GaN Systems

GN001 Application Note

An Introduction to GaN Enhancement-mode HEMTs

March 08, 2022
GaN Systems Inc.

Content

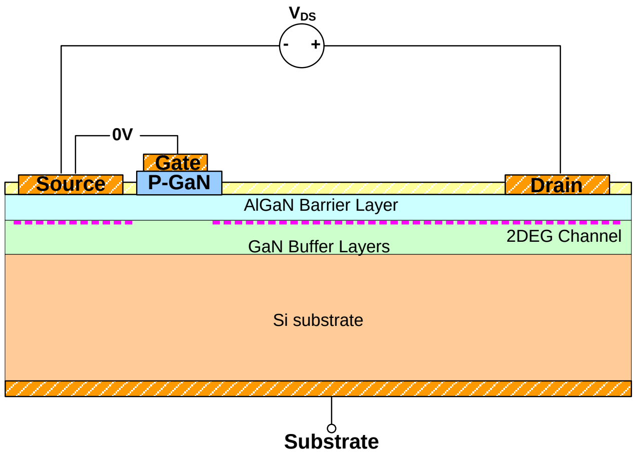
- ❑ Basics and Mechanism
  - ❑ GaN Material and 2D Electron Gas (2DEG)
  - ❑ Enhancement-mode GaN HEMT
  - ❑ GaN Systems Simple-driven GaN technology
- ❑ Characteristics
- ❑ Design Resources

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

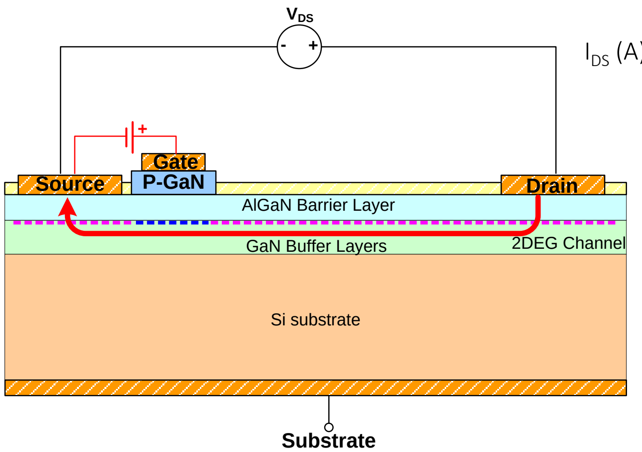
Basic structure of GaN E-HEMT

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

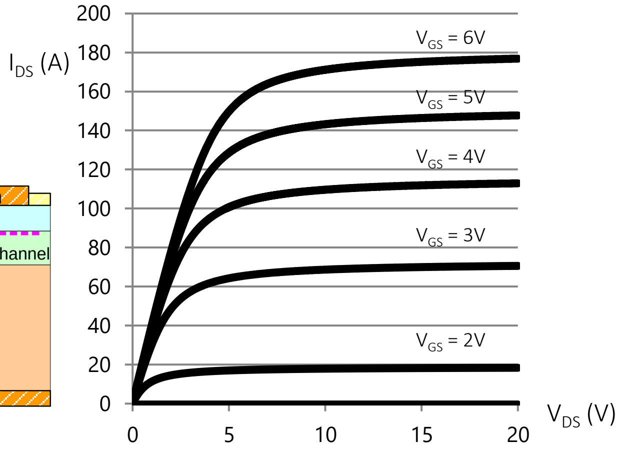
- A lateral 2-dimensional electron gas (2DEG) channel formed on AlGaN/GaN hetero-epitaxy structure provides very high charge density and mobility
- For enhancement mode operation, a gate is implemented to deplete the 2DEG underneath at 0V or negative bias. A positive gate bias turns on the 2DEG channel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



OFF State



ON State



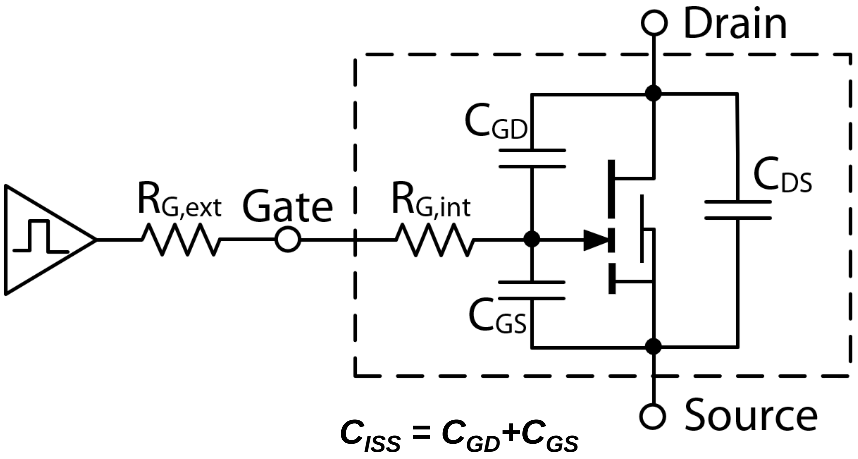
I_{DS} vs. V_{DS} Characteristics

Simple-driven GaN Technology

GaN Systems

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



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**

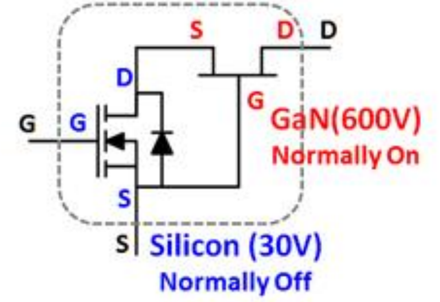
GaN Technology Comparison

GaN Systems

GaN Systems E-mode HEMT

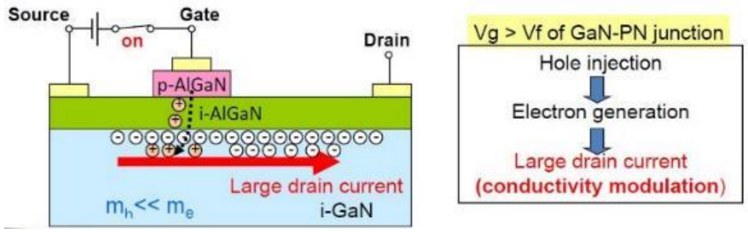
- **True Enhancement mode**
- **Simple 3-terminal power switch**
- **Best FOM and performance**
- **Island technology - Easy to scale**
- **GaNPx embedding package**
- **No reverse recovery loss**
- **Easy to parallel**

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

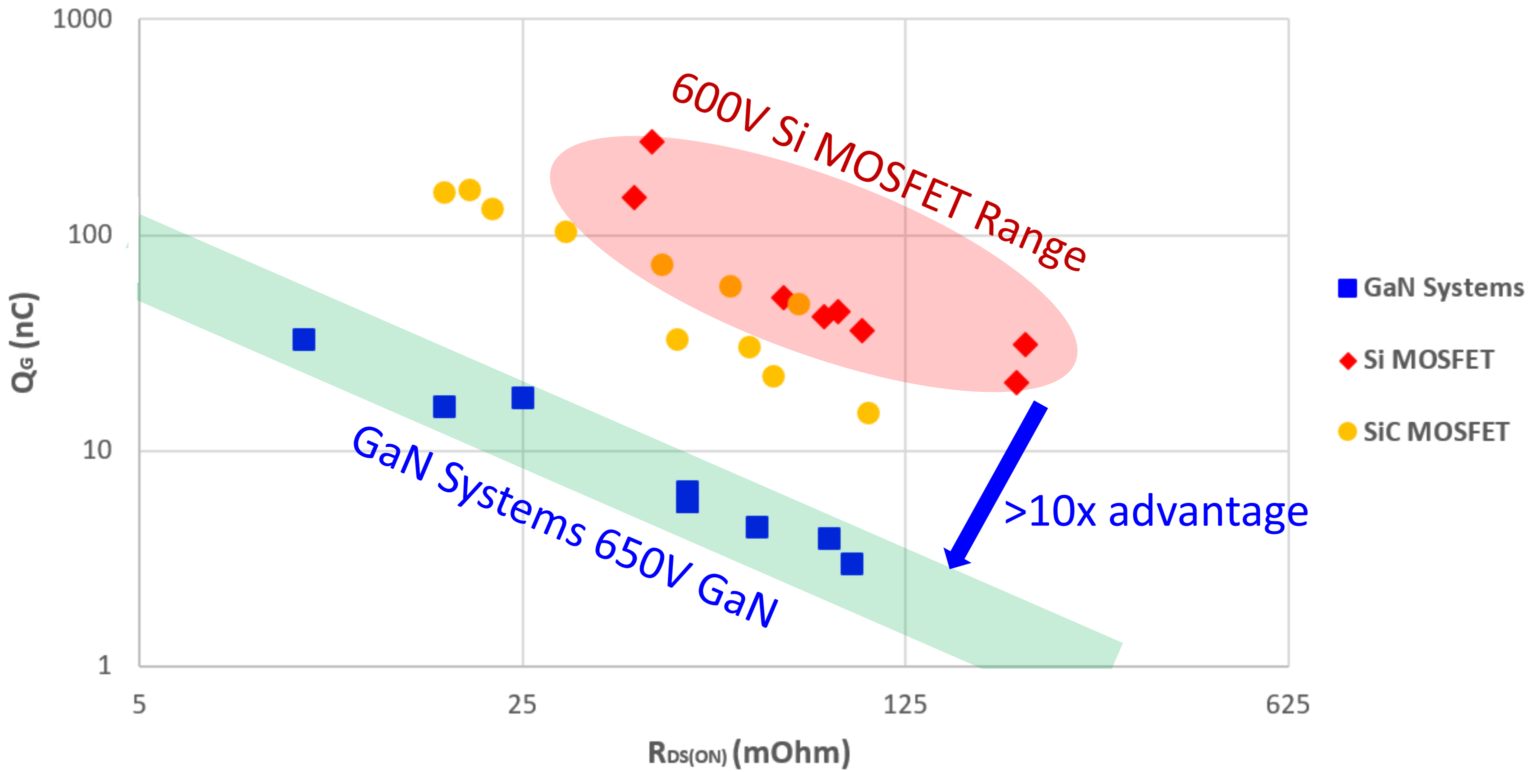
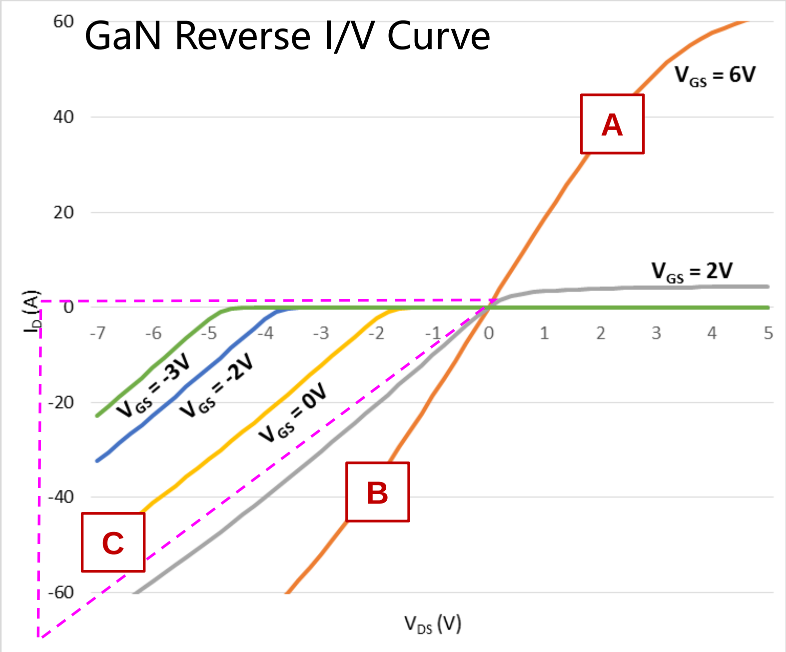


Figure of Merit of 650V/600V Power Switches (Feb.2020 update)

- 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



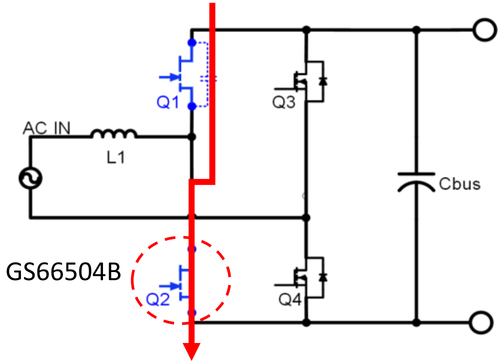
	Gate	GaN E-HEMT	MOSFET	Si IGBT
A	ON	$R_{DS(ON)}$		
B	ON	$R_{DS(ON)}$		
C	OFF	$V_{TH}+V_{GS(OFF)}$ $R_{DS(REV)}$		

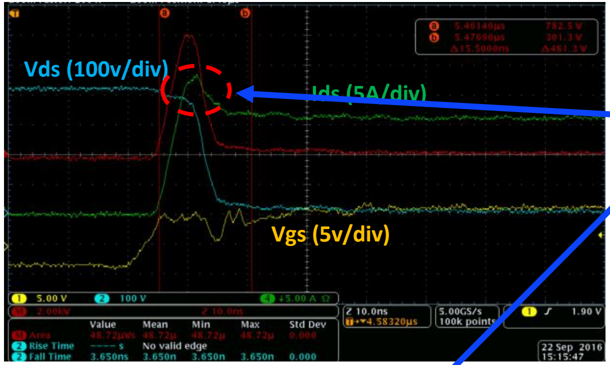
- When gate is OFF (during dead time), 2DEG exhibits like a diode with $V_F= V_{TH(GD)}+ V_{GS(OFF)}+ I_{SD} * R_{SD(ON)}$

- 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)

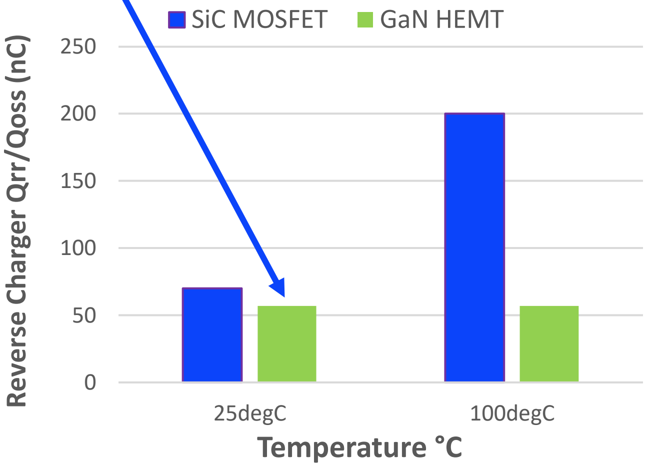
For more info: https://gansystems.com/wp-content/uploads/2020/01/Common-misconceptions-about-the-MOSFET-body-diode.pdf

Zero Reverse Recovery

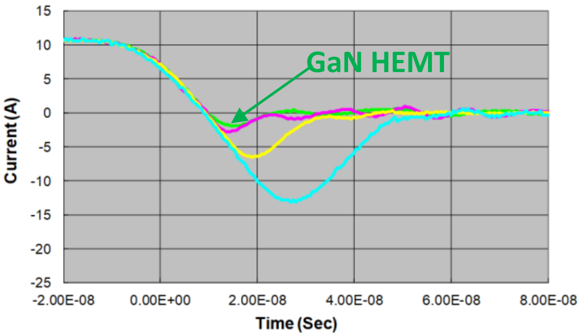




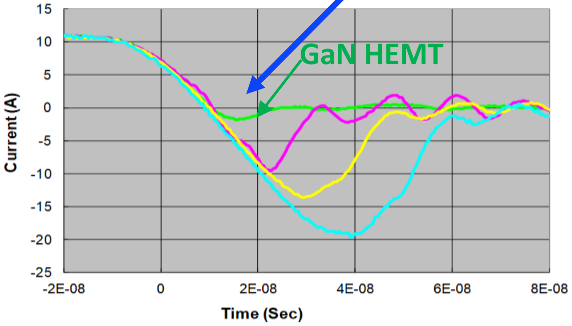
- Qoss only,
- There is zero reverse recovery in GaN HEMT



Reverse Characteristics @ Tj=25°C



Reverse Characteristics @ Tj=100°C



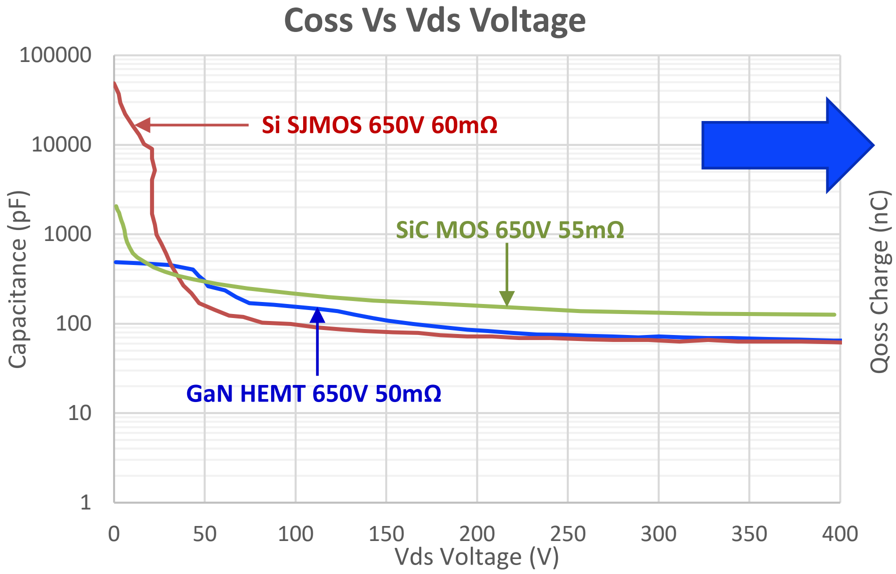
GaN HEMT 650V/15A   SiC MOSFET 650V/120mΩ   Si MOSFET 650V/15A   Si diode 650V/15A

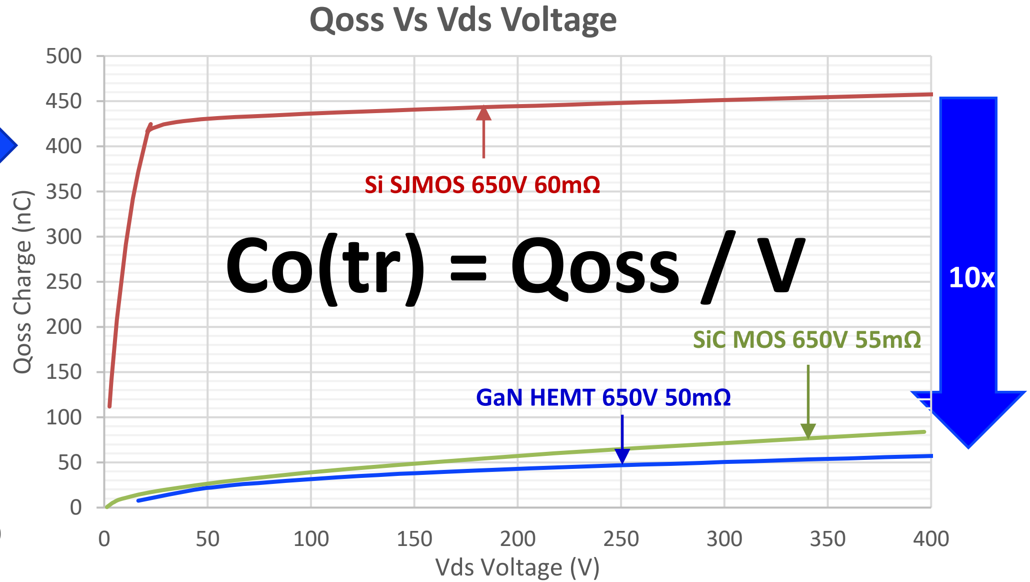
❖ Zero reverse recovery results in **lower switching loss** and **less EMI noise**

Output Capacitance

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

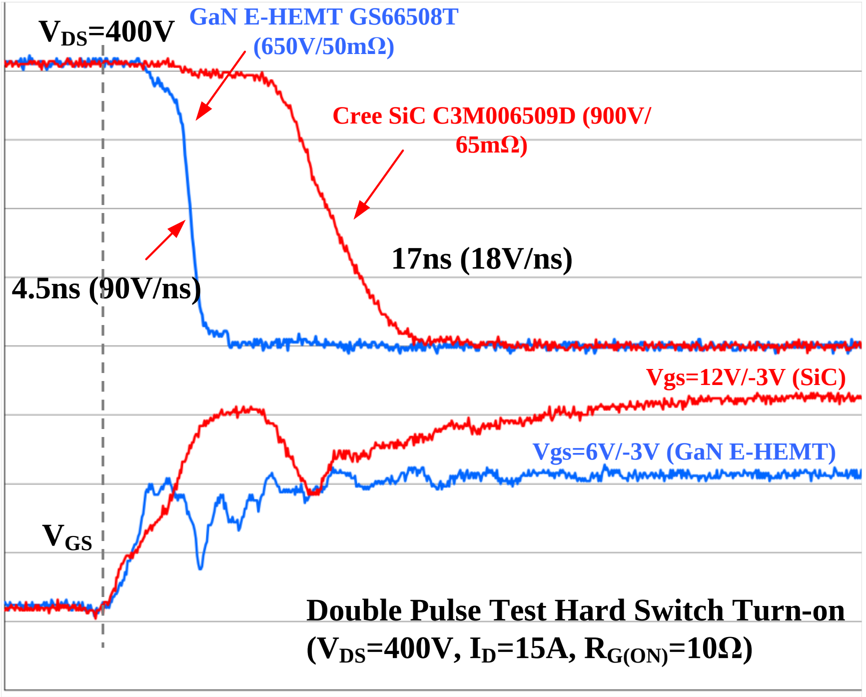
Coss curve → Qoss curve → Co(tr) value

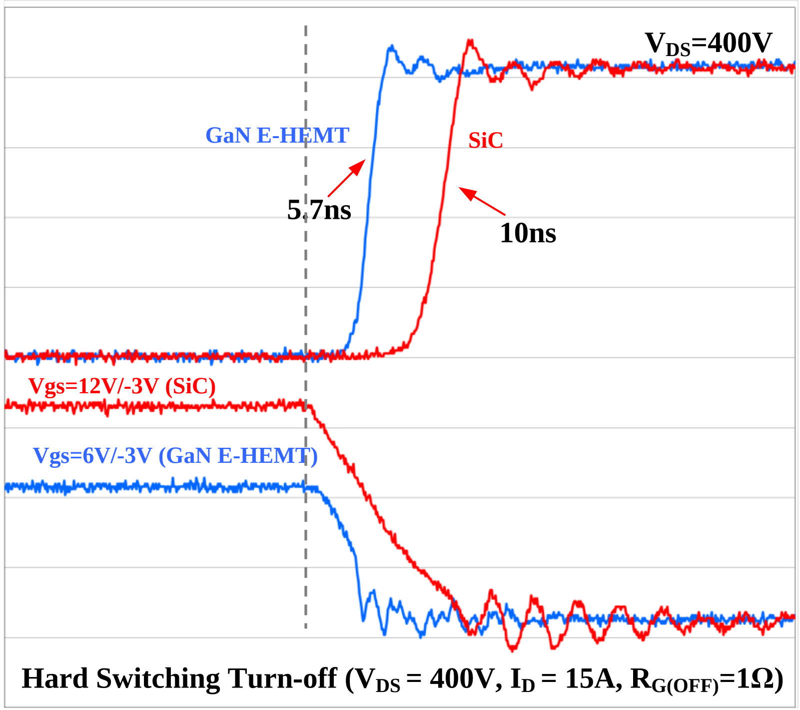




- Si SJMOS has **~10x** higher Co(tr) than GaN; SiC MOS has **~50%** higher Co(tr) than GaN.
- Smaller output capacitance results **in lower switching loss** and **easier zero voltage switching realization (ZVS)**

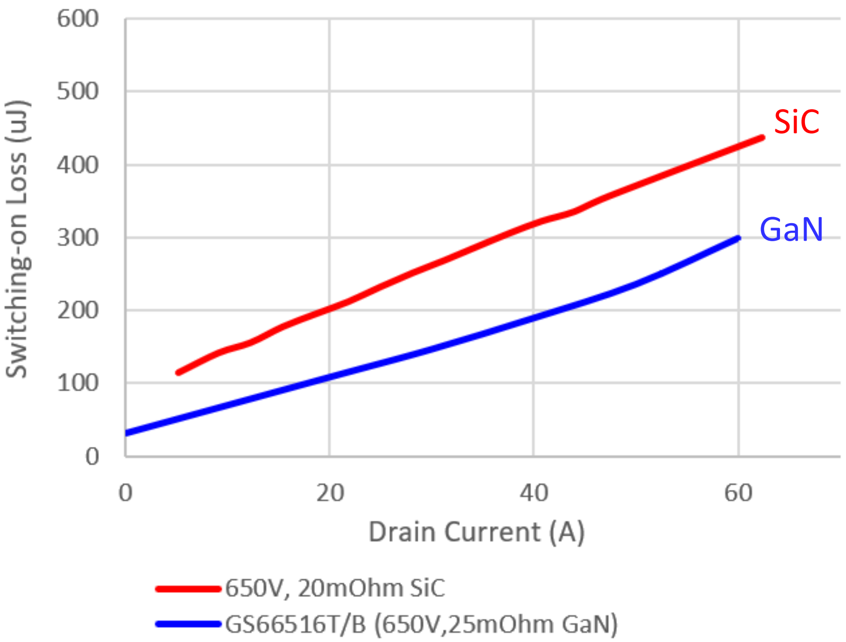
Faster Switching Transition

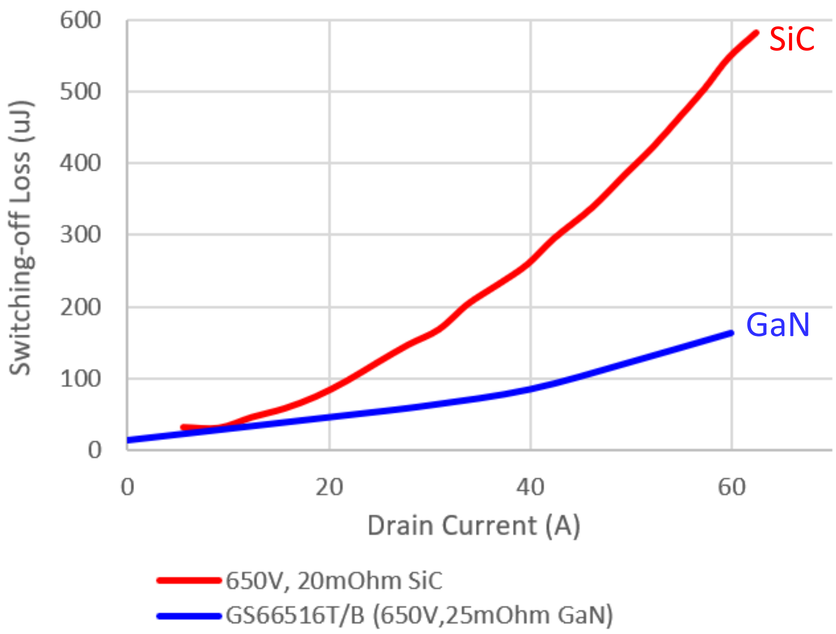




- GaN has **4x faster turn-on** and **2x faster turn-off** than state of art SiC MOSFET with similar $R_{DS(ON)}$
- Faster switching transition results in **lower switching loss**
- Layout is important for maximize the performance of GaN HEMTs. For more info: GN009 https://gansystems.com/

Switching Energy





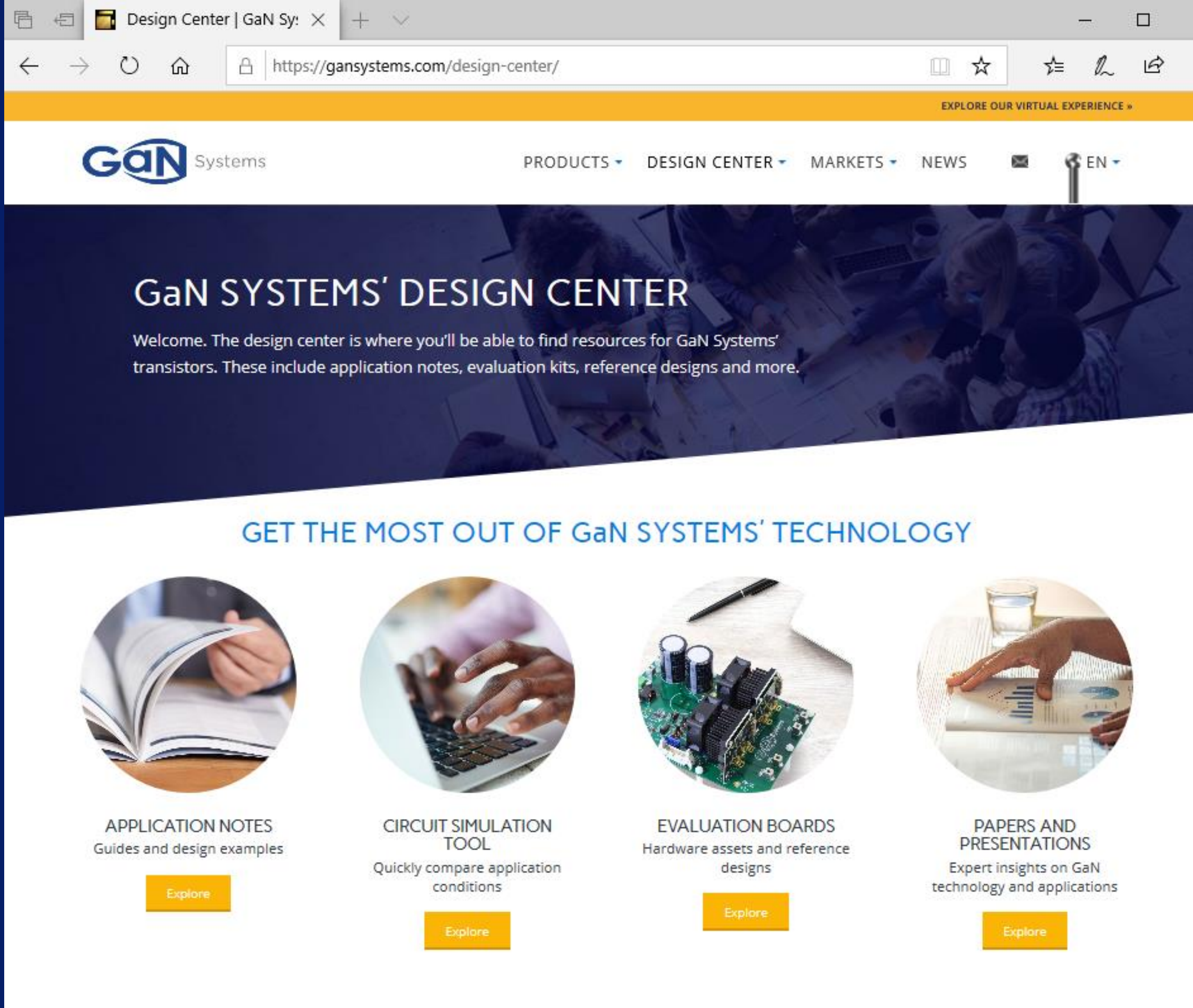
- The switching loss of a GaN HEMT is **significantly lower** than 650V SiC MOSFET with similar $R_{DS(ON)}$

Content

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

GaN Systems Design Center

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



GaN Systems

APP NOTES

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

GaN Systems

PRODUCTS ▾ DESIGN CENTER ▾ MARKETS ▾ COMPANY ▾ EN ▾

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.

App Notes – Chinese

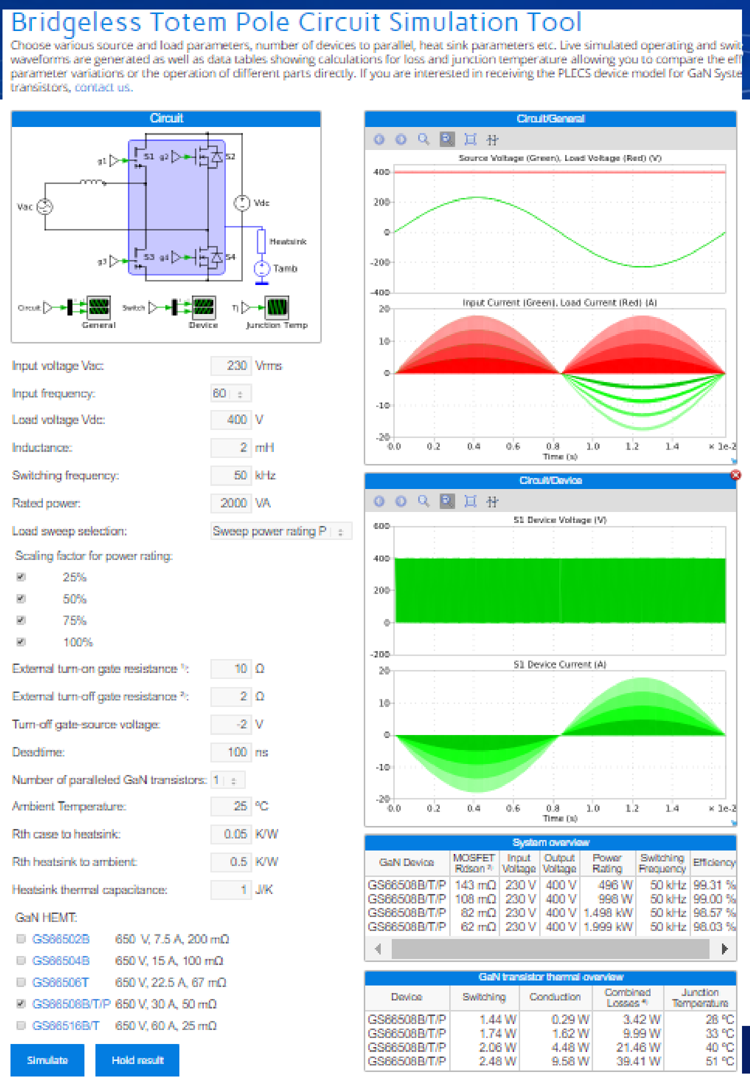
Document #	App Notes
GN001	An Introduction to GaN E-HEMTs
GN002	Thermal Design for Packaged GaN*PX*® Devices
GN003	Measurement Techniques for High-Speed GaN E-HEMTs
GN004	Design considerations of paralleled GaN HEMT
GN006	SPICE model for GaN HEMT usage guidelines and example
GN007	Modeling Thermal Behavior 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
GN012	Gate Driver Design with GaN E-HEMTs

Document #	App Notes – Japanese 日本語
GN001	GaN E-HEMTの概要
GN002	GaNPX® パッケージデバイスの熱設計
GN003	高速GaN E-HEMTの測定技術
GN004	GaN HEMTの並列動作の考慮事項
GN007	RCサーマルSPICEモデルを用いたGaNPXパッケージの熱モデル
GN008	LTSpiceを用いたGaNのスイッチングロスのシミュレーション
GN009	GaN E-HEMTを実装するPCBのレイアウト設計手順
GN010	GaN Systems' E-HEMTのためのEZDrive ソリューション
GN011	GaNPX®パッケージデバイスのはんだ付けに関する推奨事項
GN012	ゲートドライバ回路設計

GaN Systems

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/



GaN Systems Hardware Tools


65W PD QR & ACF Chargers


100W PFC + QR Type-C USB PD 2C port Charger


250W AC/DC PFC & LLC Charger


400W Class D Audio Amp & SMPS Eval Kit


12V High-Efficiency Class D Audio Reference Designs


650V test kit


EZDrive™ Eval Kit


650V 300W~500W Low Power IMS2 GaN Half-Bridge & driver board


50W Wireless Power Amplifier


100W Wireless Power Amplifier


300W Wireless Power Amplifier


100V Buck/Boost Evaluation Board with Driver GaN Power Stage


650 V Universal Motherboard


650V 150A HB IPM

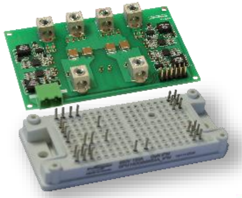

3KW High Efficiency LLC

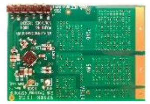

3kW bridgeless totem pole PFC


High Power Dual Half Bridge Full Bridge, driver board

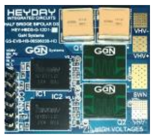

Non-isolated Half Bridge Driver evaluation board

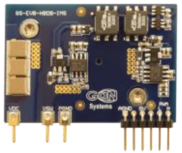

650 V GaN E-HEMT Daughter Board


650V 150A FB Module With driver board


100V High-Speed GaN Half-Bridge


High Power half bridge driver board


650 V Half Bridge Bipolar Gate Drive Evaluation Board


650 V Universal HB Isolated Driver Motherboard for IMS2 & IMS3


3kW & 6kW IMS3 half bridge power boards


650 V 30A & 60A GaN Half-Bridge and Driver with Over Current Protection

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

DESIGN CENTER

- Overview
- Application Notes
- Online Simulation Tools
- Featured Developments
- Papers, Webinars, Articles and Presentations
- Partners

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

GaN Systems

https://gansystems.com/

Application Notes

Document #	App Notes
GN001	An Introduction to GaN E-HEMTs
GN002	Thermal Design for Packaged GaN*PX*® Devices
GN003	Measurement Techniques for High-Speed GaN E-HEMTs
GN004	Design considerations of paralleled GaN HEMT
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
GN012	Gate Driver Design with GaN E-HEMTs

Document #	App Notes – Japanese 日本語
GN001	GaN E-HEMTの概要
GN002	GaNPX® パッケージデバイスの熱設計
GN003	高速GaN E-HEMTの測定技術
GN004	GaN HEMTの並列動作の考慮事項
GN007	RCサーマルSPICEモデルを用いたGaNPXパッケージの熱モデル
GN008	LTSpiceを用いたGaNのスイッチングロスのシミュレーション
GN009	GaN E-HEMTを実装するPCBのレイアウト設計手順
GN010	GaN Systems' E-HEMTのためのEZDrive ソリューション
GN011	GaNPX®パッケージデバイスのはんだ付けに関する推奨事項
GN012	ゲートドライバ回路設計

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

Seven Steps to Highly Effective GaN Designs

Webinar: Benefits and Advantages of a GaN-based 3kW AC/D...

Webinar: Using Simulation to Maximize GaN Powered Design

GaN Transistors: Moving To Mainstream

Webinar: Comprehensive System Design with GaN

Boosting efficiency in fast-charge adapters

2021 Technology Predictions in Power Electronics

Webinar: Gate Driver Circuit Design for GaN Power Applic...

GaN Technology and The Renewable Energy World

A Modular Designed Three-phase High-efficiency High-powe...

WEBINAR: Class D Audio with GaN

GaN in Class-D Audio: Advantages with GaN Systems – A ...

etc ...

Tomorrow's power today™

Product and application support at

gansystems.com