



GN001 Application Note

An Introduction to GaN Enhancement-mode HEMTs

March 08, 2022
GaN Systems Inc.

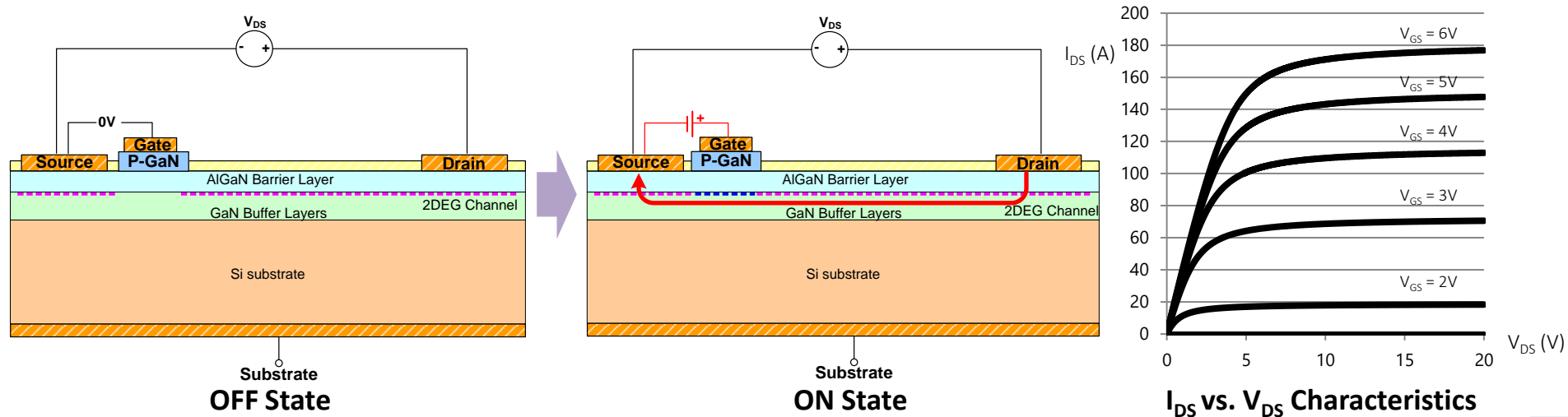


- ❑ Basics and Mechanism
 - ❑ GaN Material and 2D Electron Gas (2DEG)
 - ❑ Enhancement-mode GaN HEMT
 - ❑ GaN Systems Simple-driven GaN technology
- ❑ Characteristics
- ❑ Design Resources

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

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

- A lateral 2-dimensional electron gas (2DEG) channel formed on AlGaIn/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

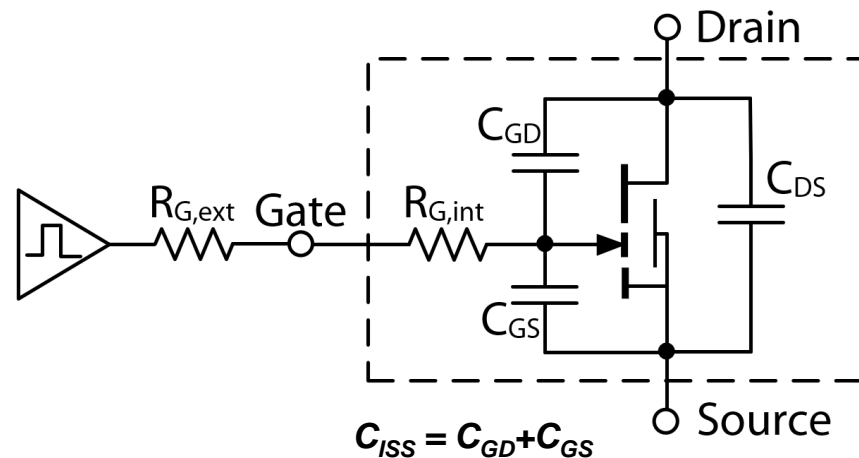


Common with Si MOSFET

- 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

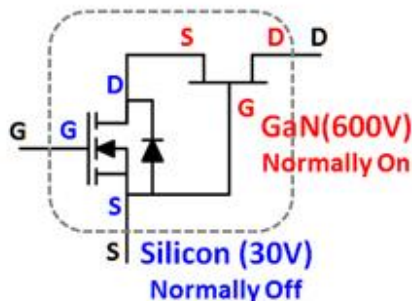
❖ GaN HEMTs are **simple to drive**, for more info please refer to application note **GN012**

GaN Systems E-mode HEMT



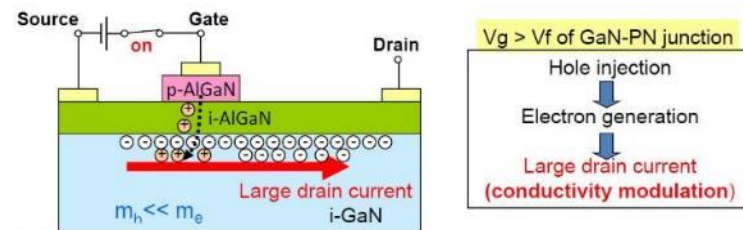
- **True Enhancement mode**
- **Simple 3-terminal power switch**
- **Best FOM and performance**
- **Island technology - Easy to scale**
- **GaNPx embedding package**
- **No reverse recovery loss**
- **Easy to parallel**

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

- ❑ Basics and Mechanism

- ❑ Characteristics

 - ❑ Figure of merit

 - ❑ Reverse conduction Characteristics

 - ❑ Zero reverse recovery

 - ❑ Output capacitance

 - ❑ Switching transition

 - ❑ Switching energy

- ❑ Design Resources

Figure of Merit

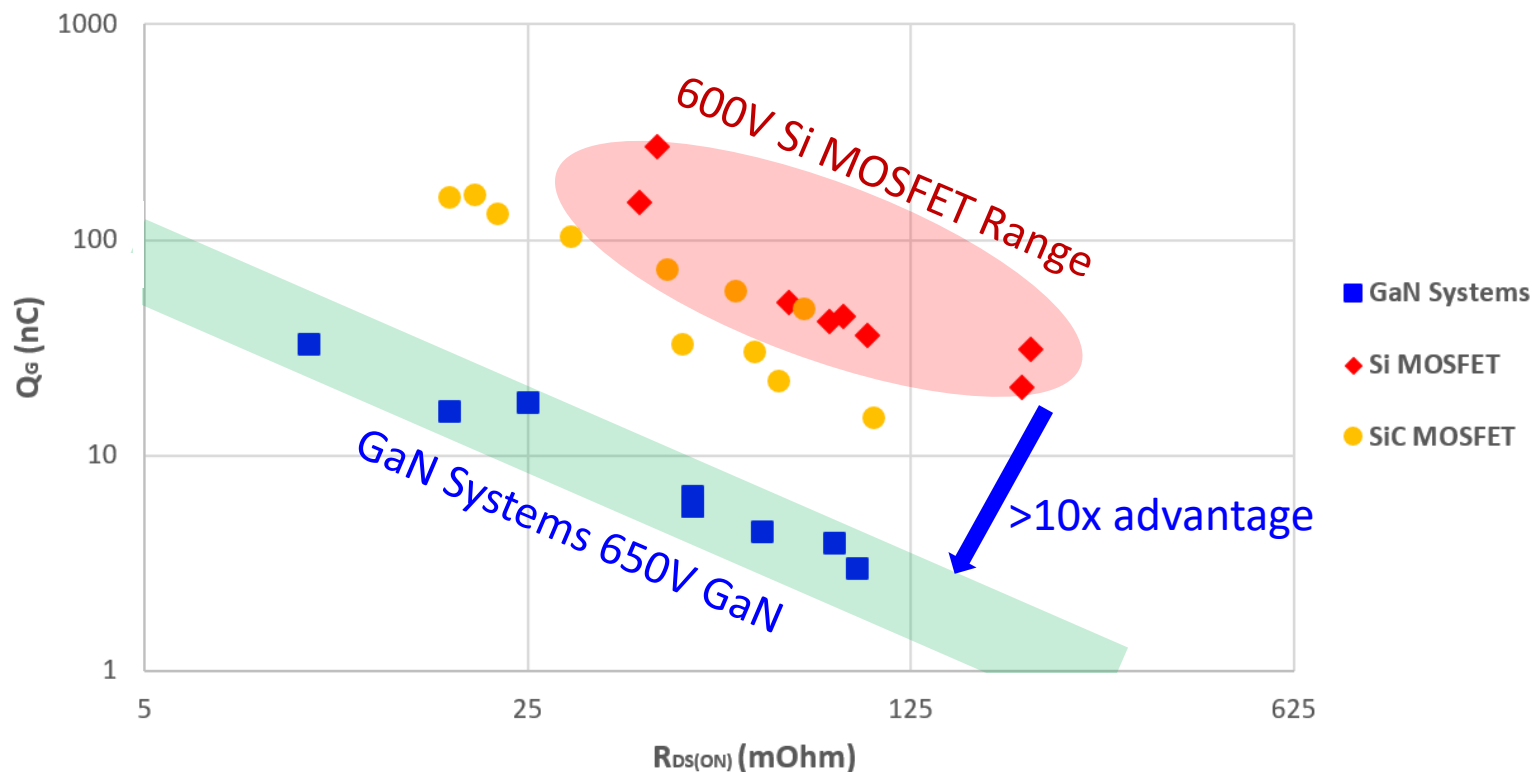
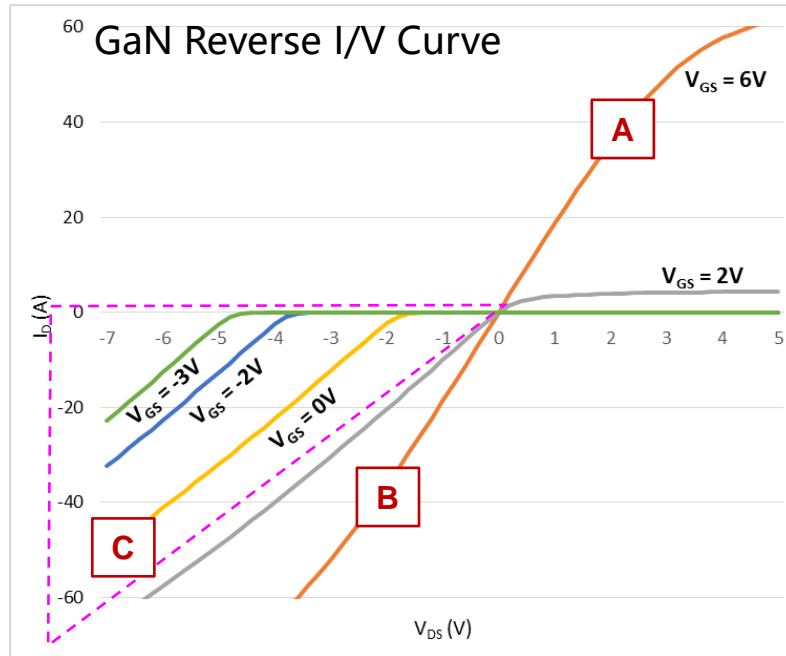


Figure of Merit of 650V/600V Power Switches (Feb.2020 update)

- ❖ 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**

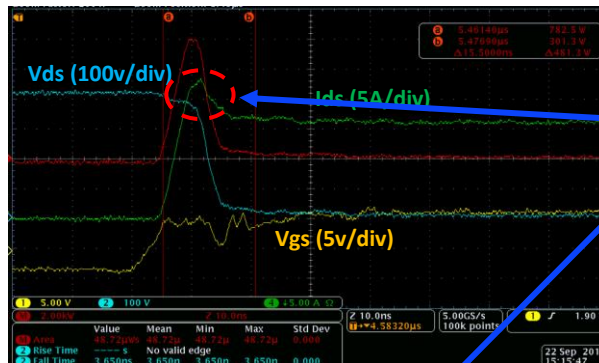
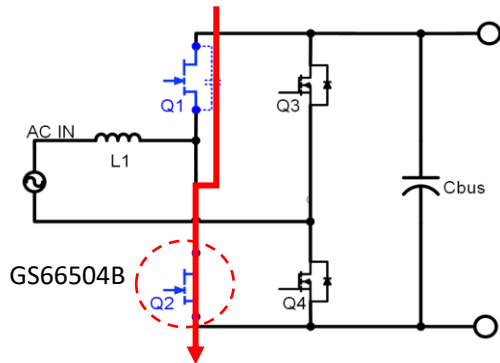


- When gate is OFF (during dead time), 2DEG exhibits like a diode with $V_F = V_{TH(GD)} + V_{GS(OFF)} + I_{SD} * R_{SD(ON)}$

	Gate	GaN E-HEMT	MOSFET	Si IGBT
A	ON			
B	ON			
C	OFF			

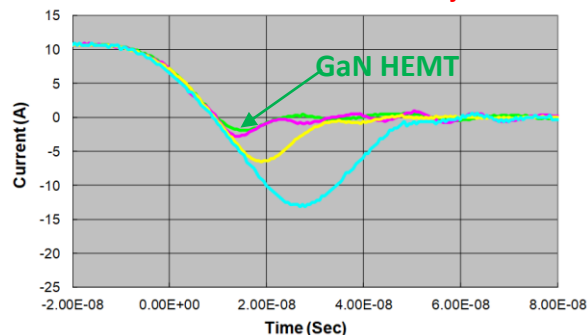
- ❖ There is **no body diode** (as with Si and SiC MOSFETs)
- ❖ But, GaN 2DEG can conduct in 3rd quadrant – **No need for anti-parallel diode** (as in Si IGBT)

Zero Reverse Recovery

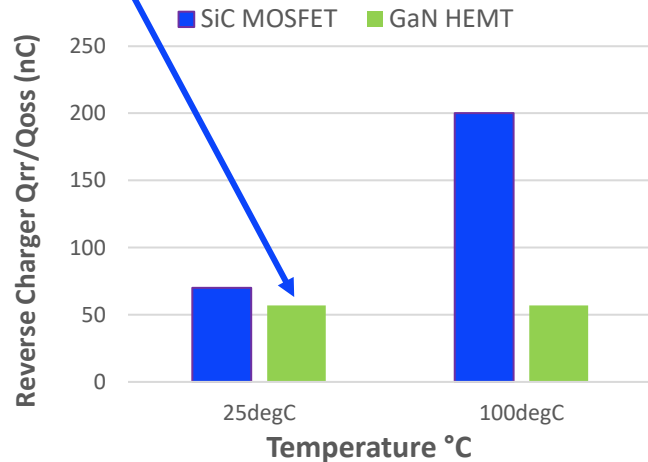
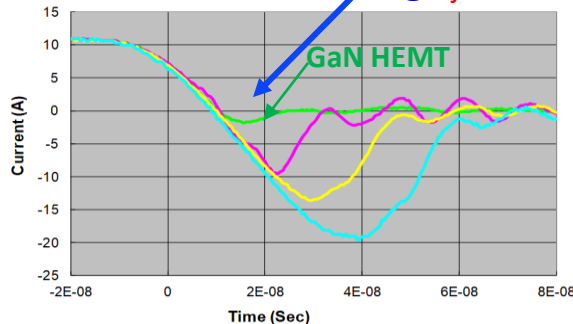


- Qoss only,
- There is zero reverse recovery in GaN HEMT

Reverse Characteristics @ $T_j=25^\circ\text{C}$



Reverse Characteristics @ $T_j=100^\circ\text{C}$

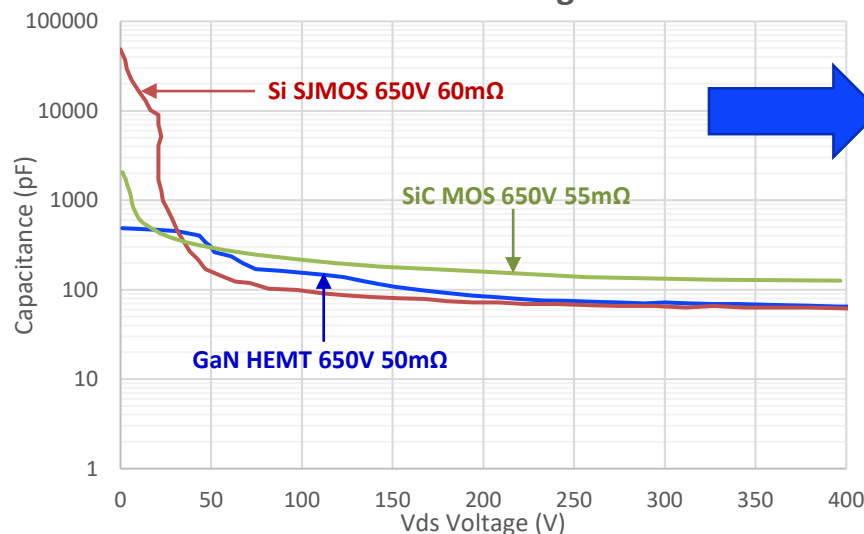


❖ Zero reverse recovery results in **lower switching loss** and **less EMI noise**

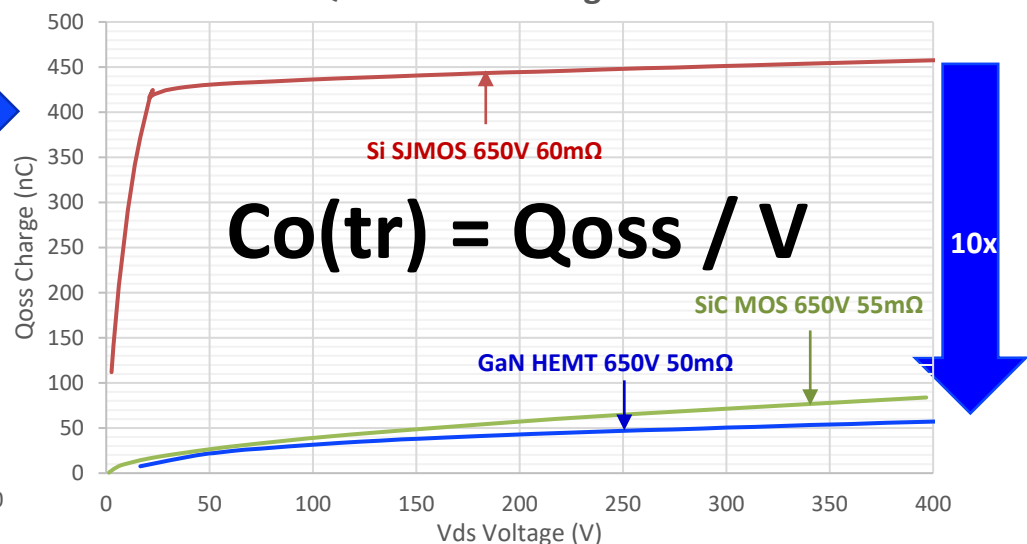
$$\begin{cases} Q_{oss} = C_{o(tr)} \cdot V \\ Q_{oss} = \int_0^{V_{ds}} C_{oss}(v) dv \end{cases}$$

Coss curve \rightarrow Qoss curve \rightarrow Co(tr) value

Coss Vs Vds Voltage

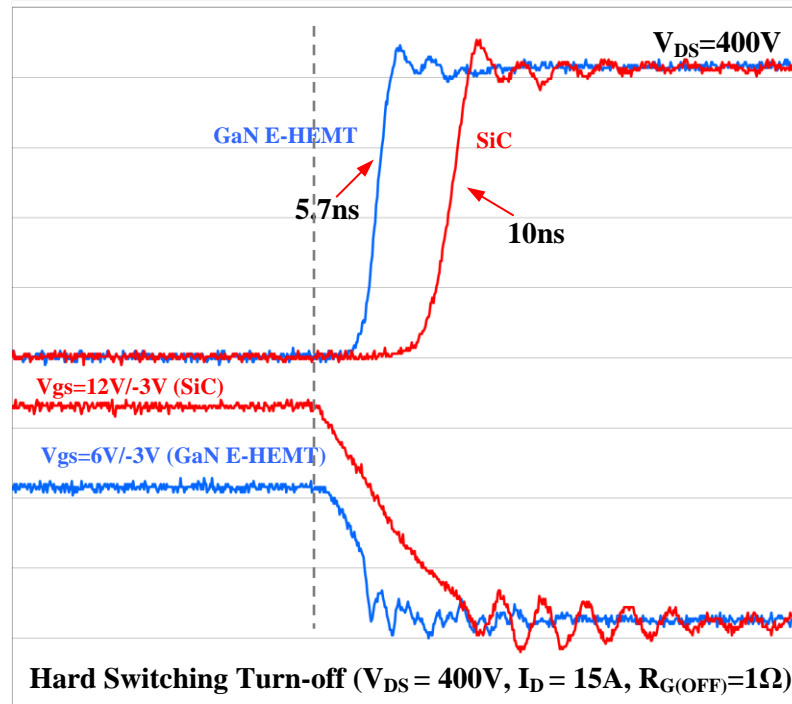
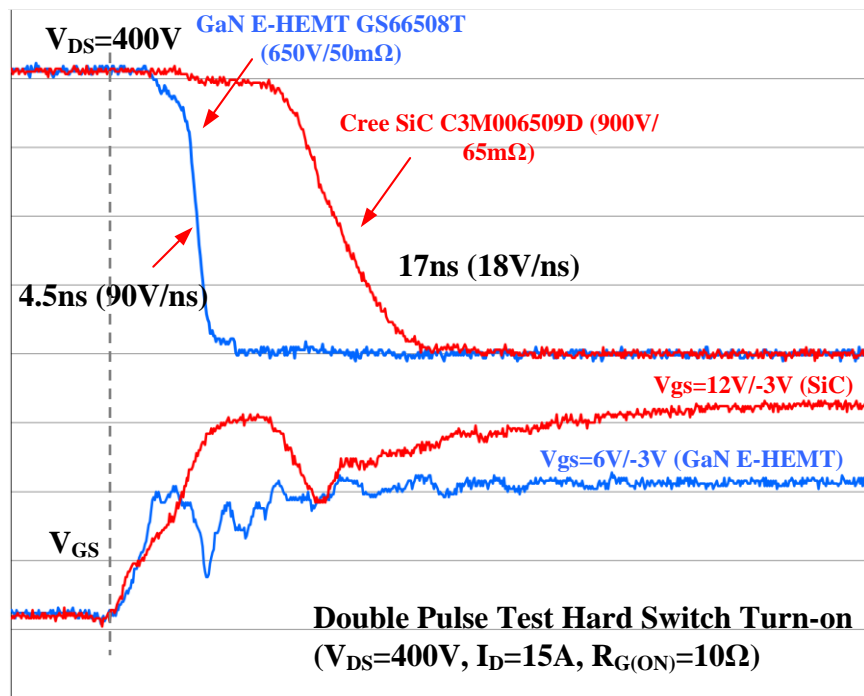


Qoss Vs Vds Voltage

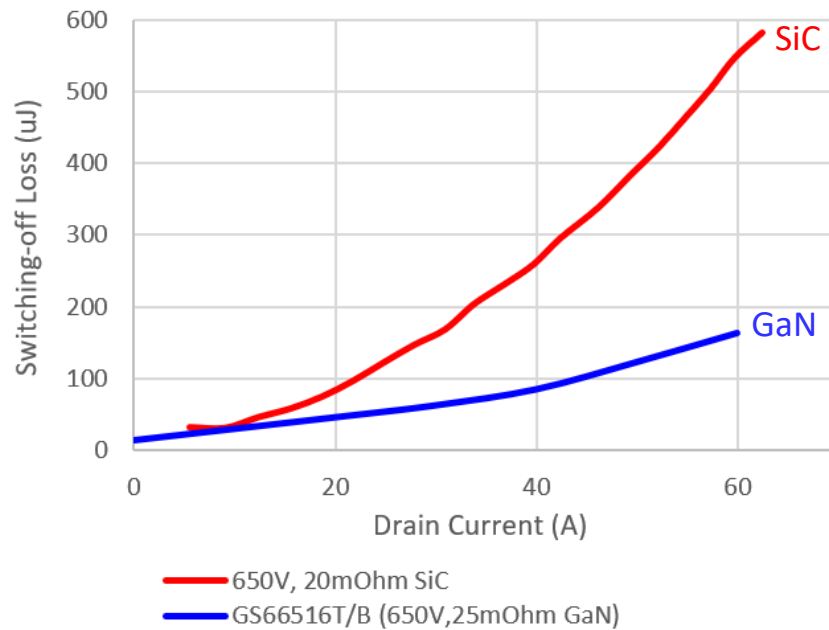
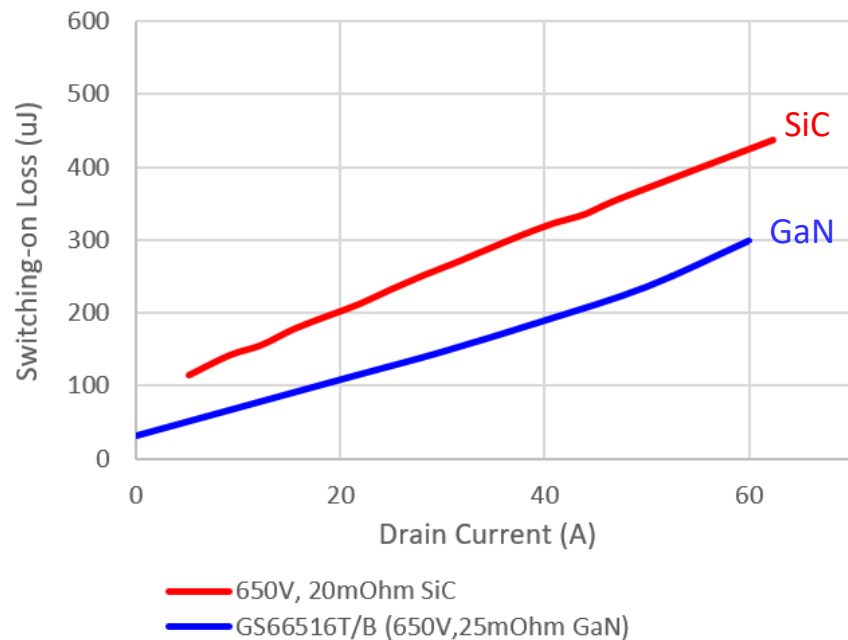


$$C_{o(tr)} = Q_{oss} / V$$

- ❖ 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)**



- ❖ 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/>



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

- ☐ Basics and Mechanism
- ☐ Characteristics
- ☒ Design Resources

GaN Systems Design Center

- **Many resources available**

- Easy to find
- Easy to use



The screenshot shows a web browser window with the address bar displaying "https://gansystems.com/design-center/". The website has a white header with the "GaN Systems" logo on the left and navigation links for "PRODUCTS", "DESIGN CENTER", "MARKETS", and "NEWS" on the right. A blue banner below the header contains the text "GaN SYSTEMS' DESIGN CENTER" and a welcome message. Below the banner, a section titled "GET THE MOST OUT OF GaN SYSTEMS' TECHNOLOGY" features four circular images, each representing a resource: "APPLICATION NOTES" (a hand flipping a book), "CIRCUIT SIMULATION TOOL" (hands typing on a laptop), "EVALUATION BOARDS" (a green circuit board), and "PAPERS AND PRESENTATIONS" (a hand pointing at a document with a bar chart). Each resource has a brief description and an "Explore" button.

Design Center | GaN Sy: X

https://gansystems.com/design-center/

EXPLORE OUR VIRTUAL EXPERIENCE »

GaN Systems


PRODUCTS ▾ DESIGN CENTER ▾ MARKETS ▾ NEWS

EN ▾

GaN SYSTEMS' DESIGN CENTER


Welcome. The design center is where you'll be able to find resources for GaN Systems' transistors. These include application notes, evaluation kits, reference designs and more.

GET THE MOST OUT OF GaN SYSTEMS' TECHNOLOGY




APPLICATION NOTES
Guides and design examples

Explore




CIRCUIT SIMULATION TOOL
Quickly compare application conditions

Explore



EVALUATION BOARDS
Hardware assets and reference designs

Explore



PAPERS AND PRESENTATIONS
Expert insights on GaN technology and applications

Explore

APP NOTES

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

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 GaN ^{PX} ® Packaged Devices
GN012	Gate Driver Design with GaN E-HEMTs

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GN001	GaN E-HEMTの概要
GN002	GaN ^{PX} ® 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GaN ^{PX} 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	GaN ^{PX} ®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

Online Simulation Tool



PRODUCTS ▾ DESIGN CENTER ▾ MARKETS ▾ NEWS EN ▾

Welcome to the GaN Systems Circuit Simulation Tools

The Circuit Simulation Tool allows you to compare application conditions by implementing specific operating values. Choose various source and load parameters, number of devices to parallel, heat sink parameters etc. Live simulated operating and switching waveforms are generated as well as data tables showing calculations for loss and junction temperature allowing you to compare the effect of parameter variations or the operation of different parts directly.

You may also download the PLECS device model files for GaN Systems' transistors.

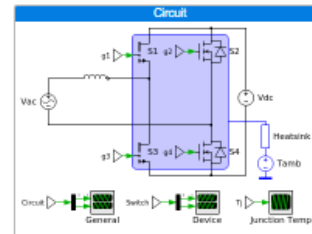
- › BRIDGELESS TOTEM-POLE PFC
- › SINGLE-PHASE, 2-LEVEL INVERTER
- › SINGLE-PHASE, 3-LEVEL HALF-BRIDGE INVERTER
- › SINGLE-PHASE T-TYPE 3-LEVEL INVERTER
- › ISOLATED HALF-BRIDGE LLC CONVERTER
- › ISOLATED PHASE-SHIFT FULL BRIDGE CONVERTER
- › THREE-PHASE TRACTION INVERTER
- › DUAL ACTIVE BRIDGE

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



Bridgeless Totem Pole Circuit Simulation Tool

Choose various source and load parameters, number of devices to parallel, heat sink parameters etc. Live simulated operating and switching waveforms are generated as well as data tables showing calculations for loss and junction temperature allowing you to compare the effect of parameter variations or the operation of different parts directly. If you are interested in receiving the PLECS device model for GaN Systems transistors, contact us.



Input voltage Vdc: 230 Vrms

Input frequency: 60 Hz

Load voltage Vdc: 400 V

Inductance: 2 mH

Switching frequency: 50 kHz

Rated power: 2000 VA

Load sweep selection: Sweep power rating P

Scaling factor for power rating:
☒ 25%
☒ 50%
☒ 75%
☒ 100%

External turn-on gate resistance Rg: 10 Ω

External turn-off gate resistance Rg: 2 Ω

Turn-off gate-source voltage: -2 V

Deadtime: 100 ns

Number of paralleled GaN transistors: 1

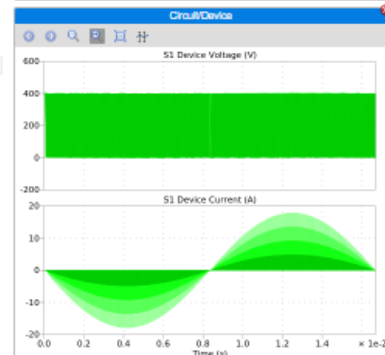
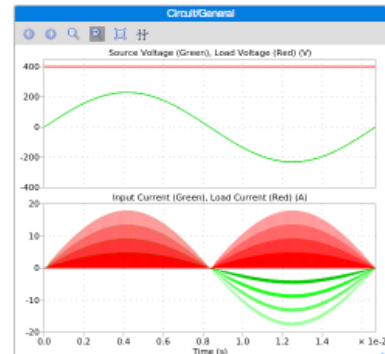
Ambient Temperature: 25 °C

Rth case to heatsink: 0.05 K/W

Rth heatsink to ambient: 0.5 K/W

Heatsink thermal capacitance: 1 J/K

GaN HEMT:
☐ GS66502B 650 V, 7.5 A, 200 mΩ
☐ GS66504B 650 V, 15 A, 100 mΩ
☐ GS66506T 650 V, 22.5 A, 67 mΩ
☒ GS66508B/T/P 650 V, 30 A, 50 mΩ
☐ GS66516B/T 650 V, 60 A, 25 mΩ



System Overview					
GaN Device	MOSFET Rds(on) *	Input Voltage	Output Voltage	Power Rating	Switching Frequency
GS66508B/T/P	143 mΩ	230 V	400 V	496 W	50 kHz
GS66508B/T/P	108 mΩ	230 V	400 V	996 W	50 kHz
GS66508B/T/P	82 mΩ	230 V	400 V	1,496 kW	50 kHz
GS66508B/T/P	62 mΩ	230 V	400 V	1,999 kW	50 kHz

GaN transistor thermal overview				
Device	Switching	Conduction	Combined Losses *	Junction Temperature
GS66508B/T/P	1.44 W	0.29 W	3.42 W	28 °C
GS66508B/T/P	1.74 W	1.62 W	9.99 W	33 °C
GS66508B/T/P	2.06 W	4.48 W	21.46 W	40 °C
GS66508B/T/P	2.48 W	9.58 W	39.41 W	51 °C

Simulate

Hold result

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



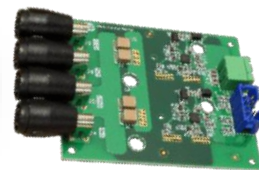
12V High-Efficiency Class D
Audio Reference Designs



650V test kit



EZDrive™ Eval Kit



50W Wireless Power
Amplifier



100W Wireless Power
Amplifier



300W Wireless Power
Amplifier



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



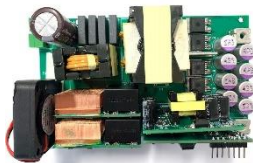
650 V Universal Motherboard



650V 150A HB IPM



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



3KW High Efficiency LLC



3kW bridgeless
totem pole PFC



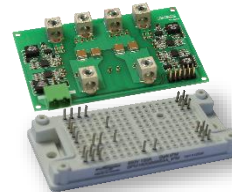
High Power Dual Half Bridge
Full Bridge, driver board



Non-isolated Half Bridge
Driver evaluation board



650 V GaN E-HEMT Daughter
Board



650V 150A FB Module
With driver board



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



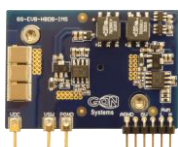
100V High-Speed
GaN Half-Bridge



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



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

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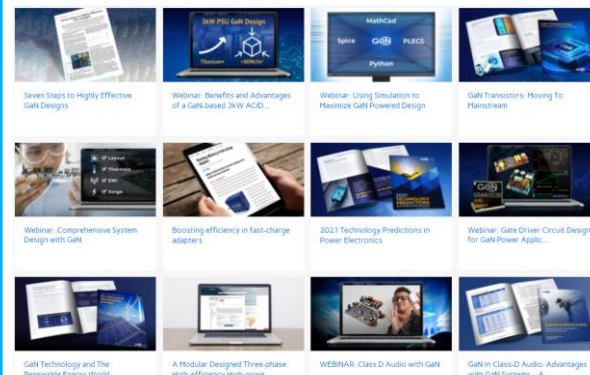
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GN012	ゲートドライバ回路設計

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



etc ...



Product and application support at
gansystems.com