Implementing an Isolated Half-Bridge Gate Driver

By Brian Kennedy

Many applications, ranging from isolated dc-to-dc power supply modules that call for high power density and efficiency, to solar inverters, where high isolation voltage and long-term reliability are critical, use isolated half-bridge gate drivers to control large amounts of power. This article will discuss details of these design concepts to illustrate the ability of isolated half-bridge gate driver ICs to provide high performance in a small package.

A basic half-bridge driver with optocoupler isolation, shown in Figure 1, controls output power by driving the gates of high- and low-side N-channel MOSFETs (or IGBTs) with signals of opposite polarity. The drivers must have low output impedance, to reduce conduction losses, and fast switching—to reduce switching losses. For accuracy and efficiency, the high- and low-side drivers need very closely matched timing characteristics in order to reduce the dead time when one switch of the half bridge turns off before the second switch turns on.

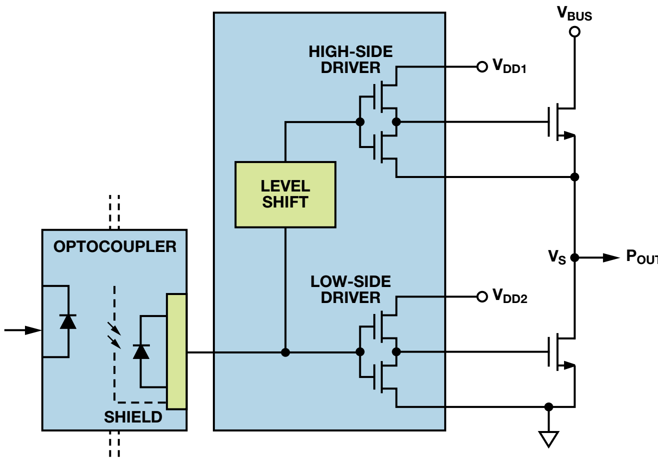

Figure 1. High-voltage half-bridge gate driver.

As shown, a conventional approach to implementing this function uses an optocoupler for isolation, followed by a high-voltage gate-driver IC. A potential drawback of this circuit is that the single isolated input channel relies on the high-voltage driver circuit for the needed channel-to-channel timing match, as well as the required dead time. Another concern is that high-voltage gate drivers do not have galvanic isolation; instead, they rely on the IC's junction isolation to separate the high-side drive voltage from the low-side drive voltage. 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.

Optocoupler Gate Driver

Another approach, shown in Figure 2, avoids the problems of high-side to low-side interactions by using two optocouplers and two gate drivers to establish galvanic isolation between the outputs. The gate-driver circuit is often included in the same package as the optocoupler, so two separate optocoupler-gate-driver ICs are commonly required to complete the isolated half bridge—increasing the physical solution size. Note also that the optocouplers are manufactured separately, even if two are packaged together, limiting the ability to match the two channels. Allowing for this mismatch will increase the required dead time between switching one channel off and turning the other channel on, reducing efficiency.

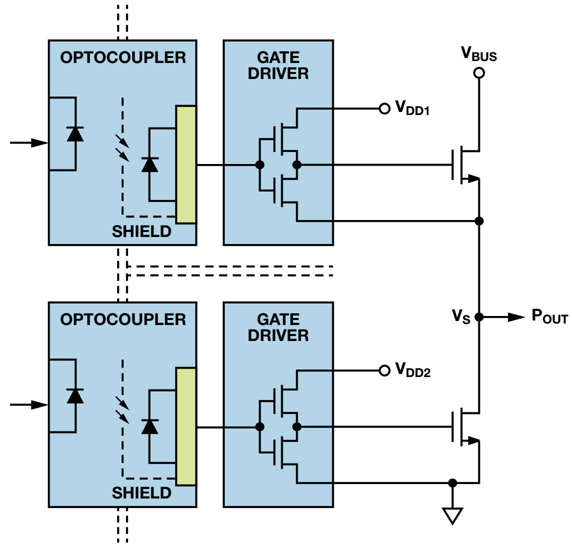

Figure 2. Dual optocoupler half-bridge gate driver.

The optocoupler's response speed is limited by the capacitance of the primary side light-emitting diode (LED); while driving the output to speeds up to 1 MHz, it will also be limited by its propagation delay (500 ns max) and slow rise and fall times (100 ns max). To run an optocoupler near its maximum speed, the LED current must be increased to more than 10 mA, consuming more power and reducing the optocoupler's lifetime and reliability—especially in the high-temperature environments common in solar inverter and power supply applications.

Pulse Transformer Gate Driver

Next, consider circuits where the galvanic isolation is provided by transformer coupling. Their lower propagation delays and more accurate timing can provide a speed advantage over optocouplers. In Figure 3, a pulse transformer is used; it can operate at the 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. Here, the gate driver differentially drives the primary of the pulse transformer; the two secondary windings drive each gate of a half bridge. In this application, pulse transformers have the advantage of not requiring isolated power supplies to drive the secondary side MOSFETs.

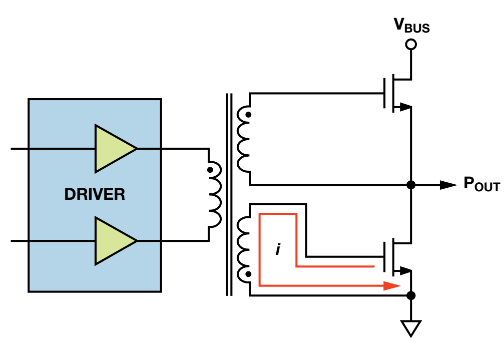

Figure 3. Pulse transformer half-bridge gate driver.

However, a problem can occur when large transient gate-drive currents flowing in the inductive coils cause ringing. This can switch the gate on and off when not intended, damaging the MOSFETs. Another limitation of pulse transformers is that they may not work well in applications that require signals with more than 50% duty cycle, as they can deliver only ac signals, and the core flux must be reset each half cycle to maintain a volt-second balance. A final difficulty: the magnetic core and isolated windings of the pulse transformer require a relatively large package which, combined with the driver IC and other discrete components, creates a solution that may be too large for many high-density applications.

Digital Isolator Gate Driver

Consider now applying a digital isolator in an isolated half-bridge gate driver. The digital isolator in Figure 4 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 robust isolated power supply and inverter applications.

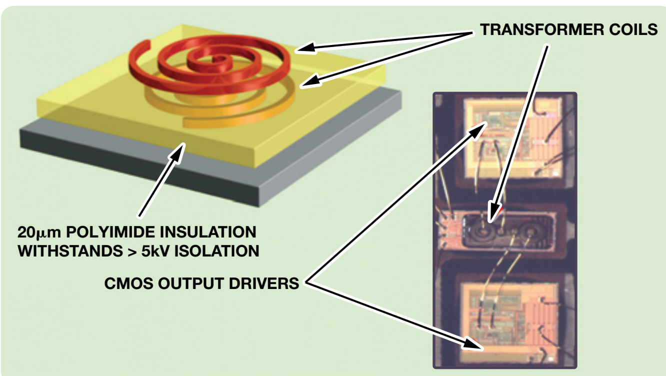

Figure 4. Digital isolator with transformer isolation.

As shown 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 (dashed lines) is provided between input and output, and between the two outputs, eliminating high-side to low-side interactions. The output drivers feature a low output impedance to reduce the conduction losses—and a fast switching time to reduce the switching losses.

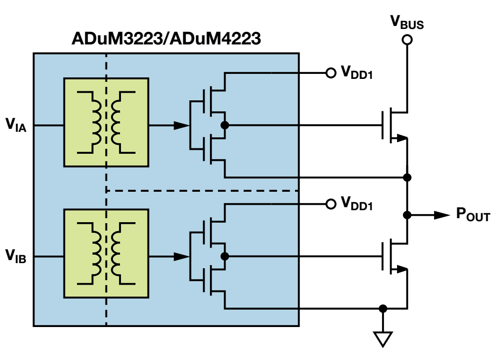

Figure 5. Digitally isolated 4-A gate driver.

Unlike an optocoupler design, the high- and low-side digital isolators are manufactured on a single integrated circuit, with inherently matched outputs for better efficiency. Note that the high-voltage gate driver integrated circuit shown in Figure 1 has additional propagation delay in the level-shifting circuit, so it cannot match channel-to-channel timing characteristics as well as the digital isolator. Furthermore, integration of the gate drivers with isolation in a single IC package reduces the footprint of the solution to a minimum.

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, a rapidly changing voltage transient (high *dV/dt*) that capacitively couples across an isolation barrier can cause logic transition errors across the barrier. In an isolated half-bridge driver application, this could turn on both switches in a cross-conduction episode 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 reduced by the addition of a shield between the LED and the receiver; a technique used in most optocoupler gate drivers. The shield can improve the *common-mode transient immunity* (CMTI) from a standard optocoupler rating of less than 10 kV/μs to as much as 25 kV/μs for an optocoupler gate driver. This rating may be suitable for many gate-driver applications, but CMTI of 50 kV/μs or more may be needed for power supplies with large transient voltages, and for solar inverter applications.

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, as four-terminal differential devices, can provide low differential impedance to the signal and high common-mode impedance to the noise—which can result in excellent CMTI. On the other hand, digital isolators that use capacitive coupling to create a changing electric field and transmit data across the isolation barrier are two-terminal devices, so 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 upset the data at the isolator output. An example of a capacitor-based isolator data upset is shown in Figure 6, where the output (Channel 4, green line) has glitched low for 6 ns during a common-mode transient of only 10 kV/μs.

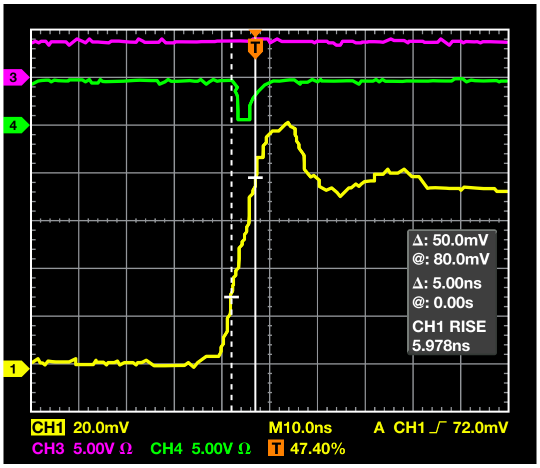

Figure 6. Capacitor-based digital isolator with CMTI of <10 kV/μs.

This data was taken merely at the *threshold* level of upsetting the capacitor-based isolator transient; a much larger transient could cause the upset to 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 kV/μs without a data upset at the output (Figure 7).

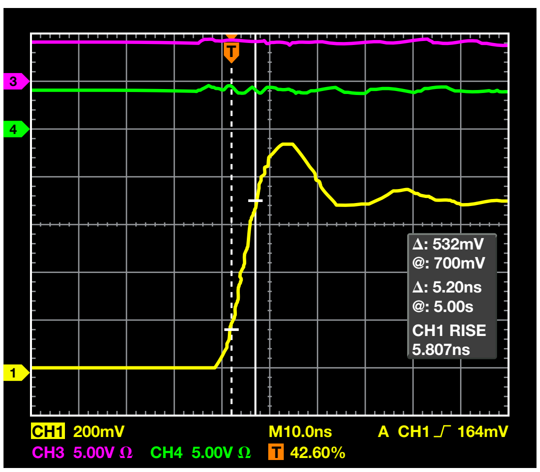

Figure 7. Transformer-based digital isolator with CMTI of 100 kV/μs (ADuM140x).

Isolated Half-Bridge Drivers Provide 4-A Peak Output Currents

The ADuM3223/ADuM4223 isolated half-bridge gate drivers, shown in Figure 8, use *i*Coupler® technology to provide independent, isolated outputs for driving the gates of the high-side and low-side IGBT and MOSFET devices used in motor control, switching power supplies, and industrial inverters. Combining high-speed CMOS with monolithic transformer technology, these isolation components provide precise timing, high reliability, and better overall performance than optocouplers or pulse transformers. Each output may be continuously operated up to 565 V_{PEAK} relative to the input, thereby supporting low-side switching to negative voltages. The differential voltage between the high side and low side may be as high as 700 V_{PEAK}. Switching at up to 1 MHz, the outputs can provide 4-A peak currents. The CMOS-compatible inputs provide 50-kV/μs common-mode transient immunity. The drivers operate with a 3.0-V to 5.5-V input supply, providing compatibility with lower voltage systems. Specified from –40°C to +125°C, they are available in 16-lead SOIC packages. Priced at $1.70 in 1000s, the ADuM3223 provides 3-kV rms isolation in a narrow body. Priced at $2.03 in 1000s, the ADuM4223 provides 5-kV rms isolation in a wide body.

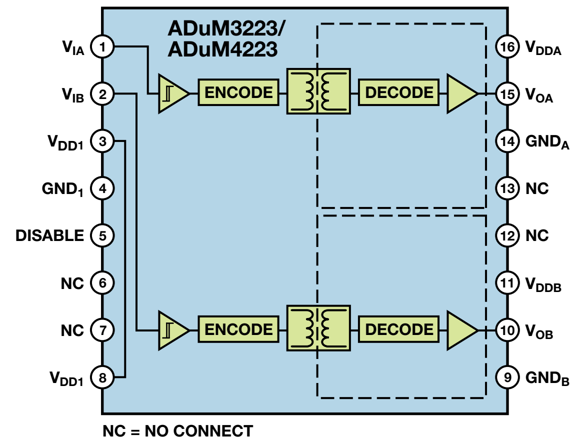

Figure 8. ADuM3223/ADuM4223 block diagram.

Summary

For isolated half-bridge gate-driver applications, the integrated transformer-based digital isolator has been shown to offer numerous advantages over optocoupler- and pulse-transformer-based designs. Size and design complexity are dramatically reduced through integration, greatly improving timing. Robustness is improved through galvanic isolation of the output drivers, and transformer coupling results in higher CMTI.

References

Coughlin, Chris. Technical Article, *Common-Mode Transient Immunity*.

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Author

Brian Kennedy [brian.kennedy@analog.com] is an applications engineer with the Digital Isolator Group at Analog Devices. He has been with ADI since April 2008 and is responsible for power supply digital isolation products. He has a Bachelor of Science in Electrical Engineering (BSEE) from State University of New York (Buffalo).