Please note that effective July 26, 2021, the former Infrastructure and Automotive business of Silicon Labs is now part of Skyworks' Mixed Signal Solutions. All Silicon Labs registered trademarks that may be contained herein remain the sole property of Silicon Laboratories, Inc. and are only for nominative descriptive purposes and do not represent any sponsorship or endorsement of such product(s) by Silicon Labs.

SKYWORKS®

skyworksinc.com

CMOS Isolators for Home Appliance Motor Control

Introduction

The home appliance market uses three-phase, pulse-width-modulated (PWM) motors in a number of end applications including air conditioners, washers, dryers 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 and control feedback paths. While optocouplers have traditionally provided this isolation, most designers have begun moving to complementary metallic oxide semiconductor (CMOS) isolators, which offer substantial improvements over optocouplers in the areas of performance, power, size, reliability and cost-per-channel.

Optocoupler Technology vs. CMOS Isolator Technology

An optocoupler is a hybridized device containing a light-emitting diode (LED), optically transparent insulating film (dielectric) and an output die containing a photo detector and output stage. Optocoupler operation is simple: the output-side photodetector converts light to current, which drives the output stage in proportion to LED brightness. In spite of this simple operating principle, optocouplers are notorious for relatively poor performance and reliability due to their underlying process and packaging technologies. Light emissions from the Gallium Arsenide-based (GaAs) LED change with temperature and device age, complicating design and often forcing design compromises. LEDs also have an intrinsic wear-out mechanism ("LOP") that permanently reduces LED emissions by 20% or more and is worsened by elevated temperature and LED current. This reduction in LED output further worsens optocoupler timing and output drive performance. The single-ended architecture of optocouplers (and high internal capacitive coupling) results in poor common-mode transient immunity (CMTI), which can increase optocoupler error rates in electrically noisy environments. These and other issues (e.g. high power consumption, external BOM and large footprint per channel) require added design efforts to compensate for the fundamental weaknesses of optocouplers.

Silicon Labs CMOS isolators use conventional CMOS process technology and ON/OFF keying modulation to transmit digital data through the isolation barrier and offer 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. CMOS offers very high device integration and speed, low-power operation and exceptionally high reliability. The combination of advanced circuit design techniques and CMOS processing enable Silicon Labs' fast 150 Mbps data rate (t_{PD} = 10 ns), 5.6 mW/channel power consumption and resistance to temperature and age effects. The isolation barrier time-dependant device breakdown (TDDB) is in excess of 60 years at the full data transmission speed of 150 Mbps, worst case operating temperature and maximum VDD.

- **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 and adds the benefits of 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 provides high rejection of common-mode transients (CMTI > 60 kV/µs), external RF field immunity to 300 V/m and magnetic field immunity beyond 1000 A/m for error-free operation.

- **The Use of Proprietary Design Techniques to Suppress EMI**
  Devices in this family meet the emission standards of FCC Part B and are tested using automotive J1750 (CISPR) test methods. For more information on CMOS isolator emissions, susceptibility and reliability vs. optocouplers, see Silicon Labs white paper "*CMOS Isolators Supersede Optocouplers in Industrial Applications*" available at www.silabs.com/isolation.

CMOS isolator operation is straightforward; an isolator channel (Figure 1) consists of a two-die structure in which the transmitter and receiver are separated by a differential capacitive isolation barrier. Logic high at the isolator input turns the transmitter on, sending a carrier across the isolation barrier to the receiver, which asserts 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.

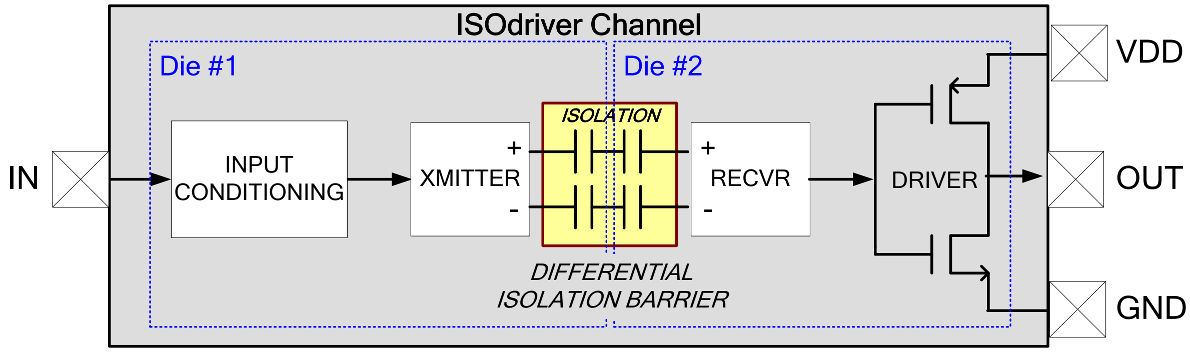


Figure 1. CMOS Isolator Top-Level Block Diagram

Silicon Labs CMOS isolators can service most applications currently served by digital optocouplers. Like optocouplers, CMOS isolators can be used for safely isolation, voltage level shifting and ground noise mitigation.

Consumer appliances using variable-speed, three-phase motors represent a significant opportunity for CMOS isolators. Specialized devices, such as high-speed isolated drivers *("ISOdrivers")* and multi-channel digital isolators (up to six channels per package) provide high performance, low external BOM, high reliability, and competitive cost for many applications.

Isolation in Consumer Motor Control Applications

There are many areas of the home that require the use of small three-phase motors. In addition to appliances, such as washers and dryers, there are other areas, such as heating and air conditioning systems, air movers (fans, exhaust blowers) and pool pumps that require controls of one form or another. Table 1 lists the more common end applications.

Table 1. Home Appliances

TYPICAL APPLIANCE MOTOR APPLICATIONS	
- Adjustable Bed	- Garbage Disposal
- Air-Conditioner Blower/Compressor	- Heater Blower
- Attic Ventilator	- Humidifier
- Ceiling Fan	- Jet Pump
- De-Humidifier	- Pool Pump
- Dishwasher	- Portable Electric Heater
- Dryer	- Refrigerator Fan/Compressor
- Electric Tools (Saw, Grinder, Sander, Compressor)	- Sump Pump
- Exhaust Fan	- Trash Compactor
- Freezer	- Treadmill
- Garage Door Opener	- Washer

Motors used in home appliance applications are typically fractional or low-horsepower types with power ratings from 0.25 hp (186 W) to 3 hp (2,238W). While safety certification agencies mandate the use of isolators to protect consumers, isolators are also used in these systems for signal level shifting and electrical noise (ground loop) reduction.

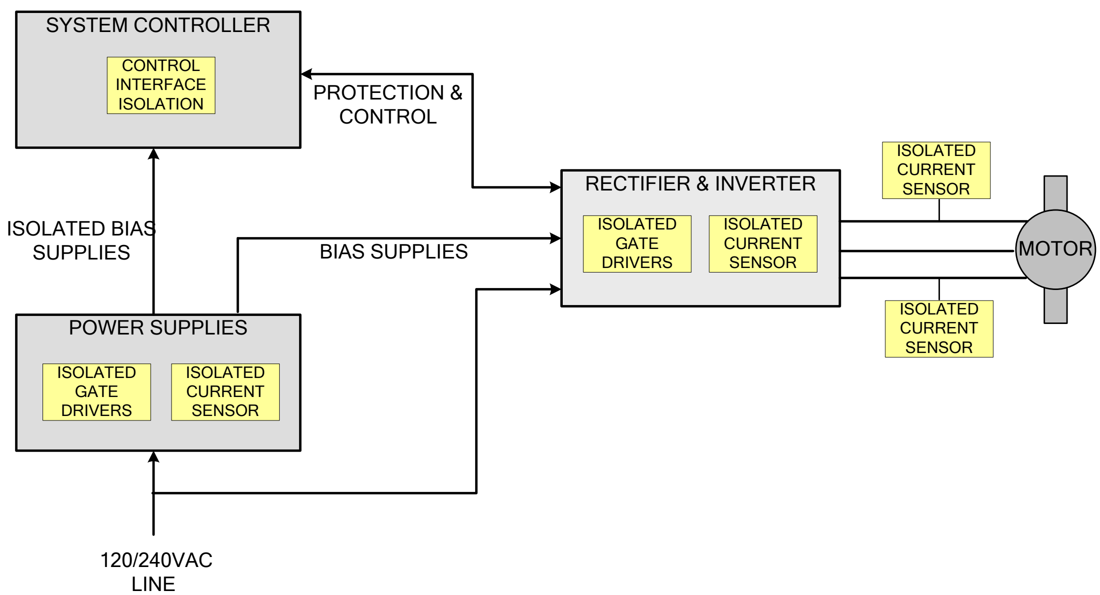


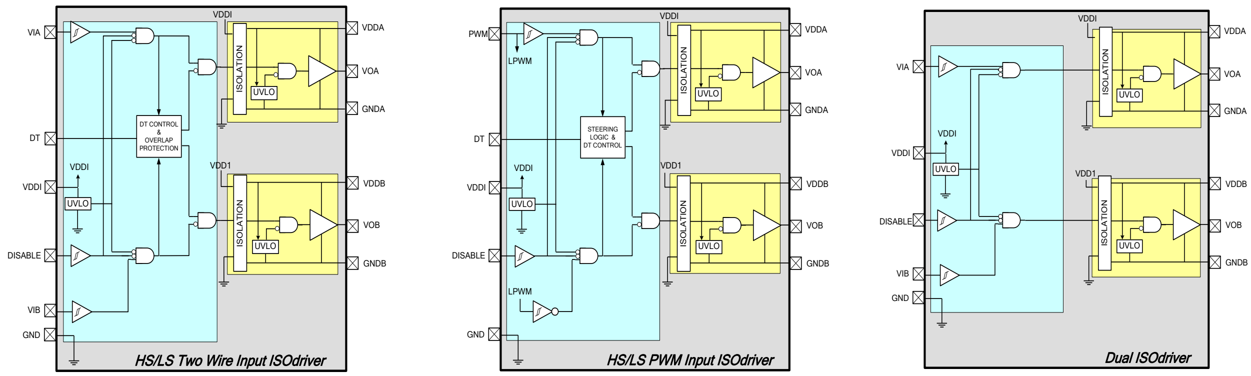
Figure 2. Appliance Motor Control Top-Level Block Diagram

Figure 2 is a typical three-phase home appliance motor control system block diagram showing where galvanic isolation is used. Some systems include isolated and/or non-isolated power supplies to provide bias or to provide high-voltage dc to the switching circuits. These supplies typically require isolated gate drivers. The system may use a small microcontroller for system management, which is powered from an isolated supply. This controller requires isolation to protect against voltage surges into low-voltage areas exposed to the user. The rectifier and inverter together convert the line-derived dc input into ac, which, ultimately, drives the three-phase electric motor. These circuits require both safety isolation and level shifting to drive switches riding on high common-mode voltages. Power stage circuits like these typically require isolated gate drivers.

Isolated Gate Drivers

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. At a minimum, IGBT isolated gate drive motor applications require competitive installed cost, high peak output drive, high reliability over elevated temperature conditions and high CMTI. Fast propagation delay times may also be required for fractional-horsepower applications having a high modulation frequency. The three most popular isolated gate drive options are: 1) a single-package optocoupler plus driver (i.e. “optodriver”), 2) a two-chip solution consisting of an optocoupler and an external high-voltage driver IC, or 3) a gate drive transformer circuit. Optocoupler-based drivers exhibit performance and reliability deficiencies regardless of how they are implemented. For example, low CMTI remains an issue that can be addressed with additional external circuitry, but these circuits tend to overdrive the optocoupler, reducing service life. Optodrivers, such as the Avago HCPL-3120, are essentially optocouplers with a higher drive output buffer forming a single-package isolated gate driver. Heat dissipated by the internal driver is easily transferred to the optocoupler, degrading performance and contributing to shorter service life. The two-chip solution (optocoupler plus external HVIC driver) externalizes the driver and improves optocoupler reliability but at an increased cost. Many designers choose lower cost gate drive transformer-based isolated driver solutions because they provide more uniform timing than optocouplers and at lower cost. However, a transformer-based drive topology cannot transmit dc or low frequency and, therefore, imposes maximum duty cycle and ON-time limitations. In addition, they require additional external reset circuitry or a dc blocking capacitor to prevent transformer core saturation. These timing restrictions and added reset BOM overhead make gate drive transformers most useful in systems operating with maximum duty cycles of 50% or less and/or relatively short ON-times.

The Si823x *ISOdriver* is an integrated CMOS multi-channel isolator with 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 like gate drive transformer designs. These devices are offered in three base configurations: a high-side/low-side isolated driver with separate control inputs for each output (Figure 3a), a single PWM input (Figure 3b) or a dual isolated driver (Figure 3c).



A) Two-Wire Input High-Side/Low-Side B) One Wire (PWM) Input High-Side/Low-Side C) Dual ISOdriver

Figure 3. ISOdriver Family

All devices are offered with 0.5 A and 4.0 A peak output current options and isolation ratings of 1 kV, 2.5 kV and 5 kV. The high-side/low-side versions have built-in overlap protection and an integrated adjustable dead time generator. The dual ISOdriver version has no overlap protection or dead time generator.

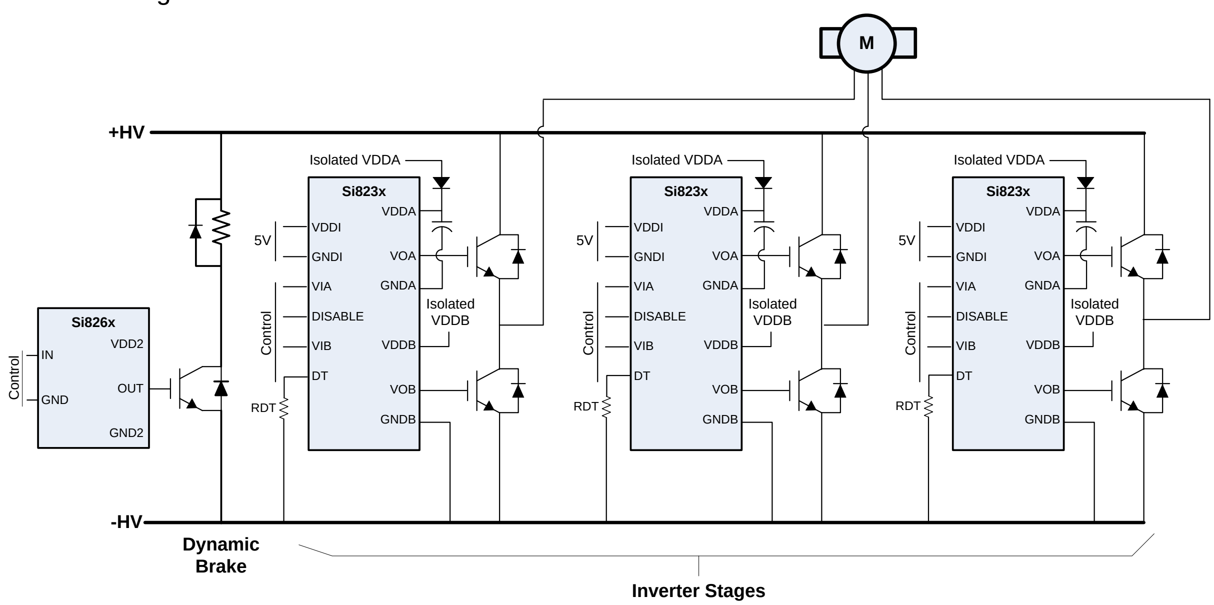


Figure 4. Three-Phase Motor Control Power Stage

Figure 4 shows an example three-phase ac motor drive for home appliances in which each IGBT pair is driven by a high-side/low-side ISOdriver. The DT input of each driver determines the amount of dead time added between switching phases and can be adjusted over a 4 to 950 ns range with an external resistor to ground. (If dead time is not used, DT should be connected to VDD). The dynamic brake is driven by a single-channel Si826x ISOdriver that is available with either a conventional digital input, or an “optocoupler” input that mimics LED behavior. The Si826x is pin-compatible with many standard optocoupler-based optodrivers, including the HCPL-3120. Table 2 below compares the attributes of CMOS isolated drivers with those using optocoupler and gate drive technologies.

Table 2. Isolated Driver Technology Comparison

	Si823x ISOdriver	Opto + Driver	Gate Drive XFMR	ADuM Isolated Gate Driver	Digital Isolator + Driver
Prop Delay (nS)	50	300+	10	160	~100
Stability Over Time & Temperature	✓	POOR: Up to 70% prop delay variation in over temp.	✓	✓	✓
External BOM Components	5	17	12	5	8
Reliability	✓	POOR: LED wearout with temp/ageing	✓	✓	✓
Peak IOUT(max)	4	Various	Various	0.1	Various
Dead Time Generator	Built-In	-	-	-	-
Overlap Protection	Built-in	-	-	-	-
Summary	Best Solution	Poor performance over temp, poor reliability, high BOM	Bulky, no integrated protection, EMI source	Low drive strength, liimited choice of isolation ratings	Multi-package design, large footprint

For more detailed ISOdriver information, please see the Si823x ISOdriver data sheet and the Silicon Labs white paper, "***Improving Isolated SMPS, UPS and other Power Systems with CMOS Isolation Products"***.

Brushless dc motors (BLDC), also called permanent magnet dc synchronous motors, have rapidly gained popularity because of their desirable characteristics. From a performance perspective, the BLDC behaves like a dc motor with linear relationships between current and torque and voltage and rotational speed. BLDC motors offer advantages over brushed dc motors and induction motors including better speed versus torque characteristics and dynamic response, high efficiency and reliability, long operating life, noiseless operation, higher speed ranges and reduced electromagnetic interference (EMI) emissions. In addition, the ratio of delivered torque to the size of the motor is higher, making it useful in applications where space and weight are critical factors. The BLDC speed controller shown in Figure 9 regulates BLDC speed by varying the average voltage across the motor phases using pulse-width modulation. This single-sided PWM, 120 degree conduction mode, two-quadrant controller approach is simple and capable of driving the motor in both directions.

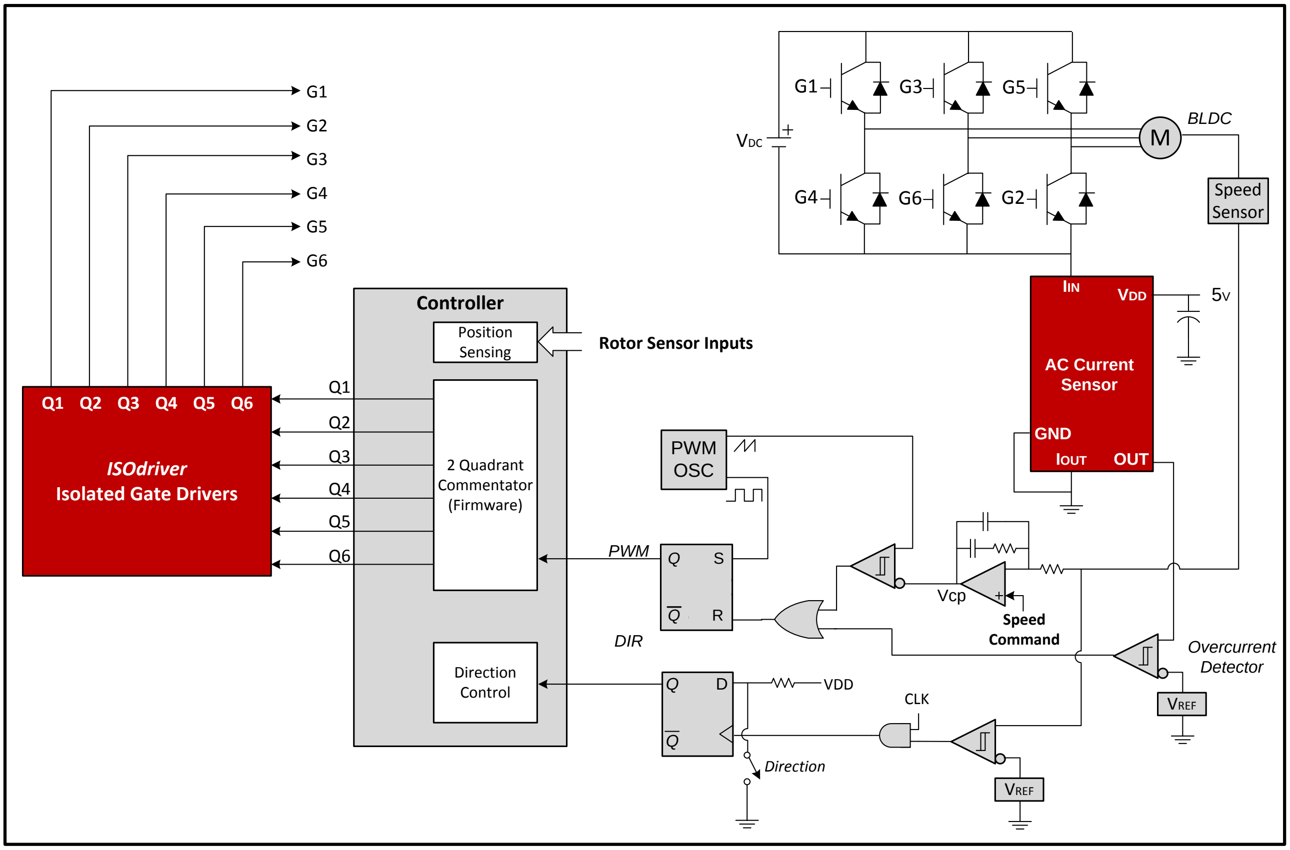


Figure 5. BLDC Feedback Speed Control Using Si8xxx ISOdrivers

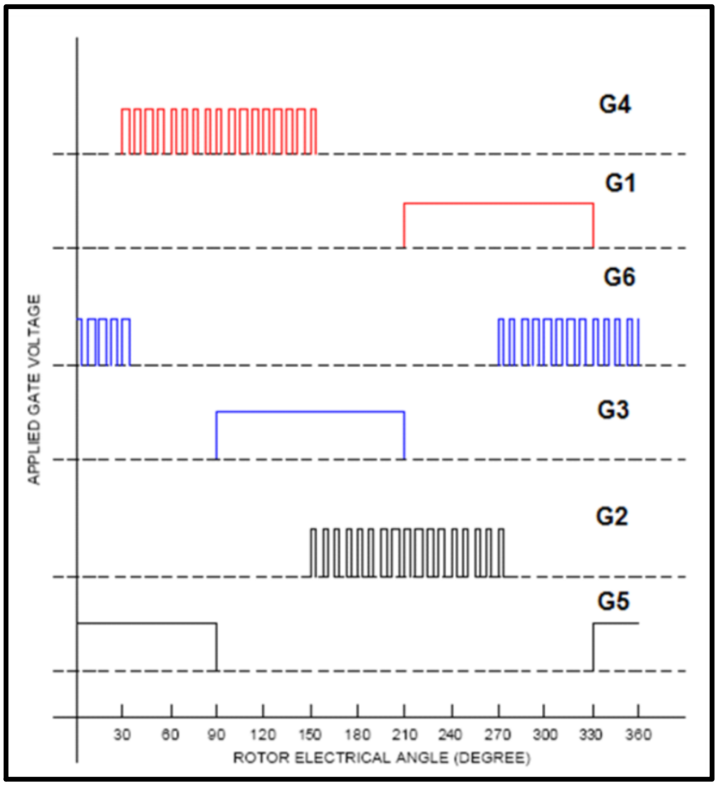


Figure 6. 120 Degree Motor Commutation Timing Diagram

The voltage switching scheme is simple as well; only two of the six switches are on at any time, alternately switching the voltage to motor phases. The voltage waveforms for all six gates of the Figure 9 controller are shown in Figure 10 (the gate voltage timing sequence is: G1 and G2, G2 and G3, G3 and G4, G4 and G5, G5 and G6, G6 and G1). Figure 12 shows a simplified feedback torque controller that is only a slight variation of the speed controller shown in Figure 9.

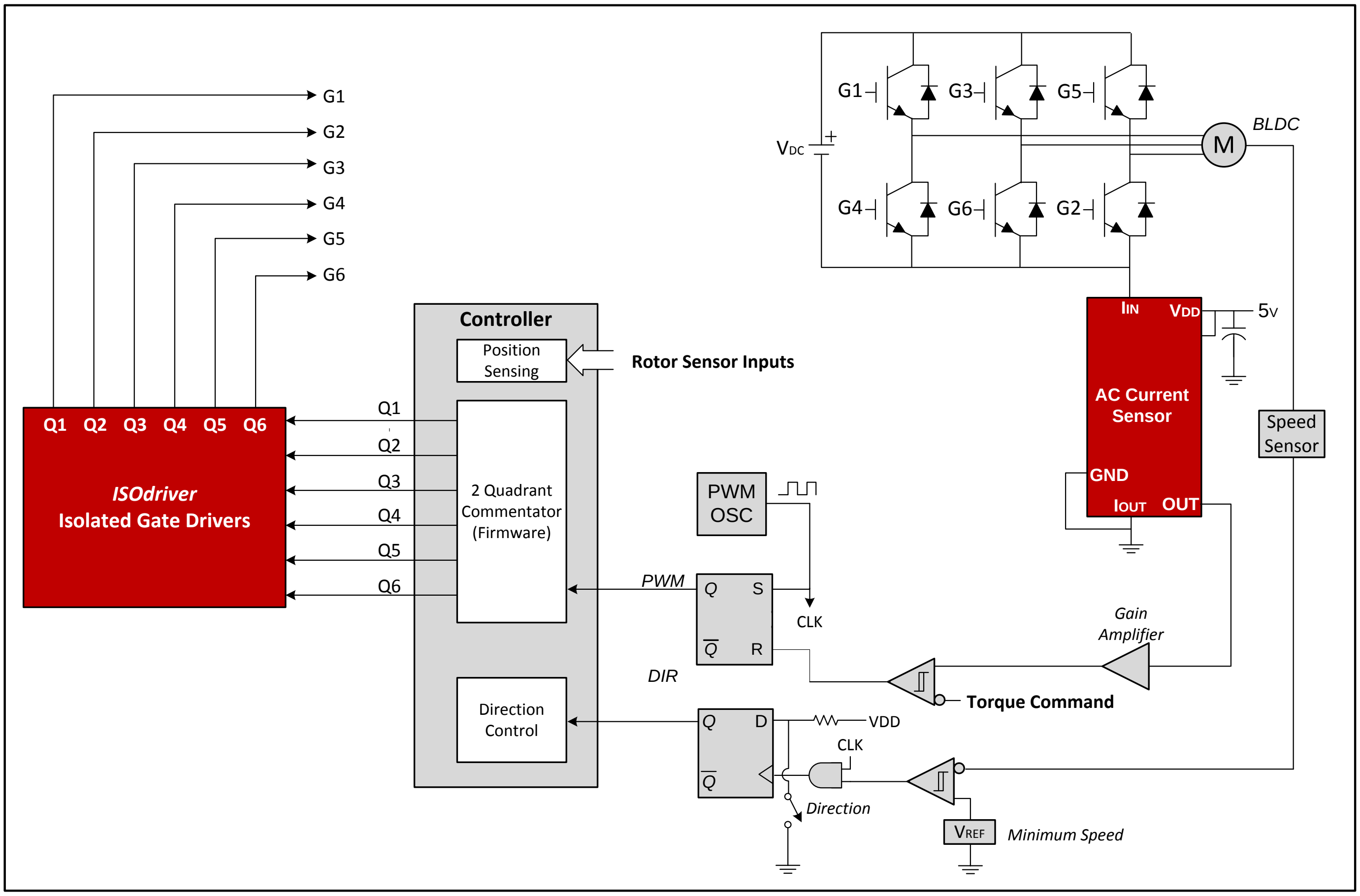


Figure 7. Torque Control Using the Si823x ISOdrivers

Summary

There are many areas of the home that require the use of small 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, have traditionally been used for such applications. Silicon Labs CMOS isolation technology has given rise to isolated gate drivers, multi-channel digital isolators that offer higher capability and significant gains in performance and reliability compared to legacy devices.

Related Documents

1. Silicon Labs application note AN486: *"High-Side Bootstrap Design Using Si823x ISOdrivers in Power Delivery Systems"*

2. Silicon Labs application note AN490: *"Using ISOdrivers in Isolated SMPS, UPS, AC Inverter and Other Power Systems."*

3. Silicon Labs application note AN583: *"Safety Considerations and Layout Recommendations for Digital Isolators"*

4. Silicon Labs white paper: CMOS Digital Isolators_WP.pdf; Title: *"CMOS Digital Isolators Supersede Optocouplers in Industrial Applications"*