

SKYWORKS®

Silicon-Based Isolated Gate Driver for Industrial Motor Control

skyworksinc.com

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Isolated Gate Drivers in Three-Phase Motors

The industrial motor control market uses three-phase, pulse-width-modulated (PWM) motors in several end applications, including air conditioners, washers, dryers, pool pumps, and garage door openers. Many of these applications require variable speed and/or torque, and the controllers that provide this capability must be low-cost, reliable, and efficient. Such controllers frequently require isolation for several circuits, such as the gate drive, current measurement, and control feedback paths. While optocouplers have traditionally provided this isolation, most designers have moved to silicon-based isolators, which offer substantial improvements over optocouplers in performance, power, size, reliability, and cost per channel.

A three-phase motor usually has three high-side/low-side IGBT transistor pairs, plus one motor-brake IGBT, for a total of seven isolated driver channels as shown in the figure below. At a minimum, IGBT-isolated gate-drive motor applications require a competitive installed cost, high peak output drive, high reliability under elevated-temperature conditions, and high CMTI. Fast propagation delays may also be required for fractional-horsepower applications with high modulation frequencies. Figure 1. illustrates a typical isolated-driver subcircuit for a three-phase motor. In this example, the dynamic brake is driven by a Skyworks' single-channel Si826x IsoDriver, available with either a conventional digital input or an LED emulator input that mimics LED behavior. The three phases that control the motor's spin are controlled by six of Skyworks' Si82xx IsoDrivers, which will be detailed later in this paper, as there are several to choose from.

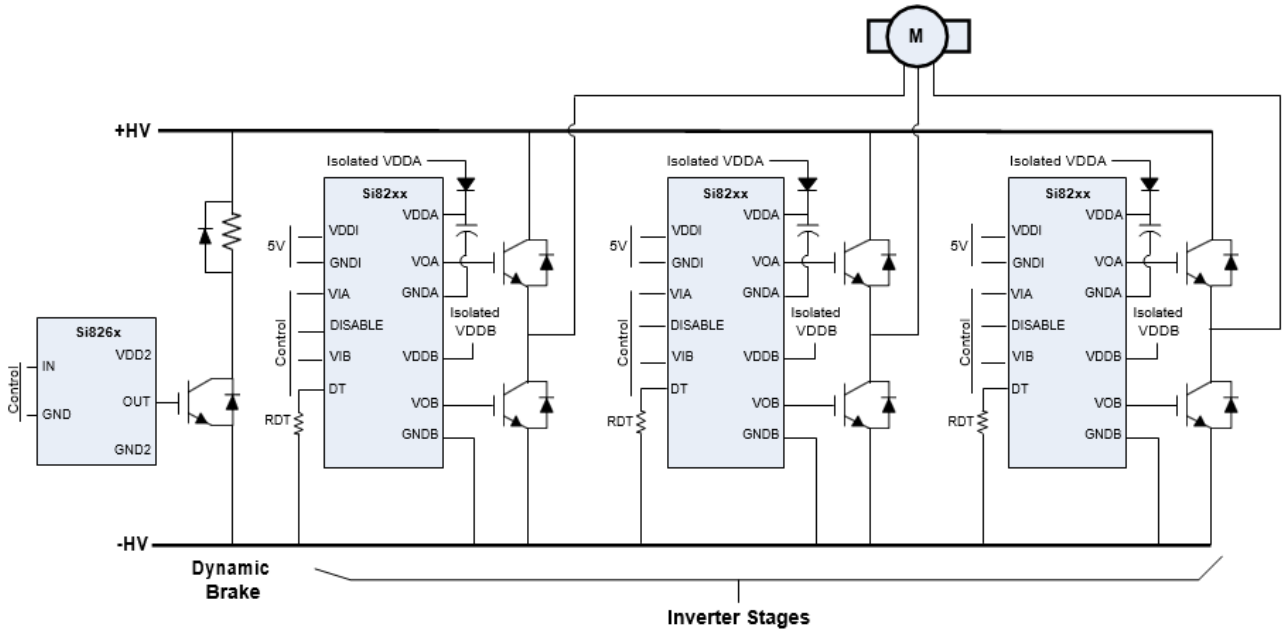


Figure 1. Three-Phase Motor Control Power Stage

Skyworks' Isolated Gate Drivers

Silicon-based isolators use conventional CMOS process technology and ON/OFF keying modulation to transmit digital data across the isolation barrier, offering superior performance and reliability compared to optocouplers. These key technology differences are:

The Use of Mainstream, Low-Power CMOS Process Technology Instead of GaAs
CMOS is arguably the most robust, best-performing, and most widely sourced process technology in the world. It offers very high device integration and speed, low-power operation, and exceptionally high reliability.

The Use of a High-Frequency Carrier Instead of Light
The use of a high-frequency carrier further enables low operating power and high-speed operation (up to 150 Mbps with less than 10 ns delay for the digital-isolator version) and offers precise frequency discrimination for higher noise rejection and simplified packaging compared to optocouplers.

The Use of a Fully Differential Isolation Path Instead of Single-Ended
The differential signal path and high receiver selectivity provide high rejection of common-mode transients, yielding CMTI > 200 kV/µs and immunity to external RF fields up to 200 V/m.

20-year Isolation Barrier Rating
Per IEC60747-17, the governing standard, manufacturers must proof-test their couplers' barrier via time-dependent device breakdown to ensure a 20-year life with a failure rate of less than 1 ppm.

For more information on silicon-based isolator emissions, susceptibility, and reliability vs. optocouplers, see Skyworks Solutions Inc.'s white paper "CMOS Isolators Supersede Optocouplers in Industrial Applications," available at https://www.skyworksinc.com.

Selecting Skyworks' Isolated Gate Drivers

Silicon-based isolator operation is straightforward; an isolator channel (see Figure 2.) consists of a two-die structure in which the transmitter and receiver are separated by a differential capacitive isolation barrier. A logic high at the isolator input turns the transmitter on, sending a carrier across the isolation barrier to the receiver, which asserts a logic high at the output when sufficient in-band carrier energy is detected. Conversely, logic low at the input inhibits transmitter operation, causing the receiver to drive the output low.

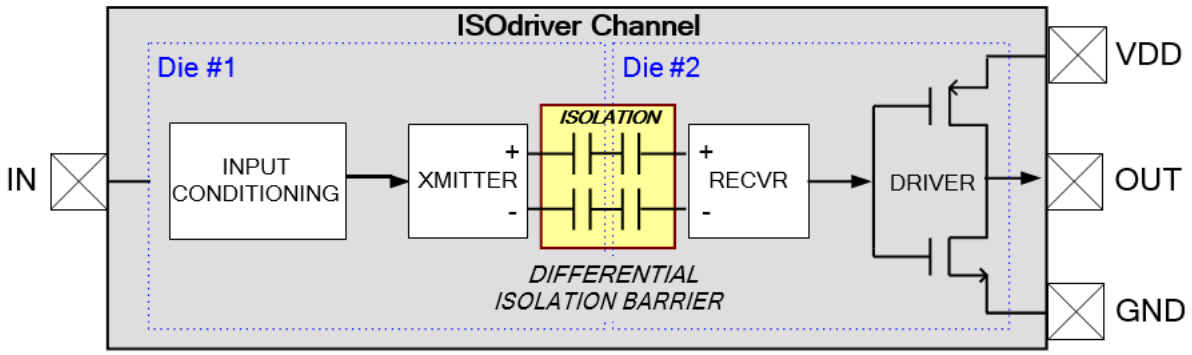


Figure 2. Silicon-based Isolator Top-Level Block Diagram

The Skyworks' Si82xx IsoDriver is an integrated silicon-based multi-channel isolator with an on-chip output gate driver circuit that offers higher reliability, substantial timing improvements, and higher CMTI compared to optocouplers. It also has no timing restrictions, unlike optocoupler and gate-drive transformer designs. These devices are offered in three base configurations: a single, a high-side/low-side isolated driver with separate control inputs for each output, or a dual isolated driver. The high-side/low-side versions have built-in overlap protection and an integrated adjustable dead time generator. The dual IsoDriver (aka universal) version removes overlap protection/dead-time, allowing the supervising controller to set the dead time. The various families are offered with current drive options from 0.5 Amps to 6.0 Amps.

When selecting an IsoDriver (see the figure below), the three most common questions a designer will ask are:

1. What high-voltage switch do I need to use to drive these motors?
2. How much current will I need to drive the switch?
3. What protection do I need to use to protect the switch from overvoltage or overcurrent events?

The two most common HV switches used in motor control are traditional MOSFET or an IGBT. However, GaN and SiC are being explored today due to their inherent advantages in high-speed and space-constrained applications. MOSFETs are rather easy to drive and protect, but IGBTs/GaNs/SiCs usually require additional protection circuitry, such as DESAT protection and OCP/OVP. Protection of the switch is beyond the scope of this paper, so please refer to "AN1288: Si828x External Enhancement Circuits" for more details on that topic. Regardless, most designer's initial questions can be answered by reviewing Figure 3.

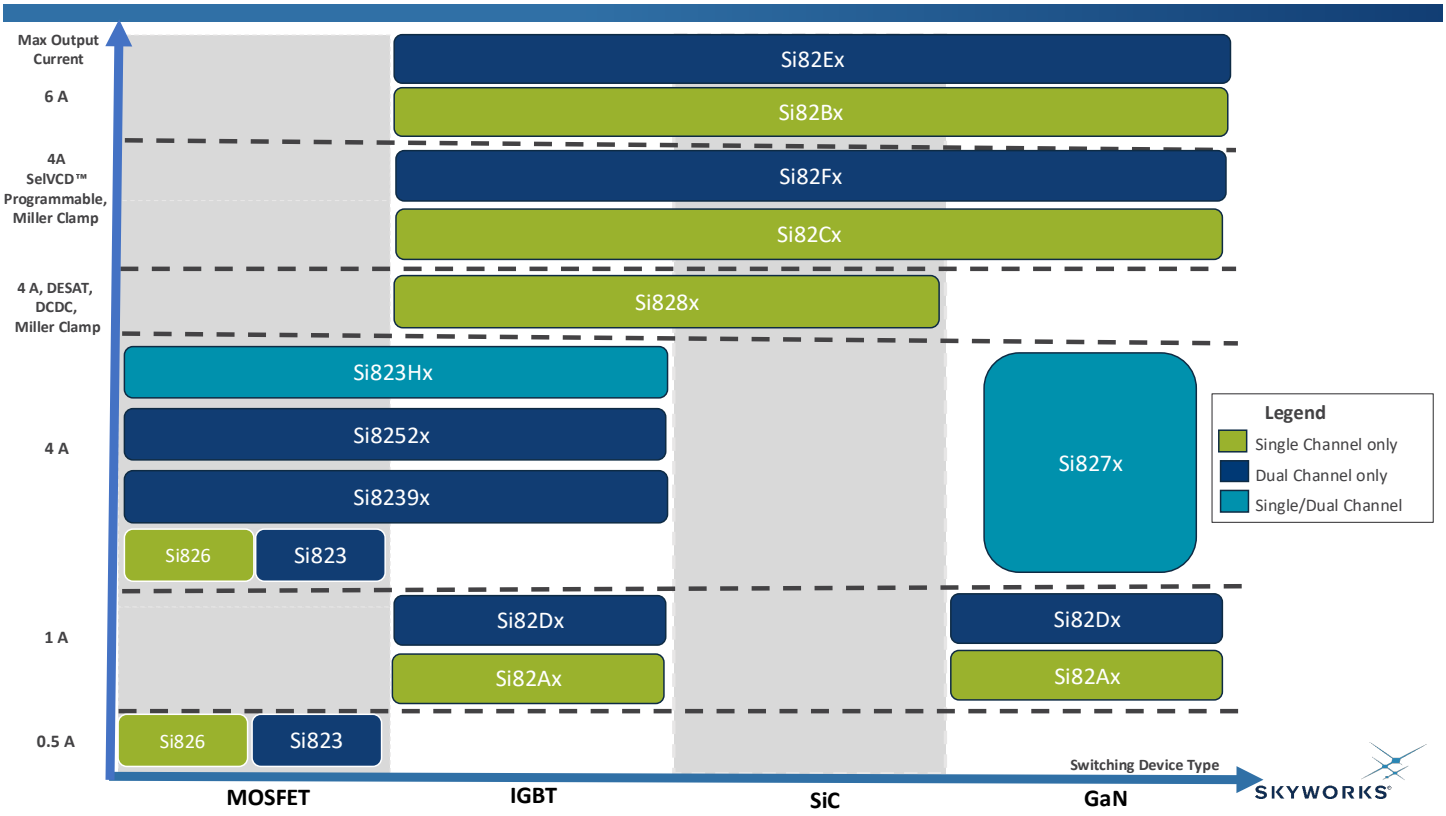


Figure 3. Skyworks' IsoDriver Portfolio for Motor control

For more detailed IsoDriver information concerning Skyworks' IsoDrivers, please visit www.skyworksinc.com.

Safety Considerations for IsoDriver in Motor Control Applications

The next level of concern for the design when choosing an IsoDriver to drive a switch, which in turn is used to turn the motor, is to consider the safety requirements of the IsoDriver, as its main goal is to level shift from the low-voltage domain to the high-voltage domain and relay the system's controller's command to the motor as desired. To accomplish this, the designer needs a basic understanding of the key safety terms that a safety component, such as an IsoDriver, must comply with to keep the system safe for end users from electric shock. The two illustrations in Figure 4. detail some of the basic safety terms that a motor control designer should familiarize themselves with.

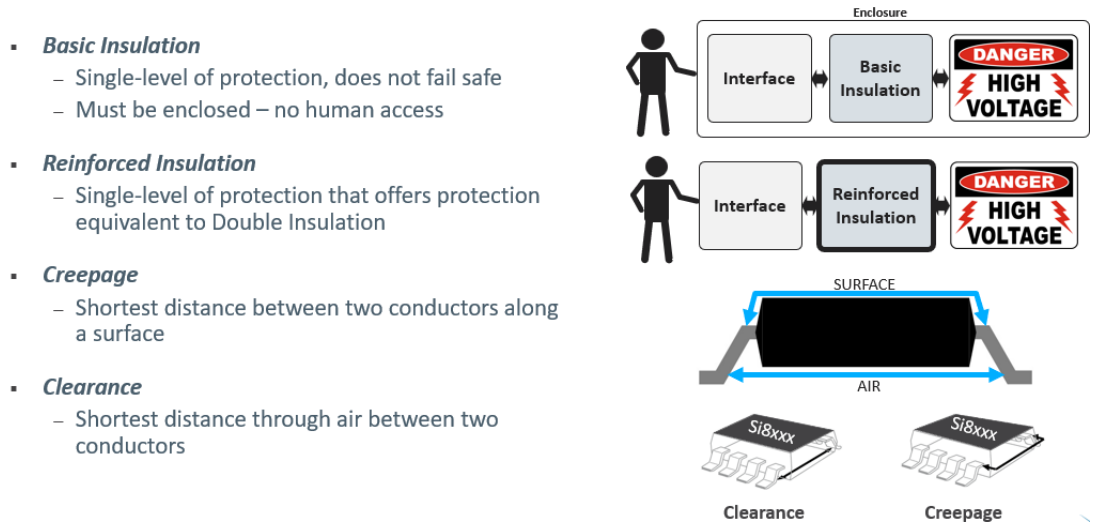


Figure 4. Safety Terms

With these key terms in mind, we can now address some safety features required on an IsoDriver. This all starts with the standard for motors that regulates their safety: IEC 61800-5-1 – electrical safety. The first two critical parameters to satisfy are creepage and clearance. Table 10. in IEC 61800-5-1 dictates the creepage requirements, which are much harder to meet than the clearance needs and will be the focus of this discussion.

Table 10 – *Creepage distances*

Column 1	2	3	4	5	6	7	8	9	10	11	12
Working voltage (RMS)	PWBs [a]		Other insulators								
	Pollution degree		Pollution degree								
	1	2	1	2				3			
				Insulating material group				Insulating material group			
	[b]	[c]	[b]	I	II	IIIa	IIIb	I	II	IIIa	IIIb
V	mm	mm	mm	mm	mm	mm		mm	mm	mm	
≤ 2	0,025	0,04	0,056	0,35	0,35	0,35		0,87	0,87	0,87	
5	0,025	0,04	0,065	0,37	0,37	0,37		0,92	0,92	0,92	
10	0,025	0,04	0,08	0,40	0,40	0,40		1,0	1,0	1,0	
25	0,025	0,04	0,125	0,50	0,50	0,50		1,25	1,25	1,25	
32	0,025	0,04	0,14	0,53	0,53	0,53		1,3	1,3	1,3	
40	0,025	0,04	0,16	0,56	0,80	1,1		1,4	1,6	1,8	
50	0,025	0,04	0,18	0,60	0,85	1,20		1,5	1,7	1,9	
63	0,04	0,063	0,20	0,63	0,90	1,25		1,6	1,8	2,0	
80	0,063	0,10	0,22	0,67	0,95	1,3		1,7	1,9	2,1	
100	0,10	0,16	0,25	0,71	1,0	1,4		1,8	2,0	2,2	
125	0,16	0,25	0,28	0,75	1,05	1,5		1,9	2,1	2,4	
160	0,25	0,40	0,32	0,80	1,1	1,6		2,0	2,2	2,5	
200	0,40	0,63	0,42	1,0	1,4	2,0		2,5	2,8	3,2	
250	0,56	1,0	0,56	1,25	1,8	2,5		3,2	3,6	4,0	
320	0,75	1,6	0,75	1,6	2,2	3,2		4,0	4,5	5,0	
400	1,0	2,0	1,0	2,0	2,8	4,0		5,0	5,6	6,3	
500	1,3	2,5	1,3	2,5	3,6	5,0		6,3	7,1	8,0	
630	1,8	3,2	1,8	3,2	4,5	6,3		8,0	9,0	10,0	
800	2,4	4,0	2,4	4,0	5,6	8,0		10,0	11	12,5	[e]
1 000	3,2	5,0	3,2	5,0	7,1	10,0		12,5	14	16	
1 250	4,2	6,3	4,2	6,3	9	12,5		16	18	20	

Table 1: IEC 61800-5-1, Table 10.

IEC 61800-5-1 specifies stringent creepage (and creepage, but not discussed here) distances for adjustable-speed power drive systems, requiring reinforced insulation for user-accessible circuits based on voltage, pollution degree, and material group.

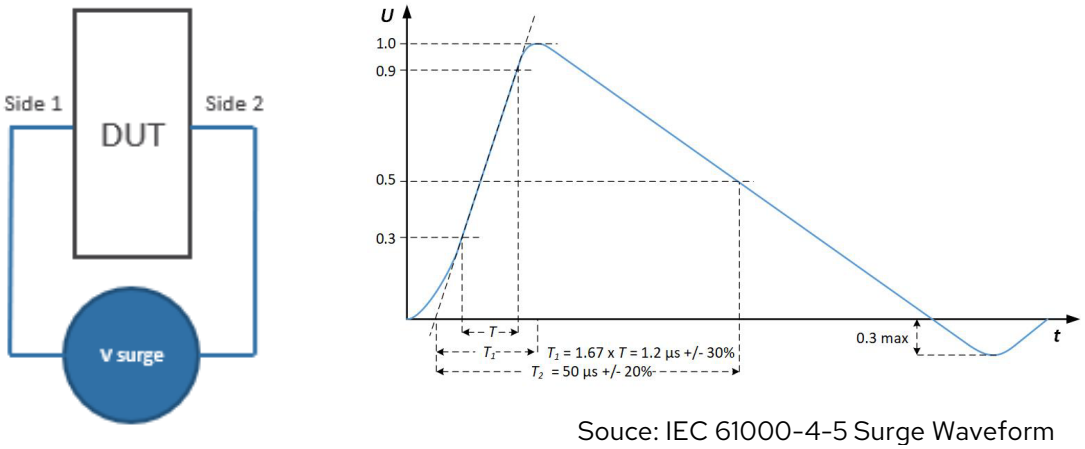
Key Creepage Requirements for 61800-5-1 Include:

- Insulation Type: Reinforced insulation is generally required between high-voltage circuits and user-accessible parts (equivalent to basic + supplementary insulation).
- Pollution Degree (PD): Most industrial applications are classified under PD 2, but harsher environments require higher distances (PD 3).
- Material Group: Determined by the Comparative Tracking Index (CTI) of the material. Group I (CTI ≥ 600) allows smaller creepage than Group II or III.
- Working Voltage: Creepage distances scale with the operating voltage (e.g., 1000V applications often require over 10 mm spacing for reinforced insulation).

- PCB Design: Creepage rules apply to inner PCB layers, not just top/bottom.

To service these needs, Skyworks' IsoDrivers are generally offered in 2 package flavors with 4mm and 8mm of creepage, respectively. As illustrated in Table 10 of 61800-5-1, those two packages meet the creepage requirements for most motor applications. Soon, Skyworks will release a double-wide package (600-mil) that will serve most of the remaining applications. Additionally, note that Skyworks' IsoDrivers are certified to CTI Group I, Pollution Degree 2, further reducing the creepage requirement in the end system.

A second key parameter to consider is the IsoDriver's surge capability. A surge is synonymous with a lightning strike event that the motor's electronics might be exposed to in a real-world application. To measure this, an IsoDriver is proof tested at the safety agency, typically VDE, to a 1.2/50µs signal at up to 10 kV peak (see Figure 5.). Note that supporting 10kVpk surge capability is a key metric for an isolation safety component, such as an opto- or a silicon-based coupler. The component must withstand a 10kVpk surge to be granted a reinforced insulation rating. Anything less and it is relegated to a basic insulation rating. See IEC 60747-17 for more details. Regardless, the surge test is quite stringent per IEC60747-17, the component standard for a silicon-based isolator, where the device must withstand 50 hits of the event in both directions across the barrier. This is more stringent than most end-system standards, which only require 5 bipolar events. Per 61800-5-1 Table 19, the impulse test voltage for the end motor control system, depending on the motor, can be up to 12 kV peak for the IsoDriver. The level of the requirement is usually divided between motors connected to the supply mains and those not connected to them. An IsoDriver with a 10 kV peak reinforced rating can meet the majority of 61800-5-1's requirements. Refer to Table 19 in 61800-5-1 (not shown here) for more details, as it is the designer's responsibility to select an IsoDriver according to their system's needs.



Souce: IEC 61000-4-5 Surge Waveform

Figure 5: Surge Proof Testing Circuit and Signature

For this paper's discussion, the final IsoDriver safety parameter we'll consider is an IsoDriver's ability to transmit clean, uncorrupted data. This is important as motor control drive trains commonly use half-bridge designs as noted earlier. It is highly undesirable to have both switches of a half-bridge on at the

same time, as this could lead to catastrophic, destructive events were it to happen. The most common cause of this is when a common-mode transient crosses an IsoDriver's barrier due to its poor common-mode rejection. Such high common-mode transient events can occur on every switching cycle of a half-bridge and can cause data corruption, as shown in Figure 6. below. The noisy spike events in the middle of the digital pulse indicate that both switches in the half-bridge are on simultaneously, potentially causing a system shoot-through failure.

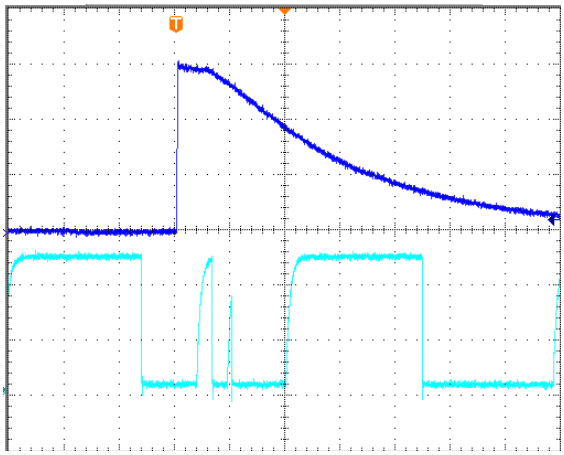


Figure 6: CMTI failure event

High dV/dt transient across the barrier can cause communication errors without damaging the isolator. However, these events can and will be transmitted to the HV switches, causing shoot-through. A measure of an IsoDriver's ability to prevent shoot-through events is an IsoDriver's CMTI rating. This is a measure of its capability to resist the effects of common-mode transients, such as false turn-on, which could cause high- and low-side FETs to turn on simultaneously, shorting Vbus to GND and leading to Catastrophic destruction! False turn-off is less likely to cause damage in most applications.

A common test circuit is shown in the Figure 7. below. Optocouplers have traditionally been rated in the sub-10kV/µs range, making them woefully inadequate for modern-day motor control designs. Unfortunately, little can be done to address a driver component's lack of CMTI performance. The best option is to choose a higher-rated IsoDriver that is more than adequate for the motor system's high-voltage switching events. As shown in the next section of the paper, Skyworks' latest offerings of up to 200kV/µs is more than adequate for most motor control designs these days.

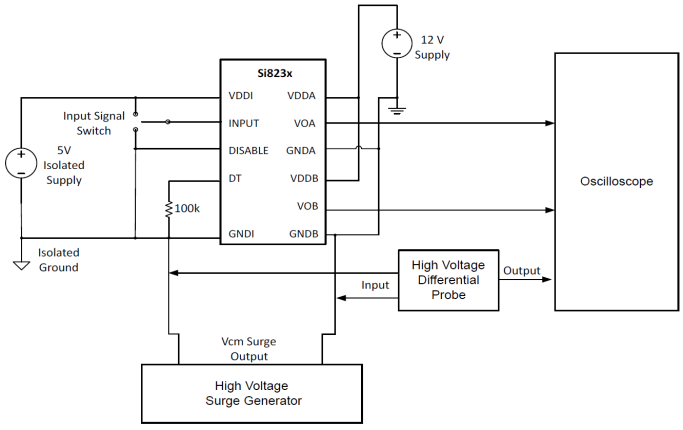


Figure 7: IsoDriver CMTI Test Circuit

Observed CMTI Performance – Positive CMT, PWM = 0 or 1, Si823x

PWM Input	VOA (no CMTI)	VOB (no CMTI)	VOA	VOB
1	1	0	1 to 0, CMTI >30kV/us	0 to 1, CMTI >50kV/us
0	0	1	0 to 1, CMTI >50kV/us	1 to 0, CMTI >100kV/us

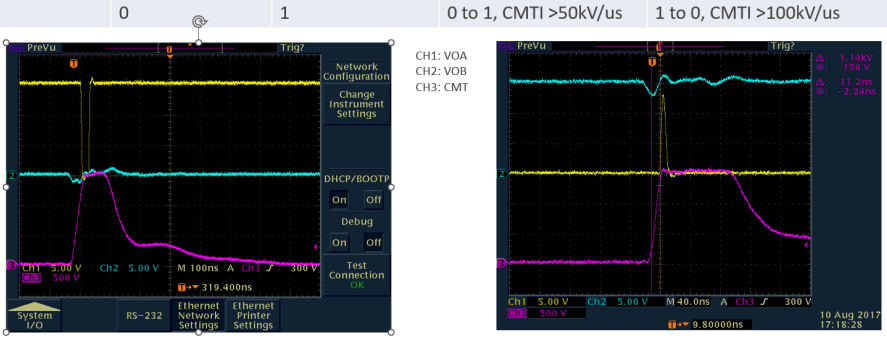


Figure 8: Si823x's CMTI Test Results

To conclude this section, note that optocouplers' CMTI performance has traditionally been rated in the sub-10kV/µs range, making them woefully inadequate for modern-day motor control designs. Unfortunately, little can be done to address a driver component's lack of CMTI performance. The best option is to choose a higher-rated IsoDriver that is more than adequate for the motor system's high-voltage switching events. As shown in the next section of the paper, Skyworks' latest offerings of up to 200kV/µs is more than adequate for most motor control designs these days.

Skyworks' IsoDriver Offering from a Safety Perspective

Skyworks offers numerous IsoDrivers for motor control. Table 2. illustrates their performance levels from a voltage-safety perspective. As the table illustrates and per 60747-17, the international component standard for silicon-based isolators, they offer a 20-year lifetime rating with reinforced rated working voltages up to 2121Vp. They also offer air surge ratings up to 8 kVp and oil (or potted) surge ratings to 10.4 kVp. This offering, relative to the 61800-5-1 motor safety rating requirements, meets most safety requirements for motor control applications. Note that Skyworks' digital isolator and current-monitoring sensor are also detailed in the table below; however, they are beyond the scope of this paper.

Technology	Gen1	Gen2	Gen3	Gen4
Family	Si822x/3x/4x, Si8239x Si841x/2x, Si86xx	Si827x, Si875x	Si826x, Si8285/6, Si8281/2/3/4,Si86xxT, Si87xx, Si88xx, Si8920, Si823Hx/8252x	Si82Ax-Fx, Si858x, Si86Sxx, Si8921/22/3x/4x
Viorm (life-time working voltage)	560 to 1050Vp	630Vp	630 to 1414Vp	630 to 2121Vp
Viotm (1 min rating)	3535 to 6000Vp	3535 to 4000Vp	5302 to 7070Vp	3535 to 8484Vp
Viosm (surge in oil)	4000Vp	4000Vp	4000 to 8000Vp	10,400Vp
Vimp (surge in air)	3077 Vp	3077Vp	3077 to 6154Vp	8000Vp
Rating in Years	20	20	20	20
Safety Rating	Basic	Basic	Basic	Reinforced

Table 2. Skyworks Solutions Safety performance per IEC 60747-17

Summary

Many products require three-phase motors, including washers, dryers, heating and air-conditioning systems, and more. These end applications frequently require galvanic isolation for safety, ground-noise mitigation, and/or voltage-level shifting. Legacy technologies, such as optocouplers and Hall-effect current sensors, have traditionally been used for these applications. Skyworks' silicon-based isolation technology has enabled isolated gate drivers, multi-channel digital isolators, and current sensors that offer greater capability and significant gains in performance and reliability compared to legacy devices.

Related Documents

1. Skyworks Solutions Inc. application note AN486: "High-Side Bootstrap Design Using Si823x IsoDrivers in Power Delivery Systems."

2. Skyworks Solutions Inc. application note AN490: "Using IsoDrivers in Isolated SMPS, UPS, AC Inverter and Other Power Systems."

3. Skyworks Solutions Inc. application note AN583: "Safety Considerations and Layout Recommendations for Digital Isolators."

4. Skyworks Solutions Inc. white paper: CMOS Digital Isolators_WP.pdf; Title: "CMOS Digital Isolators Supersede Optocouplers in Industrial Applications."

5. Arrow white paper: Motor control Inverters: An Overview of Architecture and Control Algorithms.



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