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Find Past Recorded Sessions at: [https://www.silabs.com/support/training](https://www.silabs.com/support/training)
WELCOME

WELCOME
SILICON LABS LIVE
Internet Infrastructure and Industrial Automation Tech Talks
Evolution of the Isolated Gate Driver in an Energy Conscious World

DAVID SEYMOUR | SENIOR FIELD APPLICATION ENGINEER
Efficiency and power density driving change

The basic MOSFET gate driver function

Driver evolution to support IGBTs (Insulated Gate Bipolar Transistor)

Driver evolution to support SiC (Silicon Carbide)

Driver evolution to support GaN (Gallium Nitride)

Future driver enhancements

Summary
Isolation Technologies

CAPACITIVE (SILICON LABS, TI)
- High speed
- Low emissions
- High immunity
- High reliability/stability

INDUCTIVE OR TRANSFORMER (ADI)
- High speed
- High emissions
- Low immunity
- High reliability/stability

OPTICAL (BROADCOM, TOSHIBA, VISHAY)
- Low speed
- Low emissions
- Low immunity & stability
- “Fail open” perception
- No external power supply
Silicon Labs Isolation Portfolio

**Digital Isolator**
- **Si86xx**
  - 1-6 ch, 5kVrms
  - Pin 2 pin - ADI, TI
  - Faster, less noise
- **Si86xxT**
  - Si86xx + 10kV surge
  - Reinforced VDE
  - Robust isolation
- **Si88xx**
  - Si86xx + dc/dc
  - 5W power, 80% eff
  - Low noise
- **Si838x**
  - For PLC inputs
  - 8 ch high speed
  - Sinking/sourcing
- **Si87xx**
  - Replaces Optos
  - Faster, robust
  - Same price

**Isolated Analog /ADC**
- **Si8900**
  - 10 bit ADC
  - 3 analog inputs
  - UART, I²C or SPI
- **Si8920**
  - Analog isolator
  - Differential I/O
  - Shunt R sensing
- **Si8921/22**
  - Current sensor
  - SE or DIFF output
  - High performance
- **Si893x**
  - Voltage sensor
  - SE, DIFF, or DSM output
- **Si894x**
  - Current sensor
  - DSM Output
  - High performance

**Isolated Drivers**
- **Si823x**
  - Drives MOSFET based systems
- **Si826x**
  - Replaces Opto-drivers
- **Si827x**
  - Fast MOSFETs
  - GaN FETs
- **Si828x**
  - Drives IGBT systems
- **Si823Hx**
  - 20 V VDDI
  - 30 ns max latency
  - 100 kV/us CMTI

- **Si834x**
  - Isolated Switch
  - 12/24V digital out
  - Lamps & inductors
- **Si875x**
  - SSR replacement

[https://www.silabs.com/isolation/isolated-gate-drivers](https://www.silabs.com/isolation/isolated-gate-drivers)
Efficiency and Power Density Driving Change

<table>
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<tr>
<th>BACKUP UPS INVERTER</th>
<th>SOLAR INVERTER</th>
<th>5G BASE STATION</th>
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</table>
| Low Cost UPS Inverter  
Battery (DC) \(\rightarrow\) AC (110-240)  
*MOSFET or IGBT Power Switch* | Solar Inverter  
Up to 1000 VDC \(\rightarrow\) AC (110-240)  
*SiC Power Switch* | DCDC for 5G Base Stations  
3x Power Demand of 4G  
*SiC or GaN Power Switch* |
Automotive’s Influence

- **120kW traction inverters**
- **Power densities > 20kW/l (target 2025)**
- **400 VDC → 240 VAC**
- **SiC Power Switch**

- **Level 3 OBC (On-Board Charger)**
  - **High efficiency and light weight**
  - **110/220 VAC ↔ 400VDC**
  - **SiC or GaN Power Switch**

- **DC/DC Converter**
  - **High efficiency and Light Weight**
  - **400 VDC → 12 VDC**
  - **IGBT, SiC or GaN Power Switch**
Power Switch Applications

- **Silicon MOSFET**
  - Low to mid-power applications
  - Reached theoretical performance limit
- **IGBT - Insulated Gate Bipolar Transistor**
  - Scaled for High voltage, high power
  - Least expensive per watt at high power
  - Slower but perfect for motor control
- **SiC - Silicon Carbide (breakthrough)**
  - High voltage, high current, high temperature
  - Faster switching requires gate drivers that can tolerate high dV/dt
- **GaN - Gallium Nitride (breakthrough)**
  - Low(er) voltage, high current
  - Fastest switching (higher dV/dt)
  - Narrow gate drive voltage range
Power Switch Influence on Gate Driver

Yet even higher CMTI
Narrow gate drive window

Yet even higher working voltage
Faster DSAT detection
Higher CMTI
Enhanced safety features

Higher working voltage
Miller Clamp
DSAT detection

MOSFET
IGBT
SiC
GaN
10 kW SiC Heat Sink
10 kW IGBT Heat Sink
10 kW IGBT Heat Sink
Isolated Gate Driver Evolution

Transformer Gate Drive Circuit
(older & less integration)

Modern Gate Driver
(newer & more integration)
Gate Driver Fundamentals

- A gate driver should
  - Turn power switches on and off safely and efficiently
  - Maximizing the performance capabilities of the switch

- The basic MOSFET driver features
  - Supply appropriate drive voltages
  - Provide ample source/sink current to effectively turn on and off FET
  - Keep MOSFET in secured off state in the absence of adequate supply voltage (input and output)
  - Provide isolation for high-side switch and meet compliance requirements
Basic MOSFET Driver Features

- Input
  - Logic-level complementary or PWM inputs
  - UVLO
  - Dead time (DT) control

- Isolation
  - Up to 5kV

- Output
  - Up to 24v drive voltage
  - UVLO
  - 0.5 to 4.0A peak drive current

Si8230/3
### Background: What About MOSFET Short Circuit Protection?

- MOSFET is commonly used in DCDC converter
- PWM controller provides short protection
  - External current sensing
  - PWM controller terminates on cycle
  - Cycle by cycle current protection

#### Problem:
Stalled Motor (Stall Current)

#### Solution:
Current Sense for feedback
- IGBT common in motor drive
- **Problem**: Current sense/feedback to controller slow
  - Controls and protects motor, but not IGBT
  - Cannot detect short & respond fast enough
- **Solution**: Gate driver evolved to protect IGBT
IGBT Introduces Driver Challenges

- Higher working voltages (>1000V)
- Slow switching
- Complex design
- Slow turn off due to minority charge recombination
- Independent on and off timing (speed up turn off)
- Secured off - state (large Miller current)
- Higher peak drive current (large device)
- Short circuit detection and protection
  - DSAT detection
  - Soft shutdown

Dr. B. Jayant Baliga

IGBT Equivalent Circuit

IGBT Symbol
Enhancements for IGBT – Independent H/L Drive Signals

- **Independent Drive Signals**
  - Different ON and OFF drive strengths set by $R_H$ and $R_L$
  - Faster turn-off than turn-on minimizes shoot-through current
  - Provides designer flexibility when optimizing for efficiency

![Diagram showing Independent Drive Signals](image)

- $R_H = R_L$
- $R_H = 2 \times R_L$
Enhancements for IGBT – Negative Drive Level – Secured Off-state

- Driving $V_{GE} < 0V$
- IGBT require $V_{GE} = 0V$ to turn off effectively
- Driving $V_{GE} < 0V$ common to ensure noise immunity
Enhancements for IGBT – Miller Clamp (Secured Off-State)

- **Miller Clamp**
  - Turn off Q2, turn on Q1 → VCE going from 0V to DC-Link+
  - High dV/dt on drain of IGBT causes gate voltage spike due to Miller current flow through RL
  - Miller clamp provides strong pulldown on gate when driving low (VL is active) *AND* the sensed gate voltage is < 2V

**Problem**

Without Miller Clamp

- VCE (Q2)
- VTH (Q2)
- VGE (Q2)

**Solution**

With Miller Clamp

- VCE (Q2)
- VGate (Q2)
- VTH (Q2)

Shoot-Through Current!!

**Problem**

- Without Miller Clamp
- Shoot-Through Current!!

**Solution**

- With Miller Clamp
- Shoot-Through Current!!
Enhancements for IGBT – DESAT Detect/Soft Shutdown/FAULT

- Desaturation protection w/ fault indication
  - Load overcurrent/short condition causes IGBT to desaturate ($V_{CE} > 7v$)
  - DSAT detects $V_{CE}$ rise > 7v and performs soft shutdown
  - IGBT DESAT detect $\rightarrow$ shut down timing
    - < 3uS for IGBT
    - < 1.2uS for SiC
    - < 200nS for GaN and 10’s ns typical!
Silicon Labs Answer: Si8285 - Basic IGBT Driver Features

- **Input**
  - Logic-level complementary inputs
  - UVLO
  - RDY indication
  - Reset
  - Fault indication

- **Isolation**
  - Up to 5kV

- **Output**
  - Up to 30V drive voltage
  - UVLO
  - Desaturation detection
  - Independent drive signals
  - Soft shutdown
  - Negative drive support
  - Miller clamp
Advantages

- Low on resistance
- Better thermal conduction & higher temperature
- Faster switching speeds ($dV/dt$)
  - Higher (CMTI) immunity
  - High current drive capability
- Smaller geometry & linear DESAT curve
  - Faster DESAT detection and soft shutdown (<1.2uS)
- Fragile – cannot handle prolonged overcurrent

Next generation driver features

- Faster desaturation detection and soft shutdown
- Higher VDDB & UVLO
- CMTI > 100kV/µs
- Higher drive current
Lower *total gate charge* means lower current drive requirement, right??

\[ I_G = C_{GD} \times \frac{dV}{dt} \]

**Background: Demystifying Gate Drive Current Requirement**

- Miller capacitance = 300pF  
  Target switching rate = 10kV/µs  
  \[ I_G = 300e^{-12} \times 10e9 = 3A \]

- Miller capacitance = 100pF  
  Target switching rate = 100kV/µs  
  \[ I_G = 100e^{-12} \times 10e10 = 10A \]

- Miller capacitance = 25pF  
  Target switching rate = 200kV/µs  
  \[ I_G = 25e^{-12} \times 20e10 = 5A \]
Background: Comparing IGBT and SiC Switching Losses

- $E_{ON}/E_{OFF}$ - switching losses
- IGBT switching losses > SiC
  - $E_{ON}$ -> body diode recovery
  - $E_{OFF}$ -> minority carrier recombination
- SiC 50% less $E_{ON}/E_{OFF}$ than IGBT
- Faster switching
  - better efficiency (good)
  - higher power density (good)
  - higher common-mode noise (bad)
Adapting Si828x for High-Performance SiC

- Improved CMTI
  - New “high CMTI” version of Si828x coming soon (100kV/µs)

- Increase drive current
  - Addition of external buffer to Si828x
  - Drive current 100% scalable to customer needs

- Faster DSAT detection and soft-shutdown
  - Detection and shut down < 1.2uS
  - External soft-shutdown circuit
  - May be tuned to specific SiC FET

- External Miller clamp to eliminate PCB trace inductance and improve robustness
## Selecting Isolated Driver for SiCs

<table>
<thead>
<tr>
<th>Device</th>
<th>Isolation Rating (kV)</th>
<th>Max Prop Delay (ns)</th>
<th>Peak Source Current (A)</th>
<th>Peak Sink Current (A)</th>
<th>CMTI (kV/µs)</th>
<th>Miller Clamp</th>
<th>Output UVLO (V)</th>
<th>DSAT Response** (µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si823Hx</td>
<td>3.75</td>
<td>30/116*</td>
<td>4</td>
<td>4</td>
<td>100</td>
<td>No</td>
<td>12</td>
<td>No</td>
</tr>
<tr>
<td>Si827x</td>
<td>2.5</td>
<td>60/75*</td>
<td>1.8</td>
<td>4</td>
<td>200</td>
<td>No</td>
<td>12</td>
<td>No</td>
</tr>
<tr>
<td>Si828x</td>
<td>5</td>
<td>50</td>
<td>2.5</td>
<td>3</td>
<td>35</td>
<td>Internal</td>
<td>12</td>
<td>2.7</td>
</tr>
<tr>
<td>Si828xEC + Booster</td>
<td>5</td>
<td>50</td>
<td>Scalable</td>
<td>Scalable</td>
<td>100</td>
<td>External</td>
<td>12</td>
<td>0.8</td>
</tr>
</tbody>
</table>

* w/ deglitch option
** DSAT detection to Vout @ 10%
What About GaN?

- Low on resistance (undoped GaN) ..reduced heat dissipation
- Very fast switching (2-5x lower gate charge than SiC) for improved efficiency
- Very tight gate drive voltage range (-3V to 6.5V)
- Requires faster protection (<200nS)
- New but evolving quickly for power electronics (650V max)

- Driver features
  - CMTI > 200kV/µs
  - Low gate drive voltage (UVLO)
Basic GaN Single Gate Driver Features – Si8271

- Input
  - Logic-level complementary inputs
  - UVLO
  - Enable pin
- Isolation
  - Up to 2.5kV (adequate for 650V GaN)
- Output
  - Up to 30V drive voltage
  - 1.8A source, 4A sink drive capability
  - UVLO (below 5V)
  - Negative drive support
  - Independent drive signals
### The Future of Gate Drivers

<table>
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<th>IGBT &amp; MOSFET</th>
<th>GAN</th>
<th>SIC</th>
</tr>
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<tbody>
<tr>
<td><img src="image1" alt="IGBT" /> <img src="image2" alt="MOSFET" /></td>
<td><img src="image3" alt="GaN" /></td>
<td><img src="image4" alt="SiC" /></td>
</tr>
</tbody>
</table>

- **IGBT & MOSFET**
  - Speeds improving
  - No known challenges with existing driver family

- **GAN**
  - Voltage ratings improving (upwards of 650V)
  - Possible integration of gate driver
  - Possible partnerships

- **SIC**
  - Integrated short circuit protection
  - Fault reporting (automotive)
  - Serial interface w/ diagnostics (automotive)
  - ISO 26262 safety compliant development process (automotive)
What About EVB’s?

**Si8274ISO-KIT**
- Si827x-based evaluation board (Si827xEVB)
- Si8271, 1-input, 4 A, 2.5 kVRMS Single ISOdriver, and one of the following options:
  - Si8273, 2-input, 4 A, 2.5 kVRMS HighSide/Low-Side ISOdriver
  - Si8274, PWM-input, 4 A, 2.5 kVRMS High-Side/Low-Side ISOdriver
  - Si8275, 2-input, 4 A, 2.5 kVRMS Dual ISOdriver

**Si8284 Isolated Gate Driver Evaluation Kit**
- Discusses hardware overview and setup, including:
  - Si8284 low voltage side connections
  - DC-DC operation
  - Si8284 isolated gate drive connections
- Offers alternative configurations. • Demonstrates driver functionality. • Shows Si8284-EVB schematics and silkscreen/copper layout. • Includes the bill of materials and ordering guide.
Design Resources

- Isolation Selector Guide

- Application Notes
  - https://www.silabs.com/support/resources.ct-application-notes.p-isolation
  - Common use case implementation, Includes Design Guides, Advanced Load Driving Considerations
Summary

- Energy consciousness is driving higher efficiencies and power densities for isolated switch technology
- Gate driver features and performance closely linked to power switch technology
- Legacy power switches (MOSFET, IGBT) well covered by present gate driver portfolio
- GaN power switching presently covered by Si827x, though higher voltage GaN technology is emerging
- SiC power switches team focus
  - Opportunistic coverage with legacy drivers
  - Enhanced CMTI Si828x
  - Focused work w/ SiC partner
  - NPIs (value, performance and safety drivers)
Thank You!

Q & A