TI Webinar Series

Using Isolated Gate Drivers for MOSFET, IGBT and SiC applications

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High Power Driver Solutions, HVPS, SVA
Texas Instruments
This webinar is intended to provide

✓ An understanding of an isolated driver

✓ A guideline on how to and when to identify an isolated driver and the type of driver depending on the power switch and application

X This webinar is not intended to discuss details on isolation technology – That will be discussed in a webinar on October 20th, 2017.
Motivation in power management

- Highest efficiency
- Lowest noise
- Lowest cost
- Smaller size

Optimal Power Solution
Agenda

• Isolation:
  • Definition, why isolate, how to isolate and applications
• Concept of power electronics and definition of a gate driver
• Types of gate driver
• Motivation for an isolated gate driver
  • Walking through an example application
• Types of isolation techniques, terminology and standards
• Isolated gate driver requirements
• MOSFET vs IGBT isolated gate driver and applications
• Wide band gap semiconductors
  • Value of SiC and gate driver requirements
• More information on TI isolated gate driver family and isolation
What is Isolation

A means of transporting data & power between a high voltage and a low voltage circuit while preventing:

• Hazardous DC or
• Uncontrolled transient current from flowing in between the two circuits.
Why isolate?

• To protect from and safely withstand high voltage surges that would damage equipment or harm humans
• To protect expensive controllers – intelligent systems
• To tolerate large ground potential differences and disruptive ground loops in circuits that have high energy or are separated by large distance
• To communicate reliably with high side components in high-voltage high performance solutions
When to use isolation?

- More than one conductive path between two circuits creates a ground-loop
- Multiple ground paths can lead to unintended compensation currents
How to isolate?

- Ground loops can be broken by
  - Disconnecting the grounds
  - Common-mode chokes
  - Frequency selective grounding
  - Differential amplifiers
  - Galvanic isolators

*Only galvanic isolation provides protection for very large potential differences*
Applications

*For switched-mode power electronic applications involved in high-power and high-voltage conversion*
Electronic devices and integrated circuits (ICs) used for isolation are called isolators.
Electronic devices and integrated circuits (ICs) used for isolation are called isolators

A conceptual power drive system block diagram
Let us take a step back and understand
- The concept of power electronics
- What is a gate driver
‘Power Switch’ - Fundamental Component in Power Electronics

Power Switches control flow of current in power electronic circuits by operating in 2 states (ON/OFF)

Ideal switch:

- Blocking loss, $P_{OFF} = V_{OFF} \times I_{OFF} = 0$
- Conduction loss, $P_{ON} = V_{ON} \times I_{ON} = 0$

4 quadrant operation

Power Switches are dominated by Switch Mode Power conversion

- GATE (G) terminal controls ON/OFF status of switch
- Modern Power Electronics dominated by Switch Mode Power conversion

MOSFET

IGBT
How does GATE terminal of a Power Switch Work?

Let’s take example of a power MOSFET

- GATE terminal controls ON/OFF state of MOSFET
- $V_{GS} =$ Voltage Between Gate & Source
- To turn **ON**: Apply a positive voltage, $V_{GS} > $ Threshold level
- To turn **OFF**: $V_{GS} < $ Threshold level
- GATE is a capacitive input, high-impedance terminal
- 2 parasitic capacitors inside MOSFET internal structure ($C_{GS}$, $C_{GD}$)
Now, about Gate Drivers....
What is a Gate Driver

*It is a power amplifier that accepts a low-power input from a controller IC and produces the appropriate high-current gate drive for a power MOSFET*

Gate Driver device applies voltage signal ($V_{GS}$) between Gate ($G$) & Source ($S$) of power MOSFET, while providing a high-current pulse

- To charge/discharge $C_{GS}$, $C_{GD}$ QUICKLY
- To switch ON/OFF power MOSFET QUICKLY

---

**Gate Driver**

Switch Turn-On

Switch Turn-Off
Why are Gate Drivers Necessary in Power Electronics?

Turn-ON

\[ V_{GS} \]

\[ V_{TH} \]

\[ V_{DS} \]

\[ I_D \]

\[ t_0 \]

\[ t_1 \]

\[ t_2 \]

\[ t_3 \]

\[ t_4 \]

Turn-OFF

\[ t_0 \]

\[ t_1 \]

\[ t_2 \]

\[ t_3 \]

\[ t_4 \]

Switching On Loss

\[ \int_{t_1}^{t_3} V_{DS}(t) \cdot I_D(t) dt + E_{OSS} \]

\[ t_1 \sim t_3 \propto \frac{1}{I_{Drv}} \]

Stronger Driver \( \rightarrow \) lower switching loss

Fast charge/discharge of \( C_{GS}, C_{GD} \) reduces power loss in time intervals
Types of Gate Drivers – Based on Switch Position/Arrangement

1. Low Side Drivers
Used to Drive GND referenced switches

2. High side-Low Side Drivers
Used to Drive 2 switches connected in Bridge Arrangement
Topologies in switched mode power electronics

Input ($V_{IN}$, $I_{IN}$, $P_{IN}$)

Switch Mode Power Converter

Output ($V_{OUT}$, $I_{OUT}$, $P_{OUT}$)

Half-Bridge

Full-Bridge

Flyback

Push Pull

3-ph Inverter
Let's look at a power supply application
Power Supply application

Primary

- AC Line: 85-265 VAC
- Distribution BUS Voltage (48, 24, 12 V)
- Isolated Feedback
- Rectified AC 385 V - 400 V
- Boosted DC Output
- Main Card Power 3.3 V
- Local DC/DC

Secondary

- PFC Boost
- PWM
- Local POL Regulators

There is high voltage involved on the primary side of DC/DC

- PFC Boost
- PWM is main loop to regulate Vo, provides proper duty cycle
- Local POL Regulators

Reduces Harmonic Content, lowers peak current and makes load look Resistive

PWM is main loop to regulate Vo, provides proper duty cycle

PWM is main loop to regulate Vo, provides proper duty cycle
Server / Telecom Power Supply example

AC 85~265V

EMI Filter

PFC (Power Factor Correction)

DC

400V

PFC (Power Factor Correction)

#n

PFC (Power Factor Correction)

#2

PFC (Power Factor Correction)

#1

DC

- DC

#n

DC

- DC

#m

DC

- DC

#1

48V

Batteries

On Board

Bus Converters

POLs

12V

uProcessor, Memory, HDD...

All pictures are Used under Fair use, 2015

1. 1Ch/2Ch low side driver

2. High and low side driver

100V / 600V

Texas Instruments
Based on the positioning/placement of the controller, isolation is required between the controller and the driver.
Traditional method of isolation: Transformer

TYPE A
Consider an Isolator + Driver

High side and Low side Gate driver

TYPE B
### Comparison between Gate Drive Transformer & High & Low Side Driver with isolator

<table>
<thead>
<tr>
<th></th>
<th>Type A</th>
<th>Type B</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{Prop}}$</td>
<td>$\approx 20\text{ns}$</td>
<td>$\approx 100\text{ns}$</td>
</tr>
<tr>
<td>Bias Power</td>
<td>NO</td>
<td>Yes</td>
</tr>
<tr>
<td>$C_{\text{IO}}$</td>
<td>$\geq 10\text{pF}$</td>
<td>$\leq 1\text{pF}$</td>
</tr>
<tr>
<td>Parasitics</td>
<td>Large (L_{LK})</td>
<td>Very small</td>
</tr>
<tr>
<td>Overshoot</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>Size</td>
<td>Bulky</td>
<td>Small</td>
</tr>
</tbody>
</table>
Trending towards integration: Isolated gate driver

**TYPE B**
- CMTI > 100V/ns
- 5kVrms reinforced isolation
- Prop: 25ns Typ.
- Match./TPWD < 5ns
- 110mm²

**TYPE C: ISO Driver**
- CMTI > 100V/ns
- 5kVrms reinforced isolation
- T_{Prop}: 25ns Typ.
- Match./TPWD < 5ns
- 110mm²
Trending towards integration: Isolated gate driver

**TYPE A**

<table>
<thead>
<tr>
<th>Type A</th>
<th>W (mm)</th>
<th>L (mm)</th>
<th>H (mm)</th>
<th>Area (mm²)</th>
<th>Vol (mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCC27324</td>
<td>5</td>
<td>6.2</td>
<td>1.75</td>
<td>31</td>
<td>54.25</td>
</tr>
<tr>
<td>GA3550-BL</td>
<td>17.4</td>
<td>24.13</td>
<td>10</td>
<td>420</td>
<td>4200</td>
</tr>
<tr>
<td><strong>SUM</strong></td>
<td><strong>451</strong></td>
<td><strong>4254</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TYPE B**

<table>
<thead>
<tr>
<th>Type B</th>
<th>W (mm)</th>
<th>L (mm)</th>
<th>H (mm)</th>
<th>Area (mm²)</th>
<th>Vol (mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO7520C</td>
<td>10.5</td>
<td>10.6</td>
<td>2.65</td>
<td>111.3</td>
<td>295</td>
</tr>
<tr>
<td>UCC27714</td>
<td>8.75</td>
<td>6.2</td>
<td>1.75</td>
<td>54.25</td>
<td>95</td>
</tr>
<tr>
<td>MURS360</td>
<td>8.1</td>
<td>6.1</td>
<td>2.4</td>
<td>49.41</td>
<td>119</td>
</tr>
<tr>
<td><strong>SUM</strong></td>
<td><strong>215</strong></td>
<td><strong>509</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TYPE C: ISO Driver (UCC21520)**

- CMTI>100V/ns
- 5kVrms reinforced isolation
- $T_{prop}$: 25ns Typ.
- Match./$T_{PWd}$ < 5ns
- $110\text{mm}^2$
Why is driver + isolation integration trend important?

- Adding isolation is becoming mandatory as part of regulatory compliance
- System solutions becoming smaller in size
  - Datacenters – space limited – but more storage
  - Telecom bay stations and RRUs – Higher data transactions
- Higher efficiency
  - Switching to higher voltages
  - More intelligence to systems → More protection of controls
- Higher performance density
- Isolation robustness
- Availability of high voltage devices
  - Wide band gap devices – SiC, GaN
Construction of an isolated gate driver

Multichip module

Visit the UCC21520 webpage
Types of isolation methods

- Capacitive
- Optical
- Inductive
TI uses Capacitive Isolation Technology

- SiO$_2$ is the most stable dielectric over temperature and moisture
- Highest lifetime in the industry, >1.5 kV$_{\text{RMS}}$ for 40 years
  - Superior transient protection for harsh environments, >12.8kV
- Leverage advantages of TI’s process technology
  - Manufacturing repeatability leading to tight part-to-part skew
  - Integration path with many other circuits
  - No wear out mechanisms, low defect levels, high MTBF
Value of Capacitive isolation

**Higher power density, enabling smaller solutions**

High drive currents reduces switching losses with a rise time of 6ns and fall time of 7ns for a 1.8nF load for high frequency switch mode power applications (UCC21520)

**Isolation robustness**

Best-in-class surge protection of 12.8kV and noise immunity greater than 100V/ns with integrated dead-time control is ideal for safety-critical applications.

**Low power consumption**

Reduced standby power as low as 1milliamps (mA) helps increase energy efficiency and increase the life of the device.
Levels of Isolation

- **Functional Isolation**
  - Functional Isolation is necessary for the proper operation of a product. There is no need for protection against electric shock.

- **Basic Isolation**
  - Basic Isolation is single level of isolation providing basic protection against electric shock.

- **Reinforced Isolation**
  - A single insulation system that provide electrical shock protection equal to double insulation.

- **Supplementary Isolation**

- **Double Isolation**
Standards that apply to Isolated drivers

• Component level Standards:
  • IEC 60747-5-5 (VDE 0884-5-5) 
  • VDE 0884-10 / VDE 0884-11
  • IEC 60747-17
  • UL 1577
  • ---

• System Level / End Equipment Standards
  • IEC 61800-5-1, safety requirements for adjustable speed drives
  • IEC 60601-1, Medical equipment standard
  • IEC 61010-1, safety standard for measurement, control and Lab equipment
  • IEC 60950-1, Telecom equipment standard
  • ISO 6469-3, Electric Vehicle Safety Standard
  • .....
Common Isolation Terminologies

- Isolation Rating Voltage (Vrms) : Viso
- Working/Operating/Repetitive Voltage (Vrms)
- Impulse or Surge Voltage (Vpk): Viosm
- Channel to channel voltage

- Creepage Distance
- Clearance

- Tracking
- Comparative Tracking Index (CTI)

<table>
<thead>
<tr>
<th>CTI</th>
<th>Material Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 ≤ CTI</td>
<td>I</td>
</tr>
<tr>
<td>400 ≤ CTI &lt; 600</td>
<td>II</td>
</tr>
</tbody>
</table>

- Pollution Degree 1
- Pollution Degree 2
- Pollution Degree 3

Details on these terminologies to be discussed in the Oct 20th webinar offered on isolation.
Key requirements for an isolated driver

In addition to understanding the levels of isolation,... It is important to find out about the driver functionalities:

- Propagation delay
- Common Mode Transient Immunity (CMTI)
- Rise time/fall time
- Maximum driver side supply voltage
- UVLO
- Channel to channel delay
- Protection schemes
- Dead time control and overlap
- Enable/disable features
### Type of isolated gate drivers

<table>
<thead>
<tr>
<th>Type</th>
<th>Single</th>
<th>Dual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power switch</td>
<td>MOSFET, IGBT</td>
<td>MOSFET</td>
</tr>
<tr>
<td>Pinouts</td>
<td>8, 16, 24, 32</td>
<td>16 (for SOIC), 13,14</td>
</tr>
<tr>
<td>Type of isolation</td>
<td>Basic and Reinforced</td>
<td>Basic and Reinforced</td>
</tr>
<tr>
<td>Package type</td>
<td>SOIC (narrow and wide)</td>
<td>SOIC (narrow &amp; wide), LGA</td>
</tr>
<tr>
<td>Protection features</td>
<td>Yes (for 16, 24 and 32 pins)</td>
<td>No</td>
</tr>
</tbody>
</table>

**Examples**

[Diagram of DW Package 16-Pin SOIC Top View]

[Diagram of DW Package 16-Pin SOIC Top View]
## Comparison between MOSFET and IGBT iso drivers

<table>
<thead>
<tr>
<th>Power Switch</th>
<th>MOSFET</th>
<th>IGBT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switching frequencies</td>
<td>High (&gt;20 kHz)</td>
<td>Low to Medium (5-20kHz)</td>
</tr>
<tr>
<td># Channels</td>
<td>Single and Dual</td>
<td>Single</td>
</tr>
<tr>
<td>Protection</td>
<td>No</td>
<td>Yes – Desaturation, Miller Clamping</td>
</tr>
<tr>
<td>Max Vdd (power supply)</td>
<td>20V</td>
<td>30V</td>
</tr>
<tr>
<td>Vdd range</td>
<td>0-20V</td>
<td>-10 to 20V</td>
</tr>
<tr>
<td>Operating Vdd</td>
<td>10-12V</td>
<td>12-15V</td>
</tr>
<tr>
<td>UVLO</td>
<td>8V</td>
<td>12V</td>
</tr>
<tr>
<td>CMTI</td>
<td>50-100V/ns</td>
<td>&lt;50V/ns</td>
</tr>
<tr>
<td>Propagation delay</td>
<td>Smaller the better (&lt;50ns)</td>
<td>High (not critical)</td>
</tr>
<tr>
<td>Rail Voltage</td>
<td>Up to 650V</td>
<td>&gt;650V</td>
</tr>
<tr>
<td>Typical Applications</td>
<td>Power supplies – Server, datacom, telecom, factory automation, onboard and offboard chargers, solar u-inverters and string inverters (&lt;3kW), 400-12V DCDC - Auto</td>
<td>Moto drives (AC machines), UPS, Solar central and string power inverters (&gt;3kW), Traction inverters for auto</td>
</tr>
</tbody>
</table>
Motor drive application

Gate driver options:
- 6 single channel iso drivers with no protection (8pin) and usually reinforced
- 6 single channel iso drivers with protection (DESAT, Miller clamp or split output) (16 pin)
- 3 single channel iso drivers for high side only (8 or 16 pin) along with 3 non isolated drivers
Solar micro (300W)/string (<3kW) inverter

Usually MOSFET single inverters needing isolated (basic or reinforced) drivers
State-of-the-art Power Semiconductors (Wide Band Gap)

<table>
<thead>
<tr>
<th></th>
<th>Si-MOSFET</th>
<th>IGBT</th>
<th>SiC-MOSFET</th>
<th>GaN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voltage Ratings</strong></td>
<td>20~650V</td>
<td>≥650V</td>
<td>≥650V</td>
<td>≤650V</td>
</tr>
<tr>
<td><strong>Optimal $V_{GS}$</strong></td>
<td>0~15V</td>
<td>-10~15V</td>
<td>-5~20V</td>
<td>-5~10V</td>
</tr>
<tr>
<td><strong>Max. Limit</strong></td>
<td>(±20V)</td>
<td>(-10~20V)</td>
<td>(-5~25V)</td>
<td>(±18V)</td>
</tr>
</tbody>
</table>

- I-V curves are from datasheets of Infineon, CREE, EPC.
Value of Silicon carbide in high voltage & high power applications

✓ High power density – 10x more than Silicon
  ✓ High current density
✓ High breakdown voltage
✓ Drive higher current in a reduced footprint
✓ High thermal conductivity
✓ High mobility – ability to switch at high frequencies
## Comparison of SiC to MOSFET and IGBT iso drivers

<table>
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<th>Power Switch</th>
<th>MOSFET</th>
<th>IGBT</th>
<th>SiC</th>
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<td><strong>Switching frequencies</strong></td>
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<td>Single</td>
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<tr>
<td><strong>Protection</strong></td>
<td>No</td>
<td>Yes – Desaturation, Miller Clamping</td>
<td>Yes – Current sense, Miller Clamping</td>
</tr>
<tr>
<td><strong>Max Vdd (power supply)</strong></td>
<td>20V</td>
<td>30V</td>
<td>30V</td>
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<td>-10 to 20V</td>
<td>-5 to 25V</td>
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<td>10-12V</td>
<td>12-15V</td>
<td>15-18V</td>
</tr>
<tr>
<td><strong>UVLO</strong></td>
<td>8V</td>
<td>12V</td>
<td>12-15V</td>
</tr>
<tr>
<td><strong>CMTI</strong></td>
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<td>&gt;100V/ns</td>
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<tr>
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<td>High (not critical)</td>
<td>Smaller the better (&lt;50ns)</td>
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<td>Moto drives (AC machines), UPS, Solar central and string power inverters (&gt;3kW), Traction inverters for auto</td>
<td>PFC – Power supplies, Solar inverters, DCDC for EV/HEV and traction inverters for EV, Motor drives, Railways</td>
</tr>
</tbody>
</table>

*Note: Blue font highlights similarities*
## TI isolated gate driver family

All families support MOSFETs, SiC MOSFETs, IGBTs

<table>
<thead>
<tr>
<th>Driver Type</th>
<th>ISO*****</th>
<th>UCC*****</th>
</tr>
</thead>
<tbody>
<tr>
<td># Channels</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>DESAT, Soft Turn-off, Miller clamp</td>
<td>Yes</td>
<td>No (yes for Miller Clamp)</td>
</tr>
<tr>
<td>SiC support</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Withstand Isolation voltage ($V_{ISO}$)</td>
<td>5.7kVrms / 8kVpk</td>
<td>5.7kVrms / 8kVpk</td>
</tr>
<tr>
<td>ISO working voltage ($V_{IOWM}$)</td>
<td>1.5kVrms / 2.121kVpk</td>
<td>1.5kVrms / 2.121kVpk</td>
</tr>
<tr>
<td>CMTI (Min)</td>
<td>100kV/µs</td>
<td>100kV/µs</td>
</tr>
<tr>
<td>Supply type</td>
<td>Unipolar, Bipolar</td>
<td>Unipolar, Bipolar</td>
</tr>
<tr>
<td>Peak drive current</td>
<td>2.5A/5A</td>
<td>17A</td>
</tr>
<tr>
<td>Rising and Falling time</td>
<td>20ns/20ns @1.0nF</td>
<td>10ns/10ns @1nF</td>
</tr>
<tr>
<td>VCC, Input</td>
<td>2.25V to 5.5V</td>
<td>3V to 18V</td>
</tr>
<tr>
<td>VDD, Output</td>
<td>15V to 30V</td>
<td>15V to 35V</td>
</tr>
<tr>
<td>VDD, quiescent current</td>
<td>3.6mA</td>
<td>1mA</td>
</tr>
<tr>
<td>Propagation delay (Typ)</td>
<td>76ns</td>
<td>50ns</td>
</tr>
<tr>
<td>Protection</td>
<td>UVLO, Power ready indication, Fault Feedback</td>
<td>UVLO, Disable, Programmable Dead Time</td>
</tr>
<tr>
<td>Packages</td>
<td>SOIC-16 (&gt;8mm Creepage)</td>
<td>SOIC-8 (&gt;4mm, &gt;8.5mm Creepage)</td>
</tr>
<tr>
<td>Devices</td>
<td>ISO5851, ISO5852S (split O/P)</td>
<td>ISO5451, ISO5452 (split O/P)</td>
</tr>
</tbody>
</table>
Discover more about isolation

- Reliability and isolation resources:
  - High-voltage reinforced isolation: Definitions and test methodologies
  - High-voltage isolation quality and reliability for AMC130x

- Understanding isolation terminology and relevance

- Discover our isolation glossary

- Watch part one and two of our introduction to digital isolation video series

- Join the TI E2E™ Community Isolation forum
Helpful information for readers: UCC21520

- View the UCC21520 datasheet.
- Download the application note, “UCC21520: A Universal Isolated Gate Driver with Fast Dynamic Response.”
- Watch videos about the value of an isolated driver and dynamic performance of an isolated driver.
- Learn more about TI’s gate driver portfolio and find technical resources.
- Read the Power House blog post, “Why is the cloud isolated?”
- Join the TI E2E™ Community Power Management forum
Thank you