



GN001 Application Note

An Introduction to GaN Enhancement-mode HEMTs

April 16, 2020
GaN Systems Inc.

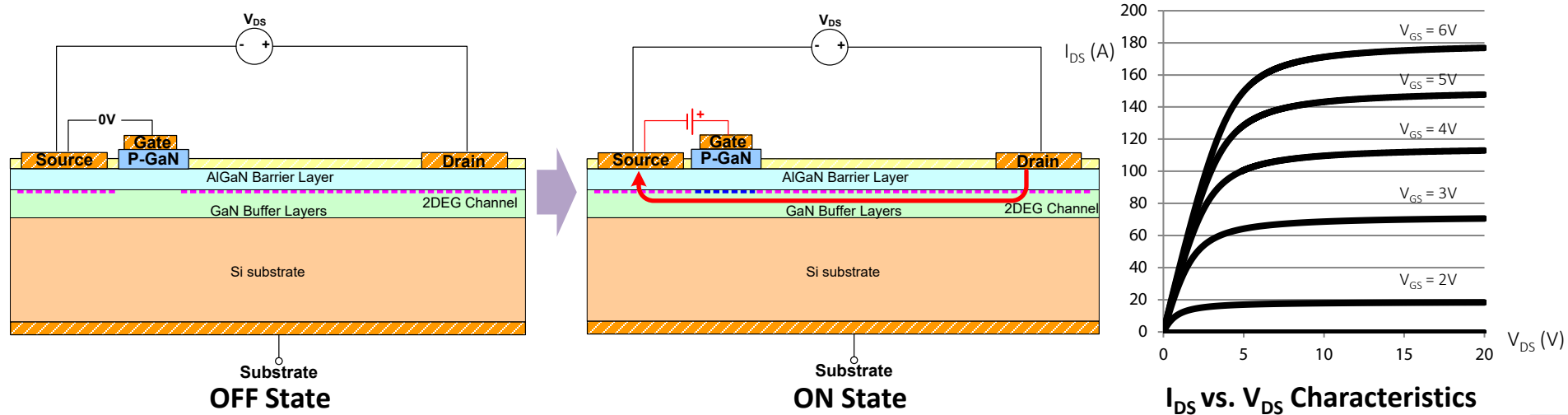


- Basics and Mechanism
 - GaN Material and 2D Electron Gas (2DEG)
 - Enhancement-mode GaN HEMT
 - GaN Systems Simple-driven GaN technology
- Characteristics
- Design Resources

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

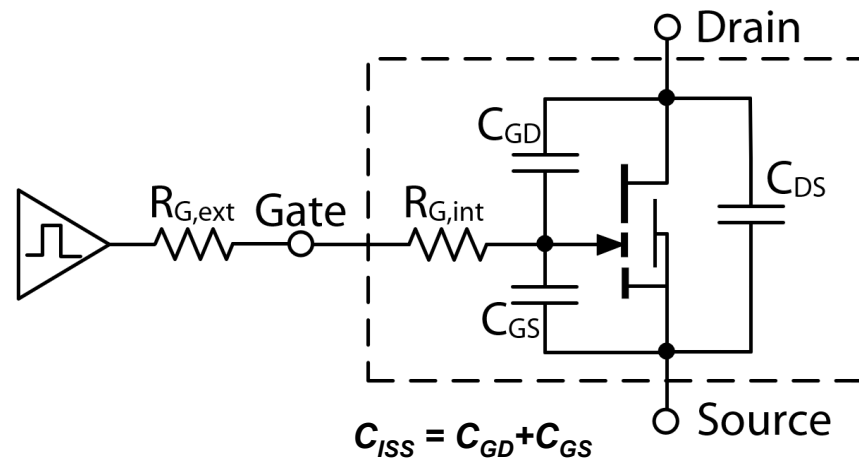
GaN Enhancement mode High Electron Mobility Transistor (E-HEMT)

- 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

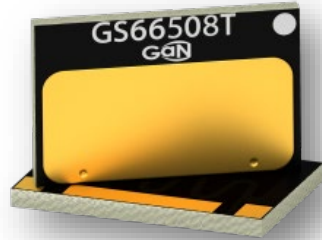
Versus other enhancement-mode GaN

- 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 |

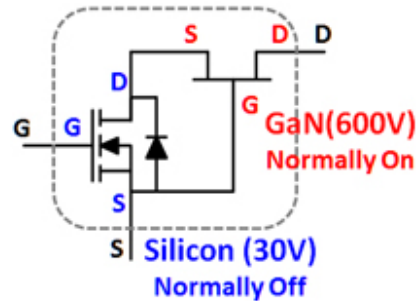
❖ GaN HEMTs are **simple to drive**, for more info please refer to application note **GN012**

GaN Systems E-mode HEMT



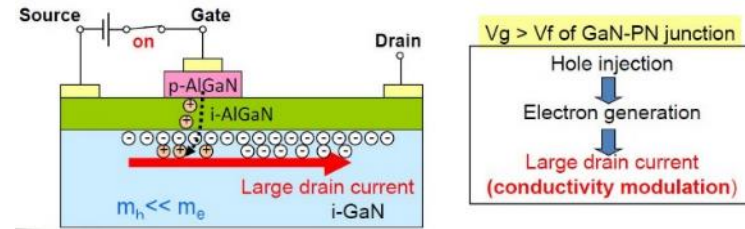
- True Enhancement mode
- Simple 3-terminal power switch
- Best FOM and performance
- Island technology - Easy to scale
- GaNPx embedding package
- No reverse recovery loss
- Easy to parallel

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

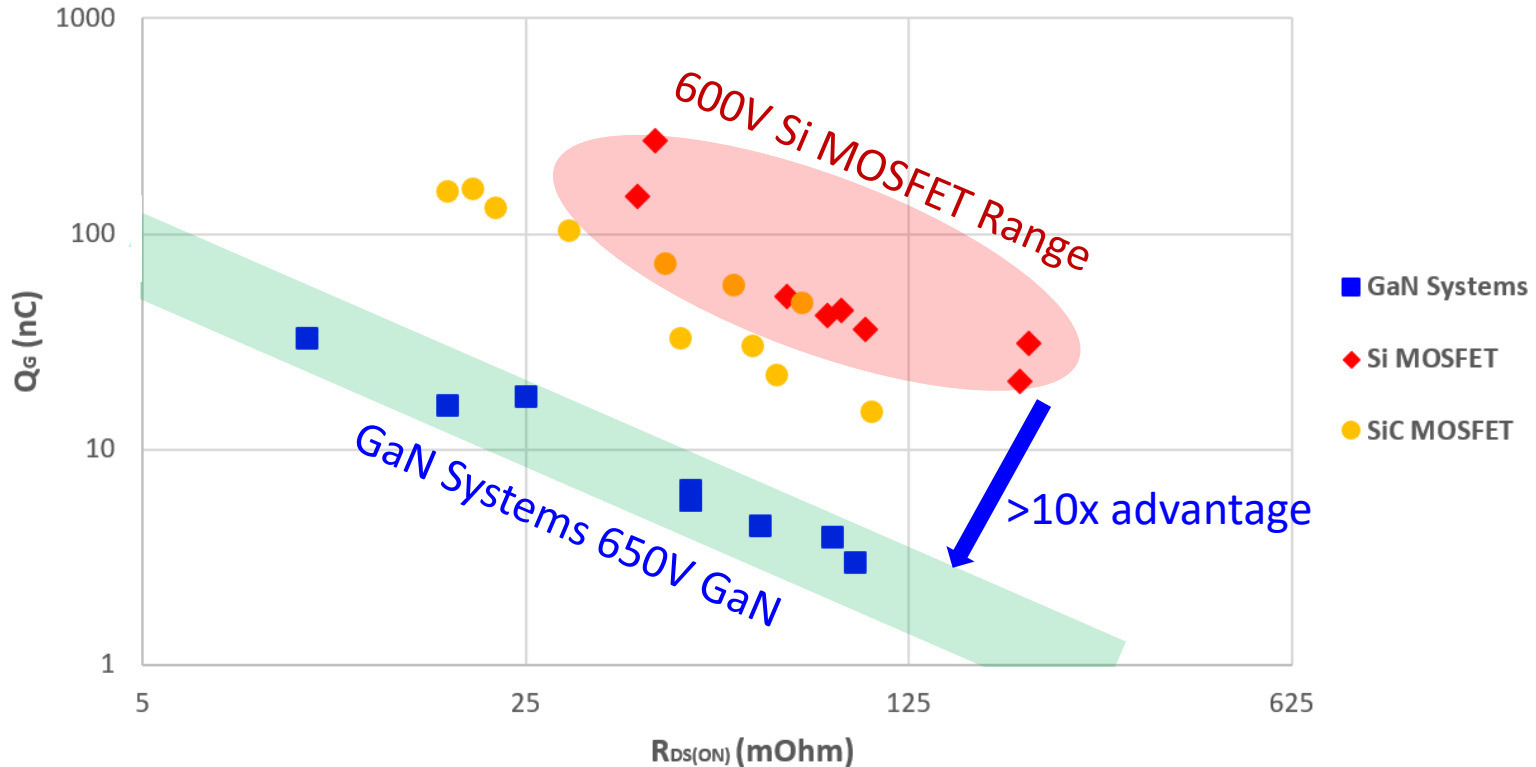
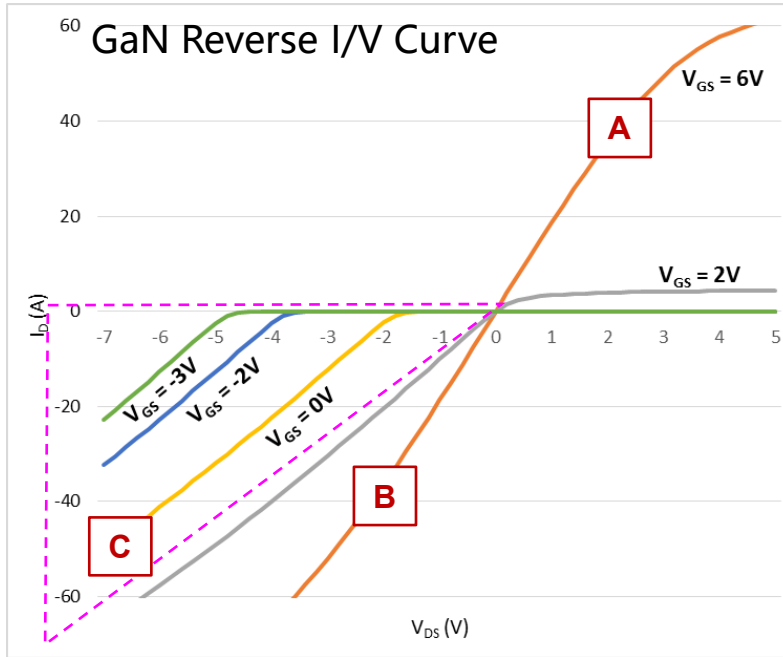


Figure of Merit of 650V/600V Power Switches (Feb.2020 update)

- ❖ 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**

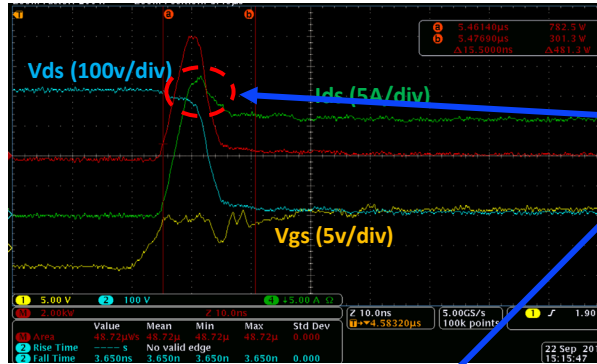
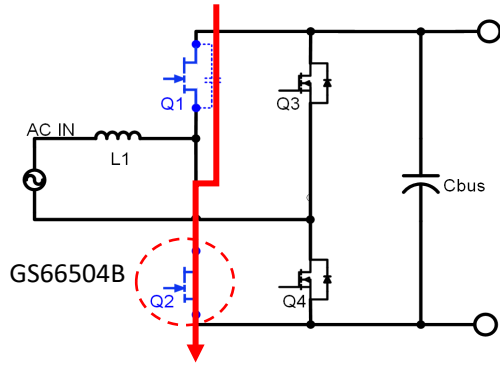


- When gate is OFF (during dead time), 2DEG exhibits like a diode with $V_F = V_{TH(GD)} + V_{GS(OFF)} + I_{SD} * R_{SD(ON)}$

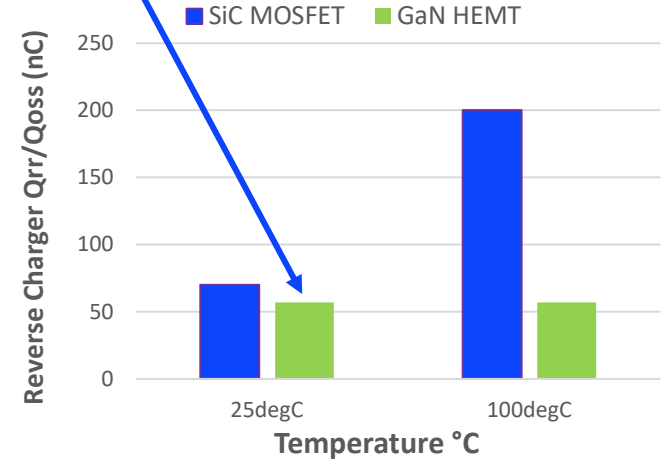
| | Gate | GaN E-HEMT | MOSFET | Si IGBT |
|----------|------|------------|--------|---------|
| A | ON | | | |
| B | ON | | | |
| C | OFF | | | |

- ❖ 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)

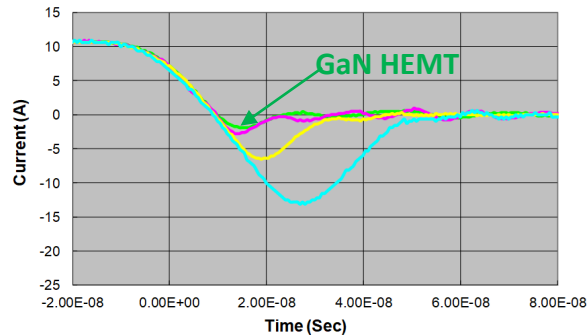
Zero Reverse Recovery



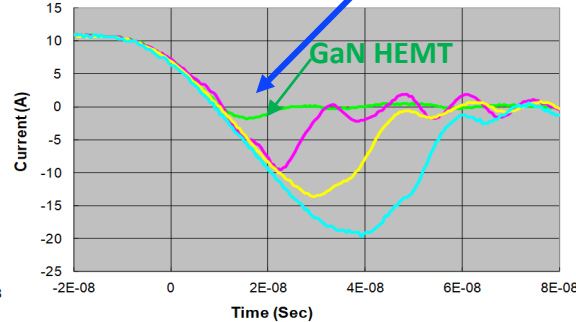
- Qoss only,
- There is zero reverse recovery in GaN HEMT



Reverse Characteristics @ Tj=25°C



Reverse Characteristics @ Tj=100°C



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

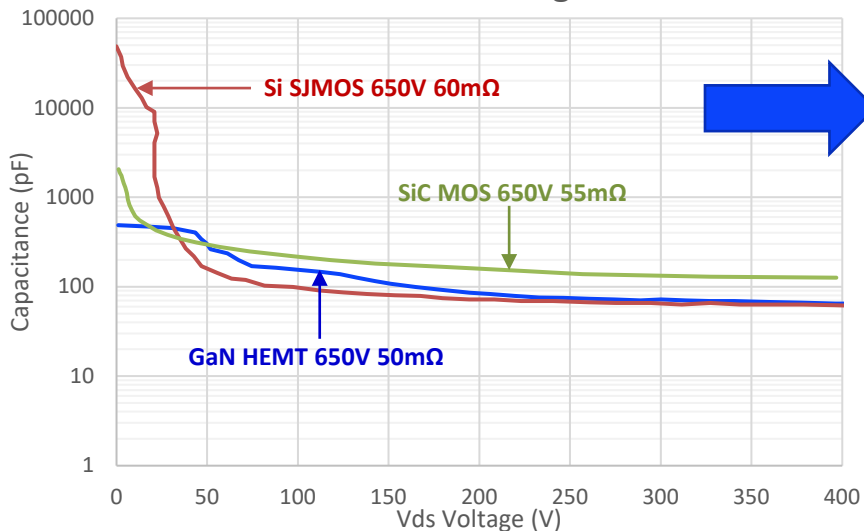
❖ Zero reverse recovery results in **lower switching loss** and **less EMI noise**

Output Capacitance

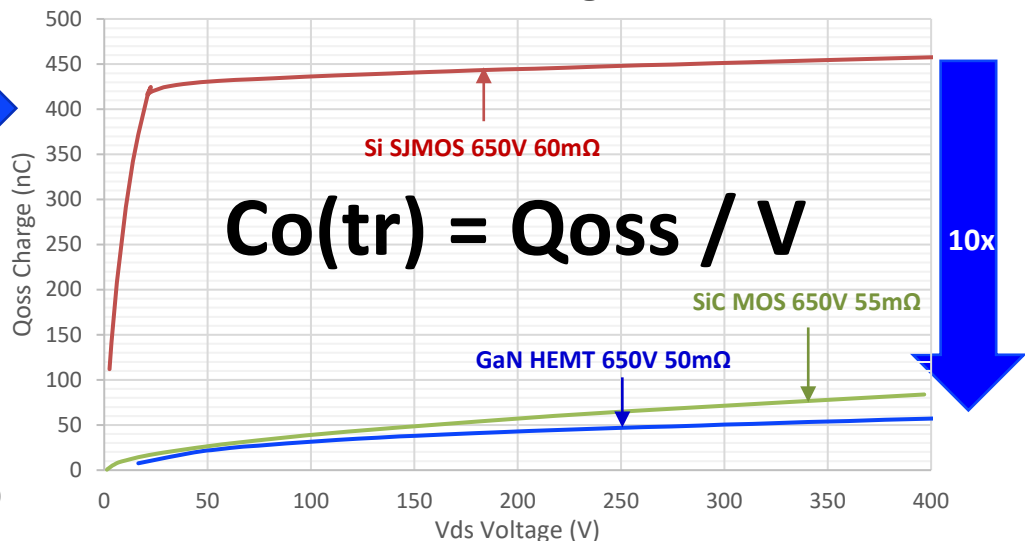
$$\begin{cases} Q_{oss} = C_{o(tr)} \cdot V \\ Q_{oss} = \int_0^{V_{ds}} C_{oss}(v) dv \end{cases}$$

Coss curve → Qoss curve → Co(tr) value

Coss Vs Vds Voltage



Qoss Vs Vds Voltage

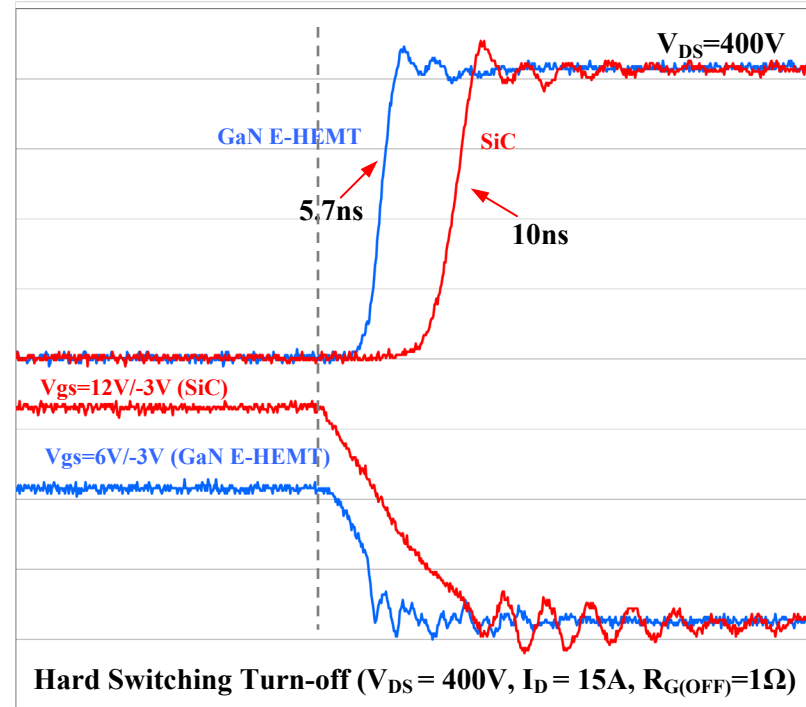
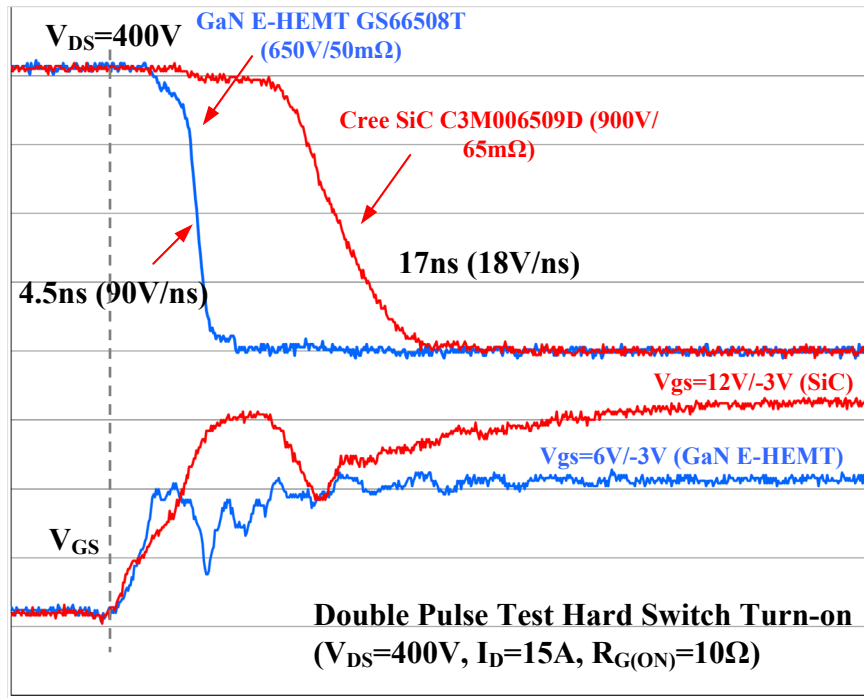


$$C_{o(tr)} = Q_{oss} / V$$

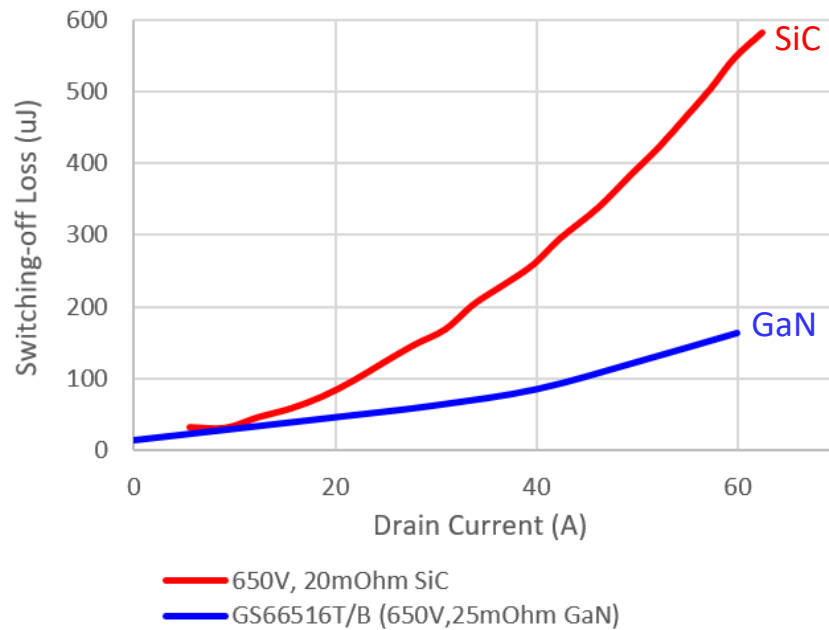
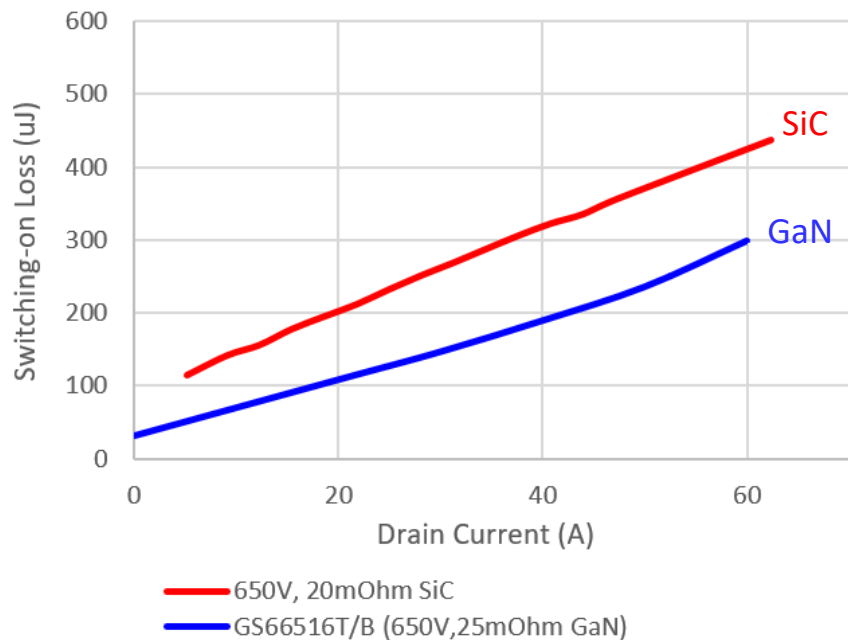
10x

- ❖ 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/>



❖ 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 the GaN Systems Design Center website. At the top, there is a navigation bar with the GaN Systems logo on the left and menu items for PRODUCTS, DESIGN CENTER, MARKETS, and NEWS on the right. Below the navigation bar is a large hero section with a dark blue background and a photograph of people working in a lab. The text in the hero section reads "GaN SYSTEMS' DESIGN CENTER" and "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." Below the hero section is a section titled "GET THE MOST OUT OF GaN SYSTEMS' TECHNOLOGY" which contains four circular icons representing different resources: Application Notes (an open book), Circuit Simulation Tool (hands typing on a laptop), Evaluation Boards (a green PCB with components), and Papers and Presentations (hands pointing at a document with a bar chart). Each icon is accompanied by a title, a brief description, and an "Explore" button.

Design Center | GaN Sy: x + v

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.

| 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 [®] 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 [®] 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 [®] Packaged Devices |

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.

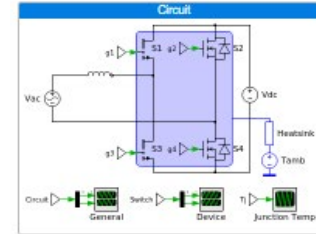
- > BRIDGELESS TOTEM-POLE PFC
- > SINGLE-PHASE, 2-LEVEL INVERTER
- > SINGLE-PHASE, 3-LEVEL HALF-BRIDGE INVERTER
- > SINGLE-PHASE T-TYPE 3-LEVEL INVERTER
- > ISOLATED HALF-BRIDGE LLC CONVERTER
- > ISOLATED PHASE-SHIFT FULL BRIDGE CONVERTER
- > THREE-PHASE TRACTION INVERTER
- > DUAL ACTIVE BRIDGE



- 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: Vrms

Input frequency: Hz

Load voltage Vdc: V

Inductance: mH

Switching frequency: kHz

Rated power: VA

Load sweep selection: :

Scaling factor for power rating:

- 25%
- 50%
- 75%
- 100%

External turn-on gate resistance R_g: Ω

External turn-off gate resistance R_g: Ω

Turn-off gate-source voltage: V

Deadtime: ns

Number of paralleled GaN transistors: :

Ambient Temperature: °C

R_{th} case to heatsink: K/W

R_{th} heatsink to ambient: K/W

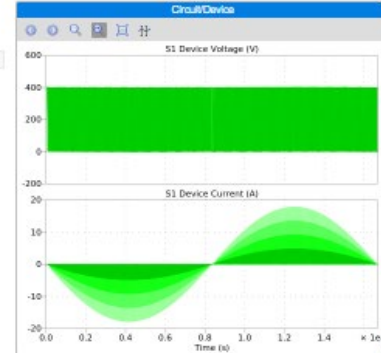
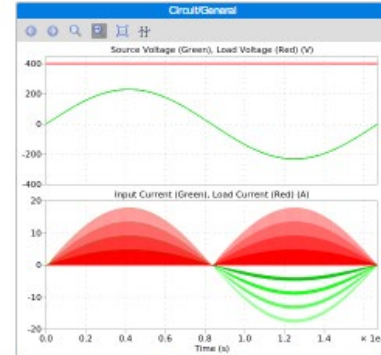
Heatsink thermal capacitance: J/K

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
- GS66506B/T/P 650 V, 30 A, 50 mΩ
- GS66516B/T 650 V, 60 A, 25 mΩ

Simulate

Hold result



| System overview | | | | | | |
|-----------------|--------------------------|---------------|----------------|--------------|---------------------|------------|
| GaN Device | MOSFET R _{on} * | Input Voltage | Output Voltage | Power Rating | Switching Frequency | Efficiency |
| GS66508B/T/P | 143 mΩ | 230 V | 400 V | 496 W | 50 kHz | 99.31 % |
| GS66508B/T/P | 108 mΩ | 230 V | 400 V | 998 W | 50 kHz | 99.00 % |
| GS66508B/T/P | 82 mΩ | 230 V | 400 V | 1,498 kW | 50 kHz | 98.57 % |
| GS66508B/T/P | 62 mΩ | 230 V | 400 V | 1,999 kW | 50 kHz | 98.03 % |

| GaN Transistor thermal overview | | | | |
|---------------------------------|-----------|------------|-------------------|----------------------|
| Device | Switching | Conduction | Combined Losses * | Junction Temperature |
| GS66508B/T/P | 1.44 W | 0.29 W | 3.42 W | 26 °C |
| GS66508B/T/P | 1.74 W | 1.62 W | 9.59 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 |

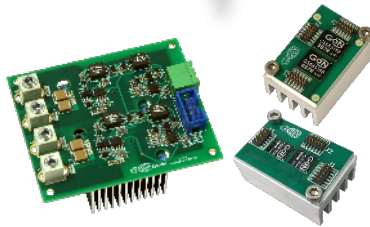
GS665MB-EVB Motherboard
+ GS665xxDB-EVB Daughterboard
Half bridge power stage



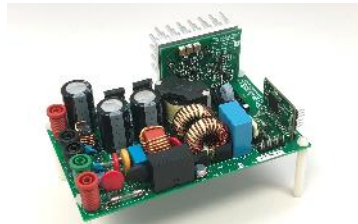
GSP65MB-EVB
+ GSP65RxxHB-EVB
2-7 kW Insulated Metal Substrate
Configurable Full/Half Bridge Evaluation kit



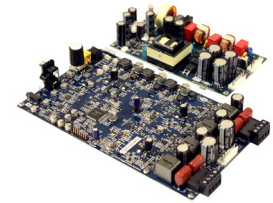
GSP665x-EVBIMS2
2-6 kW Insulated Metal Substrate
Configurable Full/Half Bridge Evaluation kit



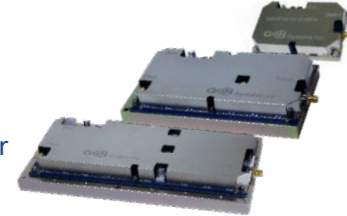
GS1200BTP-EVB
1.2kW Bridgeless Totem Pole Power Factor
Correction Evaluation Board



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

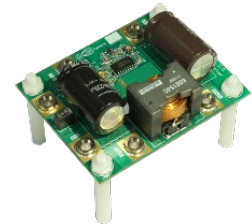


GS-EVB-HB-66508B-ON1
650V, ultra-small form factor Half Bridge
power stage



25mm x 25mm Layout

GS65011-EVBEZ
EZDrive® open loop boost evaluation board



TRANSISTOR DOCUMENTS

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

REACH Statement
RoHS Certificate of Compliance

DESIGN CENTER

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



Online circuit simulation tool

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



<https://gansystems.com/>

Application Notes

| | |
|-----------|--|
| GN001 | Design with GaN Enhancement mode HEMT |
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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 ...

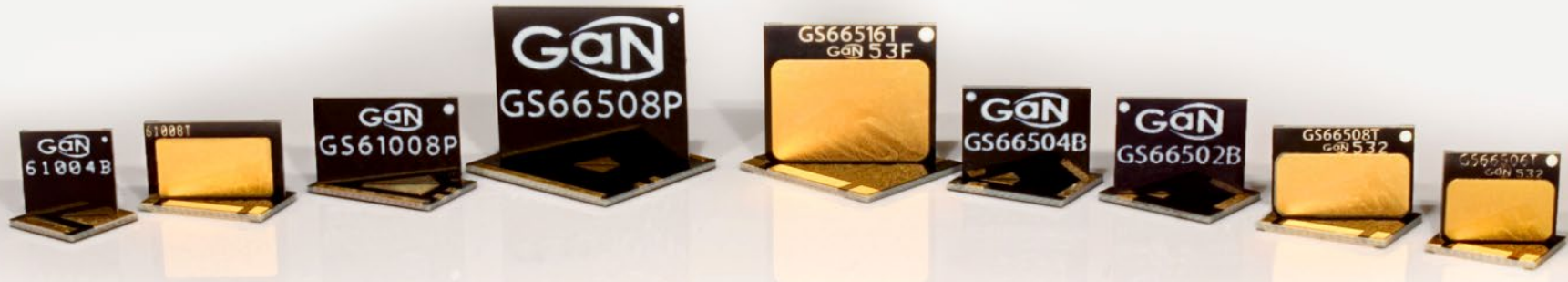
Papers, articles and presentations

| 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 ...

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