Isolation Circuits for General Purpose Analog Applications

Contents:

Introduction

To help you choose and design with Hewlett-Packard isolation components, this Designer's Guide contains analog isolation circuits for general purpose industrial applications including a low-cost circuit for motor speed and position measurement. There are two other Hewlett-Packard documents that are available to help your inverter circuit design:

- *Isolation Circuits for Inverter Gate Drive* (Publication Number 5965-8071E)
- *Isolation Circuits for Current and Voltage Sensing* (Publication Number 5965-8207E)

Information regarding Hewlett-Packard optoisolators (including data sheets and application notes) is available on the World Wide Web at:

www.hp.com/go/isolator

Overview of Analog Isolation Applications

Optoisolators transfer analog and digital signals from one circuit section or module to another in the presence of a large potential difference or induced electrical noise between the ground or common points of these modules. Examples of analog isolation applications are interfaces to: A/D converters, sensing circuits such as thermocouples and transducers, patient monitoring equipment, motor speed and position measurement circuits, audio and video amplifiers, and power supply feedback.

Hewlett-Packard offers two categories of analog optoisolators. The first category of optoisolators (such as the HCNR201 and HCPL-4562) are basic building blocks with highly linear LED and photodetector/amplifier combination. The second category of optoisolators (such as the HCPL-7820 and HCPL-7860/7870) have extra functionality and can be used to replace conventional isolation amplifiers and analog-to-digital converters.

Basic Building Blocks for Analog Isolation

HP's HCNR200/1 and HCPL4562 constitute basic optical coupling building blocks for high linearity isolation applications. Figures 1 and 2 show the respective optical coupling mechanisms for these two optoisolators. Both these isolators use high-performance AlGaAs LEDs and photodiode combinations with higher speed and linearity compared to conventional optoisolators. The HCNR200/1 LED illuminates two closely matched photodiodes, one on the input side, and another on the output side. With a suitable applications circuit for the HCNR200/1, the nonlinearity and drift characteristics of the LED can be virtually eliminated. The output photodiode produces a photocurrent that is linearly related to the light output of the LED. The close matching of the photodiodes and advanced design of the package ensure the high linearity and stable gain characteristics of the optoisolator.

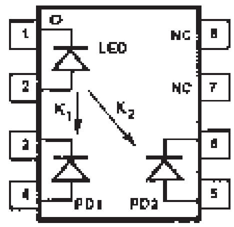


Figure 1. HCNR200/1 High Linearity Analog Isolator.

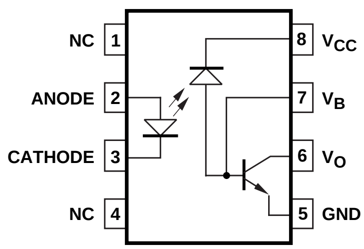


Figure 2. HCPL-4562 High Bandwidth Analog Isolator.

The HCNR200/1 optoisolator can be used as a basic analog isolation building block for a wide variety of applications that require good stability, linearity, bandwidth and low cost. The HCNR200/1 is very flexible and, by appropriate design of the application circuit, is capable of operating in many different modes, including unipolar, bipolar, ac/dc, inverting and non-inverting.

The HCPL-4562 and HCNW4562 are recommended for very high bandwidth (up to 15 MHz) AC analog designs. If the output transistor is biased in the active region, the current transfer ratio relationship for the HCPL-4562 can be represented as:

$$I_C = K\,(I_F/I_{FQ})^{\,n}$$

where I_C is the collector current; I_F is the LED input current, I_{FQ} is LED input current at which K is measured; K is the collector current when $I_F = I_{FQ}$; and n is the slope of I_C vs. I_F on logarithmic scale.

The exponent n varies with I_F, but over some limited range of ΔI_F, n can be regarded as a constant. For ac-signal applications, the HCPL-4562 can be biased at an appropriate quiescent current where the ratio of the incremental photodiode current to incremental LED current is nearly constant. Figure 3 shows the linearity characteristics of the HCPL-4562.

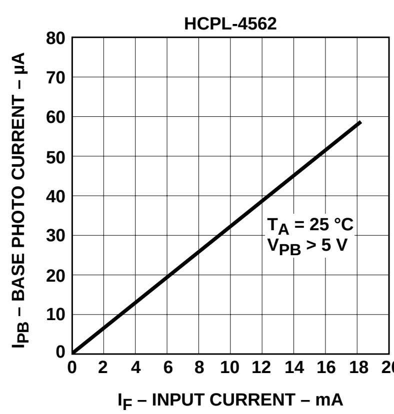


Figure 3. HCPL-4562 Base Photo Current vs. Input Current.

Integrated High-CMR Isolation Amplifiers and A/D Converter

HP offers integrated high common-mode rejection isolation amplifiers and A/D converters for applications where high accuracy, small size, low component count, and electrical noise immunity are major issues. The HCPL-78xx series of isolation amplifiers and A/D converters use sigma-delta analog-to-digital conversion techniques for internally coupling the signal. By deploying these circuit techniques, the nonlinearity and drift characteristics of the LED are eliminated. Figures 4 and 5 conceptually describe HP's isolation amplifier and A/D converters.

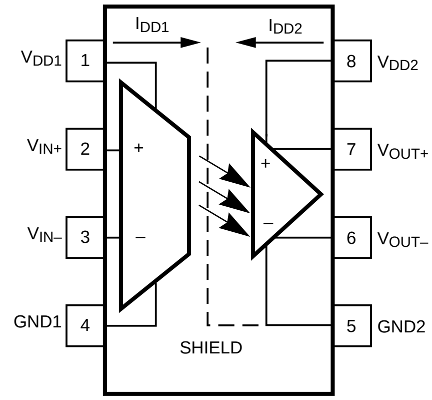


Figure 4. High CMR Analog Isolation Amplifier.

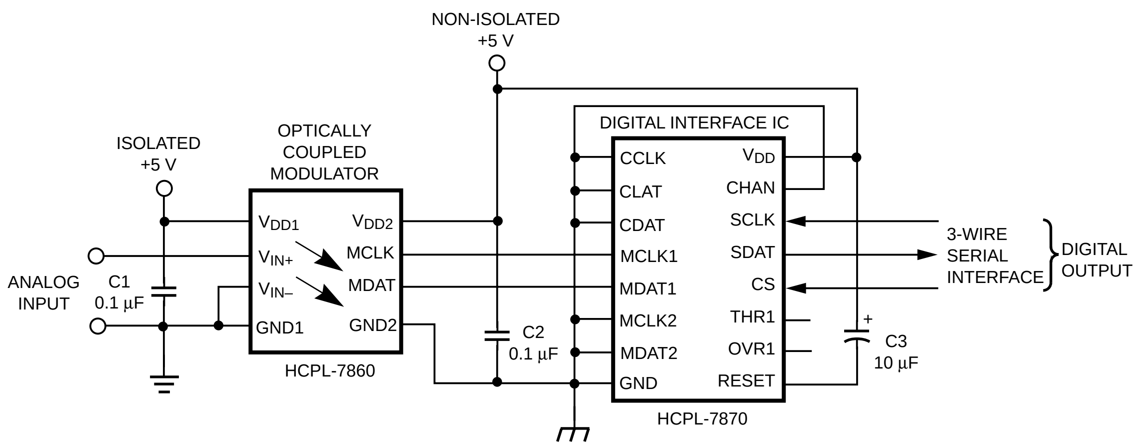


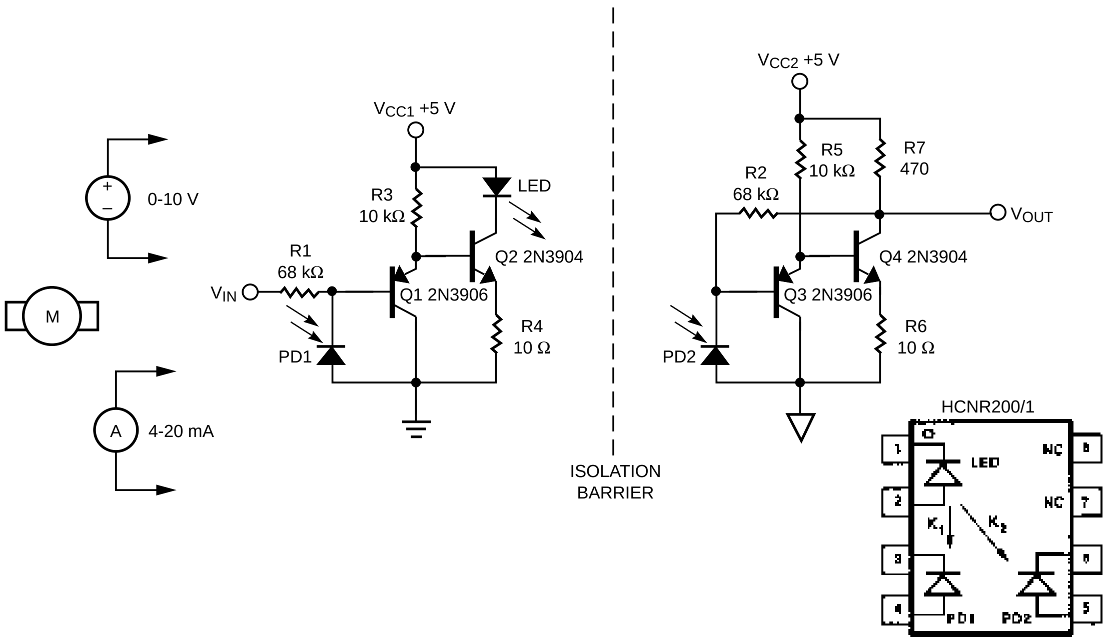
Figure 5. HCPL-7860/7870 Isolated A/D Converter.

Analog Optoisolator Selection Guide

Analog Function	Part Number	Gain Tolerance (±%)	Non-linearity (%)	Signal Bandwidth (kHz)	CMR - kV/µs (V_{CM} = 1,500 V)	VDE Insulation Rating* - V_{IORM} (V peak)
Building block for a generic Iso-Amp	HCNR200/1	5 (HCNR201)	0.01	1,000	Not Specified	1,414 (Option 050)
Building block for AC-coupled Iso-Amp	HCPL-4562	Not Specified	0.25	17,000		630 V (Option 060)
	HCNW4562		0.15	13,000		1,414
Integrated High-CMR Iso-Amp	HCPL-7800 HCPL-7800A/B	1	0.35	85	10,000	848
	HCPL-7820/25	3	0.15	200	20,000	848
	HCPL-7840	5	0.2	100	10,000	848
	HCPL-J784	5	0.2	100	10,000	891
Isolated A/D Converter	HCPL-7860 and HCPL-7870	1	0.15	22	15,000	848

Note: Refer to the technical data sheets for detailed specifications.

Low-cost Isolation Amplifier for Motor Speed and Position Measurement



Performance of Circuit

- 1.5 MHz bandwidth
- Stable gain
- Low-cost support circuit
- Circuit couples only positive voltage signals

Benefits

- Low cost solution for coupling positive voltage analog signals
- Simple way for isolating motor speed and position analog signals

Description

This is a high-speed, low-cost isolation amplifier that can be used for the measurement of motor speed and position. The analog signal coming from the motor is assumed to be 0 to 10 V, or 4 to 20 mA. This circuit can be used in applications where high bandwidth, low-cost, and stable gain are required, but where accuracy is not critical. This circuit is a good example of how a designer can trade off accuracy to achieve improvements in bandwidth and cost. The circuit has a bandwidth of about 1.5 MHz with stable gain characteristics and requires few external components.

The input amplifier is comprised of Q1, Q2, R3 and R4, while the output amplifier is comprised of Q3, Q4, R5, R6 and R7. The use of discrete transistors instead of op-amps allows the designer to trade-off accuracy to achieve good bandwidth and gain stability at low cost. R1 is selected to achieve an LED current of about 7-10 mA at the nominal input operating voltage according to the following equation:

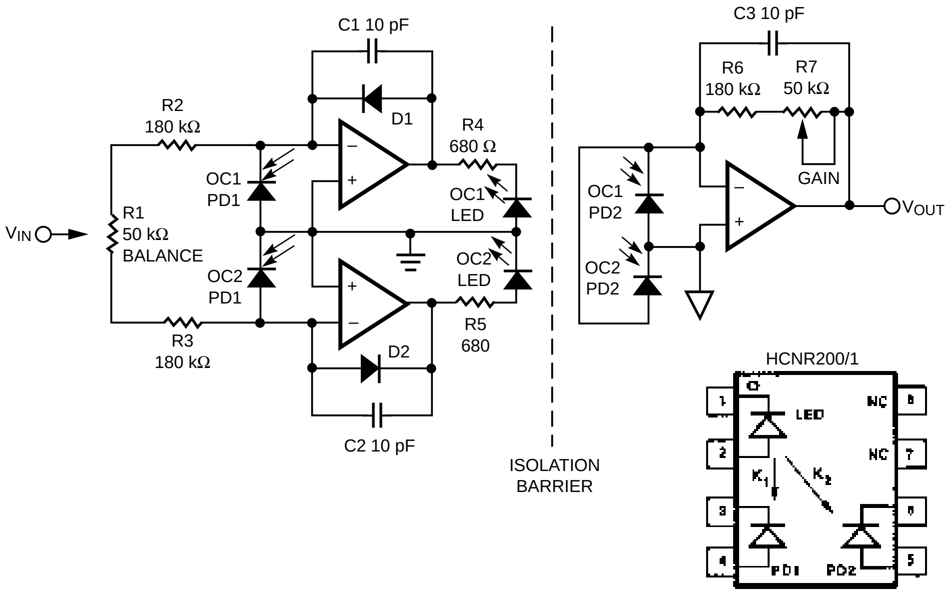
$$I_F = (V_{IN} / R1) / K1,$$

where K1 (i.e., I_{PD1} / I_F) of the optocoupler is typically about 0.5%. R2 is then selected to achieve the desired output voltage according to the equation,

$$V_{OUT} / V_{IN} = R2 / R1.$$

The purpose of R4 and R6 is to improve the dynamic response (i.e., stability) of the input and output circuits by lowering the local loop gains. R3 and R5 are selected to provide enough current to drive the bases of Q2 and Q4. And R7 is selected so that Q4 operates at about the same collector current as Q2.

Isolation Amplifier for Bipolar Signals



Performance of Circuit

- 0.01% nonlinearity
- Low transfer gain variation: ±5% (K3 of HCNR201)
- Low crossover distortion within the dc to 100 Hz frequency band

Benefits

- Low cost solution for bipolar analog signals.
- Worldwide insulation safety certification

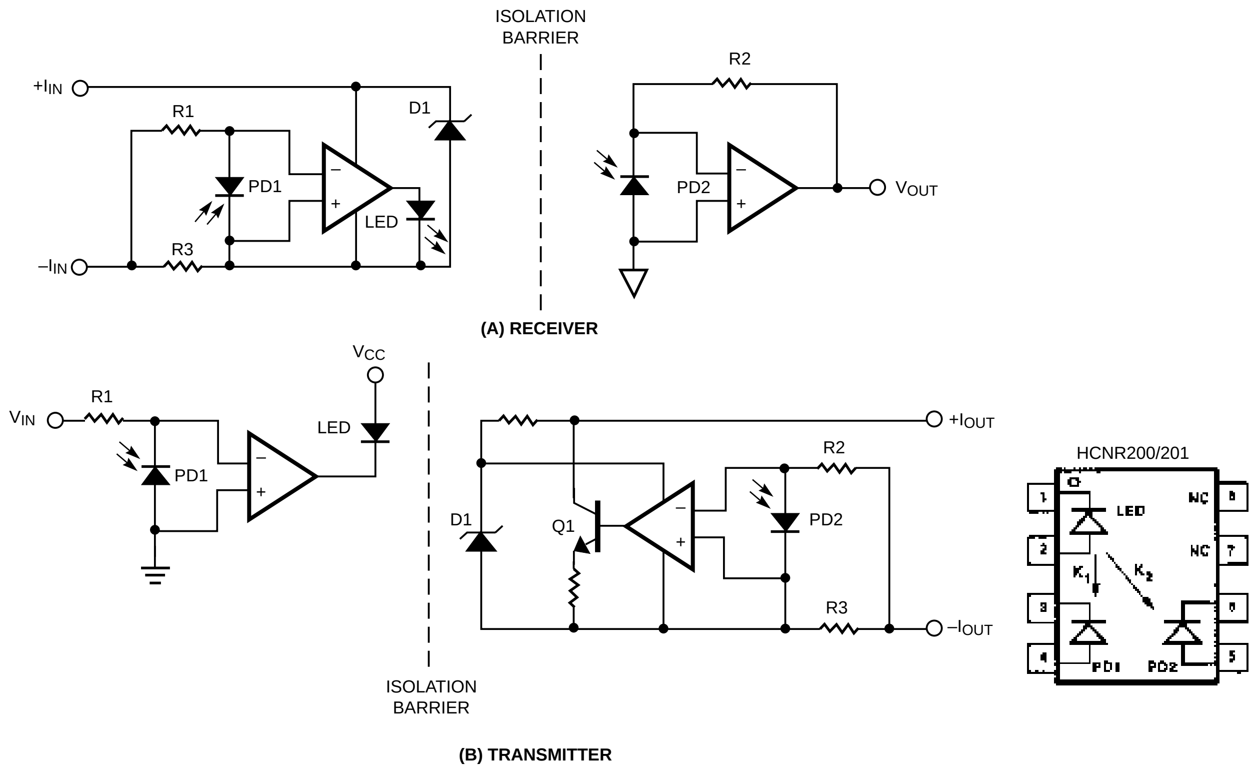
Description

This circuit shows how the HCNR200/1 high linearity optocoupler can be used for transmitting bipolar analog signals across an isolation boundary. This circuit uses two optocouplers: OC1 and OC2; OC1 handles the positive portions of the input signal and OC2 handles the negative portions.

Diodes D1 and D2 help reduce cross-over distortion by keeping both amplifiers active during both positive and negative portions of the input signal. For example, when the input signal is positive, optocoupler OC1 is active while OC2 is turned off. However, the amplifier controlling OC2 is kept active by D2, allowing it to turn on OC2 more rapidly when the input signal goes negative, thereby reducing crossover distortion.

Balance control R1 adjusts the relative gain for the positive and negative portions of the input signal, gain control R7 adjusts the overall gain of the isolation amplifier, and capacitors C1-C3 provide compensation to stabilize the amplifiers.

Isolated 4 - 20 mA Analog Current Loop Transmitter/Receiver



Performance of Circuit

- HCNR200/1 nonlinearity: 0.1%
- HCNR201 gain tolerance: ±5%

Benefits

- Low-cost, simple circuit
- No isolated power supply needed on the 4 - 20 mA side of the circuit

Description

The HCNR200/1 Analog Optocoupler isolates both the transmitter and receiver circuit from the 4 - 20 mA Analog Current Loop. One important feature of this circuit is that the loop side of the circuit is powered by the loop current. No isolated power supply is required.

The zener diode D1 on the input side of the receiver circuit regulates the supply voltage for the input amplifier, while R3 forms a current divider with R1 to scale the loop current down from 20 mA to an appropriate level for the input circuit (<50 mA).

In this simple circuit, the input amplifier adjusts the LED current so that both of its input terminals are at the same voltage. The loop current is then divided between R1 and R3. I_{PD1} is equal to the current in R1 and is given by the following equation:

$$I_{PD1} = I_{LOOP} \cdot R3 / (R1+R3).$$

The ratio of the output voltage to the loop current is,

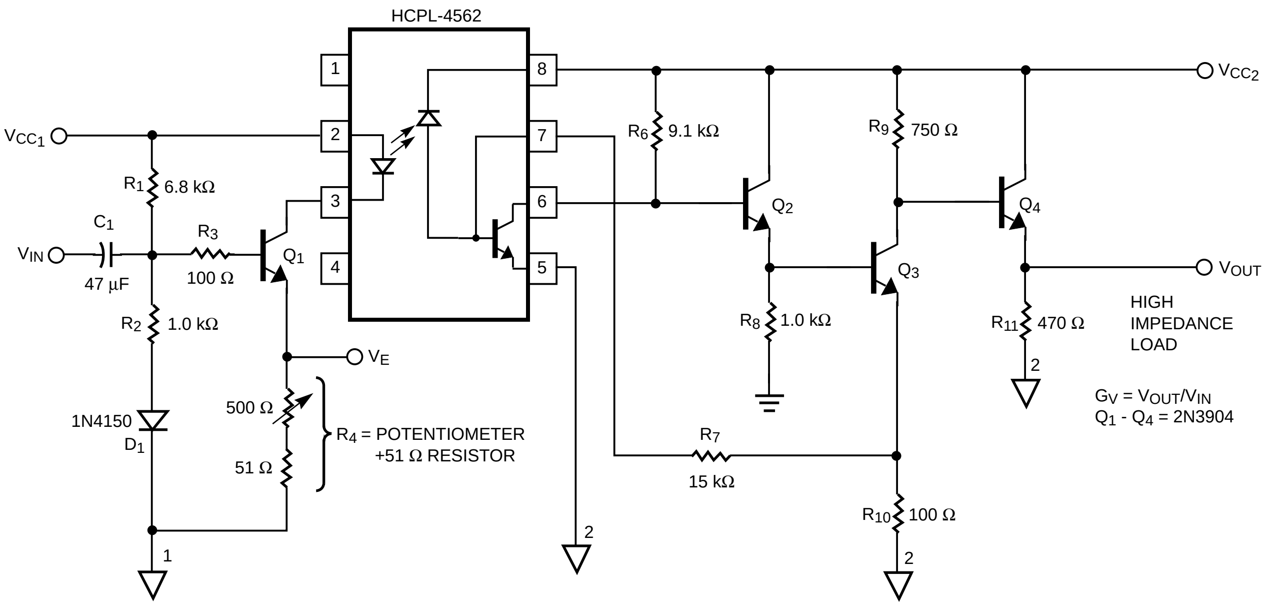
$$V_{OUT} / I_{LOOP} = K \cdot (R2 \cdot R3) / (R1+R3).$$

One can see that the relationship is constant, linear, and independent of the characteristics of the LED.

The 4 - 20 mA transmitter circuit is a little different from a standard isolated amplifier circuit, particularly the output circuit. The output circuit does not directly generate an output voltage which is sensed by R2, it instead uses Q1 to generate an output current which flows through R3. This output current generates a voltage across R3, which is then sensed by R2. An analysis similar to the one above yields the following expression relating output current to input voltage:

$$I_{LOOP} / V_{IN} = K \cdot (R2+R3)/(R1 \cdot R3)$$

15 MHz AC-Coupled Isolation Amplifier



Performance of Circuit

- Typical bandwidth: 15 MHz
- Typical Gain variation: -1.1 dB at 5 MHz with reference at 0.1 MHz
- Isolation Mode Rejection: 122 dB at 120 Hz

Benefits

- Cost-effective, high performance video interface circuit

Description

This circuit, with the HCPL-4562 Wideband Analog/Video Optocoupler, is optimized for video signal coupling. The peaked response of the detector circuit helps extend the frequency range over which the gain is relatively constant. The number of gain stages, the overall circuit topology, and the dc bias points are all chosen to maximize the bandwidth.

The application circuit incorporates several features that help maximize the bandwidth performance of the HCPL-4562. Most important of these features is peaked response of the detector circuit that helps extend the frequency range over which the voltage gain is relatively constant. The number of gain stages, the overall circuit topology, and the choice of DC bias points are all consequences of the desire to maximize bandwidth performance.

To use the circuit, first select R1 to set V_E for the desired LED quiescent current by:

$$I_{FQ} = \frac{V_E}{R_4} \cong \frac{G_V V_E R_{10}}{(\partial I_{PB}/\partial I_F) R_7 R_9} \quad (1)$$

For a constant value $V_{IN_{p-p}}$, the circuit topology (adjusting the gain with R_4) preserves linearity by keeping the modulation factor (MF) dependent only on V_E.

$$I_{F_{p-p}} \cong V_{IN}/R_4 \quad (2)$$

$$\frac{I_{F_{p-p}}}{I_{FQ}} \cong \frac{I_{PB_{p-p}}}{I_{PBQ}} = \frac{V_{IN_{p-p}}}{V_E} \quad (3)$$

$$\text{Modulation Factor (MF): } \frac{i_{F_{p-p}}}{2\, I_{FQ}} = \frac{V_{IN_{p-p}}}{2\, V_E} \quad (4)$$

continues

For a given G_V, V_E, and V_{CC}, DC output voltage will vary only with h_{FEX}.

$$V_O = V_{CC} - V_{BE_4} - \frac{R_9}{R_{10}} \; [V_{BEX} = (I_{PBQ} - I_{BXQ}) \, R_7] \quad (5)$$

Where:

$$I_{PBQ} \cong \frac{G_V \, V_E \, R_{10}}{R_7 R_9} \qquad (6)$$

and,

$$I_{BXQ} \cong \frac{V_{CC} - 2 \, V_{BE}}{R_6 \; h_{FEX}} \qquad (7)$$

For 9 V < V_{CC} < 12 V, select the value of R11 such that:

$$I_{C_{Q4}} \cong \frac{V_O}{R_{11}} \le \frac{4.25 \text{ V}}{470 \, \Omega} \le 9.0 \text{ mA} \qquad (8)$$

The voltage gain of the second stage (Q_3) is approximately equal to:

$$\frac{R_9}{R_{10}} \bullet \frac{1}{1 + s \, R_9 \left[C_{CQ_3} + \dfrac{1}{2\pi \, R'_{11} \, f_{T4}} \right]} \qquad (9)$$

Increasing R'_{11} (R'_{11} includes the parallel combination of R_{11} and the load impedance) or reducing R_9 (keeping R_9/R_{10} ratio constant) will improve the bandwidth.

Finally, adjust R_4 to achieve the desired voltage gain.

$$G_V \cong \frac{V_{OUT}}{V_{IN}} \cong \frac{\partial I_{PB}}{\partial I_F} \left[\frac{R_7 R_9}{R_4 R_{10}} \right] \qquad (10)$$

where typically $\dfrac{\partial I_{PB}}{\partial I_F} = 0.0032$

Definitions:

G_V = Voltage Gain

I_{FQ} = Quiescent LED forward current

$i_{Fp\text{-}p}$ = Peak-to-peak small signal LED forward current

$V_{INp\text{-}p}$ = Peak-to-peak small signal input voltage

$i_{PBp\text{-}p}$ = Peak-to-peak small signal base photocurrent

I_{PBQ} = Quiescent base photocurrent

V_{BEX} = Base-Emitter voltage of HCPL-4562/HCNW4562 transistor

I_{BXQ} = Quiescent base current of HCPL-4562/HCNW4562 transistor

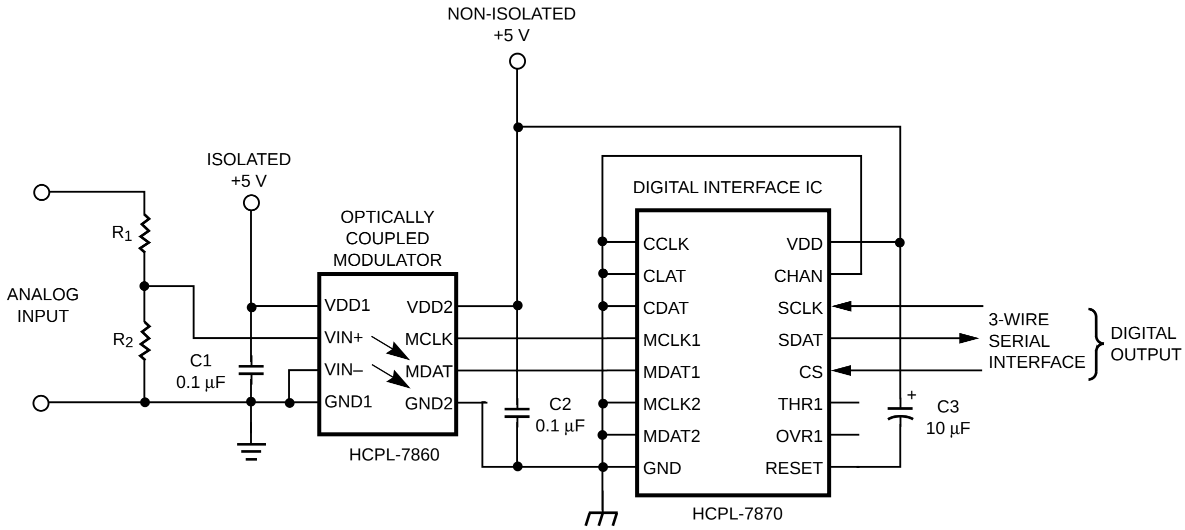
h_{FEX} = Current Gain (I_C/I_B) of HCPL-4562/HCNW4562 transistor

V_E = Voltage across emitter degeneration resistor R_4

f_{T_4} = Unity gain frequency of Q_4

C_{CQ_3} = Effective capacitance from collector of Q_3 to ground

Isolated 15-bit A/D Converter



Performance of Isolated A/D Converter

• Resolution due to linearity:	12 bits at t_{DELAY} = 18 µs 14 bits at t_{DELAY} = 94 µs
• Common-mode transient rejection:	dV/dt = 15 kV/µs @ V_{CM} = 1500 V
• Signal-to-Noise:	SNR = 62 dB (minimum)
• Regulatory Isolation Ratings:	V_{ISO} = 3750 V (per UL 1577) V_{IORM} = 848 V; V_{IOTM} = 6000 V
• Input Offset Drift:	4 µV / °C (typical)
• Reference Voltage Tolerance:	± 4% (± 1% within shipment tube)

Benefits

- Integrated analog-to-digital converter means fewer components required.
- High common-mode transient rejection ensures no corruption of data.
- Low gain temperature-coefficient and offset voltage ensure high accuracy measurements.

Description

The HCPL-7860 Isolated Modulator and the HCPL-7870 Digital Interface IC together form an isolated programmable two-chip analog-to-digital converter. The isolated modulator allows direct measurement of analog signals through the resistor divider circuit R1 and R2 while the digital interface IC can be programmed to optimize the conversion speed and resolution.

In operation, the HCPL-7860 Isolated Modulator optocoupler converts a low-bandwidth analog input into a high-speed one-bit data stream by means of a sigma-delta (ΣΔ) oversampling modulator. The Digital Interface IC converts the single-bit data stream from the Isolated Modulator into fifteen-bit output words and provides a serial output interface that is compatible with SPI®, QSPI®, and Microwire® protocols, allowing direct connection to a microcontroller. The isolated A/D converter provides fast over-range detection (i.e. for short-circuit detection) and adjustable threshold detection (for over-current detection). The Digital Interface IC may be programmed to one of five different conversion modes and three different pre-trigger modes. It also has programmable offset calibration, for even higher accuracy.

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Technical References:

1. Information regarding Hewlett-Packard optoisolators (including data sheets and application notes) is available on the World Wide Web at:

www.hp.com/go/isolator

2. *Designer's Guide to Isolation Circuits for Inverter Gate Drive* (Publication Number 5965-8071E)

3. *Designer's Guide to Isolation Circuits for Current and Voltage Sensing* (Publication Number 5965-8207E)

4. *Regulatory Guide to Isolation Circuits* (Publication Number 5965-5853E)

5. The data sheets in the following table are available through the Components Sales Response Center at Tel: 1-800-235-0312 or through a Faxback service at Tel: 1-800-450-9455.

Hewlett-Packard Data Sheets

HP Part Number	Title	HP Publication Number	HP Faxback ID Number
HCNR200 HCNR201	High Linearity Analog Optocoupler	5965-3577E	12139
HCPL-4562 HCNW4562	High Bandwidth, Analog/Video Optocoupler	5965-3597E	53869
HCPL-7820 HCPL-7825	High CMR Isolation Amplifier	5965-3591E	80432
HCPL-7840	Analog Isolation Amplifier	5965-4784E	12130
HCPL-J784	High Insulation Analog Isolation Amplifier	New*	
HCPL-7800/A/B	High CMR Isolation Amplifier	5965-3592E	55807
HCPL-7860/ 7870/0870	Isolated 15-bit A/D Converter	5965-5255E	11997

* The "New" HP Optocouplers will soon be assigned Publication and Faxback ID Numbers. Contact your sales representative to order the data sheet.

For technical assistance or the location of your nearest Hewlett-Packard sales office, distributor or representative call:

Americas/Canada: 1-800-235-0312 or (408) 654-8675

Far East/Australasia: Call your local HP sales office.

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