



The eGaN® FET
Journey Continues

GaN Transistors for Efficient Power Conversion

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Efficient Power Conversion Corporation

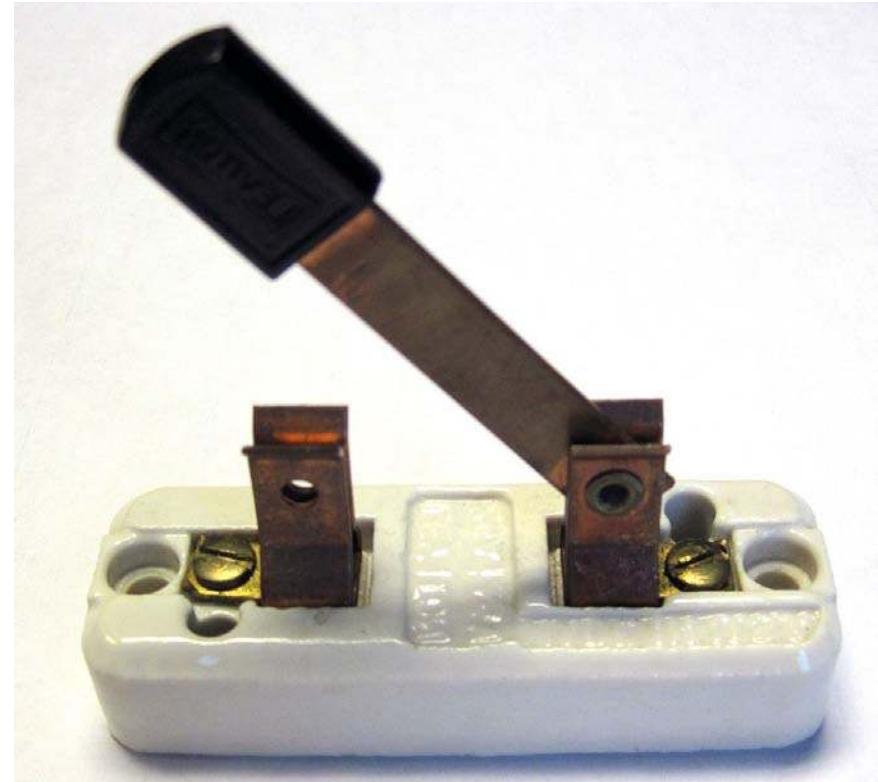
Agenda



- The GaN Journey Begins
- Enhancement Mode GaN FETs
- Improving Power Conversion Efficiency
- What is in the future?

The Ideal Power Switch

- Block Infinite Voltage
- Carry Infinite Current
- Switch In Zero Time
- Zero Drive Power
- Normally Off

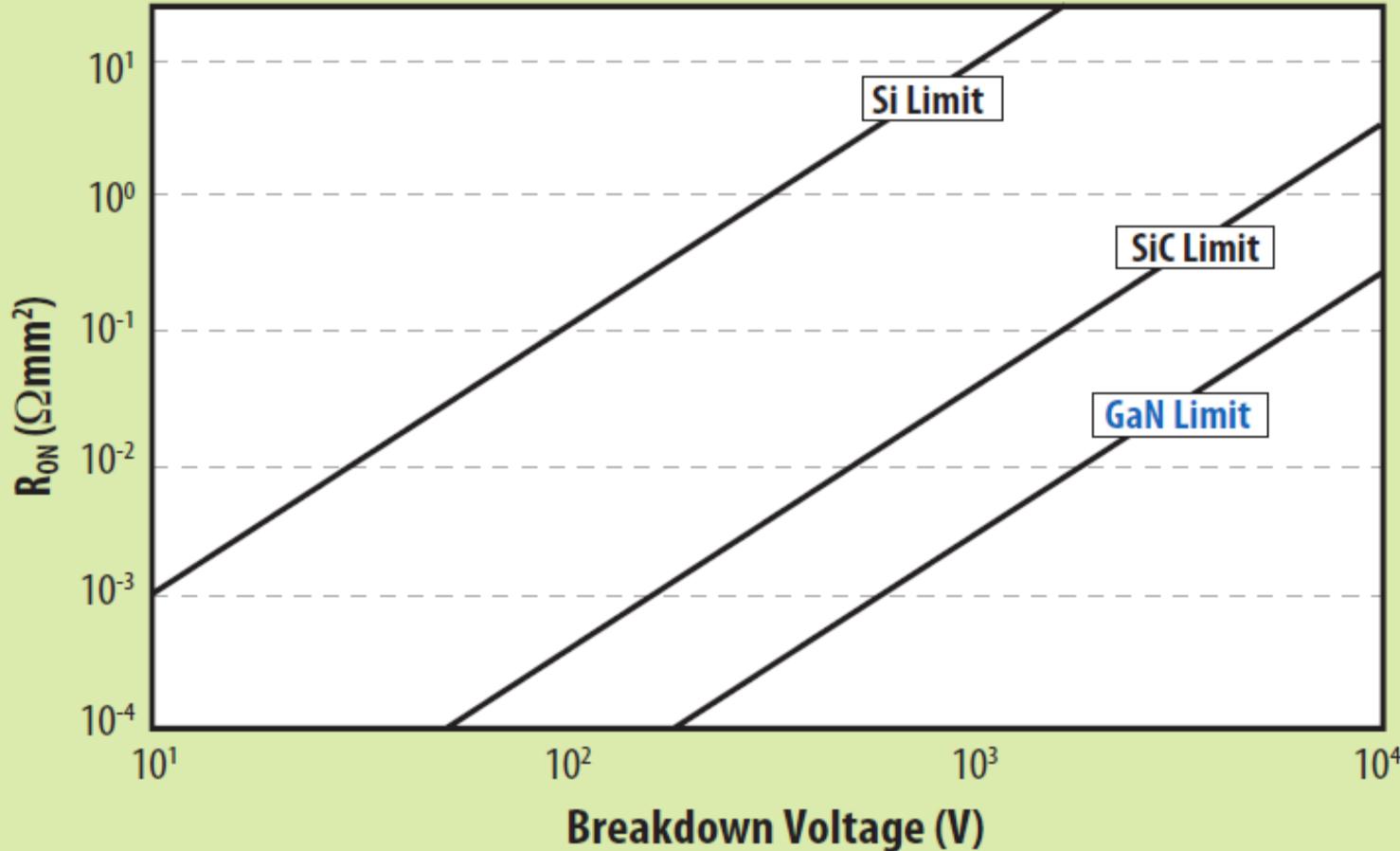


Material Comparison



Properties*	GaN	Si	SiC
E_G (eV)	3.4	1.12	3.2
E_{BR} (MV/cm)	3.3	0.3	3.5
V_s ($\times 10^7$ cm/s)	2.5	1.0	2.0
μ (cm ² /Vs)	990 - 2000	1500	650

Material Comparison



Theoretical on-resistance vs blocking voltage capability for silicon, silicon-carbide, and gallium nitride

GaN vs SiC Comparison



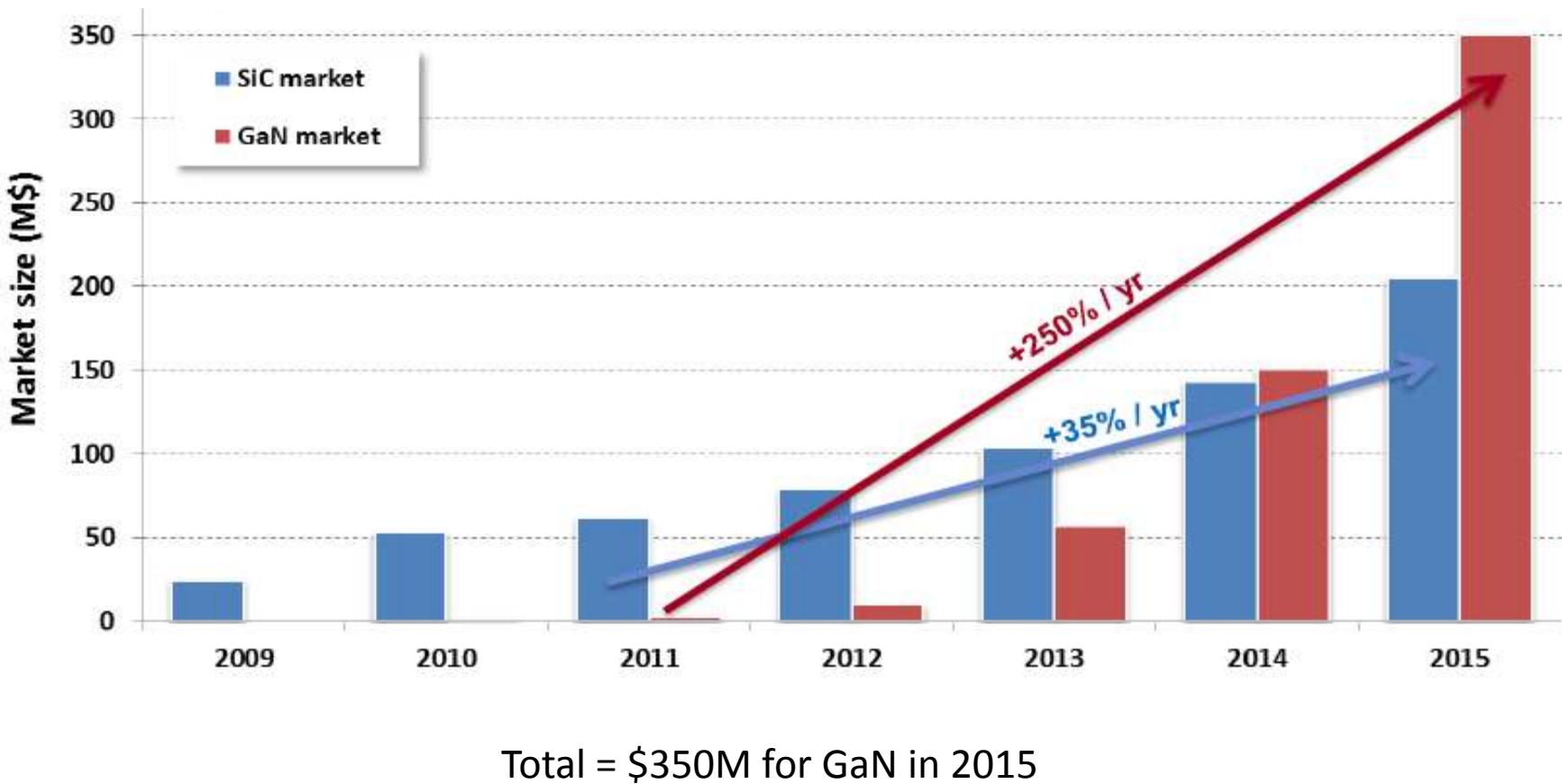
Pro GaN

- GaN mobility almost 3 times SiC
- GaN on silicon can be manufactured in a standard silicon foundry on large diameter wafers
- GaN-on-silicon starting material can be much lower cost than SiC
- Monolithic integration of multiple power and analog devices is straightforward

Pro SiC

- SiC thermal conductivity is 3 times GaN
- SiC vertical devices may be more straightforward to manufacture than GaN-on-silicon

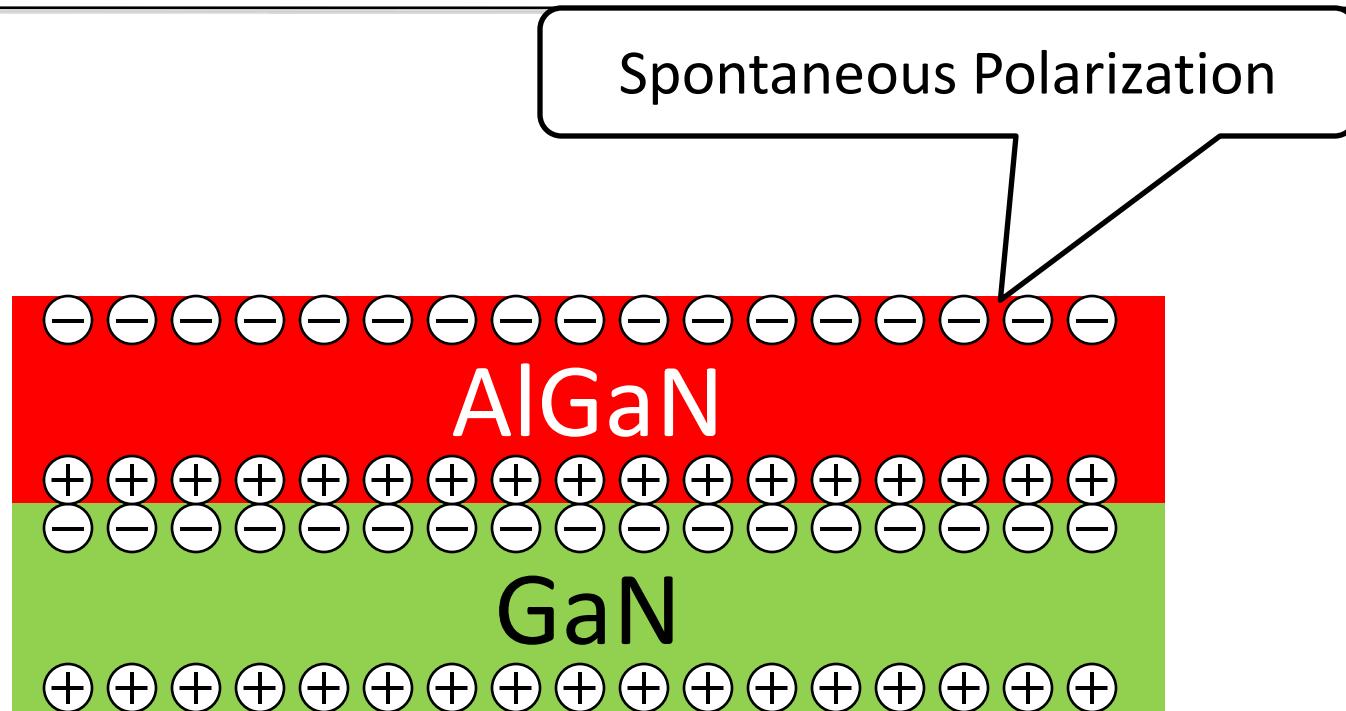
GaN Market Projection



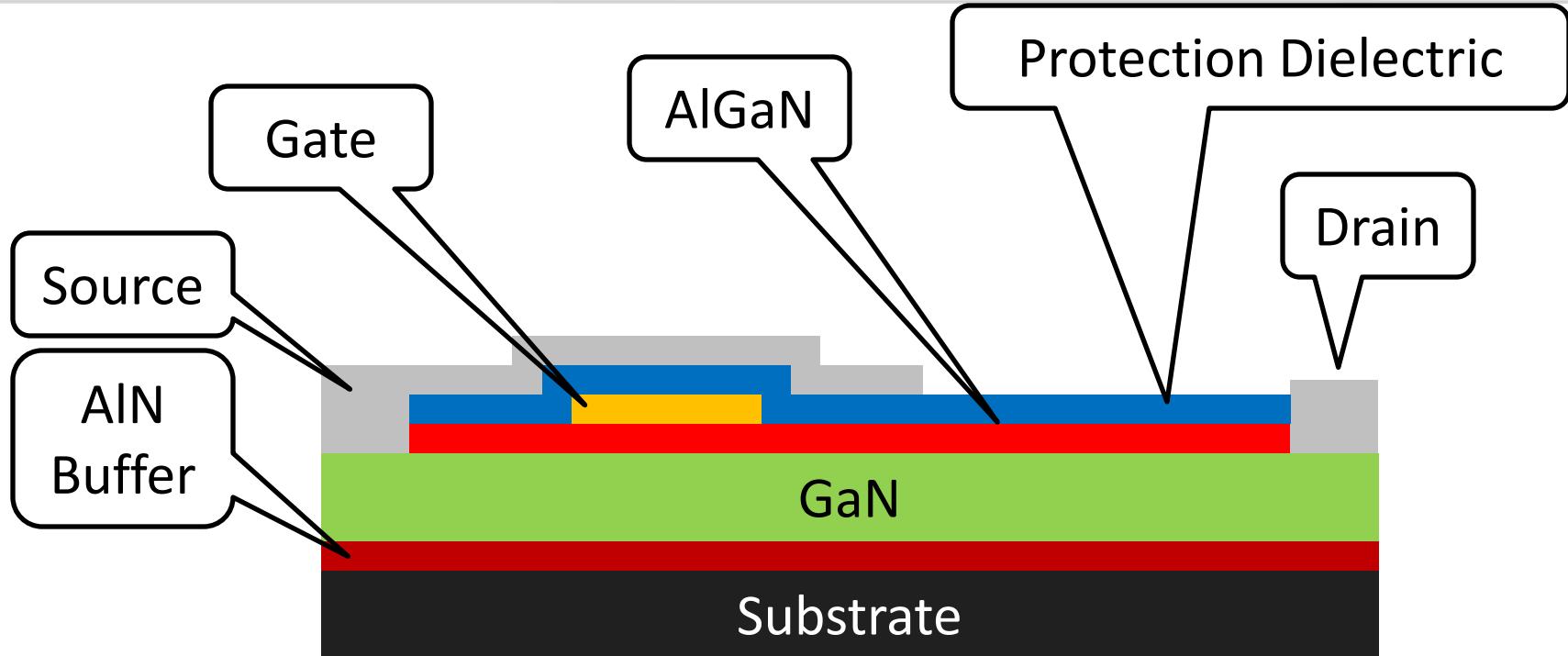
Source: Yole Development

How Does a GaN HEMT Work?

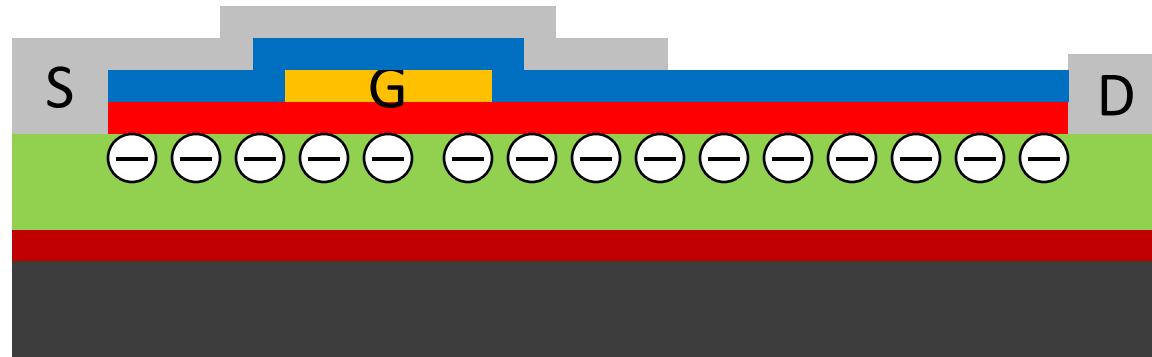
GaN + AlGaN



Device Construction Concept

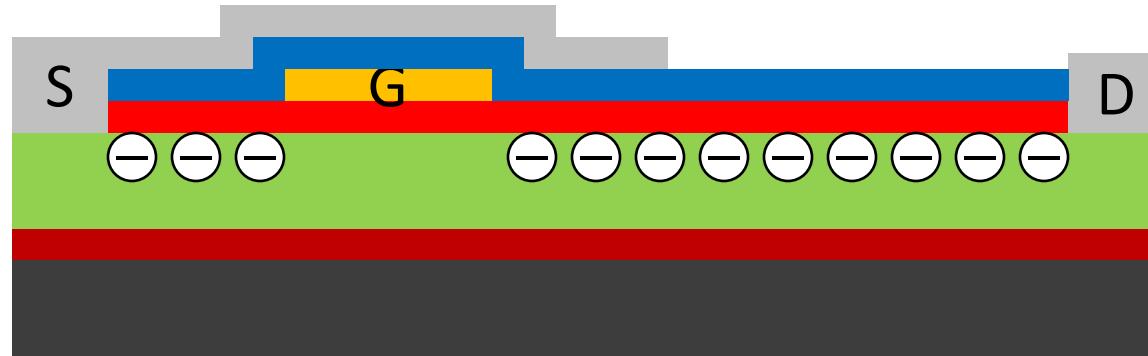


Normally ON Devices



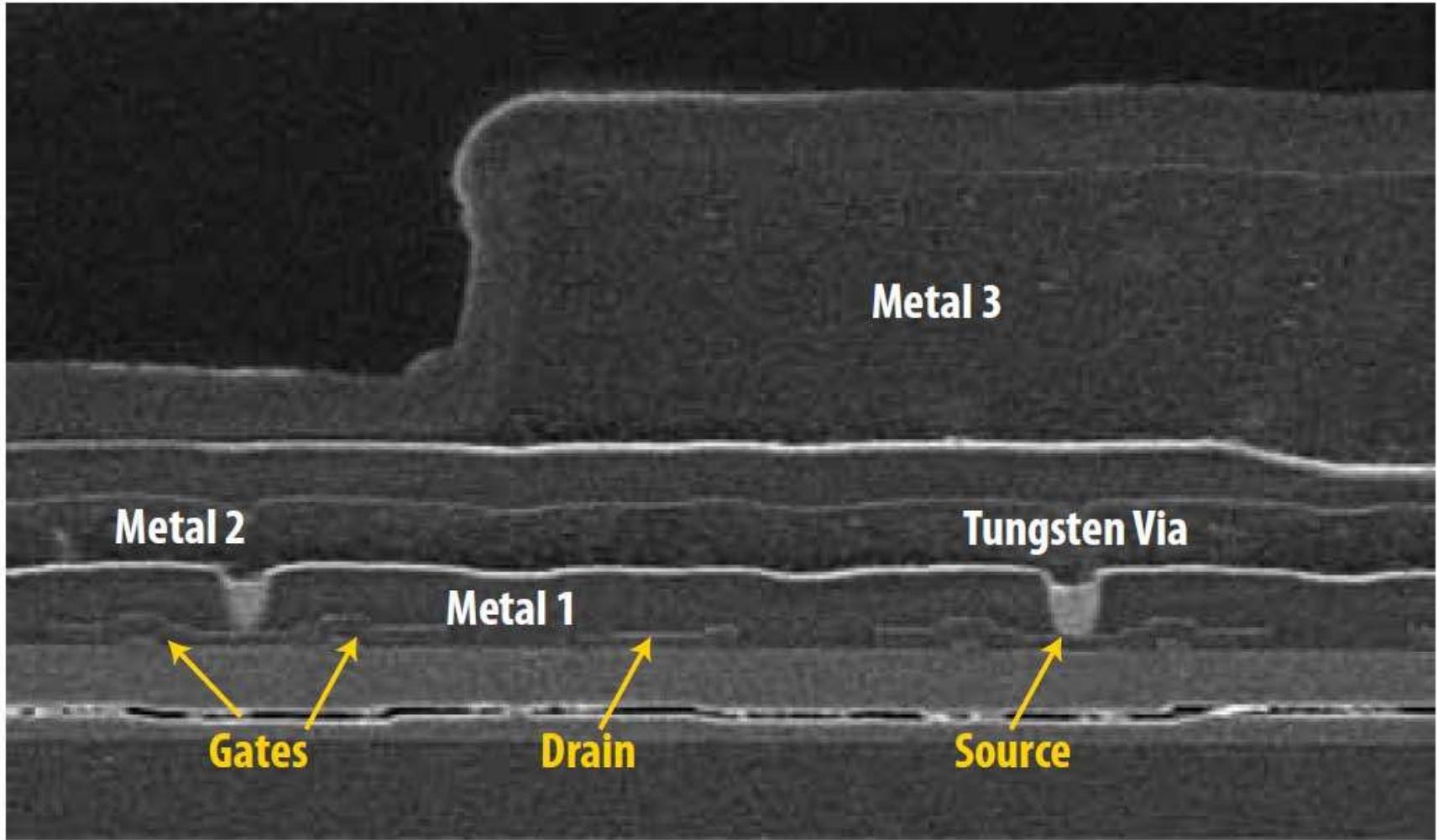
In a normally ON device the 2DEG can only be removed under the gate electrode when a negative gate voltage is applied relative to the source

Normally Off Devices – eGaN® FETs

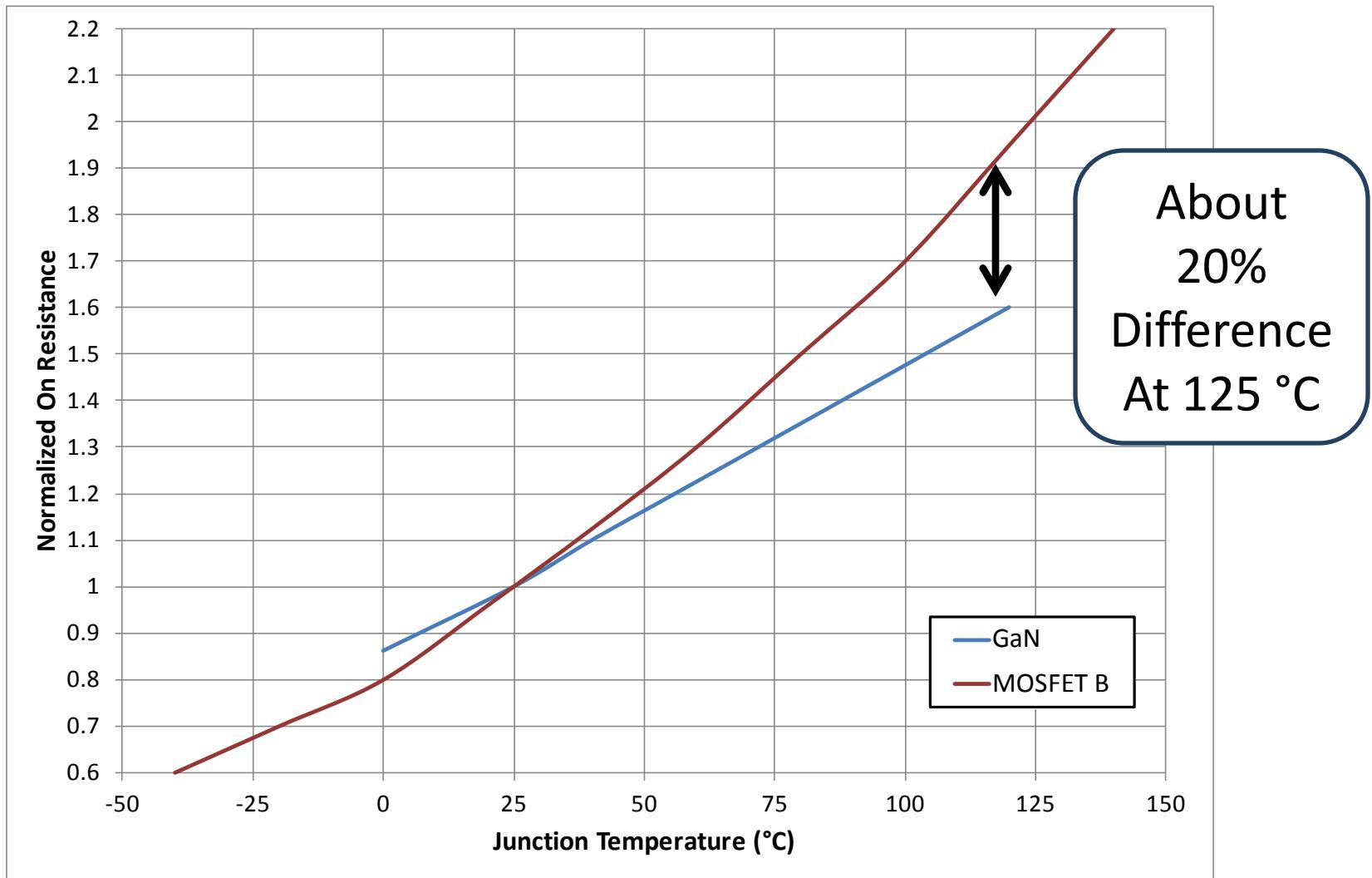


At zero volts on the gate the 2DEG is depleted under the enhancement mode gate electrode and is restored by a positive voltage on the gate relative to the source

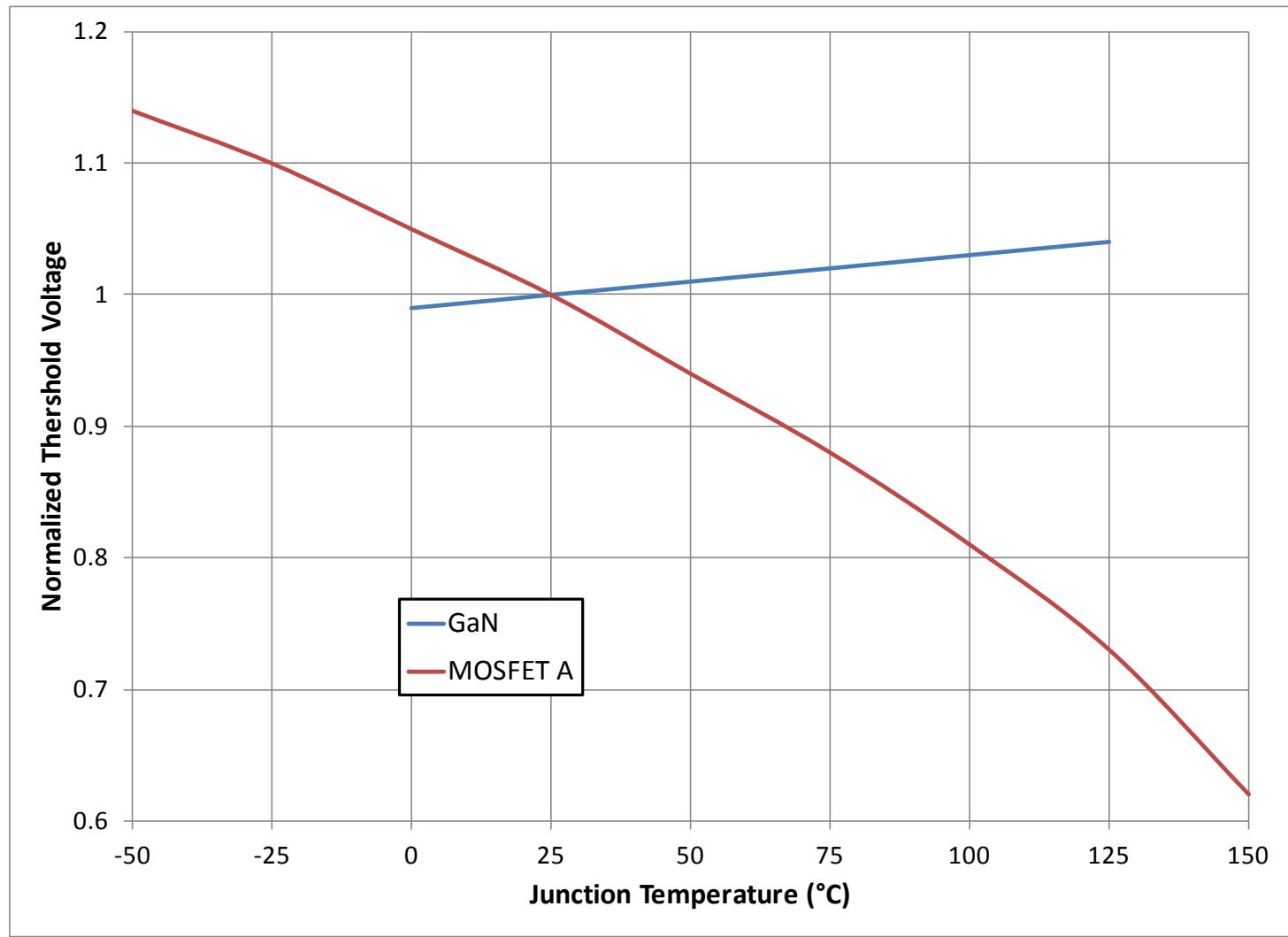
SEM of an eGaN® FET



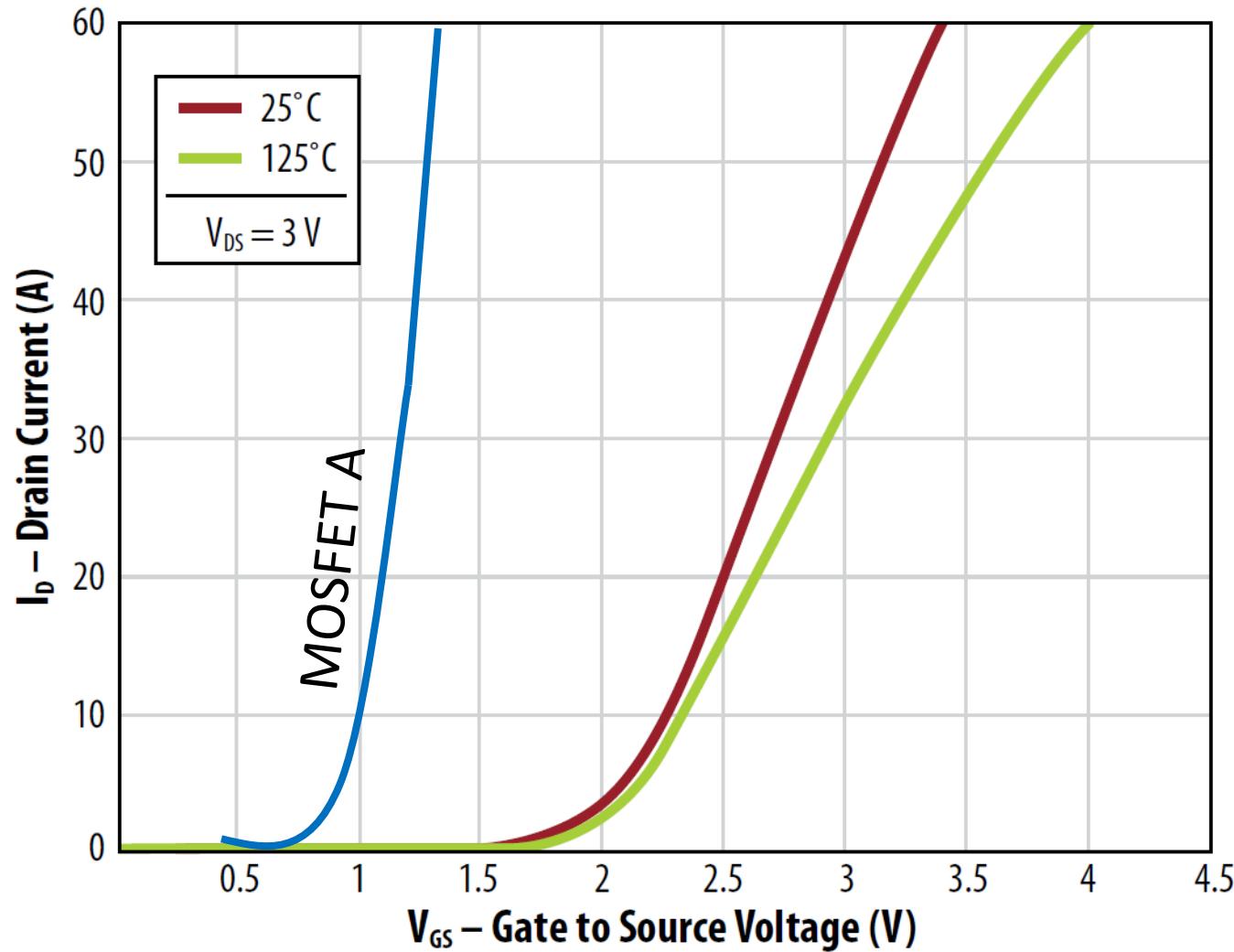
On Resistance vs Temperature



Threshold vs Temperature



eGaN®FET Reverse Conduction



Total Gate Charge

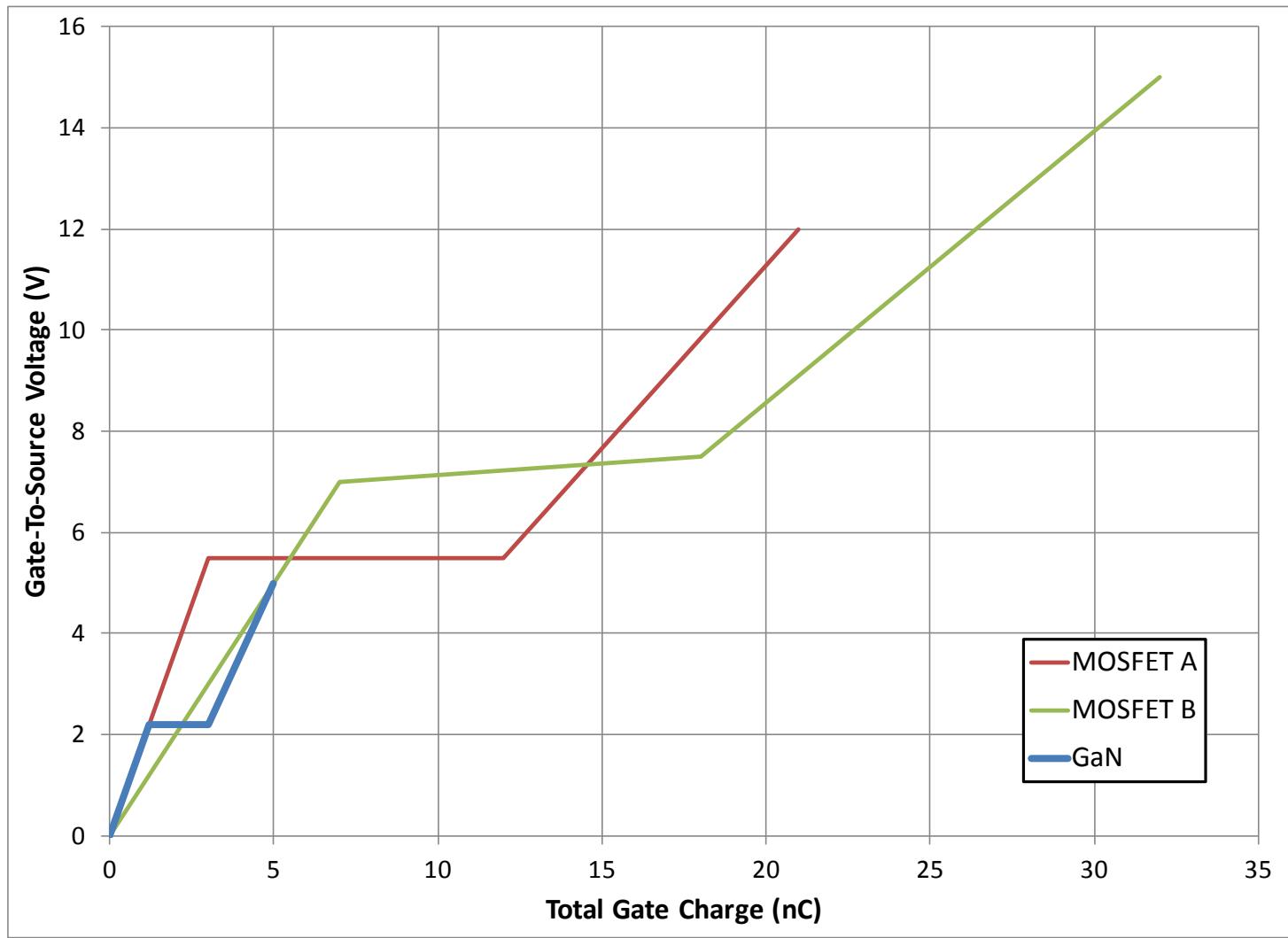
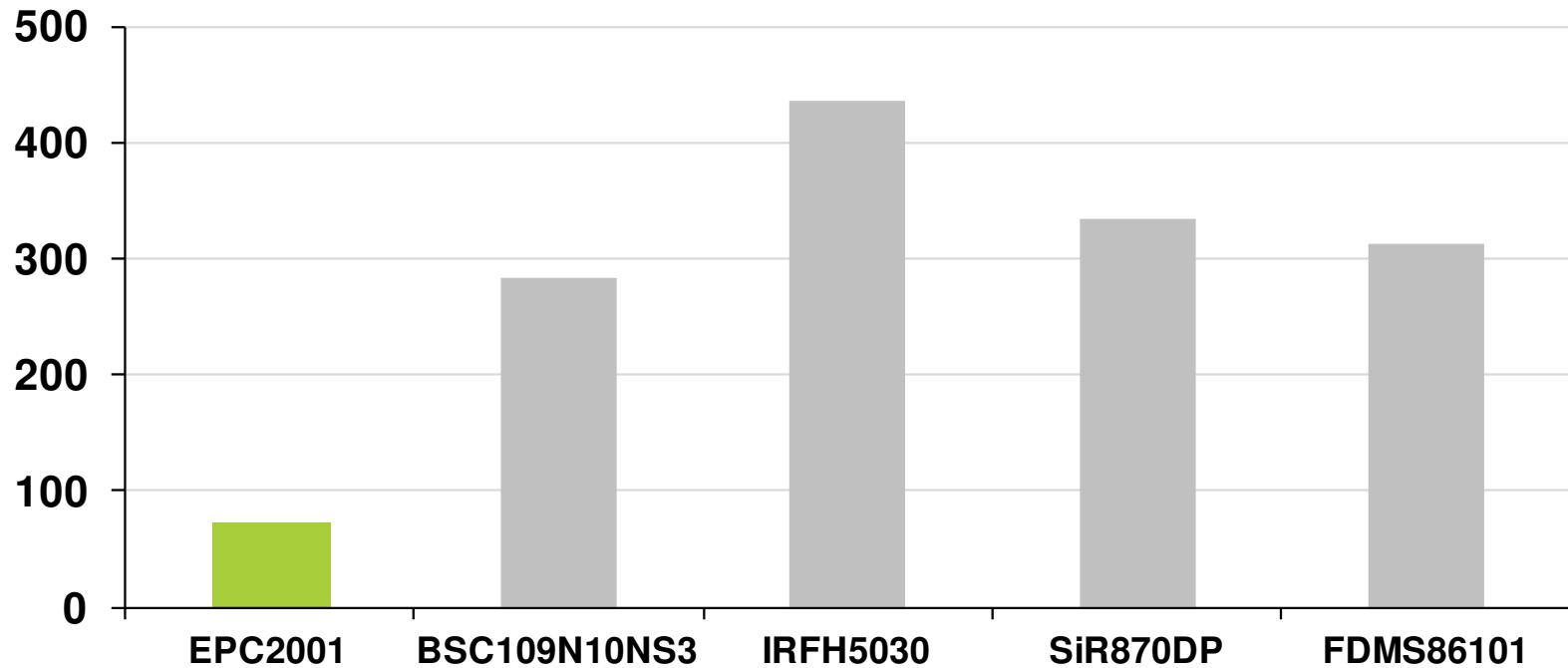


Figure of Merit



FOM = $R_{dson} \times Q_g$ (100V)

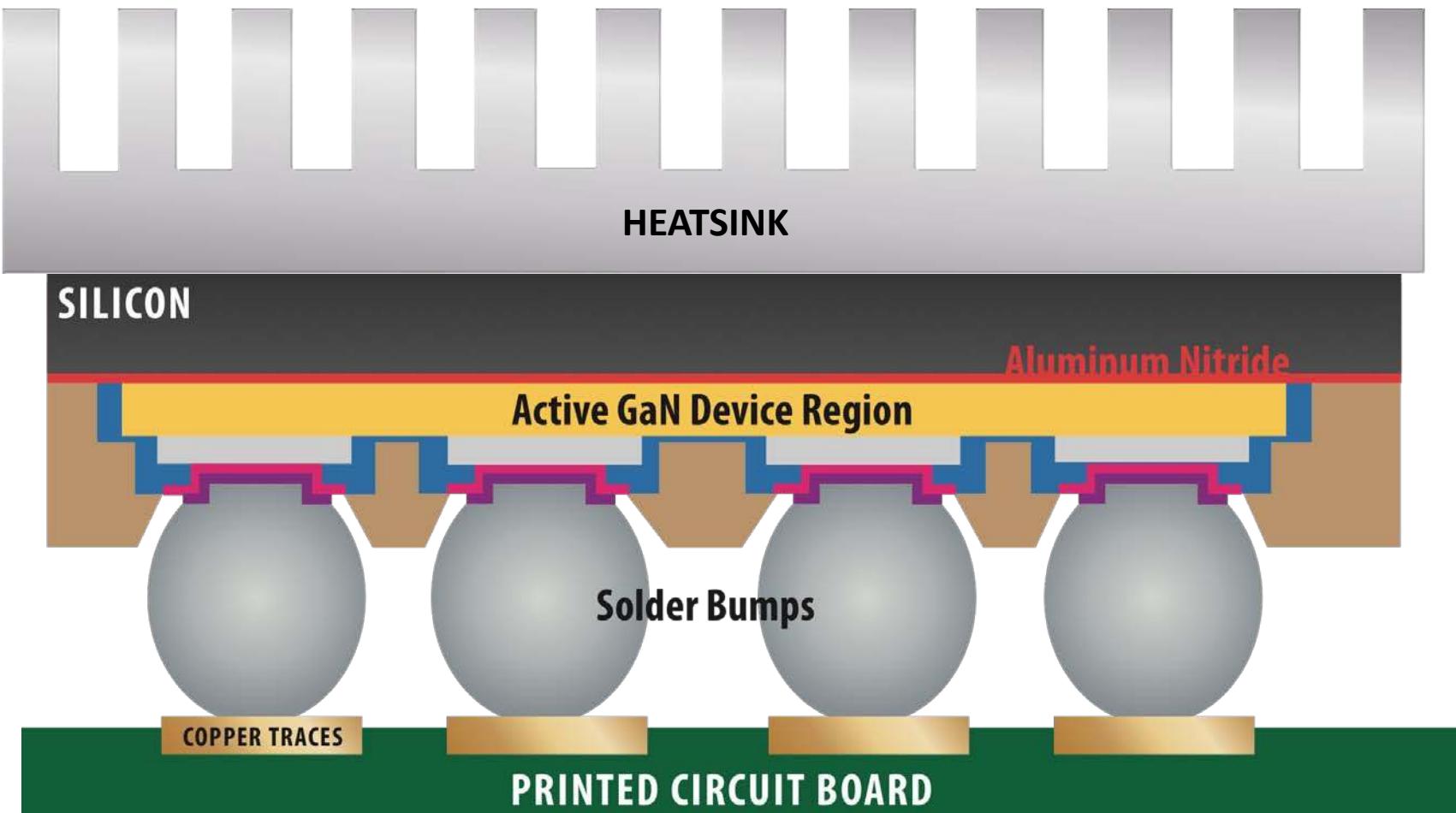


Package Wish List

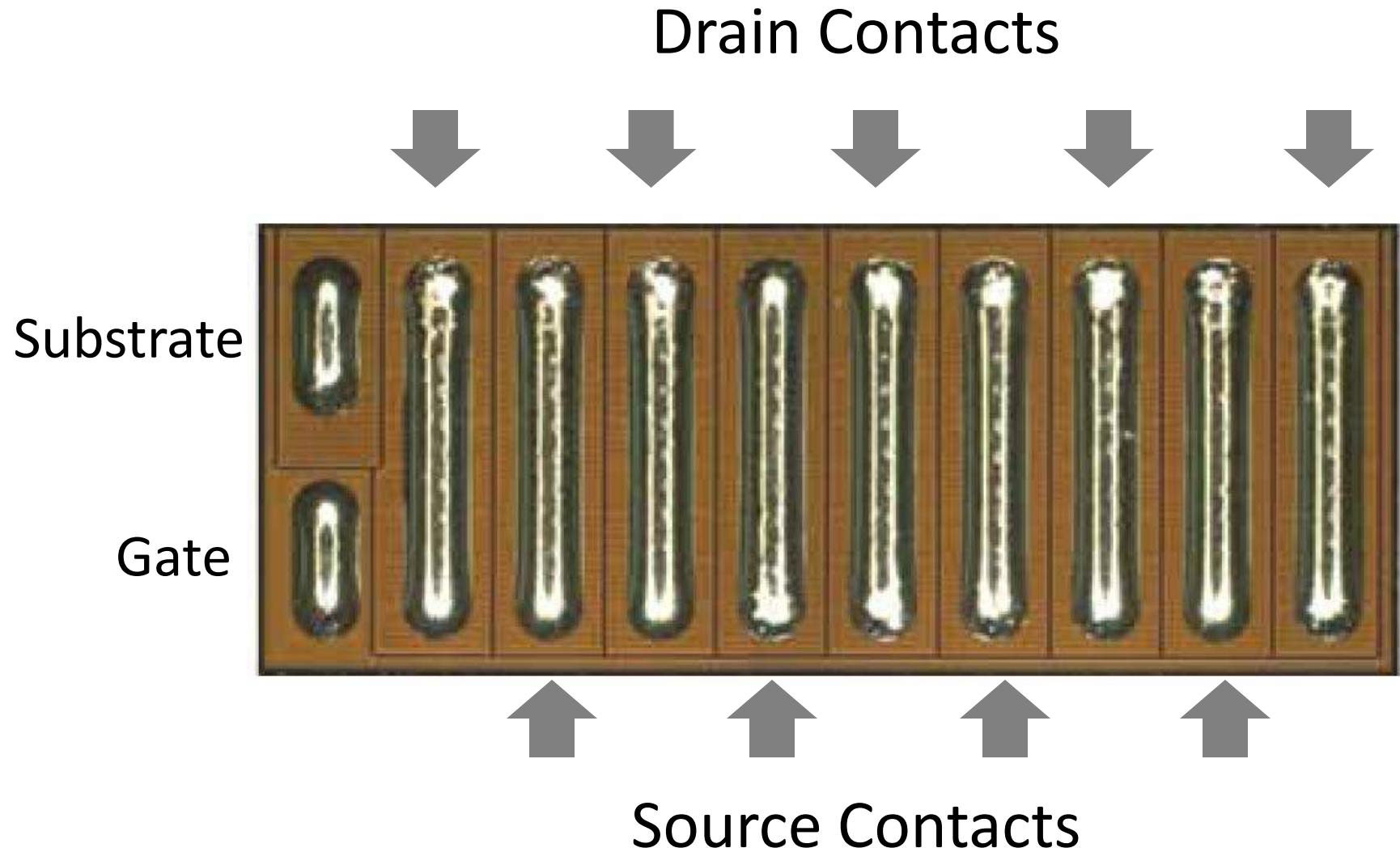


- Low parasitic resistance
- Low parasitic inductance
- Low thermal resistance
- Small size
- Low cost

Flip Chip LGA Assembly



LGA Construction



Size Comparison



eGaN FET



5.76 mm²

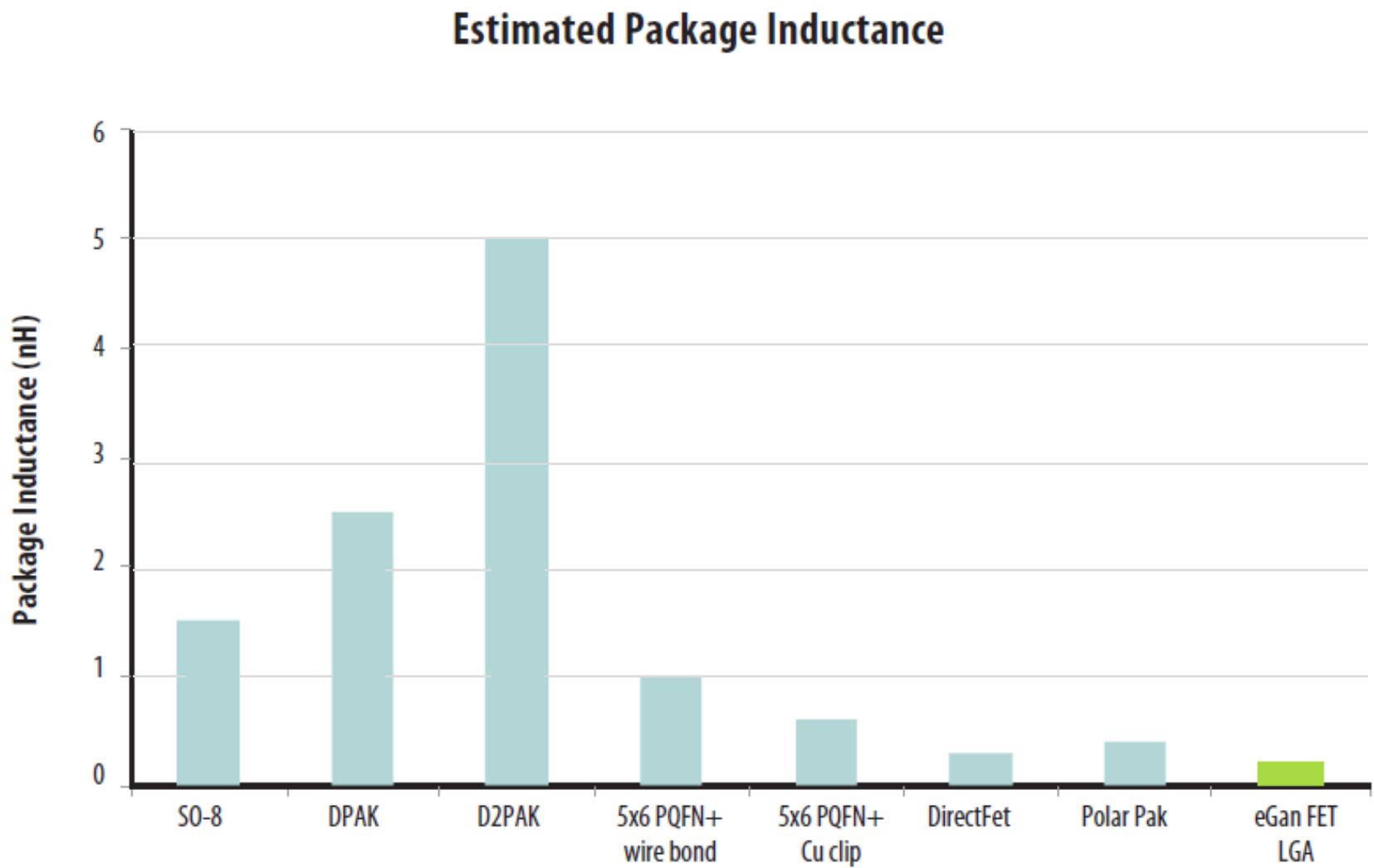
Drawn To Scale

D-PAK



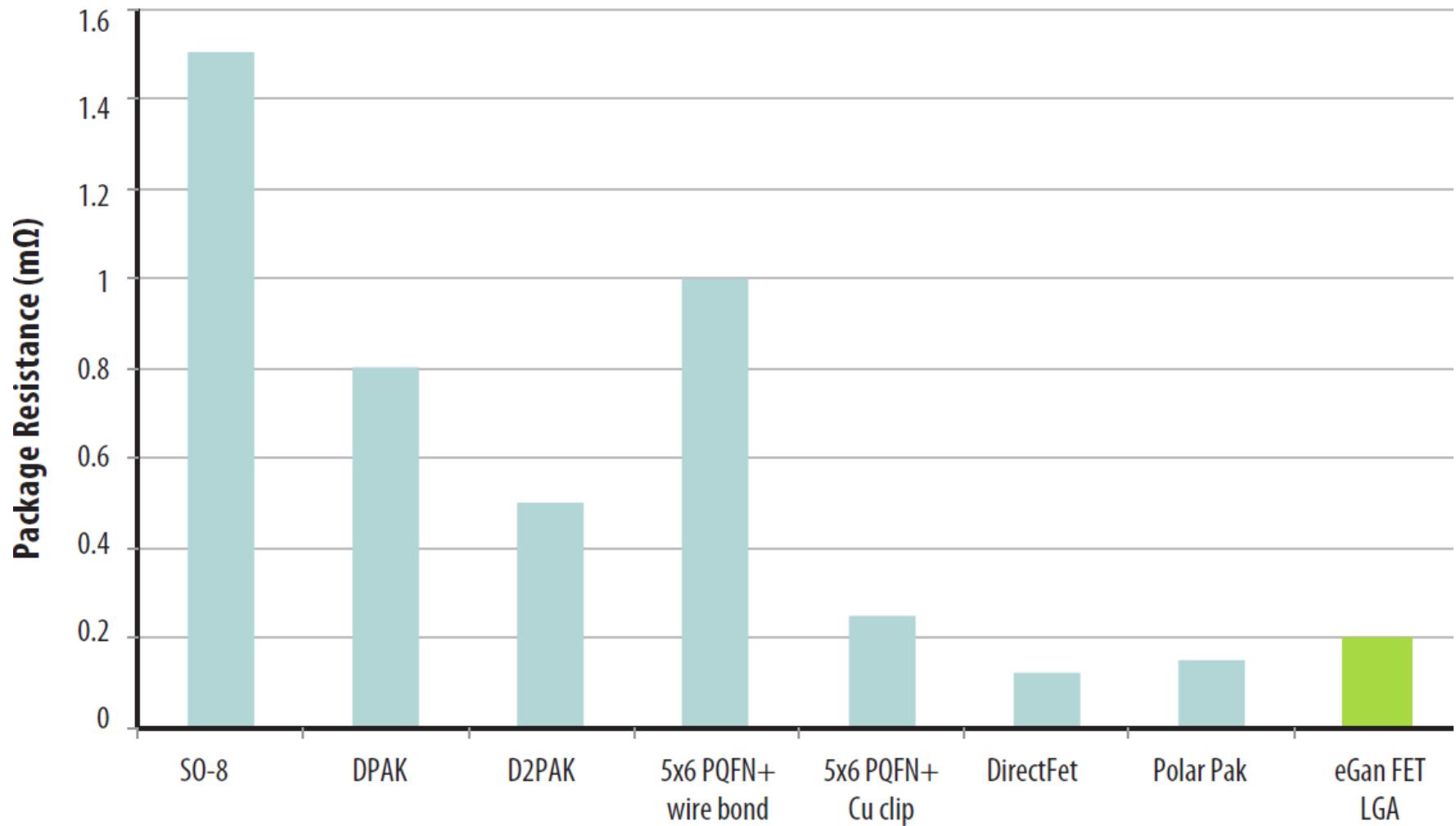
65.3 mm²

Package Inductance



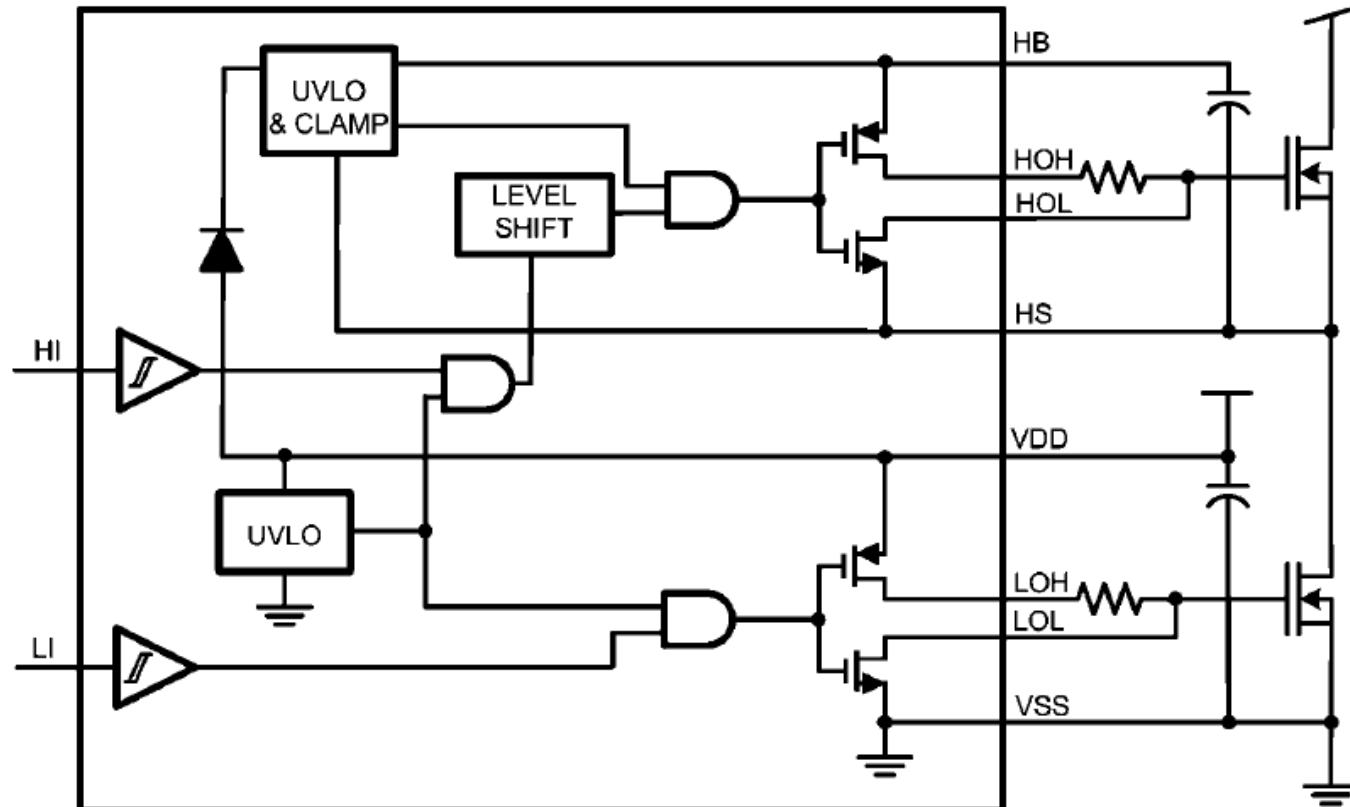
Package Resistance

Estimated Package Resistance



The Opportunity to Improve DC-DC Efficiency

Integrated Gate Driver Solution



30162903

LM5113 from Texas Instruments

Buck Converter

Advantage:

- **High power density and high efficiency**

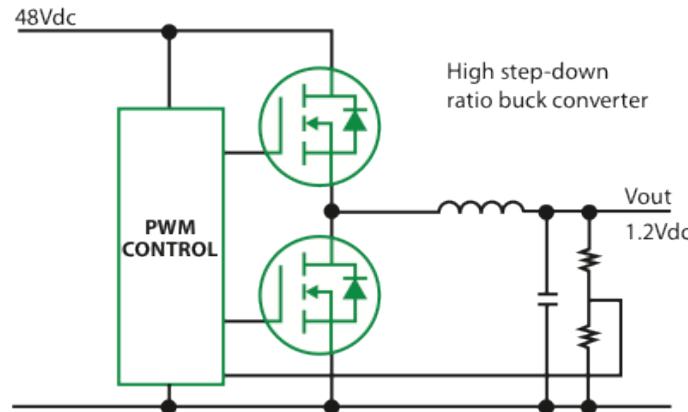
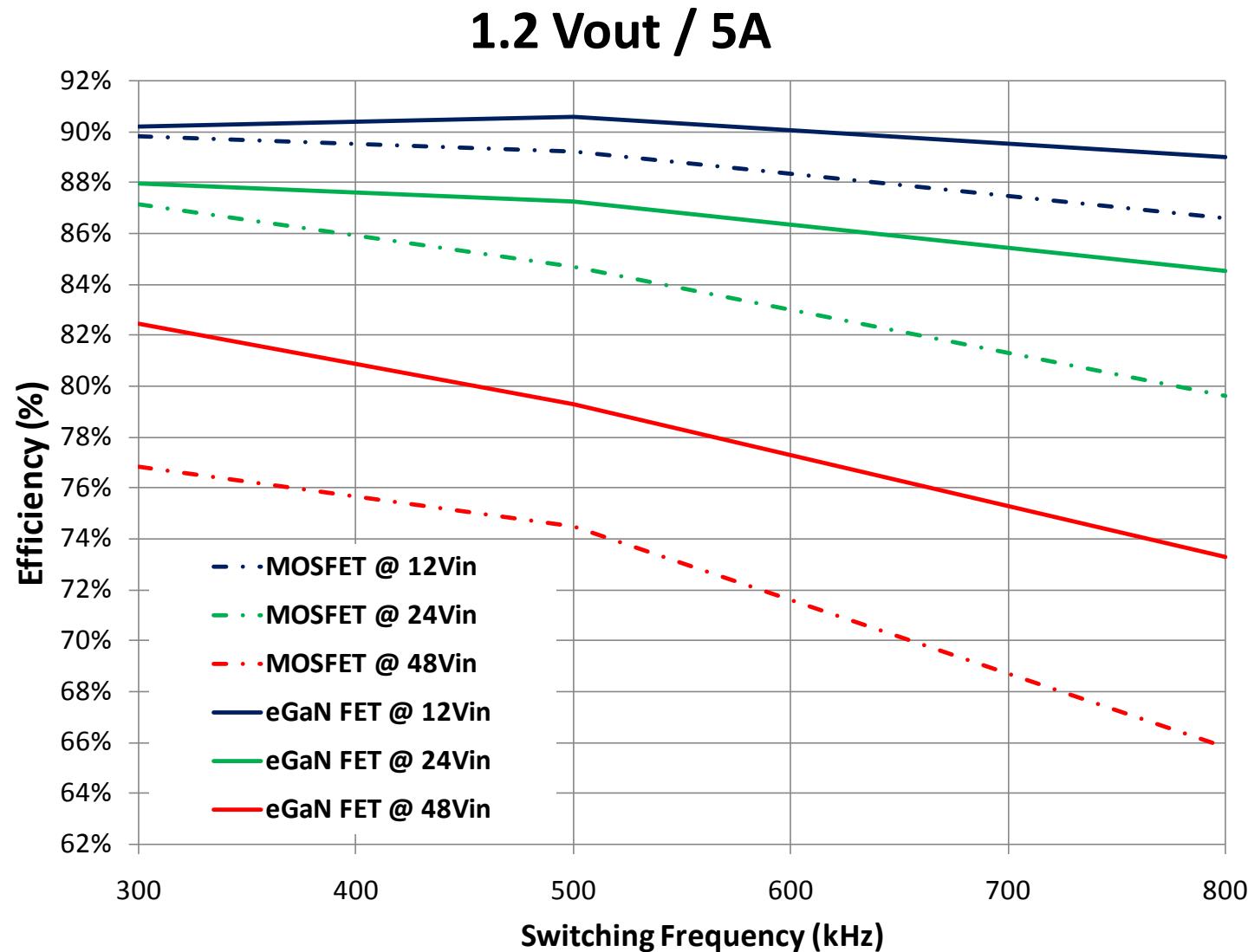


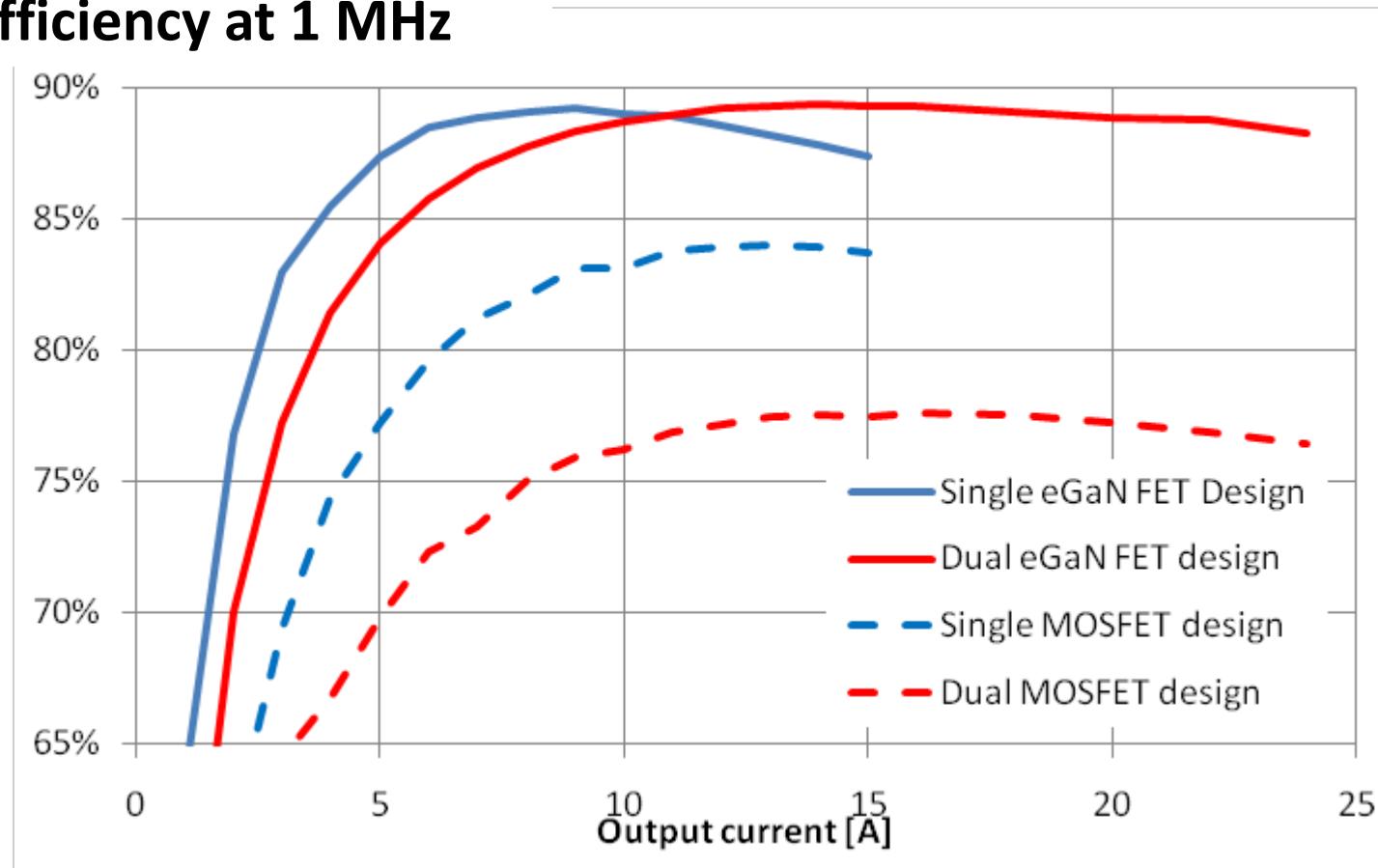
Figure 7 – Buck converter with an input voltage of 48 VDC and output voltage of 1.2 VDC

Efficiency vs Frequency



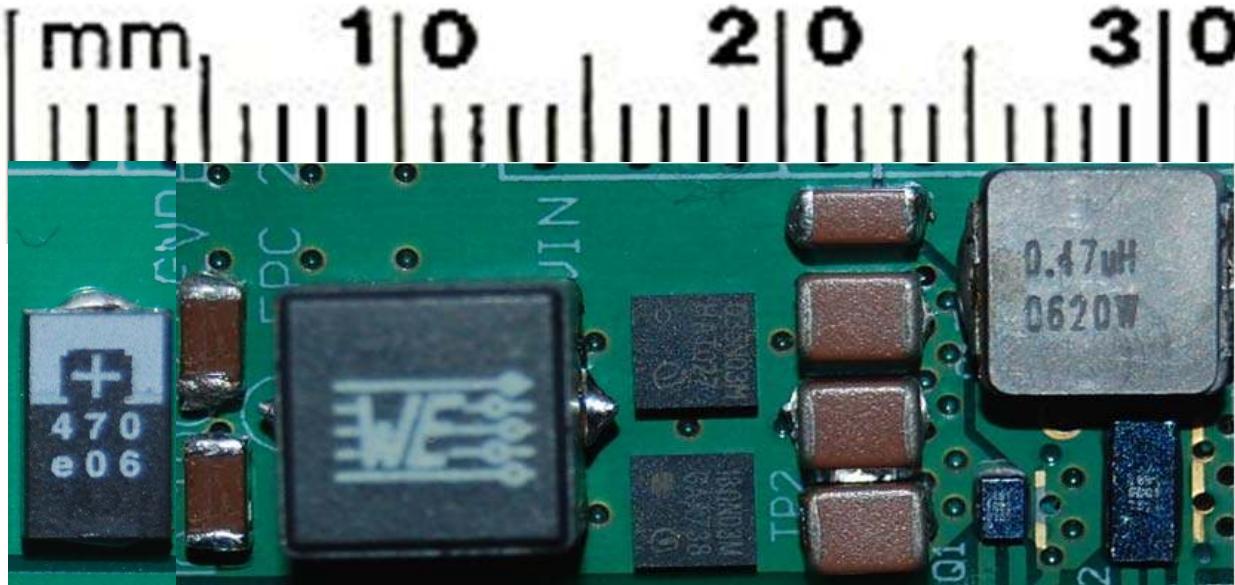
Parallel FET Buck Converter

Efficiency at 1 MHz



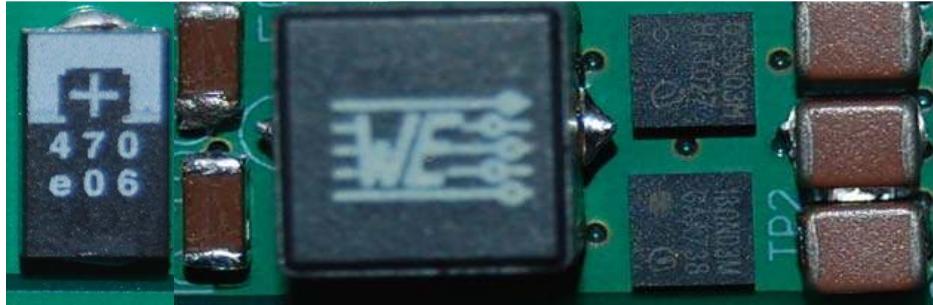
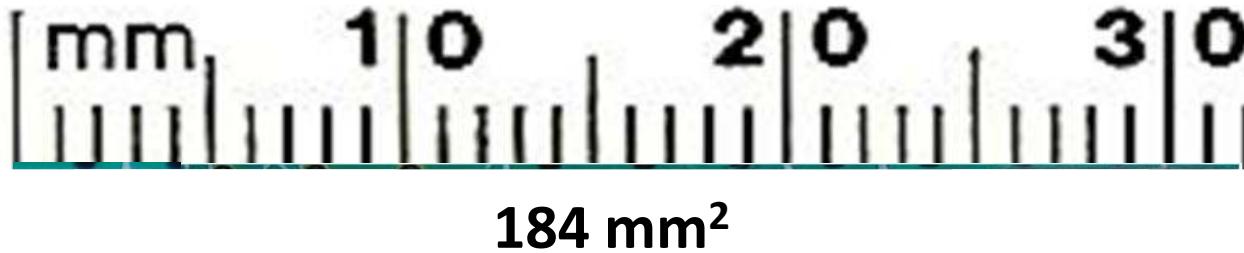
$12 \text{ V}_{\text{IN}} - 1.2 \text{ V}_{\text{OUT}}$

Buck Size Comparison



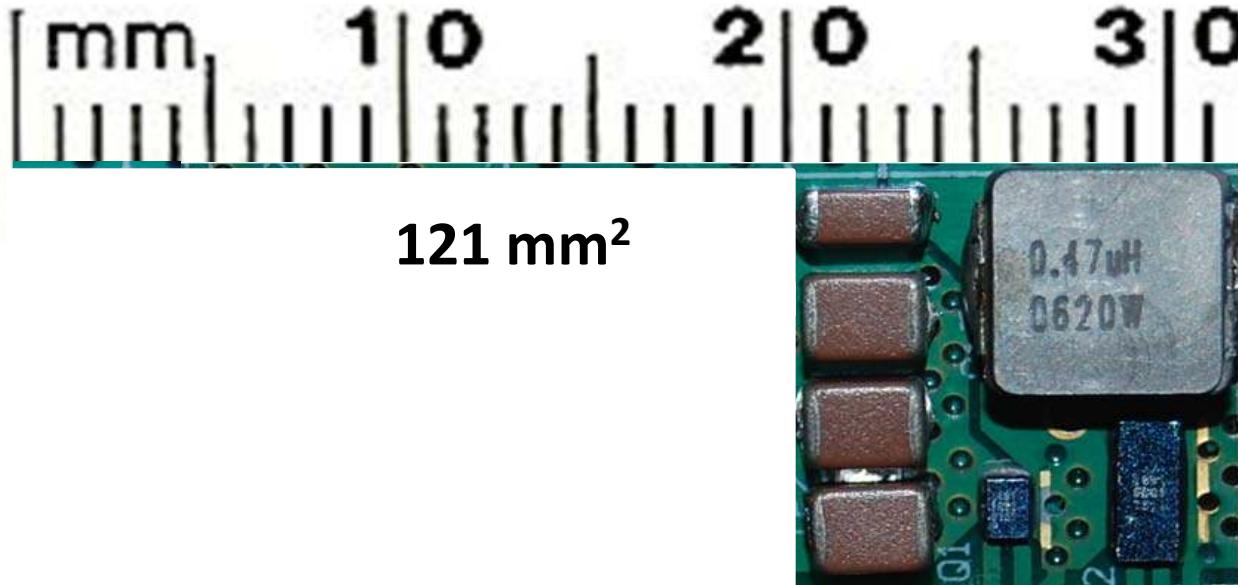
A 24V-1.2V Buck converter was built with both with eGaN FETs and state-of-the-art silicon power MOSFETs

Buck Size Comparison



The MOSFET-based circuit measures 184 mm²

Buck Size Comparison



**A 24V-1.2V Buck converter with eGaN FETs is 50% smaller
and has 30% less power losses at 800 kHz.**

Isolated Full Bridge Converter

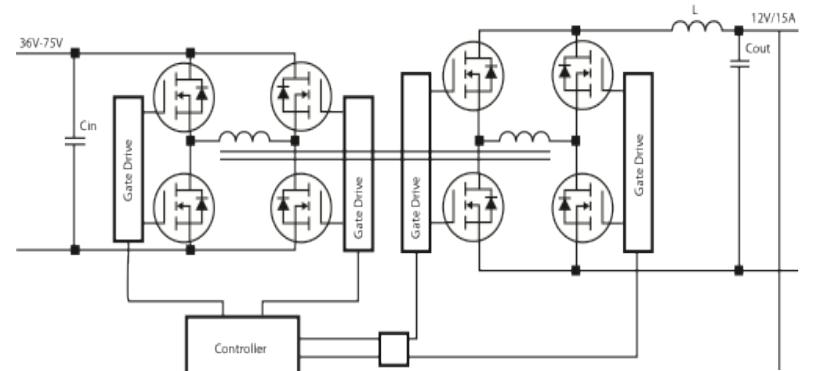


Advantage:

- Isolation and high power density at high power

36~75 V

12 V
15 A
180 W



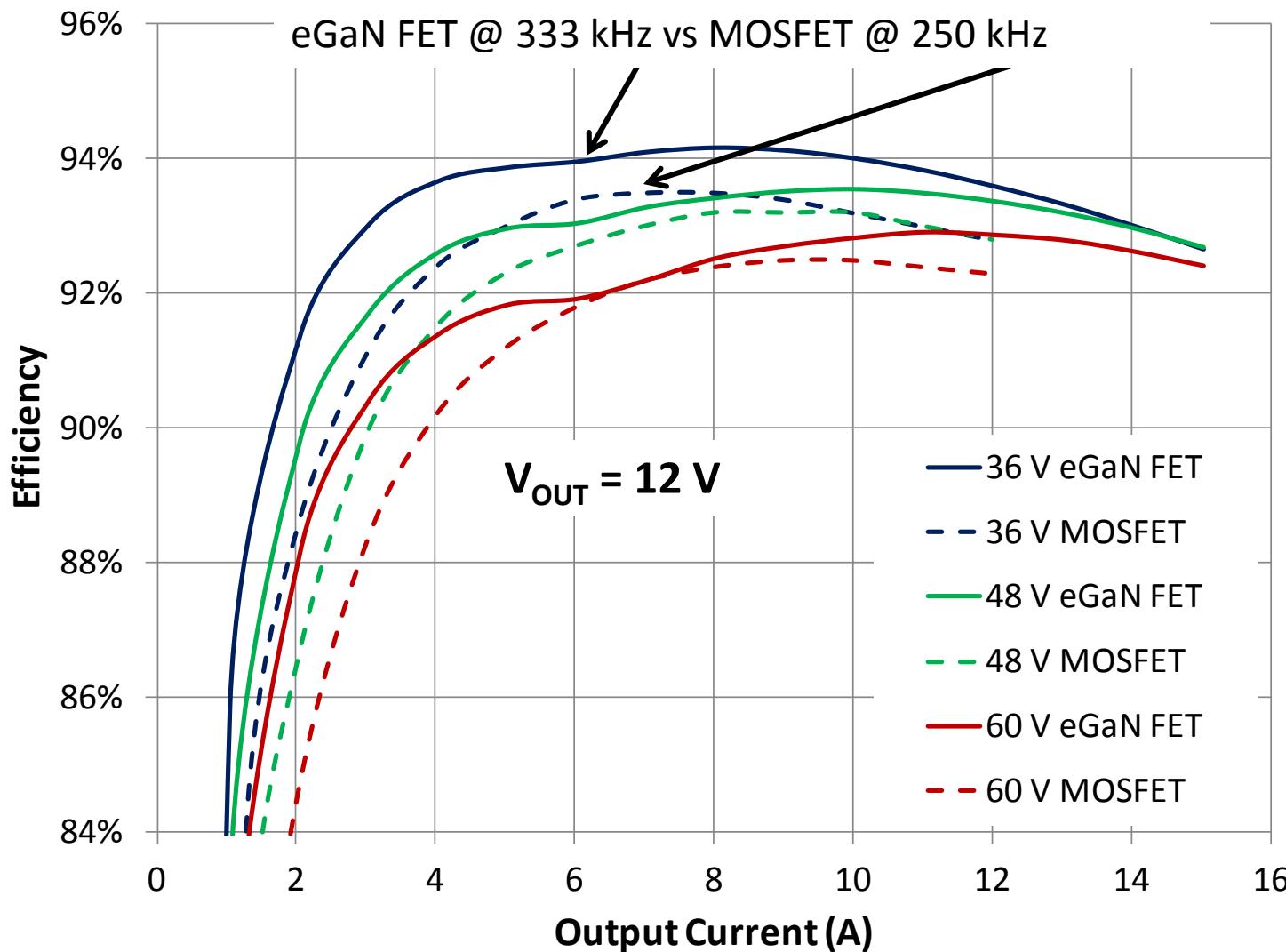
~48 V

~53V
700 W
2-phase

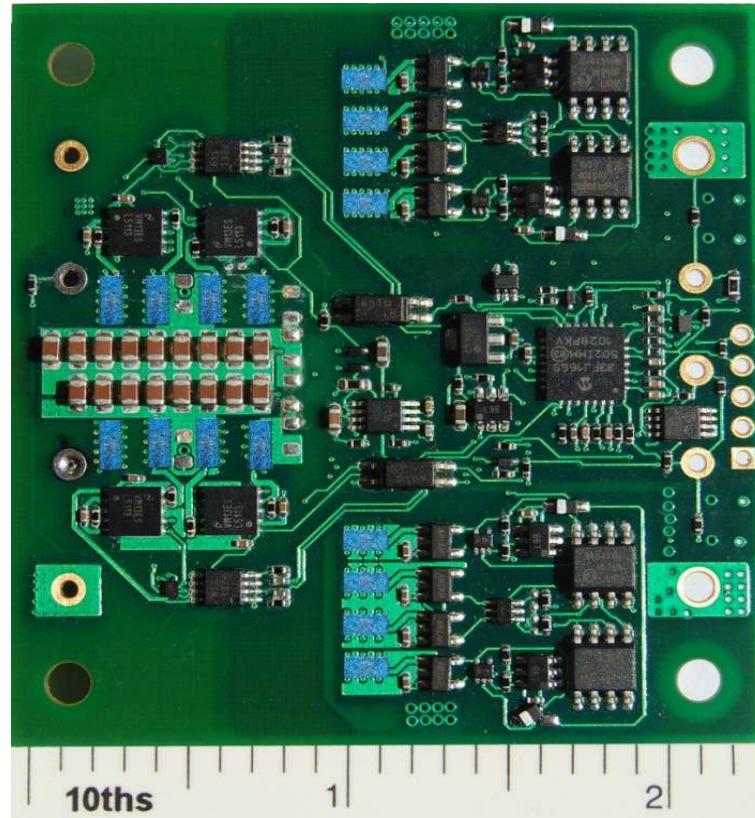
Isolated Full Bridge Converter



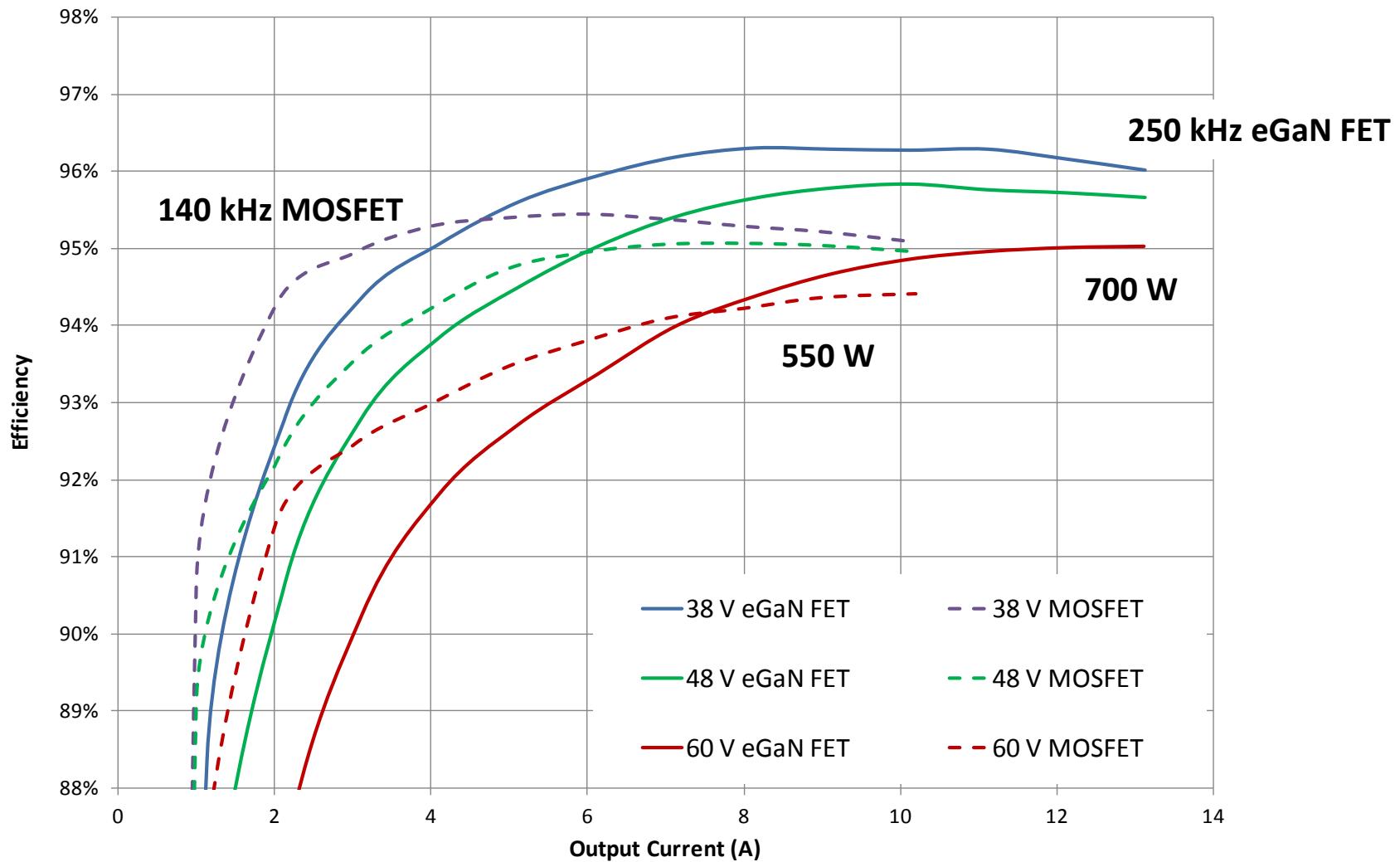
Isolated Full Bridge Converter



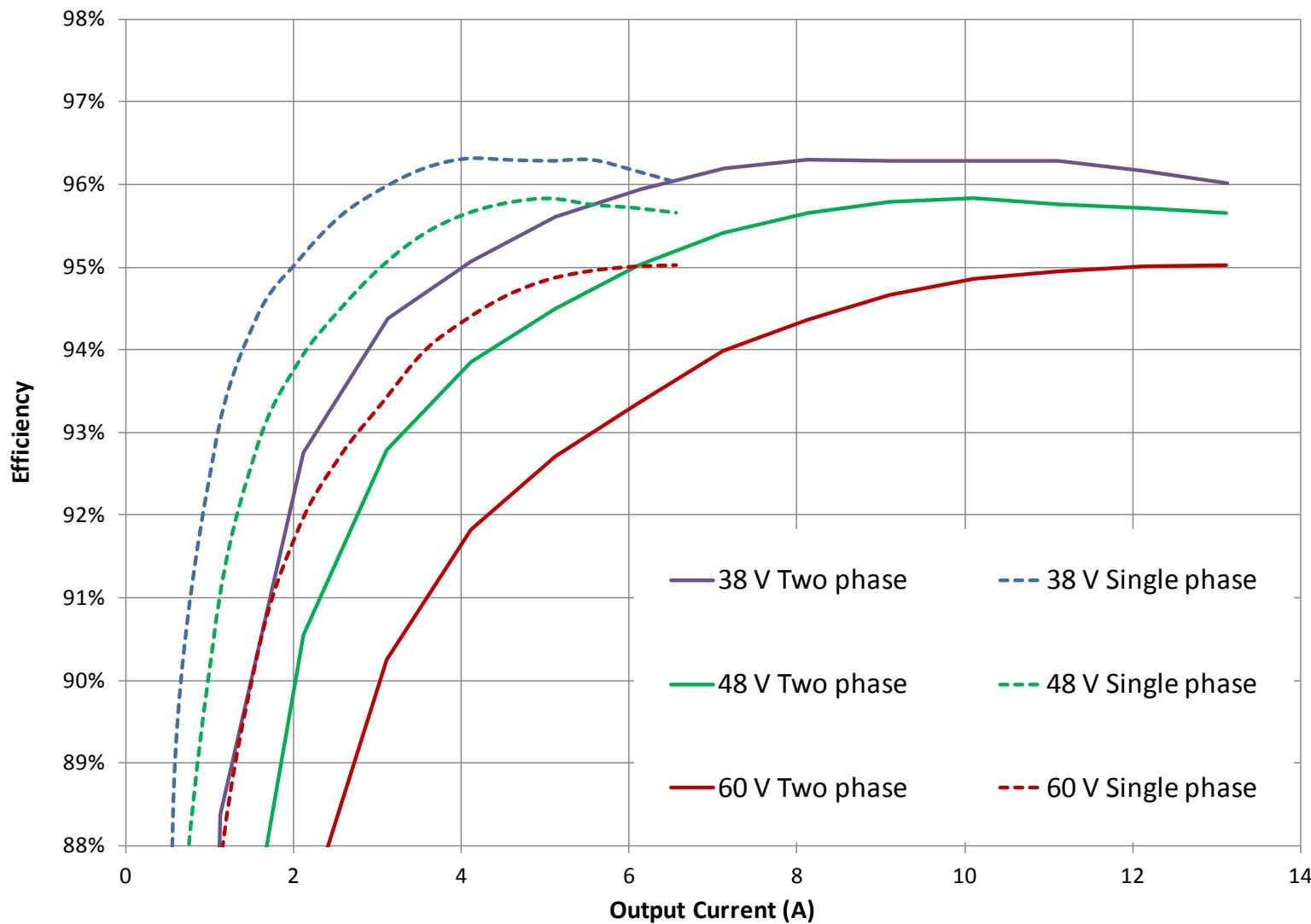
PoE-PSE Full Bridge Converter



PoE-PSE Full Bridge Converter

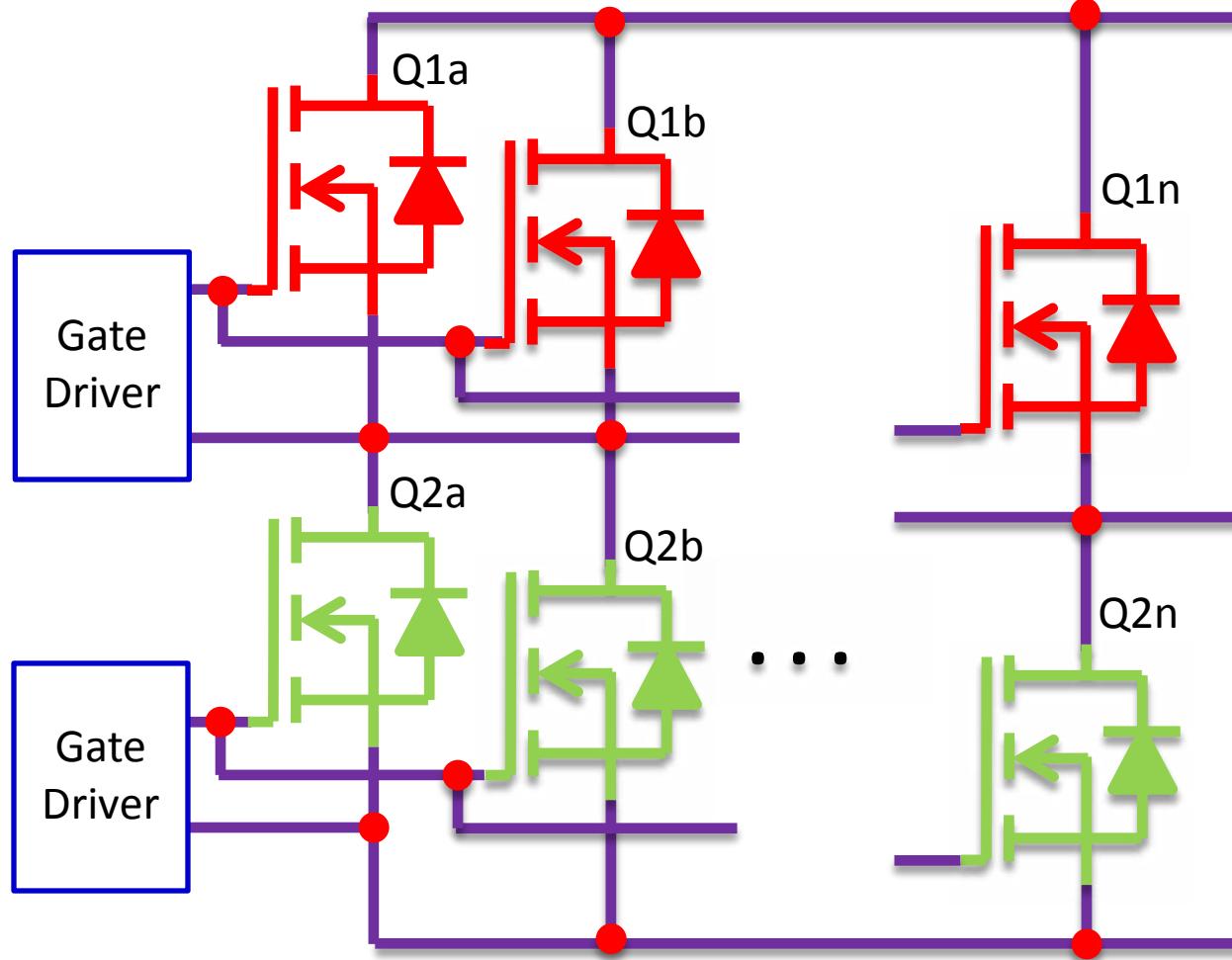


PoE-PSE Full Bridge Converter



Paralleling eGaN®FETs

Half-Bridge Topologies



Introducing the PIF

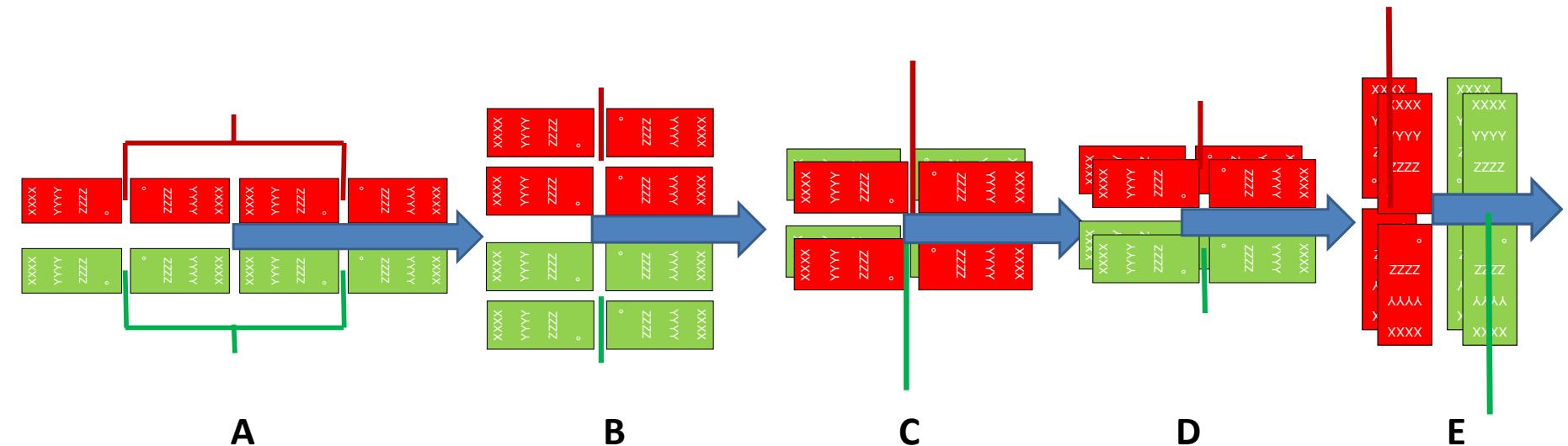


- Based on minimum switching time that maintains dv/dt and di/dt immunity
- Normalizes evaluations relative to a single FET
- Can be used to predict switching performance

$$PIF_n = \frac{\frac{dv_1}{dt} + \frac{di_1}{dt}}{\frac{dv_n}{dt} + \frac{di_n}{dt}}$$

Note: dv_x/dt and di_x/dt
are in units of time

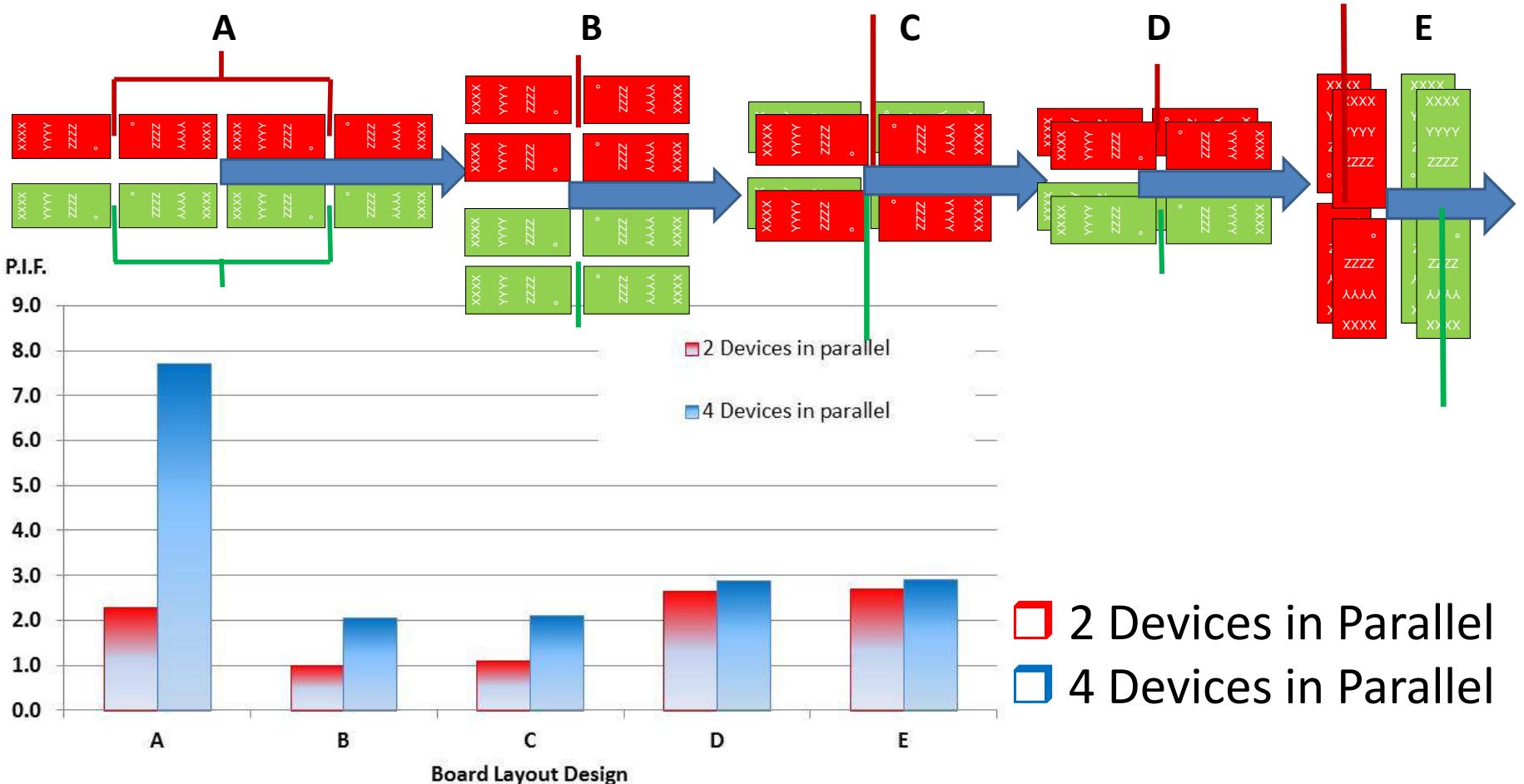
Half Bridge Layout Evaluations



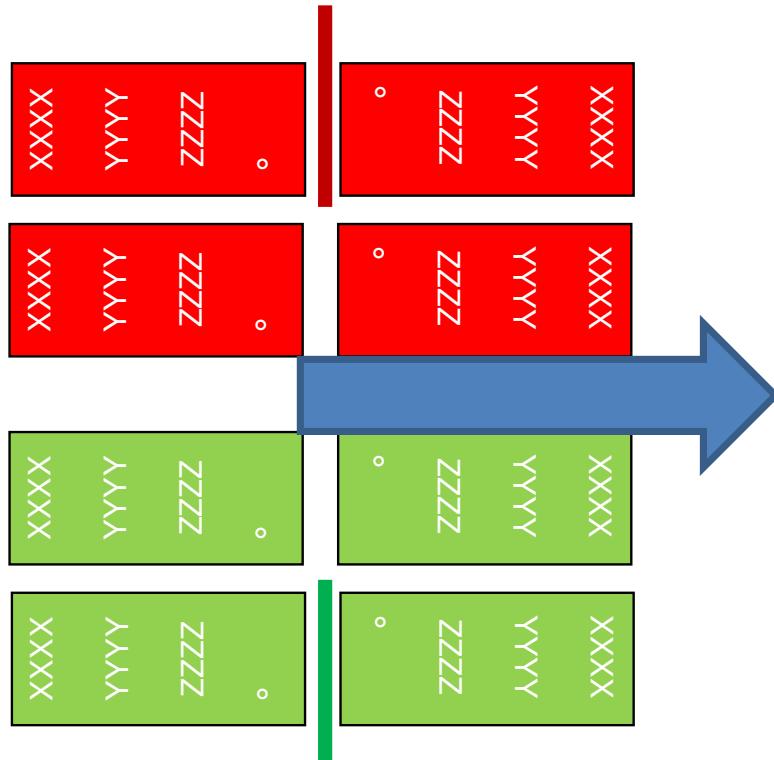
Single Component Sided

Double Component Sided

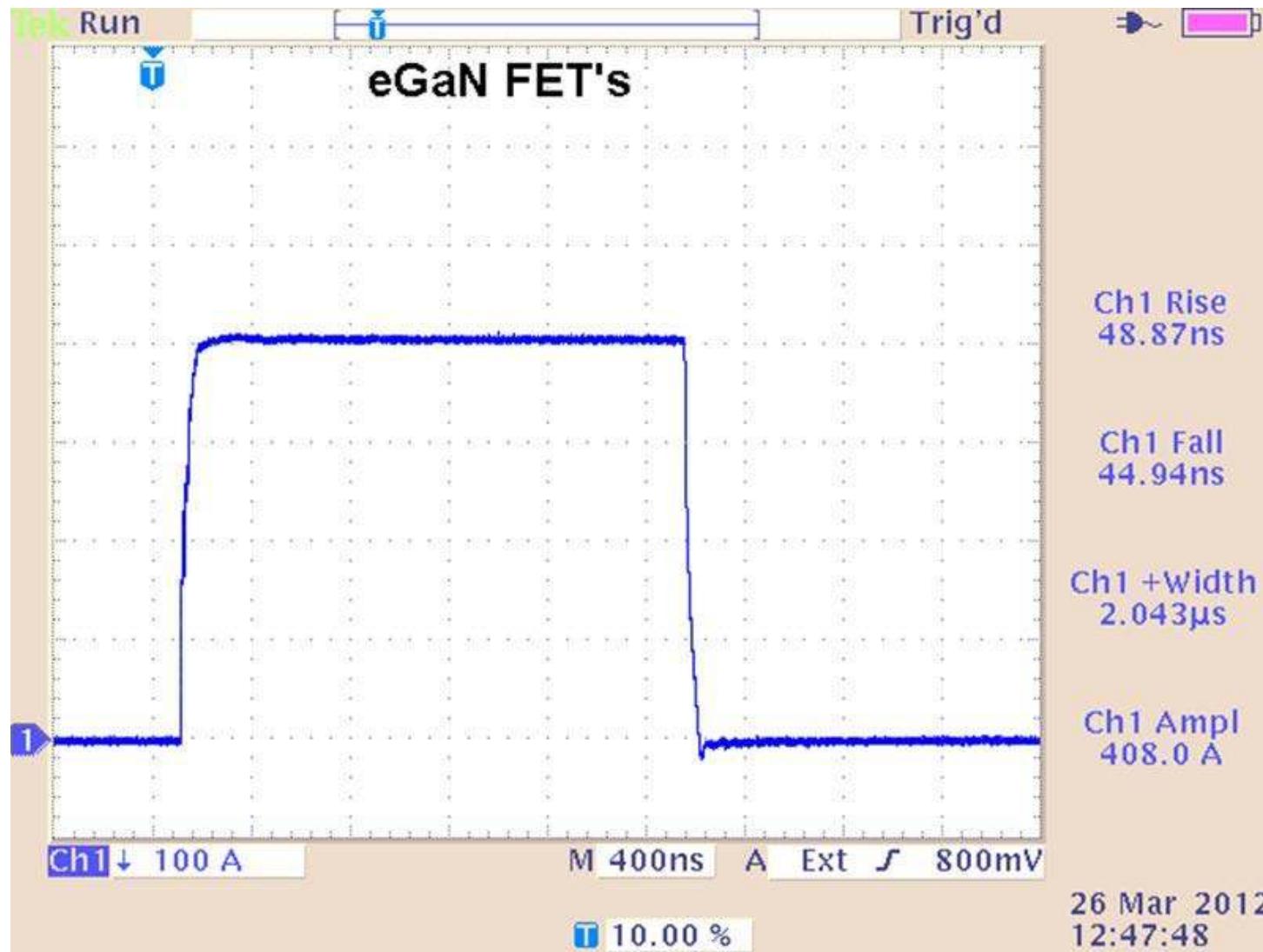
PIF for Half Bridge Layouts



Best Layout Configuration



Four FETs Operating in Parallel



What's in the Future?

Breaking Down the Barriers



- Does it enable significant new capabilities?
- Is it easy to use?
- Is it VERY cost effective to the user?
- Is it reliable?

Breaking Down the Barriers



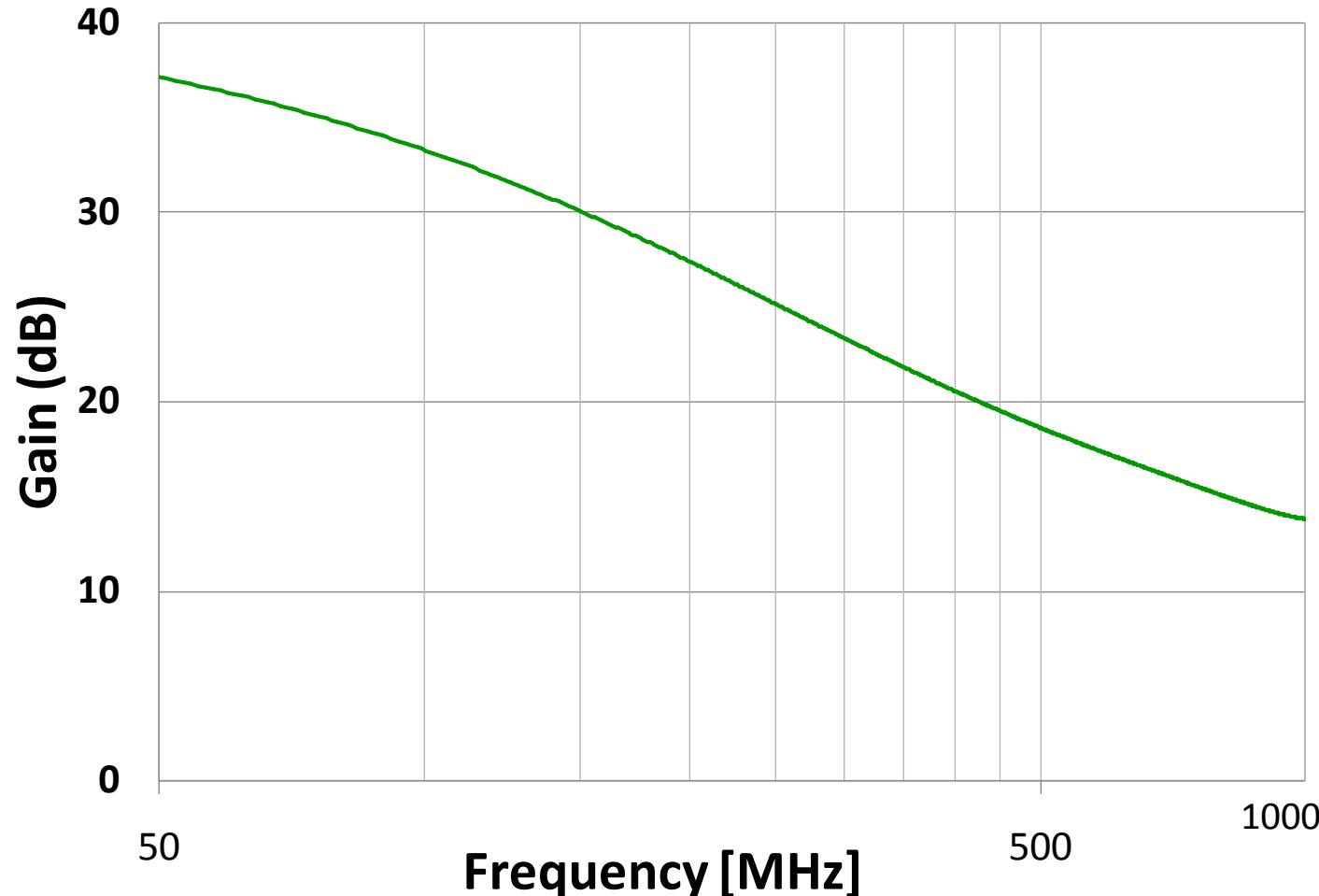
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Applications for eGaN® FETs

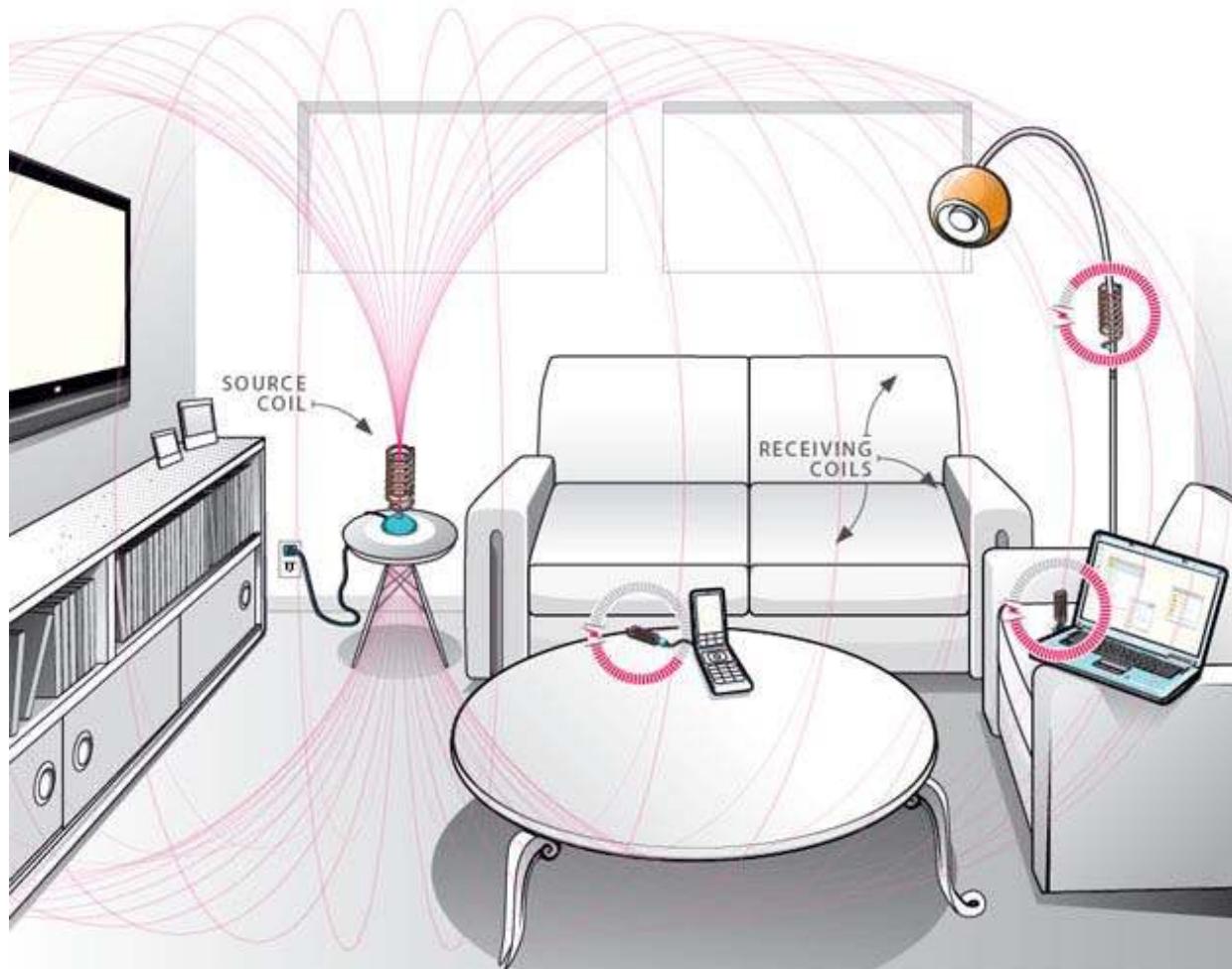


- Wireless Power Transmission – GaN Enabled
- RF DC-DC “Envelope Tracking” – GaN Enabled
- RadHard
- Power Over Ethernet
- RF Transmission
- Network and Server Power Supplies
- Power Factor Correction
- Point of Load Modules
- Solar Microinverters
- Energy Efficient Lighting
- UPS Systems
- Class D Audio

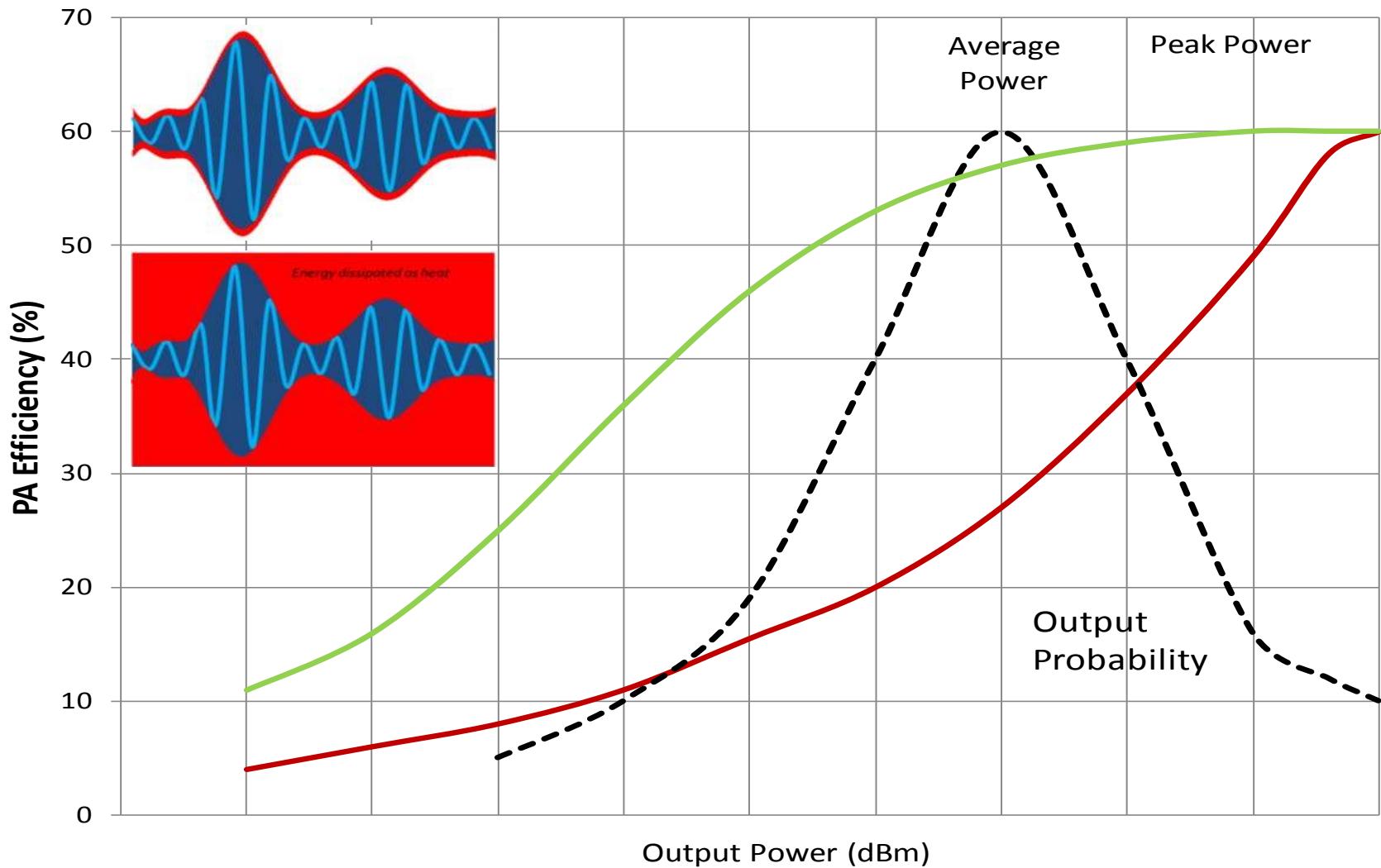
EPC 2012 Maximum Gain vs Frequency 200 V eGaN FETs



Wireless Power



RF Envelope Tracking



Breaking Down the Barriers



- Does it enable significant new capabilities?
- Is it easy to use?
- Is it VERY cost effective to the user?
- Is it reliable?

Is it easy to use?



It's just like a MOSFET

except

**The high frequency capability makes circuits using eGaN
FETs sensitive to layout**

**The lower $V_{G(MAX)}$ of 6 V makes it advisable to have V_{GS}
regulation in your gate drive circuitry**

**The ultra-small LGA increases the concentration of heat
on the PCB**

Breaking Down the Barriers



- Does it enable significant new capabilities?
- Is it easy to use?
- Is it **VERY** cost effective to the user?
- Is it reliable?

Silicon vs eGaN® FET Wafer Costs

	2011	2015
Starting Material	same	same
Epi Growth	<i>higher</i>	<i>~same?</i>
Wafer Fab	same	lower
Test	same	same
Assembly	lower	lower
OVERALL	higher	<i>lower!</i>

Breaking Down the Barriers

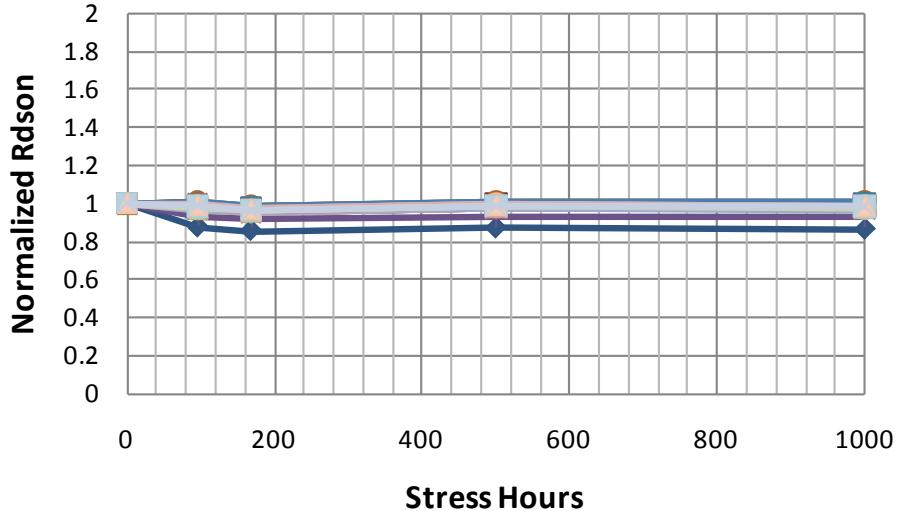


- Does it enable significant new capabilities?
- Is it easy to use?
- Is it VERY cost effective to the user?
- Is it reliable?

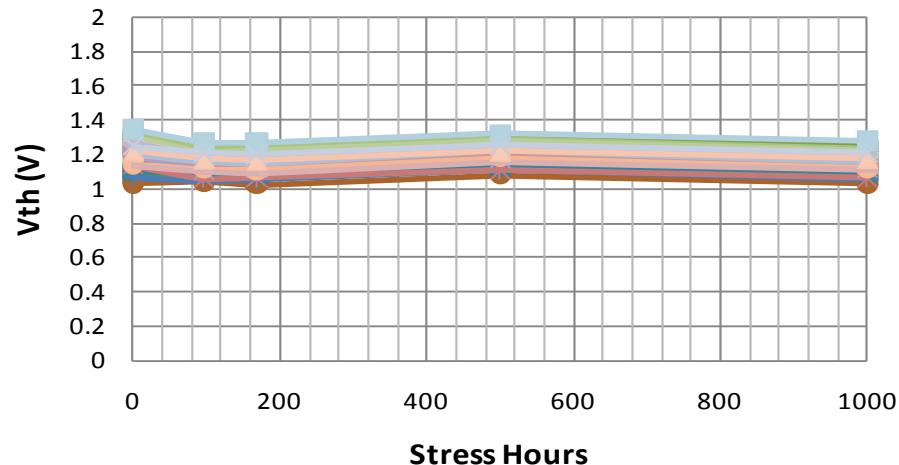
eGaN® FETs are Reliable



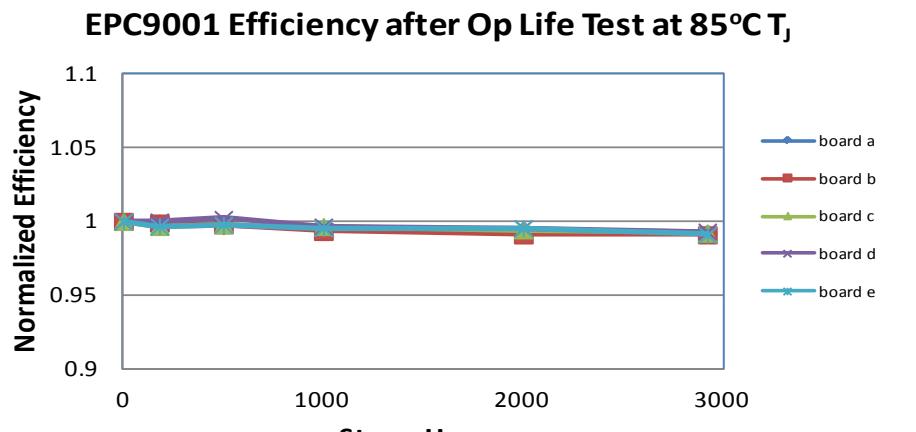
EPC2001 $R_{DS(ON)}$ after 100V_{DS} HTRB at 125°C



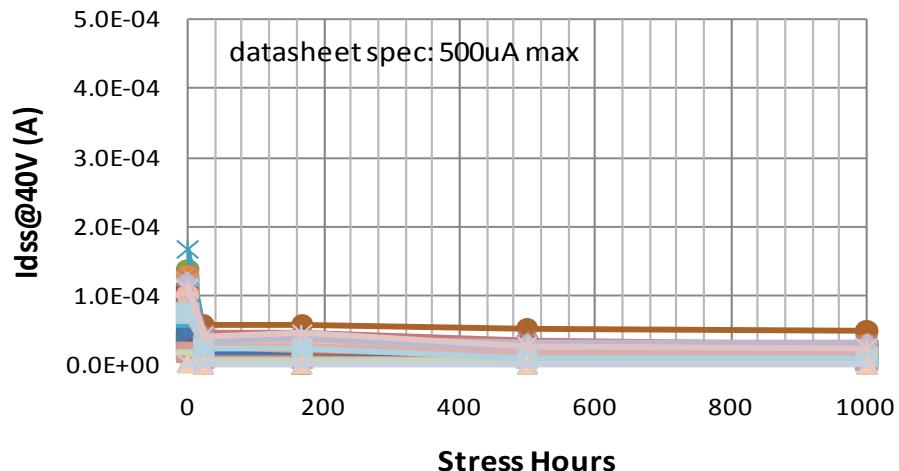
EPC2001 $V_{GS(TH)}$ after 100V_{DS} HTRB at 125°C



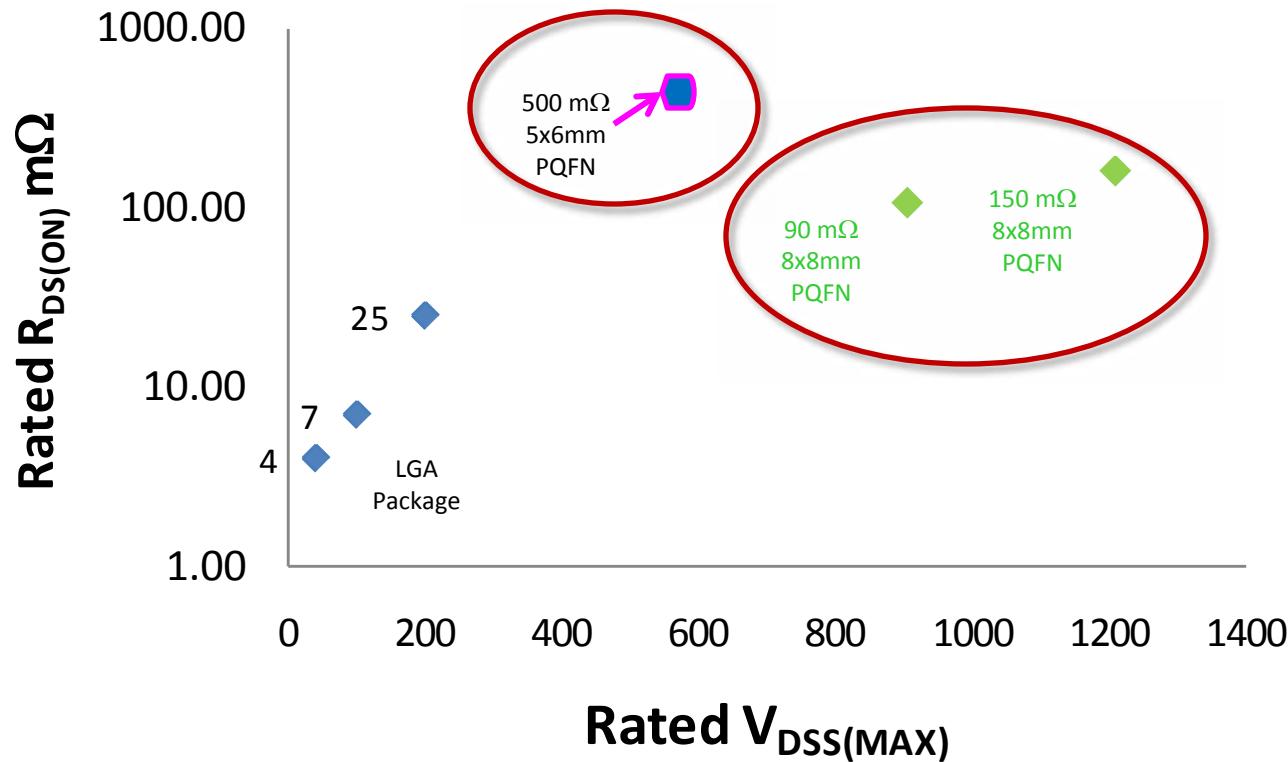
EPC9001 Efficiency after Op Life Test at 85°C T_j



EPC2015 Idss after 40V H3TRB at 85°C/85%RH

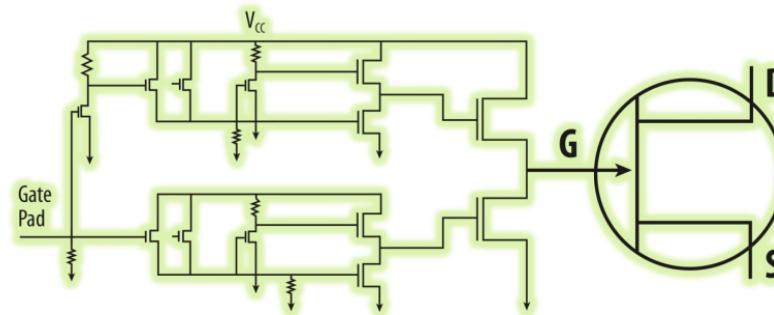


Beyond 600 Volts

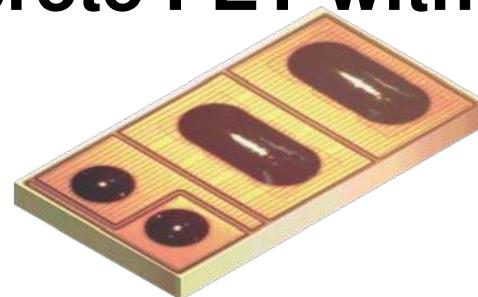


Beyond Discrete Devices

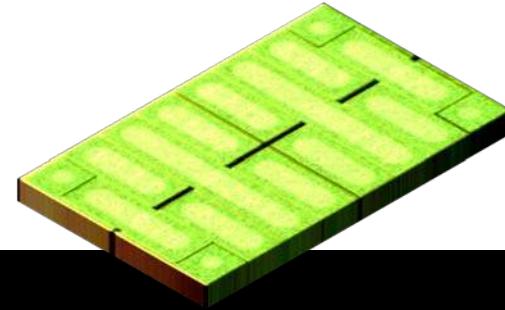
Driver On Board



Discrete FET with Driver



Full-Bridge with Driver and Level Shift



Summary

- eGaN FETs are straightforward to use, but care must be taken due to the higher switching speeds compared with power MOSFETs
- eGaN FETs will replace silicon power MOSFETs in power conversion applications with a low-cost and higher efficiency solution
- Higher voltage devices and the integration of analog plus power will enhance the performance and cost-effectiveness of eGaN FETs



*The end of the road
for silicon....*

*is the beginning of
the eGaN FET
journey!*

