GaN Basics and Applications

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AVE BV

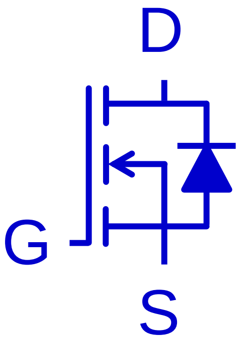
Agenda

- GaN FETs
- vs Silicon MOSFETs
- GaN ICs
- Layout techniques
- Thermal design
- Applications
- Support

GaN FETs

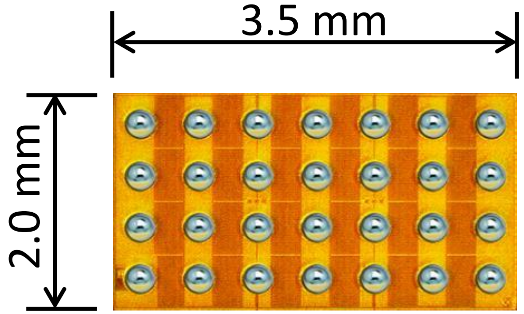
GaN FET is:

- 3-terminal transistor
- voltage controlled – e-mode
- reverse “diode” function

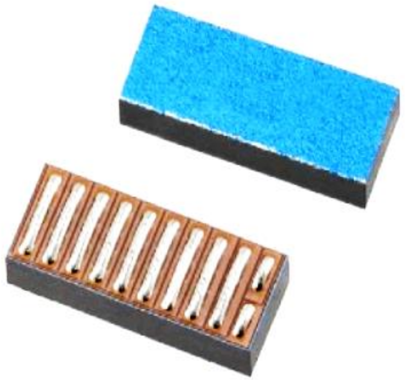


Terminals

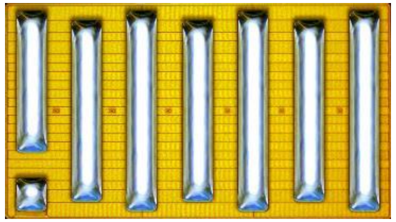
- Gate (G)
- Drain (D)
- Source (S)



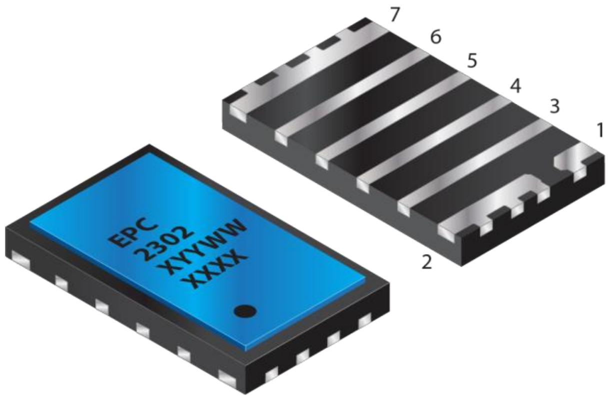
Ball Grid Array (BGA)



Chip Scale Package (CSP)

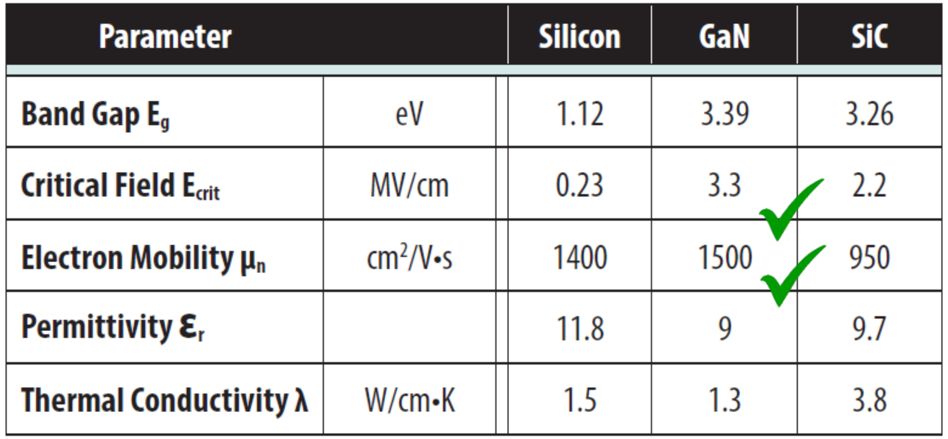


Land Grid Array (LGA)



Flip Chip Quad Flat Pack (FCQFN)

Why GaN



Parameter		Silicon	GaN	SiC
Band Gap E_g	eV	1.12	3.39	3.26
Critical Field E_{crit}	MV/cm	0.23	3.3 ✓	2.2
Electron Mobility μ_n	cm²/V•s	1400	1500 ✓	950
Permittivity ε_r		11.8	9	9.7
Thermal Conductivity λ	W/cm•K	1.5	1.3	3.8

Table 1.1: Material properties of GaN, SiC, and Si

$V_{BR} = \tfrac{1}{2}\, w_{drift} \cdot E_{crit}$ → Drift region is 10 smaller

$q \cdot N_D = \varepsilon_o \cdot \varepsilon_r \cdot E_{crit} / w_{drift}$ → # of electrons is 100 bigger

$$R_{DS(on)} = w_{drift} / q \cdot \mu_n \cdot N_D$$

$$\boxed{R_{DS(on)} = 4 \cdot V^2{}_{BR} \,/\, \varepsilon_o \cdot \varepsilon_r \cdot \mu_n \cdot E^3{}_{crit}}$$

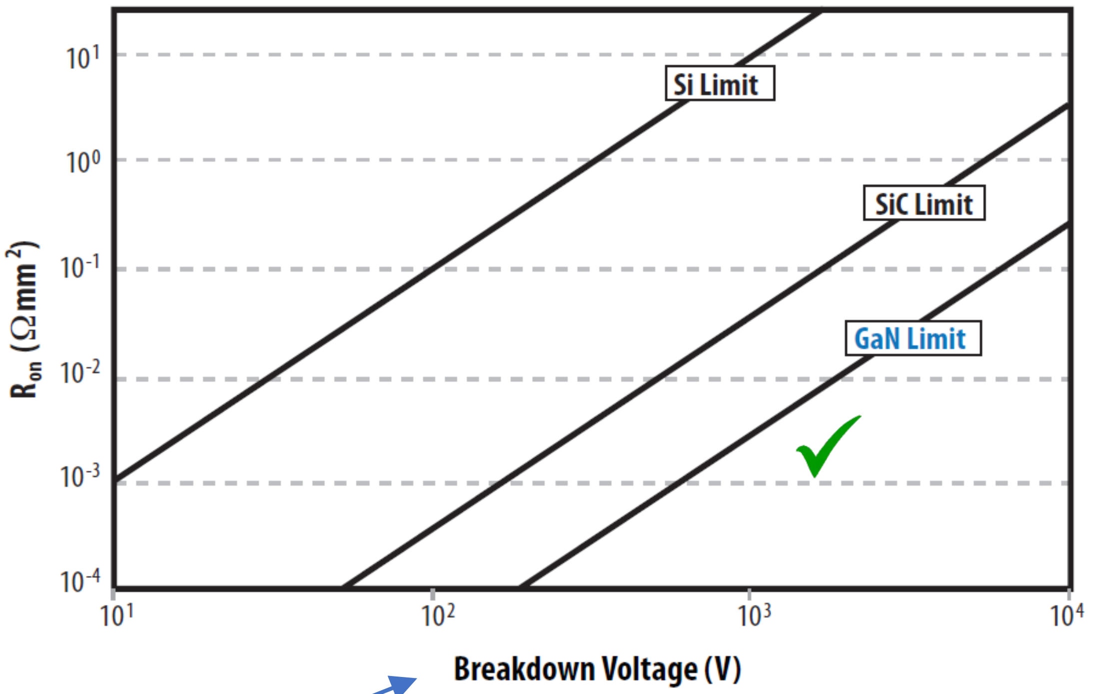
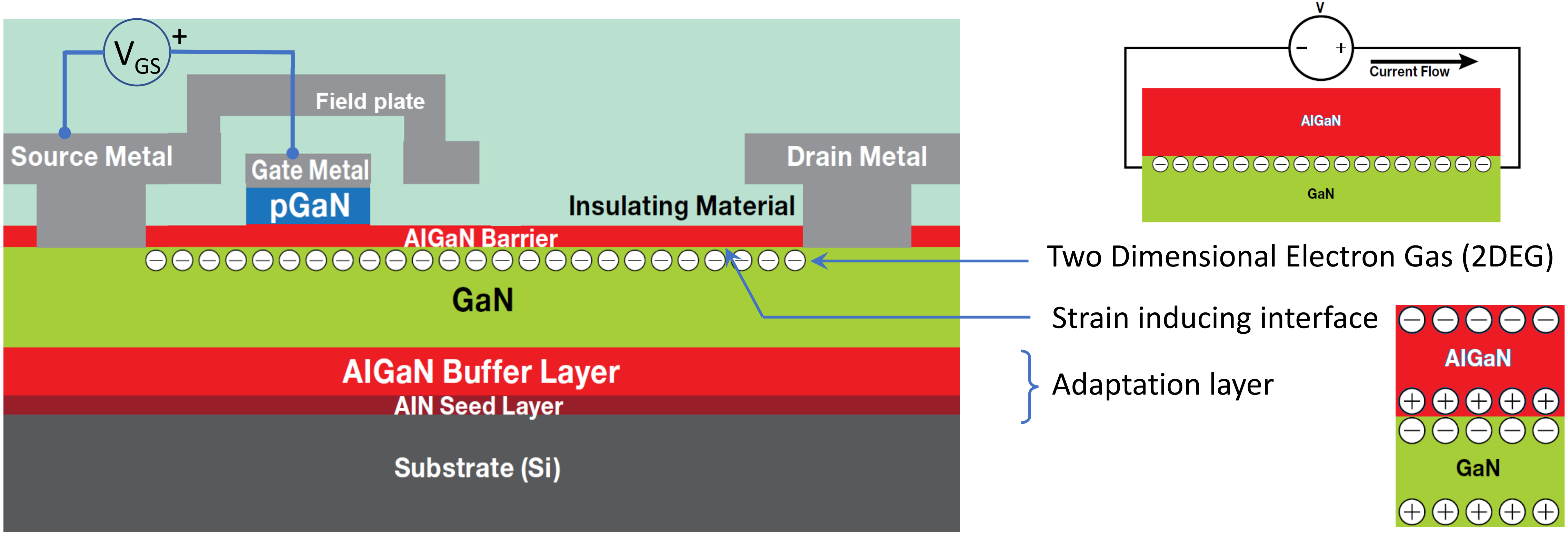


Figure 1.1: Theoretical on resistance vs blocking voltage capability for Si, SiC, and GaN based power devices.

eGaN® FET Structure



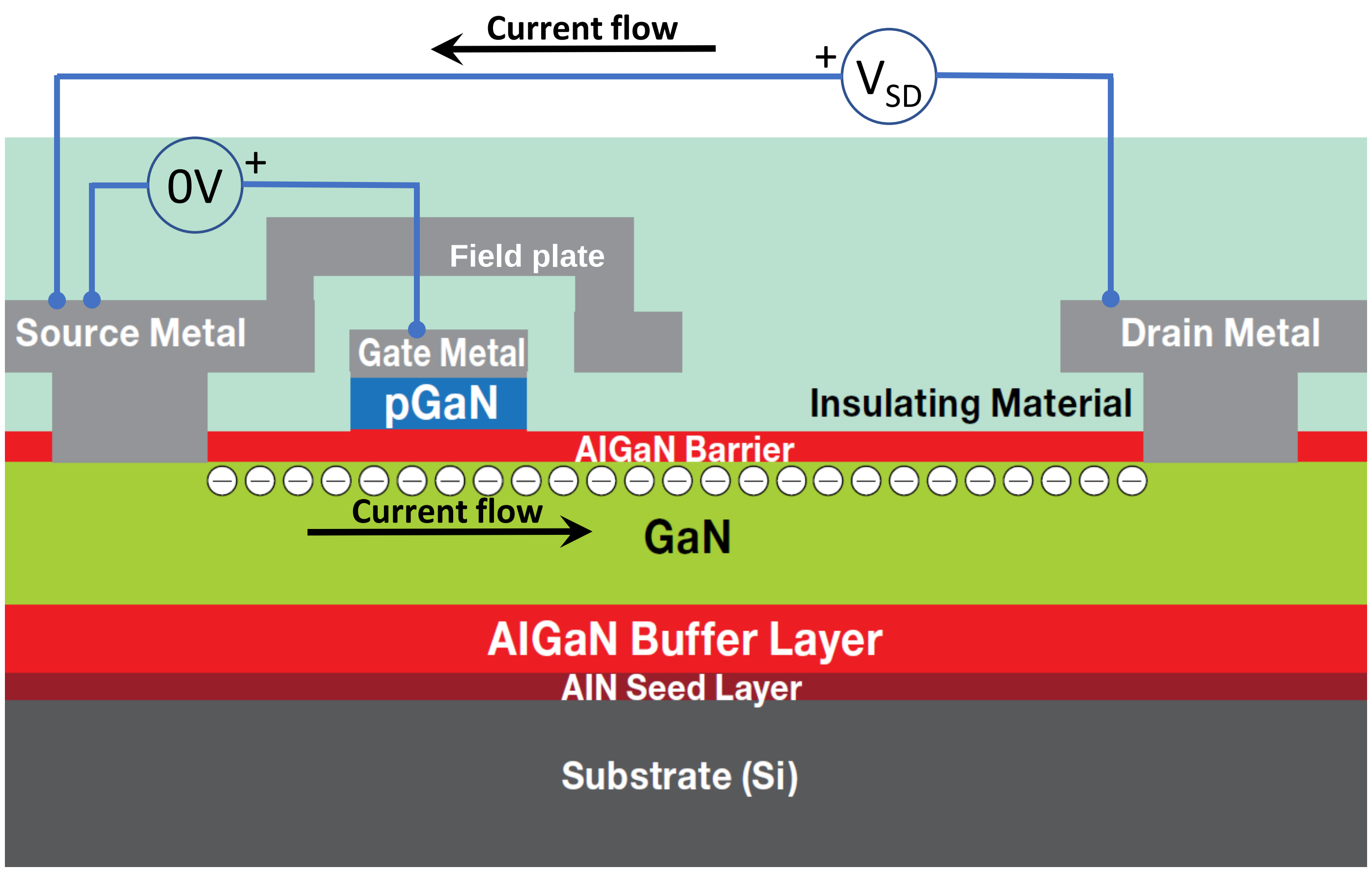
Two Dimensional Electron Gas (2DEG)

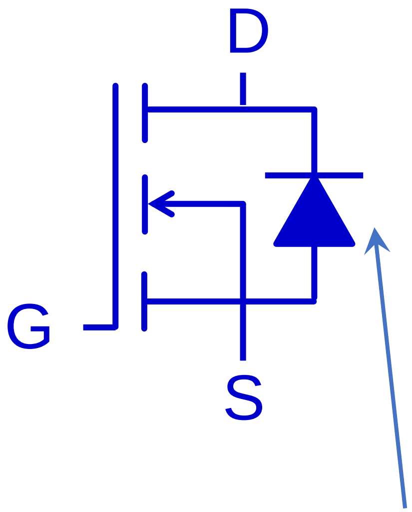
Strain inducing interface

Adaptation layer

- Voltage controlled transistor
- e-mode: normally off, $V_{GS(TH)} \approx 1.5$ V
- Bidirectional conduction
- Lateral conduction device

eGaN® FET Reverse Conduction





DIODE FUNCTION

WITH NO RECOVERY

When V_{SD} reaches about $V_{GS(TH)}$, channel closes

⇒ reverse conduction mechanism, based on majority carriers

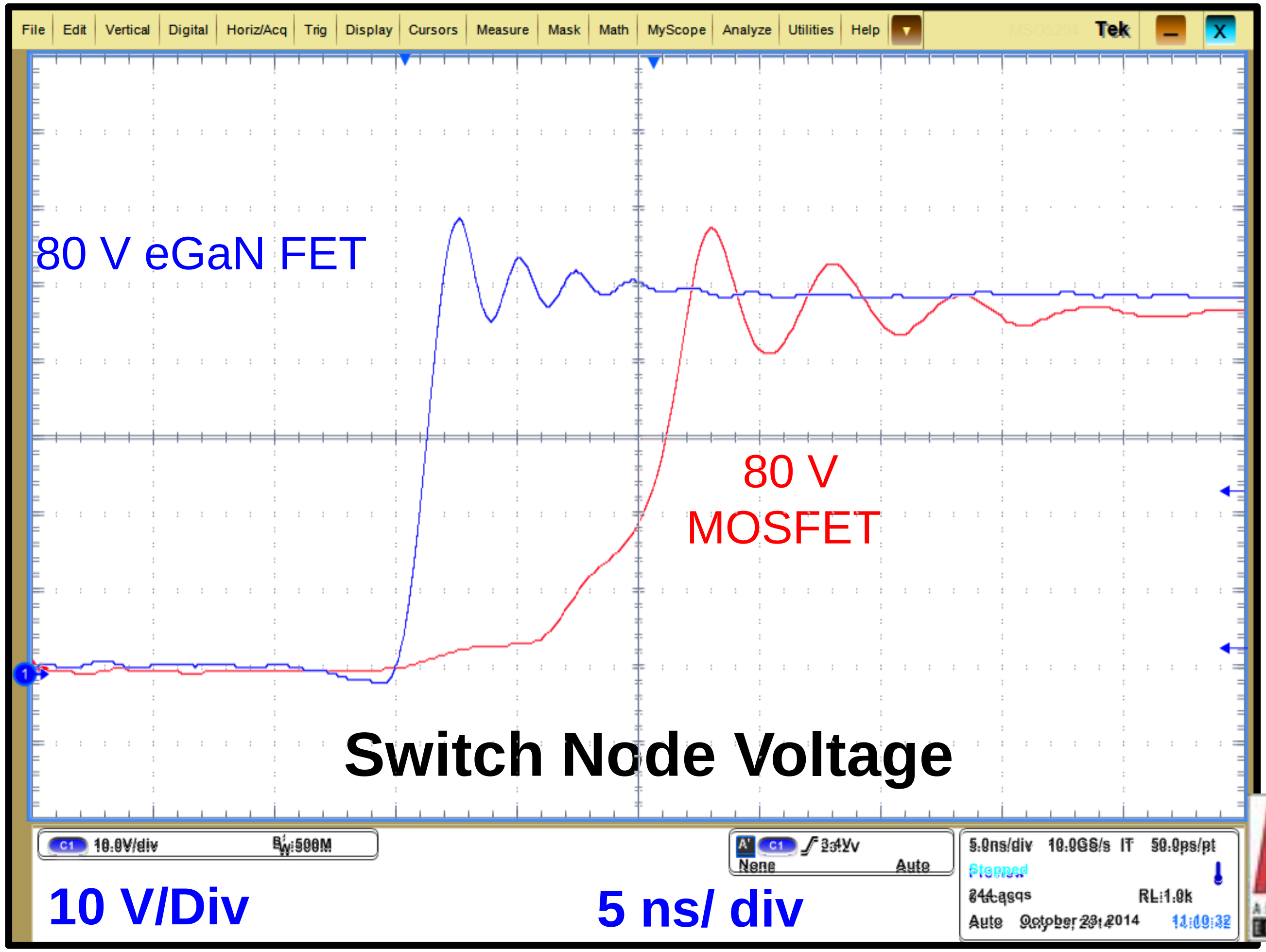
High Switching Speed Zero Recovery

Silicon MOSFETs Qrr

- increases with temperature
- increases with turn off dI/dt
- increases with dead time
- snappy ⇒ overshoot

eGaN FET zero Qrr

- **eliminates losses**
- **removes EMI noise source**

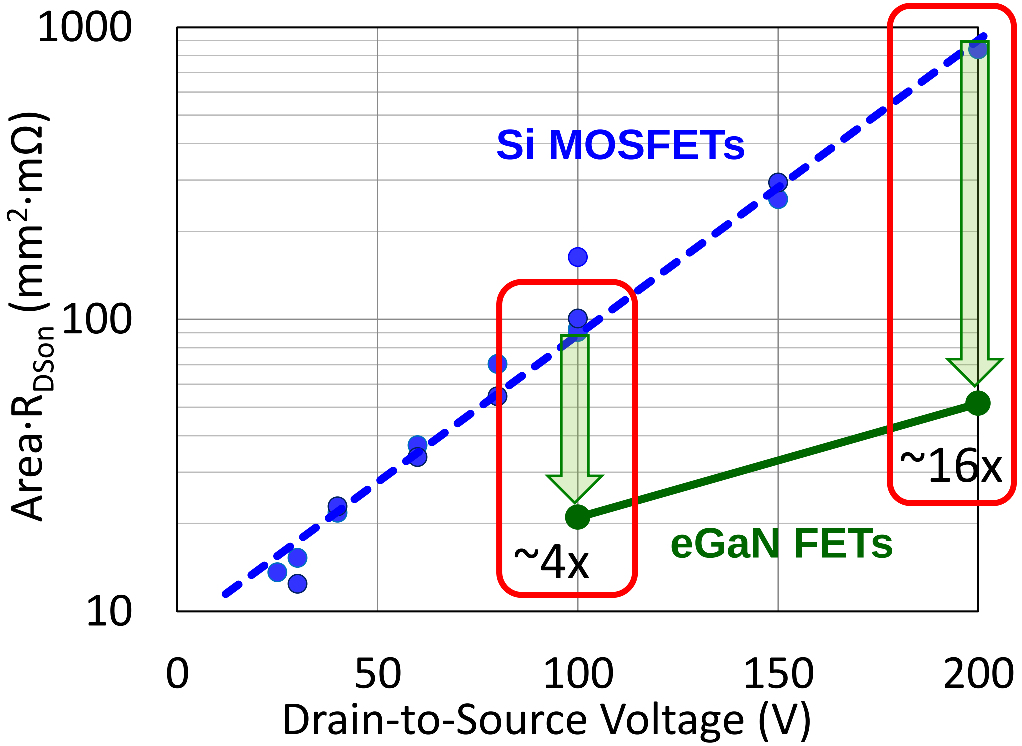


V_{IN}=48 V I_{OUT}=20 A

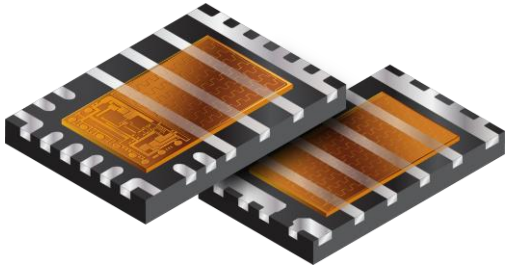
GaN vs Silicon

With respect to MOSFETs, GaN FETs:

  - Better FOM ~ 4-16 times
  - Lower Q_G ~ 5-10 times
  - Lower R_{DSon} at $V_{GS} = 5$ V
  - Lower Q_{OSS} ~ 2-4 times
  - Lower Q_{GD} & Q_{GS2} ~ 5-10 times
  - Zero Q_{RR}



- Enables higher frequency operation
- GaN Technology now integrates driver function

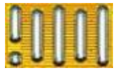


GaN vs Silicon – 80-100V

Benchmmark
Si MOSFET

BSZ070N08LS5

3.3 x 3.3 mm



1.5 x 2.5 mm

Gen6

Parameter	BSZ070N08LS5 (@ 10 V_{GS})	EPC2204 (@ 5 V_{GS})	EPC2619 (@ 5 V_{GS})
V_{DS}	80 V	100 V	80 V
$R_{DS(on)}$ max	7 mΩ	6 mΩ	4 mΩ
$R_{DS(on)}$ * Area	88.5	16.5	12
$R_{DS(on)}$ * Q_G	83	25	27
$R_{DS(on)}$ * Q_{OSS}	171	110	87
$R_{DS(on)}$ * Q_{GD}	29.5	3.5	3
R_{TJC} to top	62 °C/W max	1 °C/W typ	1 °C/W typ
Device Size	11 mm^2	3.75 mm^2	3.75 mm^2

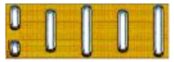
Parameter	Infineon 80 V	Gen5 100 V	Gen6 80 V
Q_G typ	14 nC	5.7 nC	8.3 nC
Q_{GD} typ	5 nC	0.8 nC	0.9 nC
Q_{OSS} typ	29 nC	25 nC	27 nC
Q_{RR} typ	27 nC	0 nC	0 nC

Lower numbers means better performance

GaN vs Silicon – 200V

Si MOSFET Benchmark

9.9 mm x 11.7 mm



4.6 mm x 1.6 mm

eGaN FET

Parameter	IPT111N20NFD (@ 10 V_{GS})	EPC2215 (@ 5 V_{GS})	EPC2304 (@ 5 V_{GS})	EPC GaN FET Improvement
$R_{DS(on)}$ typ	9 mΩ	6 mΩ	3.1 mΩ	3x lower
$R_{DS(on)}$ max	11.1 mΩ	8 mΩ	5 mΩ	2x lower
Q_G typ	65 nC	10 nC	20 nC	3x lower
Q_{GD} typ	8 nC	1.6 nC	3.2 nC	3x lower
Q_{OSS} typ	162 nC	68 nC	116 nC	30% lower
Q_{RR} typ	309 nC	0 nC	0 nC	Infinitely lower
Device Size	115 mm^2	7.4 mm^2	15 mm^2	8x smaller

15 times smaller, less losses, no reverse recovery, higher f_{SW}

eGaN® FET vs Si MOSFET

eGaN FET	Silicon MOSFET
Fully turned on at 5V	Fully turned on at > 8V
Robust turn off at 0 V (Miller ratio < 1)	Turn off at 0 V (Miller ratio > 1)
Lateral conduction device	Vertical conduction device
Smaller die and parasitics	Larger die/device and parasitics
Reverse conduction with zero recovery, V_{SD}≈2.5V	Body diode with recovery charge & losses, V_{SD}≈1V
No Spirito effect, full SOA	Hot spot formation and reduced SOA
No switching speed limitation	Parasitic BJT can be triggered by body diode recovery and by dV/dt
Intrinsic radiation tolerance	SEE and radiation induced failures
Small leakage currents, not a real issue	Negligible (≈0) leakage currents
Tolerant to V_{DS} overvoltage. No avalanche.	Avalanche when V_{DS} overvoltage. Energy rating.

GaN IC Device Structure

High Voltage
Level-Shifting
and Analog
GaN Devices

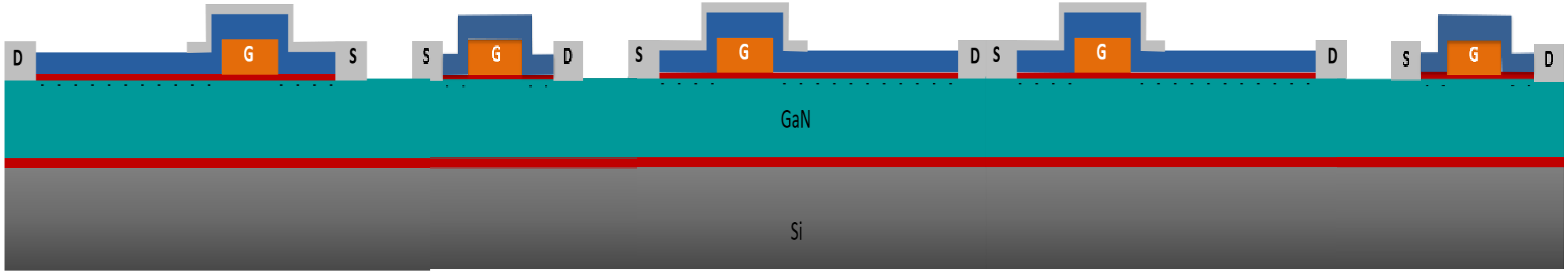
Low Side
Fixed Ref
Low Voltage
Logic/Analog
GaN Devices

Integrated Half-Bridge

Low Side
Power
eGaN Device

High Side
Floating
Power
eGaN Device

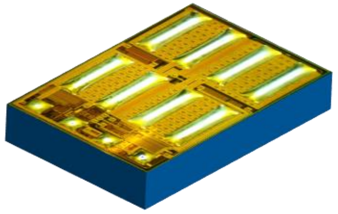
High Side
Floating
Low Voltage
Logic/Analog
GaN Devices

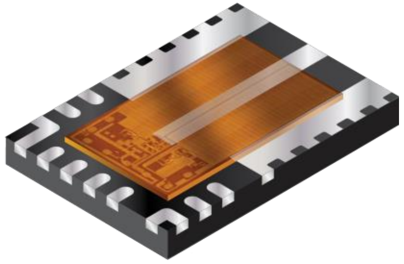


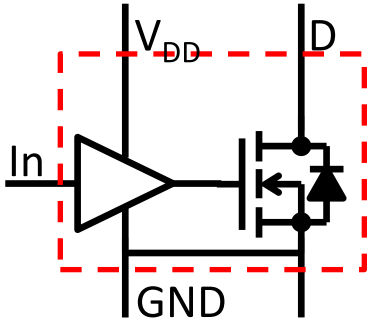
GaN Integrated Circuits

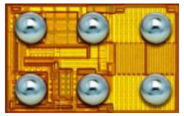
Monolithic GaN power stage with driver

- Near zero common source inductance
- Driver matched to FETs
- Thermal balancing*
- Layout friendly

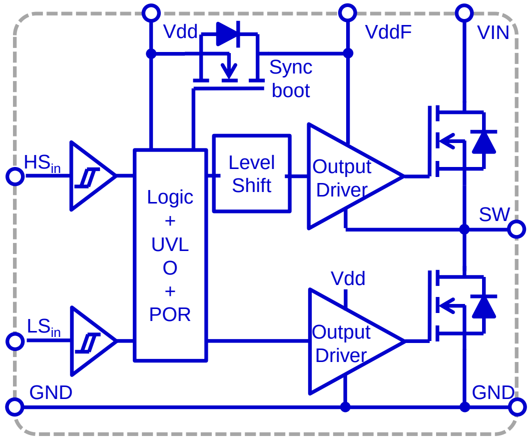




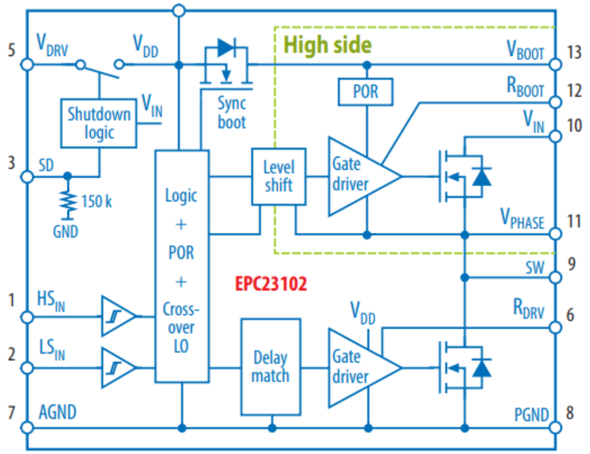




40 V, 15 Apk



80 V, 10 mΩ



100 V, 6.6 mΩ

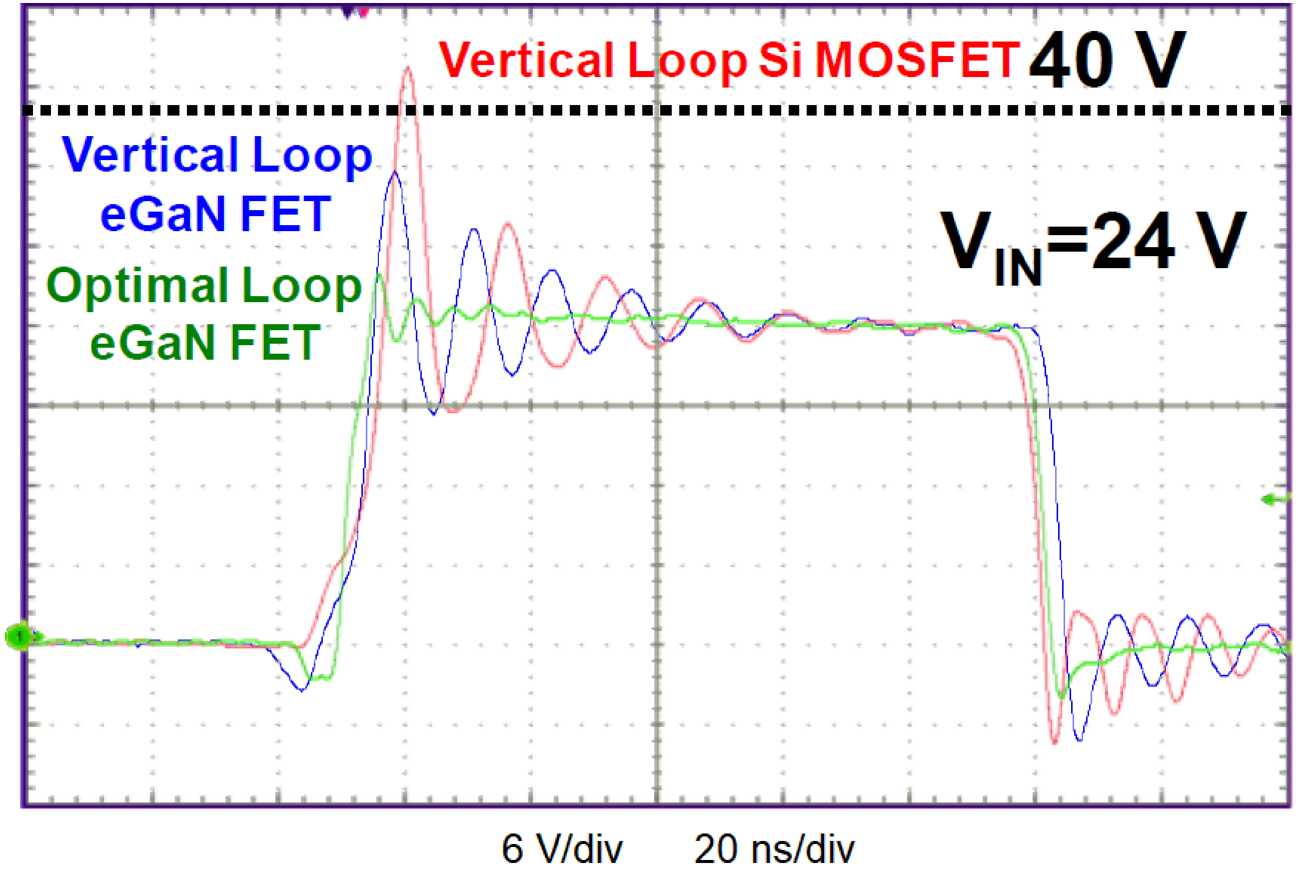
High Switching Speed Caveats

- Needs low parasitics layout
- Small power loop inductance reduces overshoot and ringing

⇒ Lower losses

⇒ Lower VDS ratings

⇒ Reduced EMI



Switch Node Voltage

Why GaN?

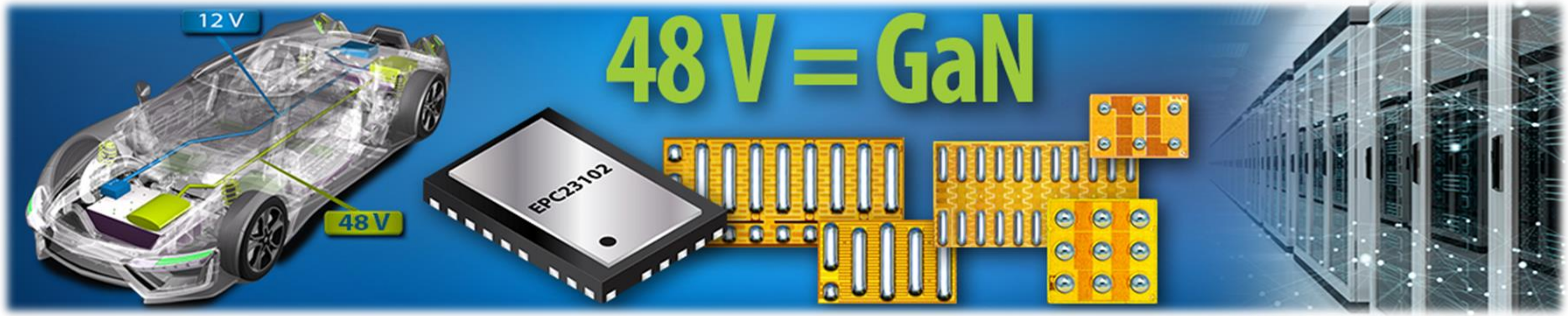
Compared with Si MOSFETs and PMICs, GaN is:

- Smaller
- Faster / more efficient / less heat generation
  - Higher switching speed / lower switching losses
  - No reverse recovery losses
  - Lower output capacitance losses
- Lower cost, at system level
- More reliable
- Multiple power devices in the same die ⇒ monolithic ICs
- Easy paralleling for high power

When GaN

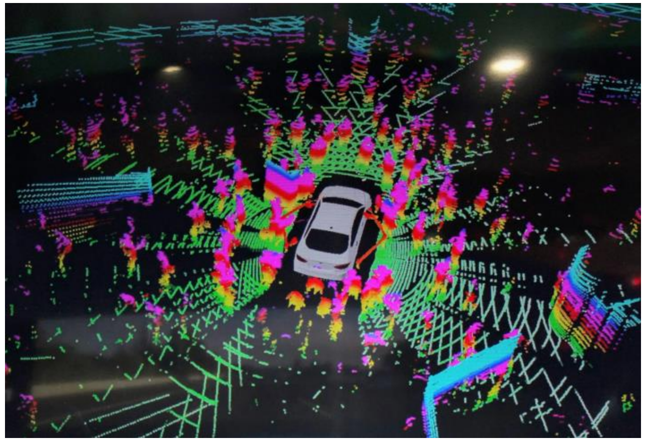
Are your requirements:

- High power density, compact and light solution?
- High efficiency, low losses?
- High (up to MHz) switching frequency?
- Nanosecond switching time?
- Radiation tolerant?



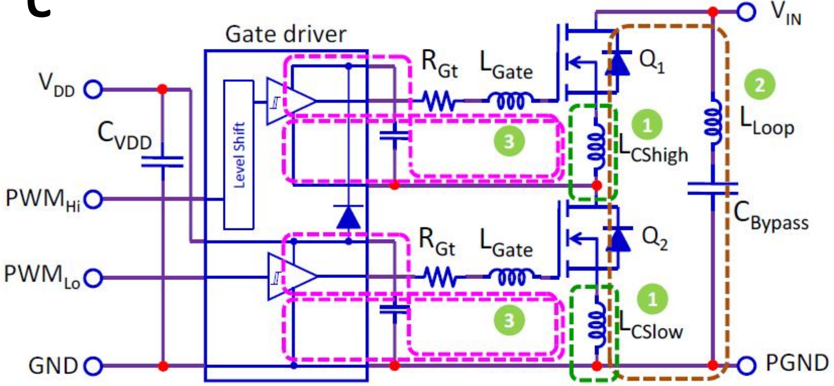
Applications

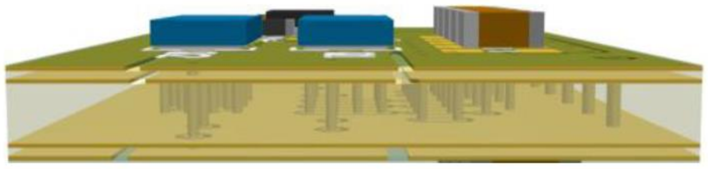
- DC-DCs
  - Hard switched buck/boost DC-DCs (i.e. solar)
  - IBCs, full bridge or resonant (i.e. data centers)
  - Synchronous Rectification
- Motor Drives
  - Micromobility: e-Scooters / e-bikes / small e-cars
  - Servodrives: robots / automation
  - Power tools, forklifts, battery operated equipment
  - Drones
- Lidar
- Class-D Audio / Ultrasound drivers
- AC-DCs: multilevel PFC rectifiers



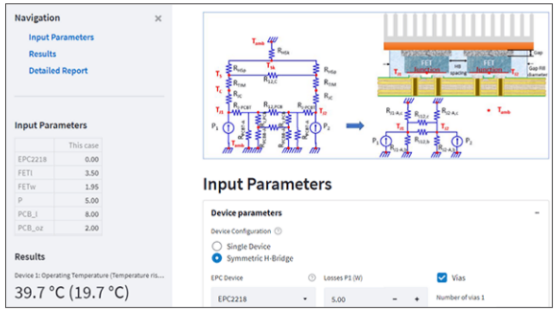
Design Support

- Layout
- Thermal
  - Thermal tool
  - TIM materials
- Design support
  - Selection tool
  - Spice models
- Assembly
  - Guidelines
  - Landpattern design
- Application Notes
- Books





GaN FET Thermal Calculator



Navigation

Input Parameters

Results

Detailed Report

Input Parameters

	This case
EPC2218	0.00
FETl	3.50
FETw	1.95
P	5.00
PCB_l	8.00
PCB_oz	2.00

Results

Device 1: Operating Temperature (Temperature ris...

39.7 °C (19.7 °C)

Input Parameters

Device parameters

Device Configuration

○ Single Device
● Symmetric H-Bridge

EPC Device: EPC2218

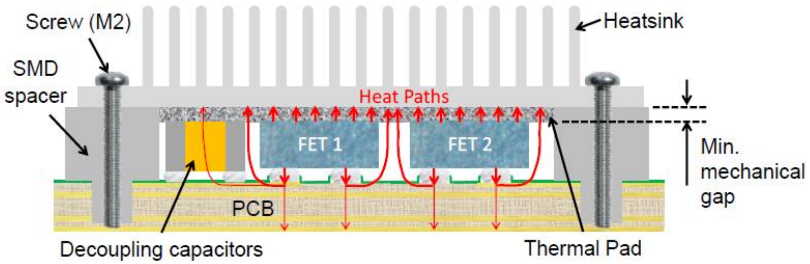
Losses P1 (W): 5.00

☑ Vias

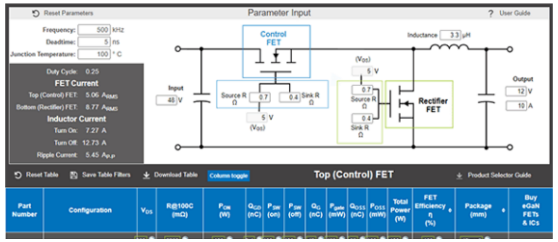
Number of vias 1

The GaN FET Thermal
parameters of PCB-mc
convection, and backsi
heatsink. The model ac
sizes, power losses, TI

Launch Calculator



GaN FET Selection Tool for Buck Converters



Parameter Input

Frequency: 500 kHz

Deadtime: 5 ns

Junction Temperature: 100 °C

Duty Cycle: 0.25

FET Current

Top (Control) FET: 5.06 A_{RMS}

Bottom (Rectifier) FET: 8.77 A_{RMS}

Inductor Current

Turn On: 7.27 A

Turn Off: 12.73 A

Ripple Current: 5.45 A_{P-P}

Input 48 V

Inductance 3.3 µH

Source R Ω 0.7

Sink R Ω 0.4

(V_{GS}) 5 V

Source R Ω 0.7

Sink R Ω 0.4

(V_{GS}) 5 V

Output 12 V

10 A

Top (Control) FET

Part Number	Configuration	V_{DS}	R@100C (mΩ)	P_{ON} (W)	Q_{GD} (nC)	P_{SW} (on)	P_{SW} (off)	Q_G (nC)	P_{gate} (mW)	Q_{OSS} (nC)	P_{OSS} (mW)	Total Power (W)	FET Efficiency η (%)	Package (mm)	Buy eGaN FETs & ICs

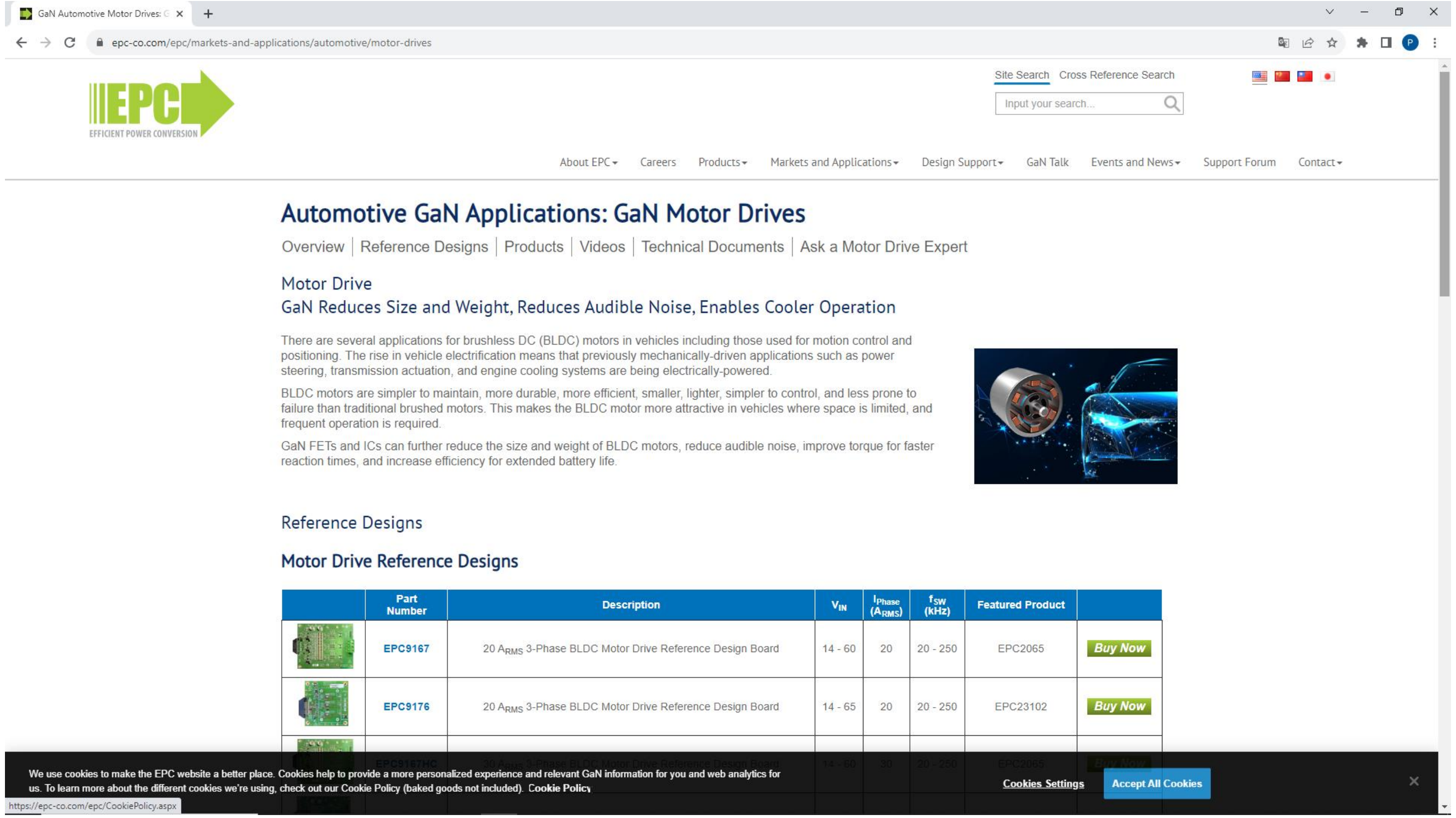
The GaN FET Selectio
tool that uses estimatic
this selection tool is to

Launch Calculator

AVE
ADDED VALUE
ELECTRONICS

E&A
ELECTRONICS' APPLICATIONS 23

For more information



Automotive GaN Applications: GaN Motor Drives

Overview | Reference Designs | Products | Videos | Technical Documents | Ask a Motor Drive Expert

Motor Drive
GaN Reduces Size and Weight, Reduces Audible Noise, Enables Cooler Operation

There are several applications for brushless DC (BLDC) motors in vehicles including those used for motion control and positioning. The rise in vehicle electrification means that previously mechanically-driven applications such as power steering, transmission actuation, and engine cooling systems are being electrically-powered.

BLDC motors are simpler to maintain, more durable, more efficient, smaller, lighter, simpler to control, and less prone to failure than traditional brushed motors. This makes the BLDC motor more attractive in vehicles where space is limited, and frequent operation is required.

GaN FETs and ICs can further reduce the size and weight of BLDC motors, reduce audible noise, improve torque for faster reaction times, and increase efficiency for extended battery life.

Reference Designs

Motor Drive Reference Designs

	Part Number	Description	V_{IN}	I_{Phase} (A_{RMS})	f_{SW} (kHz)	Featured Product	
	EPC9167	20 A_{RMS} 3-Phase BLDC Motor Drive Reference Design Board	14 - 60	20	20 - 250	EPC2065	Buy Now
	EPC9176	20 A_{RMS} 3-Phase BLDC Motor Drive Reference Design Board	14 - 65	20	20 - 250	EPC23102	Buy Now
	EPC9167HC	30 A_{RMS} 3-Phase BLDC Motor Drive Reference Design Board	14 - 60	30	20 - 250	EPC2065	Buy Now

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