An Introduction to GaN Enhancement-mode HEMTs
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

I_{DS} vs. V_{DS} Characteristics
Simple-driven GaN Technology

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

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<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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<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>
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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
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

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

- **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 ~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 $R_{DS(ON)}$. 
Content

- Basics and Mechanism
- Characteristics
- Design Resources
GaN Systems Design Center

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

- Layout
- Gate Driver
- Paralleling
- Thermals
- Simulation
- Soldering
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/](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

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

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

100V Buck/Boost Evaluation Board with Driver GaN Power Stage
Non-isolated Half Bridge Driver evaluation board
650 V GaN E-HEMT Daughter Board
650V 150A FB Module With 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
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650 V 30A & 60A GaN Half-Bridge and Driver with Over Current Protection

650V 300W-500W Low Power IMS2 GaN Half-Bridge & driver board
Design Tools and Resources at gansystems.com

Application Notes

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FAQ – Frequently Asked Questions

- 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?

Papers, articles and presentations

- Webinar: Benefits and Advantages of a GaN-based 330 A MOSFET
- Webinar: Driving GaN Forward – How GaN is Changing Power System Design
- Technical Roadmap: Power Electronics for GaN Applications
- TechTalk: Understanding Current Limit Design with GaN
- TechTalk: GaN Transistor for Renewable Energy
- TechTalk: GaN Technology and the Sustainable Energy World
- TechTalk: High-frequency High-power with GaN
- TechTalk: Power Electronics with GaN Systems
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