HCNR200 and HCNR201

Applications in Motor Drive and Current Loop

Application Note 5394

Abstract

This note covers operation and applications of the HCNR200 and HCNR201 high-linearity analog optocouplers. Internal operation and the servo control mechanism of the optocouplers are described in detail. A couple of application examples are presented, ranging from motor control current sensing to traditional current loop communication in process control. The evaluation board for these optocouplers is also introduced in this note.

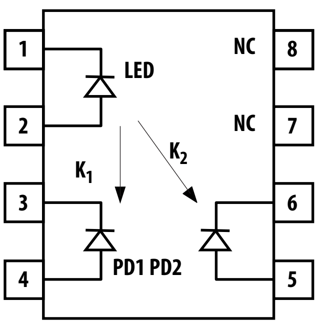

Figure 1. Schematic of the HCNR200 and HCNR201.

Figure 2. HCNR200 and HCNR201 400 mil widebody DIP-8 package.

Introduction

The HCNR200/201 high-linearity analog optocoupler consists of a high-performance AlGaAs LED that illuminates two closely matched photodiodes, PD1 and PD2, as shown in Figure 1. The input photodiode, PD1 can be used to monitor, and therefore stabilize, the light output of the LED. As a result, the nonlinearity and drift characteristics of the LED can be virtually eliminated. The output photodiode PD2 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 optocoupler [1]. The HCNR200/201 is available in a 400 mil widebody DIP-8 package (see Figure 2) with gull wing surface mount option. Table 1 shows the selection guide for the HNCR200/201.

The HCNR200/201 can be used to isolate analog signals in a wide variety of applications that require good stability, linearity, bandwidth and low cost. The HCNR200/201 is very flexible and, by appropriate design of the application circuit, is capable of operating in many different modes, including: unipolar/ bipolar, AC/DC and inverting/non-inverting. The HCNR200/201 is an excellent solution for many analog isolation problems, among which a couple of application examples are discussed here.

Table 1. Selection guide for HCNR200 and HCNR201.

		Transfer Gain Tolerance (%)	DC Non-Linearity (%)	CTR (%)	CTR (%)	V_{ISO} (V_{RMS})	
Part Number	**Package**	**Max.**	**Max.**	**Min.**	**Max.**	**Min.**	**V_{IORM} (Vpeak)**
HCNR200	400 mil widebody	±15	0.25	0.25	0.75	5000[a]	1414[b]
HCNR201	400 mil widebody	±5	0.05	0.36	0.72	5000[a]	1414[b]

Notes:
a. Recognized under UL 1577.
b. Approved under IEC/EN/DIN EN 60747-5-2, available for option 050.

Current Sensing and Voltage Monitoring Applications

The HCNR200/201 can be applied for current sensing and voltage monitoring in various application areas, such as motor control drives, switching power supply feedback loops, as well as inverter systems. As part of the motor control drives, variable-speed motor drives are finding increasing applications not only in industrial applications but also home appliances. Among the key components such as IGBTs/ MOSFETs, gate drivers, and of course the microcontroller unit (MCU), analog current and voltage sensors are critical to feed back information to the MCU for stable and protected system control. Because of the presence of high voltages, it is necessary, and often mandated by safety and regulatory agencies, that people operating the motors and low voltage digital electronics are protected through galvanic isolation. The HCNR200/201 provides very high insulation voltage (5 kVrms/1 min rating) and is suitable for DC bus voltage monitoring, DC bus current sensing, and AC phase current sensing, as well temperature and positioning sensing.

Figure 3 shows these applications (framed in the box named Analog Isolation Block) in a typical motor drive block diagram [2]. From this figure, one can figure out that resistors R2 and R5 measure the HV DC bus voltage and DC bus current respectively, while resistors R3 and R4 measure motor phase current. Parameters such as temperature and position can be sensed by appropriate sensors attached to the motor, whose output is fed to another Analog Isolation Block. All the parameters are then transferred across the isolation barrier and collected by the MCU. Figure 4 A and B [1] show a simplified schematic of the Analog Isolation Block for unipolar input and bipolar input circuit.

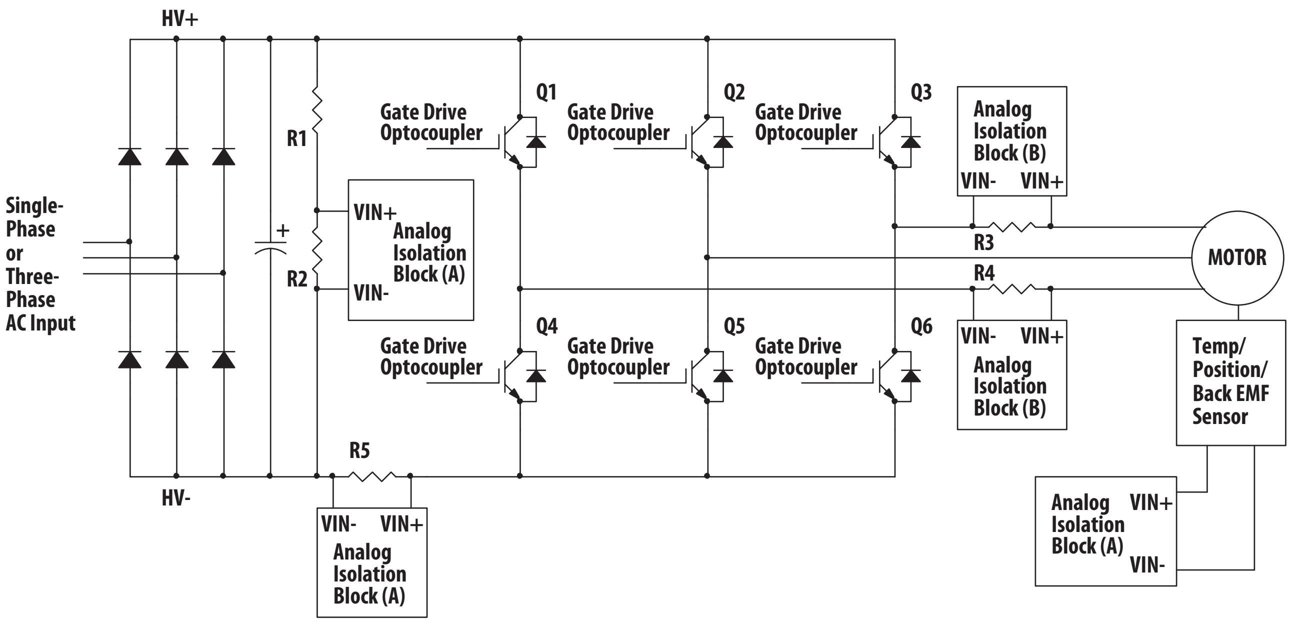

Figure 3. A typical motor drive block diagram.

Theory of Operation

The operation [1, p. 15] of the circuit may not be immediately obvious just from inspecting Figure 4A, particularly the input part of the circuit. The op-amp always tries to maintain the same input voltages at its two inputs in a linear feedback, close loop connection. Thus, the input side op-amp A1 always tries to place zero volts across the photodiode PD1. Now, if some positive voltage V_{IN+} is applied at the input, the op-amp output would tend to swing to the negative rail causing the LED current to flow. This V_{IN+} will cause a current to flow through R1, and the LED light output will be detected by PD1 which generates a current I_{PD1}. Assuming that A1 is a perfect op-amp, no current flows into the inputs of A1; therefore, all of the current flowing through R1 will flow through PD1. Since the "+" input of A1 is at 0 V, the current through R1, and therefore I_{PD1} as well, is equal to V_{IN+}/R1, or

$$I_{PD1} = V_{IN+}/R1.$$

Notice that I_{PD1} depends ONLY on the input voltage and the value of R1 and is independent of the light output characteristics of the LED. As the light output of the LED changes with temperature, amplifier A1 adjusts I_F to compensate and maintain a constant current in PD1. Also notice that I_{PD1} is exactly proportional to V_{IN+}, giving a very linear relationship between the input voltage and the photodiode current. The relationship between the input optical power and the output current of a photodiode is very linear. Therefore, by stabilizing and linearizing I_{PD1}, the light output of the LED is also stabilized and linearized. And since light from the LED falls on both of the photodiodes, I_{PD2} will be stabilized as well.

Since PD1 and PD2 are identical to each other, I_{PD2} should be equal to I_{PD1} ideally. In reality, the relation includes a coefficient K_3. So we have

$$I_{PD2} = K_3 \times I_{PD1},$$

where K_3 is the transfer gain defined in the data sheet (K_3

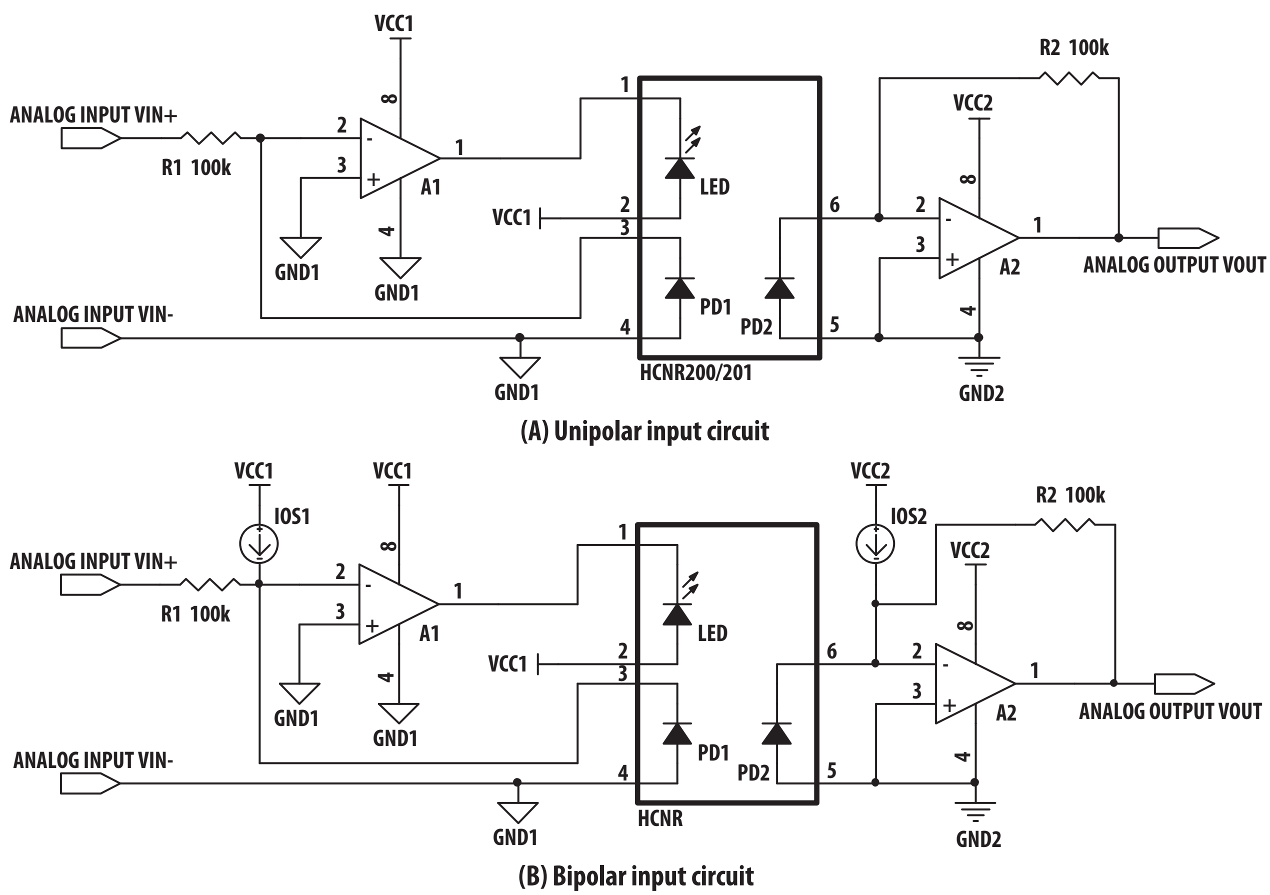

Figure 4. Simplified schematic of the analog isolation block for (A) unipolar input, and (B) bipolar input.

$= I_{PD2}/I_{PD1} = 1$). Amplifier A2 and resistor R2 form a transresistance amplifier that converts I_{PD2} back into a voltage, V_{OUT}, where

$$V_{OUT} = I_{PD2} \times R2.$$

Combining the above three equations yields an overall expression relating the output voltage to the input voltage,

$$V_{OUT}/V_{IN+} = K_3 \times (R2/R1).$$

Therefore the relationship between V_{IN+} and V_{OUT} is constant, linear, and independent of the light output characteristics of the LED. The gain of the Analog Isolation Block circuit can be adjusted simply by adjusting the ratio of R2 to R1.

Figure 4A is in a unipolar configuration that accommodates only positive voltage input. Figure 4B is configured to accommodate a bipolar input (a signal that swings both positive and negative). Two current sources, I_{OS1} and I_{OS2}, are added to offset the signal so that it appears to be unipolar to the optocoupler. Current source I_{OS1} provides enough offset to ensure that I_{PD1} is always positive. The second current source, I_{OS2}, provides and an offset to obtain a net circuit offset voltage of a desired value (e.g., a 0 V may be desired if both positive and negative power supplies are used, whereas a midway voltage could be more appropriate for the case of single positive power supply circuit). Current sources I_{OS1} and I_{OS2} can be implemented as simply as resistors connected to suitable voltage sources. Note that the offset performance is dependent on the matching of I_{OS1} and I_{OS2} and is also dependent on the gain of the optocoupler.

Isolation Amplifiers for Current Sensing and Voltage Monitoring

Besides the HCNR200 and HCNR201, Avago Technologies provides a range of Miniature Isolation Amplifiers and Isolated A/D converters for direct interface with an MCU or digital signal processing (DSP) unit, to serve the purpose of current sensing and voltage monitoring. This kind of sophisticated analog optoisolator is increasingly replacing Hall-Effect sensors to measure and monitor feedback parameters such as AC phase currents, DC rail/bus currents, DC bus voltages and temperature.

Some key advantages of using Isolation Amplifiers and Isolated A/D converters are [2, 3]:

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

Current Loop Communication Application

In the process control industry, current loops have become the standard method for sensor signal transmission [4]. This method is especially useful for long distance transmission (up to 10 km). A current loop is a very flexible communication interface. There are a couple of types of current loops: analog (a linear current represents the analog signal), logic (high and low logic levels represent MARK and SPACE states), and a combined analog and digital current loop that uses the HART® (Highway Addressable Remote Transducer) communication protocol. Compared to voltage signals, current loops have the following benefits:

- Insensitive to noise and immune to errors from line impedance
- Long-distance transmission without amplitude loss
- Inexpensive 2-wire cables
- Lower EMI sensitivity
- Detection of offline sensors, broken transmission lines, and other failures

Adding insulation to the 4-20 mA current loop is important to protect system electronics from electrical noise and transients, which are commonly present in the industrial process-monitoring applications. The insulation barrier allows transducers to be galvanically separated by hundreds or even thousands of volts. The HCNR200 and HCNR201 offer the highest level of safety and regulatory performance available today, which make them suitable for these applications. The widebody package has a 400 mil lead spacing to satisfy demanding external creepage and clearance requirements. The UL/CSA Viso withstand voltage rating is 5000 Vrms (1 minute), and the IEC/EN/DIN EN 60747-5-2 working voltage specification is 1414 Vpeak. The construction has 1 mm of internal clearance (through insulation distance) and 10 mm of external creepage, and 9.6 mm of external clearance. These devices are suitable for not only applications that require reinforced insulation but also failsafe design thanks to its construction. In addition to the HCNR200/201, the HCPL-4100 and HCPL-4200 optically coupled 20 mA current loop transmitter and receiver, respectively, are also offered for systems using a 20 mA logic current loop [5, 6].

An example block diagram of a 4-20 mA analog current loop transmitter and receiver is shown in Figure 5 and 6 [1, Figure 21, 22], respectively.

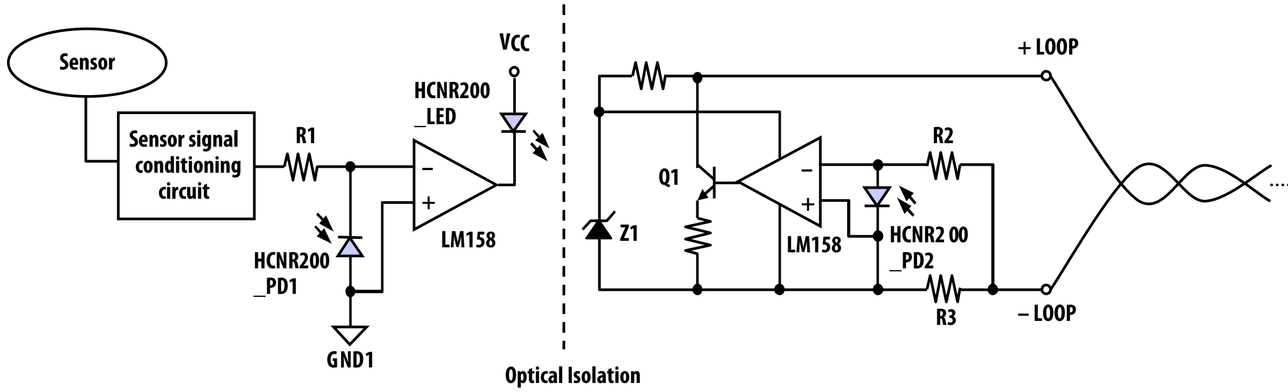

Figure 5. Block diagram of a 4-20 mA analog current loop transmitter.

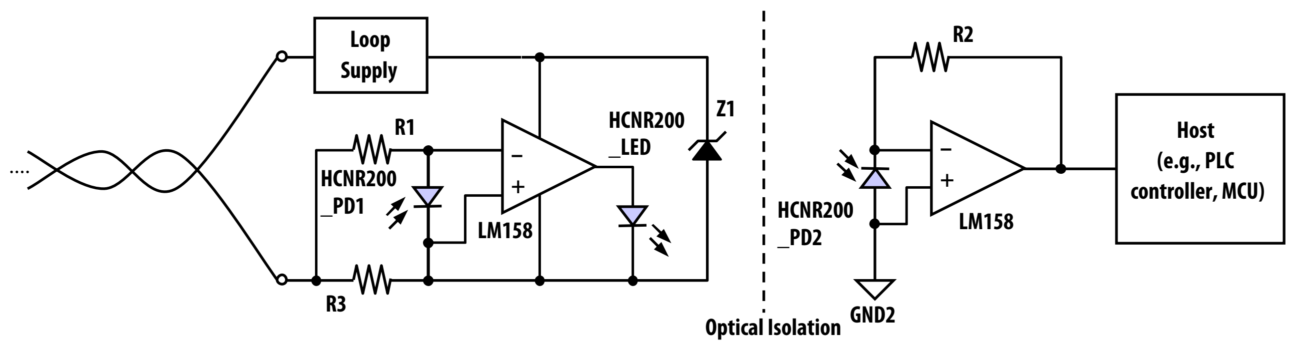

Figure 6. Block diagram of a 4-20 mA analog current loop receiver.

The Evaluation Board

The HCNR201/200 evaluation board helps designers quickly evaluate these high-linearity analog optocouplers. Figures 7 and 8 show the schematic of this evaluation board and its picture, respectively. Besides the HCNR201/200, this evaluation board also consists of two op-amps, at the input side and output side respectively. Refer to the Theory of Operation section to see how this circuit works in details. This evaluation board is suitable for motor control applications such as current sensing, voltage monitoring, temperature and positioning feedback.

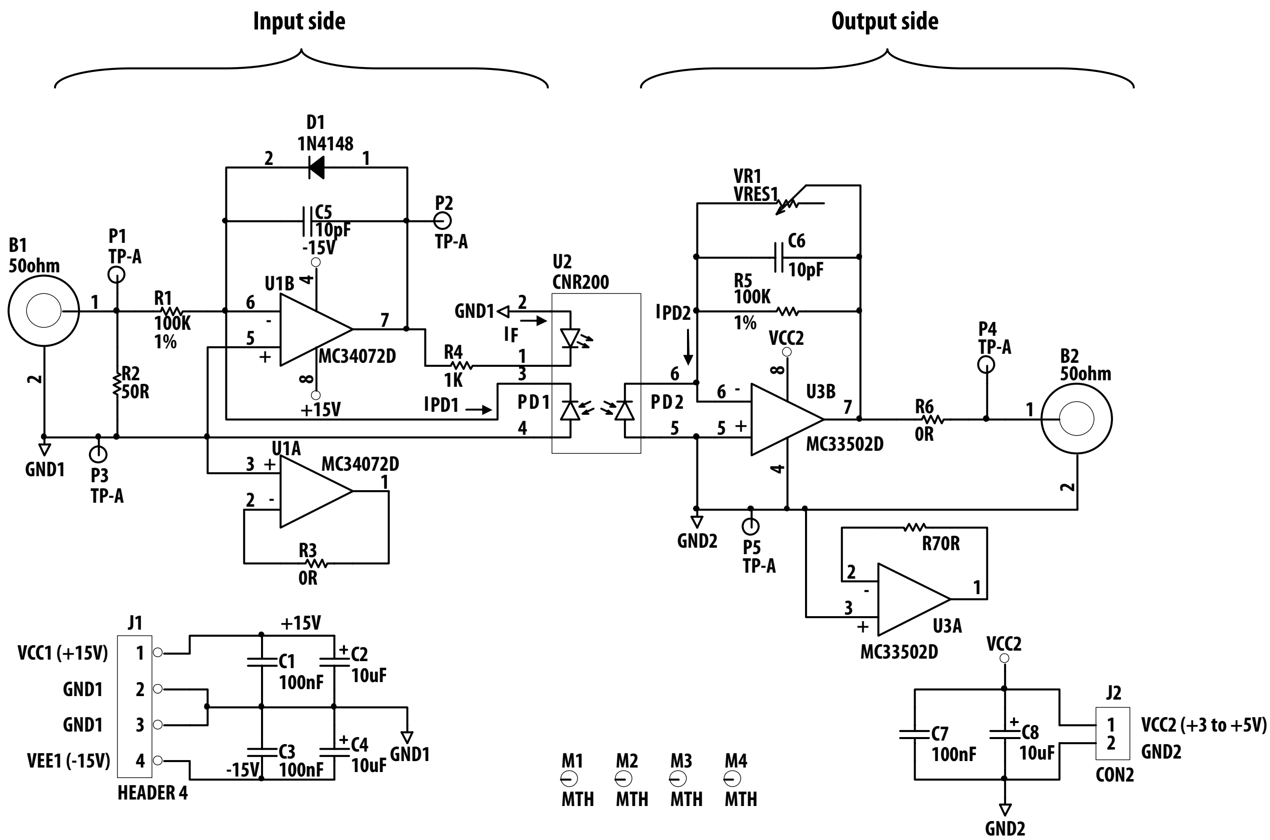

Figure 7. Schematic of the evaluation board.

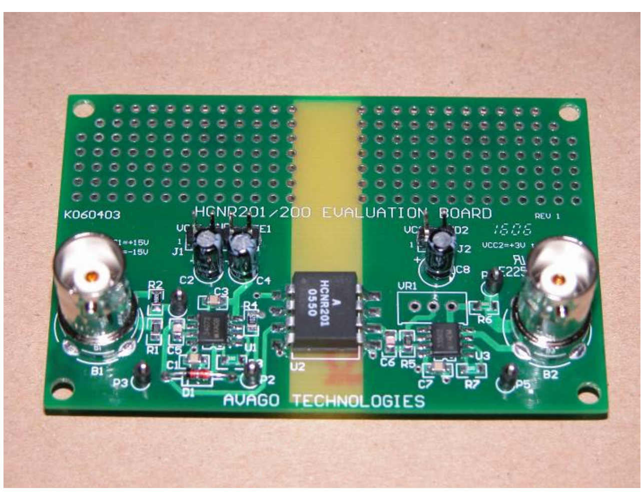

Figure 8. PCB of the evalution board.

Linear Input Range

Thanks to the superior performance and the design flexibility of the HCNR200/201, these devices are seeing more and more applications. This has attracted the introduction of some similar products into the market. Some products consist of LED and PIN photodiodes, while some other products come with LED and phototransistors. All of them appear in the similar elements arrangement to utilize the servo-feedback advantages for better linearity performance. Thanks to the inherent high LED-to-photodiode linearity, the close matching of the photodiodes and advanced design of the package, the HCNR200 and HCNR201's high linearity and stable gain characteristics are ensured. This superior performance has made them stand out from their peers.

In addition to the differentiation of the linearity performance, one more point worth consideration during component selection is the circuit's linear input range (LIR). A circuit's LIR determines the input signal dynamic range that can enjoy the linearity claimed on the sheet, which is in turn determined by a particular optocoupler's linear response range specified in its data sheet. For example, on the HCNR200 and HCNR201 data sheet, it is specified that the HCNR200's DC NonLinearity (Best Fit) has a typical value of 0.01% and a maximum value of 0.25% under Test Conditions of 5 nA < I_{PD} < 50 µA, 0 V < V_{PD} < 15 V [1, p. 7]. Test conditions of photodetector current or worked-out photodetector current (when LED current is specified) in respective data sheet are used to calculate the LIR of the circuit.

Assumptions about application circuit topology must be made to reach a comparison of LIR for various linear analog optocouplers from different vendors. In this case, the application circuit shown in Figure 4A has been used to calculate the LIR of input voltage. From the comparison chart shown in Figure 9, it can be seen that the HCNR200/201 has a much wider linear response range, which means a circuit using the HCNR200/201 enjoys a much wider linear input voltage range than its counterparts (60 dB wider than that of Comp A, and 66 dB wider than that of Comp B).

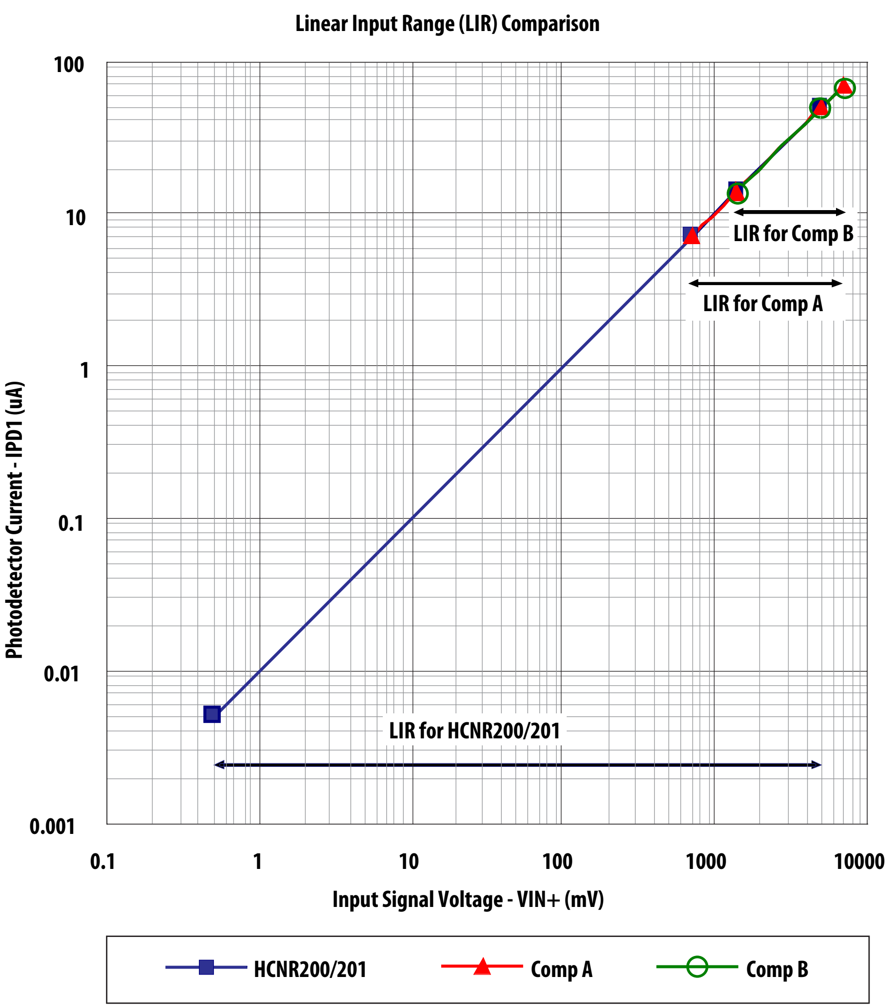

Figure 9. Comparison of different optocoupler's linear input range.

Summary

In a typical application, an external feedback amplifier can be used with PD1 to monitor the light output of the LED and automatically adjust the LED current to compensate for any non-linearities or changes in light output of the LED. The feedback amplifier acts to stabilize and linearize the light output of the LED. The output photodiode then converts the stable, linear light output of the LED into a current, which can then be converted back into a voltage by another amplifier. By appropriate design of the application circuit, these well-established and versatile analog optocouplers are capable of operating in many different modes to meet various analog isolation needs.

References

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[2] "Optocouplers for Variable Speed Motor Control Electronics in Consumer Home Appliances," Jamshed N. Khan, Avago Technologies, White Paper, Publication No. 5989-1059EN, May 12, 2004.

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[4] "Understanding the Power of HART Communication," Ron Helson, HART Communication Foundation, March 2003.

[5] "Optically Coupled 20 mA Current Loop Transmitter Technical Data," Avago Technologies, Publication No. 5989-2099EN, December 28, 2004.

[6] "Optically Coupled 20 mA Current Loop Receiver Technical Data," Avago Technologies, Publication No. 5989-2100EN, December 28, 2004.

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