Gate Driver Circuit Design with GaN E-HEMTs

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GaN Systems Inc.
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

GaN HEMTs are simple to drive

<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>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum rating</td>
<td>-20/+10V</td>
<td>-/+20V</td>
<td>-/+20V</td>
<td>-8/+20V</td>
</tr>
<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>
</tbody>
</table>
650V Drivers

- GaN Systems GaN HEMTs are compatible with most drivers for silicon devices.
- When the driver supply voltage ($V_{DD}$) is higher than +6V (the recommended turn-on $V_{GS}$ for GaN), a negative $V_{GS}$ generating circuit is required to convert the $V_{GS}$ into $+6/(V_{DD}-6)$ V, refer to page 7.
- $V_{DD}$ is recommended to $\leq 12$V.

Most popular solutions:

<table>
<thead>
<tr>
<th>Gate Drivers</th>
<th>Configuration</th>
<th>Isolation</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si8271</td>
<td>Single switch</td>
<td>Isolated</td>
<td>Split outputs</td>
</tr>
<tr>
<td>Si8273/4/5</td>
<td>Half-Bridge</td>
<td>Isolated</td>
<td>Dead time programmability</td>
</tr>
<tr>
<td>ADuM4121ARIZ</td>
<td>Single Switch</td>
<td>Isolated</td>
<td>Internal miller clamp</td>
</tr>
<tr>
<td>ACPL-P346</td>
<td>Single Switch</td>
<td>Isolated</td>
<td>Internal miller clamp</td>
</tr>
<tr>
<td>HEY1011</td>
<td>Single Switch</td>
<td>Isolated</td>
<td>Power Rail Integrated</td>
</tr>
<tr>
<td>NCP51820</td>
<td>Half Bridge</td>
<td>Non-Isolated</td>
<td>Bootstrap voltage management</td>
</tr>
<tr>
<td>RAA226110</td>
<td>Single Switch</td>
<td>Non-Isolated</td>
<td>Programmable Source Current and Adjustable Overcurrent Protection</td>
</tr>
</tbody>
</table>
100V/80V Drivers

- GaN Systems GaN HEMTs are compatible with most of the drivers for silicon devices.
- When the driver supply voltage ($V_{DD}$) is higher than +6V (the recommended turn-on $V_{GS}$ for GaN), a negative $V_{GS}$ generating circuit is required to convert the $V_{GS}$ into $+6/-(V_{DD}-6)$ V, refer to page 7.
- $V_{DD}$ is recommended to $\leq$12V.

Most popular solutions:

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<thead>
<tr>
<th>Gate Drivers</th>
<th>Configuration</th>
<th>Split Outputs</th>
<th>Bootstrap voltage management</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCP51810</td>
<td>Half-Bridge</td>
<td>Yes</td>
<td>Yes</td>
<td>High Speed</td>
</tr>
<tr>
<td>uP1966A</td>
<td>Half-Bridge</td>
<td>Yes</td>
<td>Yes</td>
<td>General Purpose</td>
</tr>
<tr>
<td>LMG1205</td>
<td>Half-Bridge</td>
<td>Yes</td>
<td>Yes</td>
<td>General Purpose</td>
</tr>
<tr>
<td>MDC901</td>
<td>Half-Bridge</td>
<td>Yes</td>
<td>Yes</td>
<td>High Current</td>
</tr>
</tbody>
</table>
• GaN Systems GaN HEMTs are compatible with most of the controllers for silicon devices.
• When the driver supply voltage ($V_{DD}$) is higher than +6V (the recommended turn-on $V_{GS}$ for GaN), a negative $V_{GS}$ generating circuit is required to converter the $V_{GS}$ into $+6/(V_{DD}-6)$ V, refer to page 7.
• $V_{DD}$ is recommended to $\leq$12V.

Most popular solutions:

<table>
<thead>
<tr>
<th>Configurations</th>
<th>Controllers</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flyback</td>
<td>NCP1342</td>
<td>650V, Quasi-resonant</td>
</tr>
<tr>
<td>- Adapters</td>
<td>UCC28600</td>
<td>600V, Quasi-resonant</td>
</tr>
<tr>
<td>- Chargers</td>
<td>NCP1250</td>
<td>650V, Fixed frequency</td>
</tr>
<tr>
<td>- Other low-power AC/DCs</td>
<td>LTC7800</td>
<td>60V, Sync rectifier control, up to 2.2MHz</td>
</tr>
</tbody>
</table>
Controllers with Driver Integrated for GaN - continued

- GaN Systems GaN HEMTs are compatible with most of the controllers for silicon devices.
- When the driver supply voltage ($V_{DD}$) is higher than $+6V$ (the recommended turn-on $V_{GS}$ for GaN), a negative $V_{GS}$ generating circuit is required to converter the $V_{GS}$ into $+(V_{DD}-6)$ V, refer to page 7.
- $V_{DD}$ is recommended to $\leq12V$.

Most popular solutions:

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<thead>
<tr>
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<th>Controllers</th>
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<tbody>
<tr>
<td><strong>LLC</strong></td>
<td><strong>NCP13992</strong></td>
<td>600V, current mode controller</td>
</tr>
<tr>
<td>- Adapters</td>
<td><strong>NCP1399</strong></td>
<td>600V, current mode controller, off-mode operation</td>
</tr>
<tr>
<td>- Chargers</td>
<td><strong>UCC256404</strong></td>
<td>600V, optimized burst mode, low audible noise and standby power</td>
</tr>
<tr>
<td>- Flat panel displays</td>
<td><strong>UCC256301</strong></td>
<td>600V, hybrid hysteric mode, low standby power, wide operating frequency</td>
</tr>
<tr>
<td>- Industrial power</td>
<td><strong>NCP1615 / NCP1616</strong></td>
<td>700V, critical conduction mode operation</td>
</tr>
<tr>
<td>- Appliances</td>
<td><strong>UCC28180</strong></td>
<td>Programable frequency, continuous conduction mode operation, no AC line HV sensing</td>
</tr>
<tr>
<td>- LED Drivers</td>
<td><strong>HR1203</strong></td>
<td>700V, CCM/DCM Multi-mode PFC control, adjustable dead-time and bust mode switching LLC</td>
</tr>
</tbody>
</table>
Driver Circuit Examples

Single switch driver

- **Isolated**
  - 0V $V_{GS(OFF)}$
    - Single Isolated Driver
      - EZDrive®
    - Negative $V_{GS(OFF)}$
      - With voltage divider
        - Digital Isolator + Non-isolated Driver
  - Non-Isolated 0V $V_{GS(OFF)}$  
    - Single Isolated Driver
      - EZDrive®

Half/Full Bridge driver

- Isolated
  - Implement two single switch drivers
    - Bootstrap driver
  - Non-Isolated 0V $V_{GS(OFF)}$
    - Bootstrap driver + EZDrive®

Paralleling GaN

- Driver Circuit for GaN HEMT in Parallel

* When is negative $V_{GS(OFF)}$ needed?*
Single GaN ➤ Isolated ➤ 0V VGS(OFF) ➤ Single Isolated Driver

- 0V $V_{GS(OFF)}$ for low voltage or low power applications, or where the deadtime loss is critical
- Optional CM Choke for better noise immunity

Example I: Driver with separate outputs for switch ON/OFF (SI8271)

Example II: Driver with single output for switch ON and OFF (ADUM4121)
Single GaN → Isolated → Negative $V_{GS(OFF)}$ → EZDrive®

- Negative $V_{GS}$ voltage is applied by the 47nF capacitor
- Compatible with bootstrap circuit
- Applicable from 1kW ~ 100kW power range
- Optional CM Choke for better noise immunity

For more info about GaN EZDrive®, please refer to GN010: https://gansystems.com/
Single GaN → Isolated → Negative $V_{GS(\text{OFF})}$ → with Voltage divider

- Negative $V_{GS}$ voltage is generated by the voltage divider (5.8V Zener diode and 1kOhm resistor)
- Robust and easy to layout
- Applicable for applications from low power to higher power (1kW ~ 100kW)
- Optional CM Choke for better noise immunity

Example: SI8271 driving circuit with voltage divider ($V_{GS}=+6V/-3V$)
• To enable non-isolated driver or buffer with high sink current capability where isolation is required
• For high power applications: e.g. EV motor drive, PV inverter, etc
• Optional CM Choke for better noise immunity

Example: SI8610 (digital isolator) + UCC27511(Non-isolated driver) ($V_{GS}$=+6V/-6V)
Single GaN → Non-Isolated → 0V $V_{GS(\text{OFF})}$

- For single-ended applications (Class E, Flyback, Push-pull etc)
- Or to work with a digital isolator for the high-side switch

Example: UCC27511 driving circuit ($V_{GS}$=+6V/0V)
• Negative $V_{GS}$ voltage is applied by the 47nF capacitor
• Compatible with bootstrap circuit
• Optional CM Choke for better noise immunity

Example: UCC27511 driving circuit ($V_{GS} = +6V/-3V$))

For more info about GaN EZDrive®, please refer to GN010: https://gansystems.com/
Half/Full Bridge $\rightarrow$ 0V $V_{\text{GS(OFF)}}$ $\rightarrow$ Bootstrap

- For low power applications
- Choose the bootstrap diode with low $C_J$ and fast recovery time

Example: NCP51820 Bootstrap driving circuit ($V_{\text{GS}}$=+6V/0V)
• EZDrive® can get a negative voltage on 47nF capacitor, which can be used as turn off voltage
• Turn on/off slew rate is controllable with external resistors to optimize EMI
• Suitable for low power application

Example: NCP51530 Bootstrap driving circuit with EZdrive® (V_{GS}=+6V/-3V)

For more info about GaN EZDrive®, please refer to GN010: https://gansystems.com/
Driver Circuit for GaN HEMT in Parallel

- For HEMTs in parallel, add additional 1ohm gate and source resistors (as highlighted below)

Example: UCC27511 non-isolated driving circuit for single GaN ($V_{GS}=+6V/0V$)

Example: Bootstrap driving circuit for half-bridge ($V_{GS}=+6V/0V$)

For more info about GaN in parallel, please refer to GN004: https://gansystems.com/
Appendix

- Gate driving tips for $V_{GS(OFF)}$
- When is $V_{GS(OFF)}$ needed?
- $V_{GS(OFF)}$ vs. Switching-off Loss
- Trade-off between Switching-off Loss and Deadtime Loss
When is negative $V_{GS(OFF)}$ needed?

- Negative $V_{GS(OFF)}$ can increase noise immunity
- Negative $V_{GS(OFF)}$ can reduce switching-off loss especially under high-current
- Deadtime loss increases as Negative $V_{GS(OFF)}$ increase (more info please refer to page 8, APPNOTE GN001)
- There is a tradeoff between switching-off and deadtime loss for $V_{GS(OFF)}$ selection. -3V $V_{GS(OFF)}$ is recommended to start with for above 0.5kW applications.
Switching-off loss of GS66516B vs. current at $V_{BUS}=400$ V, 25°C, $R_G=1\Omega$

Negative $V_{DROff}$ reduces the switching off energy under high current.
Relation between total loss and deadtime of GS66516B at $I_D=10\text{A}$, $25\text{ }\degree\text{C}$

$$t_d > \frac{C_{eq}V_{bus}}{i_{Switching}} \quad (1)$$

$$0.5 \cdot L \cdot i_{Smin}^2 > i_{Smin} \cdot V_{SD} \cdot (t_d - \frac{C_{eq}V_{DC}}{i_{Smin}}) + 0.5 \cdot C_{eq} \cdot V_{DC}^2 \quad (2)$$

- Deadtime loss increases as $V_{GS(OFF)}$ increases
- A too short dead time will result in losing ZVS, while a too long dead time will cause additional loss
Trade-off between Switching-off Loss and Deadtime Loss

Half-bridge overall loss vs. switching current under different negative turn-off gate voltage $V_{\text{DRoff}}$ (a) with deadtime $t_D=40$ nS, (b) with deadtime $t_D=100$ nS, (c) with deadtime $t_D=200$ nS.

- Negative $V_{\text{DRoff}}$ is will make the power stage more efficient under higher power.
- Precise dead time control is the key to higher system efficiency.