### Controlling synchronous rectifiers with digital isolators

Brian King, Applications Engineer, Texas Instruments - June 14, 2010

Many of today’s switching power supplies implement synchronous rectifiers to improve efficiency. In isolated topologies, the power-supply controller typically is located on the primary side of the isolation barrier, while the synchronous rectifiers are located on the secondary side. The control signals must bridge the isolation boundary with minimal delay.

Gate drive transformers are the most popular method of accomplishing this. While less common, optocouplers are sometimes used. Some topologies lend themselves to implementing self-driven synchronous rectifiers, where the gate drive signals are derived directly from the power transformer. The emergence of capacitive-coupled digital isolators presents a new solid-state solution to driving synchronous rectifiers.

**Figure 1** shows a functional drawing of a digital isolator, the ISO721M. It contains a logic input and an output buffer, separated by a silicon dioxide insulation barrier. The digital isolator conditions the input signal and differentiates the signal across the isolation barrier through capacitive coupling.

On the secondary side of the isolator, a differential comparator receives the signal and translates it to a logic output. The dielectric and capacitor symmetry within the integrated circuitry results in close capacitive matching, and provides immunity to fast voltage transients between the input and output grounds. A separate, periodic, update pulse is sent to notify the secondary circuitry that the primary circuitry is operating properly. If this pulse is absent on the secondary for more than 4 μs, the output enters a failsafe mode, where the output is held high. These devices are packaged in a surface mount 8-pin small outline package.

**Figure 1: The capacitively-coupled digital isolator uses balanced signals to work robustly in high dV/dt environments.**
The performance characteristics of these digital isolators are more than adequate for switching power supply applications. The isolation barrier of a typical digital isolator provides galvanic isolation of 4000 V. Most isolated power supplies require 1500 V or 3000 V of isolation. Moreover, digital isolators provide immunity to transients up to 50 kV/μs, which is a necessity in the high dV/dt environment created by switching power supplies. The maximum data rate of a digital isolator is typically around 150 Mbps, while switching power supplies typically run at frequencies between 100 kHz and 1 MHz.

Propagation delays are critical when controlling synchronous rectifiers. Too much delay can lead to shoot-through currents. Shoot-through occurs when the primary power switch reverses the polarity of the voltage on the primary of the transformer before the secondary synchronous rectifiers have had a chance to commutate to the off-state. When this happens, the transformer’s secondary windings are basically shorted out by the secondary synchronous rectifiers, resulting in large shoot-through currents and excessive power dissipation. Typically, propagation delays below 100 ns are manageable in switching power supplies. The maximum delay time of a digital isolator is on the order of 10 ns.

Digital isolators are designed for digital applications like industrial field bus, computer peripheral interface, servo control interface, and data acquisition. As a result, they require extra circuitry to interface with power supply controllers. The isolators need either a 3.3 V or 5 V supply on the primary side to run the internal logic. Some power supply controllers contain auxiliary reference voltages that may be used; however, their current capacity must not be exceeded. Digital isolators can draw up to 4 mA from the primary side supply (V_{CC1}). Alternatively, a small linear regulator can be used to power the isolator.

The logic input signal must also be conditioned. The gate drive output signals from power-supply controllers are usually 12 V or more. Translating this signal can be done with a few discrete components, as shown in Figure 2. While the gate drive signal is high, D2 clamps the input to a couple hundred mV above V_{CC1} and R1 limits the current from the controller gate drive. But, the resistance of R1 and input pin parasitic capacitance results in a significant delay. C1 is added to reduce the delay by speeding up the rising edge transition at the isolator input. D1 allows for a very rapid turn off during the falling edge of the gate drive signal.

![Figure 2: The logic-level input of the digital isolator requires conditioning](Click on image to enlarge)
The secondary side of the digital isolator also requires extra circuitry to interface with the analog world. The secondary side logic supply (VCC2) also requires either a 3.3 V or 5 V supply, which can be provided by a low-power linear regulator. The logic-level output of the isolator is insufficient for directly driving the gates of the synchronous rectifiers. The drive signal must be sent to a MOSFET driver IC, which must have minimal propagation delays and adequate current driving capacity.

**Figure 3** shows the schematic of a 6 V/120 W forward converter in an isolated 48 V input design using a digital isolator. The primary MOSFETs (Q4 and Q5) are controlled by the UCC2897A controller. The gate drive of the UCC2897A (labeled DRV in the schematic) is conditioned and sent to the ISO721M logic input. Two TPS71550 low-power linear regulators provide bias power to the ISO721M. The isolator sends its logic output signal to the TPS28225 MOSFET driver, which generates LGATE and UGATE signals to drive two sets of synchronous FETs.

![Figure 3](image)

*Figure 3: A digital isolator controls synchronous rectifiers in a 120 W active-clamp forward. (Click on image to enlarge)*

In this forward converter, power is passed from input-to-output when Q4 and Q5 are on. For proper operation, Q1 and Q2 must be on at the same time as Q4 and Q5. During the off time of Q4 and Q5, the other set of synchronous rectifiers, Q7 and Q8, are turned on. The combined propagation delay from the UCC2897A to the gate of the synchronous MOSFETs is on the order of 50 ns. A 20- gate resistor (R3) was added to slow down the turn-on of the primary FETs to compensate for this slight delay.

The ISO721M gate drive circuit uses a minimal amount of power to send the drive signal to the MOSFET driver. The use of synchronous rectifiers allows this 20 A supply to achieve a maximum efficiency of over 94 percent. **Figure 4** shows a photograph of this reference design. The high efficiency and high level of integration allow this design to be packaged into a quarter brick form factor with no additional heat sinking. This design is also scalable to a wide range of output voltages.
Table 1 provides a comparison of four different synchronous rectifier control techniques. Self-driven synchronous rectifiers offer the most attractive solution, but their use is limited based on the topology, input and output voltages, and patents. Gate drive transformers provide a cost effective alternative to self-driven synchronous rectifiers, but the physical dimensions of the transformers can sometimes be a problem. With a digital isolator, propagation delays are less than encountered when using a gate drive transformer or an opto-isolated gate drive circuit. In addition, the digital isolator circuitry is low profile and requires a minimal amount of board space.

<table>
<thead>
<tr>
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<th>Optocoupler</th>
<th>Gate Drive Transformer</th>
<th>Self-Driven Synch. Rectifiers</th>
<th>Digital Isolator</th>
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<tbody>
<tr>
<td>Isolation Voltage</td>
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<td>0 to 10 Discs</td>
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Table 1: Four different synchronous rectifier control techniques compared. (*Requires additional conditioner circuits with 25 to 50 ns additional delay)
Digital isolators provide a solid state method of controlling synchronous MOSFETs in isolated switching power supplies. Additionally, the digital isolator circuitry consumes less than 100mW, minimizing the impact on residual power loss. Although the example shown here is a simple forward converter, digital isolators have much potential in topologies where more complicated logic is required for synchronous rectifiers, like full-bridge and interleaved topologies.

**References:**
Relevant datasheets and other technical documents include:

- [http://www.ti.com/iso721m-ca](http://www.ti.com/iso721m-ca)
- [http://www.ti.com/ucc2897a-ca](http://www.ti.com/ucc2897a-ca)
- [http://www.ti.com/tps71550-ca](http://www.ti.com/tps71550-ca)
- [http://www.ti.com/tps28225-ca](http://www.ti.com/tps28225-ca)

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