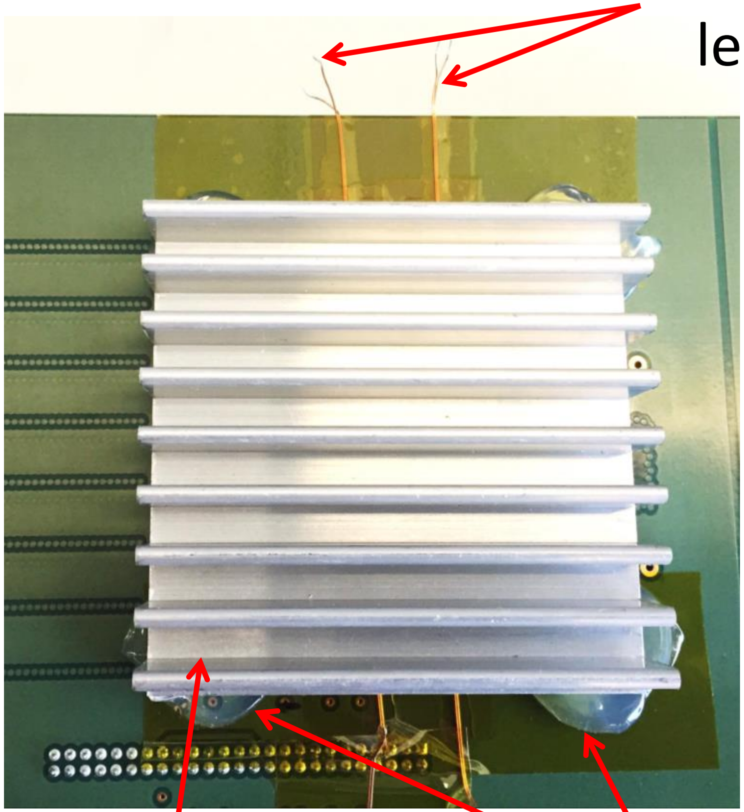
EPC EFFICIENT POWER CONVERSION

Sensor



Kapton (for insulation due to 140 V and switch-node)

Sensor leads



Heat-sink

RTV adhesive

Heatsink Details

- Effective fin height = 7 mm (1/2 actual)
- A_{fin_eff} = 8.96 cm^2
- A_{base_eff} = 28.35 cm^2
- A_{total} = 37.31 cm^2

[1] Rough estimate

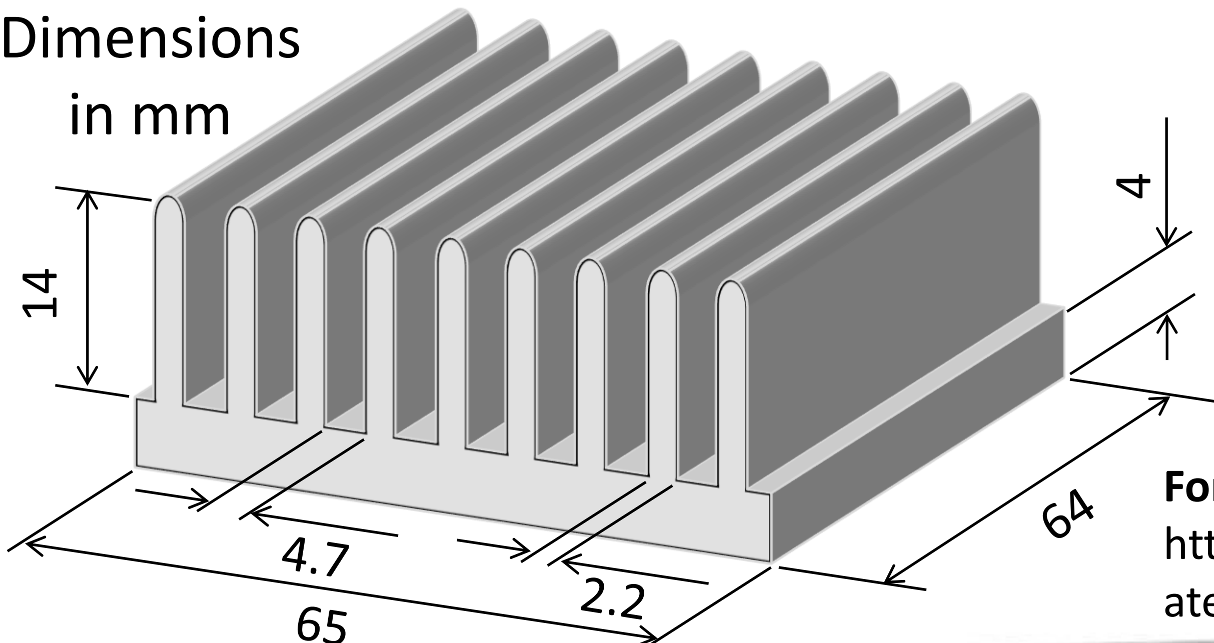
$$R_{\theta HS} = \frac{50}{\sqrt{A_{total}}}$$

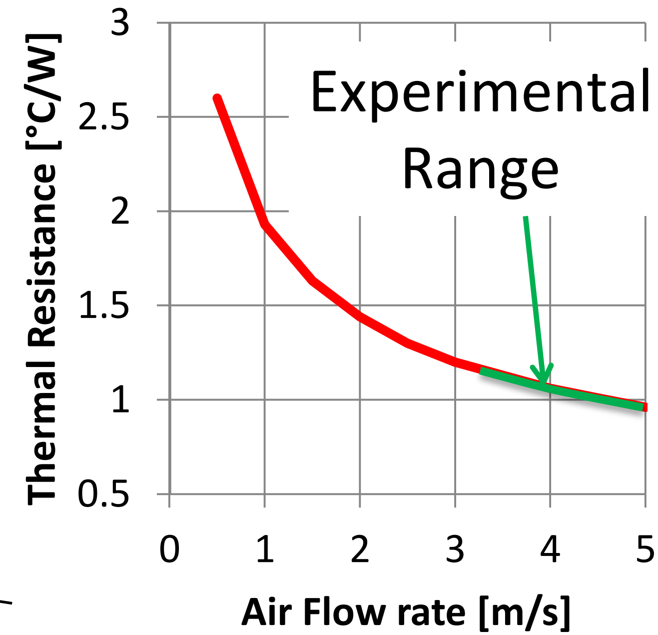
[2] Calculator from http://sound.whsites.net/heatsinks.htm

Convection cooling only

- $R_{\Theta HS}$ = 8.19 °C/W [1]
- $R_{\Theta HS}$ = 8.56 °C/W [2]

Dimensions in mm



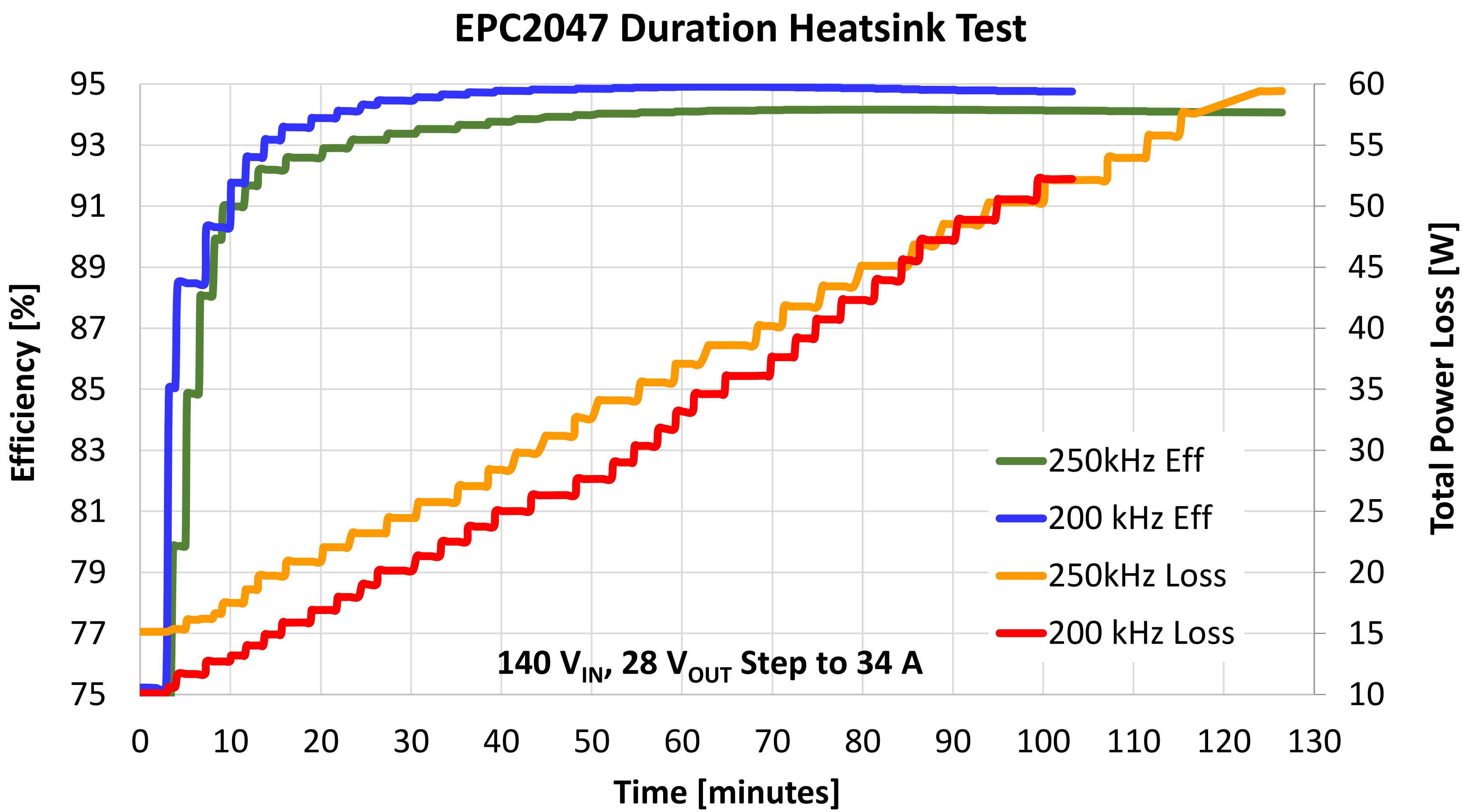


Forced Air Cooling

http://www.myheatsinks.com/calculate/thermal-resistance-plate-fin/#

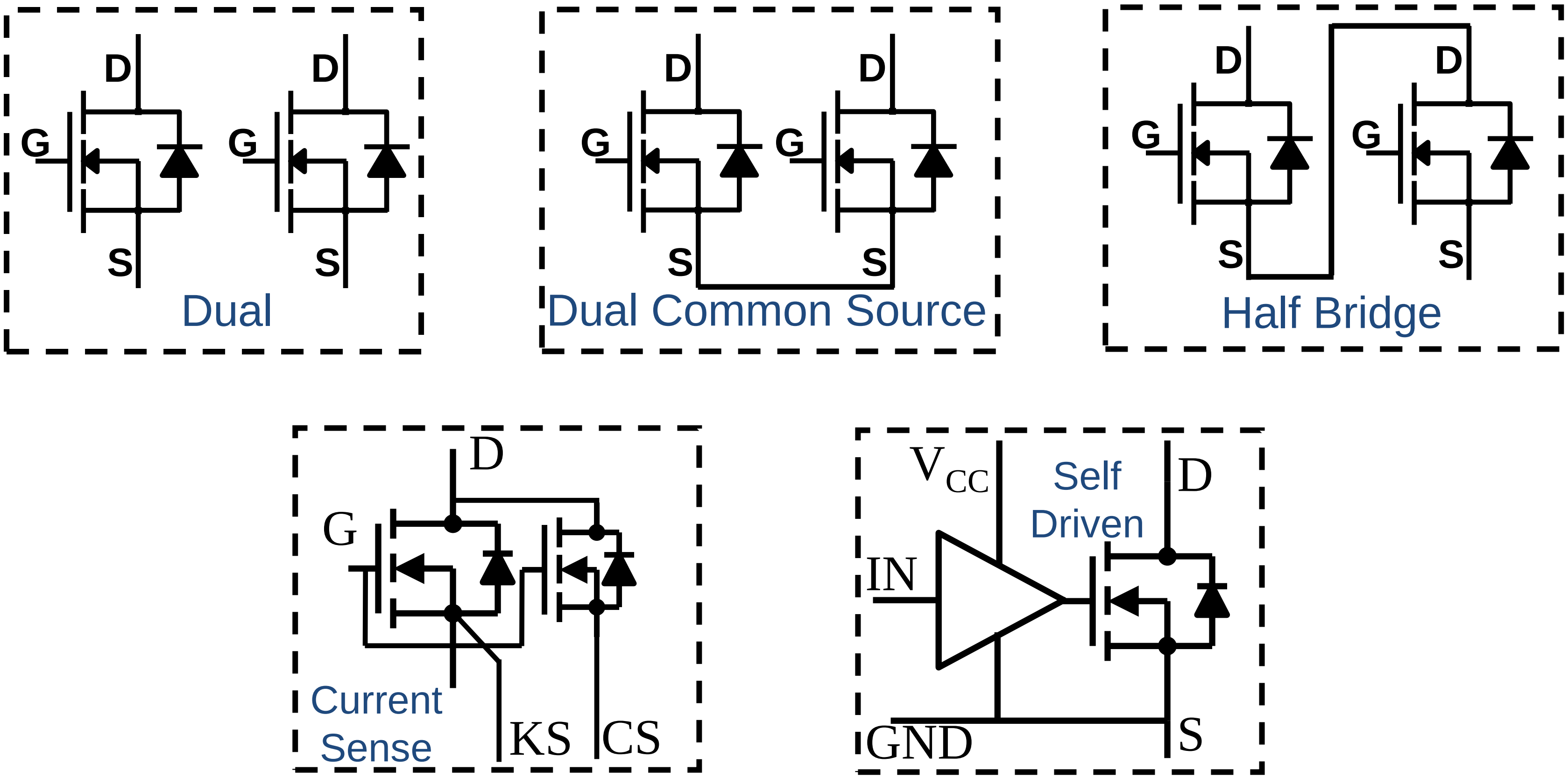
Heatsink Duration of Test

Steps indicate duration to reach thermal equilibrium



eGaN Integration

eGaN Integrated Circuits



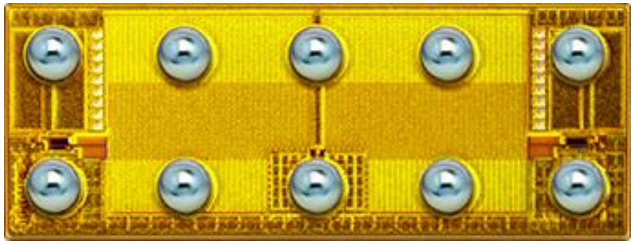
- Lateral structure allows cost effective, monolithic integration

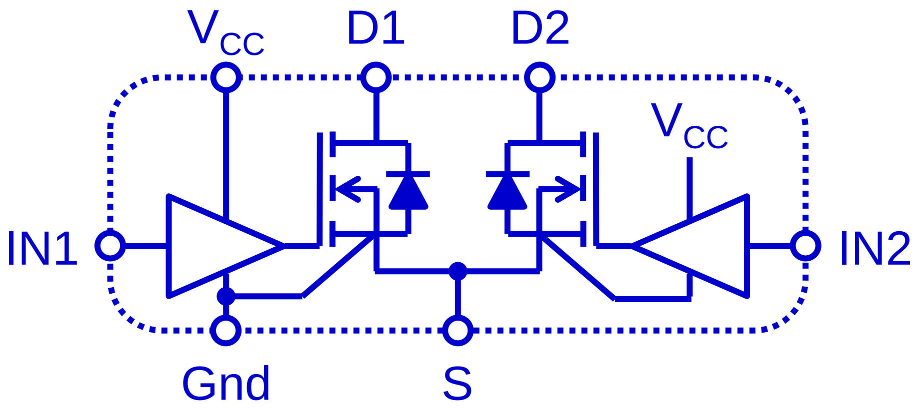
GaN Integration

Integrated Drivers

- Discrete FETs with integrated Gate driver

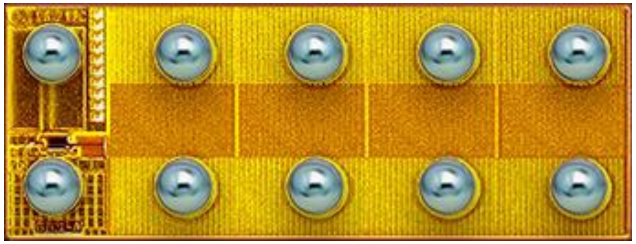
EPC2115

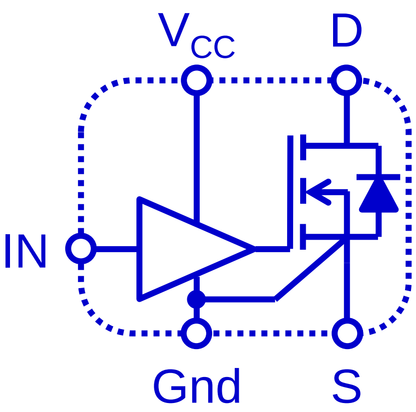




150 V, 88 mΩ

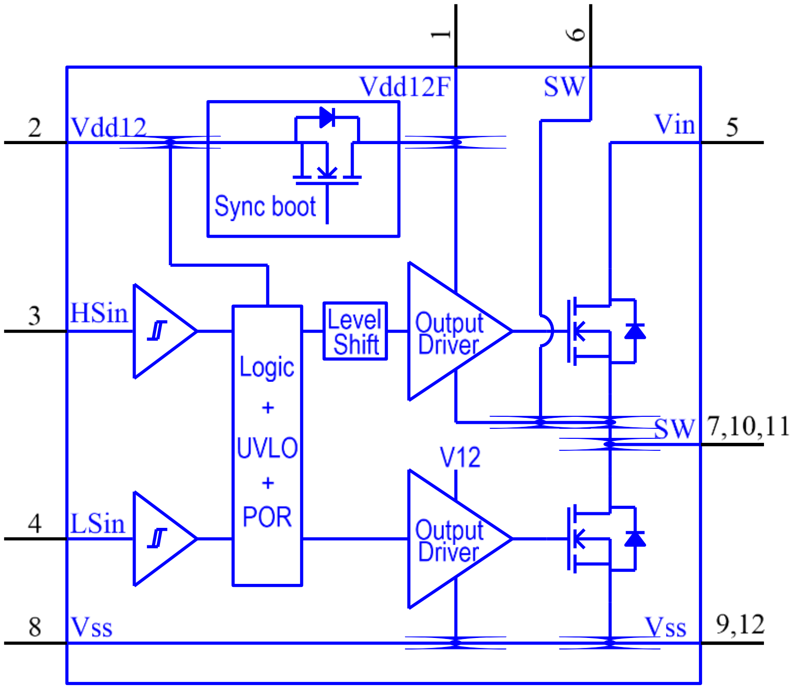
EPC2112

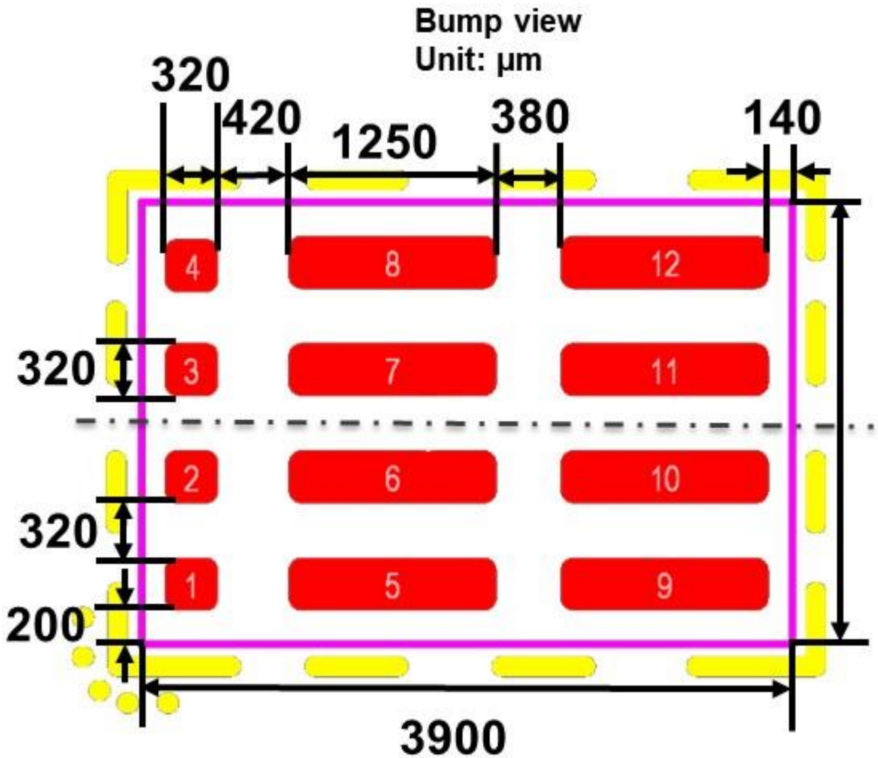




200 V , 40 mΩ

Half Bridge Power Stage IC

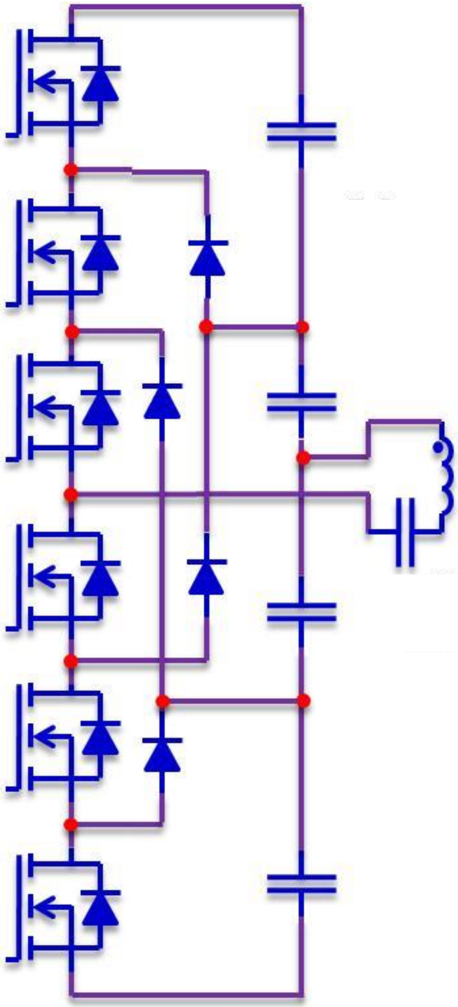




- 100 V, 10 A
- Engineering Samples Q1/19
- Basic Functional Block

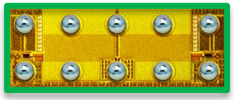
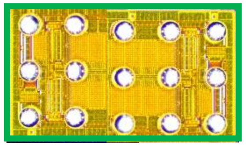
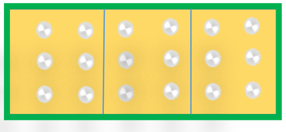
High Voltage

- EPC Focused on lower voltages
- Multi-level topologies more efficient in high voltage applications



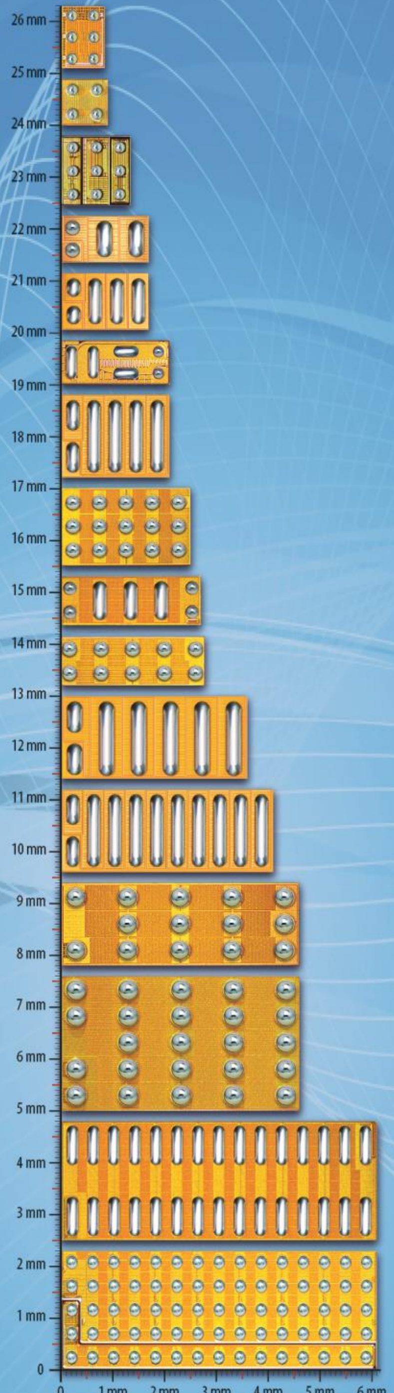
Future eGaN Technology Roadmap

Technology	Gen 5	Gen 6	Gen 7
	21mm-mΩ* 150mm	11mm-mΩ*	6mm-mΩ* 200mm

Product	Dual FETs plus driver	Half Bridge plus driver plus level shift	Multi-level plus driver plus level shift
			

2018 2019 2020 2021

* 100 V Rated Product



EPC

EFFICIENT POWER CONVERSION