High-Power 650-V and 1200-V GaN Devices for EVs Applications

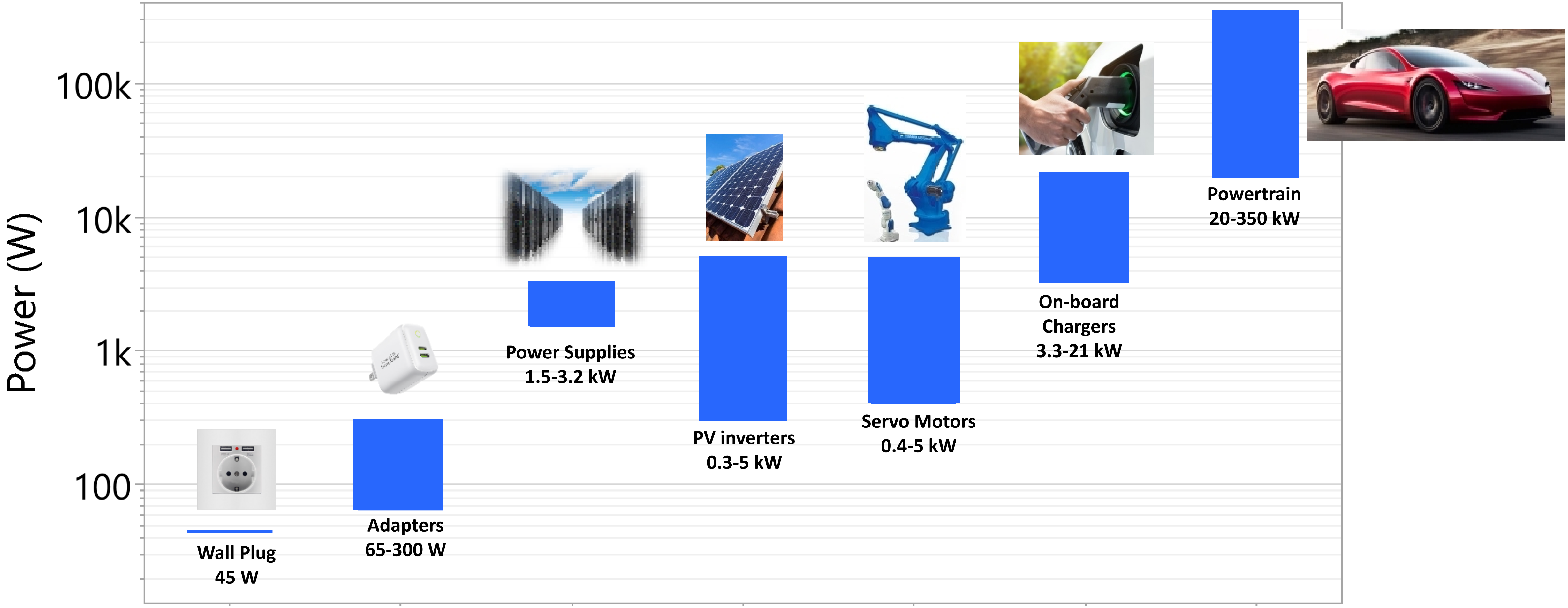
D. Bisi, G. Gupta, C. J. Neufeld, Y. Huang, T. Hosoda, M. Kanamura, R. Lal.,
L. Shen, T. Dhayagude, P. Zuk, P. Parikh, U. K. Mishra

transphorm

Presented at APEC, March 21st 2023

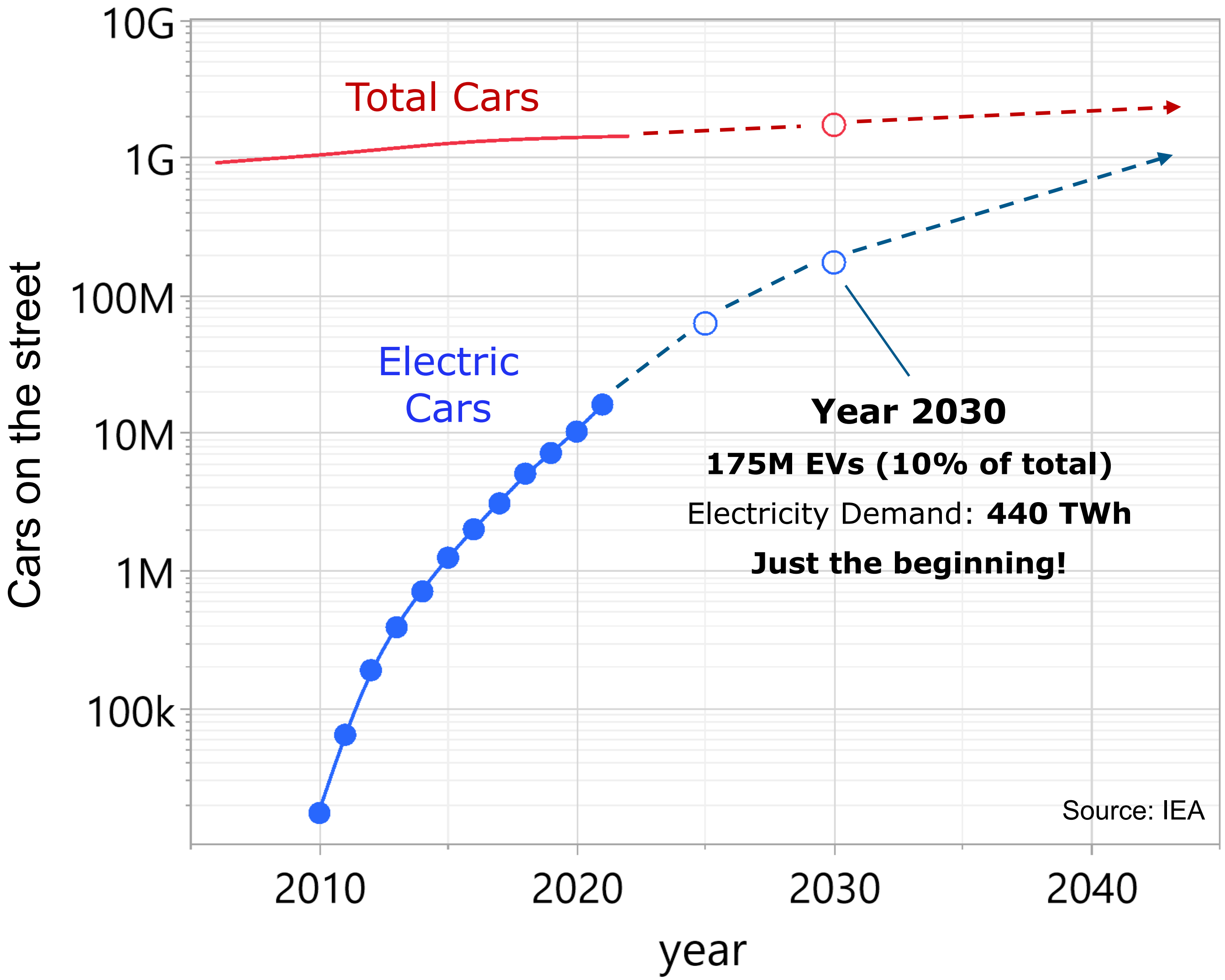
IS03.1

Broad power spectrum, one common challenge: Volume constraint



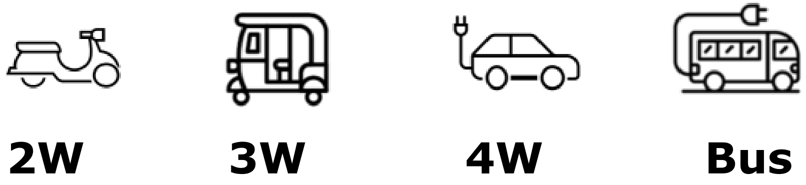
GaN can serve them all, efficiently.

Zero Emission Vehicles: Worldwide Policies & Manufacturers Pledges



	EV Target Sales	Target Date
Volvo	**100%**	2030
Ford	**100%** in Europe	2030
GM	**100%** (LDVs)	2035
Volkswagen	**70%** Europe; **50%** USA	2030
Stellantis	**70%** Europe; **35%** USA	2030

and many more.



IS03.1

The Electric Vehicle

DC-DC Auxiliary Power Module
(1 kW – 7 kW)

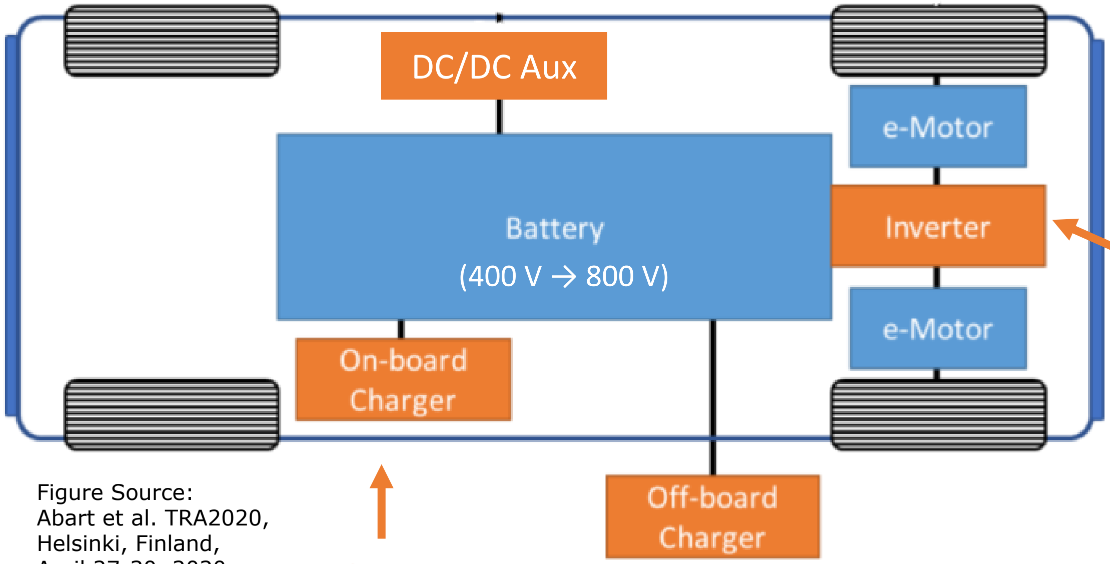
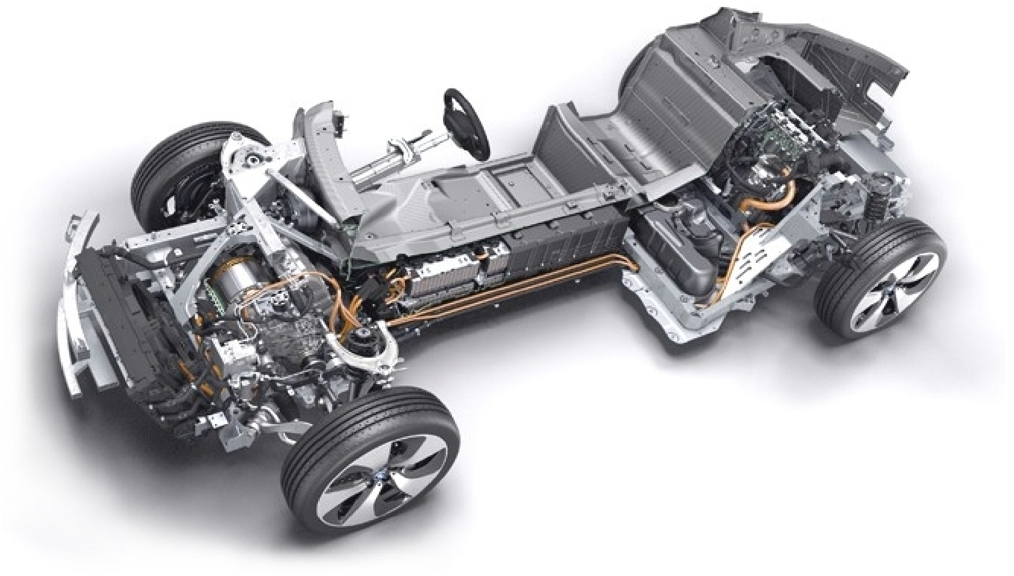


Figure Source:
Abart et al. TRA2020,
Helsinki, Finland,
April 27-30, 2020

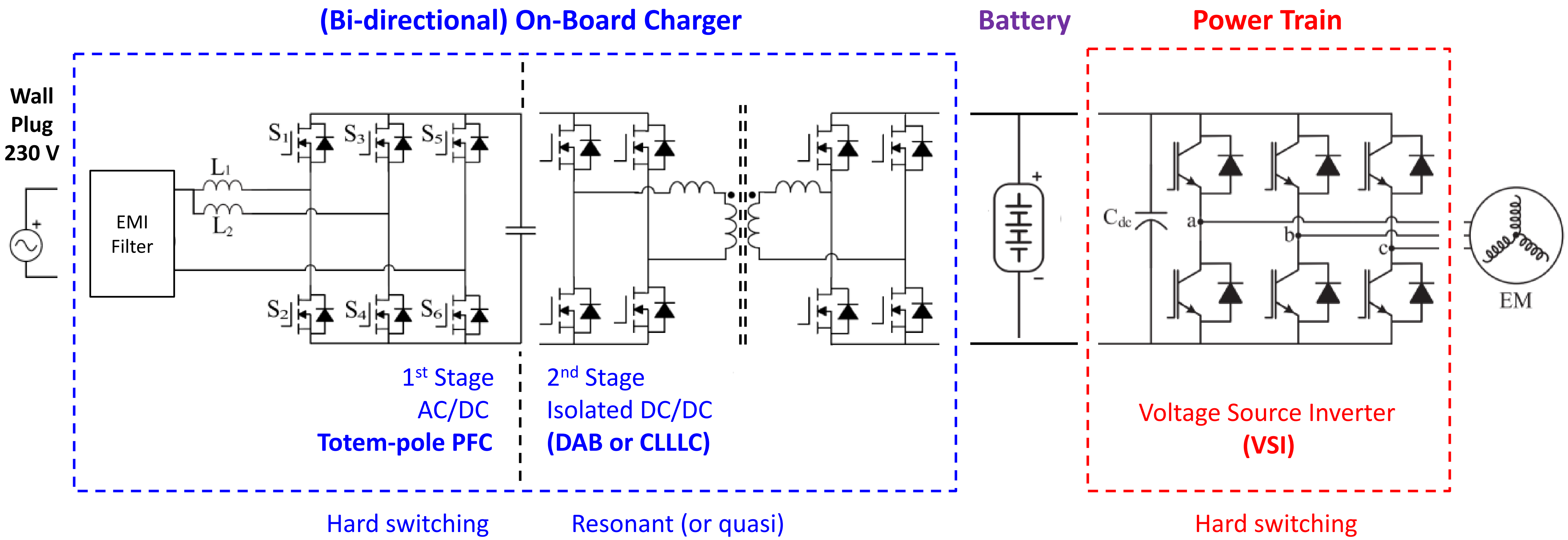
OBC
AC/DC -> DC/DC
(3.3 kW – 21 kW)

Powertrain
DC/AC
(30 – 250 kW)



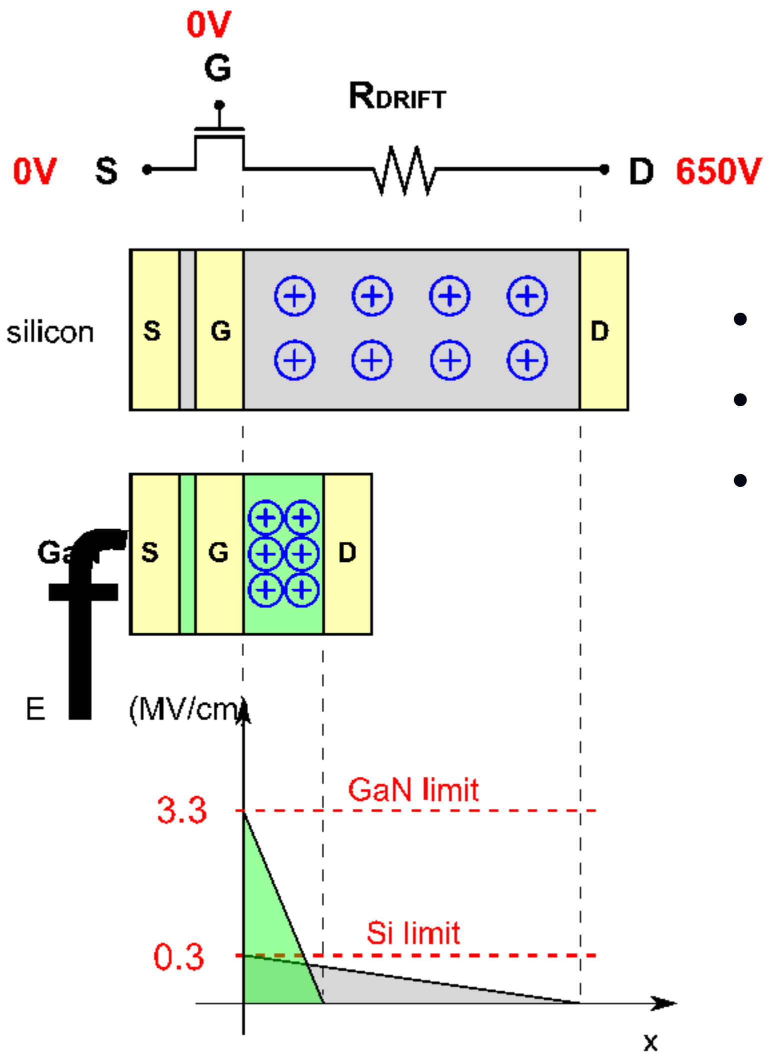
Requirements:
Efficiency
Power
Reliability

From Wall to Wheel



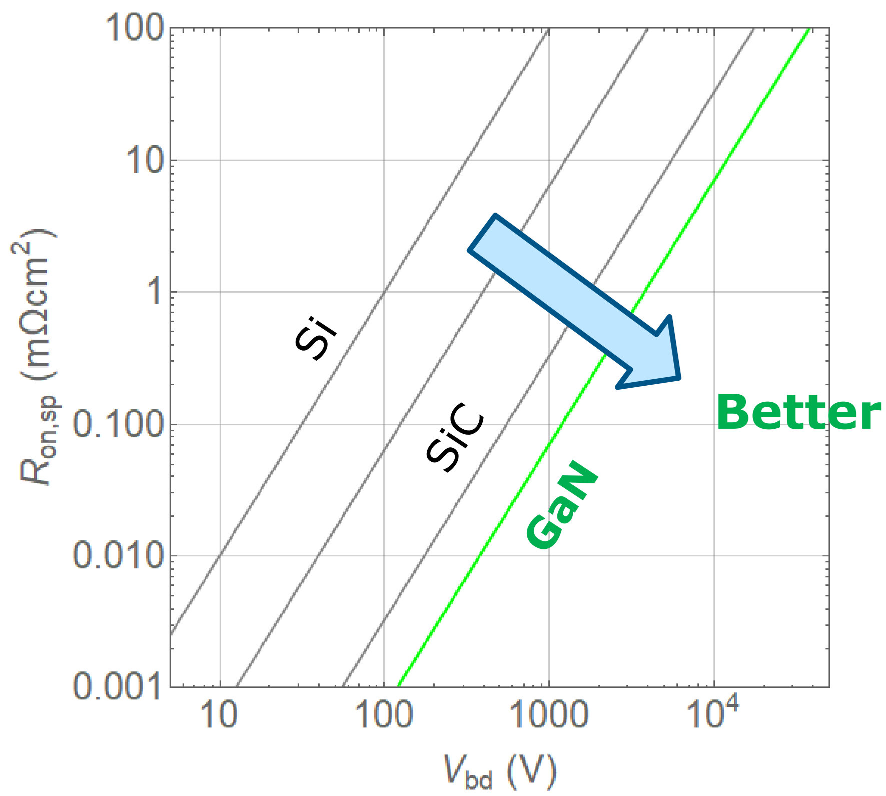
Volume constraint: High frequency & high efficiency are a must

GaN: same Voltage Rating, superior Switching Performance than Silicon

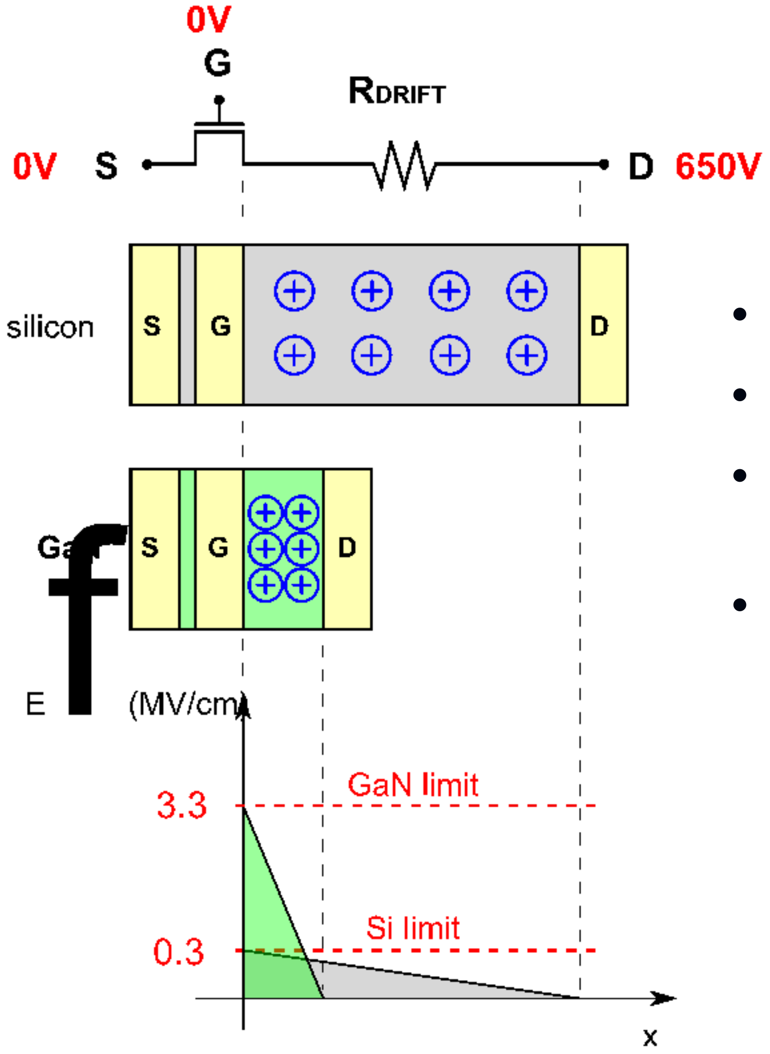


- Higher Critical field
- Higher Mobility
- Lower Specific Ron

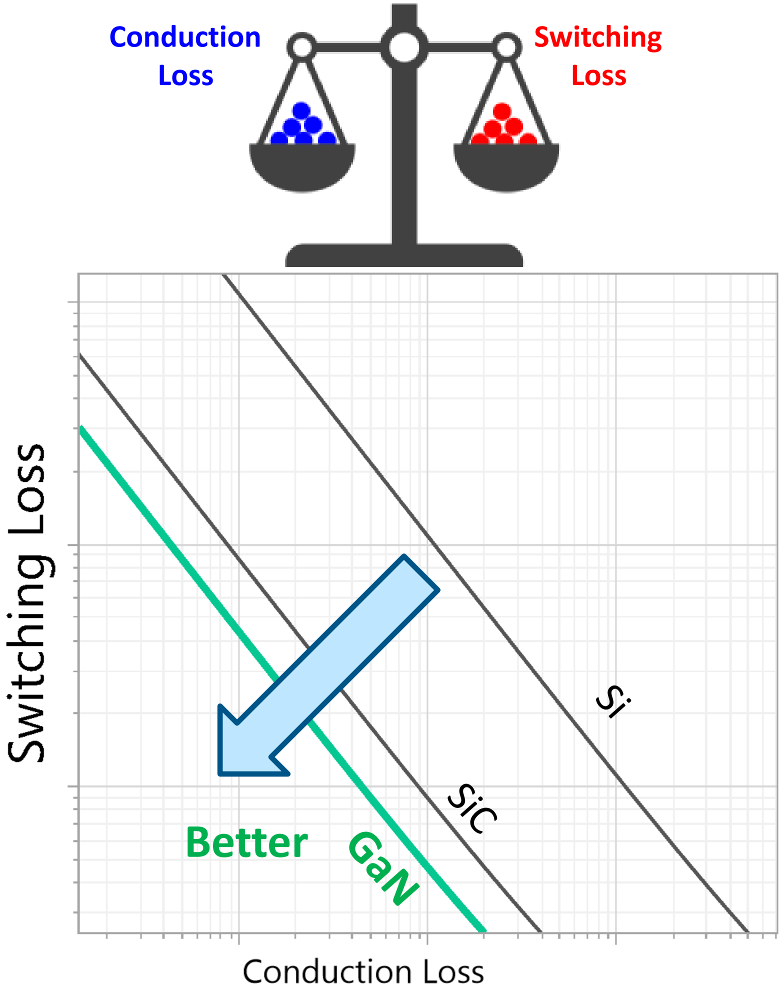
$$R_{on,sp} = \frac{4{V_{bd}}^2}{\varepsilon \cdot \mu \cdot {E_C}^3}$$



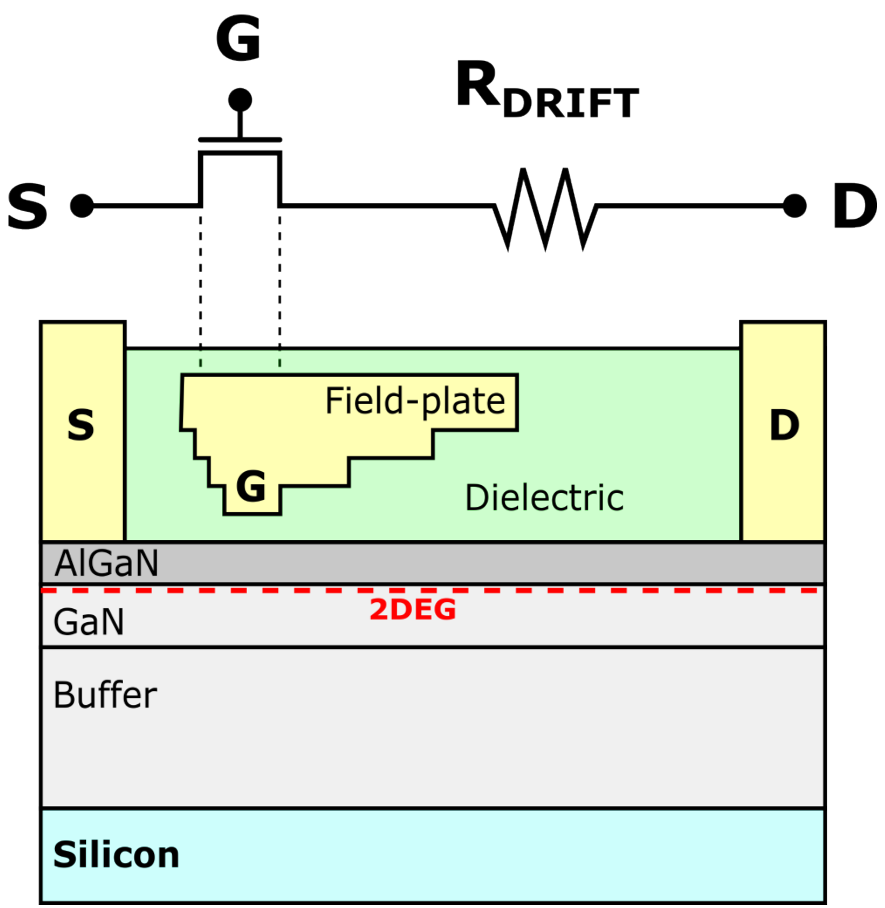
GaN: same Voltage Rating, superior Switching Performance than Silicon

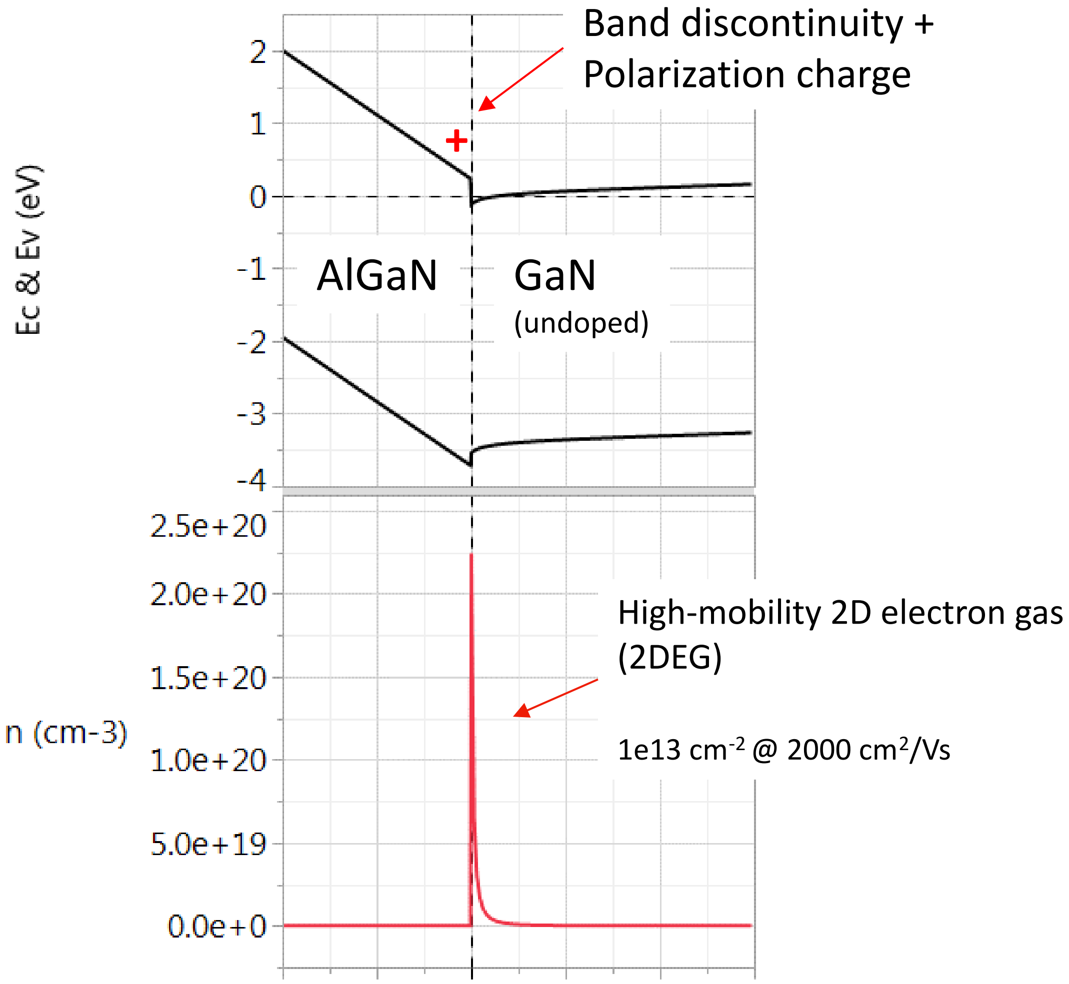


- Higher Critical field
- Higher Mobility
- Smaller stored charge
- Higher FOMs
  - $R_{on} \cdot Q_G$
  - $R_{on} \cdot Q_{OSS}$
  - $R_{on} \cdot Q_{RR}$

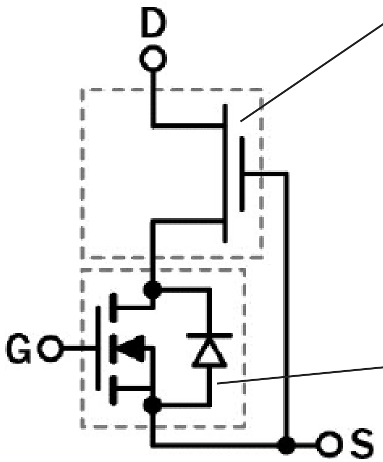


Transphorm GaN HEMTs



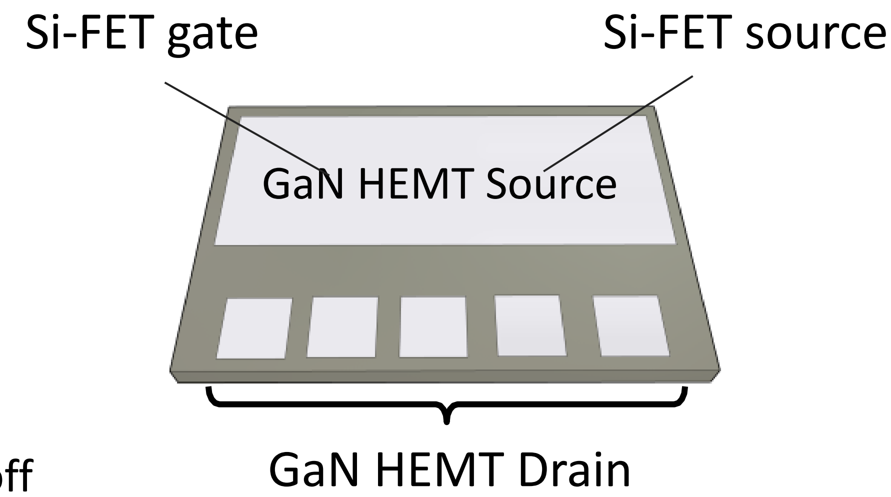


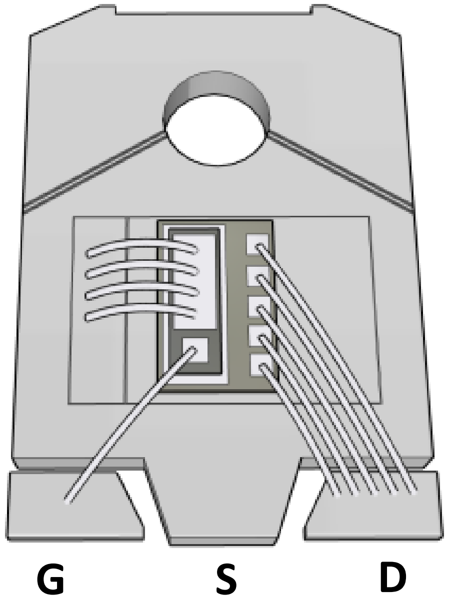
Transphorm normally-off GaN: Two-chip Cascode

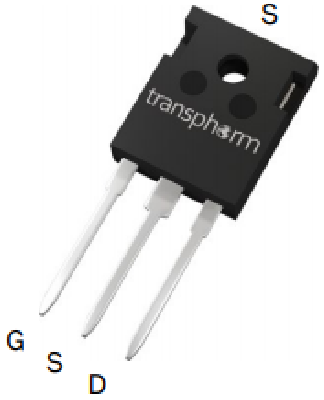


GaN HEMT:
- High voltage (≥ 650V)
- High speed

Silicon MOSFET (≤ 30 V):
- Insulated & Normally-off
- High speed
- High Threshold (4 V)
- High Vg Rating (±20 V)



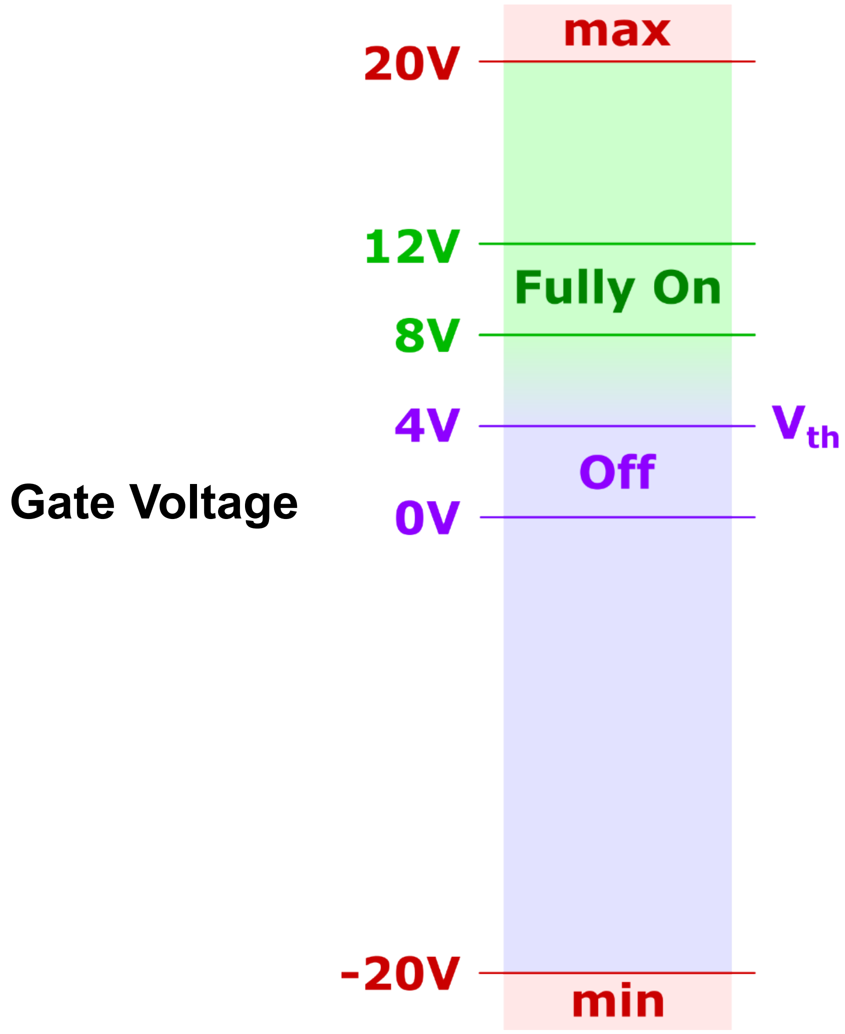




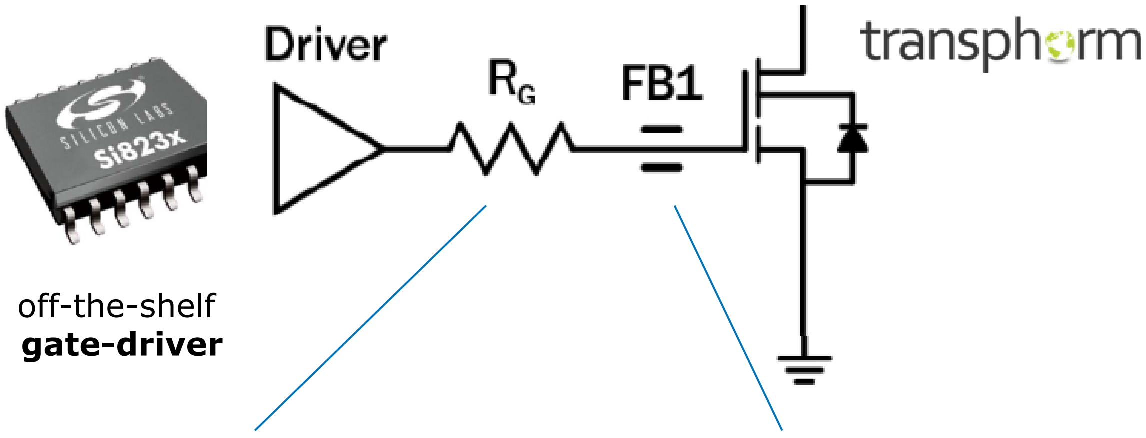
JEDEC qualified

AEC-Q101 qualified (150°C & 175°C)

Driving Transphorm GaN



- High Threshold (+4 V)
- Fully-on at +12 V
- High Gate Rating (±20 V)
- Compatible with standard gate drivers

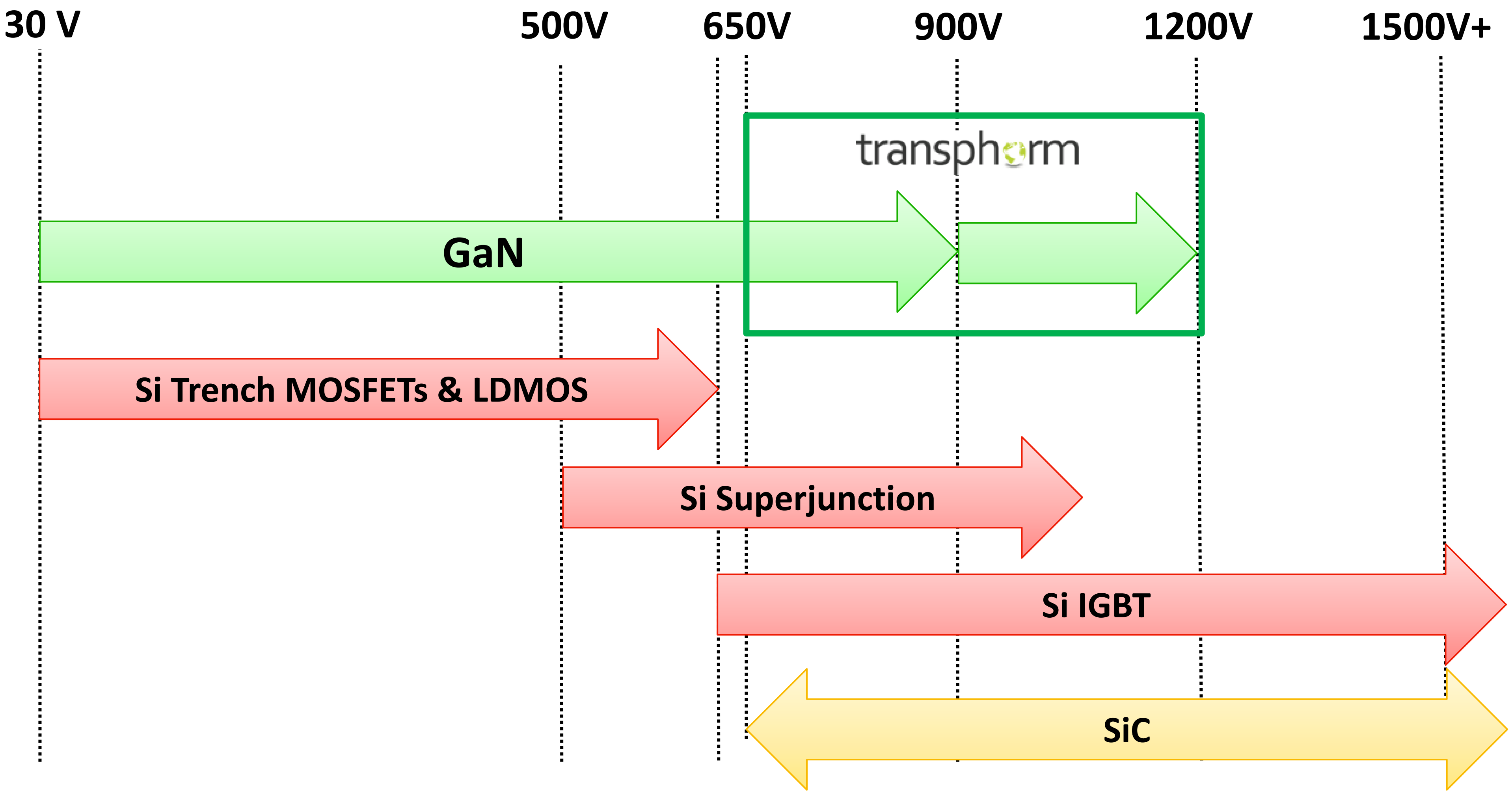


off-the-shelf
gate-driver

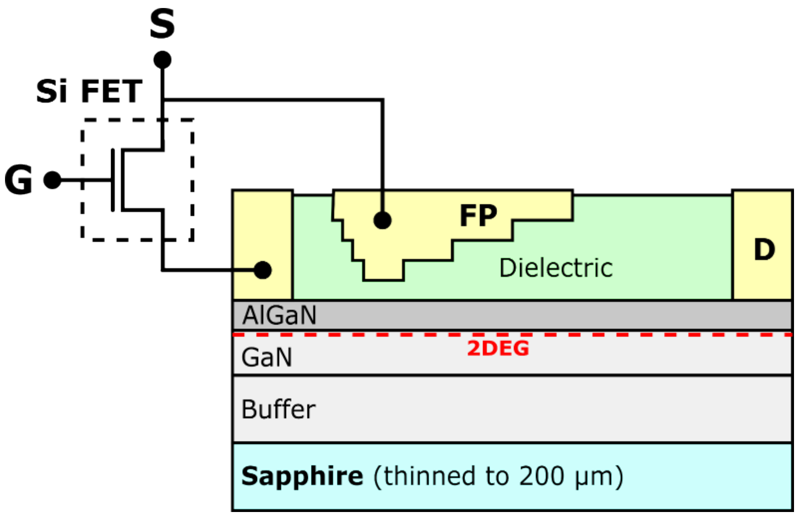
Gate resistor
(set switching speed)

Ferrite Bead
(suppress oscillations)

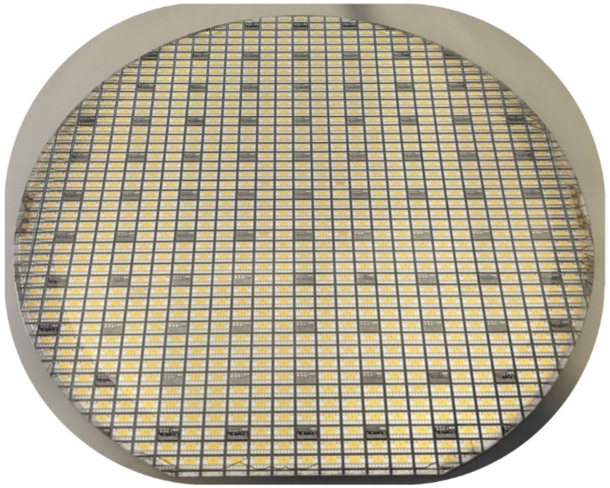
Voltage Rating

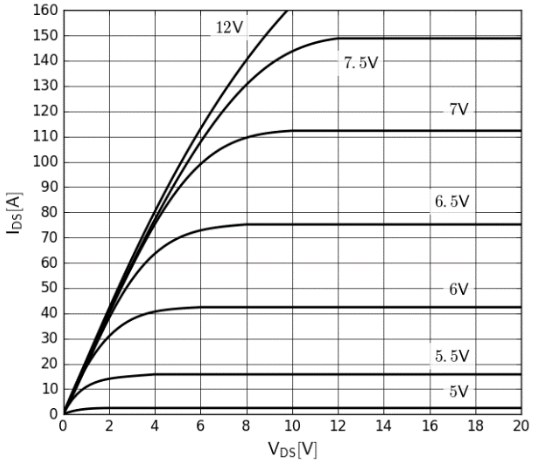


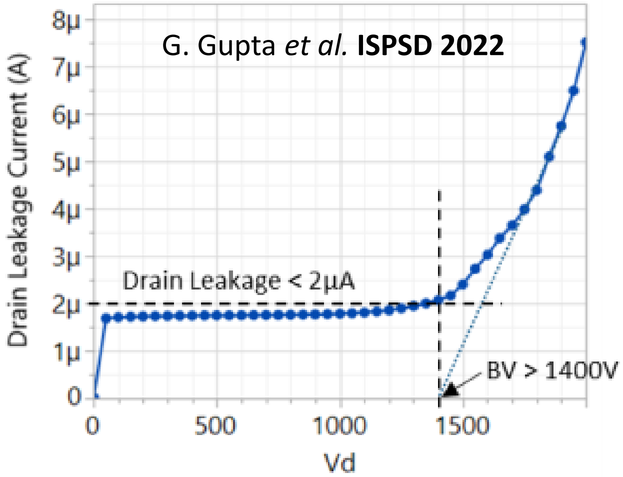
Low-Cost, High-performance 1200-V GaN



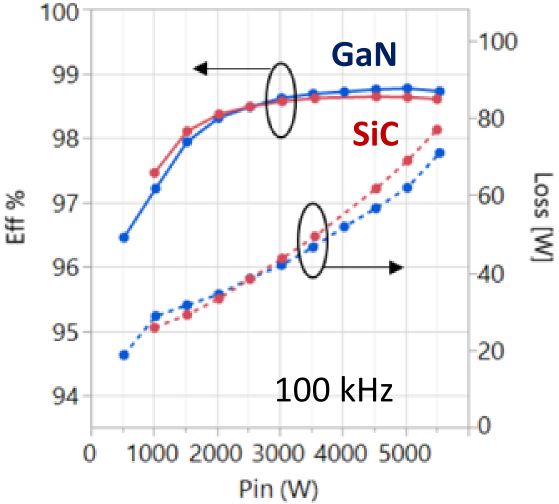
1200-V GaN HEMTs on 6” sapphire





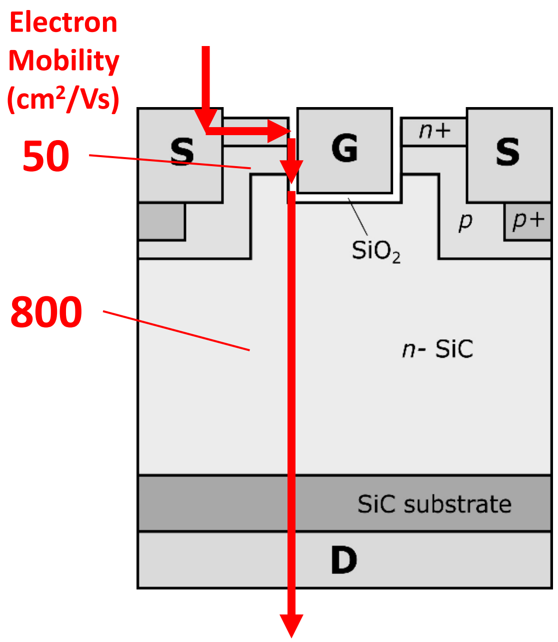


900V:450V Buck Converter

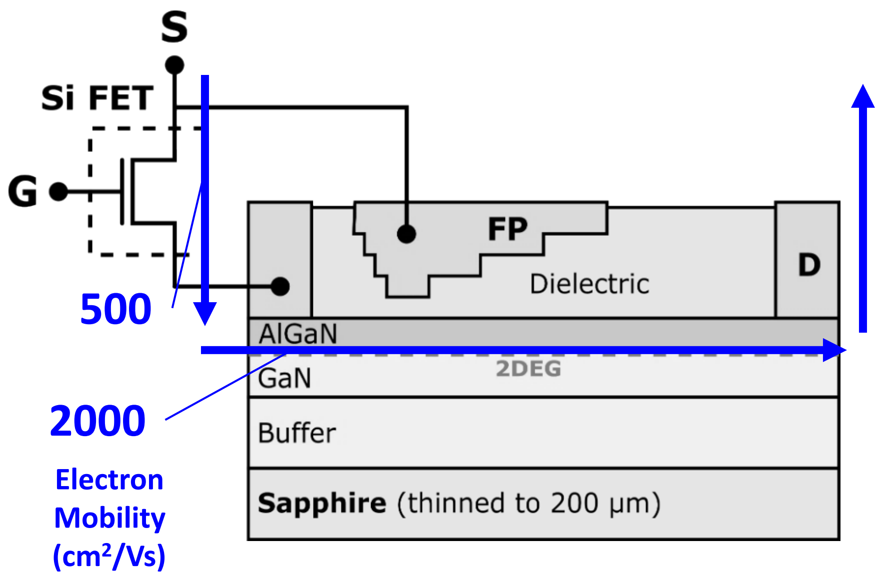


GaN vs. SiC: Higher Mobility, Less Charge

SiC MOSFET



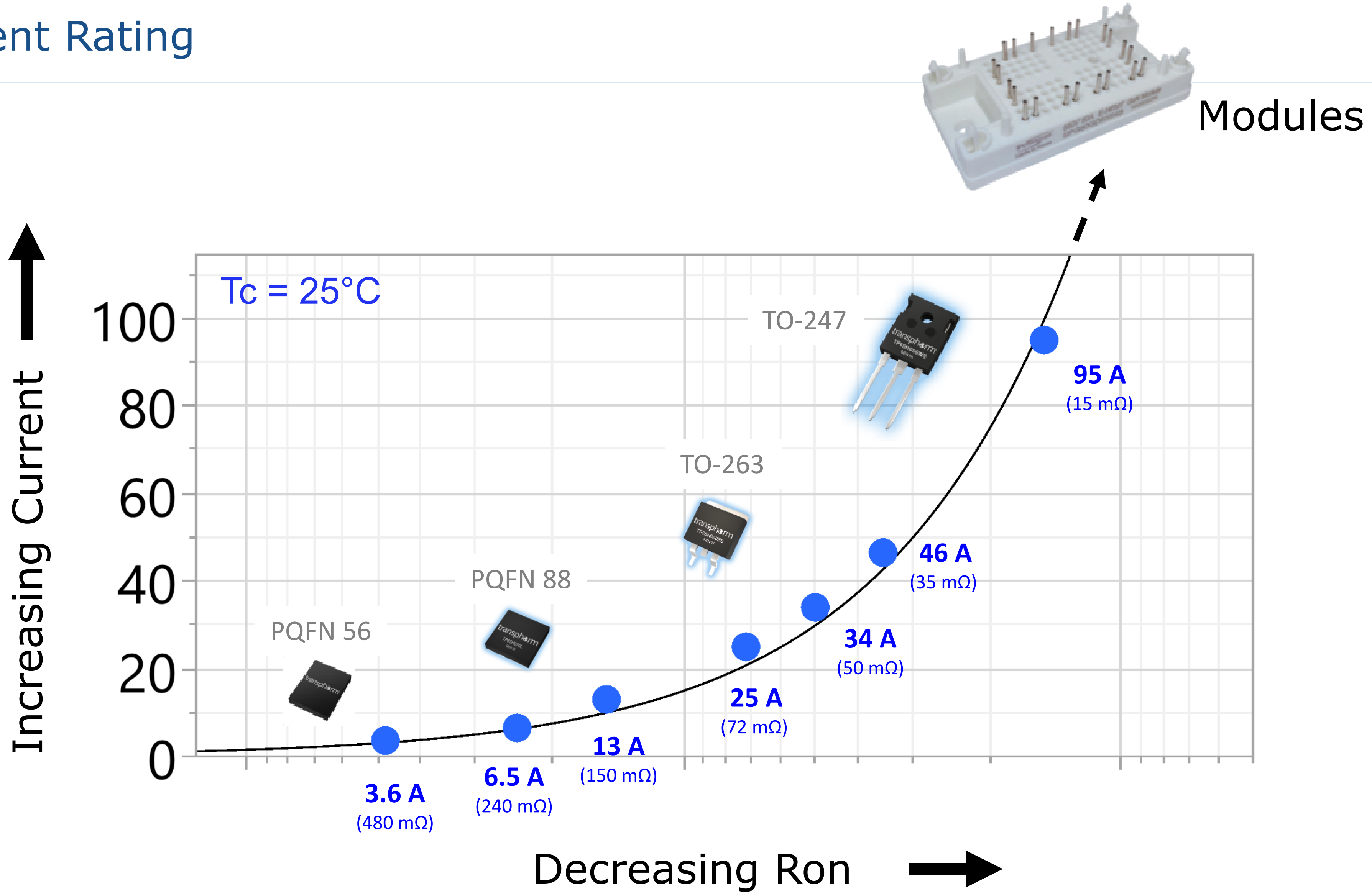
GaN HEMT



	SiC	GaN
Voltage Rating (V)	1200	1200
R_{on} (mΩ)	75	70
Q_G (nC)	**54**	**15**
Q_{GD} (nC)	**20**	**5**
Q_{RR} (nC)	**279**	**185**
$R_{th,j\text{-}c}$ (°C/W)	0.97	0.93
$I_{d,max}$ (A @ 100°C)	23	20
Material Cost	**$$$**	**$$**

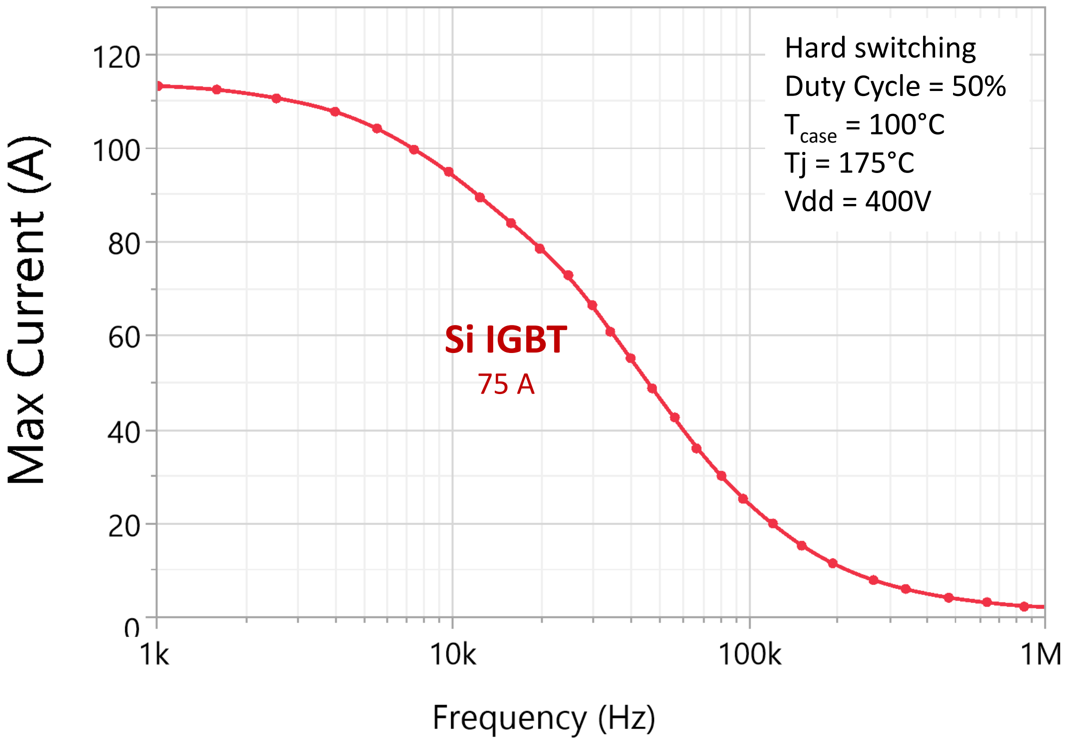
- Higher electron mobility, less gate charge, higher frequency performance.
- Projected lower material cost structure.

DC Current Rating



Comprehensive portfolio, to cover wide range of power applications.

Switching Current Rating



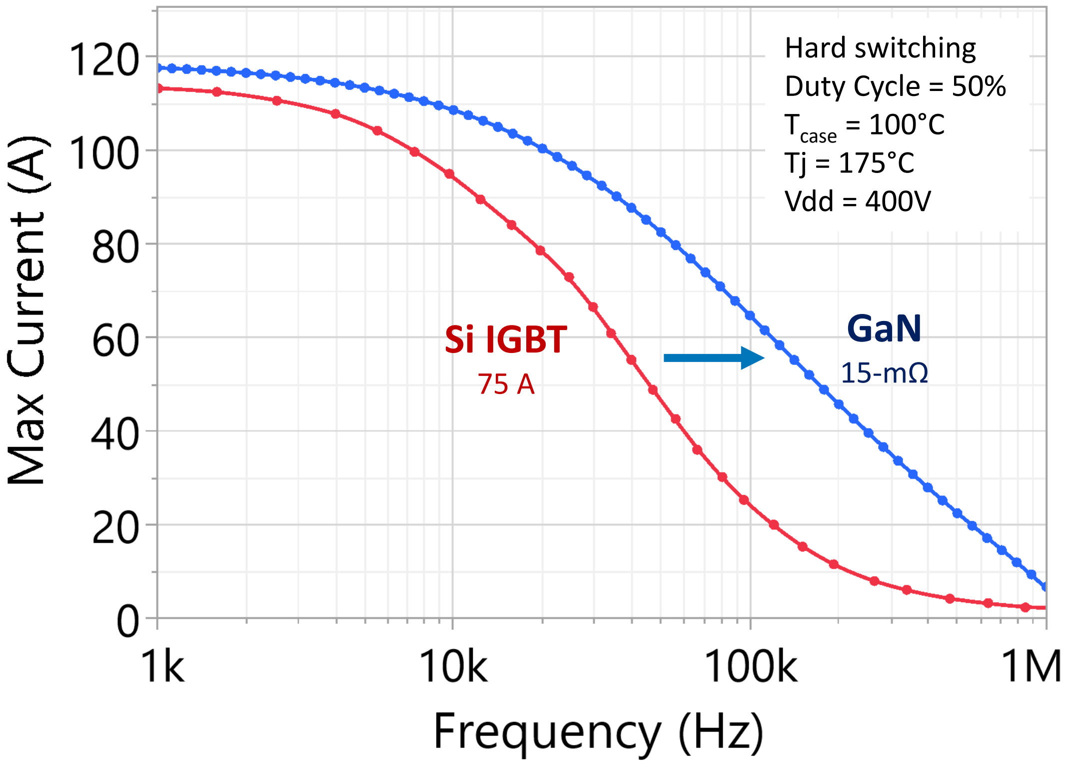
Rated current decreases with frequency due to switching losses

	Si IGBT
Device Rating	75 A
Qg (nC)	**225**
Qgd (nC)	**87**
Qrr (nC)	**high**

$$\Delta T = R_{th} \cdot \left[\; R_{on,dy} \cdot I_d{}^2 \cdot D \;\; + \;\; f \cdot (E_{on} + E_{off}) \; \right]$$

Conduction Loss **Switching Loss**

Switching Current Rating



$$\Delta T = R_{th} \cdot \left[\, R_{on,dy} \cdot I_d^{\,2} \cdot D \;+\; f \cdot (E_{on} + E_{off}) \,\right]$$

Conduction Loss

Switching Loss

GaN HEMT cascode:

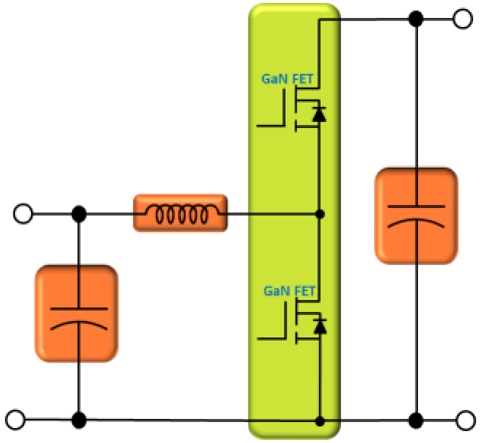
- Smaller stored charge
- Smaller switching losses
- Superior current rating at high frequency, <u>where it matters</u>.

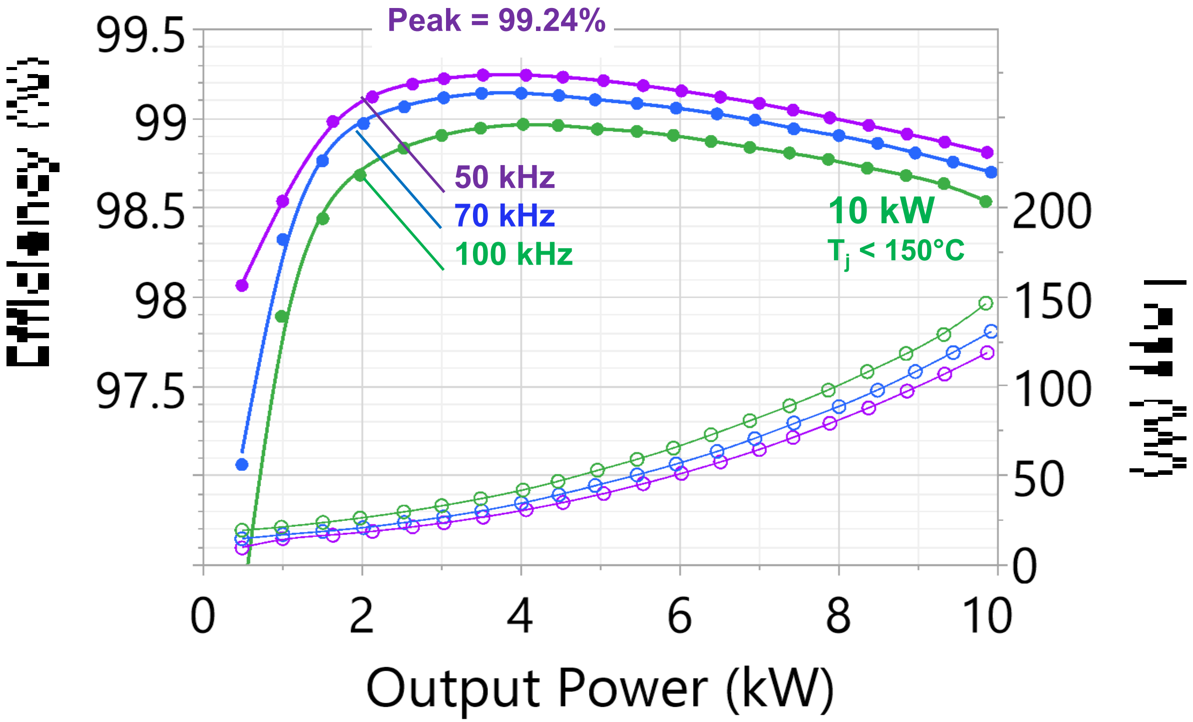
	Si IGBT	SiC MOSFET	GaN HEMT (cascode)
Device Rating	75 A	15 mΩ	15 mΩ
Qg (nC)	**225**	**188**	**74**
Qgd (nC)	**87**	**62**	**21**
Qrr (nC)	**high**	**562**	**430**

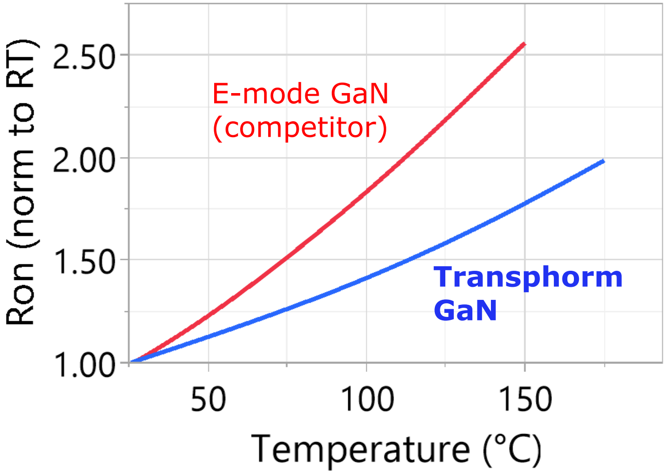
Efficient Switching to 10 kW, 100 kHz

240V:400V
DCDC CCM Boost

Gate Driver = **Si8285 (4 A)**
Gate Voltage = **0-12 V**
Rg,on = **5 Ω**
Rg,off = **15 Ω**
Deadtime = **300 ns**
Ferrite Bead = **120 Ω at 100 MHz**
DC Snubber = **10 nF + 2 Ω**

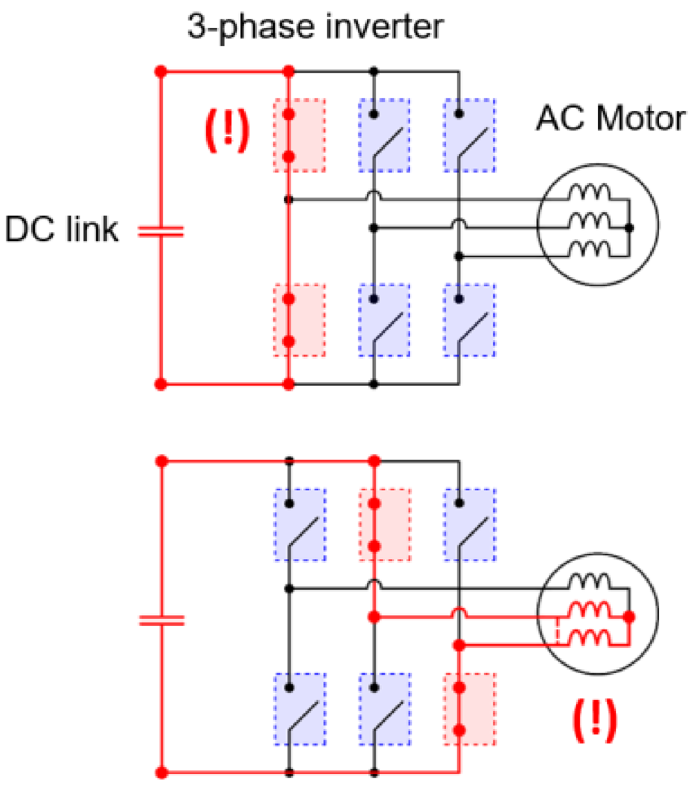


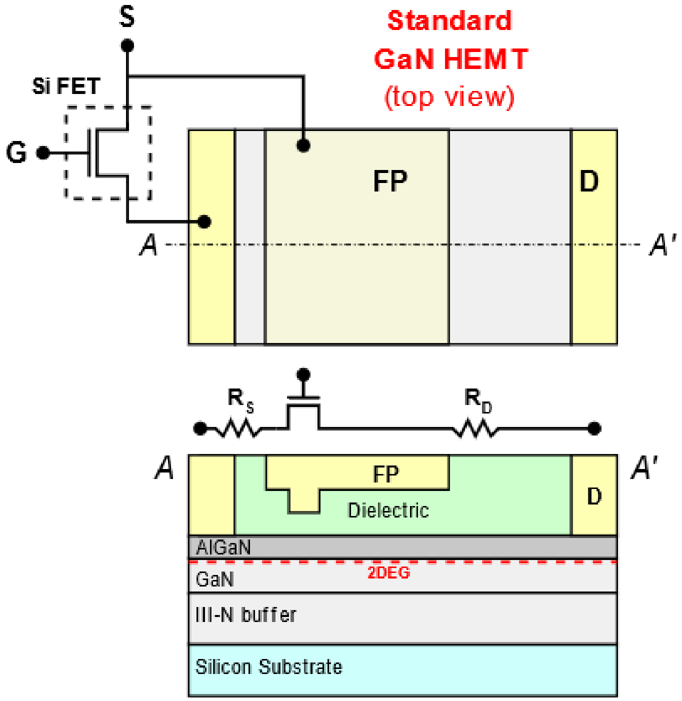


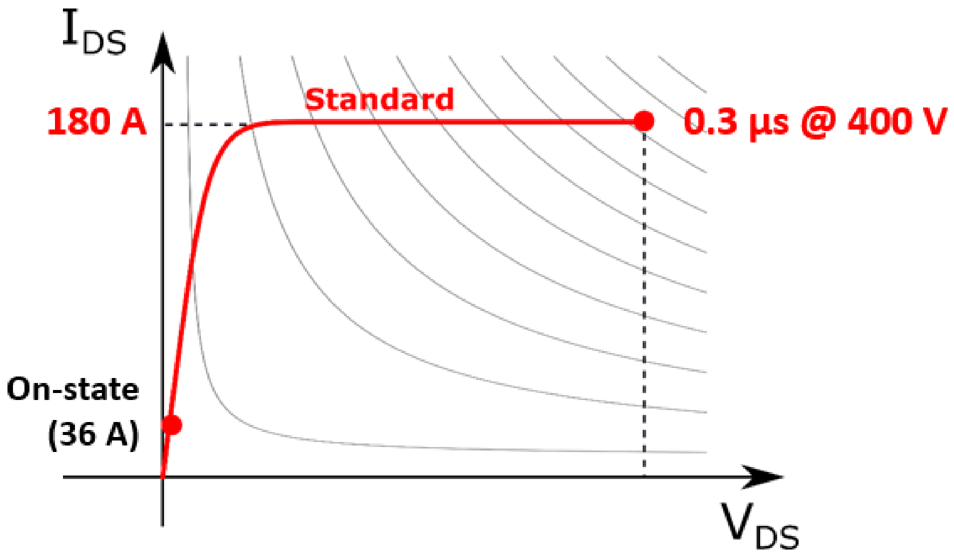


Smaller Ron temperature coefficient than E-mode competition

Short-Circuit Capability

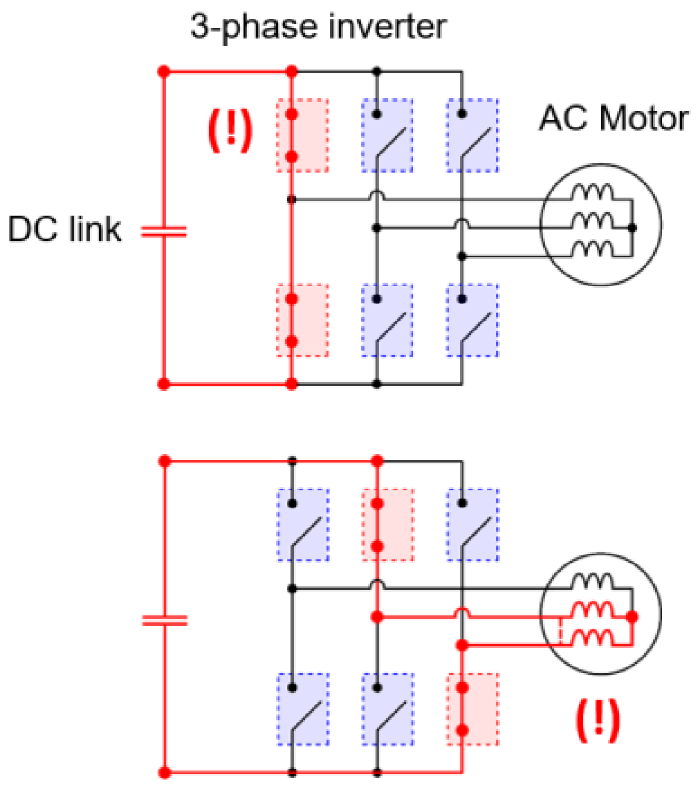


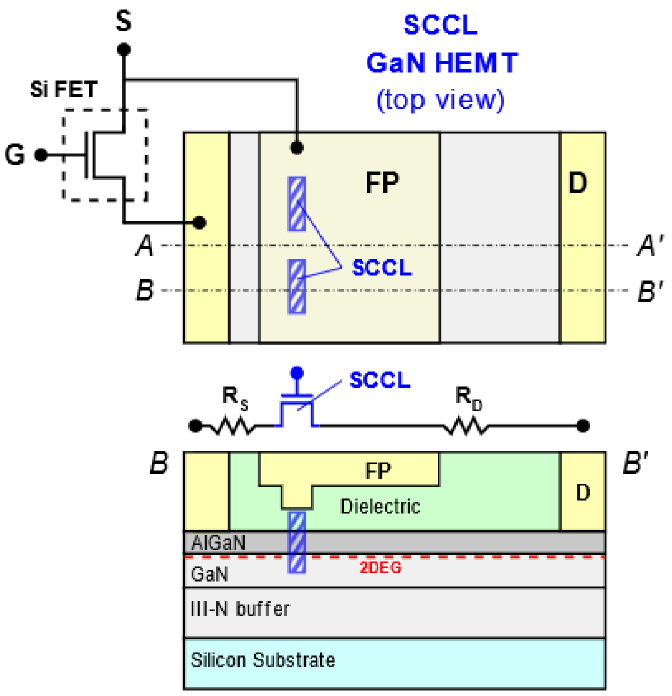




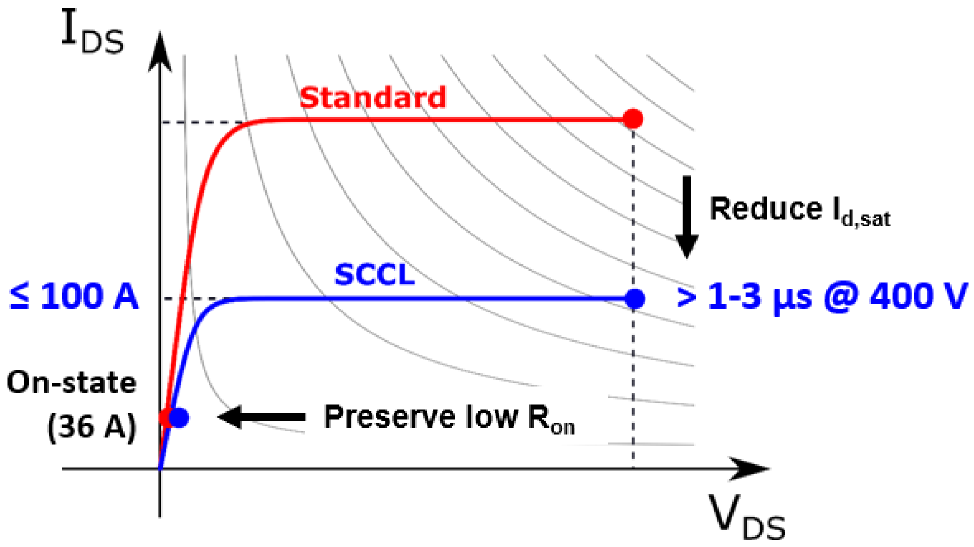
- Standard GaN HEMTs have high saturation current due to high performance 2DEG.
- Difficult to achieve short-circuit withstanding capability (!)

Short-Circuit Capability



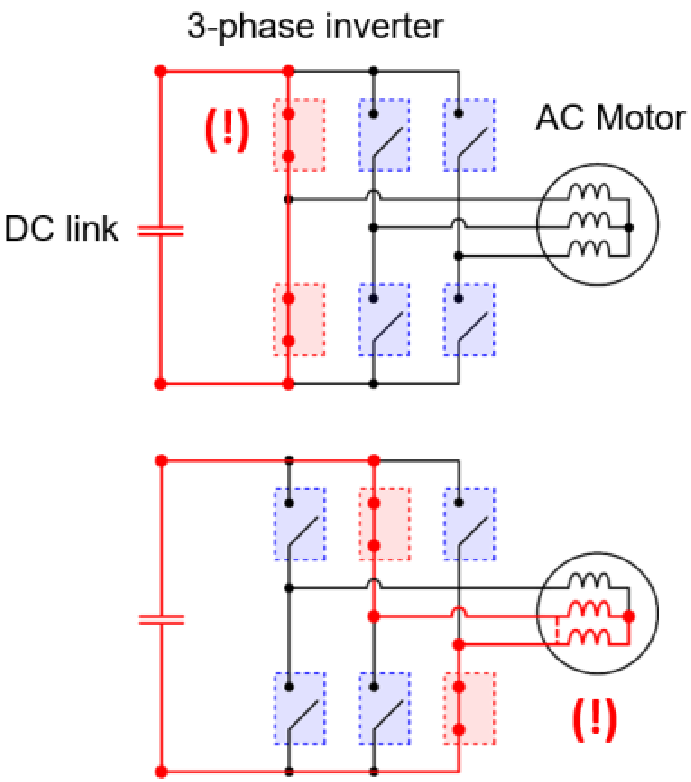


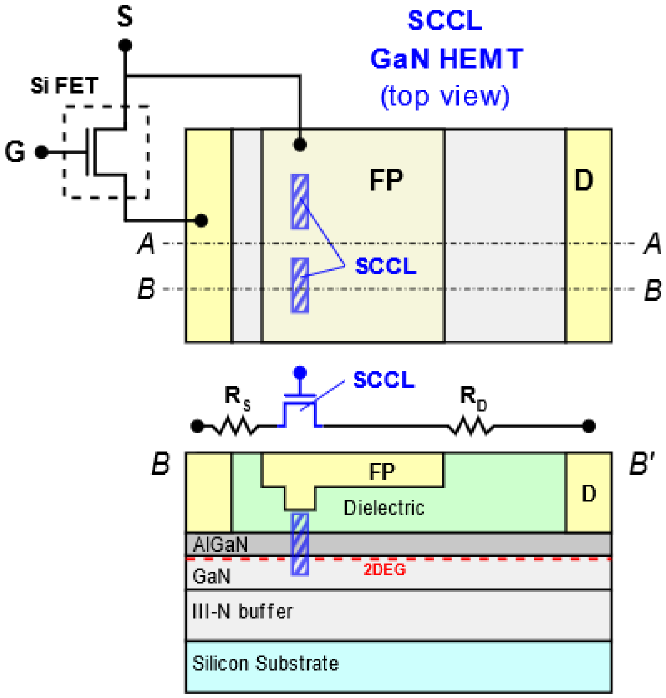
Y. Wu *et al.*, **U.S. Patents** 9443849, 8803246 & 9171910



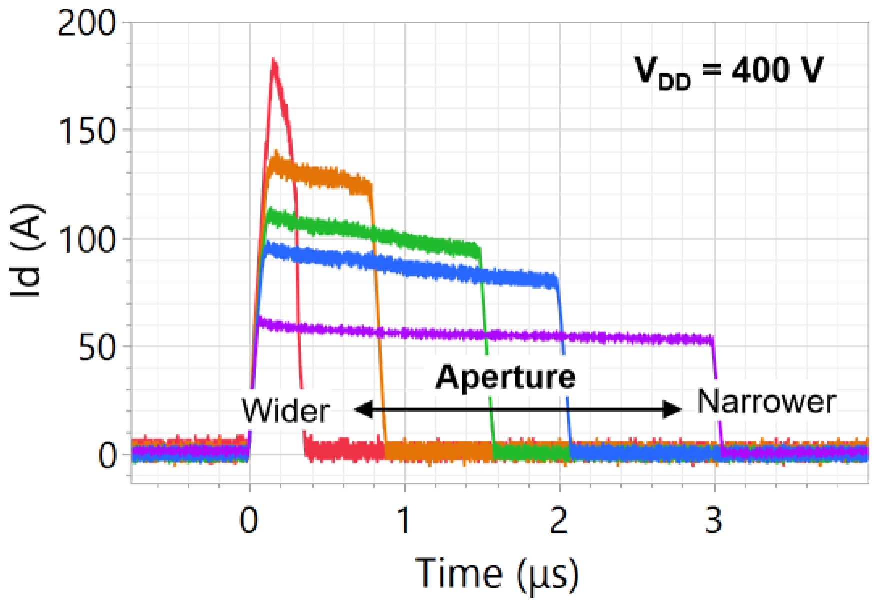
Reduces the saturation current to achieve long SCWT, while preserving low R_{on} ✓

Short-Circuit Capability





Y. Wu *et al.*, **U.S. Patents** 9443849, 8803246 & 9171910

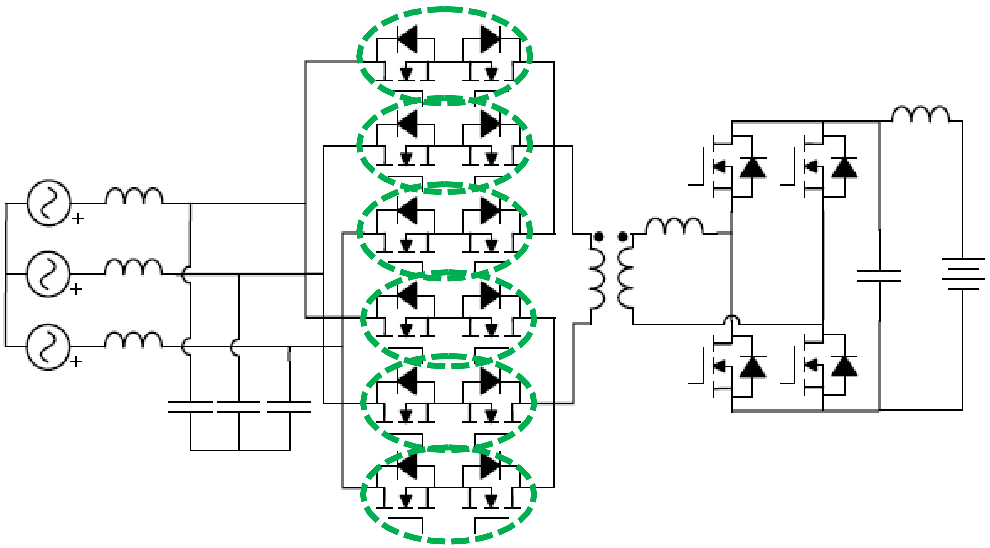


D. Bisi *et al.* **APEC 2022**

Patented, low-cost and reliable solution to increase Short-Circuit Withstanding Time of GaN HEMTs with limited penalty in on-state resistance.

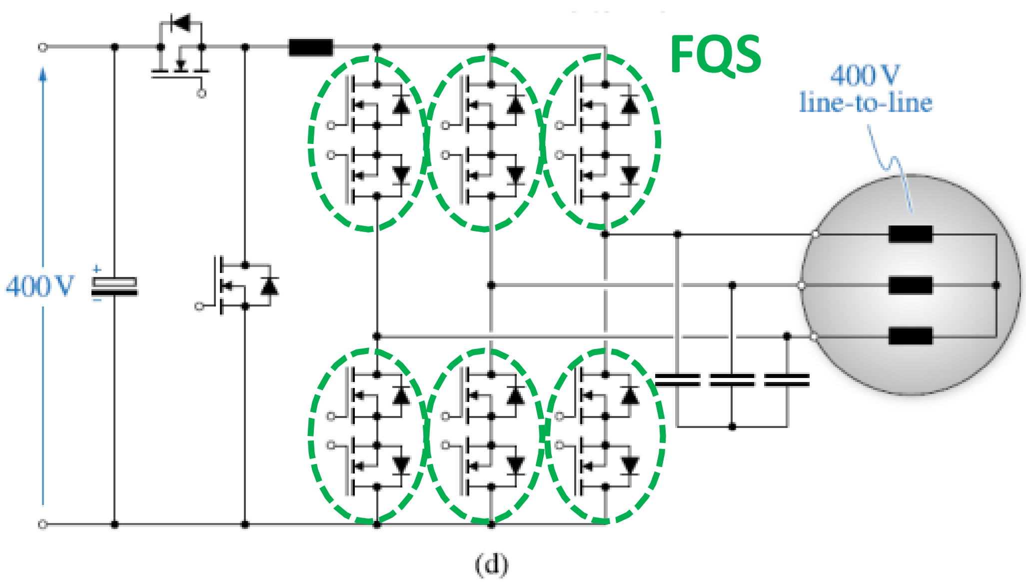
Emerging Topologies

Matrix Converters (Single Stage OBC)



FQS
(four-quadrant switch)

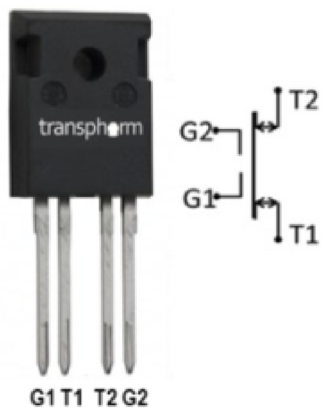
Current-Source Inverter (CSI)

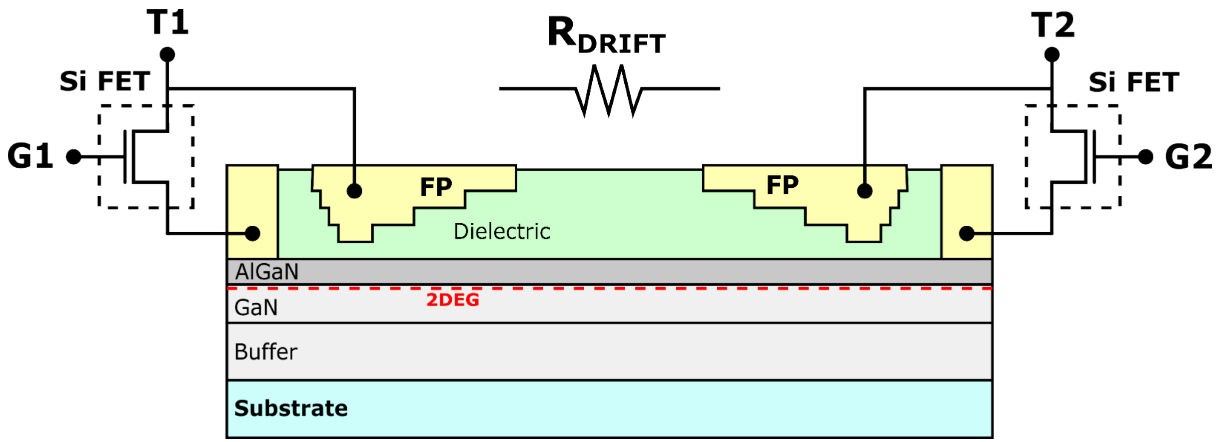


Emerging converter topologies now at academic research stage. Use FQS devices (difficult with IGBTs and SiC, easier with GaN).

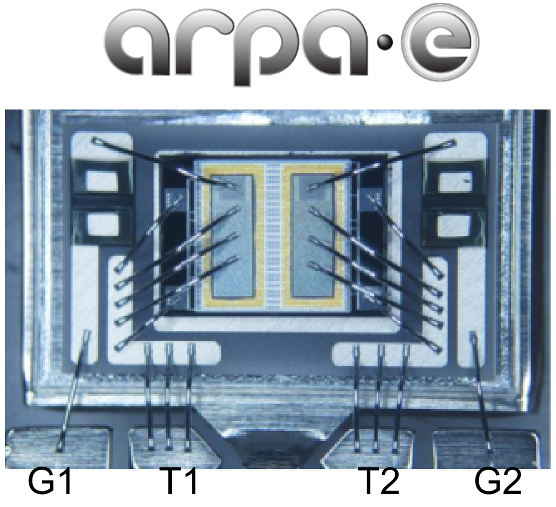
Reference: Thomas M. Jahns, “The Incredible Shrinking Motor Drive”, *Digital Object Identifier 10.1109/MPEL.2020.3011275*

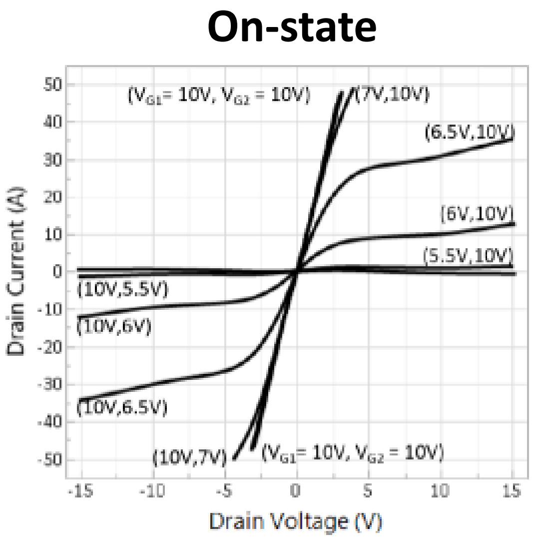
GaN Four Quadrant Switch (FQS)

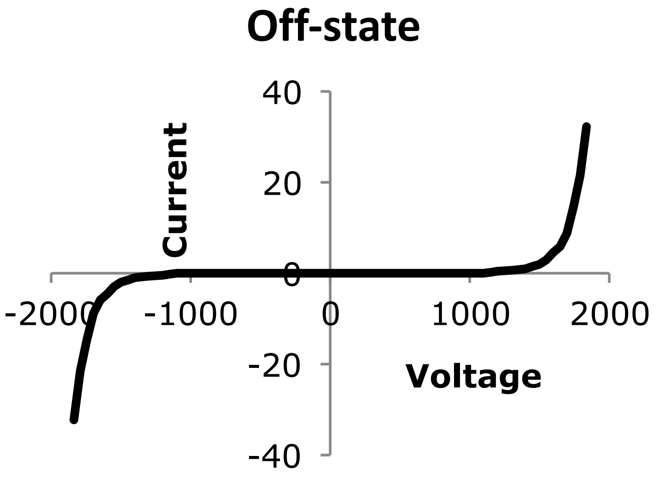




- **Shared Drift region.**
- Efficient integration thanks to GaN lateral architecture.







Summary

- Superior switching performance
- Wide Voltage Range (up to 1.2 kV)
- Wide Power Range (45 – 10 kW+)
- Demonstrated Reliability (AEC Q101, 175°C)
- Short-Circuit Capable
- Four-quadrant Switch capable

Thank you

By, Davide Bisi
Email: dbisi@transphormusa.com
Phone: +1-805-456-1300 x312

transphorm

Transphorm Copyright Notice