GN001 Application Note

An Introduction to GaN Enhancement-mode HEMTs

April 16, 2020

GaN Systems Inc.

Content

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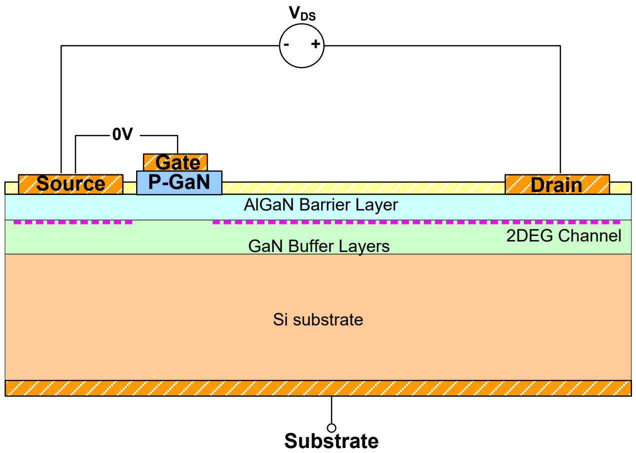
- ❑ Basics and Mechanism
  - ❑ GaN Material and 2D Electron Gas (2DEG)
  - ❑ Enhancement-mode GaN HEMT
  - ❑ GaN Systems Simple-driven GaN technology
- ❑ Characteristics
- ❑ Design Resources

Please visit http://gansystems.com or the latest version of this document

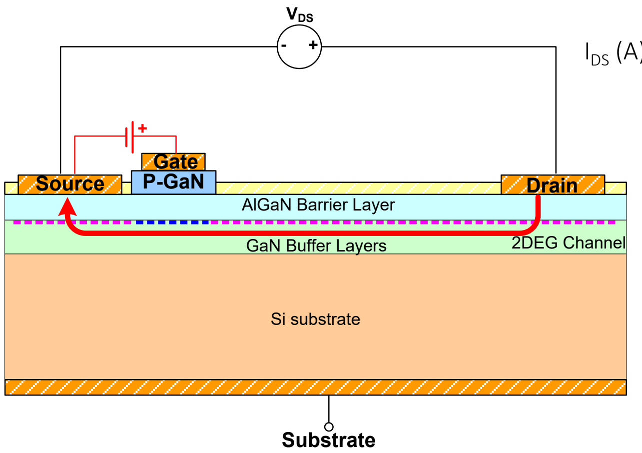
Basic structure of GaN E-HEMT

GaN Enhancement mode High Electron Mobility Transistor (E-HEMT)

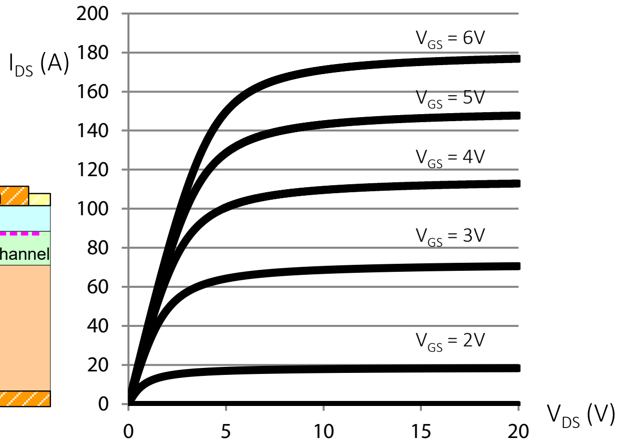
- A lateral 2-dimensional electron gas (2DEG) channel formed on AlGaN/GaN hetero-epitaxy structure provides very high charge density and mobility
- For enhancement mode operation, a gate is implemented to deplete the 2DEG underneath at 0V or negative bias. A positive gate bias turns on the 2DEG channel
- It works like a MOSFET except with better switching performance



OFF State



ON State



I_{DS} vs. V_{DS} Characteristics

Simple-driven GaN Technology

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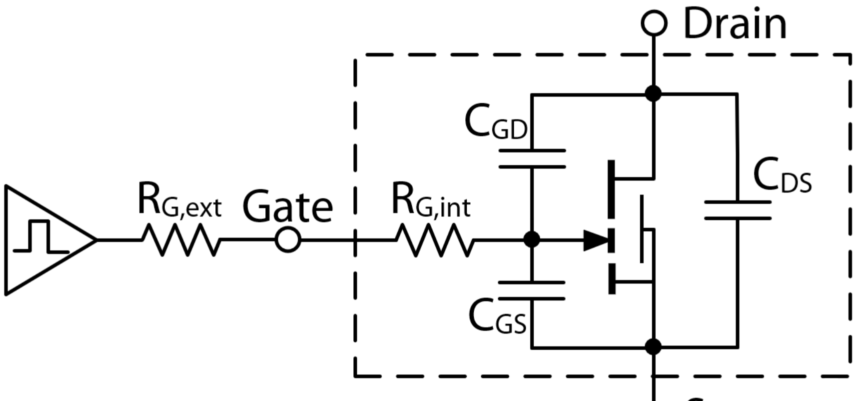
Common with Si MOSFET

- True enhancement-mode normally off
- Voltage driven - driver charges/discharges C_{ISS}
- Supply Gate leakage I_{GSS} only
- Easy slew rate control by R_G
- Compatible with Si gate driver chip



$C_{ISS} = C_{GD} + C_{GS}$

Differences

- Much Lower Q_G : Lower drive loss; faster switching
- Higher gain and lower V_{GS} : +5-6V gate bias to turn on
- Lower $V_{G(th)}$: typ. 1.5V

Versus other enhancement-mode GaN

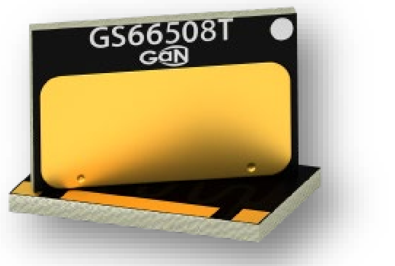
- More robust gate: -20/+10V max rating
- **No DC gate drive current required**
- **No complicated gate diode / PN junction**

Gate Bias Level	GaN Systems GaN E-HEMT	Si MOSFET	IGBT	SIC MOSFET
Maximum rating	-20/+10V	-/+20V	-/+20V	-8/+20V
Typical gate bias values	0 or-3/+5-6V	0/+10-12V	0 or -9/+15V	-4/+15-20V

❖ GaN HEMTs are **simple to drive**, for more info please refer to application note **GN012**

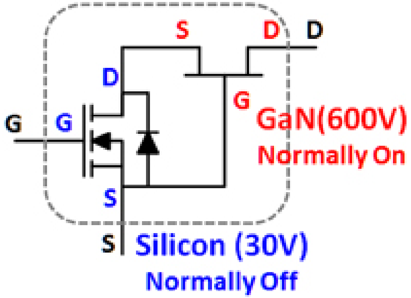
GaN Technology Comparison

GaN Systems E-mode HEMT



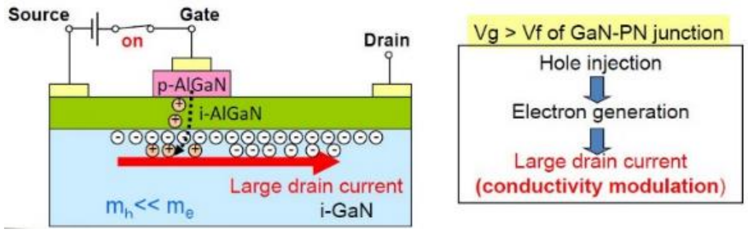
- **True Enhancement mode**
- **Simple 3-terminal power switch**
- **Best FOM and performance**
- **Island technology - Easy to scale**
- **GaNPx embedding package**
- **No reverse recovery loss**
- **Easy to parallel**

D-mode GaN (Cascode)



- D-mode technology
- Uncontrollable Speed (EMI)
- Internal Node causing reliability problems – Hard to troubleshoot
- Requires matching between Si/GaN – Hard to scale
- Reverse Recovery (Qrr)
- Difficult to parallel

GaN Gate Injection Transistor (GIT)



- High gate current required (like BJT)
- Difficult to drive – Complicated gate characteristics
- Recombination current:
  - Strong temperature dependency
  - Paralleling stability is a concern
  - Lower speed
  - Worse FOM than E-HEMT

Content

- ❑ Basics and Mechanism
- ❑ Characteristics
  - ❑ Figure of merit
  - ❑ Reverse conduction Characteristics
  - ❑ Zero reverse recovery
  - ❑ Output capacitance
  - ❑ Switching transition
  - ❑ Switching energy
- ❑ Design Resources

Figure of Merit

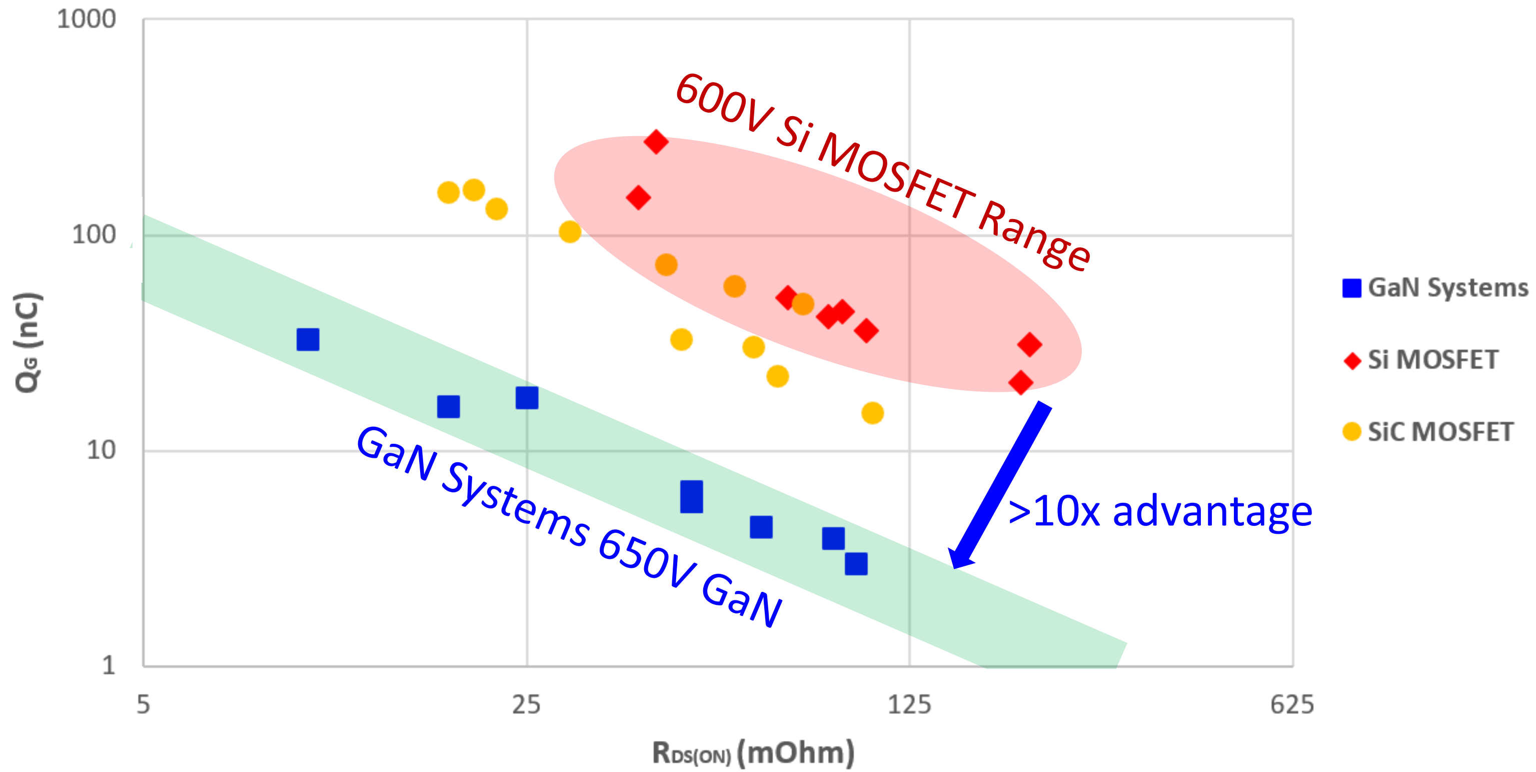
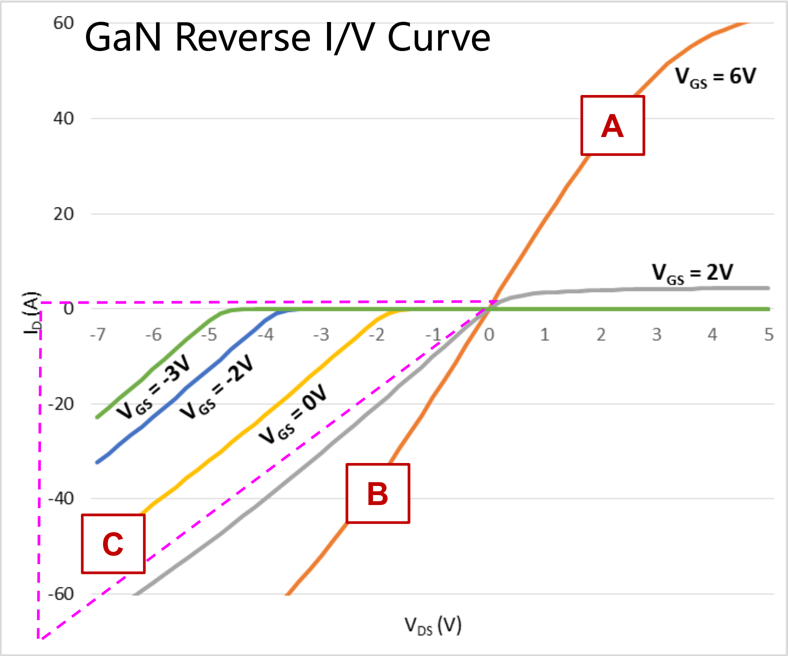


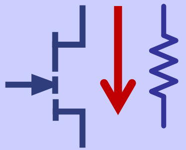
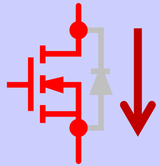
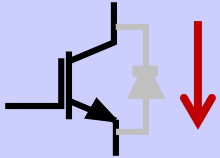
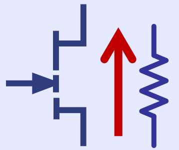
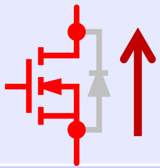
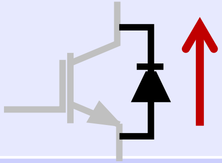
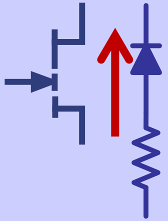
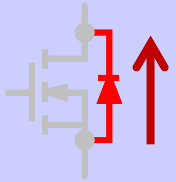
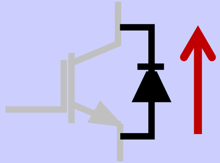
Figure of Merit of 650V/600V Power Switches (Feb.2020 update)

- GaN Systems E-mode devices have **superior R_{ON} & Q_G performance** over Si and SiC MOSFETs, resulting in **lower switching charge requirements** and **faster switching transition**

Reverse Conduction Characteristics

GaN Systems



	Gate	GaN E-HEMT	MOSFET	Si IGBT
A	ON	 $R_{DS(ON)}$		
B	ON	 $R_{DS(ON)}$		
C	OFF	 $V_{TH}+V_{GS(OFF)}$, $R_{DS(REV)}$		

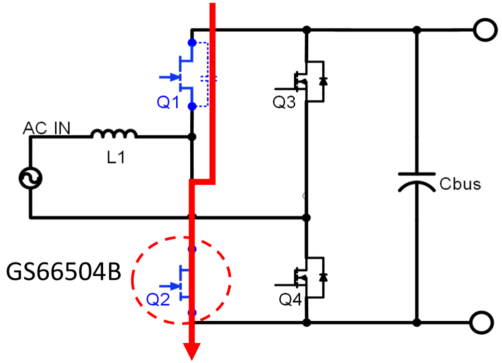
- When gate is OFF (during dead time), 2DEG exhibits like a diode with $V_F = V_{TH(GD)} + V_{GS(OFF)} + I_{SD} * R_{SD(ON)}$

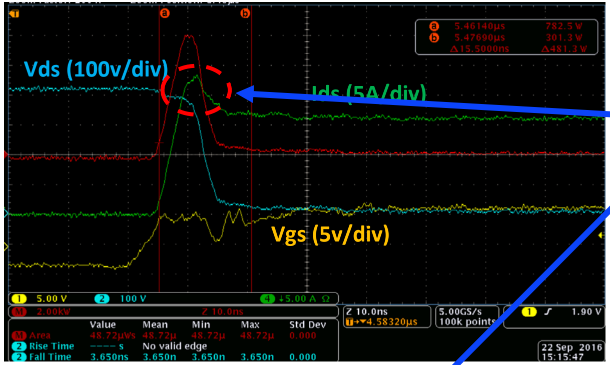
❖ There is **no body diode** (as with Si and SiC MOSFETs)

❖ But, GaN 2DEG can conduct in 3rd quadrant – **No need for anti-parallel diode** (as in Si IGBT)

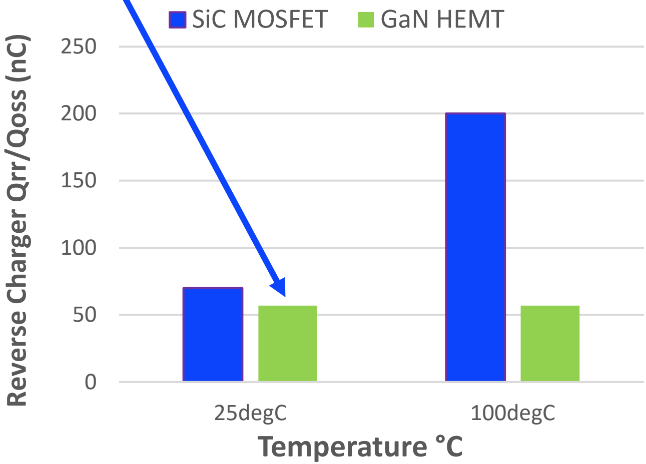
For more info: https://gansystems.com/wp-content/uploads/2020/01/Common-misconceptions-about-the-MOSFET-body-diode.pdf

Zero Reverse Recovery

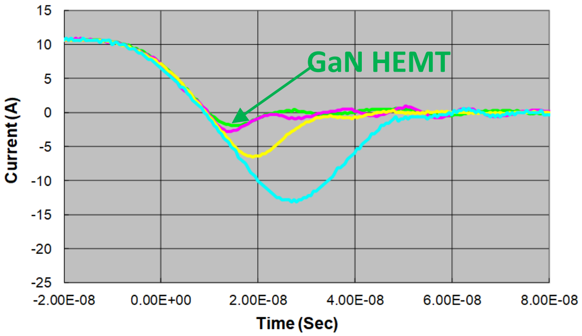




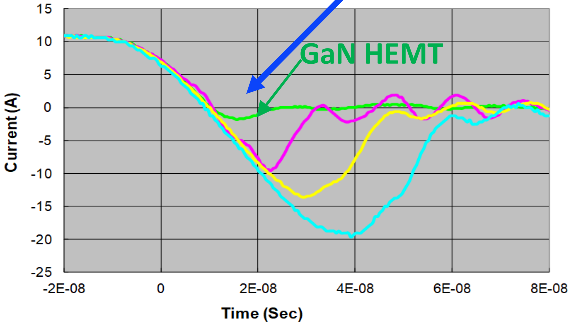
- Qoss only,
- There is zero reverse recovery in GaN HEMT



Reverse Characteristics @ Tj=25°C



Reverse Characteristics @ Tj=100°C



GaN HEMT 650V/15A — SiC MOSFET 650V/120mΩ — Si MOSFET 650V/15A — Si diode 650V/15A

❖ Zero reverse recovery results in **lower switching loss** and **less EMI noise**

Output Capacitance

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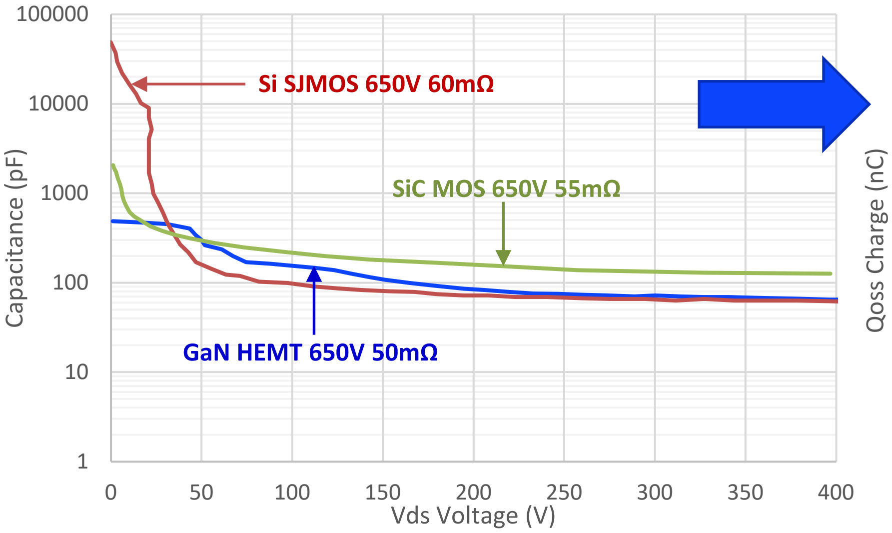
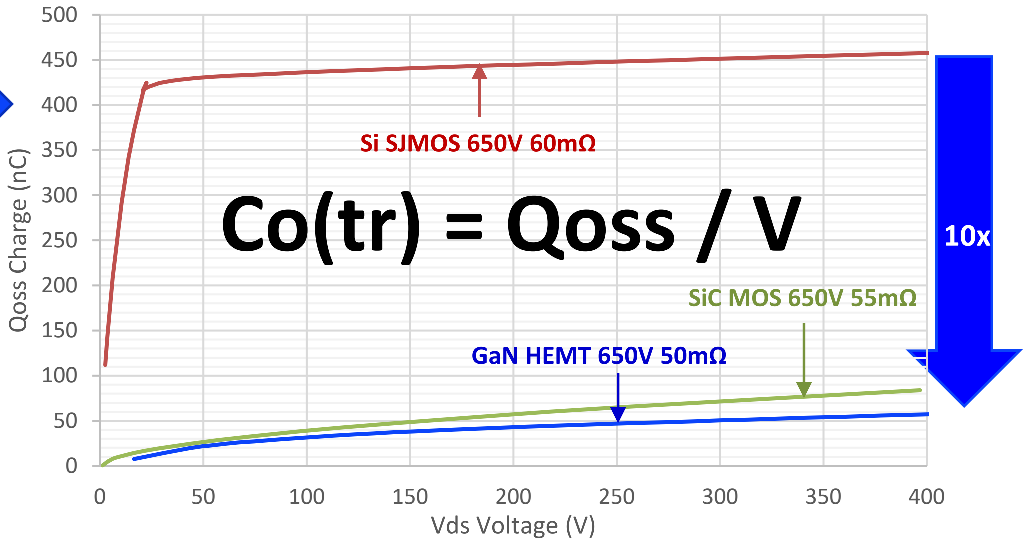
$$\begin{cases} Q_{oss} = C_{o(tr)} \cdot V \\ Q_{oss} = \int_0^{Vds} Coss(v)\, dv \end{cases}$$

Coss curve → Qoss curve → Co(tr) value

Coss Vs Vds Voltage

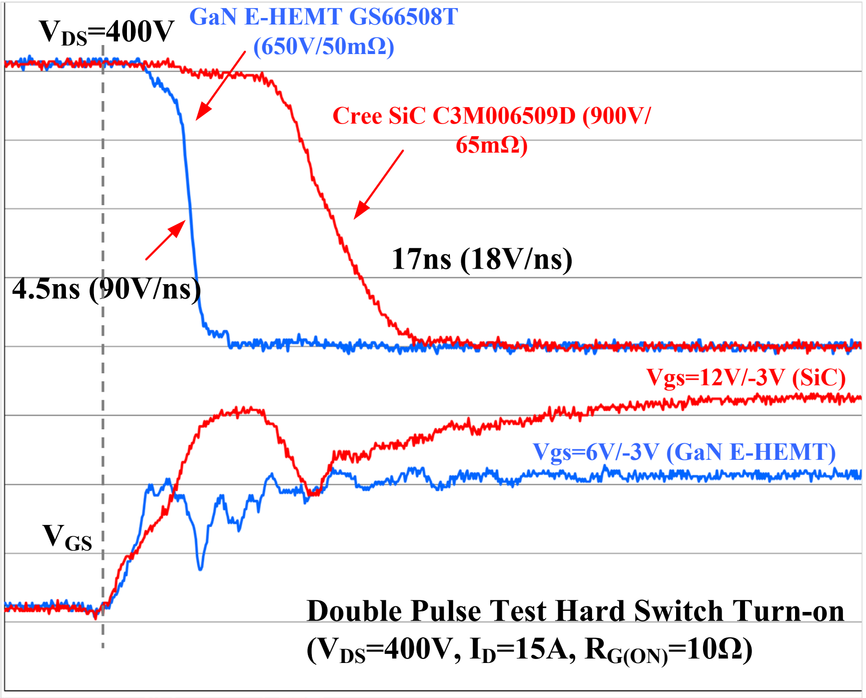


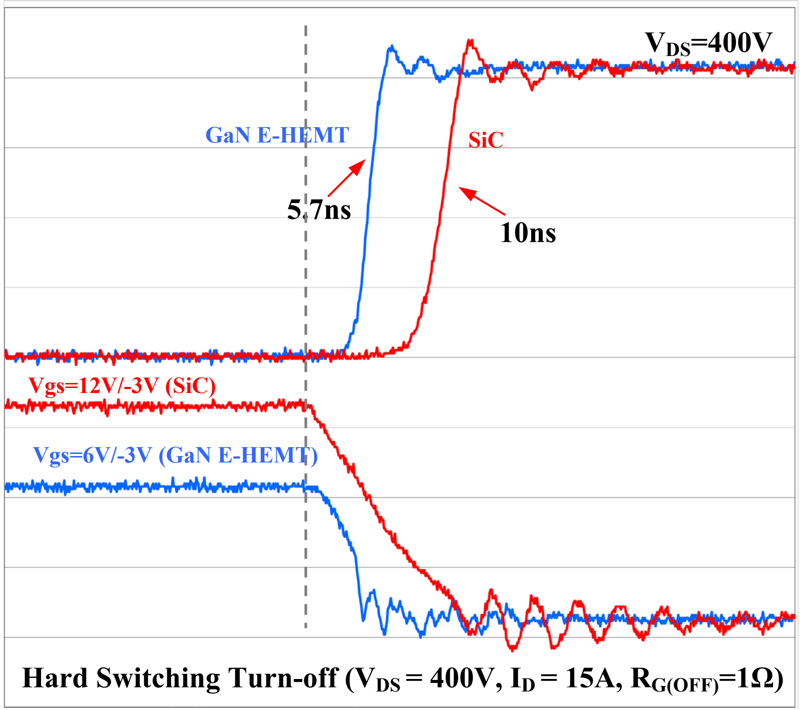
Qoss Vs Vds Voltage



- Si SJMOS has **~10x** higher Co(tr) than GaN; SiC MOS has **~50%** higher Co(tr) than GaN.
- Smaller output capacitance results **in lower switching loss** and **easier zero voltage switching realization (ZVS)**

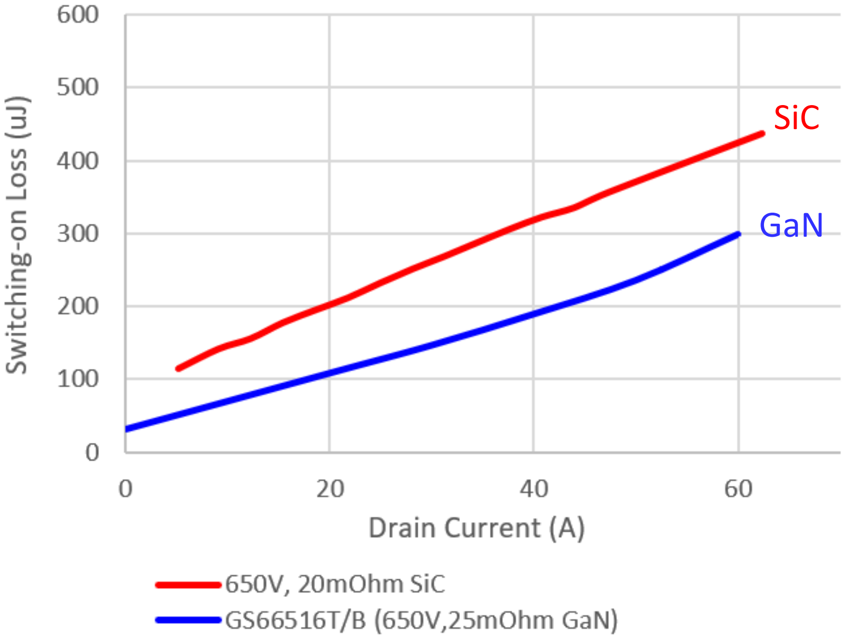
Faster Switching Transition

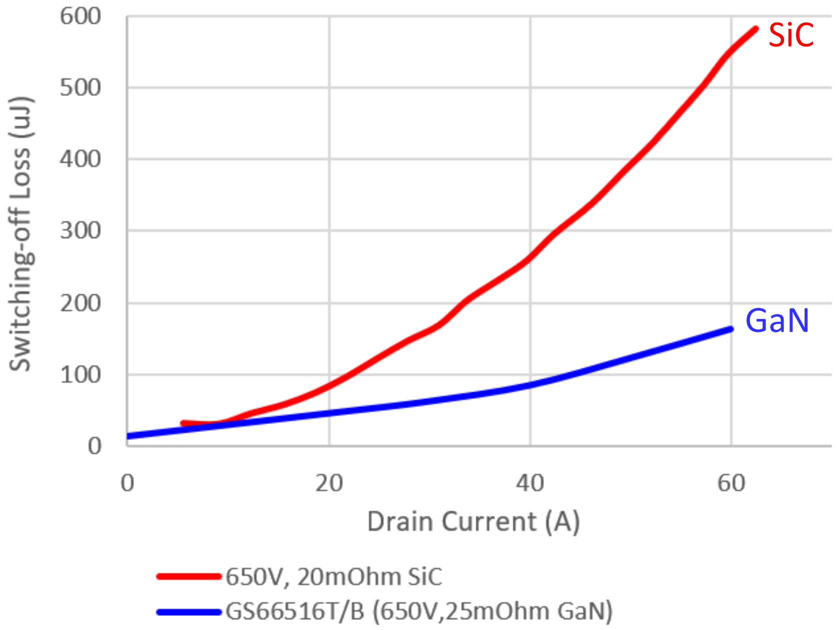




- GaN has **4x faster turn-on** and **2x faster turn-off** than state of art SiC MOSFET with similar $R_{DS(ON)}$
- Faster switching transition results in **lower switching loss**
- Layout is important for maximize the performance of GaN HEMTs. For more info: GN009 https://gansystems.com/

Switching Energy





- The switching loss of a GaN HEMT is **significantly lower** than 650V SiC MOSFET with similar $R_{DS(ON)}$

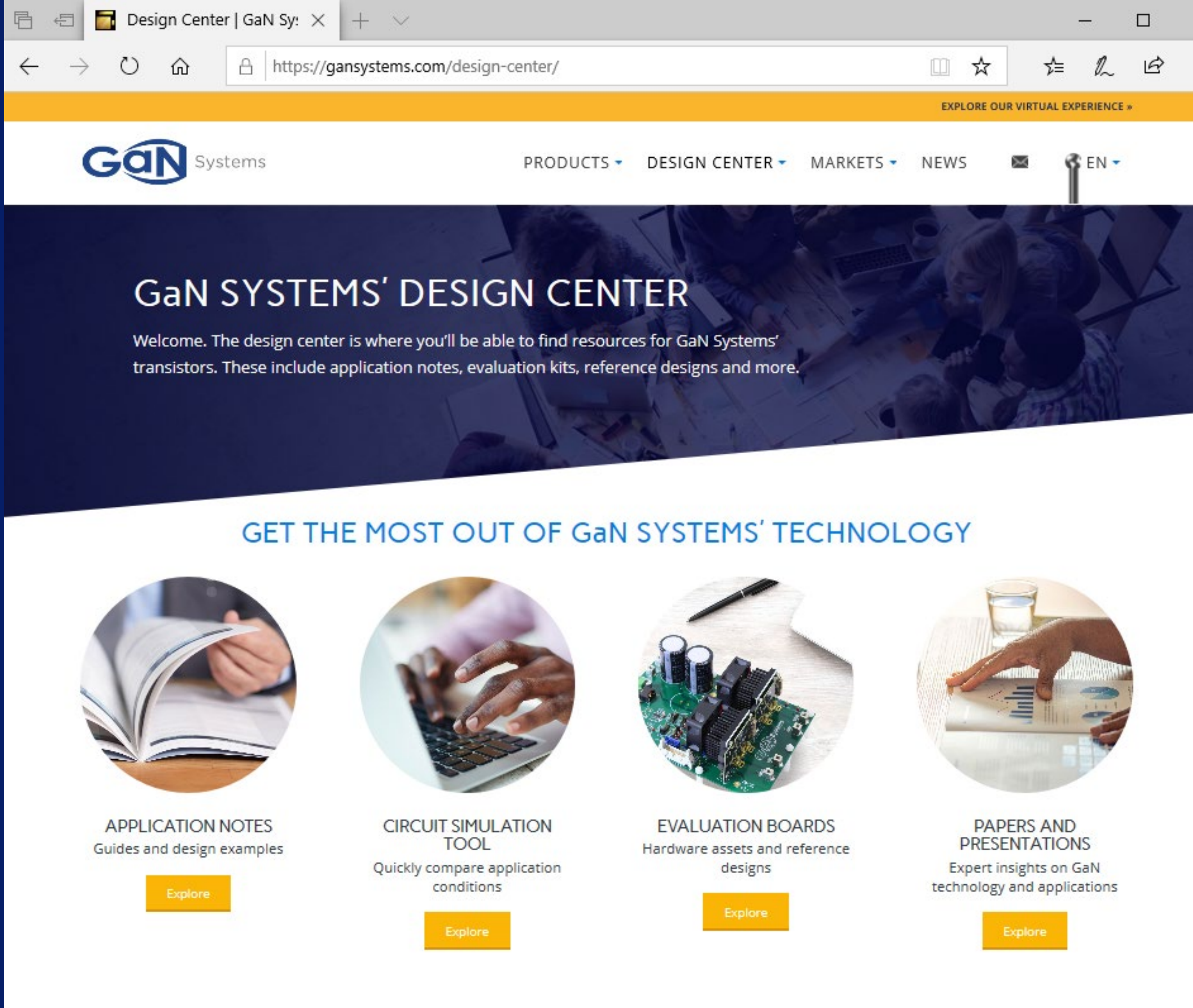
Content

- ❑ Basics and Mechanism
- ❑ Characteristics
- ❑ Design Resources

GaN Systems

GaN Systems Design Center

- **Many resources available**
  - Easy to find
  - Easy to use



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APP NOTES

- Layout
- Gate Driver
- Paralleling
- Thermals
- Simulation
- Soldering

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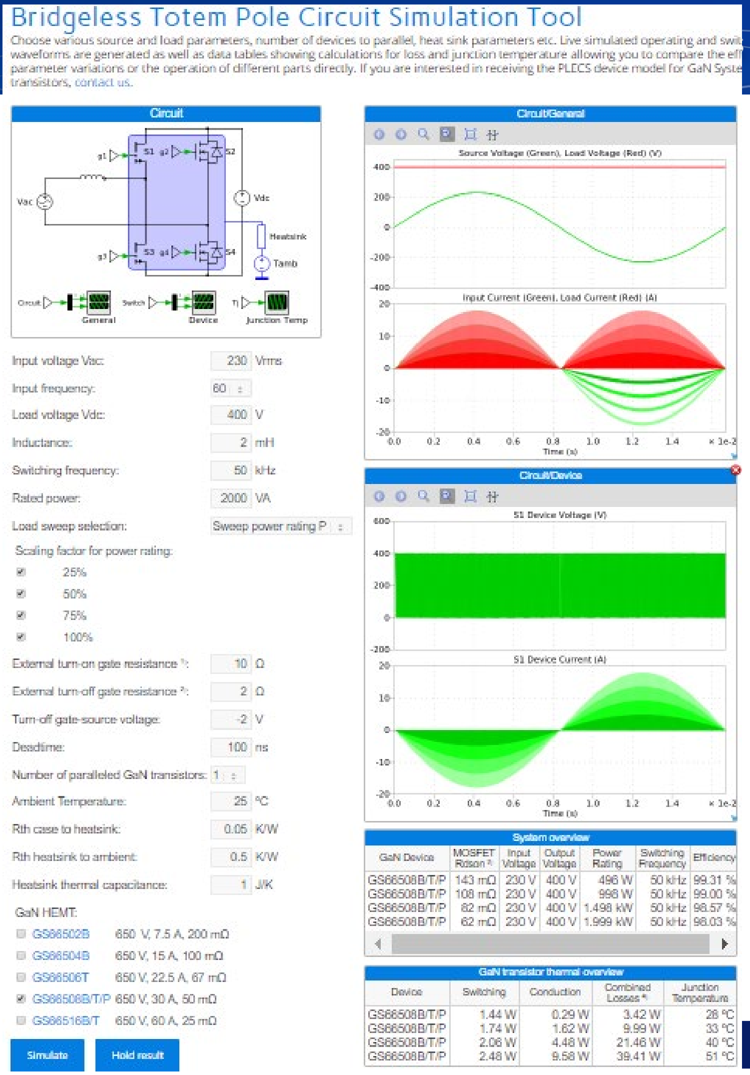
Application Notes

Our unique portfolio of GaN power transistors enables the design of smaller, lower cost, more efficient power systems that are free from the limitations of yesterday's silicon. Our application guides and design examples will help you understand and get the most out of GaN Systems' technology.

Document #	Title
GN001	Design with GaN Enhancement mode HEMT
GN001 日本語	エンハンスメントモードGaN-HEMTを用いたデザイン
GN002	Thermal Design for Top-Side Cooled GaN*PX*® packaged Devices
GN003	Measurement Techniques for High-Speed GaN E-HEMTs
GN004	Design considerations of paralleled GaN HEMT
GN005	PCB Thermal Design Guide for GaN Enhancement Mode Power Transistors
GN006	SPICE model for GaN HEMT usage guidelines and example
GN007	Modeling Thermal Behavior of GaN*PX*® packages Using RC Thermal SPICE Models
GN008	GaN Switching Loss Simulation Using LTSpice
GN009	PCB Layout Considerations with GaN E-HEMTs
GN010	EZDrive™ Solution for GaN Systems E-HEMTs
GN011	Soldering Recommendations for GaNPX® Packaged Devices

Online Simulation Tool

- PLECS model is used on GaN Systems' online simulation tool
- All GaN Systems products model and 8 topologies available online https://gansystems.com/



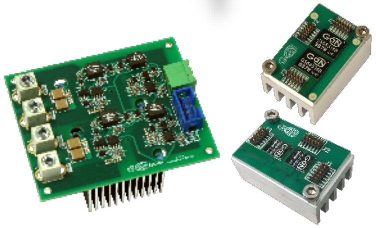
Take Full Advantage of GaN – Evaluation Boards

GaN Systems

GS665MB-EVB Motherboard
+ GS665xxDB-EVB Daughterboard
Half bridge power stage

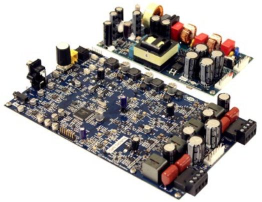
GSP65MB-EVB
+ GSP65RxxHB-EVB
2-7 kW Insulated Metal Substrate
Configurable Full/Half Bridge Evaluation kit

GSP665x-EVBIMS2
2-6 kW Insulated Metal Substrate
Configurable Full/Half Bridge Evaluation kit



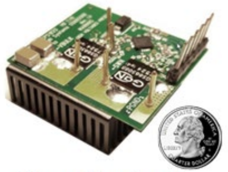
GS1200BTP-EVB
1.2kW Bridgeless Totem Pole Power Factor
Correction Evaluation Board

GS-EVB-AUD-xxx1-GS
GaN-based Class D Audio Amplifier and
Companion power supply



GSWP050W-EVBPA
GSWP100W-EVBPA
GSWP300W-EVBPA
50W, 100W to 300W+ Wireless Power Transfer
Power Amplifier Evaluation Kits

GS-EVB-HB-66508B-ON1
650V, ultra-small form factor Half Bridge
power stage



25mm x 25mm Layout

GS65011-EVBEZ
EZDrive® open loop boost evaluation board

Design Tools and Resources at gansystems.com

GaN Systems

TRANSISTOR DOCUMENTS

DOWNLOADS
- Datasheet
- Spice Models
- Step File
- Allegro Library
- Altium Library

REACH Statement
RoHS Certificate of Compliance

GaN Systems

https://gansystems.com/

DESIGN CENTER

- Application Notes
- Circuit Simulation Tools
- Evaluation Boards
- Papers & Presentations

plexim
electrical engineering software

Online circuit simulation tool

Features
- Several topologies
- GaN Systems products with paralleling options
- Change values on input variables
- Circuit and GaN transistor output waveforms

Application Notes

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FAQ – Frequently Asked Questions

All / Device Characteristics / Gate Drive / General / Getting Started / High Frequency / Package & Assembly / Thermal Management

- What are the advantages of GaN versus Silicon?
- In which industries can the use of GaN power transistors drive significant business change?
- Why should executives care as much about GaN technology as power system design engineers do?
- What is GaN Systems' product portfolio?

etc …

Papers, articles and presentations

Document Details	Date
Common Misconceptions About the MOSFET Body Diode	2020 Jan
Using MOSFET Controllers to Drive GaN E-HEMTs	2020 Jan
GaN Technologies For Electric Vehicles	2020 Jan
Optimal Design for High Frequency GaN-Based Totem Pole PFC	2020 Jan
WEBINAR: Simple Layout Steps for Maximizing GaN Design Performance	2019 Nov
The Value of GaN HEMTs in 800V and Above Applications	2019 Jun
Power Amplifier and Coil Design Optimization for Large Air Gap Applications	2019 Jun

etc …

Tomorrow's power today™

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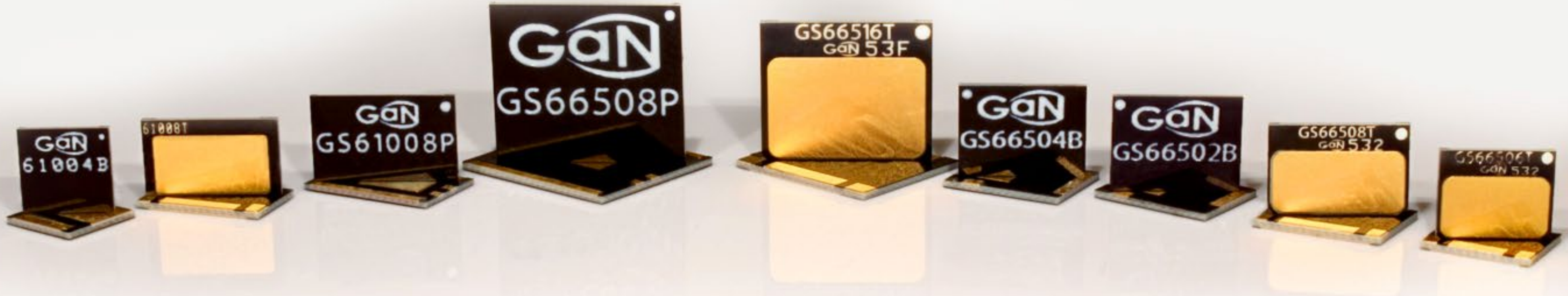

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