

# High precision optical isolation for analog signals

## 1 Introduction

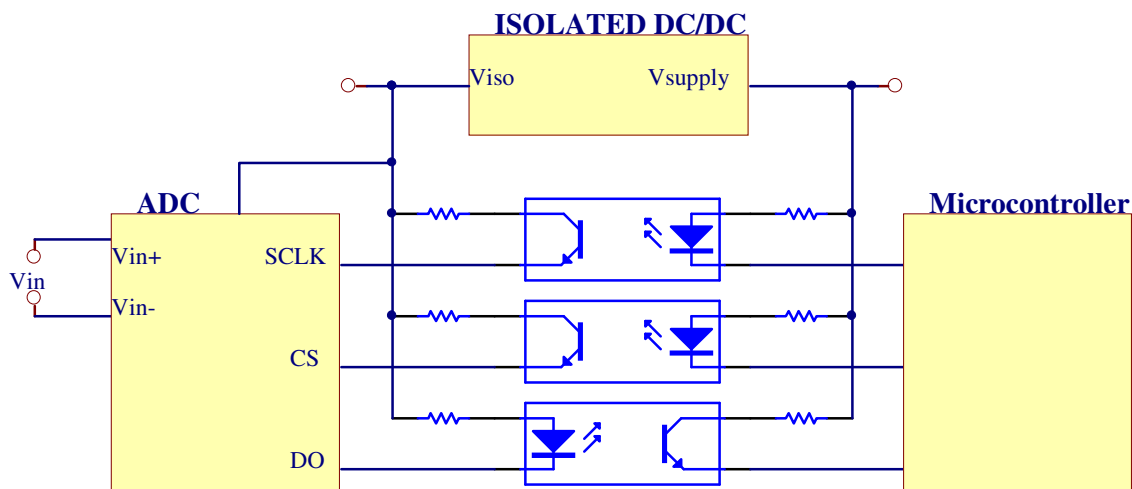
Isolating analog signals is extremely important for Industrial Automation and Medical Applications. In industrial automation, the reason is to avoid ground loops and other sources of noise, in the medical field is to protect patients from dangerous voltages.

Typically it is very expensive to achieve accurate analog signal isolation because the standard ways of isolating signals (opto-couplers, capacitance, and transformers) are not designed to isolate analog signals but digital ones. The typical solution involves the conversion from analog to digital, and the isolation of the digital signal. This solution is valid if only one signal needs to be isolated, but when trying to isolate more than one signal the cost increases very rapidly.

The Rejistor based circuit presented in this application note, allows designers to optically isolate analog signals very accurately and allows significant cost reduction when it is required to isolate multiple analog signals.

## 2 Background

The typical way to isolate Analog signals is doing an analog to digital conversion and then isolating the digital signals that interface the ADC.



**Figure 1: Analog signal isolation using an Isolated ADC**

This solution is perfectly viable when only one analog signal has to be isolated. If more than one analog signal needs to be isolated, it will require another ADC, power supply and isolation circuitry.

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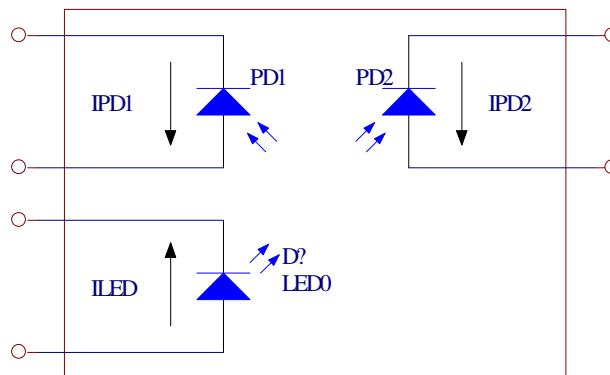
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If for example the conversion of 8 analog signals is desired, it will require the use of 8 ADC, 8 isolated power supplies and associated isolation circuitry. A more economic and simple approach could be implemented if the analog signals could be isolated in the analog domain. In this case, just one ADC with 8 analog inputs can be used.

Regular opto-couplers cannot be used for analog signals isolation, because the LED and the phototransistor or photodiode exhibit highly non linear behavior and huge gain differences between devices, making it impossible to use them for this application.

### 3 Detailed Description

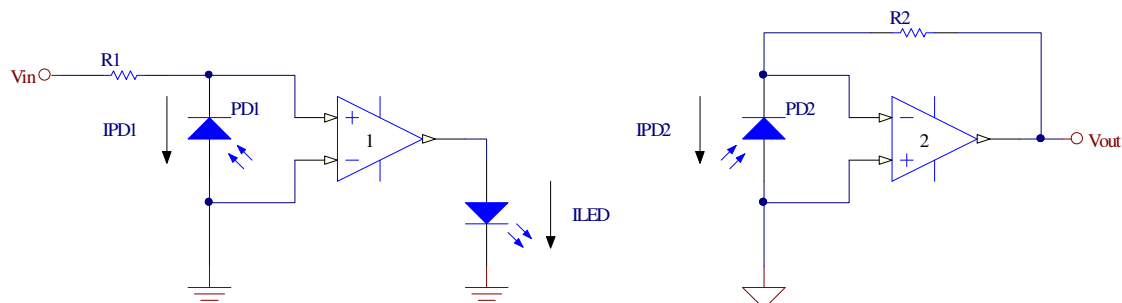
To allow analog signal isolation there are High-Linearity Analog Opto-couplers available. These devices consist of a high performance LED that illuminates two closely matched photodiodes. The idea is to use one of the photodiodes as a monitor of the LED light output and, using feedback, stabilize and eliminate the drift and non-linearity of the LED. A schematic of the internal structure of an analog opto-coupler can be seen in figure 2.



**Figure 2: Internals of an Analog Opto-coupler**

Figure 3 presents the basic circuit topology required to implement a simple analog isolation circuit using two op-amps and two resistors. In reality this circuit is too simple to operate and requires some extra components but is a good base to understand how it works.

Note that the two op-amps are physically two different op-amps, not two op-amps contained in the same package. Also note that the grounds are different (and power supplies too) because the circuit is isolated.



**Figure 3: Basic circuit for an analog opto-coupler**

In this circuit (Figure 3) A1 adjusts the LED current  $I_F$ . The LED current creates a proportional current in the photodiodes  $PD_1$  and  $PD_2$ . If the LED current increases, the  $I_{PD1}$  current also

increases, reducing the input voltage in the + input terminal of the op-amp A<sub>1</sub>, therefore op-amp A<sub>1</sub> has a negative feedback.

An op-amp with negative feedback keeps the potential between the non-inverting (+) and the inverting (–) input terminals to 0V, so that means that:

$$I_{PD1} = V_{IN} / R_1 \quad [1]$$

Because the same LED light is received in both photodiodes then  $I_{PD2}$  is proportional to  $I_{PD1}$ . Now the problem starts here. Because of fabrication issues there's no guarantee that the same amount of light is received in PD<sub>1</sub> and PD<sub>2</sub> so there is a mismatch on the currents on PD<sub>1</sub> and PD<sub>2</sub>. This can be expressed by the equation:

$$I_{PD2} = K \cdot I_{PD1} \quad [2]$$

The receiver side of the circuit has a negative feedback op-amp. In this case the feedback is provided by R<sub>2</sub>. The equations for the receiving side are:

$$I_{PD2} = V_{OUT} / R_2 \quad [3]$$

$$V_{OUT} = I_{PD2} \cdot R_2 \quad [4]$$

Combining equations [1], [2] and [4] provides:

$$V_{OUT} = V_{IN} \cdot K \cdot R_2 / R_1 \quad [5]$$

So there exists a completely linear relationship between  $V_{OUT}$  and  $V_{IN}$ . The only issue in this circuit is the K constant. This constant is usually referred as the opto-coupler gain. This gain usually has very high tolerances in the order of  $\pm 15\%$  and that's the principal reason this circuit is used infrequently; because it requires calibration that is usually performed by hand and the total error is usually in the range of 5% to 10%, making it impractical for industrial applications.

### 3.1 Rejistor Implementation

Use Rejutors to adjust the values of R<sub>2</sub> and R<sub>1</sub> to correct the effect of the opto-coupler gain. Under that condition the result becomes:

$$V_{OUT} = V_{IN} \quad [6]$$

Figure 4 shows the Rejistor-based implementation, making use of Rejutors and adding some components required to have a fully functional analog isolator.

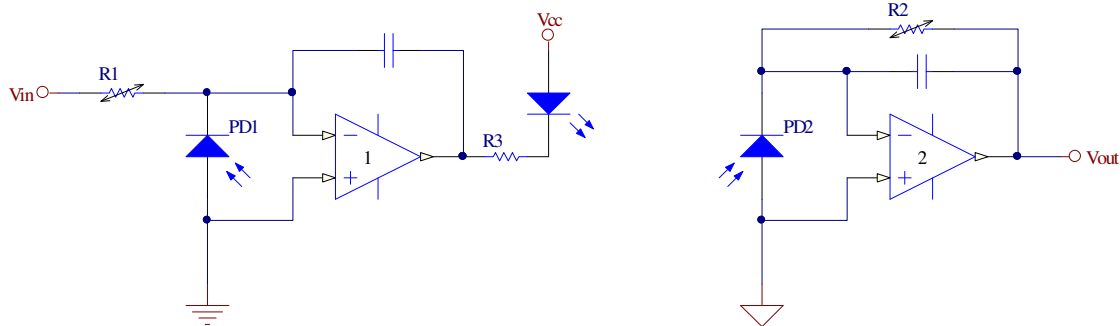
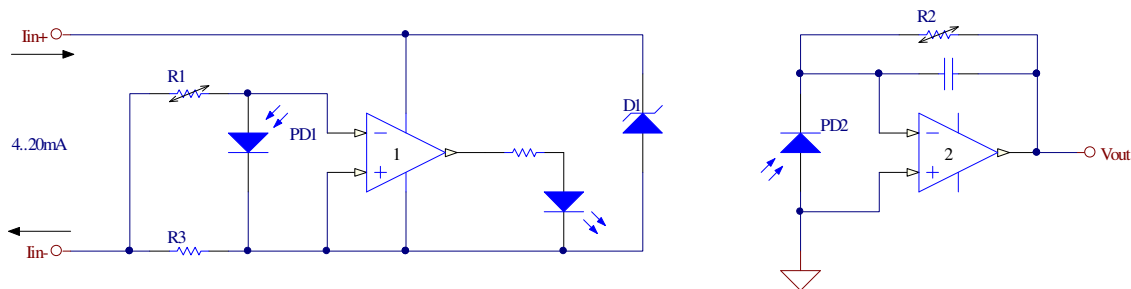


Figure 4: Circuit for an analog opto-coupler using Rejutors

This circuit could be manufactured with a single Rejistor in R1 or R2 but that will depend on the tolerance of the opto-coupler gain. As mentioned previously, the tolerance of the opto-coupler gain is around  $\pm 15\%$ , and the adjustment range of the Rejutors can be considered as  $\pm 15\%$ . With only one Rejutor and an opto-coupler with the gain in one of the extremes of the tolerance it might not be possible to match the resistance of the Rejutor to compensate the error. With two Rejutors there will always be a value that will match the output with the input, with no increase in real-estate required to implement the solution.

However, this circuit still has an issue that makes it expensive. That is the requirement of an isolated power supply to be able to provide the Vcc to the input side of the circuit.

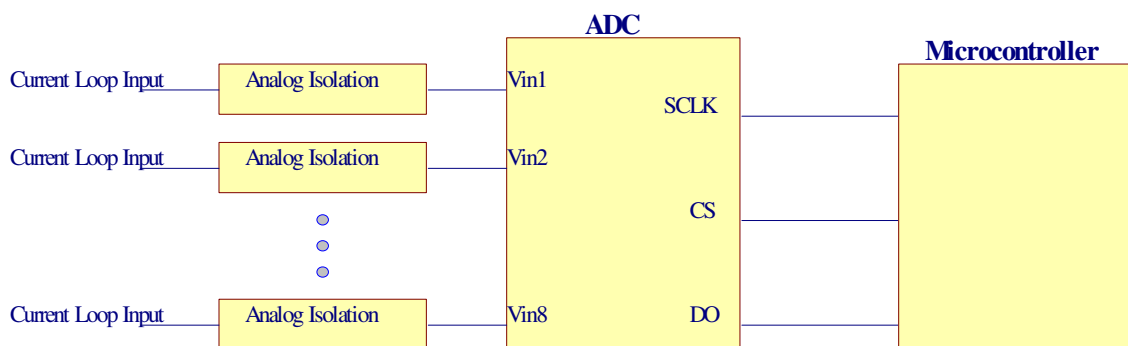
In Industrial Automation applications is standard the use of 4 - 20mA current loops. One of the reasons for starting at 4mA and not at 0mA is that the same current loop can be used to supply power to the measuring device. Just making some adjustments to this circuit produces a loop-powered analog isolator for 4 - 20mA current loops, as shown in figure 5.



**Figure 5: Loop powered 4 - 20 mA isolated analog input**

In this circuit R3 converts the analog current to voltage that will later be transferred trough the isolation. R3 doesn't need to be a Rejutor because it's value can be corrected using R1, but in some of the cases it will be more accurate and even lower cost to use a Rejutor as R3, because of the low temperature coefficient exhibited by Rejutors.

Finally, multiple isolated analog inputs can be connected to a multi input ADC as shown in figure 6.



**Figure 6: Multiple isolated analog inputs**

If 8 analog inputs are implemented in the usual way as show in figure 1, the resulting circuit will be ten-times more expensive than the circuit of figure 6.

Other of the benefits of using Rejustors is that huge savings can also be realized in production. The reason for this is that the whole calibration can be done automatically. A very simple approach to the calibration, would be feeding a precise 20mA current to all of the inputs, and then adjust the Rejustors in all the analog isolation circuits until the value measured by the ADC corresponds to 20mA in all of the inputs. The advantage of this is that any other calibration issue in the ADC or the ADC reference voltage is also calibrated with the analog isolation calibration. Providing the Rejustor calibration pins in a special header designed for that and providing the value measured by the ADC in a digital way, would allow to create a fully automatic calibration program, that would calibrate the whole circuit in a few seconds, something that if was done manually could take several minutes.

## 4 Benefits of Using Rejustors

1. Very accurate measurement that only requires factory calibration and not on site calibration. Because the Rejustor can be calibrated very accurately and that calibration is not going to change over time, one time factory calibration is enough to have a reliable product.
2. Automated calibration procedure reduces the requirement of calibration equipment or highly trained personnel in testing and production. For this application only a precision current supply is required. The calibration logic can be implemented in an external PC or even in the same product to be calibrated.
3. Smaller bill of materials. The availability of an adjustable resistor allows implementation of the circuit in a very simple way that significantly reduces the number of required components. This has a huge impact on the product cost, because is not only the number of components reduced, but the PCB footprint and PCB assembly cost is reduced.
4. With the adjusting terminals available in an external header the finished goods can be calibrated without disassembling the product and after it is completely build.
5. The Rejustor resistance is stable across a wide temperature range, ideal to use this product in an industrial temperature range.

### References:

1. Avago Technologies **HCNR200 and HCNR201** High-Linearity Analog Opto-couplers. Retrieved December 08, 2007, from the World Wide Web: [http://www.avagotech.com/products/optocouplers\\_-\\_plastic/plastic\\_high\\_linearity\\_analog\\_optocoupler/hcnr200/](http://www.avagotech.com/products/optocouplers_-_plastic/plastic_high_linearity_analog_optocoupler/hcnr200/)
2. Microbridge Technologies Rejustor™ Primer. Retrieved September 20, 2007, from the World Wide Web: <http://www.microbridgetech.com/>