Optocouplers for Variable Speed Motor Control Electronics in Consumer Home Appliances

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Abstract

In addition to industrial applications of variable-speed motor drives, home appliances is another major area where three-phase PWM motor control drives are finding increasing applications. Innumerable motors can be found in a typical home. Indeed, one can claim that the quality of life one enjoys today is directly attributable to the existence of the electric motors. Thus, the design of a low-cost, reliable, efficient, variable speed three-phase motor has become a prime focus for both appliance designers and electronic component manufacturers. The components needed for the three-phase motor electronics include IGBTs, gate drivers, inverters, microcontroller units, analog current and voltage sensors among others. It is in the area of optically isolated gate drivers and optically isolated analog current and voltage sensors that modern, state of the art, low cost, and reliable optocouplers (optoisolators) are becoming the component of first preference among the designers.

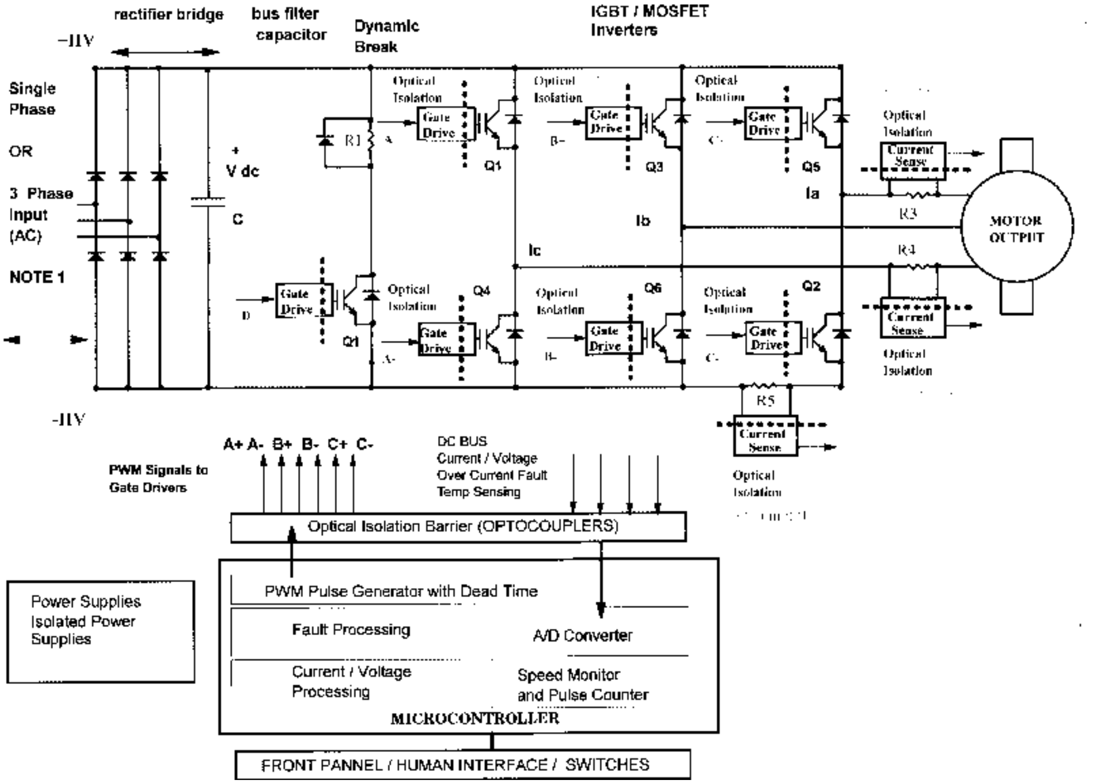

Figure 1. Typical Three-Phase Motor Control Topology Showing Optocoupler Isolation.

Note 1: Home appliance motors will invariably have single-phase 120/240 Volt AC inputs, whereas industrial class motors will generally have three-phase AC inputs.

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Three-Phase Variable Speed Motor Control Topology

Modern three-phase variable speed motor-control architecture can be divided into subsystems or components as shown in Figure 1. The key components of this topology include IGBT/ MOSFET three-phase inverters (Q1, Q2, Q3, Q4, Q5, Q6), single-phase or three-phase rectifier diode bridge, gate drivers, analog current and voltage sensors, isolated and ground-referenced power supplies, and of course the microcontroller unit. Because of the presence of high power, high voltages, and high currents in the design of a motor, it is necessary, and often mandated by safety and regulatory agencies, that people operating the motors and low-power digital electronics are protected through some form of safe galvanic isolation. Agilent Technologies provides several families of state of the art optocouplers to provide application-specific functions for variable-speed motor electronics, such as:

- Optically isolated inverter gate drivers with high peak gate-charging /discharging currents
- Optically isolated analog feedback sensors for DC bus voltage, DC bus current, and AC phase current
- Optically isolated A/D converter for direct connection to a microcontroller unit (MCU) or digital signal processing (DSP) board
- High-speed intelligent power module (IPM) drivers

Why Use Optocouplers?

Safe optical isolation using optocouplers or optoisolators is now a well-proven, well-established, and most reliable technology. Modern state of the art optocouplers are available for low- to high-speed digital data transmission applications (up to 25 Mbit/s), analog sensing, feedback, and control electronics, and application-specific applications such as inverter (IGBT/MOSFET, and IPM) gate drives.

Traditionally, optocouplers have been extensively used to safely isolate low-power, delicate, and expensive electronic components from high-power circuits. In addition, optocouplers provide excellent means of interfacing circuits with high ground potential differences, protect circuits from large common mode voltages, and eliminate noise and interference due to undesirable ground loop currents. Optocouplers are also used to provide amplification of signals, provide on/off switching, and insulate humans from electric shock or hazards of high voltage power sources, or patients from high-power medical instruments.

Advances in optocoupler design and processing technologies have allowed new optocoupler designs for application-specific areas, and provide increasing functionality and sophistication.

Variable speed motor control electronics is one area where optocouplers are finding increasing applications. In particular, specialized low-cost optocouplers optimized to provide high-output sourcing and sinking capabilities to drive inverters (IGBTs/ MOSFETs) are receiving high praises and attention. Similarly, sophisticated analog optoisolators are increasingly replacing Hall Effect sensors for measuring and monitoring AC phase currents, DC rail /bus currents, and measuring bus voltages or monitoring tempreatures.

Key advantages of using optocouplers in three-phase motor control for home appliances are:

- Low cost
- High reliability and long life
- Variable speed/frequency capability
- Ease and simplicity of design
- Small size and footprint area
- Low power dissipation
- Safe optical isolation (galvanic isolation)
- Regulatory and safety agency approvals

Where Are Motors Found in Home Appliances?

There is a plethora of motors found in a typical home. Just look around the house, and motors are found galore. These generally are small motors ranging in power from fractional horsepower 180 W (1/4 hp) to 2240 W (3 hp). Table 1 lists 46 electric motors that may be utilized in a typical home.

Where Is Optocoupler Isolation Used?

Driving the gate of an IGBT/ MOSFET is one of the primary areas where the optocoupler drive is used. And depending on the motor type or topology, various number of gate drivers are needed. Typically in a three-phase motor seven drivers would be needed, six to drive the IGBT inverter gates and one for the motor brake IGBT inverter gate. For speed, position, and phase control of a motor, numerous motor parameters are measured or monitored. Invariably, these monitored analog parameters are fed back to the microcontroller for system control. Since a microcontroller unit is typically referenced to earth ground, any

Table 1. Motors Found in a Typical Home

1	Air-Conditioner Compressor & Fan Motor	24	Radial Drill Press Motor
2	Refrigerator Compressor & Fan Motor	25	Planer Joiner Motor
3	Washer Motor	26	Bench Grinder Motor
4	Dryer Motor	27	Jig Saw Motor
5	Freezer Motor	28	Bench Sander Motor
6	Dishwasher Motor	29	Bend Saw Motor
7	Wet & Dry Vacuum Motor	30	Wood Turning Lathe Motor
8	Air-Conditioner Blower Motor	31	Air Compressor Motor
9	Ceiling Fan Motor	32	Table Saw Motor
10	Attic Fan Motor	33	Sump Pump Motor
11	Roof Top Attic Ventilator motor	34	Range Exhaust Hood Motor
12	Garage Door Opener Motor	35	Home Garbage Disposal Motor
13	Microwave Oven Motor	36	Compactor Motor
14	Electric Unit Heater Blower Motor	37	Exhaust Fan Motor
15	Pool or Spa Pump Motor	38	Spa Pump Motor
16	Jet Pump Motor	39	Power Lite ™ Flush Toilet Motor
17	Paddle Fan Motor	40	Macerator Pump Motor
18	Furnace Blower motor	41	Home Shoe Polisher Motor
19	Draft Inducer Blower Motor	42	Electric Adjustable Bed Motor
20	Oil Burner Motor	43	Forced Air Electric Heater Motor
21	Humidifier Motor	44	Cabinet Type Humidifier Motor
22	De-Humidifier Motor	45	Electric Push Button Recliner Motor
23	Radial Arm Saw Motor	46	Treadmill Motor

See Reference (1), page 83.

high-power parameters fed back from the motor to the controller needs to be isolated for protection and safety purpose. Depending on the type and cost of a motor drive, various numbers of parameters are monitored and fed back to the controller.

For a low-cost drive, one would typically measure temperature sense (IGBT heat sink temperature), bus current, and bus voltage. Thus, there would potentially be three additional analog optoisolators (other than the gate drive optocouplers) used for the low-cost drives. For a high-cost motor drive system, one would also measure zero crossing, back or counter EMF (for brushless DC motors only), brake control, and phase current. That is, in a high-cost system, greater monitoring of motor parameters would require at least four additional optoisolators, over and above those used for a low-cost motor drive (see Table 2).

Table 2. Optocoupler Applications in Variable-Speed Motor-Control Drives

Optocoupler Isolation / Application	Low-Cost Motor Drives (Home Appliances)	High-Cost Motor Drives (Industrial)
Temperature Sensing	X	X
DC Bus Current	X	X
DC Bus Voltage	X	X
Zero Crossing		X
Counter EMF (for brushless DC motors only)		X
Dynamic Brake Control		X
AC Phase Current		X

Often, various equipment-level safety standards mandate that a human operator be isolated from high voltages and potential electrical shocks. Theoretically, this isolation can be achieved at the isolation point (A) in Figure 2 below. This isolation is often required because the operator has to be protected not only from the mains voltage but also at the PWM carrier frequency. For small motor drives, and low bus voltages, this may be the only isolation necessary. And this isolation at point (A) can be easily met by using sealed plastic pushbutton switches designed for 2500 Vrms.

However, for higher power motors that have significant bus voltages, in addition to point (A) isolation one also requires isolation at point (B). Using optocouplers at point (B) provides the necessary isolation voltage levels, creepage distances, clearance distances, or distance through insulation (DTI) often required by equipment-level safety standards, and provide basic or reinforced insulation levels. Also, having isolation at the control interface allows the microcontroller to be grounded, and the operator interface only has to meet minimal low-voltage isolation levels.

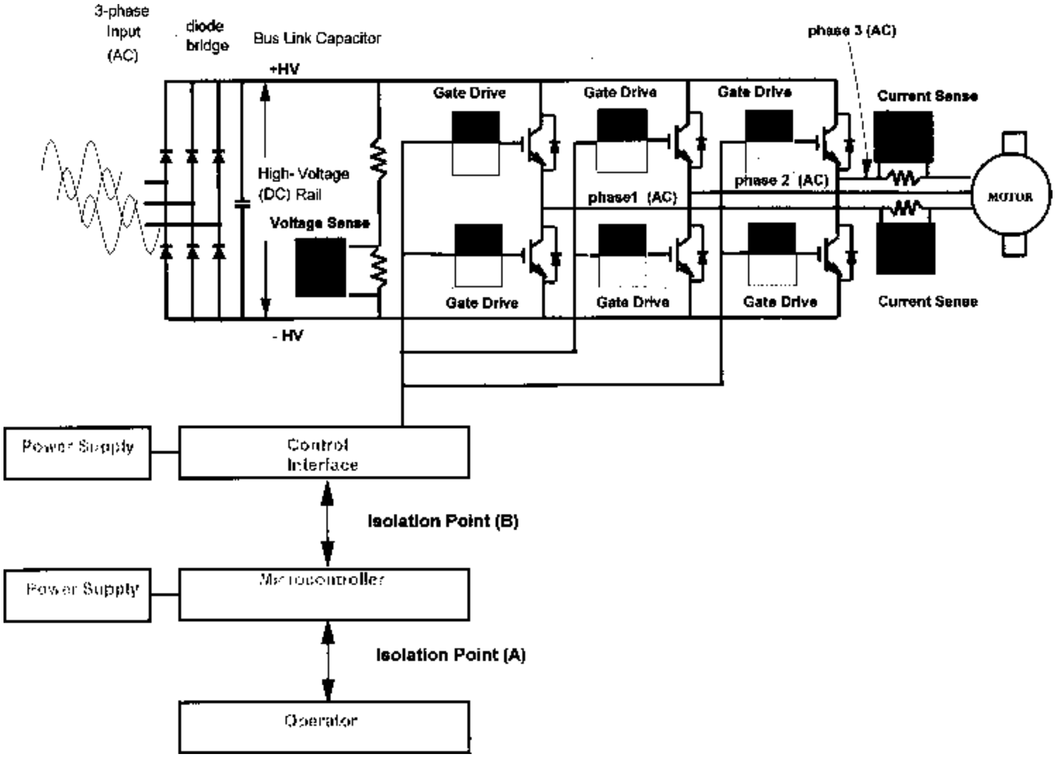

Figure 2. Motor Drive Showing Dual Isolation Points.

Various Gate Drive Topologies

Driving an IGBT or a MOSFET entails supplying enough current to the gate to charge both the gate-to-source capacitance and gate-to-drain capacitance that will cause the drain voltage to drop to the low-impedance level. There are various methods that one can employ to drive the gates. Each method has its own advantages, disadvantages, and associated costs. As usual, a designer will pick one method over another depending on the overall system requirements, cost, space issues, component count, power dissipation, reliability, efficiency, and isolation and safety requirements. Shown below are various gate drive topologies.

The key requirement for any inverter or IGBT gate driver is for it to supply the peak output current needed to switch the IGBT or MOSFET to the low-impedance state. This peak current can be easily calculated using the gate capacitant charging equations.

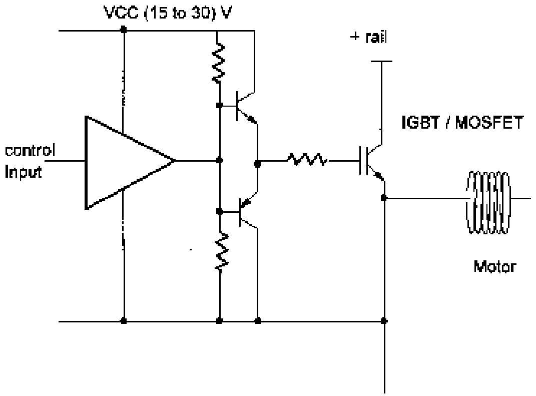

Figure 3. Typical HVIC or Discrete Inverter Gate Drive.

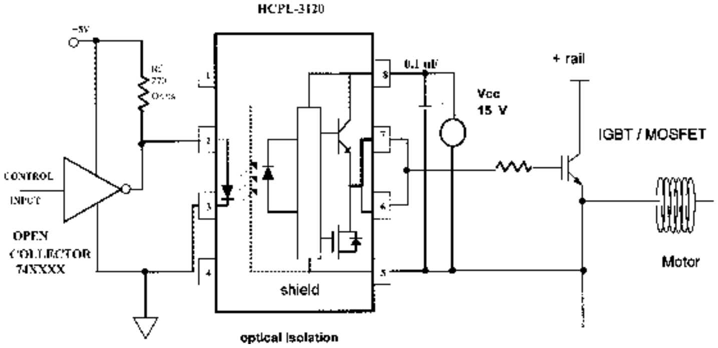

Figure 4. Typical Optocoupler Inverter Gate Drive.

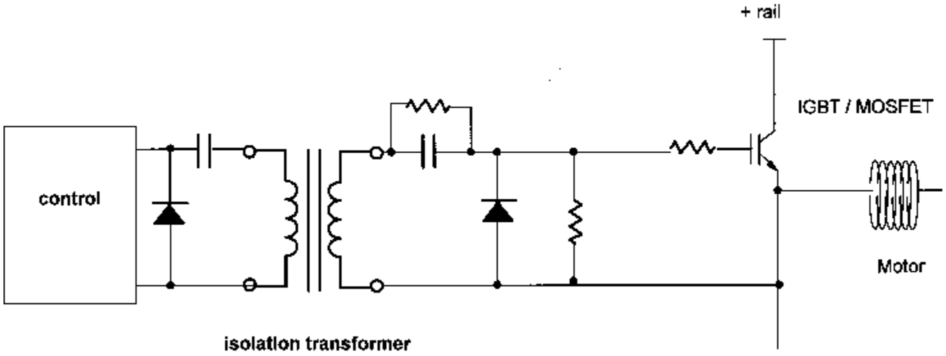

Figure 5. Typical Transformer Inverter Gate Drive.

The gate capacitance of the IGBT determines how much current is required from the driver for basic switching:

$$V_{C(GE)} = \frac{1}{C_{ge}} \bullet \int_{\tau=0}^{\tau=tsw} ig(\tau) \bullet d\tau$$

$$= \frac{1}{C_{ge}} \bullet Ig \bullet t_{SW} \qquad (1)$$

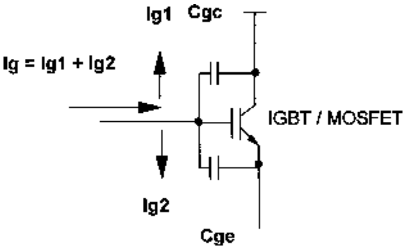

Figure 6. IGBT / MOSFET Parasitic Capacitances (Cge and Cgc).

Let us say that we have a 1200-V, 300-A IGBT that has a gate-to-emitter capacitance of 50 nF. The gate threshold voltage for turn-on for IGBTs is generally 10 to 12 V, and the switching time of the IGBT is 300 ns. The required minimum gate charging current can then be calculated as:

$$\begin{aligned} Ig2 &= (V_{C(GE)} \bullet C_{GE}) / t_{SW} \\ &= (10 \bullet 50 \bullet 10^{-9}) / 300 \bullet 10^{-9} \\ &= 1.66 \text{ A} \qquad (2) \end{aligned}$$

However, additional current is required to charge the gate to collector capacitance (Cgc). Let us assume that this Cgc has a value of 500 pF. If the bus voltage is 400 V, then the drain collector voltage must fall from a bus voltage of 400 V to a low impedance state output voltage below 2 to 1 V. Thus, the current through this capacitor will be given by:

$$\begin{aligned} Ig1 &= (400 \bullet 500 \bullet 10^{-12}) / \\ &\quad 300 \bullet 10^{-9} \\ &= 0.67 \text{ A} \qquad (3) \end{aligned}$$

This shows that the peak output current consists of two components, and is the minimum amount needed to be sourced from the inverter gate driver to safely turn on the IGBT. In this case, the driver must supply a minimum peak current of 2.33 A to safely switch on the IGBT.

The gate voltage will finally be charged to the maximum output high voltage of the gate driver. And the charging equation is an exponential and can be written as (Note: VOH is approximately Vcc-2 V for most Agilent gate-driver optocouplers):

$$Vg = VOH \text{ (driver)} \bullet [1 - e^{-(t/Cge \bullet Rg)}] \qquad (4)$$

And the discharge of the gate will be an exponential discharge given by:

$$Vg = VOH \text{ (driver)} \bullet e^{-(t/Cge \bullet Rg)} \qquad (5)$$

The above equation shows that the higher the VOH, the faster the gate charge up time will be. In addition, source resistance of the driver, which can be approximated as the external Rg on the output, will have an impact on the discharge time, and would need to be minimized for fast turn-off. One method of increasing the turn-off time is to introduce a negative gate voltage at turn-off. This negative gate voltage can also be easily incorporated with gate driver optoisolators. That is the supply voltage of the optoisolators can be split into two supplies, and the lower supply (say from 5 to 10 V) can be connected to the emitter of the IGBT to decrease the turn-off time of the IGBT, as shown in Figure 8.

If one does not want to use the two-supply procedure for providing negative gate voltage as indicated earlier, other methods of minimizing the discharge time of the IGBT include allowing one value of Rg for the charging cycle and another lower value of Rg at the discharge cycle. This concept is indicated in Figures 9 and 10.

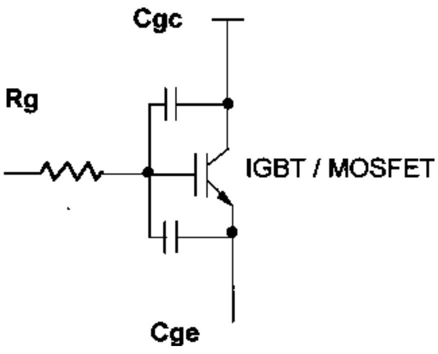

Figure 7. IGBT / MOSFET Gate Resistance and Parasitic Capacitances (Cge and Cgc).

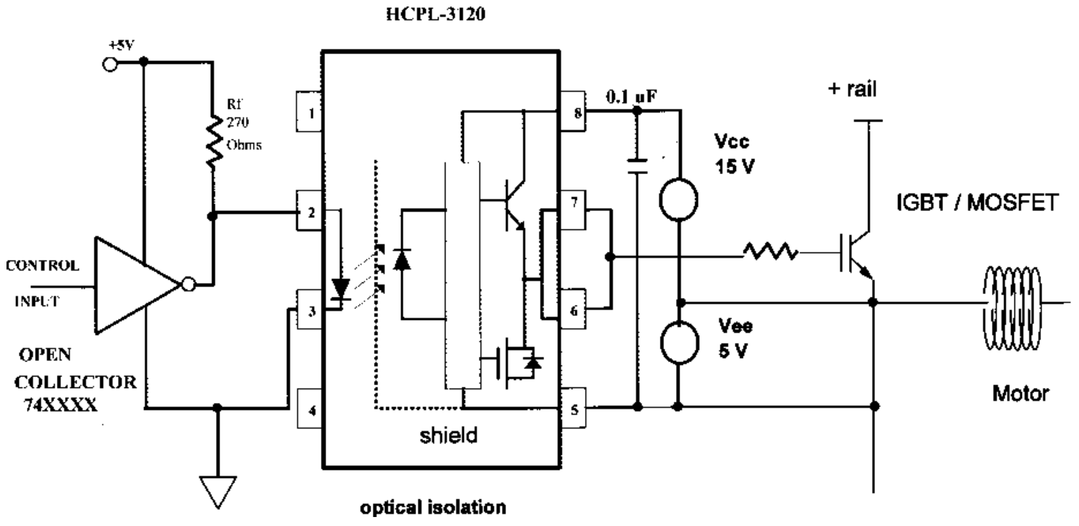

Figure 8. Optocoupler Inverter Gate Drive with Negative Gate Supply (Vee) for Fast Turn-Off.

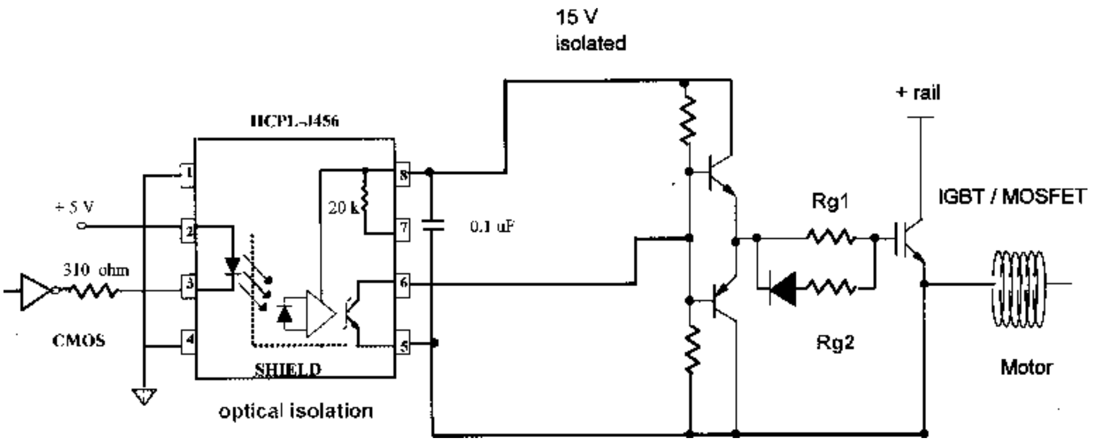

Figure 9. Splitting Gate Resistance for Fast Turn-Off (Method One).

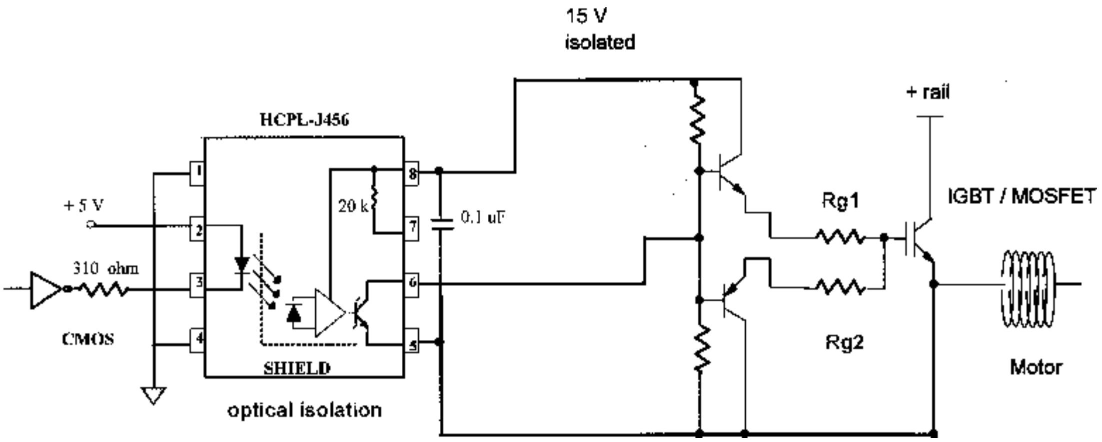

Figure 10. Splitting Gate Resistance for Fast Turn-Off (Method Two).

Key disadvantage of a transformer based gate drive topology is that one cannot transmit the coupled signal at very low frequency. Also, space and footprint area is generally much bigger compared to optocouplers. That is, if the IGBT is to be turned on for an extended period of time, the Signal will not be transmitted at a DC level. Key disadvantage of the discrete component or HVIC direct drive is that it does not provide safe galvanic isolation required by most equipment-level safety standards (IEC, VDE, UL). Thus, if using a HVIC driver, one will normally be constrained to have some isolation in conjunction with the HVIC driver. Generally, a negative gate supply cannot be used with HVIC devices for fast turn-off. And typically, one would use a low-cost optocoupler along with the HVIC in the driver path. Using an optoisolator solution thus allows one to have both a DC to high-speed drive capability, in addition to providing optical isolation and thus meeting the safety standards requirements.

Table 3 summarizes a comparative performance between the HVIC devices and optocouplers. As one can observe from this table, the major drawback of an HVIC device is that it does not provide galvanic isolation required and mandated by most equipment-level safety standards for basic and reinforced insulation levels.

Table 3. A Basic Comparison of Optocouplers and HVIC Inverter Gate Drivers

Parameter	Optocoupler	HVIC
Galvanic Isolation	Yes	No
Isolation Procedure	Air Gap / Optical / Silicone	Junction, Dielectric
Safety Standard	UL, CSA, VDE, IEC	None
Major Failure Mode	Open	Short
Reference Ground for Control Circuit	Earth Ground	HV Negative Rail (–HV)
Possible Maximum Integration*	2 Channels	6 Channels
Power Supply	Isolated Supply or a Bootstrapped Supply	Isolated Supply or a Bootstrapped Supply
Negative Gate Drive Possible	Yes	No
Cost of Solution	Gate Drive Only	Gate Drive and an Isolation Interface

*Only existing Agilent package platform is considered.

Table 4. Selection Guideline by IGBT Class and Driver Power

IGBT Rating	1200 V	600 V	600 V
Drive Power Size	All	>3.75 kW	<3.75 kW
Recommended Driver	HCPL-3120 HCPL-3150 HCPL-316J HCPL-315J	HCPL-314J	HVIC
Remarks	HVIC for this class is very expensive. Typically a negative gate drive is required.	To use an HVIC here would typically require both power and control interface isolation.	HVIC would typically need an additional isolation for safety.

Table 4 lists a basic selection guide based on IGBT power rating and class and the appropriate driver power required to switch the inverters. Typically, for higher power drives, Optoisolators will generally outperform the HVIC in terms of cost and performance. In addition, if using an HVIC, one would invariably also require some form of additional galvanic isolation. Typically, designers would normally use the HVIC along with an additional optocoupler for this galvanic isolation. Using an optocoupler to begin with precludes the necessity of the two-device solution, which is usually necessary when using the HVIC drivers.

The performance comparison of HVICs and optocouplers is shown in Table 5. It can be seen from the table that both technologies compete with each other in MOSFET and IGBT inverter gate drive applications. Choice of one device over another would depend on overall cost, reliability, safety, galvanic isolation, output power capability, etc. Primary advantage of using optocouplers compared to HVICs is that the optocouplers provide safe galvanic isolation, whereas the HVICs or discrete gate drive do not provide this safe isolation. Further, generally it is not possible to supply negative gate drive when using the HVICs. Other criteria of using optocoupler drive over an HVIC drive will depend on cost, output peak currents, desired minimization of additional external components, and safety and regulatory requirements (such as creepage, clearance, distance through insulation, etc).

Table 5. Performance Comparison of Optocouplers vs HVICs Inverter Gate Drivers

Optocoupler			**HVIC**		
Parameter	**HCPL 314J**	**HCPL 316J**	**IR 2130**	**IR 2135**	**IR2122**
Number of Channels	2	1	3	3	1
Galvanic Isolation	yes	yes	no	no	no
Type of Isolation	optical	optical	PN junction	PN junction	PN junction
Power Supply Range	10-30 V	10-30 V	10-20 V	10-20 V	10-20 V
Max. Working Voltage	VDE (600 V)	VDE (600 V)	600 V	1200 V	600 V
UL, CSA Approved	yes	yes			
VDE Approved	yes	yes			
Under Voltage Lock Out	no	yes	yes	yes	no
Fault Feedback	no	yes	yes	yes	yes
Supply Current (max.)	5 mA	5 mA	4 mA	4 mA	0.12 mA
Peak Output Current (min.)	0.4 A	2 A	0.2 A	0.2 A	0.1 A
Propagation Delay	1 µs	0.5 µs	0.675 µs	0.7 µs	0.25 µs
Operating Temperature Range	–40 -100°C	–40 -100°C	–40 -125°C	–40 -125°C	–40 -150°C
Cost/1000 Pieces (approx.)	U $2.40	U $3.40	U $5.30	U $5.70	U $1.90

Gate Drive and Current Sense Family of Optocouplers

Agilent Technologies offers a wide portfolio of optoisolators. The optocoupler family can be subdivided into six main categories: Inverter Gate Drive Optocouplers, Current Sensing Analog Isolation Amplifiers, General Purpose Analog Optocouplers, Intelligent Power Module (IPM) Drivers, Digital High Speed Optocouplers, and Hermetic Optocouplers for high reliability space and military applications.

Summarized in Tables 6, 7, and 8 are the three main product families that are used in motor control applications. These are 1) IGBT / MOSFET gate drive optocouplers, IPM drivers, and the Current/Voltage Sensing Analog optocouplers. All of these

Table 6. Product Selection Guide: Recommended Optoisolators for Inverter Gate Drive Applications

Device Type		Safety and Regulatory Approvals	Description and Features
HCPL-3120 **HCNW3120** **HCPL-J312**	8-Pin DIP Widebody 8-Pin DIP	UL Recognized: 2500 Vrms/1 min for HCPL-3120, 5000 Vrms/1min for HCNW3120, 3750 Vrms/1min for HCPL-J312 CSA Approved VDE 0884 Viorm (Working Voltage): Viorm = 1414 Vpk for HCNW3120 Viorm = 630 Vpk for HCPL-3120(060), Viorm = 891 Vpk for HCPL-J312	• 2 A Output Current IGBT Gate Drive Optoisolator • 15 kV/µs minimum CMR at Vcm = 1500 V • Under Voltage Lock-Out Protection (UVLO) with Hysteresis • 500 ns maximum switching speed • 0.5 V Maximum Low Level Output Voltage (Vol) , Reduces need for Negative Gate Drive • Low Maximum Supply Current: ICC ≤ 5 mA • Wide Operating Vcc Range: (15 to 30) V • Industrial Temperature Range: (-40 to 100)C
HCPL-3150	8-Pin DIP	UL Recognized: 2500 Vrms/1min CSA Approved VDE 0884 Viorm (Working Voltage): Viorm = 630 Vpk (060)	• 0.5 A Output Current IGBT Gate Drive Optoisolator • 15 kV/µs minimum CMR at Vcm = 1500 V • Under Voltage Lock-Out Protection (UVLO) with Hysteresis • 500 ns Maximum Switching Speed • 1.0 V Maximum Low Level Output Voltage (Vol), reduces need for Negative Gate Drive • Wide Operating Vcc Range: (15 to 30) V • Industrial Temperature Range (-40 to 100) C • Low Maximum Supply Current (ICC) ≤ 5 mA
HCPL-316J	16 Pin SO-8	VDE 0884 Viorm (Working Voltage): Viorm = 891 Vpk	• 2 A Output Current Gate Drive Optoisolator with Integrated Over-Current Protection and Fault Feedback • Integrated UVLO and IGBT Desaturation Protection • 15 kV/µs minimum CMR at Vcm = 1500 V • CMOS Compatible Input and Optically Isolated IGBT Fault Status Feedback • Wide Operating Vcc Range: (0 to 35) V • Industrial Operating Temperature Range (-40 to 100) C
HCPL-315J	SO-16 (Surface Mount) (Dual Channel)	UL Recognized: 3750 Vrms/1min for VDE 0884 Viorm (Working Voltage): Viorm = 891 Vpk	• 0.5 A Output Current IGBT Gate Drive Optoisolator • 15 kV/µs minimum CMR at Vcm = 1500 V • Under Voltage Lock-Out Protection (UVLO) with Hysteresis • 500 ns Maximum Switching Speed • 1.0 V Maximum Low level Output Voltage (Vol), reduces need for Negative Gate Drive • Wide Operating Vcc Range: (15 to 30) V • Industrial Temperature Range (-40 to 100) C • Low Maximum Supply Current (ICC) ≤ 5 mA
HCPL-314J	SO-16 (Surface Mount) (Dual Channel)	UL Recognized: 2500 Vrms/1min for HCPL-4504/0454, 5000 Vrms/1min for HCNW4504 and HCPL-45-4 (020) CSA Approved VDE 0884 Viorm (Working Voltage): Viorm: 1414 Vpk for HCNW4504	• 0.45 A Output Current IGBT Gate Drive Optoisolator • 10 kV/µs minimum CMR at Vcm = 1500 V • 700 ns Maximum Switching Speed • 1.0 V Maximum Low Level Output Voltage (Vol), reduces need for Negative Gate Drive • Wide Operating Vcc Range: (10 to 30) V • Industrial Temperature Range (-40 to 100) C • Low Maximum Supply Current (ICC) ≤ 3 mA

products are optically isolated, with safety agency isolation approvals from VDE, UL, and CSA. It will be noted that modern networks and data communication standards all require high speed digital optocouplers. Agilent Technologies also offers diverse high performance and high speed digital optocouplers for these data communication and field bus and network applications (see **www.semiconductor.agilent.com/isolator** for comprehensive optocoupler portfolio details).

Table 7. Product Selection Guide: Recommended Optoisolators for IPM (Intelligent Power Module) Gate Drive Applications

Device Type		Safety and Regulatory Approvals	Description and Features
HCPL-4506 **HCPL-0466** **HCNW4506** **HCPL-J456**	8-Pin DIP SO-8 Widebody 8-Pin DIP	UL Recognized: 5000 Vrms/1min for HCNW4506 and HCPL-4506 #020; 2500 Vrms/1min for HCPL-4506 and HCPL-0466 VDE 0884 Viorm (Working Voltage): Viorm = 1414 Vpk for HCNW4506, Viorm = 630 Vpk for HCPL-4506#060, Viorm = 891 Vpk for HCPL-J456 Viorm = 566 Vpk for HCPL-0466#060	• Intelligent Power Module and Gate Drive Interface Optoisolator • Performance specified for Common IPM Applications • 550 ns maximum propagation delay • 15 kV/us minimum CMR at Vcm = 1500 V • Minimized Pulse Width Distortion (PWD) £ 450 ns • Minimum CTR ≥ 44 % at IF = 10 mA • Industrial Operating Temperature Range (-40 to 100) C • Open Collector Output • Integrated Internal Pull-Up resistor 20 Kohm at pin 7
HCPL-4504 **HCPL-0454** **HCNW4504** **HCPL-J454**	8-Pin DIP SO-8 Widebody 8-Pin DIP	UL Recognized: 2500 Vrms/1min for HCPL-4504/0454, 5000 Vrms/1min for HCNW4504 and HCPL-45-4 (020) CSA Approved VDE 0884 Viorm (Working Voltage): Viorm: 1414 Vpk for HCNW4504 Viorm: 891 Vpk for HCPL-J454 Viorm: 630 Vpk for HCPL-4504 (060) Viorm: 566 Vpk for HCPL-0454 (060)	• High CMR, High Speed Optoisolator • 700 ns maximum propagation delay for TTL and IPM Applications • 15 kV/usec minimum CMR at VCM = 1500 V • High CTR at TA=25C: ≥ 25% for HCPL-4504/0454, ≥23% for HCNW4504 • Electrical Specifications for Common IPM Applications • Open Collector Output • Guaranteed Electrical Performance over (0 to 70) C • TTL Compatible
HCPL-4503 **HCPL-0453** **HCNW4503**	8-Pin DIP SO-8 Widebody	UL Recognized: 2500 Vrms/1min for HCPL-4503/0453, 5000 Vrms/1min for HCNW4503 and HCPL-4503 (020) CSA Approved VDE 0884 Viorm (Working Voltage): Viorm: 1414 Vpk for HCNW4503 Viorm: 630 Vpk for HCPL-4503 (060) Viorm: 566 Vpk for HCPL-0453 (060)	• High CMR, High Speed Optoisolator • 1000 ns maximum propagation delay for TTL and IPM Applications • 15 kV/usec minimum CMR at VCM = 1500 V • High CTR at TA=25C: ≥ 19% for HCPL-4504/0454, ≥19% for HCNW4503 • Electrical Specifications for Common IPM Applications • Open Collector Output • Guaranteed Electrical Performance over (0 to 70) C • TTL Compatible

Table 8. Product Selection Guide: Recommended Optoisolators for Analog Current or Voltage Sensing Applications

Device Type		Safety and Regulatory Approvals	Description and Features
HCPL-7840	8-Pin DIP	UL Recognized: 3750 Vrms/1 min CSA Approved VDE 0884:Viorm (Working Voltage): Viorm = 891 Vpk	• High CMR Analog Isolation Amplifier • 10 kV/ms minimum CMR at Vcm = 1000 V • 100 kHz Bandwidth Typical • 5% Gain Tolerance • 0.2 % Nonlinearity • Vos < ±3 mV over temperature • Low Offset Voltage and Offset Drift over Temperature • 10 mV/C Offset Drift vs Temperature • Performance Specified over (-40 to 85) C • Advanced Sigma-Delta (SD) A/D Converter Technology
HCPL-7800 **HCPL-7800A**	8-Pin DIP	UL Recognized: 3750 Vrms/1min CSA Approved VDE 0884: Viorm = 891 Vpk	• High CMR Analog Isolation Amplifiers • 10 kV/ms CMR at Vcm = 1000 V • 100 kHz Typical Bandwidth • Gain Tolerance = 1% (HCPL-7800A) • Gain Tolerance = 3% (HCPL-7800) • 0.2% Maximum Nonlinearity at –100 mV < Vin < +100 mV • 10 mV/C Offset Drift Vs Temperature • Vos < ±3 mV over temperature • Advanced Sigma-Delta (SD) A/D Converter Technology
HCPL-7860 **HCPL-J786** **HCPL-0870** **HCPL-7870**	8-Pin DIP 16-Pin SOIC 16 Pin SOIC 16 Pin DIP	VDE 0884: Viorm = 891 Vpk (Only modulator HCPL-7860/J786 is optically isolated)	• Isolated 15-bit A/D Converter • 12- bit linearity • 700 ns Conversion Time (Pre-Trigger Mode 2) • 5 Conversion Modes for Resolution/Speed Trade-off • 12-bit effective resolution with 18 µs Signal Delay (14 -bit with 94 µs delay) • Fast 3 µs Over-Range Detection • Serial I/O (SPI, QSPI, and Microwire Compatible) • +/- 200 mV Input Range with Single 5 V Supply • 1 % Internal Reference Voltage Matching • Offset Calibration • Performance Specified over (-40 to 85) C • 15 kV/µs Isolation Transient Immunity at Vcm = 1000 V
HCOL-788J	SOIC-16 Pin	UL Recognized: 3750 Vrms/1min CSA Approved VDE 0884: Viorm = 891 Vpk	• Performance Specified over (-40 to 85) C • Output Voltage Directly compatible with A/D • Fast (3 ms Typical) Short Circuit Fault Detection • 0.4% Maximum Nonlinearity • 30 kHz Typical Wide Bandwidth • 10 kV/ms CMR at Vcm = 1000 V • Ground Referenced Output Voltage, no post amplifier needed, compatible with microprocessor • Analog Rectified Absolute Output Voltage (ABSVAL) available for overload detection
HCNR200 **HCNR201**	Widebody	UL Recognized: 5000 Vrms/1min CSA Approved VDE 0884: Viorm = 1414 Vpk	• High Linearity Analog Optoisolators • 0.01% Typical Nonlinearity • Wide Bandwidth: DC to > 1 MHz • Transfer Gain K3 (Ipd1/Ipd2): +/- 15% for HCNR200, and +/-5% for HCNR201 • Low Gain Temperature Coefficient: -65 ppm/C

Different Methods of Current Measurement

After the inverter gate driver requirements, the second big challenge in motor control applications is how to measure motor phase current, bus currents, and other analog parameters like temperature or voltage. And typically, all these measurements need to be made through some type of safe isolation barrier. At the present time there are three main methods that are employed that all incorporate some type of isolation technique. These three methods are:

(1) Current Transformers

(2) Hall Effect Current Sensors

(3) Optically Isolated Analog Sensors

Each of the above methods offers some advantages and disadvantages. Thus, a designer will again pick the solution that best reduces overall cost, optimizes performance and reliability, and minimizes board space, and meets the accuracy and linearity requirements.

The current transformer current sensing method is based on the simple fact that for a given current flow in a conductor, a proportional magnetic field is generated according to Ampere's law. The primary winding in the transformer couples this magnetic field in the secondary winding of the transformer, causing a proportional current to flow in the secondary winding. Depending upon the ratio of turns, a precise secondary current representation is generated in the secondary. This current can be appropriately sensed through common op-amp linear amplification techniques. An example of this method of current measurement is shown in Figure 11.

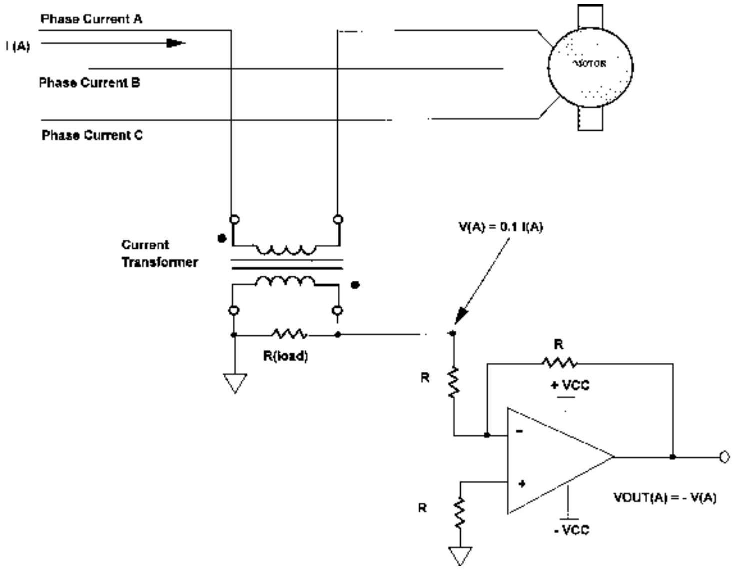

Figure 11. Using Current Transformers to Measure Motor Phase Currents.

Key advantages of using current transformers are that they provide a low-cost solution for measuring current, and provide the safety isolation, and are quite reliable. In addition, transformers generate a proportional current that intrinsically provides higher noise immunity compared to voltage measurements.

However, the disadvantages are that transformers can only measure high frequency AC currents, and may induce measurement errors at lower frequency, and couple in stray magnetic field errors. The size of the transformers is also typically large.

For analog sensing of high currents, for instance, in monitoring the phase currents of a motor, one of the major competitive technologies, although an old one, facing Agilent Technologies modern state-of-the-art optically isolated analog isolation amplifiers, are the open and closed loop Hall Effect transducers. Hall Effect transducers are based on the Hall Effect, which was discovered in 1879 by Edward H. Hall. This law states that electrons in a conductor experience force in the presence of magnetic fields, and will drift towards one side of the conductor and thus will generate a transverse Hall potential difference between two sides of the conductor. This Hall voltage can be used to linearly monitor the motor phase currents instead of the analog optoisolator techniques.

The Hall Effect, Figure 12, states that when a magnetic field (B) is applied to metal or a semiconductor carrying a current (IC) that is perpendicular to the applied field, a potential (VH) will appear across the Hall specimen, and is perpendicular to both the magnetic field and the direction of the current flow.

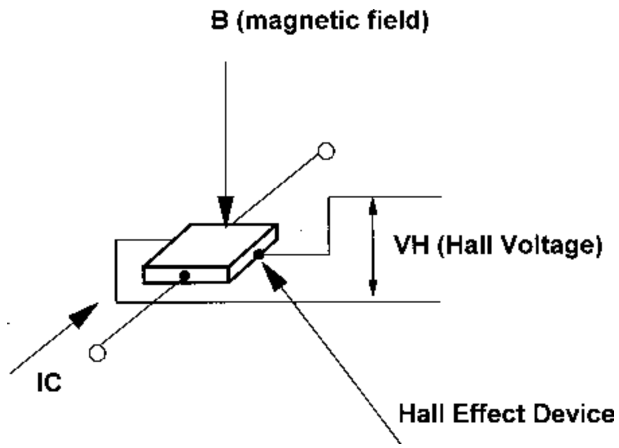

Figure 12. The Hall Effect Principle.

This relationship, which forms the basis for the Hall Effect devices, can be stated as:

$$V_H = K \times I_C \times B \qquad (6)$$

Where K is a constant of proportionality, and depends on the physical properties of the Hall specimen.

There are two types of Hall Effect transducers commercially available at this time: Open Loop Hall Effect Devices (Figure 13) and Closed Loop Hall Effect devices (Figure 14). The Hall Effect transducers are round circular devices that can be placed around the wires that are conducting the motor phase currents, or any other currents that need to be monitored, and sense the magnetic field that is generated by this conductor. The magnetic field generated by a conductor is proportional to the current flowing through it.

A Hall Effect device has a magnetic field sensor that produces a voltage proportional to the sensed magnetic field. It is evident from this that the Hall Effect transducer provides isolation capability as the sensing is conducted through the magnetic field, without the sensor coming in any physical contact with any high-voltage potential. Based on this isolation capability alone, Hall Effect devices have a potential to compete with Agilent Technologies current/voltage sensing analog isolation optoisolators. A decision to use either the Hall Effect devices or optoisolators will be dependent on competitive performance criteria like:

- Isolation Voltage Capability
- Linearity
- Zero Offset
- Response Time / Speed
- Bandwidth
- Temperature Rating
- Hysteresis
- Noise Immunity / Common Mode Rejection
- Insertion Loss
- Cost

Hall element in the Hall Effect transducers is usually a semiconductor device that generates a voltage due to the deflection of electrons in the presence of the magnetic field of a current carrying conductor. The transducer has a magnetic core to concentrate the magnetic field, which the semiconductor Hall element senses to produce a proportional voltage. Open loop transducers provide an output voltage proportional to the magnetic field. Thus, magnetic core hysteresis (i.e., zero offsets) is one of the problems associated with open loop Hall Effect transducers. Closed loop transducers, on the other hand, operate by generating a current that is fed back through a feedback winding to cancel the flux in the original magnetic field. This current is the output of the closed loop transducer and is proportional to the current that is being monitored by the transducer. The closed loop sensors have zero magnetic flux in the core, and thus are less sensitive to hyteresis. The closed loop sensors are more accurate and linear, and consequently pricier than the open loop sensors.

Advantages of Hall Effect devices are that they can measure both AC and DC currents, while providing galvanic isolation. Major disadvantage of Hall Effect devices is that they have zero current offsets (output signal for zero current flow). Key advantages of the optoisolator-based solution are determined on cost, common mode noise immunity (CMR), package profiles, and offsets.

Other parameters that are not listed, but are equally important in decision making, are response time/speed, bandwidth, temperature sensitivity, and linearity. Based on these parameters, optoisolators provide much better linearity, optoisolators are faster than open loop transducers, but perhaps equivalent or slower to closed loop transducers. In terms

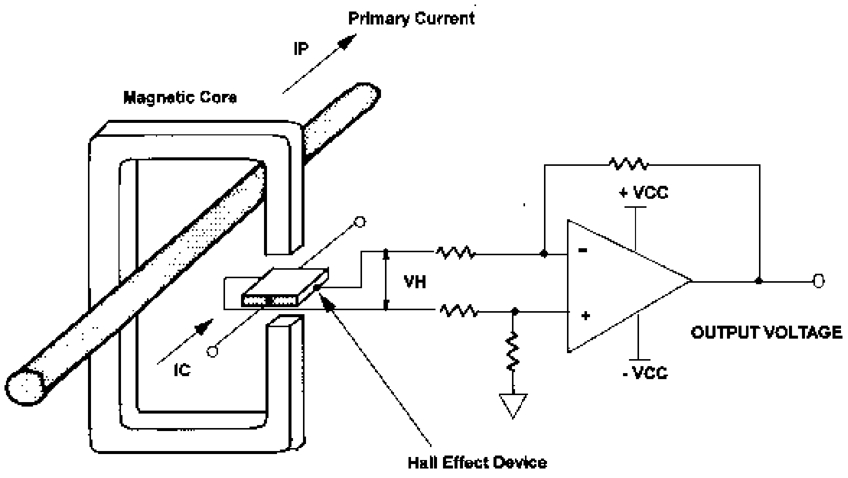

Figure 13. Open Loop Hall Effect Transducer.

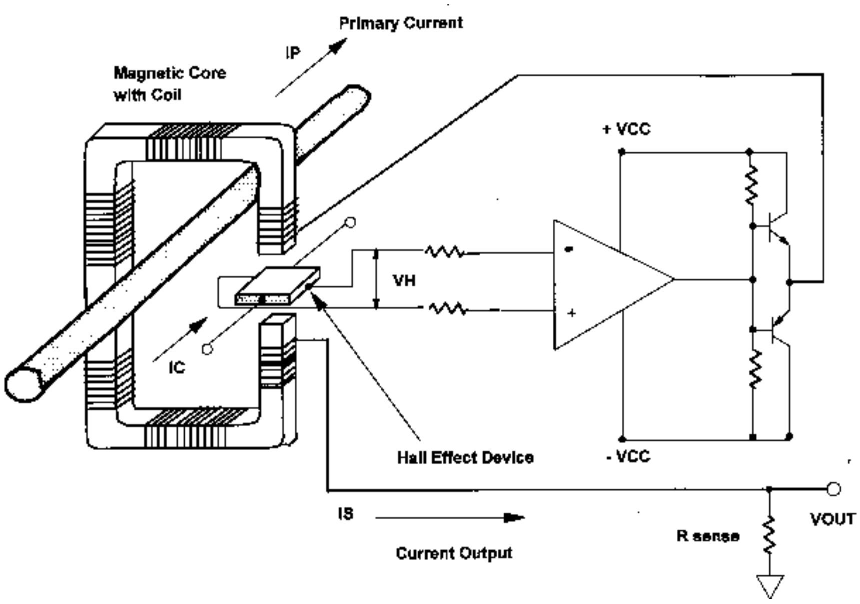

Figure 14. Closed Loop Hall Effect Transducer.

of bandwidth, optoisolators have much higher bandwidth than open loop transducers, and are approximately equivalent or slower to the closed loop transducers. Temperature sensitivity for the isolation amplifiers will depend on the temperature coefficient of an external shunt resistor, which is very low. Open and closed loop transducers have greater temperature sensitivity due to the magnetic core material and its associated hysteresis sensitivity. A major disadvantage of closed loop Hall transducers is the high power/current needed for the nulling current. Thus, overall analog isolation amplifiers provide a more advantageous, precise, economical, and reliable solution than either open or closed loop Hall Effect transducers.

Optically Isolated Analog Amplifiers

There are several classes of optically isolated analog isolation amplifiers available from Alight Technologies which includes HCPL-7800/7800A, HCPL-7840, smart current sensor with short circuit and overload protection (HCPL-788J), and optically isolated 15-bit A/D converter (HCPL-7860, HCPL-0870).

All of these isolated analog amplifiers are based on sigma-delta (ΣΔ) analog-to-digital converters which are optically coupled to an integrated output digital-to-analog converters. The analog isolation amplifiers have very high common mode transient rejection capability (CMR), which is often necessary in modern fast switching motor control electronics, in addition to providing high isolation voltages through optical transmission of the signal from the input to the output. The voltage is sensed by the isolation amplifier inputs over a low value resistor connected in parallel with the input pins. The analog linearity is guaranteed over the maximum input range of 200 mV. The output voltage of the isolation amplifier is an analog output voltage proportional to the input voltage.

The block diagram of the isolation amplifier is shown in Figure 15. The input is sampled at a high rate through a chopper stabilized differential amplifier that is a part of the ΣΔ amplifier. The input sensing at a very high rate is accomplished by a sampling rate typically between 6 to 10 MHz. This high-speed sensing guarantees that the Nyquist criterion is always met when sensing the input at high frequency signals.

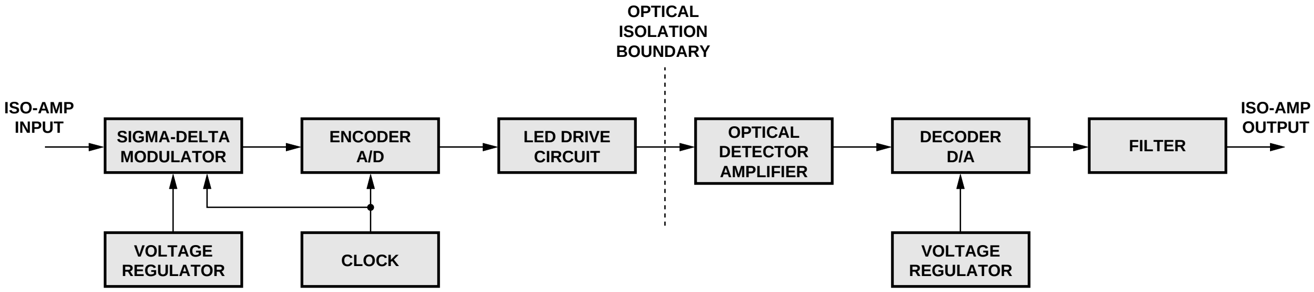

Figure 15. A Block Diagram of the Optically Isolated Analog Isolation Amplifier.

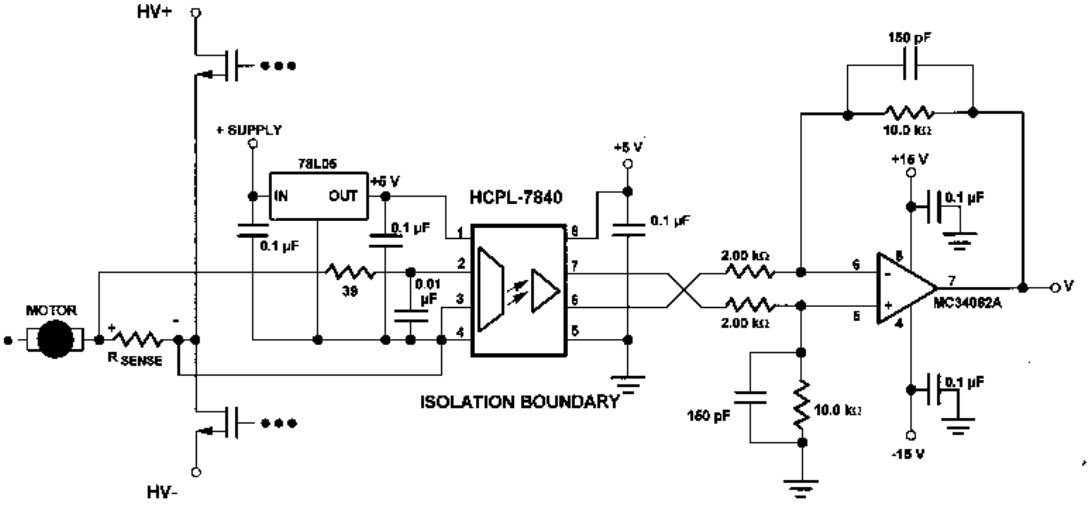

Figure 16. Typical Application Circuit using the Optically Isolated Analog Isolation Amplifier.

In operation, the sigma-delta modulator converts the analog input signal into high-speed serial bit stream. The time average of this bit stream is directly proportional to the input signal. This stream of digital data is encoded and optically transferred to the detector circuit. The detected signal is decoded and converted back into an analog signal, which is filtered to obtain the final output signal. Figure 16 shows a typical application circuit.

The input is sensed across a precision, low resistance, low inductance, and low temperature coefficient shunt resistor. Low pass filter at the input (39 Ω resistor and 0.01 µF capacitor) rejects high-frequency noise components and is an anti-aliasing filter. Post differential amplifier converts the differential output signal of the isolation amplifier to a ground referenced voltage compatible with an A/D converter at the microcontroller. The differential amplifier's bandwidth can be adjusted by the R-C filter on the feedback path, to reject and to minimize the noise at the output if necessary. Tables 9 and Table 10 give some comparative performance information between Agilent Technologies Optical Isolation Amplifiers and Hall Effect devices.

Below comparison indicates that the isolation amplifiers outperform both the open and closed loop Hall Effect devices in terms of offset drifts, gain drifts, common mode rejection, and price. In addition, optoisolators have smaller form factor, and are autoinsertible and surface mountable. These significant advantages allow the optically isolated analog amplifiers to be very competitive in low cost, reliable, accurate, and efficient motor designs.

Table 9. Performance Comparison between Isolation Amplifier and Hall Effect Devices

Parameter	Low Cost Solution (Home Appliance Motors)		High Performance Solution (Industrial Class Motors)	
Sensor Type	Open-Loop Hall Effect	HCPL-7840 & Dale LVR-3.02 Shunt Resistor	Closed-Loop Hall Effect	HCPL-7860/7870 & Isotek (PBV Series) Shunt Resistor
Gain Temp-Coefficient	0.1 %/C	0.09 %/C	0.05 %/C	0.018 %/C
25 C Offset (% of Full Scale)	1 %	1.25 %	2.6 %	0.63 %
Offset Temperature Coefficient (% of Full Scale/C)	0.05 %	0.005 %	0.06 %	0.001 %
CMRR Error (% of Full Scale)	100 % (with 10 kV/µs pulse)	0 % (with 10 kV/µs pulse)	8 % (with 2 kV/µs pulse)	0 % (with 10 kV/µs pulse)
CMR Setting Time	20 µs (with 10 kV/µs pulse)	0 µs (with 10 kV/µs pulse)	10 µs (with 2 kV/µs pulse)	0 µs (with 10 kV/µs pulse)
Package Style	High Profile (32 mm high)	Low Profile (4 mm high)	High Profile* (16 mm high)	Low Profile (4 mm high)
Current Sensing Solution Cost	$5 - 9	$4.50 - 8	$20 (approx.)	$14 (approx.)

See page 37, Reference [4]

Table 10. Comparison of Isolation Amplifiers versus Hall Effect Devices

Sensor Type	Nominal Current Measured (A_{RMS})	Uncalibrated Accuracy (25 C)	Calibrated Accuracy (25 C)	Uncalibrated Accuracy Over Temp.	Bandwidth	Solution Cost
ΣΔ Iso-Amp	Up to 25 A	4.6 %	0.2 %	7 %	100 kHz (typical)	Less Expensive
Hall -Effect (Open Loop)	Up to 25 A	4.2 %	1.2 %	16 %	25 kHz	Less Expensive
Hall-Effect (Closed Loop)	Up to 25 A	1.1 %	0.6 %	3 %	150 kHz	More Expensive

See page 356, Reference [2]

Regulatory and Safety Considerations

Optoisolator applications often include environments where high voltages are present. The ability of the optoisolator or optocoupler to sustain and to isolate high voltages, both transient as well as working, is the driving reason why optocouplers are required in many designs. Equipment operators and circuits within equipment may need safe isolation and protection from high voltages.

The safety performance of the optoisolator is determined during the design and the assembly of the product, so process control and design robustness are key to overall safety performance.

Safety standards exist both at the component level and equipment level. The optocoupler isolation voltage levels and insulation dimensions are indicated in Table 11. For equipment-level requirements, a designer will need to consider the appropriate equipment-level safety standard, and then reconcile the requirements of that particular safety standard with the specified optocoupler safety ratings as indicated in Table 11.

Table 11. Safety / Regulatory Isolation Voltage Ratings and Insulation Dimensions

Agilent Part #	UL 1577 / CSA Notice 5 Viso /1 minute			VDE 0884		External Creepage (mm) min	External Clearance (mm) min	Distance Through Insulation
				Working Voltage	Transient Voltage			
	2500 Vrms	3750 Vrms	5000 Vrms	Viorm Vpeak	Viotm Vpeak (10 sec)			(DTI) (mm) min
HCPL-3120	X			630	6000	7.4	7.1	0.08
HCNW-3120			X	1414	8000	10.0	9.6	1.0
HCPL-J312		X		891	6000	8.0	7.4	0.5
HCPL-316J		X		891	6000	8.3	8.3	0.5
HCPL-3150	X			630	6000	7.4	7.3	0.08
HCPL-315J		X		891	6000	8.3	8.3	0.5
HCPL-314J		X		891	6000	8.3	8.3	0.5
HCPL-4506	X			630	6000	7.4	7.1	0.08
HCPL-0466	X			560	4000	4.8	4.9	0.08
HCNW4506			X	1414	8000	10.0	9.6	1.0
HCPL-J456		X		891	6000	8.0	7.4	0.5
HCPL-4504	X			630	6000	7.4	7.3	0.08
HCPL-0454	X			560	4000	4.8	4.9	0.08
HCNW4504			X	1414	8000	10.0	9.6	1.0
HCPL-J454		X		891	6000	8.0	7.4	0.5
HCPL-4503	X			630	6000	7.4	7.1	0.08
HCPL-0453	X			560	4000	4.8	4.9	0.08
HCNW4503			X	1414	8000	10.0	9.6	1.0
HCPL-7840		X		891	6000	8.0	7.4	0.5
HCPL-7800		X		891	6000	8.0	7.4	0.5
HCPL-7800A		X		891	6000	8.0	7.4	0.5
HCPL-7860		X		891	6000	8.0	7.4	0.5
HCPL-J786		X		891	6000	8.0	7.4	0.5
HCPL-788J		X		891	6000	8.0	7.4	0.5
HCNR200			X	1414	8000	10.0	9.6	1.0
HCNR201			X	1414	8000	10.0	9.6	1.0

See Reference [6]

Typical Application Circuits

In this section we consider those optocoupler devices that are most pertinent for low cost motor control applications in consumer home appliance applications.

For inverter gate driver applications and for dynamic breaking, one of the drivers that would be recommended is the HCPL-314J. This driver is a low cost optically isolated driver with two channels, Thus, one package would suffice for each high side and low side inverter gate drive application. And only three devices would be needed in a three-phase variable speed motor control topology. If dynamic breaking is needed, then a fourth HCPL-314J or a single-channel device such as the HCPL-3150 can be used for this purpose. Figure 17 shows a typical application circuit using the HCPL-314J.

Minimum recommended supply voltage for the HCPL-314J is 10 to 30 V. Minimum drive current is 8 mA. With a propagation delay of 700 ns, and a minimum common mode of 10-kV/µs, the HCPL-314J is ideal for low cost motor drive applications. The Schottky diode indicated from output to ground is to prevent the substrate diode of the HCPL-314J from forward biasing in situations where inductive motor transients at the output of the HCPL-314J may go below ground. With two channels per package, one would need only three HCPL-314J optically isolated gate drivers for a three-phase motor drive.

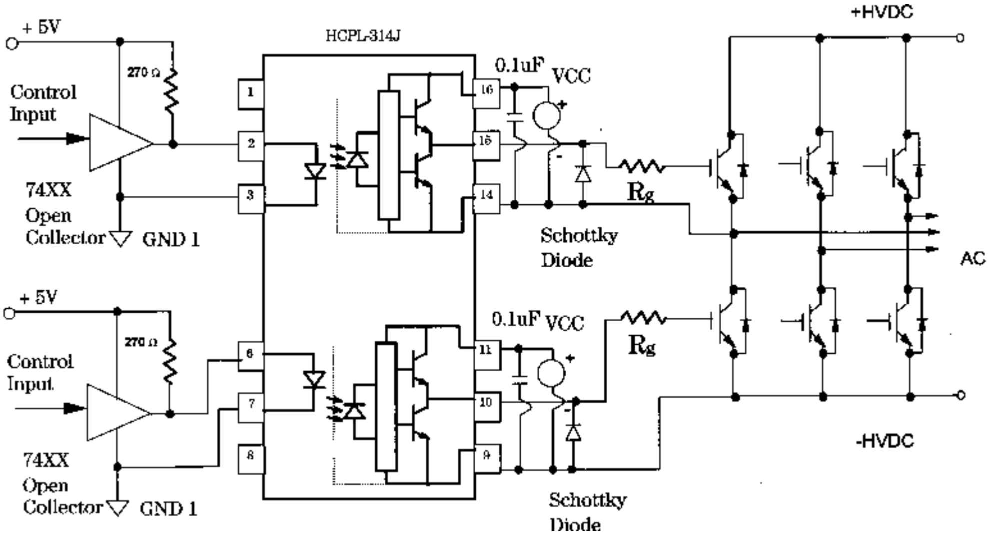

Figure 17. Typical Application Circuit Using the HCPL-314J (Dual) Inverter Gate Driver.

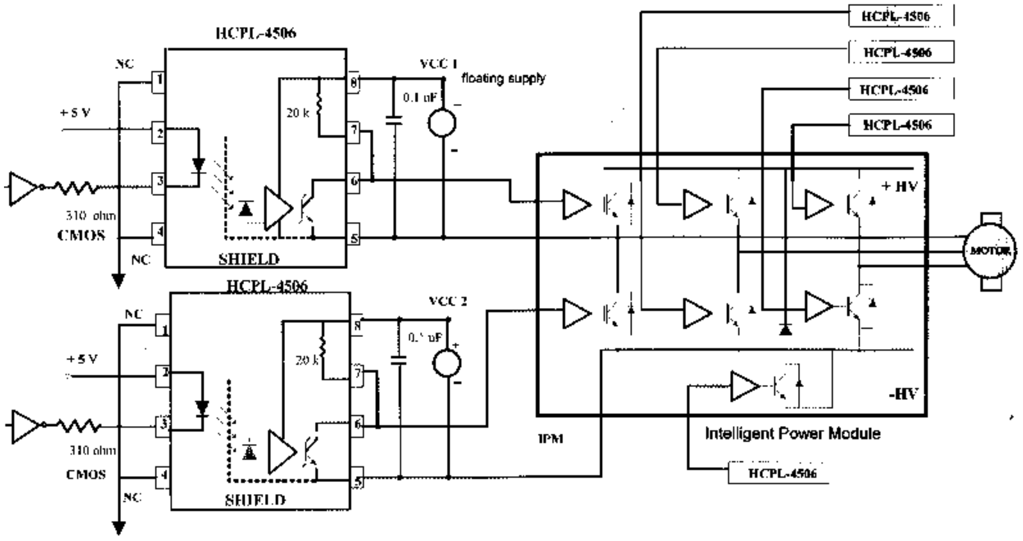

Figure 18. Typical Application Circuit Using the HCPL-4506 IPM Driver Optocoupler.

For driving an Intelligent Power Module (IPM), one does not need to use high output drive current optoisolators such as the HCPL-314J or HCPL-315J. Since an IPM has a built-in driver and IGBT in a single modular package, one can use a transistor output optocoupler such as HCPL-4504 or HCPL-4506. Such an optocoupler would require only a pull-up resistor to interface with the input of an IPM.

Shown in Figure 18 is an IPM interface using the HCPL-4506. This optocoupler has a built-in pull up resistor available at pin 7, and is optimized and ideal for IPM driver applications. The HCPL-4506 can drive a 1000 pF load capacitance at 500-ns maximum propagation delay.

An internal pull up resistor of 20 kohm is available on pin 7 of the HCPL-4506. In a noisy common mode environment, it is recommended that the unconnected pins 1 and 4 of the HCPL-4506 be grounded.

For low cost current sensing applications, for bus current, phase current, and voltage sensing for bus voltage, temperature sensing (voltage from temperature sensor of the heat sink of the IGBT or IPM), or counter electromotive voltage of the motor (for brushless DC motors only), one can use the HCPL-7840.

Figure 16 had shown the HCPL-7840 in a motor phase current sensing topology. In Figure 19 we show how a suitable voltage divider at the input (such that the sensing voltage is below 200-mV absolute value) can be used to measure the bus voltage or counter EMF of brushless DC motors.

In this case, the constraint is that the value of R1 should be kept below 1kohm, such that input impedance of the HCPL-7840 (280 kohm) and input current (1 µA typical) do not introduce offsets and inaccuracies in the measurement. An input bypass capacitor of 0.01 µF is still required, although the 39 ohm resistor can be omitted, as the voltage divider resistor will perform the same low pass filter function.

Conclusion

In this article we have shown that Agilent Technologies provides a wide portfolio of optocouplers that includes modern, state-of-the-art, reliable, sophisticated, and application-specific optoisolators for small or large variable-speed motor control applications. In particular, low cost versions of the motor control optoisolators are particularly suited for small motors in the home appliance area. In addition, we have considered various inverter gate drive topologies, and different methods of motor AC phase current or DC bus voltage or current measurements. Based on performance, cost, and size criteria, we have shown that optoisolators are very competitive devices for gate driver and current sense applications. Optoisolators outperform competitive technologies for both inverter gate driver and current or voltage sensing applications.

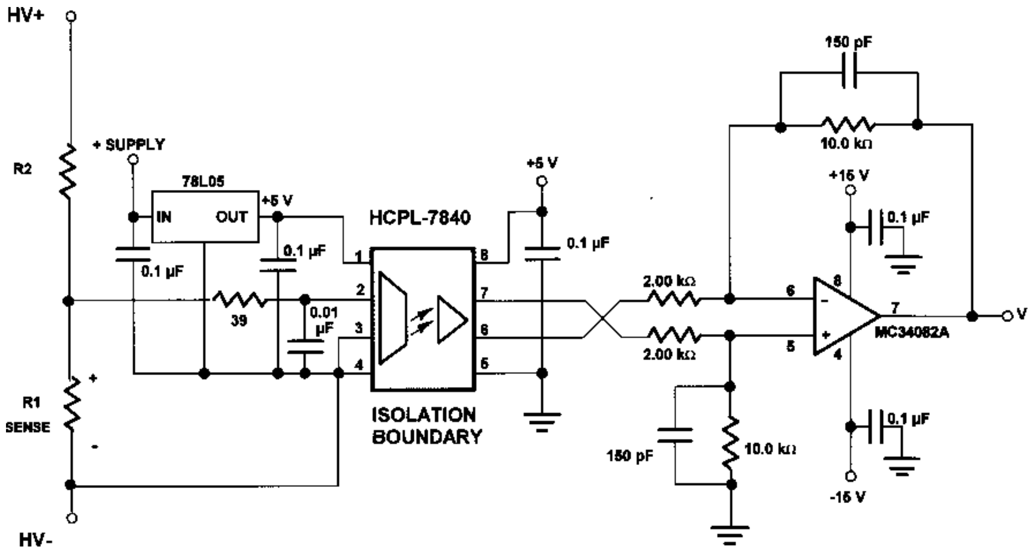

Figure 19. Typical Application Circuit Using the HCPL-7840 Iso-Amp for Voltage Sensing.

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微波光电部专业代理经销高频、微波、光纤、光电元器件、组件、部件、模块、整机；电磁兼容元器件、材料、设备；微波 CAD、EDA 软件、开发测试仿真工具；微波、光纤仪器仪表。欢迎国外高科技微波、光纤厂商将优秀产品介绍到中国、共同开拓市场。长期大量现货专业批发高频、微波、卫星、光纤、电视、CATV 器件: 晶振、VCO、连接器、PIN 开关、变容二极管、开关二极管、低噪晶体管、功率电阻及电容、放大器、功率管、MMIC、混频器、耦合器、功分器、振荡器、合成器、衰减器、滤波器、隔离器、环行器、移相器、调制解调器；光电子元器件和组件：红外发射管、红外接收管、光电开关、光敏管、发光二极管和发光二极管组件、半导体激光二极管和激光器组件、光电探测器和光接收组件、光发射接收模块、光纤激光器和光放大器、光调制器、光开关、DWDM 用光发射和接收器件、用户接入系统光光收发器件与模块、光纤连接器、光纤跳线/尾纤、光衰减器、光纤适 配器、光隔离器、光耦合器、光环行器、光复用器/转换器；无线收发芯片和模组、蓝牙芯片和模组。

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