Application Report
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Precision Voltage Offset: When Does It Matter?

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ABSTRACT

This application note offers a practical approach to helping decide if an amplifier with precision offset is required in a system. Common amplifier configurations such as non-inverting, inverting, and transimpedance are used to illustrate the decision process. These amplifier configurations are commonly used in applications such as gas sensing, motion detection, smoke detection, and current sensing. TI's LPV801/LPV802 general purpose and LPV811/LPV812 precision amplifiers are used to demonstrate whether these applications require precision or general purpose offset.

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1 Voltage Offset Modeling

In order to determine if amplifier voltage offset is important in a circuit design, one must first understand how to model offset in order to determine if offset of an amplifier is going to impact a design. The most common way to model voltage offset is by adding an ideal voltage source at the non-inverting terminal of an amplifier (see Figure 1). Evaluation of the impact of this offset voltage source is easily accomplished by using the principle of superposition.

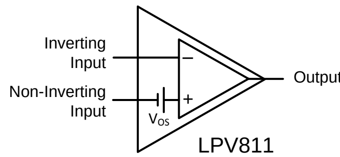

Figure 1. Voltage Offset Modeling

2 Circuit Analysis Utilizing Superposition Principle

In applying superposition to analyze circuits, one must replace all voltage sources in the circuit other than the one being evaluated with a short. Once this is accomplished, analysis of the circuit is performed. This procedure must be repeated for each voltage source in the circuit. If current sources are present in the circuit, superposition can be applied to them as well. However, instead of replacing the current with a short circuit they are replaced with an open circuit. Similar to voltage sources, only one active source is evaluated at a time. Once the analysis is complete, all the calculated values are summed in order to obtain the accumulated result. This principle simplifies the math of analyzing a circuit tremendously and should be utilized in hand calculated circuit assessments.

Multiple circuit topologies are analyzed in this application note as examples.

3 Non-Inverting Amplifier Offset Analysis

Pictured below is the topology of the non-inverting amplifier (see Figure 2).

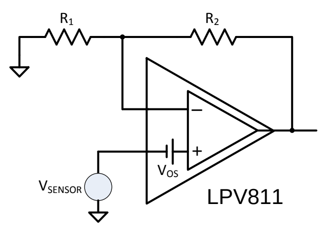

Figure 2. Non-Inverting Amplifier Configuration

In this topology, it is easily seen that the offset voltage is connected directly in series with the signal source. In many cases this signal source is the output of a sensor. At this point a decision needs to be made about how the signal source is to be connected to the non-inverting input of the amplifier. Depending on the DC level of the sensor, it may be necessary to ac-couple the signal to the non-inverting input. For example, the DC level of the sensor may be at a voltage that is outside the operating range of the amplifier or the system may require that the output of the amplifier be centered at a DC voltage other than what is present at the sensor output. Figure 3 shows how this can be accomplished.

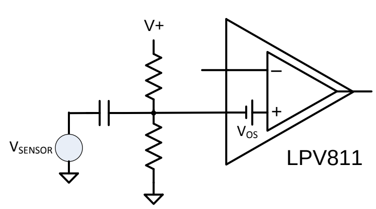

Figure 3. AC-Coupling Input Signal

Note that the voltage divider is located on the amplifier side of the ac-coupling capacitor and it provides the DC bias for the amplifier. The amplifier input pins must have a DC path to ground in order to operate properly. One thing to keep in mind when choosing the values of the resistors is the output impedance of the sensor and the power consumption of the resistor divider. For low output impedance sensors, say less than 100 ohms, a resistor divider in the 10's of kilo-ohms is sufficient in order to avoid signal loss due to the resistor divider. However, the desire to minimize power consumption may motivate a design that uses even larger resistor values than the sensor output requires. Using resistors in the Mega-ohm range are good for minimizing current consumption while 10's of Mega-ohm resistors can keep power consumption in the 100's of nano-amperes.

Now that the sensor has been properly connected to the non-inverting input, one needs to choose an appropriate gain for the amplifier. Most engineers can quickly calculate the values of R1 and R2 knowing that the gain of a non-inverting amplifier is 1 + R2/R1. Put more precisely, the gain of 1 + R2/R1 is the AC-gain of the circuit. The reason for specifying 1 + R2/R1 as the AC-gain is related to the presence of Capacitor C1.

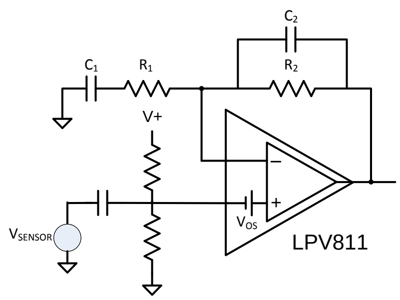

Figure 4. Non-Inverting Amplifier with AC-Gain ONLY

A bode plot for this circuit which shows gain versus frequency, shows the change in frequency response of the circuit at low and high frequencies. Note that the AC-gain and DC-gain is different because C1 blocks the flow of DC current; it creates a high-pass filter with a zero-value of 1/2πR1C1.

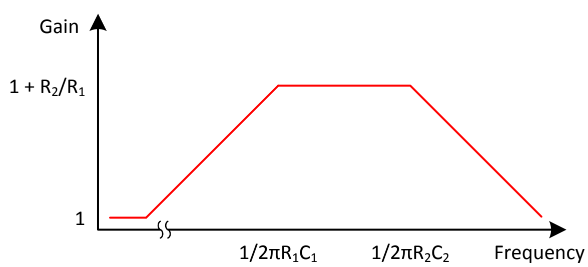

Figure 5. Bode Plot of Non-Inverting Amplifier

This means that the DC gain of this circuit is that of a voltage follower or 1V/V. This can be intuitively calculated by considering the ideal properties of an amplifier. Ideal amplifier models assume input bias currents of zero amperes. With no DC-current flowing through series pairs R1/C1 and R2/C2, the voltage at the inverting pin is the same as the voltage at the output of the amplifier. Ideal amplifiers also have the benefit of having a virtual short across the inputs when configured with negative feedback. As a result, the voltage at the non-inverting pin is the same voltage as the inverting input. With these rules applied, it can be concluded that the DC input to the non-inverting input of the amplifier does not get amplified by the gain of 1 + R2/R1. Since the DC input at the non-inverting terminal includes the bias of the resistor divider and the amplifier voltage offset, the offset voltage of the amplifier does not get amplified.

The points made earlier are further illustrated in some applications that commonly use amplifiers in their signal path

3.1 Motion Detection Application Example

Applying this information will now help determine the need for a low offset amplifier. One scenario to consider is a sensor with mV's of AC-output signal such as a passive infrared (PIR) sensor which is commonly used for motion detection. These sensors generally require amplification in the range of 1000V/V. With the AC-signal being amplified by a gain of 1000V/V, the output of the amplifier will have a large AC-signal of several volts and this will be centered around the DC input voltage set by the resistor divider in series with amplifier offset. A low power amplifier such as the LPV801 has warrantied voltage offset of 3.5mV. Since this DC-voltage offset is not amplified as shown previously by the presence of C1 in the circuit, amplifier offset voltage will contribute minimal error to the output signal which has been amplified to into the volts-range. A precision amplifier with 300uV of offset such as the LPV811 does not offer much benefit in such an application.

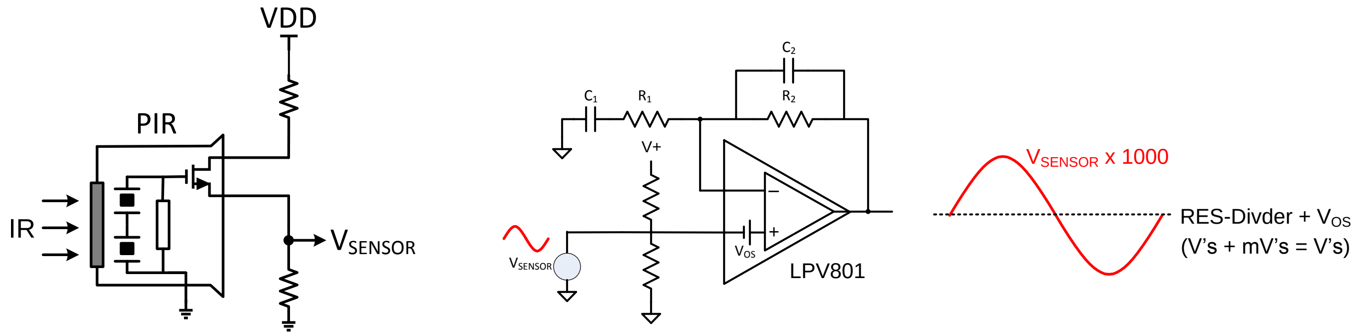

Figure 6. AC-Signal Amplification

3.2 Gas Sensing Application Example

A second scenario to consider is the amplifier configuration for an Oxygen sensor whose output is primarily a DC-current that shifts slowly with changes in oxygen concentrations. The circuit implementation looks very similar to that of the PIR sensor, except in the case of the oxygen sensing circuit, the sensor output is DC-coupled to the non-inverting terminal.

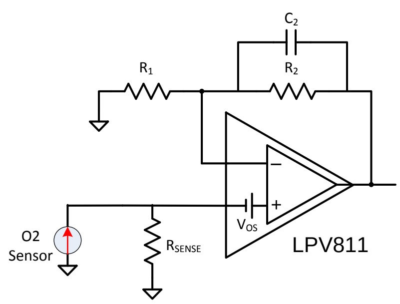

Figure 7. Oxygen Sensing Configuration

Since the sensor is DC coupled and is primarily a DC output signal, capacitor C1 must be replaced with a short circuit. This allows the voltage drop across RSENSE to be amplified by the gain of the amplifier (1+ R2/R1). The bode plot is similar to the previous PIR application circuit except the only difference being the gain at low frequencies. The removal of C1 allows the gain to be carried all the way to DC frequency which is well suited for the oxygen sensing application.

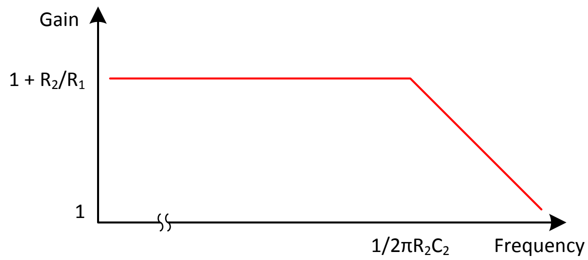

Figure 8. Bode Plot of DC-Coupled Signal

In Figure 7, the voltage across RSENSE is in series with the amplifier offset voltage. As a result, the offset and sensor signal output gets gained by the same ratio. Recall that in the PIR application circuit, the offset did not get amplified by the same gain as the sensor output. Since both are gained by the same ratio, it is critical to make sure that the amplifier offset is more than a factor of ten times lower than the sensor output voltage. In the case of the oxygen sensor which nominally outputs 100uA at normal oxygen concentration levels of 20.9%, the sensor output voltage is approximately 10mV if the current is shunted with a 100 ohm resistor. The LPV801 with 3.5mV of warrantied voltage offset is no longer suitable for this application since its offset is in the same amplitude range as the sensor output. A more suitable amplifier in this case would be the LPV811 or LPV812 with better than 300uV of warrantied offset. This significantly reduces the error contribution of amplifier voltage offset and allows optimal gain of the sensor output.

3.3 Non-Inverting Amplifier Application Summary

Regardless of the sensor being utilized in an application, the key to determining the need for a low-offset amplifier primarily depends on the gain of the amplifier configuration at DC. With C1 present in a non-inverting amplifier configuration, the gain at DC is unity. So offset of the amplifier is not amplified by the gain of the circuit. However, when C1 is eliminated from the feedback network, the DC and AC gain are equal. Now an amplifier with low offset, such as the LPV811 and LPV812 needs to be considered.

4 Inverting Amplifier Offset Analysis

It is left as an exercise to apply the same logic to inverting amplifier configurations as shown in Figure 9. Once again, the amplifier configuration with C1 will generally be well served with an amplifier with general purpose offset such as the LPV801 and LPV802, while the amplifier configuration without C1 will be best served with a low-offset amplifier such as LPV811 and LPV812.

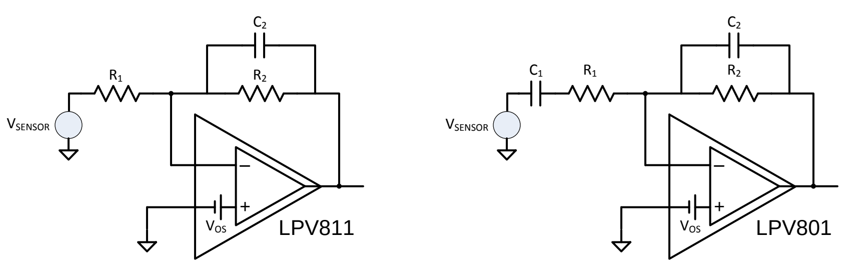

Figure 9. Inverting Amplifier Configurations

5 Transimpedance Amplifier Configurations

One last amplifier configuration to consider is the transimpedance amplifier configuration (see Figure 10). In this amplifier configuration, a sensor output current is converted to a voltage at the output of the amplifier.

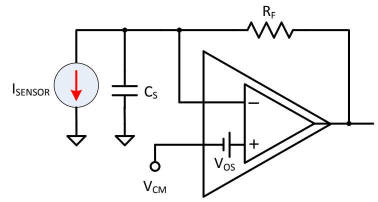

Figure 10. Transimpedance Amplifier Configuration

Applying ideal amplifier conditions, it is assumed that the input bias current on the inverting input is negligible. This is the case with CMOS input stages especially. With this assumption, all of the sensor output current passes through the feedback resistor RF and gets converted to a voltage. This voltage rides on top of the common mode voltage (VCM) that is applied at the non-inverting terminal. Since there are two sources present in the circuit, one must apply superposition during circuit analysis. As stated previously, the sensor output current is converted to a voltage equal to ISENSE x RF. The common mode voltage at the non-inverting pin which is in series with the amplifier offset voltage sees a different gain. Applying superposition, the sensor which acts like a variable current source is replaced by an open circuit. An actual model of the sensor could be seen as a large capacitor in series with the sensor but that will not change our DC analysis of the gain for the common mode voltage and amplifier offset. Since the sensor is replaced with an open circuit, one now recognizes the amplifier configuration as that of a voltage follower.

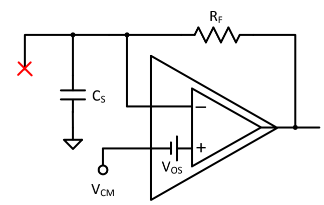

Figure 11. Simplified Circuit After Applying Superposition

So the gain of the common mode voltage and amplifier offset is unity. Since a general purpose amplifier such as the LPV801 and LPV802 has an offset voltage in the mV's range, this does not contribute a significant amount of error when summed with VCM. In addition, a highly amplified current is present at the output of the amplifier with the common mode voltage and amplifier offset. In this application, using an amplifier with general purpose offset is very acceptable.

5.1 Two-Lead Gas Sensing Application

There are of course exceptions to this rule and analysis. Such an exception to this general transimpedance amplifier analysis is a two-lead gas sensor which is common for sensing carbon monoxide gas. In this application, the common mode voltage is generally set at zero volts.

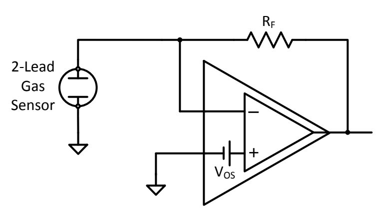

Figure 12. Carbon Monoxide Sensing Application

So any amplifier offset will be seen directly across the sensor due to the virtual short assumption of ideal amplifier analysis with negative feedback. For some sensors, applying a negative bias across the sensor creates an undesirable effect on the sensor and should be minimized. In this instance, choosing a low offset amplifier such as the LPV811 and LPV812 is recommended

5.2 Ambient Light / Photo-Electric Smoke Detection

Another exception for transimpedance amplifiers are versions are variations of the circuit that include a Feedback-T network. The addition of the Feedback-T creates DC gain for the amplifier. Since the DC gain can be significant, in the range of 10x to 50x, this sort of configuration would benefit from a low impedance amplifier.

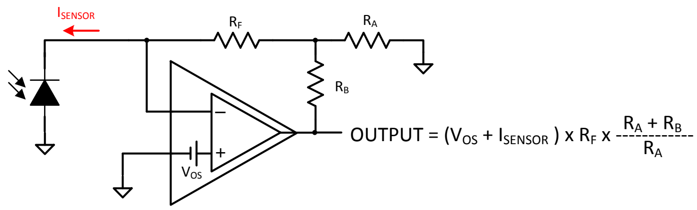

Figure 13. Transimpedance Amplifier with Feedback-T

Common applications for this configuration are photo-electric smoke detectors or ambient light sensors where the feedback resistors approach the Giga-ohm range. Large resistors like this can be expensive and thus the network-T provides a low-cost means for increasing the value of the feedback resistor. The analysis of the network-T is left as an exercise to the reader. Figure 13 shows the configuration and transfer function for such a circuit.

6 Conclusion

In conclusion, the answer to the question “When does precision offset matter?” is always “It depends”. One must always perform the DC and AC analysis of the circuit to determine the error contribution of amplifier voltage offset. The key is to look for ac-coupling capacitors and beware of feedback network-T circuits. Precision amplifiers are a system designer’s best friend when the situation requires them. Below is a summary table of the applications and amplifier configurations that were discussed and the importance of offset in each.

Table 1. Offset Analysis Summary

Amplifier Configuration	Common Applications	Sensor Signal and Amplifier Offset Analysis	Amplifier Requirement
Non-Inverting with AC-Gain Only	Motion Detection	OUTPUT = $V_{SENSOR} \times A_V + V_{OS}$	General Purpose Amplifier since Offset is not amplified (LPV801/LPV802)
Non-Inverting with DC & AC Gain	Gas Sensing - O2	OUTPUT = $(V_{SENSOR} + V_{OS}) \times A_V$	Precision Amplifier since Offset is amplified (LPV811/LPV812)
Inverting with AC-Coupled Input	Secondary Gain Stage in Motion Detection	OUTPUT = $V_{SENSOR} \times A_V + V_{OS}$	General Purpose Amplifier since Offset is not amplified (LPV801/LPV802)
Transimpedance	Electrochemical Sensing - CO	OUTPUT = $I_{SENSOR} \times A_V + V_{OS}$	General Purpose Amplifier since Offset is not amplified (LPV801/LPV802) except for 2-lead sensors where reverse-biasing of the sensor can damage or impact performance of the sensor
Transimpedance with Feedback-T	Ambient Light Sensing	OUTPUT = $I_{SENSOR} \times A_V + V_{OS} \times$ (Feedback-T Ratio)	Precision Amplifier since Offset is amplified by the Feedback-T Ratio (LPV811/LPV812)

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (October 2016) to A Revision	Page
• Deleted word "not" from row 2 in Offset Analysis Summary table.	7

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