Silicon Carbide Power Devices: Advanced Gate Driving Techniques
About AgileSwitch
Who we are

- Founded January 2010 by serial entrepreneurs Albert Charpentier and Rob Weber
- Based in Philadelphia, PA (US East Coast)
- 20+ team members
- 20+ products
- Global sales, marketing and support
- Member: Power America

2002 Ludlow St, Philadelphia, PA 19103, USA

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SIC APPLICATIONS & ASSOCIATED PROBLEMS
SiC Application Areas – Early Adopters

- Heavy Duty Vehicles
- Traction APU
- PV / Solar
- Induction Heating
- Electric Vehicles & Chargers
- Wind
- Energy Storage
- Welding

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Problems associated with driving SiC MOSFETs

1. SiC MOSFETs switching at a high frequency results in a high di/dt, this causes:
   - Vds - Voltage overshoot
   - Oscillation in the Vds
2. SiC MOSFETs have very narrow short circuit withstand window
3. Susceptibility to noise
4. Feedback is critical – Temperature, Voltage, Current
5. High Temperature Operation
GATE DRIVING TECHNIQUES
IGBT Gate Driver

Design Trade-Off:
Larger Rg = smaller di/dt = more losses
Smaller Rg = larger di/dt = less losses

di/dt control achieved by modifying Rg
Alternatively, Cge can be used to reduce di/dt
SiC - Gate Driver – Implemented with IGBT driving technique

Crude control of the SiC MOSFETs can be achieved using the IGBT Gate Driver technique:
1) Large $R_{g\text{off}}$
   1) Lower $V_{ds}$ overshoot
   2) Damped oscillation of $V_{ds}$

Trade off is:
1) Higher switching loss
2) Slower DSAT response time
SiC - Gate Driver – Augmented Turn-Off

This technique provides precise switching control, and features:
1) Low Gate Resistor Value – $R_g$(on) & $R_g$(off)
2) $di/dt$ control is achieved through the use of Augmented Turn-Off
Augmented Turn-Off™ Explained

Conventional Solution

Conventional

Augmented Turn-Off™

AgileSwitch Augmented Turn-Off™

R\textsubscript{G} = 5.6Ω

R\textsubscript{G} = 0Ω

More Efficient
Augmented Turn-Off™

- AgileSwitch’s Augmented Turn-Off helps designers reduce switching losses, reduce ringing in the Vds and suppress stray/loop inductance induced overshoot voltages
  - There are two operation loops
    - Normal Operation
      - The Gate Voltage has an intermediate step between on & off
      - The measurable benefit is reduced switching loss, ringing and overshoot voltage
    - Short Circuit Condition
      - The Gate Voltage has one or more intermediate steps between on & off
      - Augmented Turn-Off helps reduce stress on the Power Semiconductor, in addition to reducing ringing and overshoot voltage
Advanced Gate Driving for Silicon Carbide MOSFETs
Ideal SiC Driver

Augmented Turn-Off™

- Reduced Ringing, Voltage overshoot
- Lower Switching Losses
- Precise DSAT Control

Advanced Fault Monitoring

- Enhanced Reliability
- Better Diagnostics
- Shortened Design Cycle
- Design Flexibility

Software Configurable

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# Ideal SiC Driver – Feature Table

<table>
<thead>
<tr>
<th>Features</th>
<th>Ideal</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SiC Gate Driver – Solution 2</strong></td>
<td>high</td>
<td>kV/us</td>
</tr>
<tr>
<td><strong>Interface Voltage</strong></td>
<td>Single Ended/ Differential</td>
<td></td>
</tr>
<tr>
<td><strong>Direct Mounting</strong></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td><strong>Flying Lead Option</strong></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td><strong>Master/ Slave (Paralleling)</strong></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td><strong>UVLO</strong></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td><strong>OVLO</strong></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td><strong>Over Current Protection</strong></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td><strong>Augmented Turn-Off™</strong></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td><strong>Temperature Monitoring</strong></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td><strong>DC Link Voltage Monitoring</strong></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td><strong>Software Configurable (Deadtime, Desat, Turn-Off)</strong></td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
CASE STUDY
SiC MOSFET Turn-Off – Normal Operation

Conventional Gate Drive Solution

Rg = 1Ω  
Eoff = 3.9mJ

Rg = 5.6Ω  
Eoff = 5.6mJ

Rg = 10Ω  
Eoff = 12.5mJ

AgileSwitch Gate Drive Solution – Augmented Turn-Off™

Augmented Turn-Off™ Settings:  
575ns, 4.75V

Rg = 0.5Ω  
Eoff = 6.4mJ

DUT: Rohm BSM300D12P2E001
Results of Case Study

- **DUT**: Rohm BSM300D12P2E001
- **Vds** = 800V; **Ids** = 266A

### Gate Resistor Control Only

<table>
<thead>
<tr>
<th>Gate Resistor (Ω)</th>
<th>E_{OFF} Measured (mJ)</th>
<th>Overshoot (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>3.9</td>
<td>450</td>
</tr>
<tr>
<td>5.6</td>
<td>8.5</td>
<td>280</td>
</tr>
<tr>
<td>10.0</td>
<td>12.5</td>
<td>200</td>
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</tbody>
</table>

### Augmented Turn-Off

<table>
<thead>
<tr>
<th>Turn Off Level (V)</th>
<th>Turn Off Time (ns)</th>
<th>E_{OFF} Measured (mJ)</th>
<th>Overshoot (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.25</td>
<td>500</td>
<td>5.7</td>
<td>220</td>
</tr>
<tr>
<td>4.50</td>
<td>500</td>
<td>6.0</td>
<td>260</td>
</tr>
<tr>
<td>4.75</td>
<td>500</td>
<td>6.2</td>
<td>270</td>
</tr>
<tr>
<td>4.50</td>
<td>469</td>
<td>5.3</td>
<td>320</td>
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<tr>
<td>4.50</td>
<td>500</td>
<td>6.0</td>
<td>260</td>
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<td>531</td>
<td>6.2</td>
<td>260</td>
</tr>
<tr>
<td>4.50</td>
<td>575</td>
<td>6.4</td>
<td>230</td>
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<tr>
<td>4.75</td>
<td>575</td>
<td>6.4</td>
<td>220</td>
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<tr>
<td>4.75</td>
<td>625</td>
<td>7.1</td>
<td>210</td>
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</tbody>
</table>
SHORT CIRCUIT OPERATION
SiC MOSFET Turn-Off – Short Circuit Condition

**Conventional Gate Drive Solution**

Rg = 10 Ω

Purple Trace = Vge, Blue Trace = Vce

Vce Overshoot = 700V

**AgileSwitch Gate Drive Solution – Augmented Turn-Off™ (ATOff)**

Rg = 0.5 Ω + ATOff

Blue Trace = Vge, Purple Trace = Vce

Vce Overshoot = 500V
CASE STUDY 2
Wolfspeed 1700V/ 300A – 62EM1 Test Results

Normal Operation

Short Circuit Operation

Purple = Vgs;
Green = Vds;
Blue = Ids
SIC GATE DRIVER – AUGMENTED TURN-OFF
EDEM3-Programmable EconoDual™ Electrical Series

Key Switch Driver Features:
• 7 Unique Fault conditions
• Isolated Temperature Monitoring, PWM
• Isolated High Voltage Monitoring, PWM
• 2 X 3W output power
• RoHS and UL compliant design
• Interface for 5V or 15V logic levels
• Gate drive voltage +18V/-4V
• Peak gate current +/-15A

Software Programmable Features (8):
• Augmented Turn-Off™ (ATOff)
• Power supply under-voltage lockout (UVLO)
• Power supply over-voltage lockout (OVLO)
• Desaturation detection settings
• Dead time
• Fault lockout settings
• Automatic Reset settings

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62EM1-Programmable 62mm Electrical Series

Key Switch Driver Features:
- 7 Unique Fault conditions
- Temperature Monitoring, PWM
- Isolated High Voltage Monitoring, PWM
- 2 X 10W output power
- RoHS and UL compliant design
- Interface for 5V or 15V logic levels
- Gate drive voltage +20V/-5V
- Peak gate current +/-20A

Software Programmable Features (8):
- Augmented Turn-Off™ (ATOff)
- Power supply under-voltage lockout (UVLO)
- Power supply over-voltage lockout (OVLO)
- Desaturation detection settings
- Dead time
- Fault lockout settings
- Automatic Reset settings
Gate Driver Adaptations

62EM1 adapted to drive TO-247 based Half Bridge

62EM1 adapted to drive Wolfspeed CAS325M12HM2
What’s Next?

• Gate Driver IC for WBG Power Devices
  AGI 100 (Non-Isolated Gate Driver IC)
  AGI 200 (Isolated Gate Driver IC)

— Key Features

• Programmable Gate drive output voltage +22/-8V Max.
• Augmented™ Switching Control
• Peak gate current up to +/-5A
• Temperature Monitoring
• High Voltage Monitoring
• Overcurrent Current Sense
• $V_{DS}$ Monitoring (health of the device)
• UART Communication
Manufacturers Supported

*More coming soon*
How to Reach Us

- Website: www.AgileSwitch.com
- Email: info@AgileSwitch.com
- Phone: +1 484-483-3256 (US)
  +44 (0)7882 758982 (Europe)

Nitesh Satheesh: nsatheesh@AgileSwitch.com
Cliff Robins: crobins@AgileSwitch.com
Rob Weber: rweber@AgileSwitch.com
Thank you
AgileSwitch SiC Driver – Feature Description

Under Voltage Lockout (UVLO) / Over Voltage Lockout (OVLO)
• The input supply voltage is monitored to protect the SiC MOSFET from low/high voltages that would damage its long term reliability. By default, the UVLO/OVLO detect level is set to a pre-determined value, but can be modified based on the end-user requirement.
• A UVLO or OVLO will trigger the respective fault and the SiC MOSFET gate will be pulled to -Vgs

Temperature and High Voltage Monitoring
• AgileSwitch Drivers provide two 25 kHz, 3.3V PWM output signals, one each for temperature and the DC Link Voltage (between High Side drain and Low Side source).
• Users can define a threshold, which when exceeded will trigger a fault

Overcurrent Protection
• SiC MOSFET’s have limited Short Circuit withstand capability. Hence, the drivers should have the ability to respond to a short circuit quickly and appropriately.
• AgileSwitch Gate Drivers for SiC accurately monitor the Vds. The drivers are software configurable (Over Current threshold, Blanking Time, Response time)
• AgileSwitch also implements Augmented Turn-Off which is critical in controlling the aftermath of a short circuit (shutting down the FET in a high current condition)
AgileSwitch SiC Driver – Feature Description

Master/ Slave (Paralleling)
• Paralleling Power Semiconductors requires precise input trigger synchronization. Variation leads to current imbalance (+ve temperature co-efficient auto-corrects the imbalance, but this takes time)
• AgileSwitch Gate Drivers feature Master-Slave operation, wherein the triggers are synchronized and maintained with <10ns of timing difference

Software Configurability
• Each implementation of an inverter requires a unique configuration from its components. Others may call it crazy, but at AgileSwitch, we call it Tuesday.
• AgileSwitch drivers enable the user to tailor the gate drivers to their requirements. The primary features that can be configured are:
  – Augmented Turn-Off™
  – Power supply under-voltage lockout (UVLO)
  – Power supply over-voltage lockout (OVLO)
  – Desaturation detection settings
  – Dead time
  – Fault lockout settings
  – Automatic Reset settings