

## Design Fundamentals of Implementing an Isolated Half-Bridge Gate Driver

Isolated half-bridge gate drivers are used in many applications that range from isolated dc-to-dc power supply modules where high power density and efficiency are required, to solar inverters where high isolation voltage and long-term reliability are critical. These design concepts will be discussed in detail as this article explores the ability of isolated half-bridge gate driver solutions to provide high performance and a small solution size.

The isolated half-bridge driver's function is to drive the gates of high- and low-side N-channel MOSFETs (or IGBTs) with a low output impedance to reduce the conduction losses, and a fast switching time to reduce the switching losses. The high- and low-side drivers need very close matching of the timing characteristics to allow accurate and efficient switching. This reduces the deadtime from one switch of the half bridge turning off before the second switch turns on. The typical approach to implementing the isolated half-bridge gate drive function is to use an optocoupler for isolation, followed by a high voltage gate driver IC, as shown in Figure 1. One potential issue with this circuit is that there is only one isolated input channel, and it relies on the high voltage driver to have the needed matching in the timing between channels, and it also relies on the deadtime needed for the applications. Another concern is that high voltage gate drivers do not have galvanic isolation and rely, instead, on junction isolation to separate the high-side drive voltage from the low-side drive voltage in the same IC. Parasitic inductance in the circuit can cause the output voltage,  $V_S$ , to go below ground during a low-side switching event. When this happens, the high-side driver can latch up and become permanently damaged.

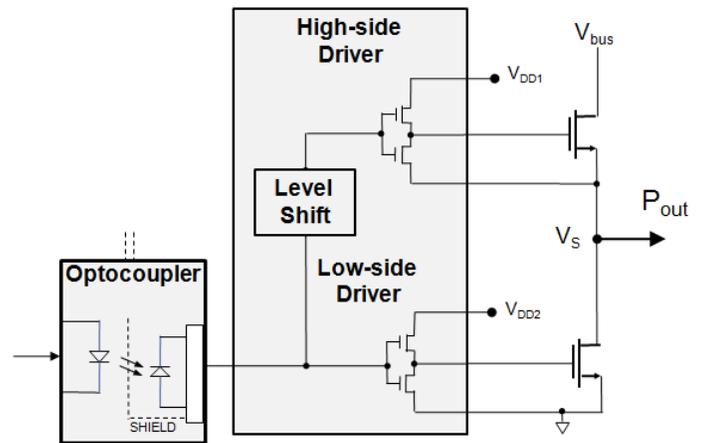


Figure 1. High Voltage Half-Bridge Gate Driver

### Optocoupler Gate Driver

The next approach, shown in Figure 2, avoids problems with high-side to low-side interactions by using two optocouplers to establish galvanic isolation between the outputs. The gate driver circuit is often included in the same package as the optocoupler, and it is most common for there to be two separate optocoupler gate driver ICs to complete the isolated half bridge, which makes for a larger solution size. It should be noted that optocouplers are manufactured as a discrete device, even if two are packaged together, so they will have limitations in channel-to-channel matching. This will increase the required deadtime between switching one channel off and turning the other channel on, reducing the efficiency. The response speed of an optocoupler is also limited due to the capacitance of the primary side light emitting diode (LED), and driving the output to speeds up to 1 MHz will be limited by its propagation delay (500 ns max) and slow rise and fall time (100 ns max). To run an optocoupler to its maximum speed, the LED current needs to be increased to more than 10 mA, consuming more power, and reducing the lifetime and reliability of the optocoupler, especially in high temperature environments common in solar inverter and power supply applications.

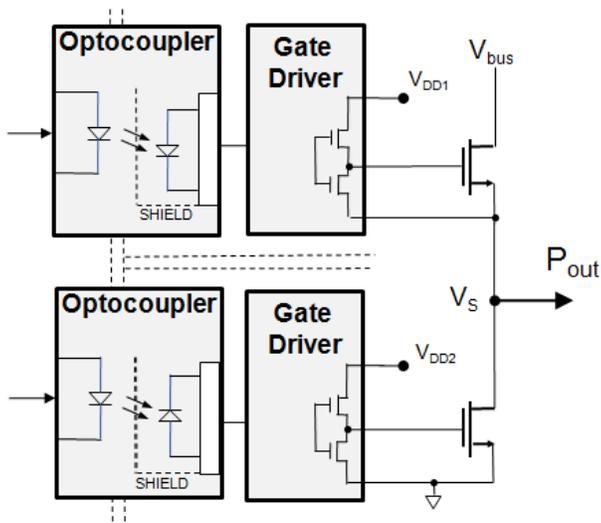


Figure 2. Optocoupler Half-Bridge Gate Driver

### Pulse Transformer Gate Driver

Next, we will look at galvanic isolators which have a speed advantage over optocouplers due to lower propagation delays and more accurate timing. A pulse transformer is an isolation transformer which can operate at speeds often needed for half-bridge gate driver applications (up to 1 MHz). A gate driver IC can be used to deliver the high currents needed for charging the capacitive MOSFET gates. The gate driver in Figure 3 will differentially drive the primary of the pulse transformer, which has two windings on the secondary to drive each gate of a half bridge. An advantage of using a pulse transformer is that it does not require isolated power supplies to drive the secondary side MOSFETs. A potential problem in this application can occur when large transient gate drive currents flow in the inductive coils, causing ringing. This can potentially switch the gate on and off when not intended, leading to damage of the MOSFETs. Another limitation with pulse transformers is they may not work well in applications that require signals that have more than 50% duty cycle. This is because transformers can deliver only ac signals since the core flux must be reset each half cycle to maintain a volt-second balance. Finally, the magnetic core and isolated windings of the pulse transformer require a relatively large package. This, combined with the driver IC and other discrete components, creates a solution that may be too large for many high density applications.

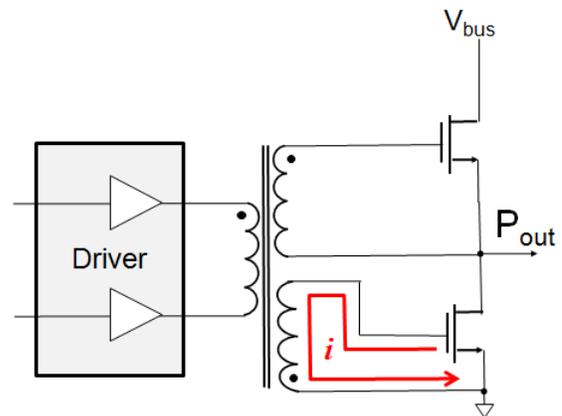


Figure 3. Pulse Transformer Half-Bridge Gate Driver

### Digital Isolator Gate Driver

Now we will look at the digital isolator approach to an isolated half-bridge gate driver. In Figure 4, the digital isolator uses a standard CMOS integrated circuit process with metal layers to form transformer coils separated by polyimide insulation. This combination achieves more than 5 kV rms (1 minute rating) isolation, which can be used in reinforced isolated power supply and inverter applications.

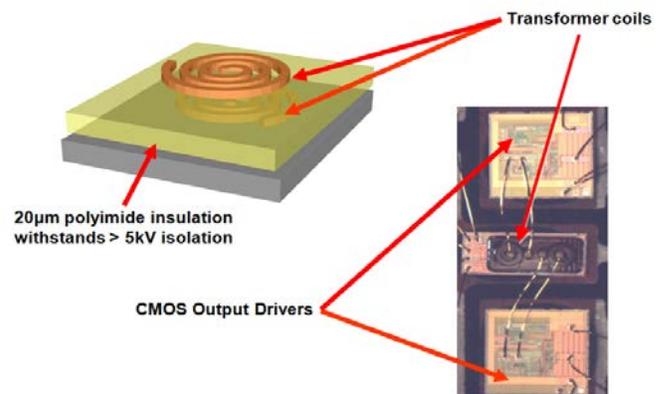


Figure 4. Digital Isolator with Transformer Isolation

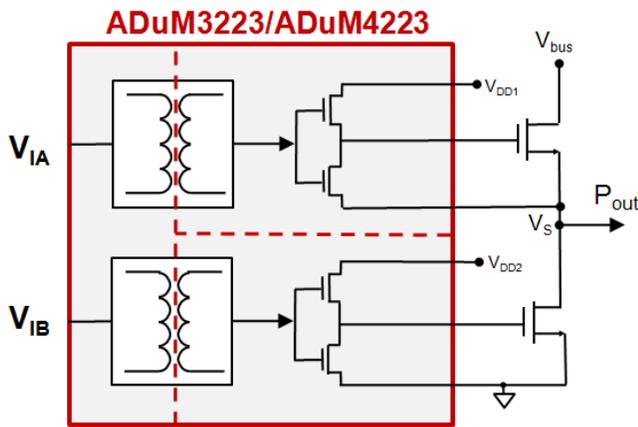


Figure 5. Digital Isolator 4 A Gate Driver

As shown in the circuit in Figure 5, the digital isolator eliminates the LED used in an optocoupler and its associated aging problems, consumes far less power, and is more reliable. Galvanic isolation is provided between the input and the output, and between the outputs, to eliminate high-side to low-side interactions. The output drivers deliver a low output impedance to reduce the conduction losses and a fast switching time to reduce the switching losses. Unlike an optocoupler design, the high- and low-side digital isolators are integrated circuits with matching outputs for better efficiency. The high voltage gate driver integrated circuit (Figure 1) has added propagation delay in the level shifting circuit, so it cannot match channel-to-channel timing characteristics like the digital isolator can. This integration of the gate drivers in the digital isolator reduces the solution size down to a single package for a much smaller solution size.

**Common-Mode Transient Immunity**

In many half-bridge gate driver applications for high voltage power supplies, very fast transients can occur across the switching elements. In these applications, if a large  $dV/dt$  can capacitively couple across an isolation barrier, it has the potential to cause logic transition errors across the barrier. In an isolated half-bridge driver application, this could turn on both switches in a cross conduction that could destroy the switches. Any parasitic capacitance across the isolation barrier tends to be a coupling path for common-mode transients. Optocouplers need to have very sensitive receivers to detect the small amount of light transmitted across their isolation barrier, and their outputs can be upset by large common-mode transients. The optocoupler sensitivity to common-mode transient voltages can be improved by the addition of a shield added between the LED and the receiver, which is how most optocoupler gate drivers are made. This shield can improve the common-mode

transient immunity (CMTI) from a standard optocoupler rated at less than  $10 \text{ kV}/\mu\text{s}$  to as much as  $25 \text{ kV}/\mu\text{s}$  for an optocoupler gate driver. For many gate drive applications,  $25 \text{ kV}/\mu\text{s}$  CMTI may be enough, but for power supplies with large transient voltages and for solar inverter applications,  $50 \text{ kV}/\mu\text{s}$  or more CMTI may be needed.

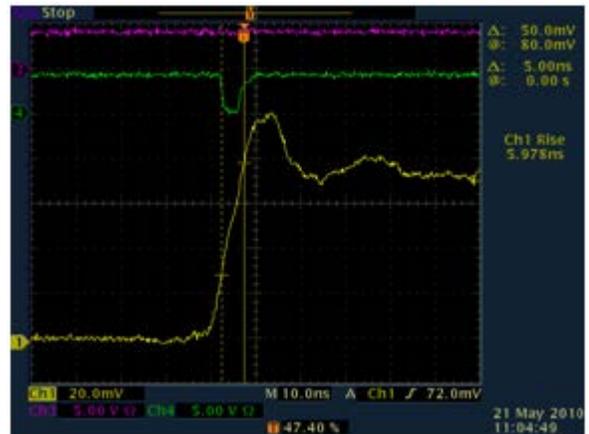


Figure 6. Capacitor-Based Digital Isolator with CMTI of  $< 10 \text{ kV}/\mu\text{s}$

Digital isolators can deliver higher signal levels to their receivers and withstand very high levels of common-mode transients without data errors. Transformer-based isolators are four terminal devices and provide low differential impedance to the signal and high common-mode impedance to the noise, which can yield excellent CMTI. Other digital isolators may use capacitive coupling to create a changing electric field and transmit data across the isolation barrier. Unlike the transformer-based isolator, the capacitor-based isolator is a two terminal device and the noise and the signal share the same transmission path. With a two terminal device, the signal frequencies need to be well above the expected frequency of the noise so that the barrier capacitance presents low impedance to the signal and high impedance to the noise. When the common-mode noise level becomes large enough to overwhelm the signal, it can cause a data upset at the isolator output. An example of a capacitor-based isolator data upset is shown in Figure 6, where the output (Channel 4) has glitched low for 6 ns during a common-mode transient of only  $10 \text{ kV}/\mu\text{s}$ . Note that this data was taken at the threshold level of upsetting the capacitor based isolator, and if the transient was larger, the upset could last for a much longer time, which could make the switching of the MOSFETs unstable. In contrast, transformer-based digital isolators have been shown to withstand common-mode transients in excess of  $100 \text{ kV}/\mu\text{s}$  without a data upset at the output (see Figure 7).

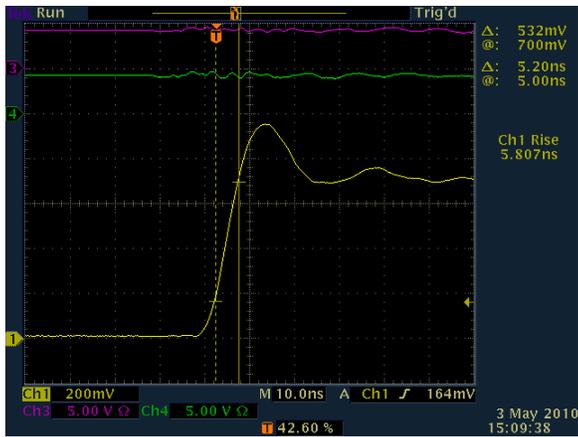


Figure 7. Transformer-Based Digital Isolator ADuM140x with CMTI of 100 kV/ $\mu$ s

In summary, for isolated half-bridge gate driver applications, the transformer-based digital isolator has been shown to offer numerous advantages over optocoupler and pulse transformer-based designs. The solution size and design complexity are dramatically reduced through integration, which leads to much improved timing performance. Robustness is also improved through galvanic isolation of the output drivers and higher CMTI.

## REFERENCES

Technical Article, *Common-Mode Transient Immunity*, Chris Coughlin (Analog Devices)

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