

Using Optical Isolation Amplifiers in Power Inverters for Voltage, Current and Temperature Sensing

by

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Abstract

Many industrial equipments and home appliances employ power inverters to perform their designed functions. In the inverter operating control loop, key feedback information on current, bus current and voltage are required to achieve smooth control. To protect the key devices in the inverter such as the IGBTs, temperature sensing is often required to protect the expensive IGBTs from being damaged due to fault conditions. As a result, miniature isolation amplifiers with built-in safety insulation have been designed to fulfill these application needs at a much better price/performance than traditional current/voltage transducers.

Introduction

A power inverter is an electrical power converter that changes DC power source to AC power source. The converted AC can be at any required voltage and frequency with the use of appropriate power switching devices, signal isolators, and control circuits. Power inverters are used in a wide range of applications, from industrial equipments such as variable-frequency motor drive, uninterruptible power supply (UPS), solar inverter, to home appliances such as induction heating, air conditioning.

Figure 1 shows a typical block diagram of a power inverter in an AC motor drive. It consists of an inverter that converts the DC bus voltage to AC power at a variable frequency to drive the motor. IGBTs are expensive power switches that form the heart of the inverter. These power devices must operate at a high frequency and must be able to withstand high voltages.

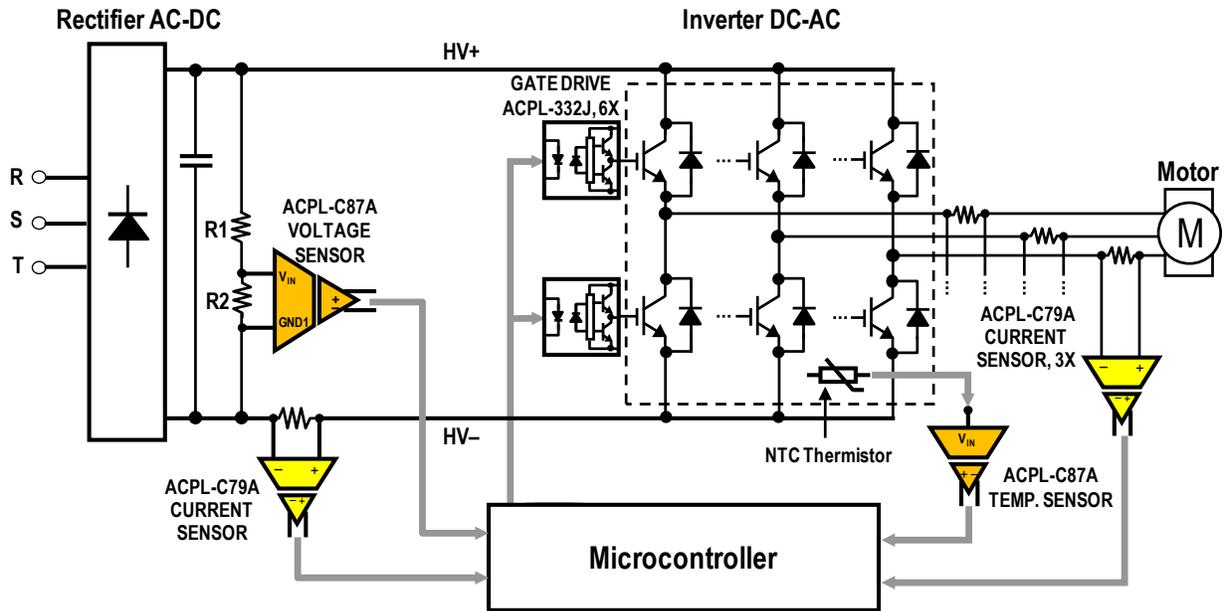


Figure 1. Block diagram of power converter in a motor drive.

The isolation amplifier (iso-amp) ACPL-C87A [1] works as a precision voltage sensor together with a resistive divider consists of R1 and R2, monitoring the DC bus voltage. The ACPL-C79A[2] works in conjunction with a shunt resistor to provide accurate current measurement. These voltage and current sensing are performed even in the presence of high switching noise. The isolated voltage sensor ACPL-C87A can also be used in isolated temperature sensing designs. In this application, the voltage sensor must linearly and accurately measure temperature and send it across the isolation barrier thus providing safety insulation.

These voltage, current and temperature information from the iso-amps are collected by the microcontroller, which uses the data to calculate the feedback values and output signals needed to provide effective control and fault management in the power converters.

How the Optical Isolation Amplifiers Work

As an example, functional blocks of the ACPL-C87A are shown in Figure 2. First the isolation amplifier senses the input voltage (single-ended analog signal) and converts it to a digital bit stream. The bit stream is then transmitted across the optical coupling pair consisting of an LED and a photodetector. This optical signal path provides the electrical insulation barrier. Because the transmitted signal is optical rather than electrical, it is immune to magnetic fields and electrical noise. The photodetector recovers the optical signal and converts it back to an electrical signal, which is decoded and filtered to reproduce an analog output signal. The output voltage, provided in differential mode for better common mode noise rejection, is proportional to input voltage with unity gain.

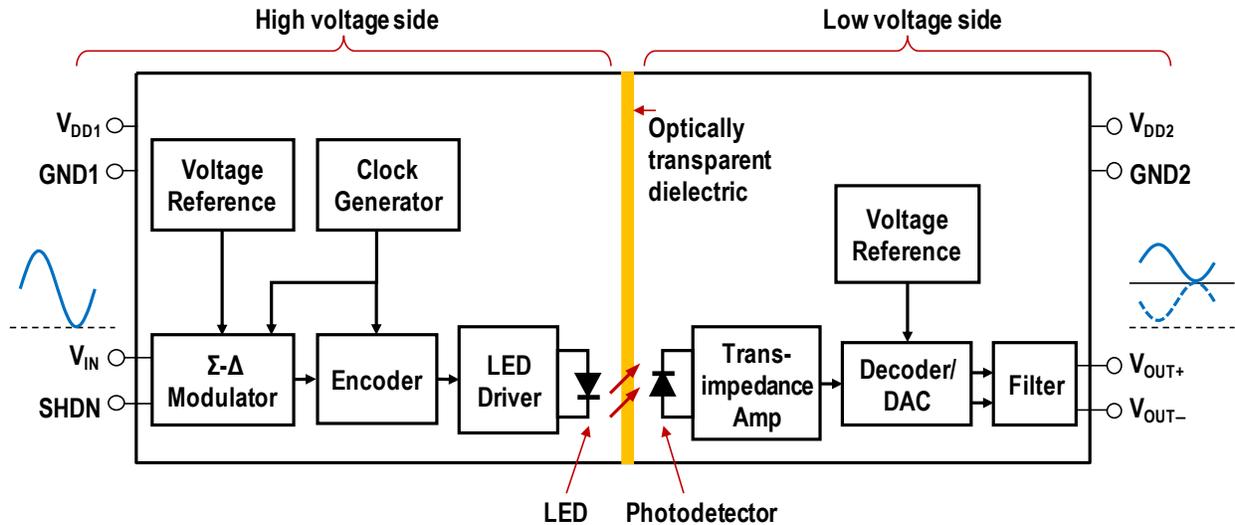


Figure 2. Internal block diagram of the ACPL-C87A.

The voltage sensor ACPL-C87A provides $\pm 1\%$ measurement accuracy. Other options include $\pm 0.5\%$ (ACPL-C87B) and $\pm 3\%$ (ACPL-C870). The ACPL-C87X family features a stretched SO-8 package that is 30% smaller than a DIP-8 package. These iso-amps have a double protection rating of $5000 V_{RMS}/1 \text{ min}$ per the UL 1577 safety standard. The $1414 V_{PEAK}$ maximum working voltage specification per IEC/EN/DIN EN 60747-5-5 ensures circuits on the low voltage side are not damaged by hazardous high voltages.

The current sensor ACPL-C79A shares all the key functional blocks of the ACPL-C87A as shown in Figure 1, except that the former is configured as differential inputs (V_{IN+} , and V_{IN-}) instead of a single-ended input (V_{IN}) and shutdown (SHDN). The other differences between the voltage sensor and current sensor are input range and gain settings. The ACPL-C87A accurately measures 0-2 V input signal, while the ACPL-C79A measures $\pm 200 \text{ mV}$ linear input range. The different input ranges are optimized for voltage sensing and current sensing respectively. The ACPL-C87A has unity gain, while the ACPL-C79A is configured with 8.2 times gain. The ACPL-C79A family shares the same package and insulation capability as that of the ACPL-C87X family.

Voltage Sensing

Using the ACPL-C87X as an isolated voltage sensor is straightforward. Select resistors to form a voltage divider to scale down the voltage signal to be measured to a level within the sensor input range. With an integrated isolation and sensing circuit, the application circuit is significantly simplified compared to alternative solutions that employ separate devices to perform sensing and isolation functions.

A detailed voltage sensing circuit with the ACPL-C87X is shown in Figure 3. Given that the ACPL-C87X's nominal input voltage for V_{IN} is 2 V, a user needs to choose resistor R1 according to Equation 1:

$$R1 = \frac{V_{L1} - V_{IN}}{V_{IN}} \times R2. \quad \text{Equation 1.}$$

For example, if V_{L1} is 600 V and $R2$ is 10 k Ω , then the value of $R1$ is 2990 k Ω .

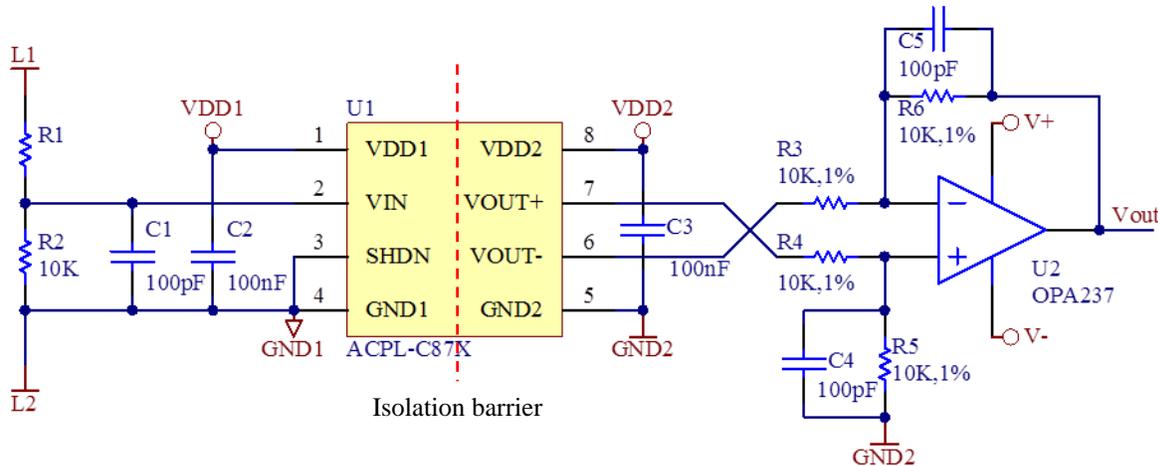


Figure 3. High voltage measurement with conversion to an isolated ground referenced output.

Choosing resistors is flexible. One method is to combine several resistors to match the target value; for example, 2 M Ω , 430 k Ω and 560 k Ω resistors in series make 2990 k Ω exactly. A V_{IN} of 2 V corresponds to a V_{L1} of 600 V. However, in the cases that V_{L1} is not 600 V, specific resistance values might be difficult to find. Another method is to round up the target value to a convenient value, for example 3 M Ω , to make resistor selection easier. In such cases, the scaling relationship may need fine tuning. In the same example with a V_{L1} of 600 V, $R1$ of 3 M Ω , and $R2$ of 10 k Ω , V_{IN} is solved to be 1.993 V.

The down-scaled input voltage is filtered by the anti-aliasing filter formed by $R2$ and $C1$, with corner frequency of 159 kHz (the value of $R1$ is usually much larger than $R2$, therefore neglected in calculation), and then sensed by the ACPL-C87X. The galvanically isolated differential output voltage ($V_{OUT+} - V_{OUT-}$) is proportional to the input voltage. The OPA237, configured as a difference amplifier, converts the differential signal to a single-ended output. This stage can also be made to amplify the signal, and, if required, low-pass filter the signal to limit bandwidth. In this circuit, the difference amplifier is designed for a gain of one with a low-pass filter corner frequency of 15.9 kHz. Resistors $R5$ and $R6$ can be changed for a different gain. The bandwidth can be reduced by increasing the capacitance of $C4$ and $C5$. The isolated output voltage V_{OUT} , which is linearly proportional to the line voltage on the high voltage side, can be safely connected to the system microcontroller.

With the ACPL-C87X gain of 1, the overall transfer function is simply:

$$V_{OUT} = V_{IN} \quad \text{Equation 2.}$$

or

$$V_{OUT} = \frac{V_{L1}}{(R1/R2)+1} \quad \text{Equation 3.}$$

The input stage of the application circuit in Figure 3 can be simplified as shown in Figure 4. R_2 and R_{IN} , the input impedance of the ACPL-C87X, create a current divider that results in an additional measurement error component that will add on top of the amplifier gain error. With the assumption that R_1 and R_{IN} have a much higher value than R_2 , the resulting loading error can be estimated to be R_2/R_{IN} .

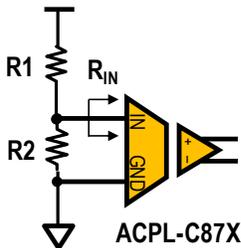


Figure 4. Simplified input stage of the ACPL-C87X circuit

With an R_{IN} of 1 G Ω for the ACPL-C87X, the loading error is negligible for R_2 values up to 1 M Ω , where the error is approximately 0.1%. Though this error is small, it can be reduced by lowering R_2 to 100 k Ω (error of 0.01% approximately).

Current Sensing

As shown in Figure 1, using the isolation amplifier to sense current can be as simple as connecting a shunt resistor to the input and getting the differential output. By choosing an appropriate shunt resistance, any range of current can be monitored, from less than 1 A to more than 100 A. In operation, currents flow through the shunt resistor and the resulting analog voltage drop is sensed by the ACPL-C79A. A differential output voltage is created on the other side of the optical isolation barrier. This differential output voltage is proportional to the current and can be converted to a single-ended signal by an op-amp or sent to the controller's ADC directly.

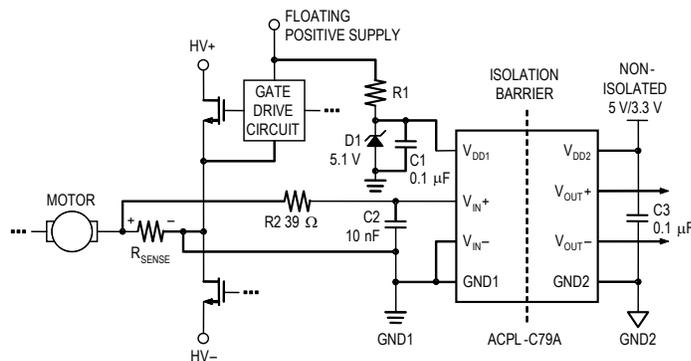


Figure 5. Typical application circuit for motor phase current sensing.

One of the benefits of using an isolation amplifier is that one sensor can fit in all the models with the shunt changed accordingly. The designer can then focus on optimizing sensor performance and easily port over the design to other models.

Selecting a shunt is easy. For example, if a compact motor has a maximum current of 10 Arms and can experience up to 50 percent overload, then the peak current is 21.1 A ($= 10 \times 1.414 \times 1.5$). Assuming the sensor input voltage of 200 mV for optimal performance, the shunt resistance would be about 10 m Ω . The maximum average power dissipation is about 1 W. Various shunt resistors are available to fulfill this type of application need. They are offered in a case size of 2512 or similar at an inexpensive price, featuring a 3W power rating, decent tolerance and temperature coefficient.

Over-current conditions in an IGBT can occur due to a phase-to-phase short, a ground short or a shoot through. The shunt + iso-amp current sensing devices on the output phases and DC bus provide fault detection in addition to current measurement (see Figure 1), and the requirement is fast response to current surges.

The ACPL-C79A has a fast 1.6 μ s response time with a step input. This allows the iso-amp to capture transients during short circuit and overload conditions. The signal propagation delay from input to output at mid point is only 2 μ s, while it takes just 2.6 μ s for the output signal to catch up with input, reaching 90% of the final levels [2].

Besides fast response time, the ACPL-C79A provides $\pm 1\%$ gain accuracy, excellent nonlinearity of 0.05% and a signal-to-noise ratio (SNR) of 60 dB. Also available are the ACPL-C79B, which offers a higher-precision gain accuracy of $\pm 0.5\%$, and the ACPL-C790, which has a $\pm 3\%$ gain tolerance.

Isolated Temperature Sensing using a Thermistor

Thermistors are widely used to measure temperature. Galvanic isolation between the potential of the thermistor and that of the system analog-to-digital converter is often required, especially when the thermistor is mounted near high voltages or in electrically noisy or poorly grounded environments. A lack of isolation can impair safety and induce electromagnetic interference (EMI).

A simple isolated temperature sensor circuit is shown in Figure 6. RT1 and R2 form a voltage divider from the floating, constant 5 V voltage source that also powers the voltage sensor. Choose RT1 and R2 so that the voltage fed into the ACPL-C87X isolation amplifier does not exceed the full-scale range of 2.46 V. The high impedance input terminal of the ACPL-C87X allows a relatively high resistance of R2 without causing a significant loading error. Select the resistor and capacitor values after reviewing the thermistor manufacturer data sheet.

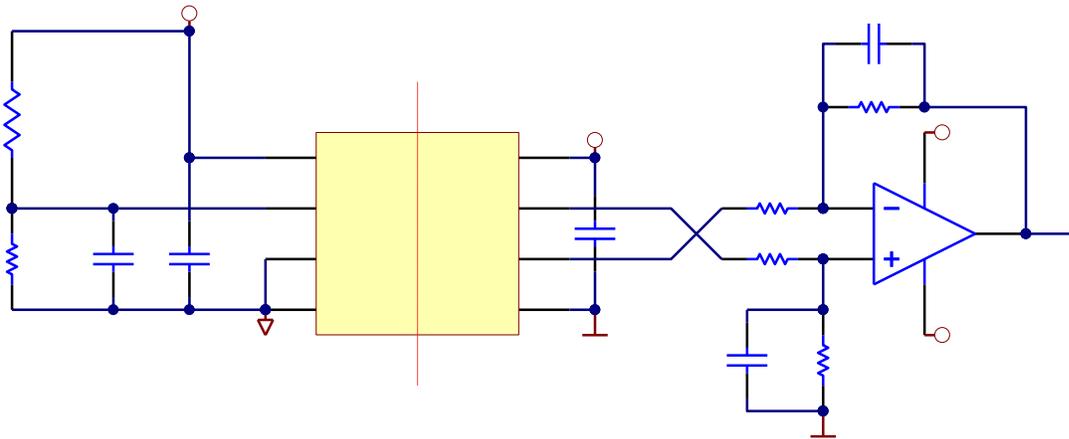


Figure 6. A simple isolated temperature sensing circuit.

Conclusion

Power inverter applications require isolated voltage sensing, current sensing for effective control, and temperature sensing for system protection against various conditions that cause overheating in the power switching devices. Designed specifically for high-voltage sensing, new generation optically isolated amplifiers, such as the ACPL-C87X, make monitoring and system protection circuits more accurate and easier to design. This iso-amp is also suitable for isolated temperature sensing. Sharing the same miniature package of the ACPL-C87X, the ACPL-C79A series are optimized for current sensing.

References

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