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 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

Basic structure of GaN E-HEMT

OFF State

ON State

IDS vs. VDS Characteristics
Simple-driven GaN Technology

Common with Si MOSFET
- True enhancement-mode normally off
- Voltage driven - driver charges/discharges $C_{\text{ISS}}$
- Supply Gate leakage $I_{\text{GSS}}$ 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

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

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
GaN Systems E-mode devices have superior R\text{ON} & Q\text{G} performance over Si and SiC MOSFETs, resulting in lower switching charge requirements and faster switching transition.
**Reverse Conduction Characteristics**

GaN Reverse I/V Curve

<table>
<thead>
<tr>
<th>Gate</th>
<th>GaN E-HEMT</th>
<th>MOSFET</th>
<th>Si IGBT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>ON</td>
<td><img src="image" alt="RDS(ON)" /></td>
<td><img src="image" alt="RDS(ON)" /></td>
</tr>
<tr>
<td>B</td>
<td>ON</td>
<td><img src="image" alt="RDS(ON)" /></td>
<td><img src="image" alt="RDS(ON)" /></td>
</tr>
<tr>
<td>C</td>
<td>OFF</td>
<td><img src="image" alt="V_{TH}+V_{GS(OFF)}" /></td>
<td><img src="image" alt="RDS(REV)" /></td>
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</table>

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

- 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)

Zero Reverse Recovery

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

Zero reverse recovery results in lower switching loss and less EMI noise
Si SJMOS has $\sim10x$ higher Co(tr) than GaN; SiC MOS has $\sim50\%$ 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/](https://gansystems.com/)
The switching loss of a GaN HEMT is **significantly lower** than 650V SiC MOSFET with similar $R_{DS(ON)}$. 

![Graph showing switching-on and switching-off losses for GaN and SiC devices.](image-url)
Basics and Mechanism

Characteristics

Design Resources
GaN Systems Design Center

• Many resources available
  ▪ Easy to find
  ▪ Easy to use
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.

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<th>Document #</th>
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<td>エンジニアリングモードGaN-HEMTを用いた設計</td>
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Online Simulation Tool

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 in 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/](https://gansystems.com/)
Take Full Advantage of GaN – Evaluation Boards

**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

**GS65011-EVBEZ**
EZDrive® open loop boost evaluation board
Design Tools and Resources at gansystems.com

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

plesim
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/

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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?

Papers, articles and presentations

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<td>Using MOSFET Controllers to Drive GaN E-HEMTs</td>
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<td>GaN Technologies For Electric Vehicles</td>
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<td>Optimal Design for High Frequency GaN-Based Totem Pole PFC</td>
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<tr>
<td>WEBINAR: Simple Layout Steps for Maximizing GaN Design Performance</td>
<td>2019 Nov</td>
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<td>The Value of GaN HEMTs in 800V and Above Applications</td>
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<td>Power Amplifier and Coil Design Optimization for Large Air Gap Applications</td>
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