GaN Transistors for Efficient Power Conversion

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Agenda

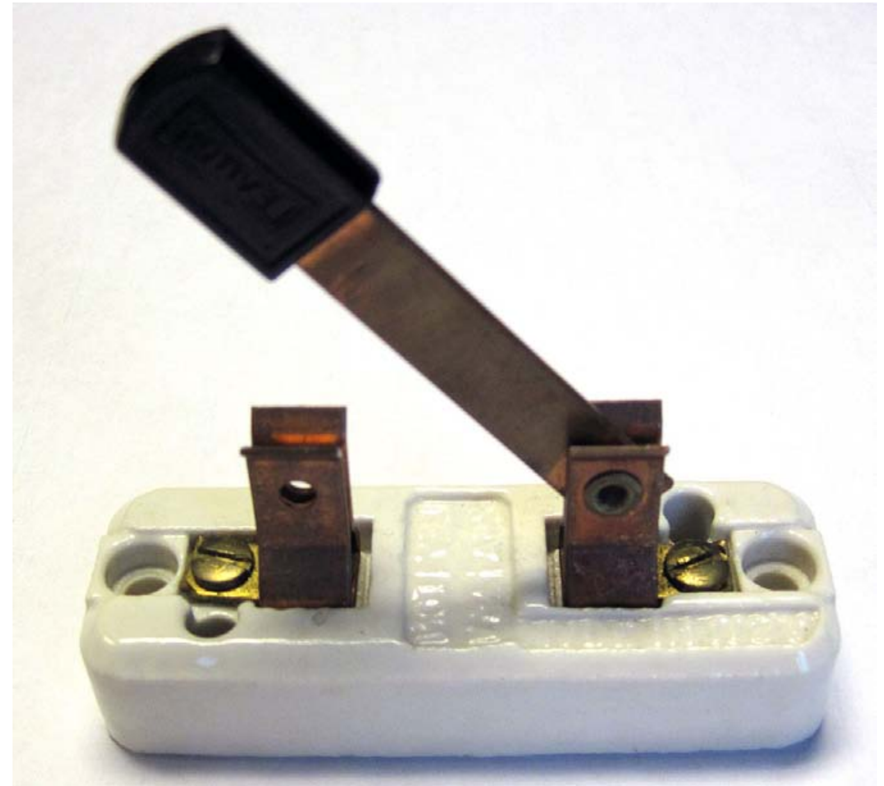
EPC
EFFICIENT POWER CONVERSION

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

The Ideal Power Switch

EFFICIENT POWER CONVERSION

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

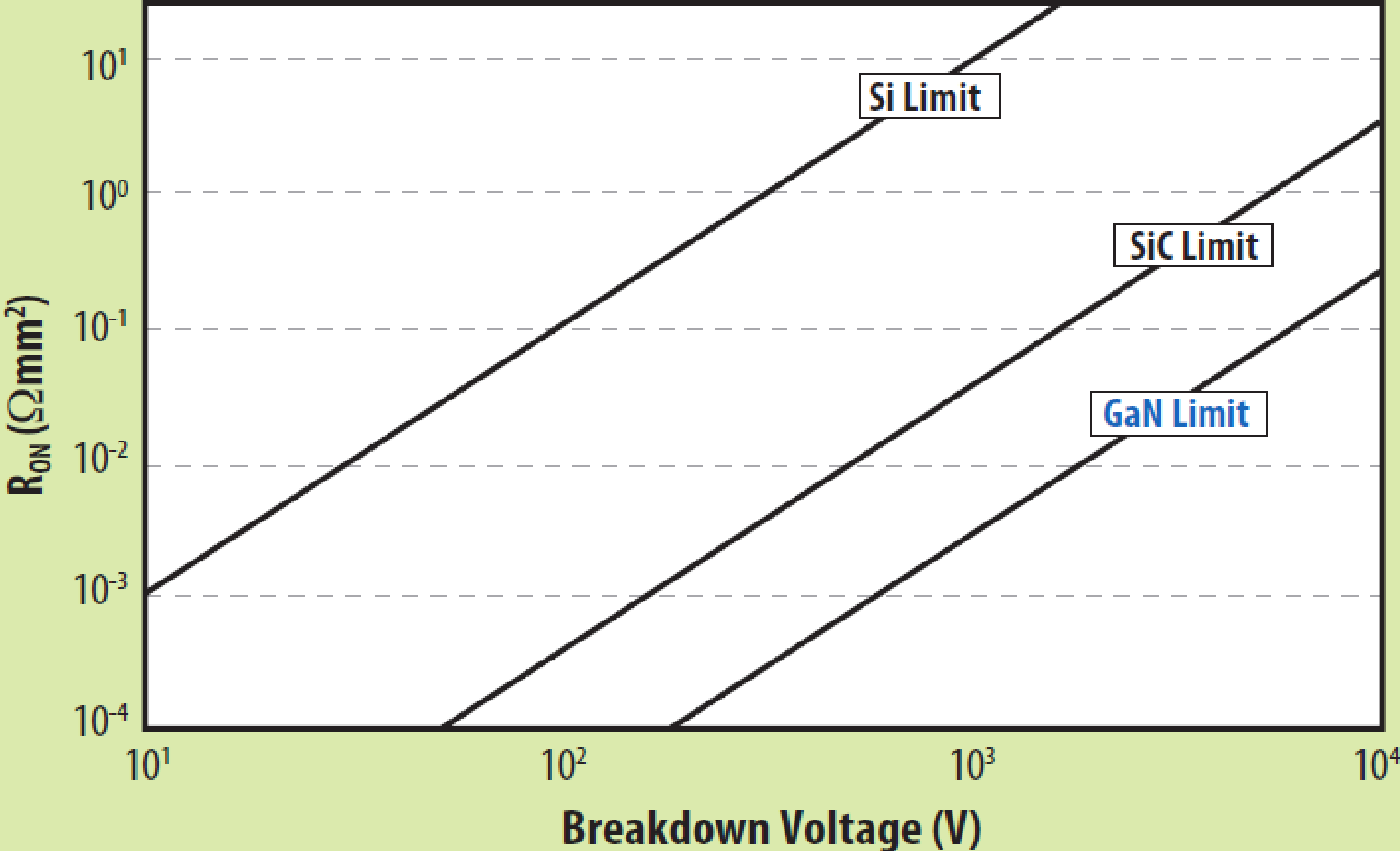


Material Comparison

EFFICIENT POWER CONVERSION

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 (x 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

EFFICIENT POWER CONVERSION

Pro GaN

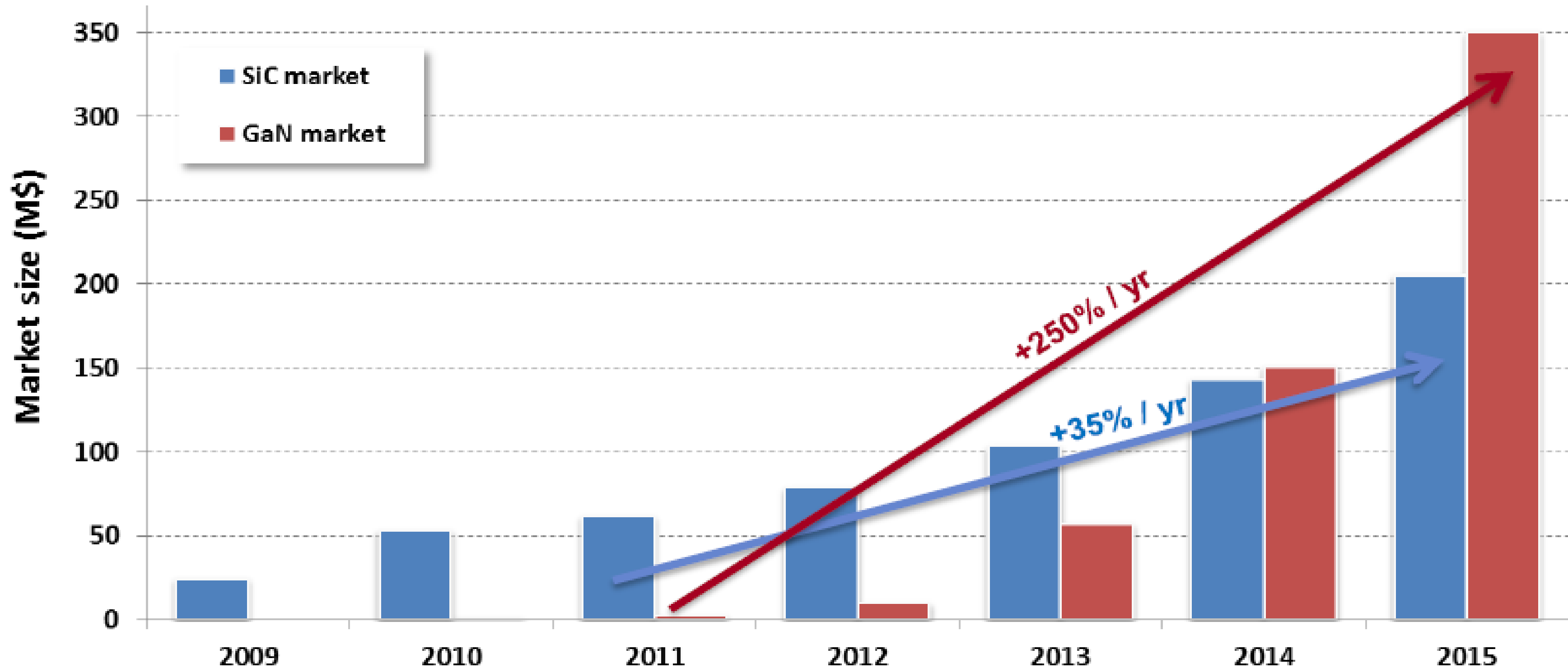
- GaN mobility almost 3 times SiC
- GaN on silicon can be manufactured in a standard silicon foundry on large diameter wafers
- GaN-on-silicon starting material can be much lower cost than SiC
- Monolithic integration of multiple power and analog devices is straightforward

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

EFFICIENT POWER CONVERSION

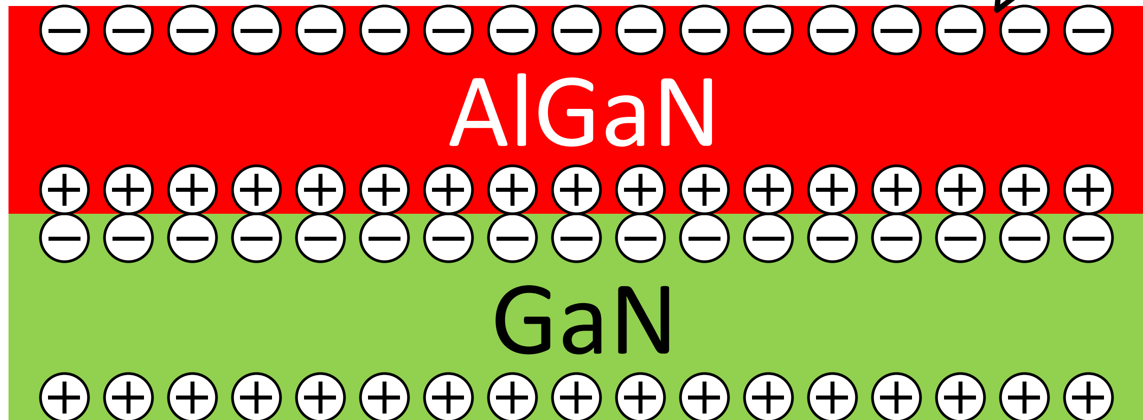


Total = $350M for GaN in 2015

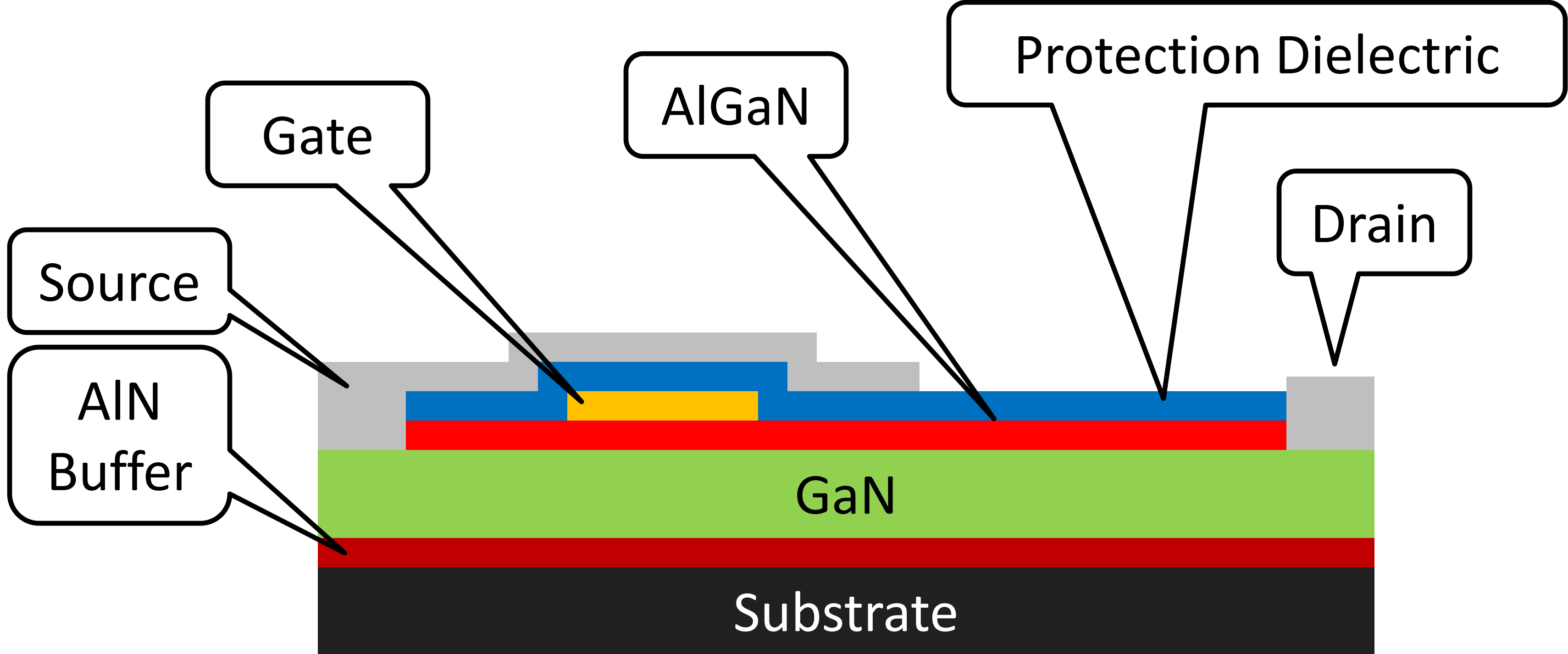
Source: Yole Development

How Does a GaN HEMT Work?

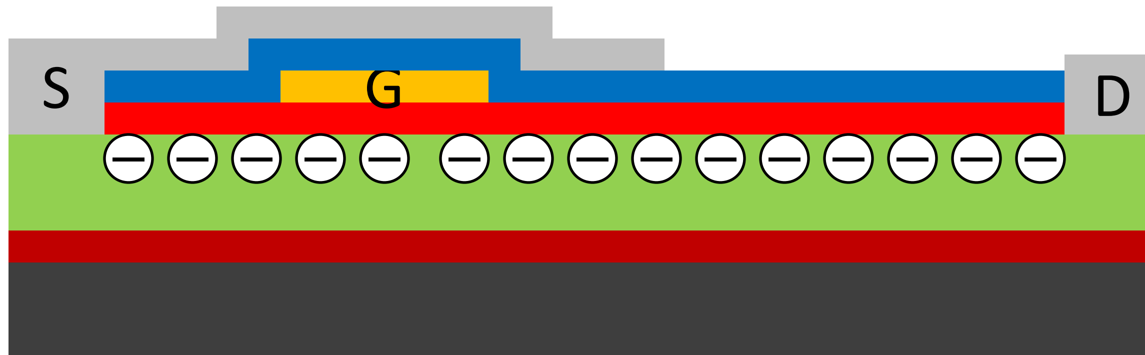
GaN + AlGaN



Device Construction Concept



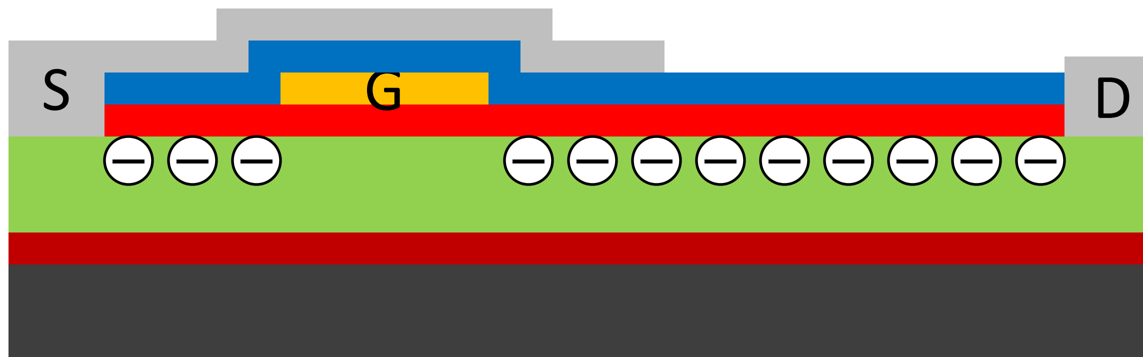
Normally ON Devices



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

EFFICIENT POWER CONVERSION



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

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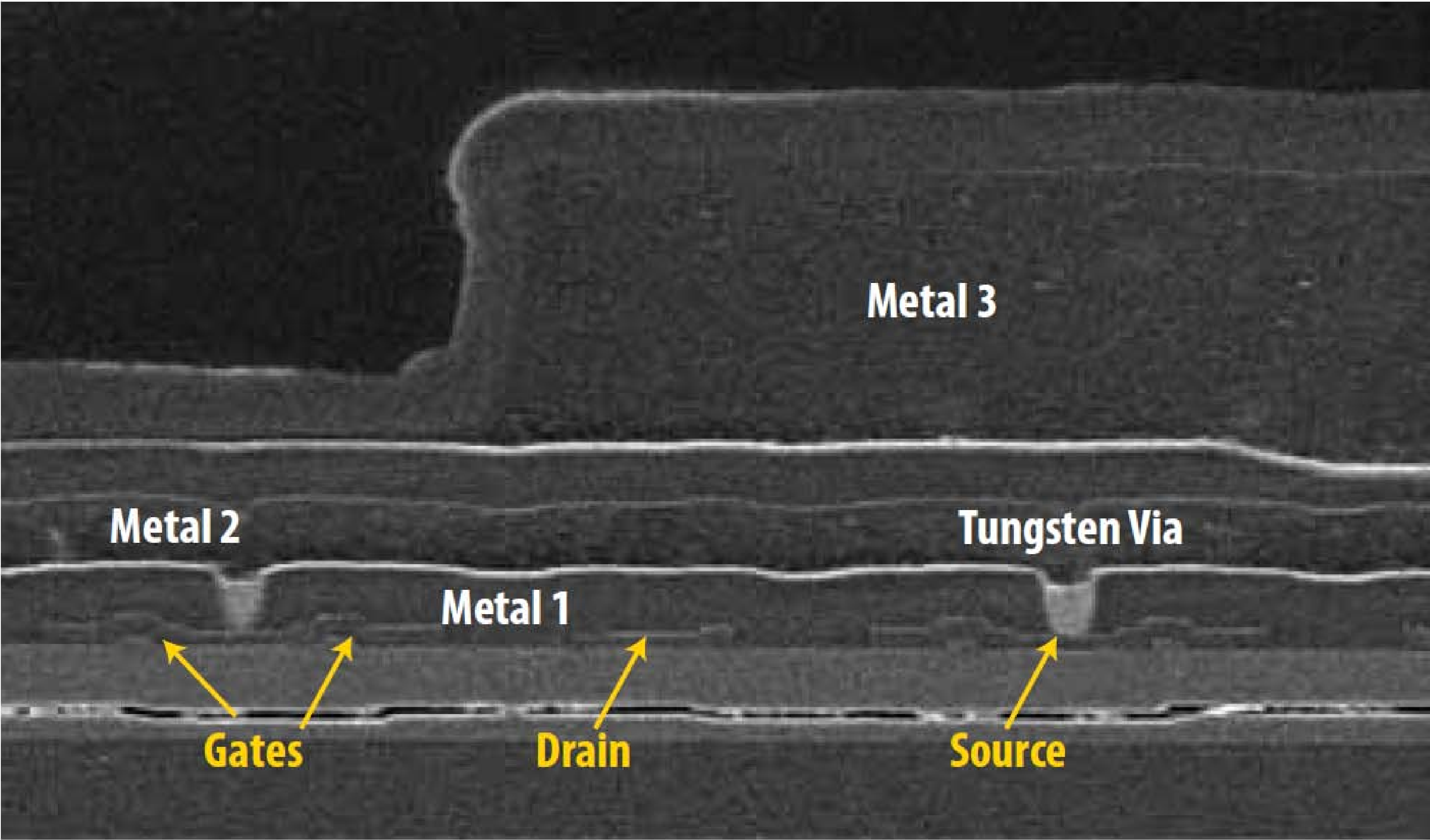
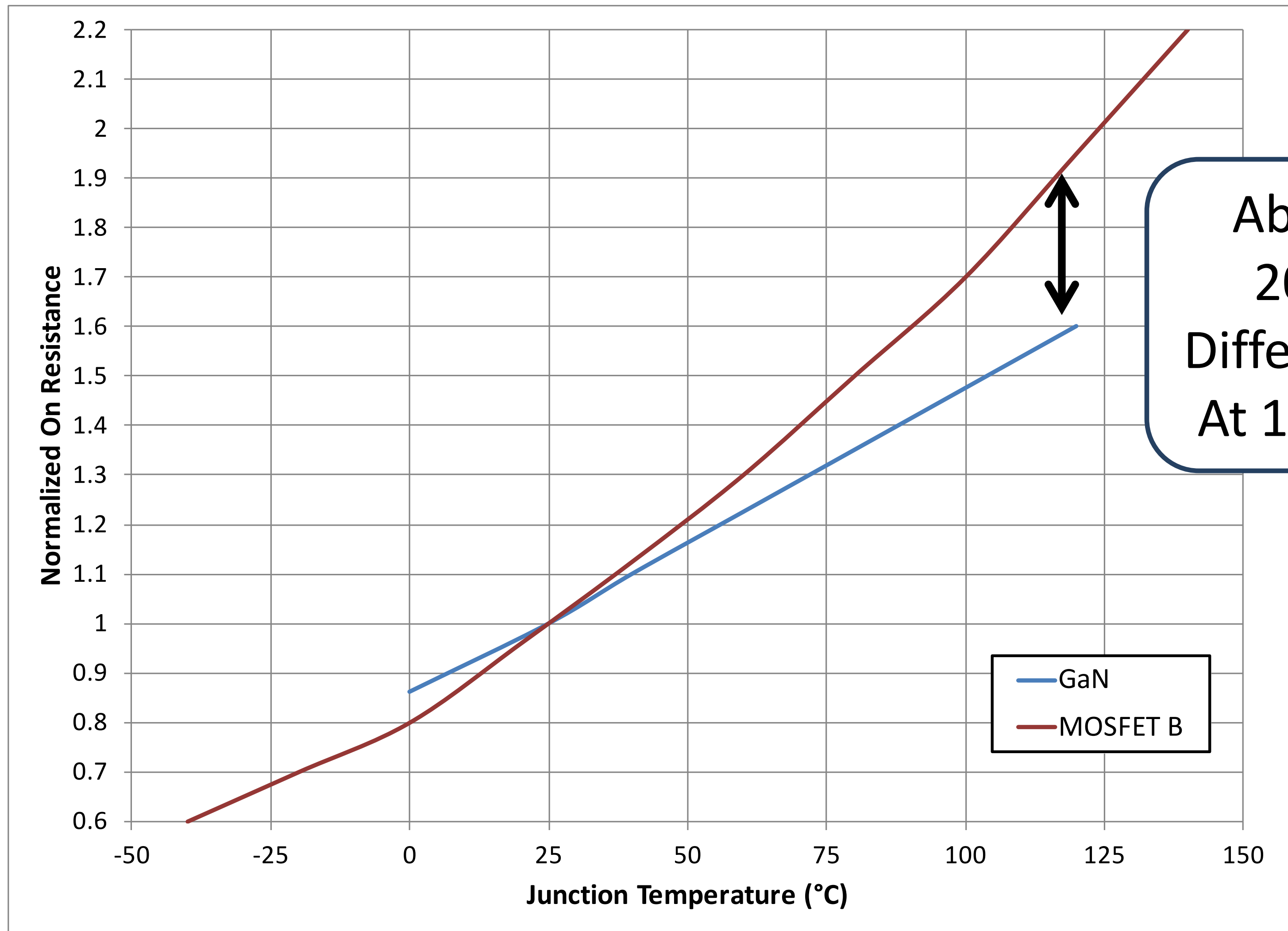
EFFICIENT POWER CONVERSION



On Resistance vs Temperature

EPC EFFICIENT POWER CONVERSION



Threshold vs Temperature

Normalized Thershold Voltage

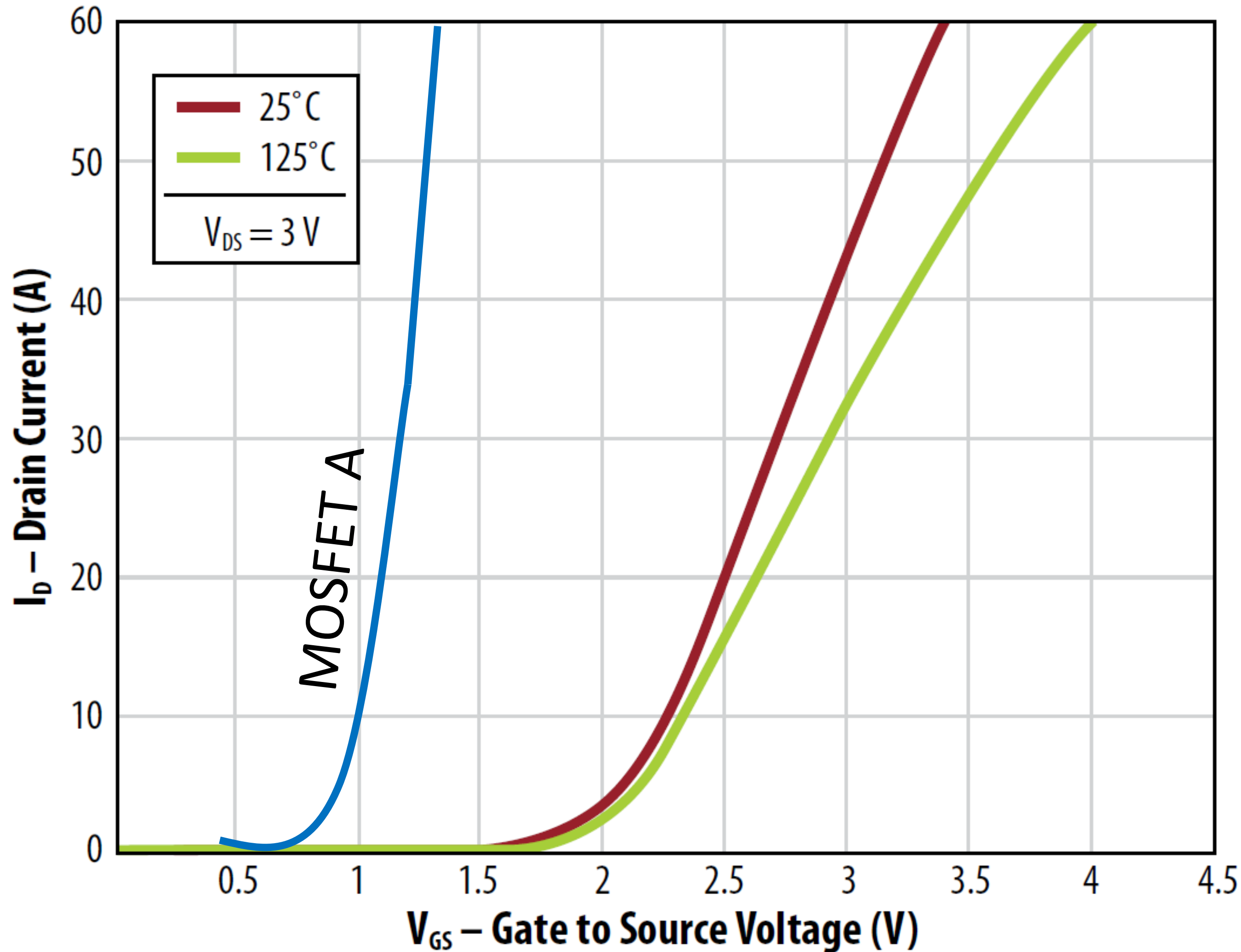
1.2
1.1
1
0.9
0.8
0.7
0.6

-50 -25 0 25 50 75 100 125 150

Junction Temperature (°C)

GaN
MOSFET A

eGaN®FET Reverse Conduction



Total Gate Charge

Gate-To-Source Voltage (V)

16
14
12
10
8
6
4
2
0

0 5 10 15 20 25 30 35

Total Gate Charge (nC)

MOSFET A
MOSFET B
GaN

Figure of Merit

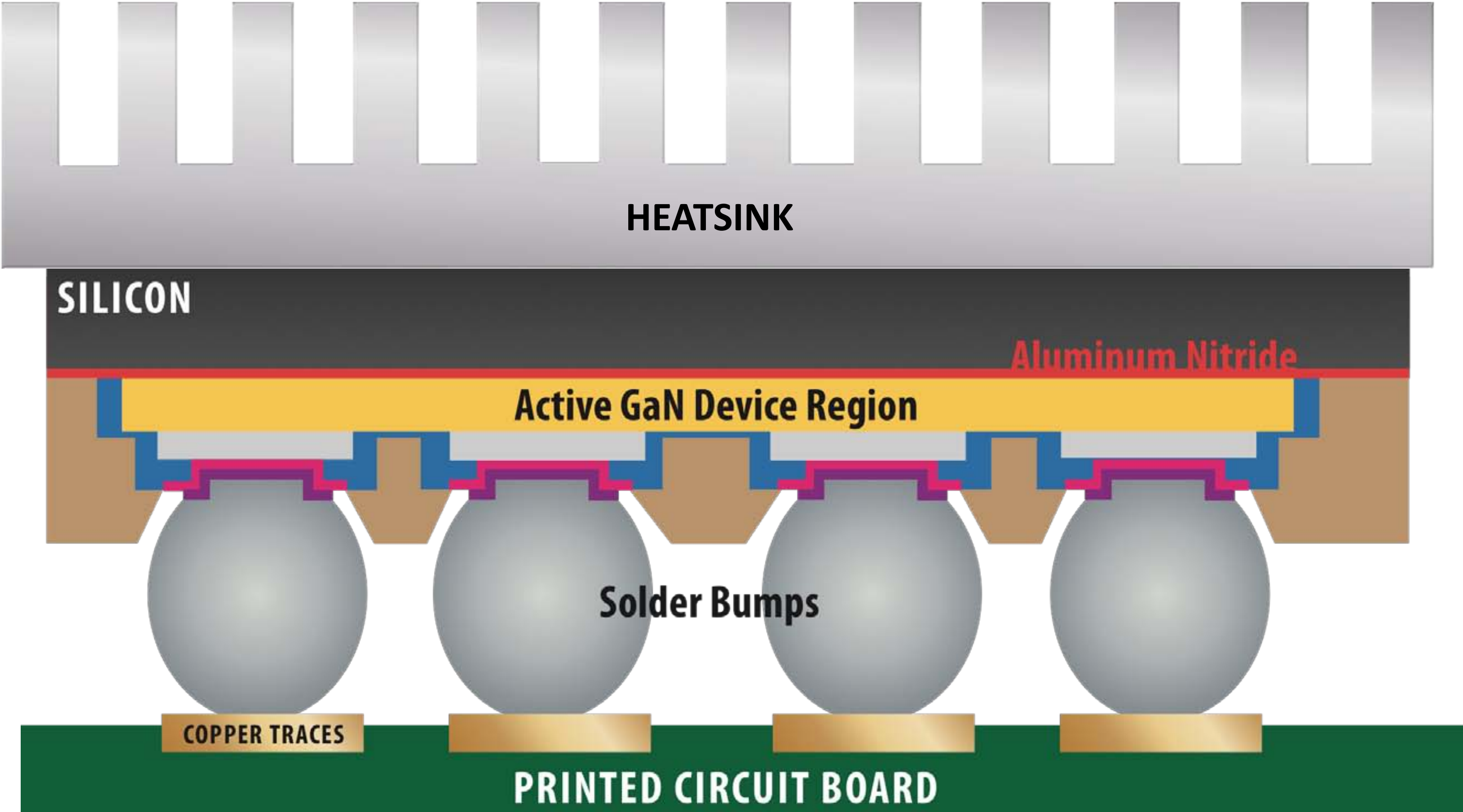
FOM = Rdson x Qg (100V)

Package Wish List

EFFICIENT POWER CONVERSION

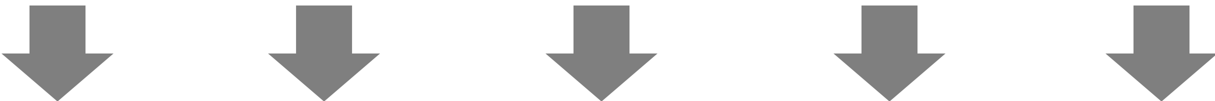
- Low parasitic resistance
- Low parasitic inductance
- Low thermal resistance
- Small size
- Low cost

Flip Chip LGA Assembly



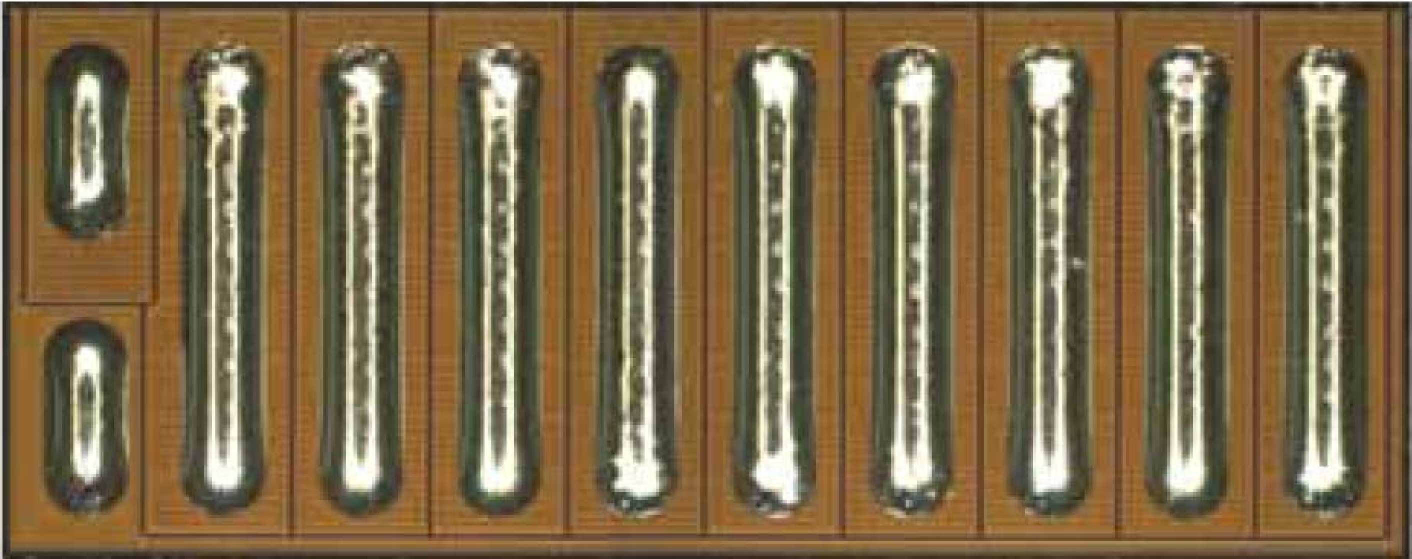
LGA Construction

Drain Contacts



Substrate

Gate



Source Contacts

Size Comparison

eGaN FET

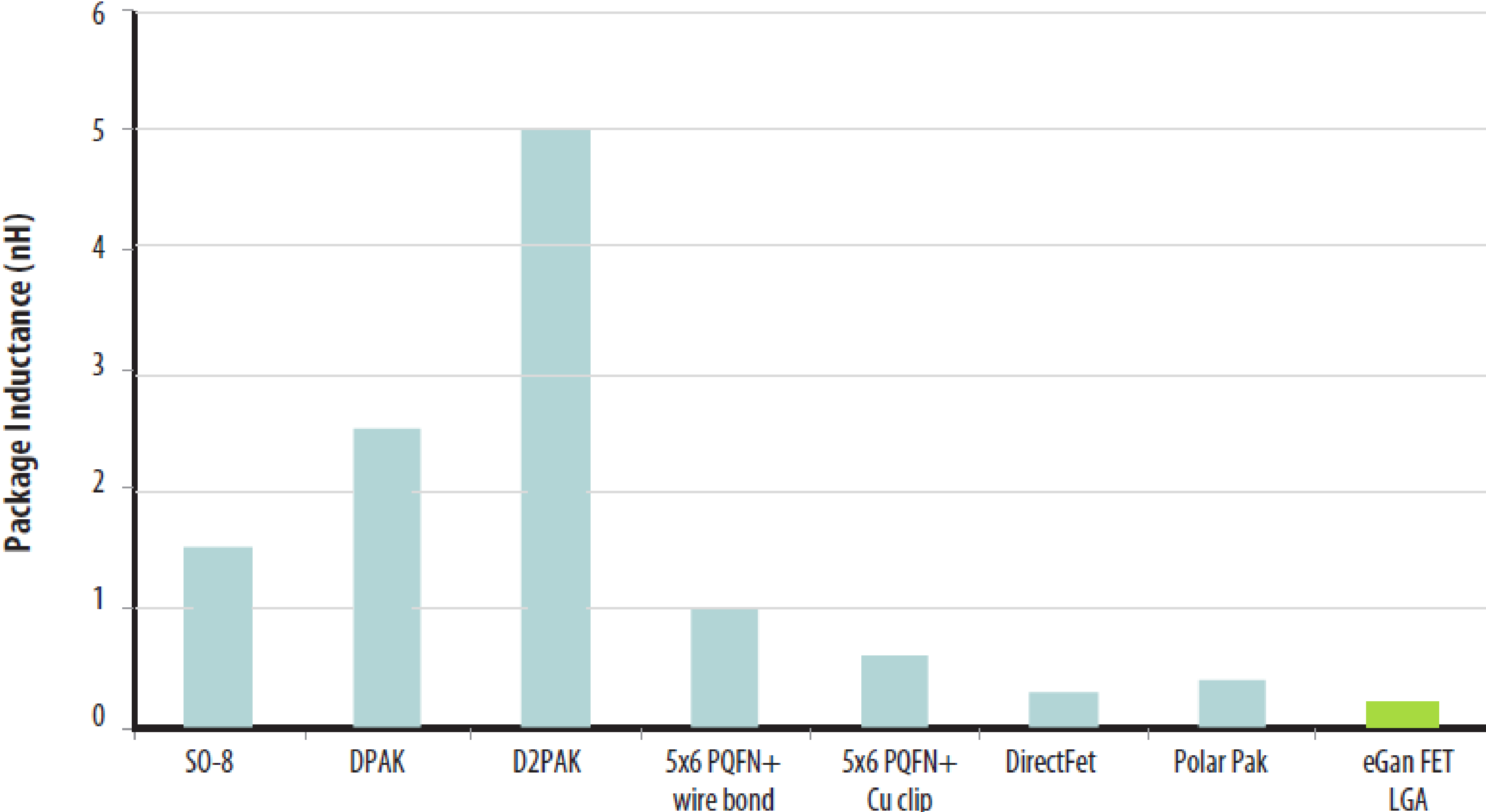
5.76 mm^2

D-PAK

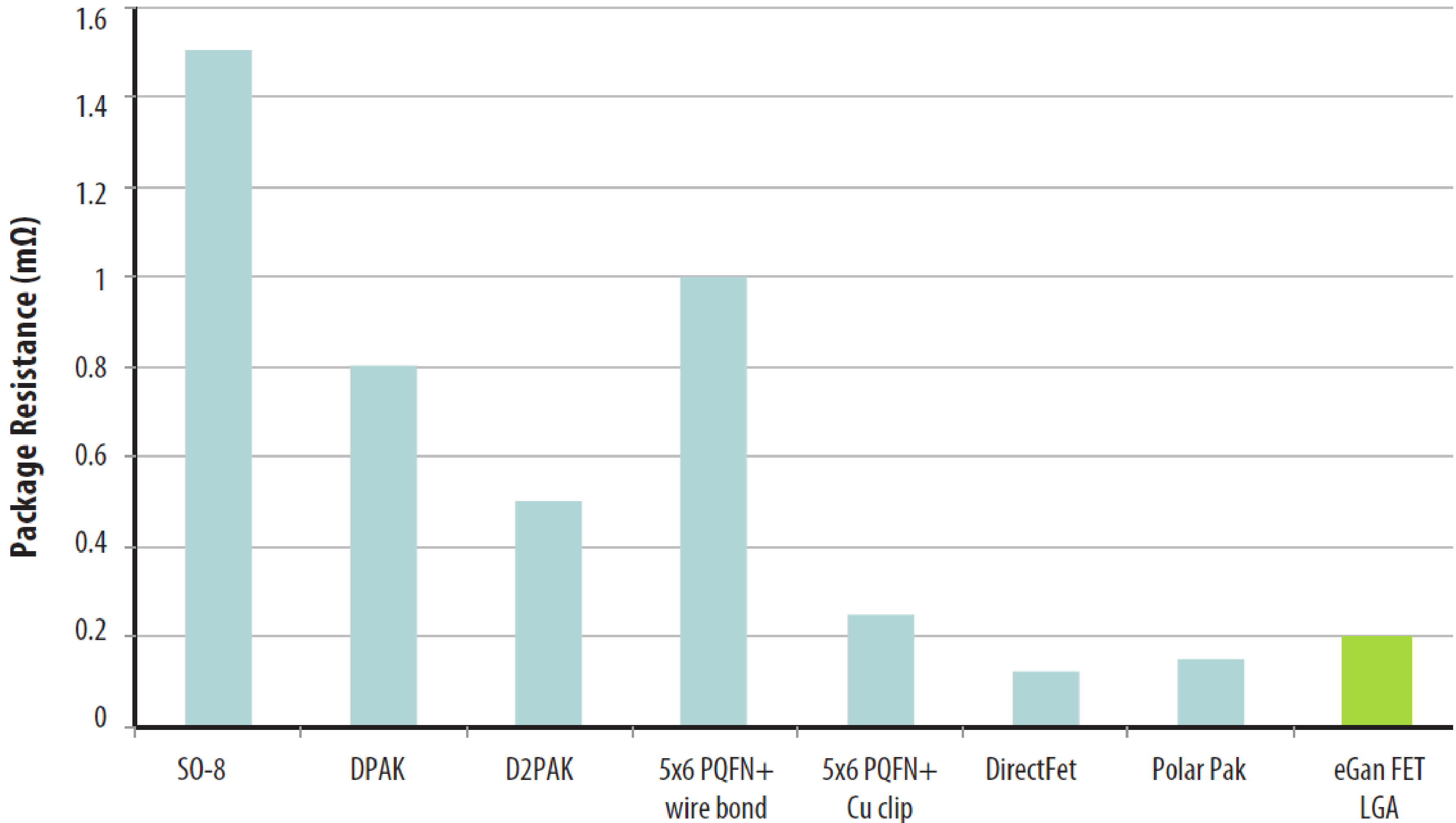
65.3 mm^2

Drawn To Scale

Package Inductance



Package Resistance



The Opportunity to Improve DC-DC Efficiency

Integrated Gate Driver Solution

LM5113 from Texas Instruments

Buck Converter

Advantage:

- **High power density and high efficiency**

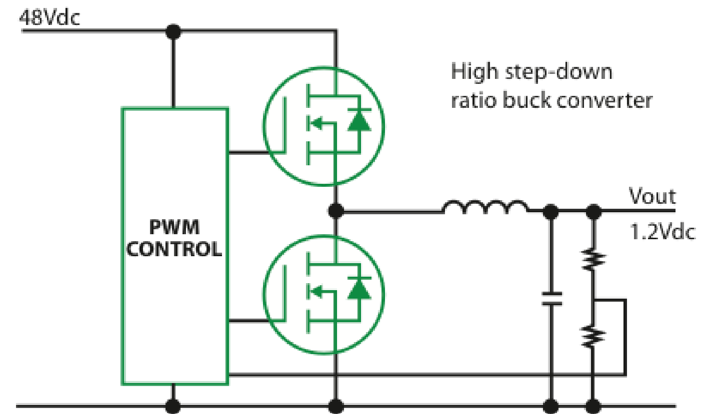
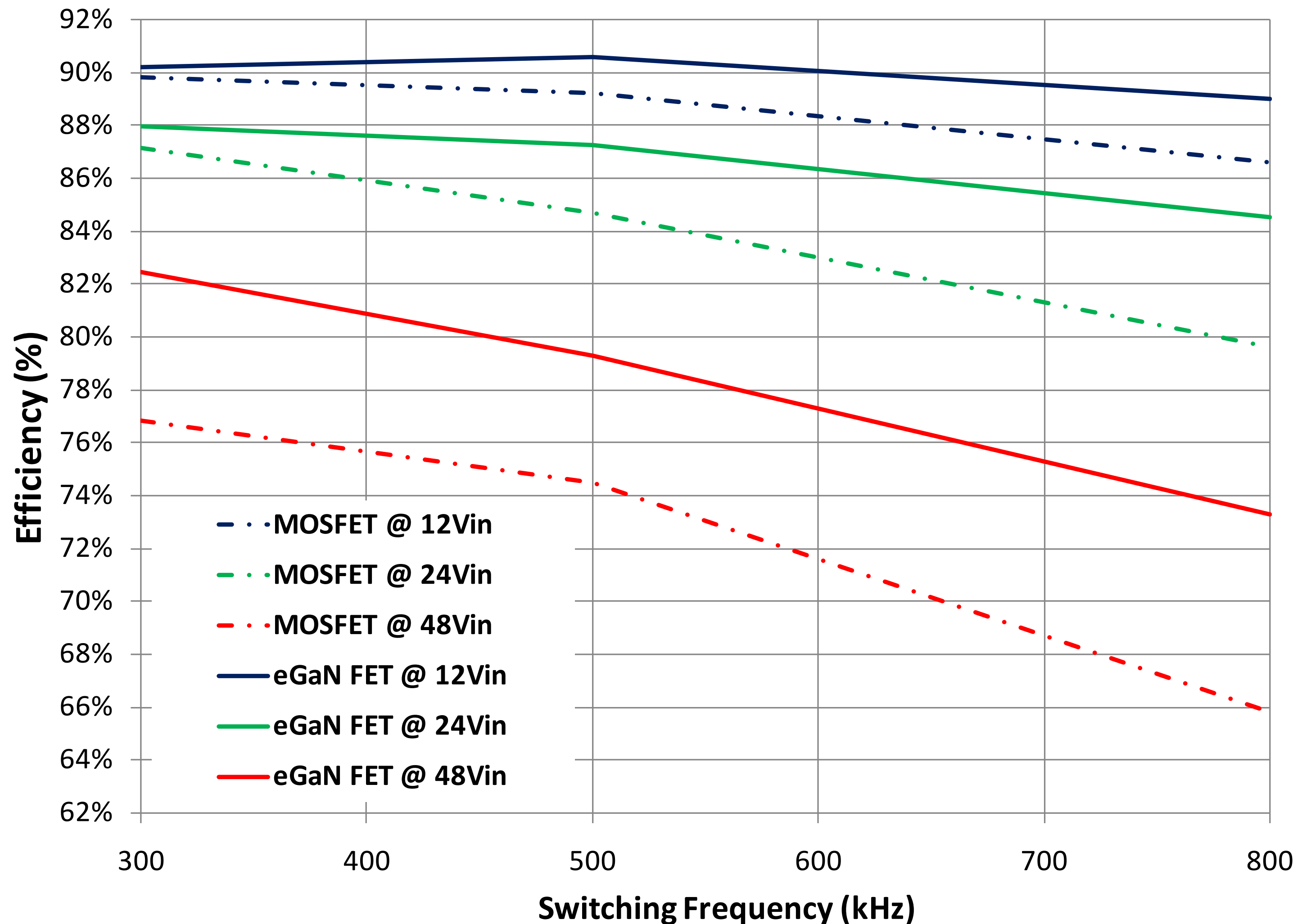


Figure 7 – Buck converter with an input voltage of 48 VDC and output voltage of 1.2 VDC

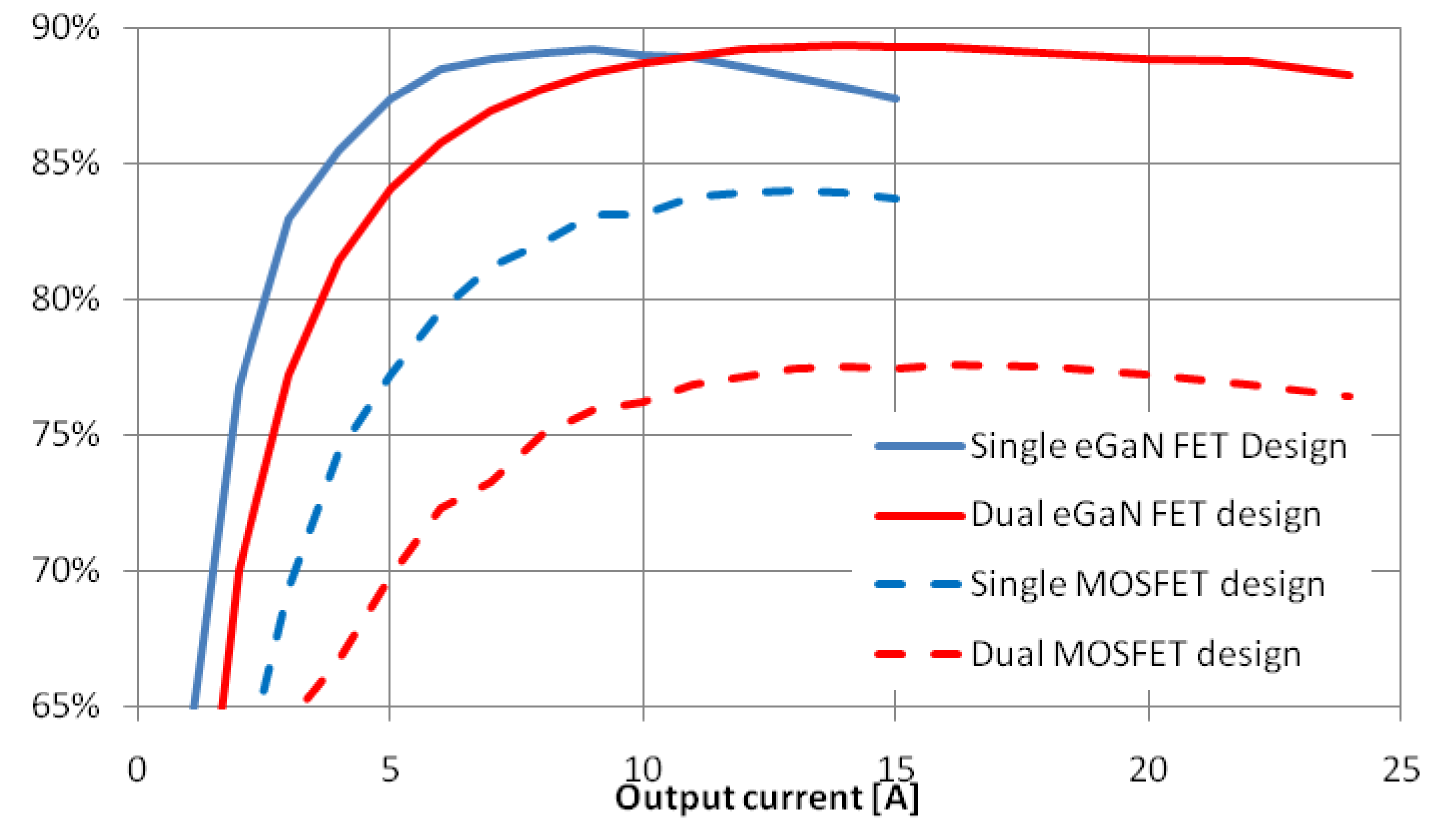
Efficiency vs Frequency



Parallel FET Buck Converter

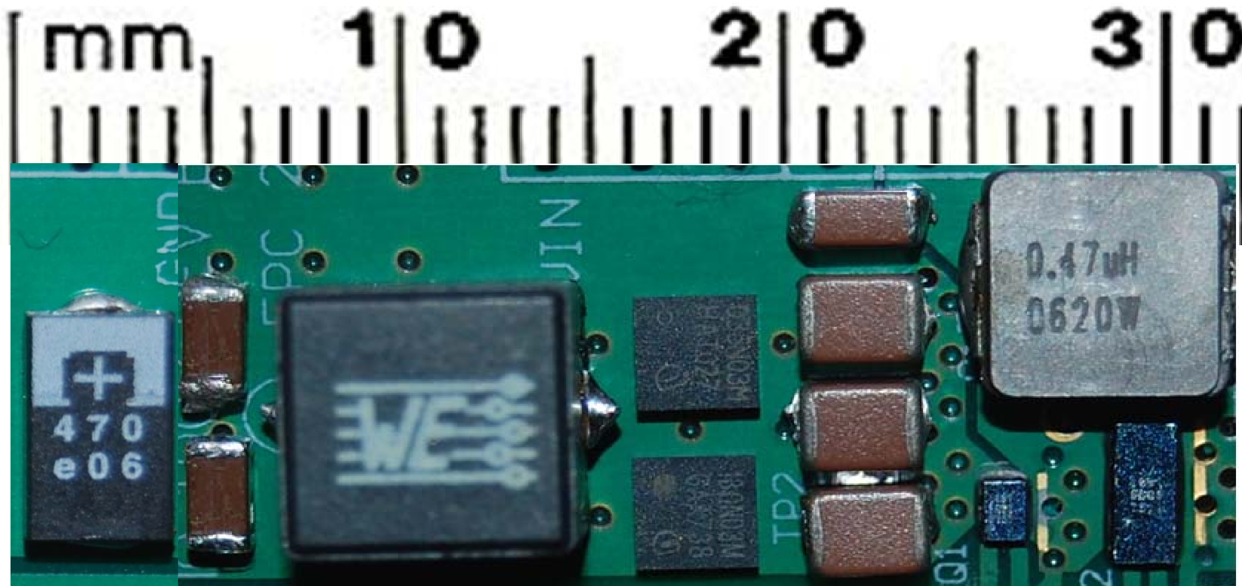
EFFICIENT POWER CONVERSION

Efficiency at 1 MHz



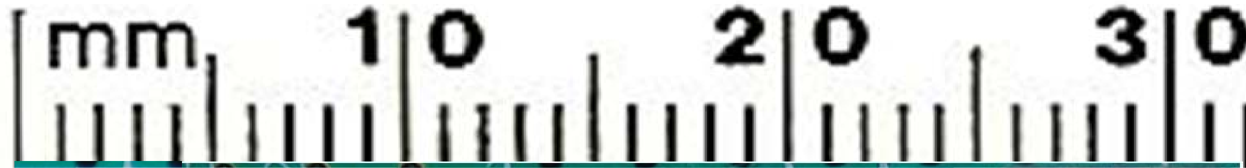
$12\ V_{IN} - 1.2\ V_{OUT}$

Buck Size Comparison

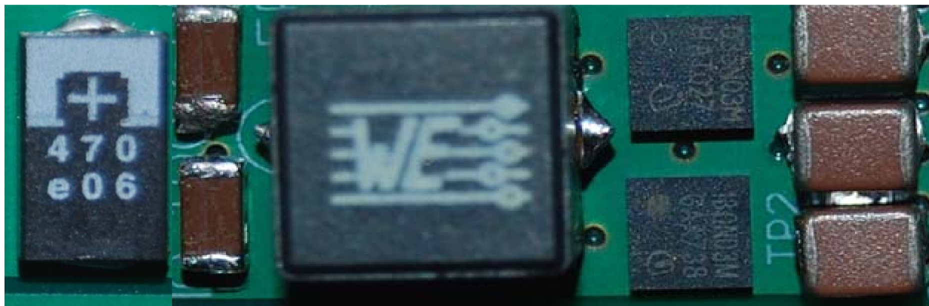


A 24V-1.2V Buck converter was built with both with eGaN FETs and state-of-the-art silicon power MOSFETs

Buck Size Comparison

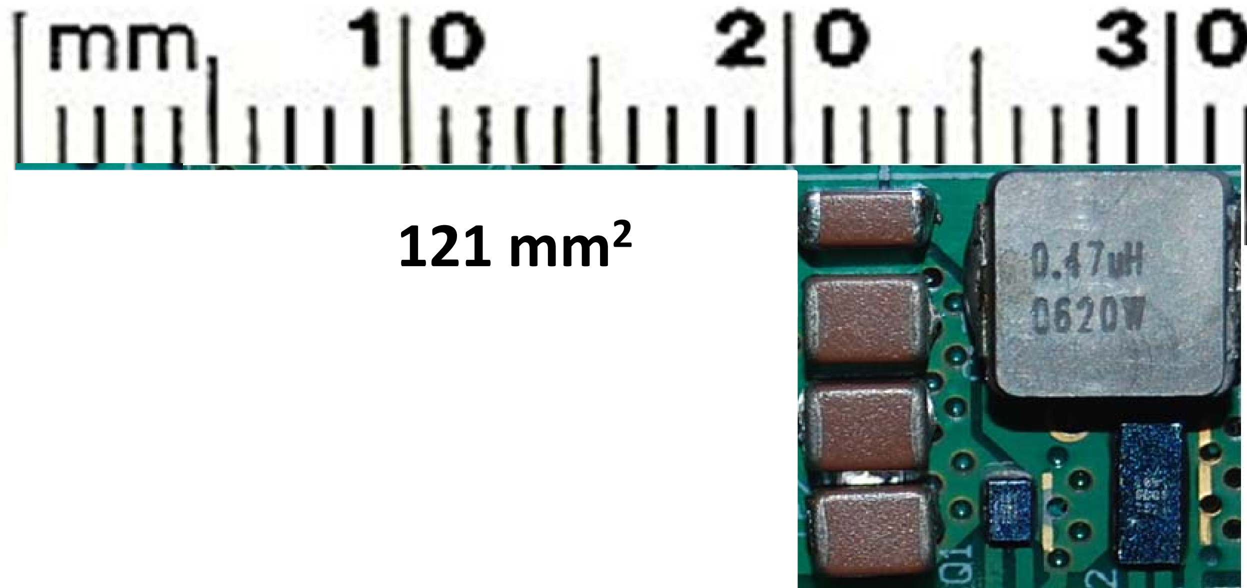


184 mm^2



The MOSFET-based circuit measures 184 mm^2

Buck Size Comparison

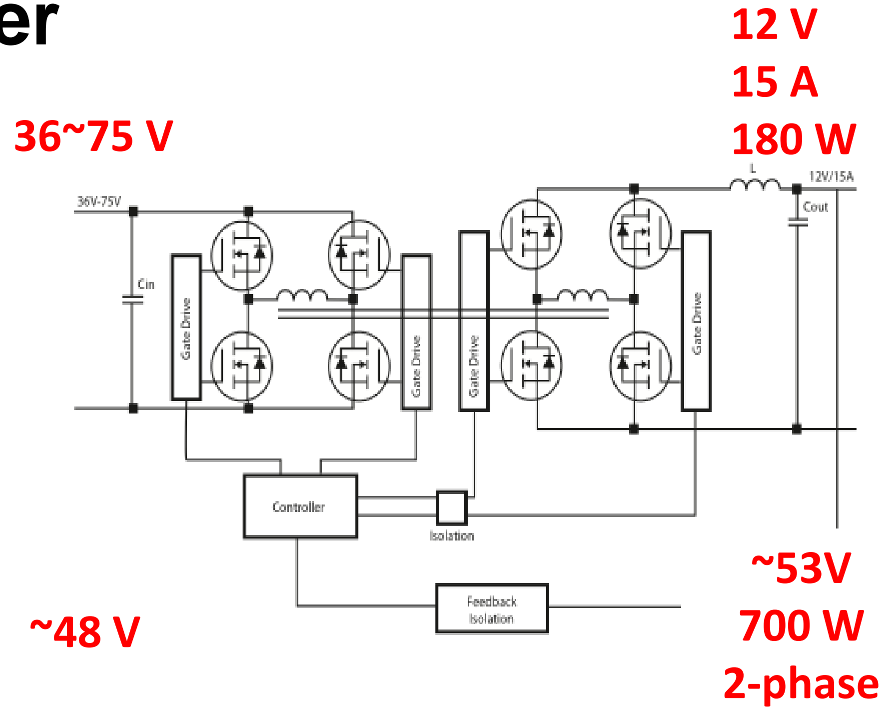


A 24V-1.2V Buck converter with eGaN FETs is 50% smaller and has 30% less power losses at 800 kHz.

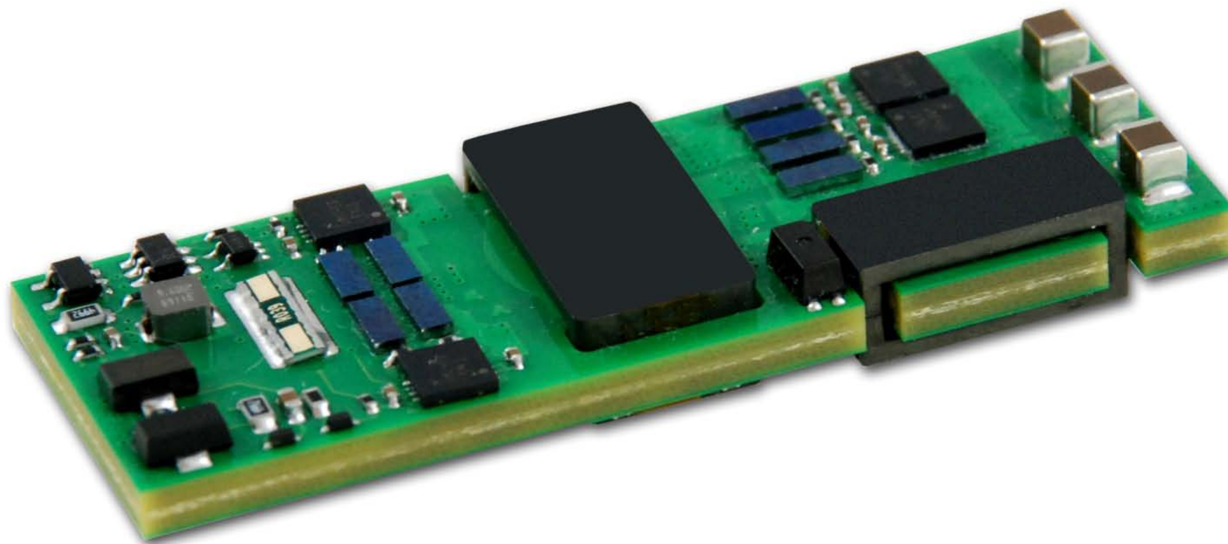
Isolated Full Bridge Converter

Advantage:

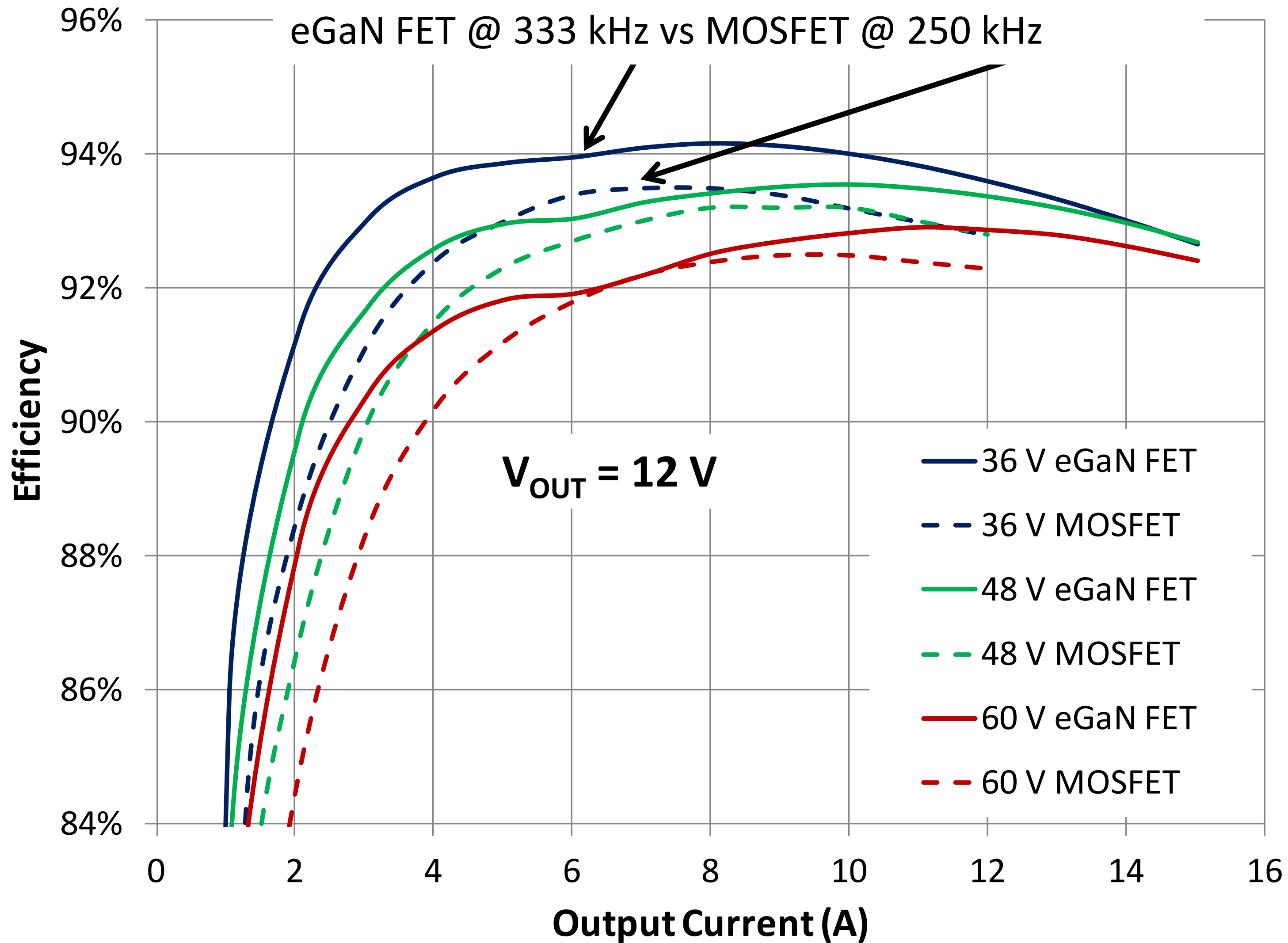
- **Isolation and high power density at high power**



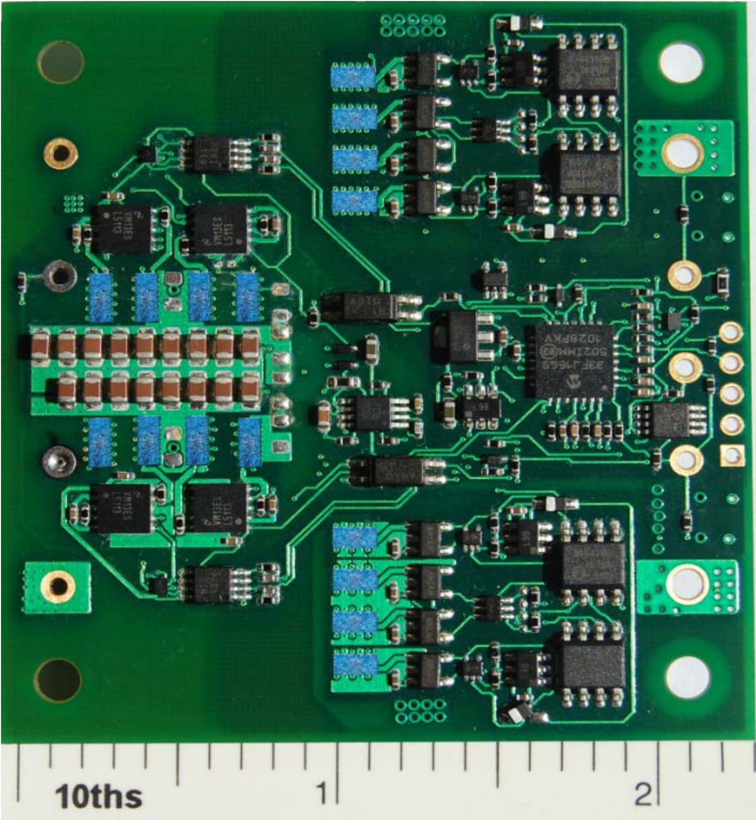
Isolated Full Bridge Converter



Isolated Full Bridge Converter



PoE-PSE Full Bridge Converter



PoE-PSE Full Bridge Converter

250 kHz eGaN FET

140 kHz MOSFET

700 W

550 W

Efficiency

98%
97%
96%
95%
94%
93%
92%
91%
90%
89%
88%

0 2 4 6 8 10 12 14

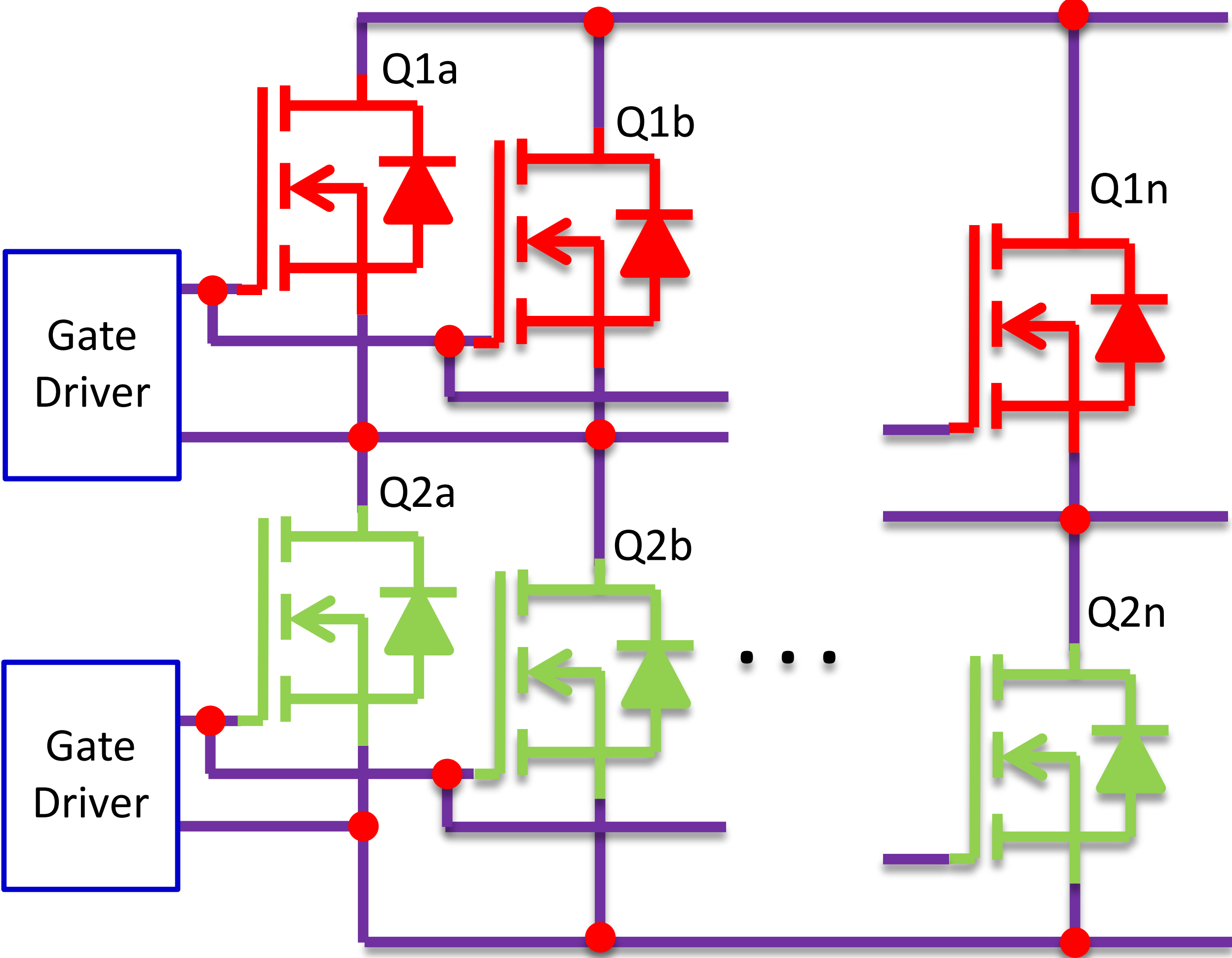
Output Current (A)

38 V eGaN FET
38 V MOSFET
48 V eGaN FET
48 V MOSFET
60 V eGaN FET
60 V MOSFET

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

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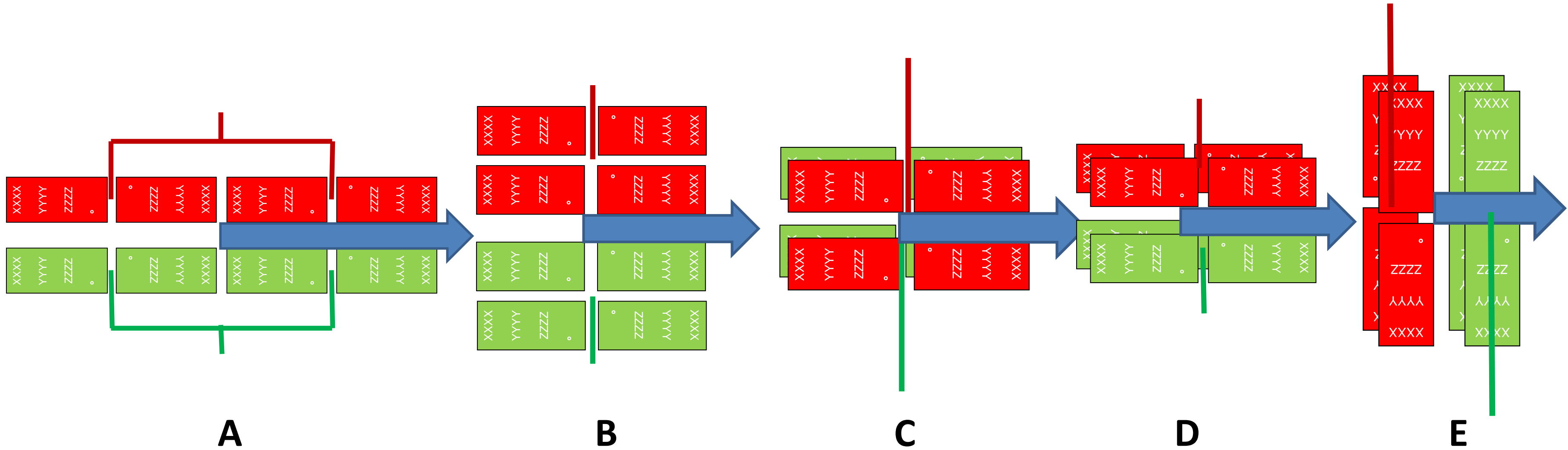
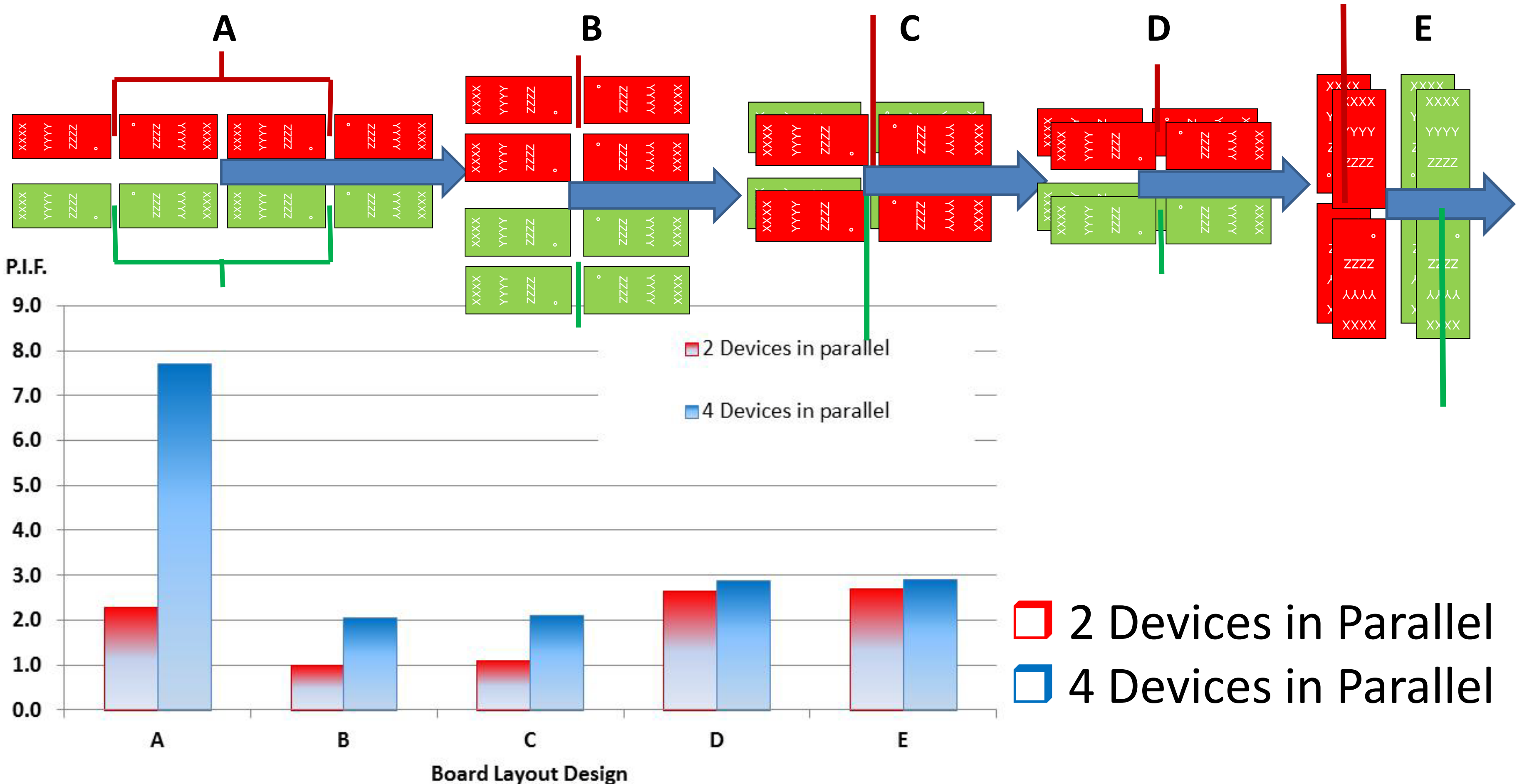


<u>Single Component Sided</u>

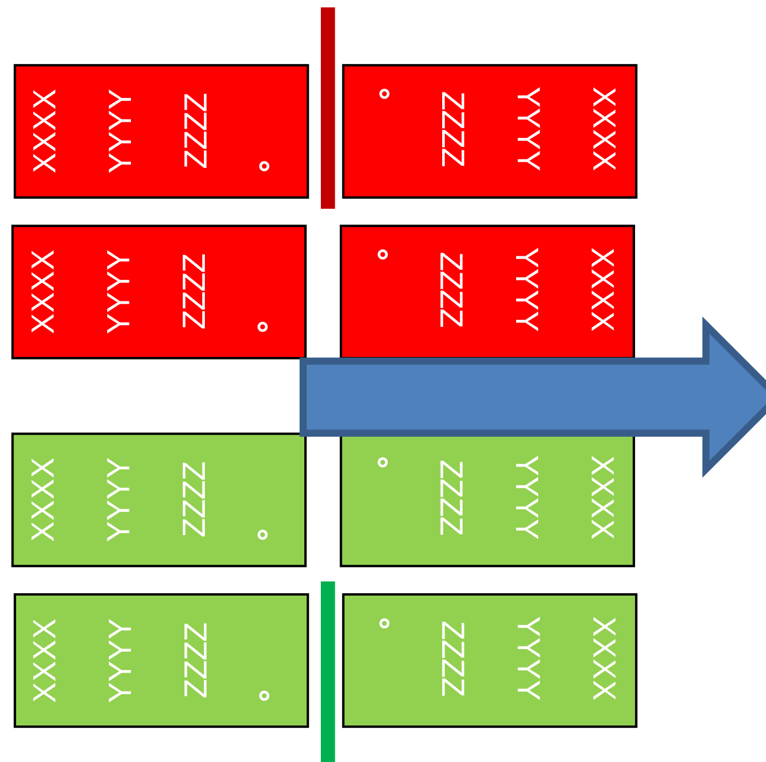
<u>Double Component Sided</u>

PIF for Half Bridge Layouts



2 Devices in Parallel
4 Devices in Parallel

Best Layout Configuration



Four FETs Operating in Parallel

Tek Run Trig'd

eGaN FET's

Ch1 Rise
48.87ns

Ch1 Fall
44.94ns

Ch1 +Width
2.043µs

Ch1 Ampl
408.0 A

Ch1 ↓ 100 A M 400ns A Ext ∫ 800mV

10.00 %

26 Mar 2012
12:47:48

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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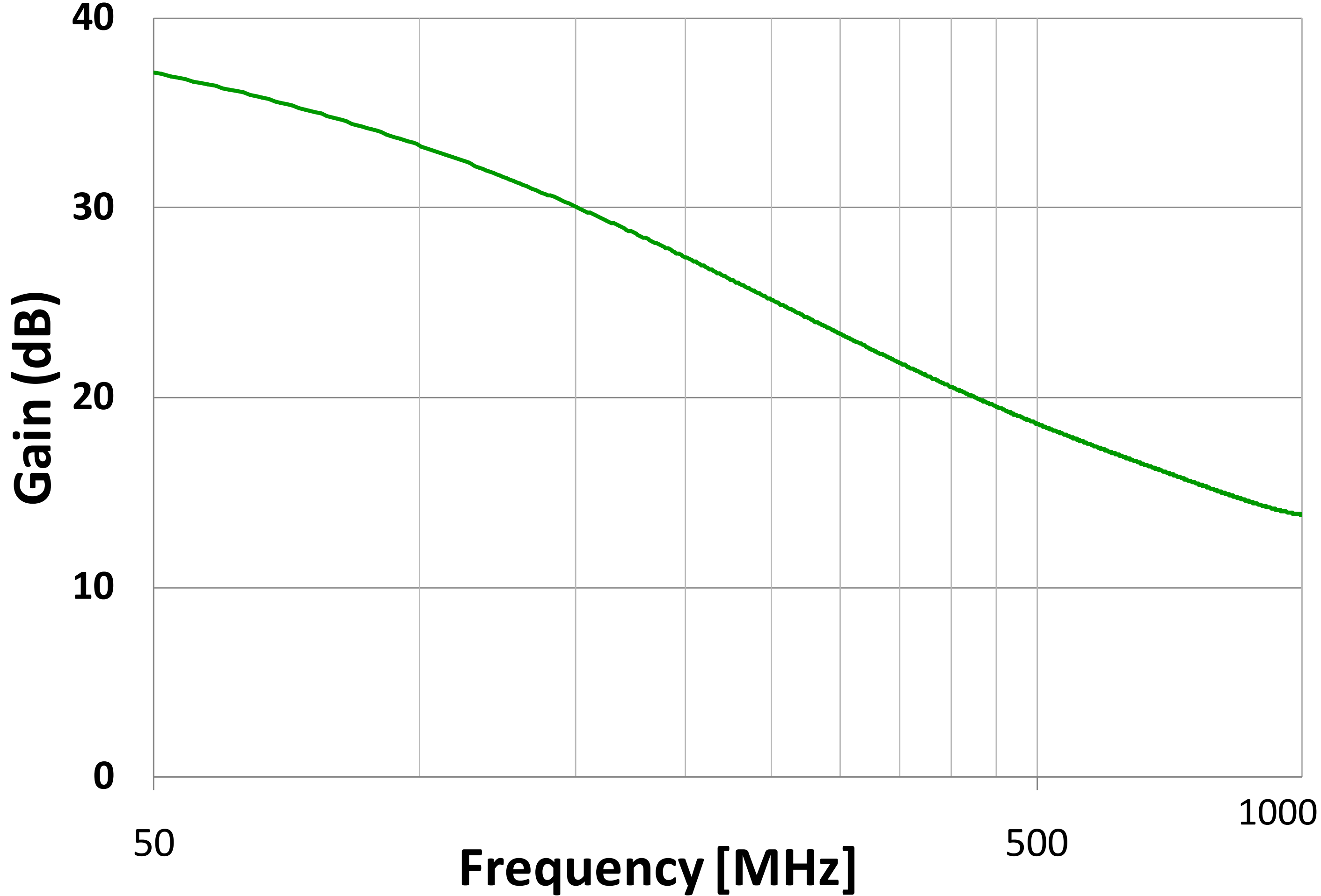
Applications for eGaN® FETs

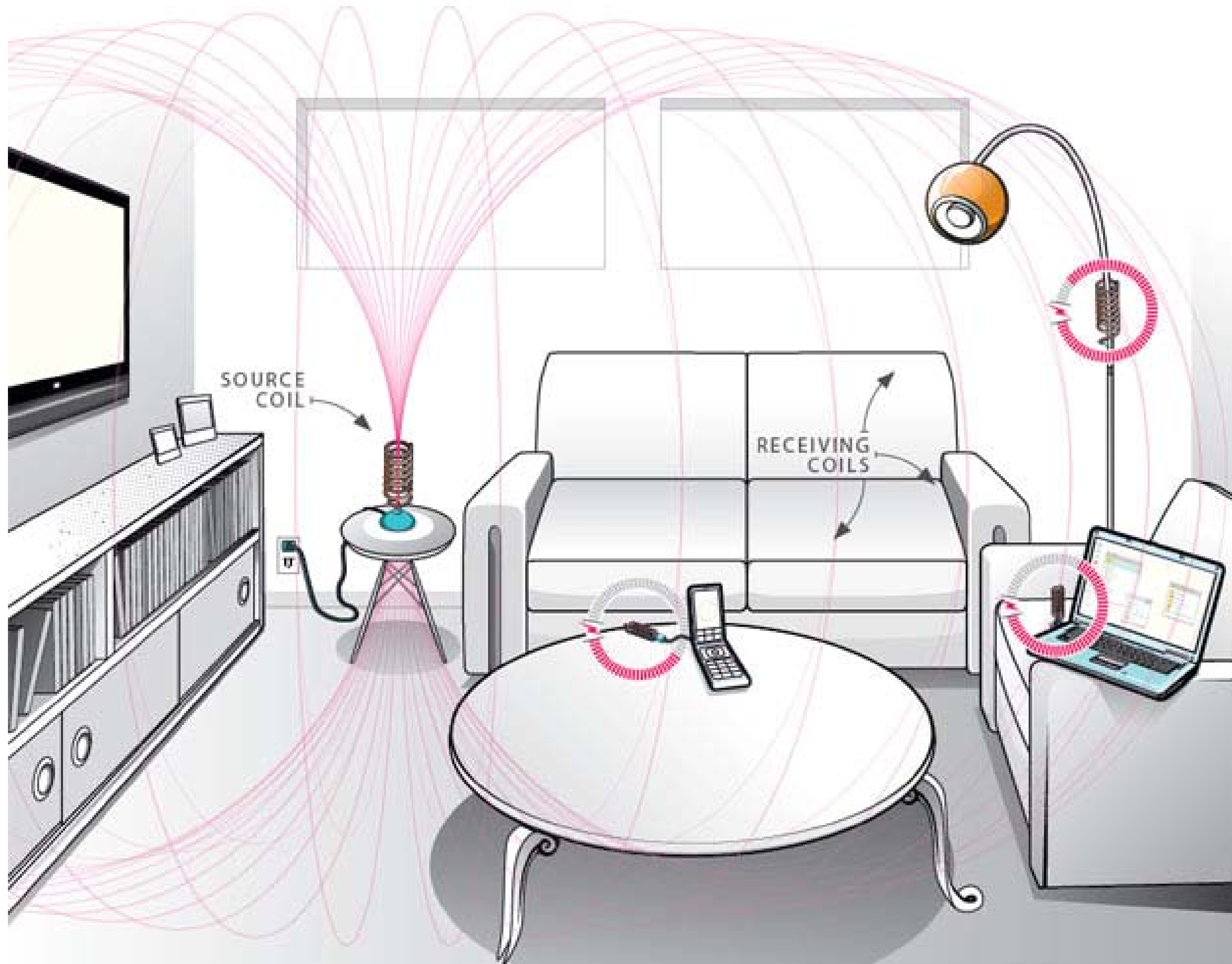
- **Wireless Power Transmission – GaN Enabled**
- **RF DC-DC "Envelope Tracking" – GaN Enabled**
- **RadHard**
- **Power Over Ethernet**
- **RF Transmission**
- **Network and Server Power Supplies**
- **Power Factor Correction**
- **Point of Load Modules**
- **Solar Microinverters**
- **Energy Efficient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

High Frequency High Voltage *and* High Power



Wireless Power

EFFICIENT POWER CONVERSION



RF Envelope Tracking

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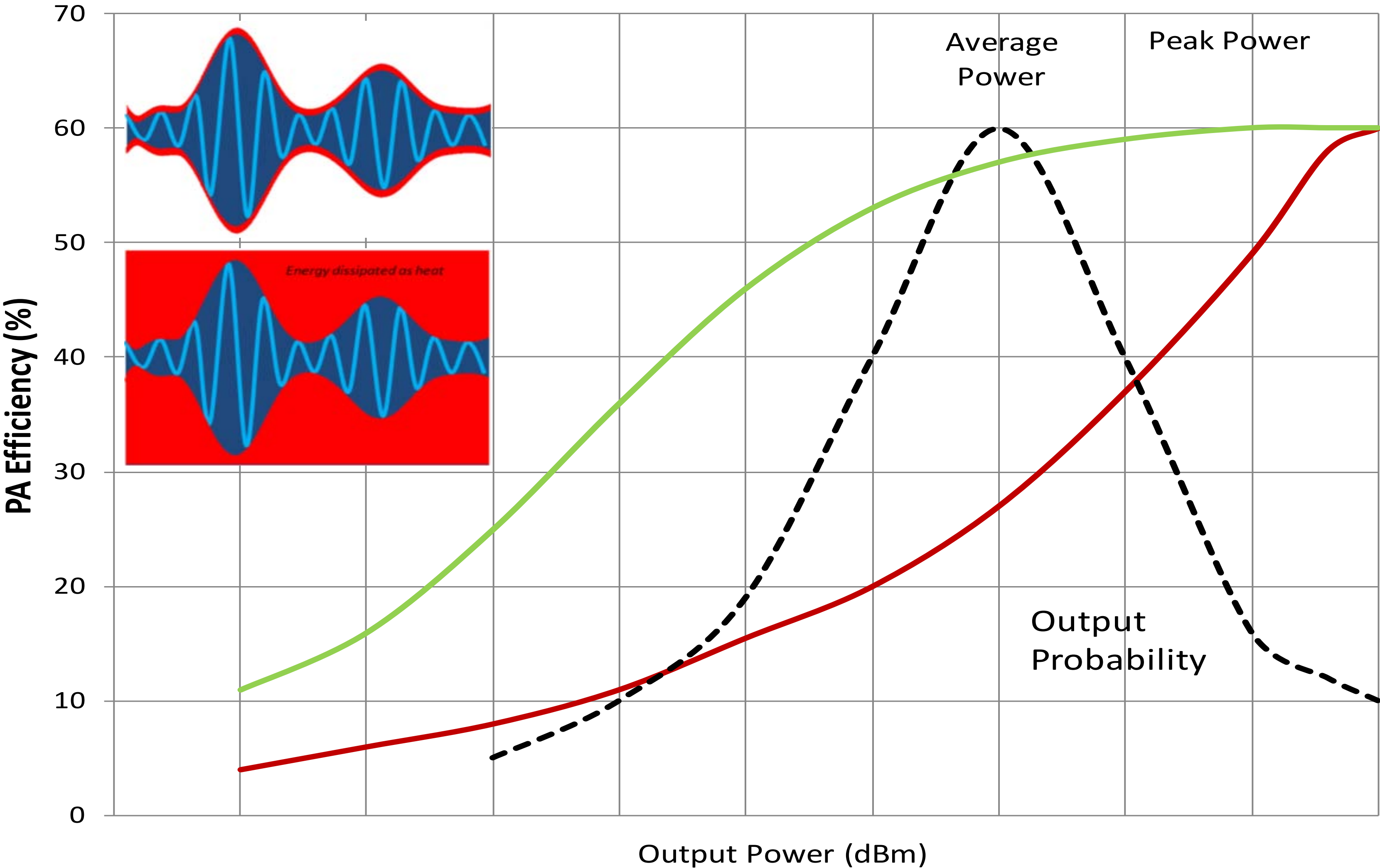
EFFICIENT POWER CONVERSION



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

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- Is it VERY cost effective to the user?
- Is it reliable?

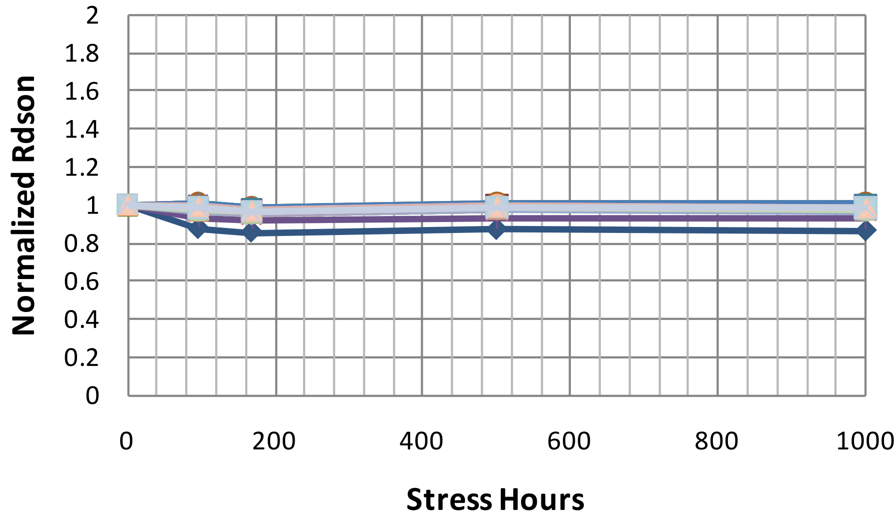
Silicon vs eGaN® FET Wafer Costs

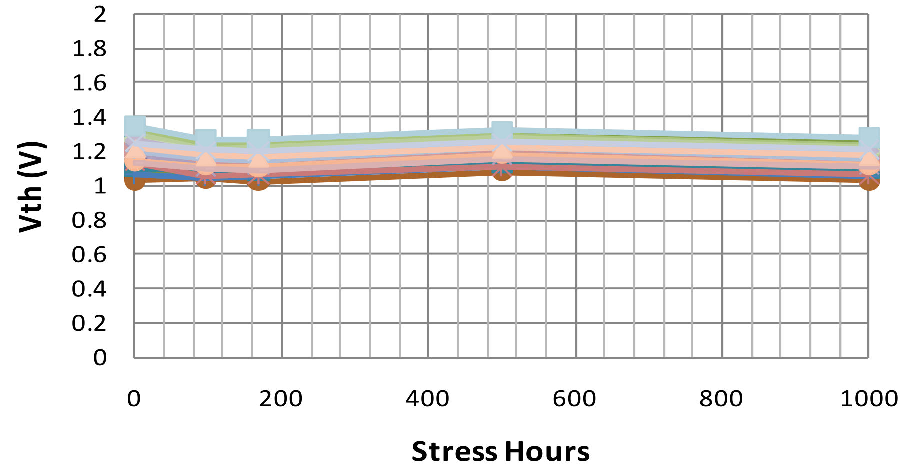
	2011	2015
Starting Material	same	same
Epi Growth	***higher***	***~same?***
Wafer Fab	same	lower
Test	same	same
Assembly	lower	lower
OVERALL	**higher**	***lower!***

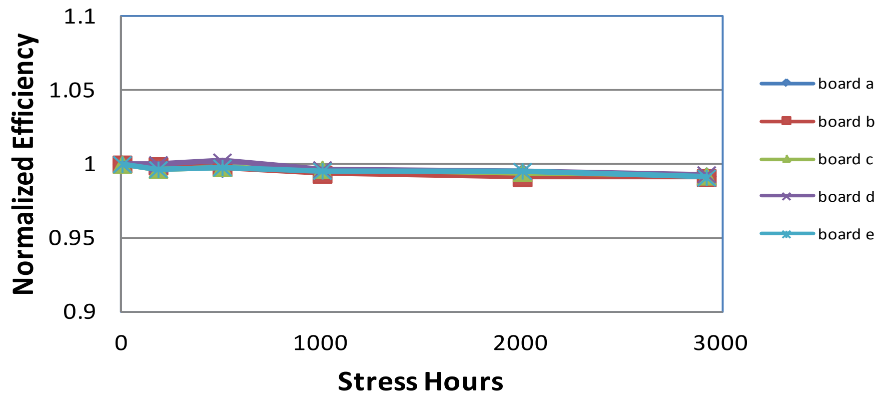
Breaking Down the Barriers

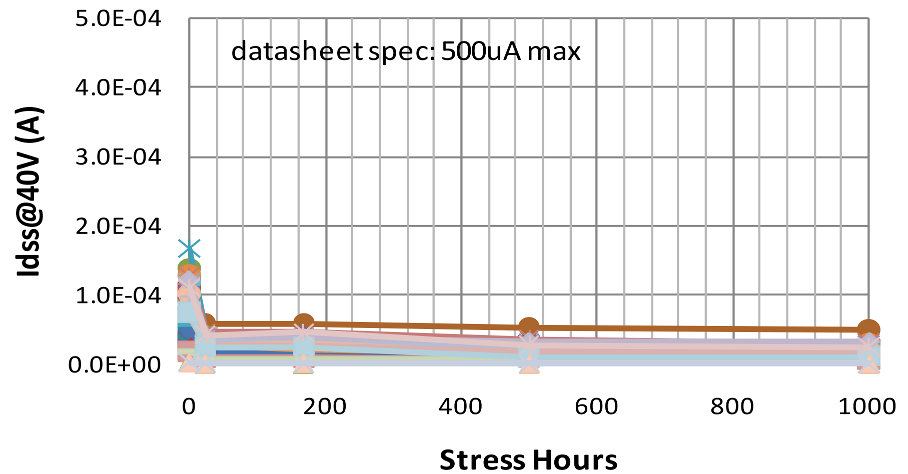
- Does it enable significant new capabilities?
- Is it easy to use?
- Is it VERY cost effective to the user?
- Is it reliable?

eGaN® FETs are Reliable



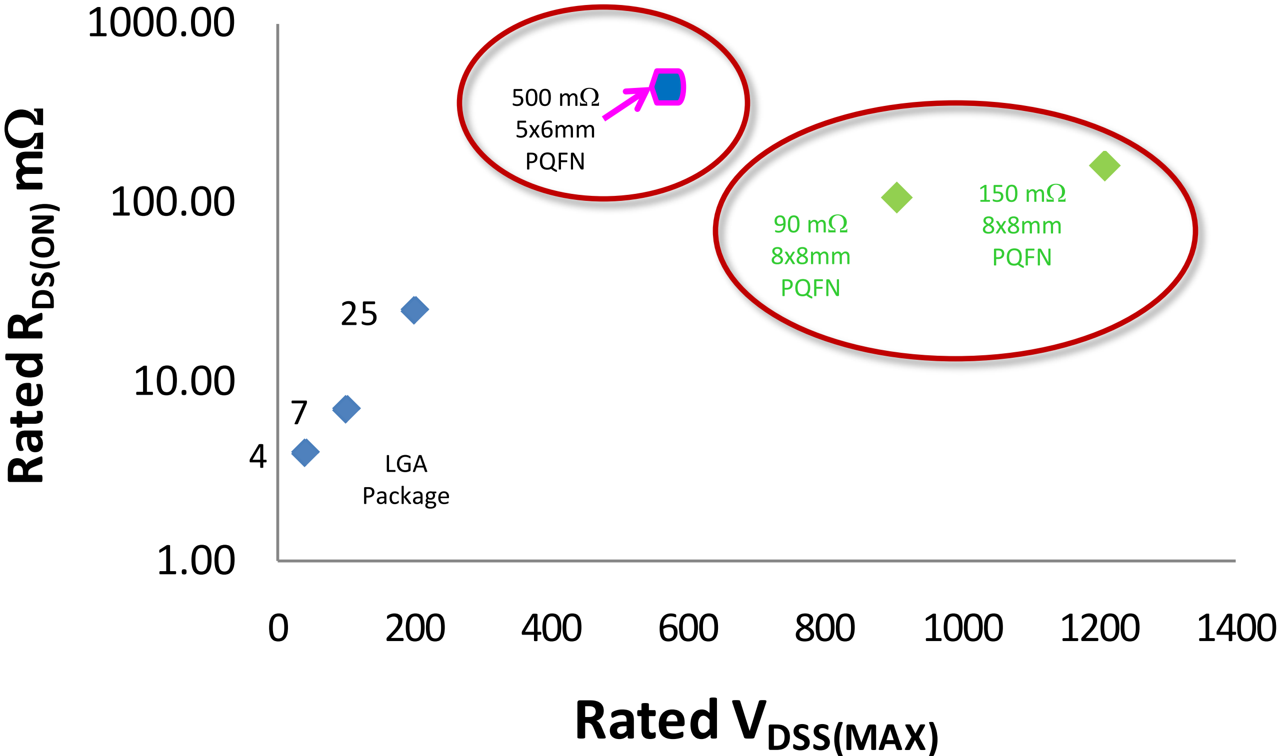






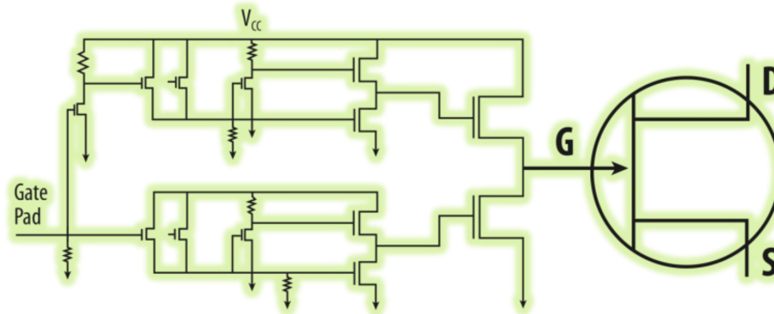
Beyond 600 Volts

EFFICIENT POWER CONVERSION

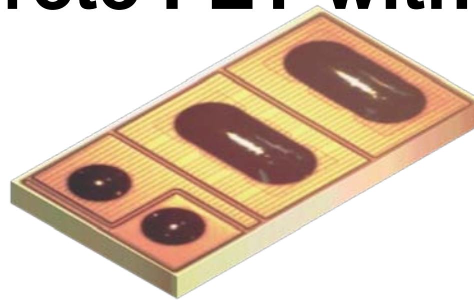


Beyond Discrete Devices

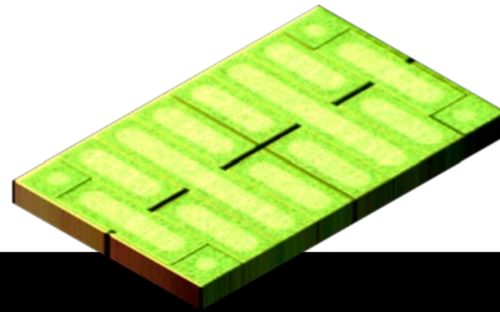
Driver On Board



Discrete FET with Driver



Full-Bridge with Driver and Level Shift



Summary

EFFICIENT POWER CONVERSION

- 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!