Digital Isolation for AC Voltage Motor Drives

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IDEA IN BRIEF

Isolation is an integral part of ac voltage motor drives. There are several methods of providing electrical isolation— primarily, optocouplers and digital isolators are used. The use of digital isolators provides several benefits as compared to traditional optocouplers—some of which include reduction in cost, component count, and improved reliability. This article will compare methods of isolation in a traditional motor controller design to highlight the benefits of digital isolators.

OPTOCOUPLER VS. DIGITAL ISOLATOR BACKGROUND

Optocouplers use light from LEDs to transmit data across an isolation barrier to a photodiode. As the LED is driven on and off, logic high and low signals are generated on the electrically isolated photodiode side. The speed of an optocoupler is directly related to the speed of the detector photodiode and the time that it takes to charge its diode capacitance. One way to improve speed is to increase the LED current, but this comes at the cost of increased power consumption.

In contrast, transformer based digital isolators use transformers to magnetically couple data across an isolation barrier. Transformers pulse current through a coil to create a small, localized magnetic field that induces current in another coil. The transmission speed in transformers is inherently much faster than optocouplers. Transformers are also differential and provide excellent common-mode transient immunity. Also, since digital isolators are transformer based and optocouplers are LED based, digital isolators provide significantly better reliability/MTTF over optocouplers.

ISOLATION IN A MOTOR DRIVE DESIGN

Figure 1 provides a block diagram of the high voltage FlexMC motor control drive developed by Boston Engineering Corporation (http://www.boston-engineering.com/), which interfaces to an ADSP-CM40x mixed-signal control processor. The drive receives a universal ac input, provides a power factor corrected (PFC) front end, and drives a permanent magnet synchronous motor (PMSM) while providing the necessary feedback conditioning for a sensored or sensorless control running on the ADSP-CM40x, an ARM® Cortex™-M4 mixed-signal control Processor with a 16-bit high precision analog front end. At the center is an isolation barrier between the high voltage power electronics and the controller. The motor power electronics are floating at high voltage potentials while the ADSP-CM40x processor is referenced to earth ground, thus the need for isolation. This paper will explore how the selection of digital isolators over optocouplers improves this design.
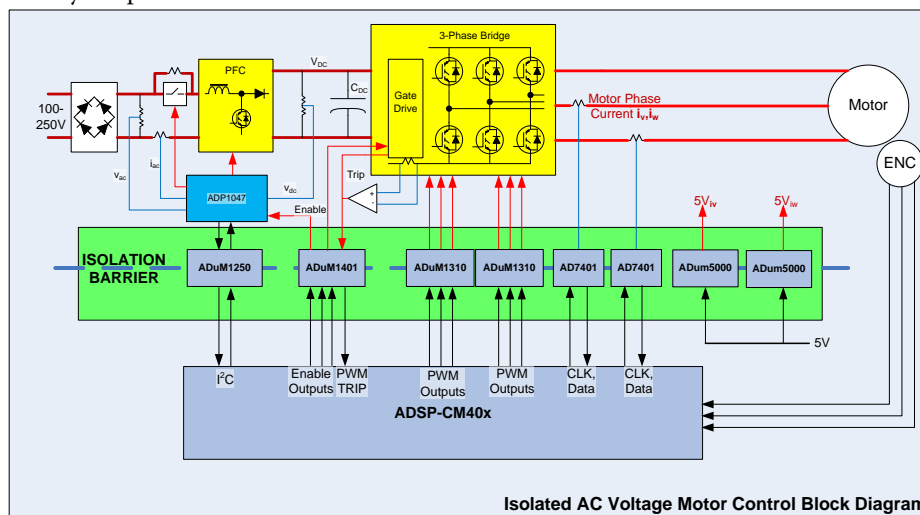

Figure 1. Motor Control Block Diagram

Two critical hardware elements to a closed loop motor control design are the pulse-width modulated (PWM) controller outputs and the motor phase current feedback. These signals, as shown in the block diagram, pass through the isolation barrier. In addition, there are several other functions that benefited from the use of isolators, including digital communication and low voltage, low power, isolated dc-to-dc conversion.

PWM ISOLATION

Pulse-width modulation of the power stage is at the heart of all motor drives. Switching frequencies are typically in the 10 kHz – 20 kHz range. Precise control of pulse widths, dead time, and channel-to-channel delay are critical when optimizing control performance. When selecting the appropriate isolation device for PWM control signals, digital isolators provide significant advantages in performance and cost over comparable optocoupler options (see comparison table shown in Table 1).

Table 1. PWM Digital Isolator vs. Optocoupler Comparison

	PWM Isolation	
	ADuM1310	**Optocoupler Solution**
Size (in^2)	0.5	0.45
Cost @ 1K Quantity ($)	3.98	9.72
Component Count	2	6
Max Rate (Mbps)	90	50
Max Propogation Delay (ns)	32	650
Output Rise/fall time (ns)	2.5	550
Channel-Channel Matching (ns)	2	500
Dielectric Insulation (Vrms)	2500	3750
MTTF (10^6 Hours)	318	12.7
Power (mW)	15	105

For example, controllers introduce dead time between switching signals to prevent any high and low side transistor pairs from conducting simultaneously (i.e. shoot through). This dead time is a function of the delays in the turn on/off of the power switches and the uncertainty in the delay introduced by the isolation circuits. The ADuM1310 digital isolator provides a channel-to-channel matching of only 2 ns, as compared to 500 ns for optocouplers. Utilizing digital isolators allows for the dead time to be greatly reduced, thus improving power inverter performance. Furthermore, as can be seen in the comparison table, in addition to performance, the ADuM1310 provides a much more integrated solution, reducing component count and BOM cost.

MOTOR PHASE CURRENTS

Most advanced motor drives utilize motor phase current as a primary feedback. To provide continuous feedback, very low resistance shunt resistors are placed in series with the motor phases. However, this adds to the complexity of trying to measure millivolt level signals and common-mode voltage swings of hundreds of volts switching at high frequency with rapid dv/dt. For this design, two AD7401A isolated Σ-Δ modulators were used to measure the motor winding current and the digital bit stream is then processed by digital filtering circuitry on the ADSP-CM40x. The built-in sinc filter on the ADSP-CM40x allows for glueless connection to the isolated Σ-Δ modulators. The third phase current can be derived mathematically from the other two to save on power dissipation and component costs. The AD7401A contains a differential track and hold stage, a Σ-Δ modulator, and digital isolation all in a single package. The high voltage side analog signal is converted to a digital serial data stream, which is then transmitted across the isolation barrier to the low voltage side. The AD7401A also contains a clock input lead which allows for the measurements on each device to be made simultaneously with a single clock source. As seen in Table 2, optocouplers with a similar level of integration and cost exist, however the digital isolator technology still provides better power consumption, speed performance, and reliability based on the fundamental construction of the devices in addition to the superior modulator performance of the AD7401A.

Table 2. Phase Current Digital Isolator vs. Optocoupler Comparison

|	Phase Current Measurement	
	AD7401A	**Optocoupler Solution**
Size (in^2)	0.18	0.15
Cost @ 1K Quantity($)	3.8	3.8
Component Count	1	1
Max Rate (Mbps)	20	10
Dielectric Insulation (Vrms)	5000	5000
MTTF (10^6 Hours)	1576	4.9
Power (mW)	70	91
Resolution (bits)	16	16
Gain Error (%)	0.5	1
SNR (dB)	80	68
Offset Drift (µV/degC)	3.5	3.5

DIGITAL COMMUNICATION

I²C is a two-wire, multidrop communication interface frequently used to provide digital or analog IO expansion capability to a controller. This approach is typically reserved for 'housekeeping' type of functions that are monitored or updated periodically. The FlexMC high voltage board uses an I²C interface to communicate with a PFC controller as well as an ADC monitoring the bus voltage, bus current, and IGBT temperature. The ADuM1250 allows for all this functionality on the high voltage side to be monitored by the ADSP-CM40x controller utilizing just a two wire peripheral interface through a single isolator. In contrast, there is no single optocoupler device that can provide I²C isolation. As a result and as can be seen in Table 3, the ADuM1250 is a clear choice over optocoupler options for I²C isolation for reasons of cost, size, component count, and performance.

Table 3. I²C Digital Isolator vs. Optocoupler Comparison

	Phase Current Measurement	
	AD7401A	Optocoupler Solution
Size (in^2)	0.3	0.2
Cost ($)	3.8	3.8
Component Count	1	1
Max Rate (Mbps)	20	10
Dielectric Insulation (Vrms)	5000	5000
MTTF (10^6 Hours)	1576	4.9
Power (mW)	70	91
Resolution (bits)	16	16
Gain Error (%)	0.5	1
Offset Drift (µV/degC)	3.5	3.5

ISOLATED POWER

Another area where the use of digital isolator technology has benefited this design is with the generation of very low level isolated power supplies. Two ADuM5000 devices were used to generate isolated 5 V supplies with up to 500 mW of power output capability. These were used to power the analog side of the Σ-Δ converters, which float with the rapidly changing motor voltage. These isolated supplies use the same technology as the data isolators so they have an internal transformer switching at 180 MHz. This frequency is three orders of magnitude higher than standard dc-to-dc converters allowing for a much smaller size. The ADuM5000 devices are a simple way to provide low power isolated voltages all in an SOIC-16 package.
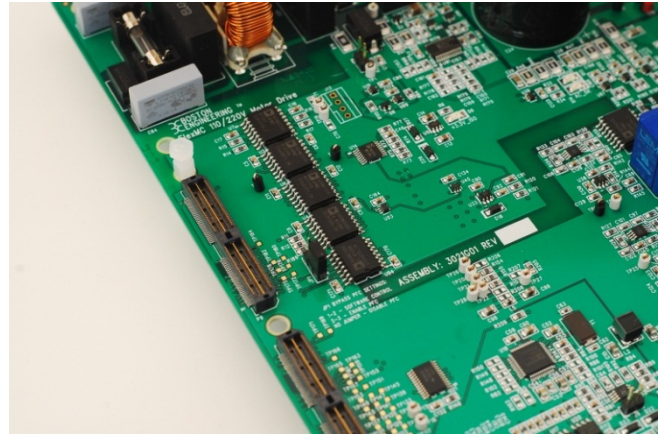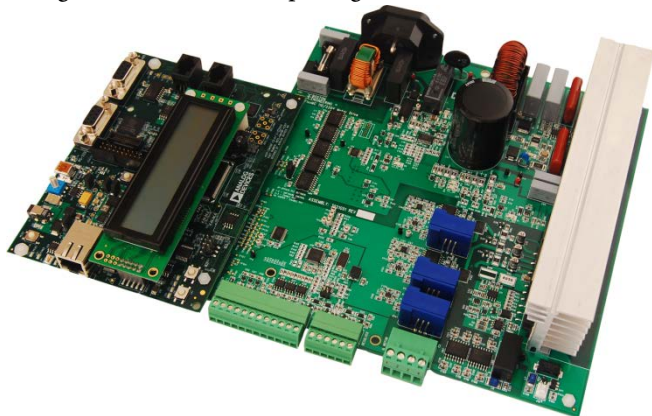
ABOUT THE AUTHOR

Gaetano (Guy) Fichera is the director Boston Engineering's Industrial & Commercial practice. He also led the development of the FlexMC Motor Control Development Platform™, a rapid-development system for any motor control solution. Boston Engineering provides product design and engineering consulting across the entire product development process – from concept through commercialization. Please visit boston-engineering.com or email info@boston-engineering.com for more information.

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