Instrumentation Amplifiers

A guide to instrumentation amplifiers and how to proper use the INA326

Zane Crawford
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Abstract
This document aims to introduce the reader to instrumentation amplifiers and its uses. This document will go over how instrumentation amplifiers operate and their design features. The INA326 by Texas Instruments is used as an example and design specifics for the INA326 are reviewed.
**Introduction**

Instrumentation amplifiers (in-amps) are circuit elements designed to allow users to extract and amplify the difference between two signals or sources. One could use an operational amplifier, but this introduces several potentials for error and/or difficulties in design. A major issue that arises from using a single op-amp is that using a single op-amp as a differential amplifier has a lower common-mode rejection (CMR), usually stemming from a negative feedback loop to increase stability. The feedback loop allows for common-mode voltages to appear on the output of the amplifier, reducing the usable range of the amplifier. Instrumentation amplifiers consist of several operational amplifiers (op-amps) and is primarily designed to combat this design flaw. Many in-amps consist of three op-amps, with two serving as a buffer for the two input circuits and the third as a differential op-amp.

![Figure 1 instrumentation amplifier.](http://en.wikipedia.org/wiki/Instrumentation_amplifier)

**Operation**

This section will cover the usual operation of instrumentation operators. This in-amp is in two stages, namely a buffering stage and a differential stage. The in-amp starts with two signals that the user would like to get the differential output. The signals are applied one each to a non-inverting terminal of the op-amps in the first stage. This allows for the input device to see a large resistance and reduce current draw. In an ideal op-amp, the voltage at the non-inverting terminal is equal to that at the inverting terminal. Therefore, at points 1 and 2, the voltage is $V_1$ and $V_2$, respectively.

The second stage of the example in-amp is a differential op-amp, with the inputs being the voltages at points 3 and 4, namely $V_3$ and $V_4$. The output of this stage is the final output, $V_{out}$. The output of this amplifier is

$$V_{out} = (V_4 - V_3)$$

Having the feedback resistors on both pins being equal makes this a unity-gain differential op-amp. In order to get the output in terms of the inputs, the relationship between $V_4 - V_3$ and $V_1 - V_2$ must be found.

Between point 3 and 4, there are three resistors with no connection to ground. This causes the current through all three resistors, I, to be equal. Therefore

$$I = \frac{V_3 - V_4}{2R + R_{gain}}$$

Also, the voltages at point 1 and 2 are known, yielding the equation
When the two equations are combined and rearranged, the equations yield

\[ I = \frac{V_1 - V_2}{R_{gain}}. \]

This relationship can be plugged into the equation for \( V_{out} \) to yield a final equation of

\[ V_{out} = (V_2 - V_1) \left( \frac{2R+1}{R_{gain}} \right). \]

**Features**

The main purpose of using an in-amp is to take the difference of two signals and gain the resulting signal. One important part of getting the best resolution is to reject signals common to both signals (common-mode rejection). The higher the ratio of wanted signal to common-mode signals is the common-mode rejection ratio (CMRR), which one would like to be infinite. When using a standard op-amp (especially in non-inverting applications), the feedback resistors allow for the common-mode voltages to be passed to the output with usually unity gain. However, in-amps, due to the differential amplifier in the second stage, has much better CMRR as it uses the op-amps full ability to attenuate common-mode signals and not pass them at unity gain through feedback resistors.

Having a high common-mode rejection ratio has the added benefit of increasing the acceptable range of inputs on the pins. Normally, the common-mode voltages would appear in the output. However, the CMRR of an in-amp will often be around 120dB, or a ratio of \( 1:10^6 \). This means for every 1V of common-mode input, only 1 \( \mu \)V would appear in the output. With less of the output being passed common-mode voltages, more of the output can be the desired signal.

One could simply use a differential amplifier to reach these same goals. This may be desirable if the common-mode voltages exceed the power supply voltages, which instrumentation amplifiers cannot handle (or at least not very large values above the power supply voltage). Unfortunately, often to achieve these goals, differential amplifiers use large resistors that add to the noise and are very sensitive to the matching of the resistors used. Instrumentation amplifiers are designed as such that there are few resistors that can be chosen that can add noise to the circuitry. Also, there is better opportunities to control the gain of the amplifier with instrumentation amplifiers, rather than change the delicate balance of the resistors of the differential amplifier.

**The INA326**

The INA326 is an instrumentation amplifier made by Texas Instruments. It has rail-to-rail input common-mode range, meaning the average range of voltages that can appear on the inverting or non-inverting pins can be anything between ground and the power supply voltage. It is capable of this by using charge pumps instead of applying the voltages directly. The INA326 also does not rely on the closely matched resistors for its gain. Due to its current-mode signal processing, it simplifies the design for the user to choosing two resistors to determine the gain.
Figure 2 INA326 by Texas Instruments. Circuit diagram of basic functionality
From figure 5, pg 12 of the INA326 datasheet

Like the example in-amp discussed before, the input signals of the INA326 go to the non-inverting inputs of the first stage of the in-amp. Ideally, the inverting terminals will have the same voltage as their non-inverting counterparts. This creates a voltage difference across $R_1$, which induces current $I_{R1}$. This is where the INA326 begins to differ from the example in-amp previously discussed. The INA326 uses a current mirror to duplicate $I_{R1}$, causing $2I_{R1}$ to be induced by the other current mirror. This causes current flow through $R_2$ equal to $2I_{R1}$ and that voltage is duplicated by $A3$.

When working with the INA326, one must be careful as it is sensitive to capacitance. If proper measures are not taken, the output will oscillate. In tests, the desired signal was still there. However, the output’s oscillations were around 250mV_{pp}, which can certainly cause problems for a project that is trying to detect voltages. To avoid these problems, it is advised that the user solders $R_1$ as close to the pins 1 and 8 as possible. In addition to soldering as close to the pins as possible, $R_1$ must be greater than 2k and $R_2$ should be greater than 100k. It was also suggested to solder resistor $R$ and the capacitor often in parallel to it onto pin 5 as well to minimize capacitance. More bypass capacitors are suggested for the power supply pins 7 and 4. If using the INA326 with a breadboard, it is also suggested to cut off pins 1 and 8 on the breakout board, as the breadboard has a high capacitance that will effect results.

Figure 3 The INA326 in a breakout board with pins 1, 5, and 8 cut off to reduce capacitance
Instrumentation amplifiers are good devices to use when trying to amplify a differential signal. Provided the signal inputs are within the power supply ranges, instrumentation amplifiers are capable of amplifying the signal with high CMR. In-amps that are rail-to-rail are becoming more common, making an in-amp's output voltage swing larger than the typical op-amp equivalent. It is important, however, to carefully examine the datasheet for different in-amps as their implementation may require certain extra components or design specifications, like the INA326’s sensitivity to capacitance.
References


