PHY 651 – LABORATORY 9

Applications of operational amplifiers with negative feedback configuration

Laboratory Goals

1. Understand key properties of operational amplifiers connected with negative feedback
2. Understand how the response of an operational amplifier connected with negative feedback change with the frequency of the voltage signal amplified.
3. Understand what we learn testing the amplifier circuit with square waves [time response] and what we learn from sine waves [frequency response].

Tutorial on the operational amplifier

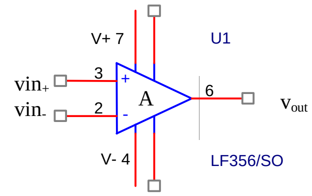
The operational amplifier is a crucial building block in several operations involving analog signals, namely signals whose amplitude carries some relevant physical information. This characteristics is opposed to the quantized nature of digital signals where one distinguishes between two states corresponding to the logical 1 or 0 respectively. Analog signals need frequently to be amplified, to reach the sensitivity of the measuring apparatus. For example, a sensor that monitors a physical quantity such as light, temperature, pressure, may produce a signal that is too low to be digitized with sufficient accuracy by your data acquisition system. Now you have two examples at your disposal, the digital oscilloscope and your labview set-up.

Additional manipulations that we may want to perform on signals are mathematical ones. We may want to sum or subtract two signals, or even to differentiate or integrated them.

The operational amplifier takes its name by the fact that it can be configured through a suitable combination of passive components connected between its terminals to perform operations and scale analog signals to reach the desired sensitivity.

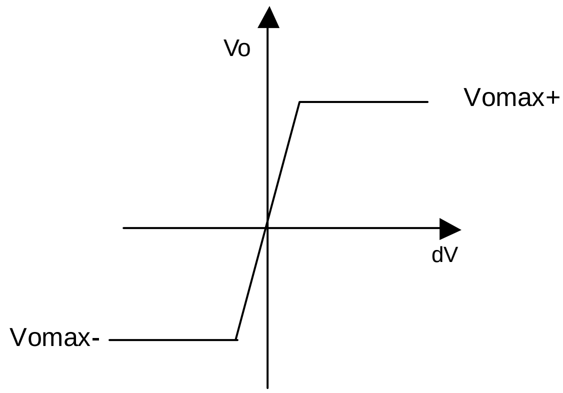
The op amp (operational amplifier) is represented by the circuit symbol shown in Figure 1. It derives its DC power from two supply rails (the voltages called V^+ and V^- in Figure 1). The amplifier has two input terminals: one inverting and the other non inverting. This terminology refers to the relative sign of the relative direction in which a voltage change at each terminal drives v_{out}. For example, and increase of vin+ produces an increase in v_{out}, while an increase in vin- produces a decrease in v_{out}.

Fig. 1



In particular, we can say that the output is controlled only by the difference between the two inputs: the operational amplifier is sensitive to the difference dV=vin+-vin-. For a very small range of dV, the gain A (called also open loop gain) is large and linear in dV. However, there is a maximum absolute value of v_{out} for any given value of V^+ and V^-, so when AdV>Vomax+ or AdV<Vomax-, the output is constant (saturated) at its extreme value. You can see this behavior depicted in Fig. 2.

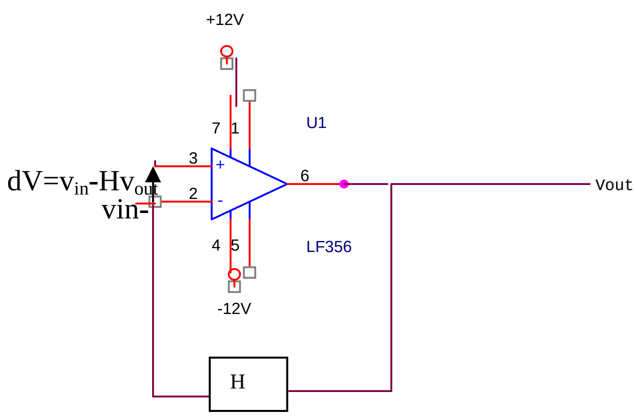
Fig.2 Static characteristic of the operational amplifier



Modern operational amplifiers are complicated devices containing many different transistor stages. I hope that some of you will be motivated in learning more about these extremely useful and versatile devices, however for this laboratory it is important that you learn to understand some very simple properties that relate differential input and output voltages.

Feedback circuits

We will start our studies by considering negative feedback circuits. Negative feedback implies that there is a connection between the v_{out} terminal and vin-. This is a self-checking system because part of the amplifier's output is fed back to the negative input and thus it subtracts from the input signal. Let us consider the circuit in Fig.3.



$dV = v_{in} - Hv_{out} \sim 0 \Rightarrow vout = v_{in}/H \Rightarrow Gain = v_{out}/v_{in} = 1/H \Rightarrow$ the gain depends only on H for ideal operational amplifiers. You should work out the relationship between V_{in} and v_{out} when A is not ∞.

You should obtain:

$$G' = \frac{1}{H}\frac{1}{1+1/AH} = \frac{A}{AH+1}$$

Note that the smaller A, the bigger the deviation from the ideal response. Through your observation of the open loop response of the OP AMP, you should be able to determine what A is at very low frequency, 100 Hz, 1 KHz, 1 MHz, 10 MHz. Note that when A<1/H, AH<1, and the gain G' starts becoming smaller than 1/H. The frequency at which A=1/H determines the frequency at which the sinusoidal response of the system becomes different than the static one. The corresponding time constant $\tau=1/f$ should be the one that you obtain from the measured rise time from the system. (remember that $\tau=0.455$ T).

Glossary

Impedance – Frequently I will speak about impedance seen at any given node. This is defined as the ratio between the voltage that would develop between this node and ground if a probe current was injected into this node.

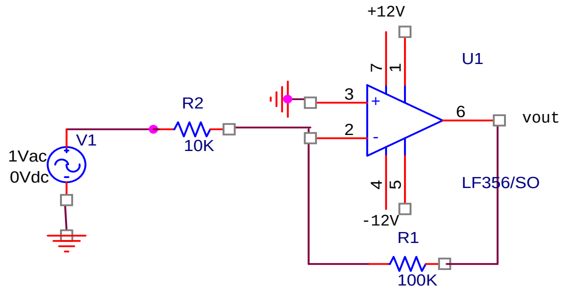
Closed Loop Configuration – An operational amplifier configured with some impendance (R, L, C) connecting the inverting-input to the output of the OP AMP

Decoupling- a component located between a voltage source and processing block or the output node and a probe point.

Settling time: in your measurements it will be defined as the time it takes for the signal to stabilize within 10% of its final value.

Rise time T: the time it takes to a signal to rise between 10% and 90% of its final value. It is related to the intrinsic time constant of the system.

Experiment 1: The operational amplifier in inverting configuration



Measurement I: Use the digital scope to measure the response to a square wave for this circuit. Observe the gain, and the rise time [time it takes to v_{out} to go between 10% and 90% of its full swing.

Measurement II: Use an input signal of sinusoidal shape, and use the digital scope to measure the gain [ratio between V_{out} and V_1] and the phase between V_{out} and V_1 at different frequencies. In particular, measure the region close to the frequency at which you would expect to see the effects of the frequency dependence of the response of the operational amplifier.

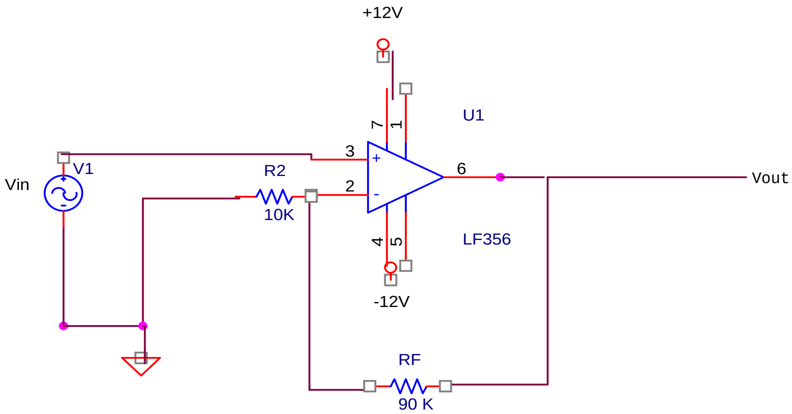
Measurement III and IV: Repeat measurement I and II changing RF to 10 K. Which changes do you see in the key properties of the gain as a function of time or frequency?

Analysis: Discuss the results that you obtained in the context of deviations from ideal behavior in an operational amplifier.

Experiment II:

The operational amplifier in non-inverting configuration

Experimental set-up: Build the circuit below



Measurement I: Use the digital scope to measure the response to a square wave for this circuit. Observe the gain, and the rise time [time it takes to v_{out} to go between 10% and 90% of its full swing.

Measurement II: With an input signal with sinusoidal time dependence, measure the gain [ratio of V_{out} and V_1] and the phase between V_{out} and V_1.

Measurement III and IV: Repeat measurement I and II changing RF to 10 K. Which changes do you see in the key properties of the gain as a function of time or frequency?Again try to predict the frequencies that would be more interesting to you.

Analysis: Discuss the results that you obtained in the context of deviations from ideal behavior in an operational amplifier.

Experiment III

Now you are in a position of designing a circuit that performs the analog sum between two waveforms and a circuit which performs the analog difference between two waveforms. Draw the circuit diagram and calculate the resistors that you would be using to assemble one such circuit. You can then build a circuit which makes the sum of the original waveform and the output of an operational amplifier circuit which has the original waveform as input and is configured with gain -2. Construct a VI which samples the input waveform and the output one using a TTL signal synchronous with the input signal as a digital trigger and display the input and output waveforms with a waveform graph. Note: for this VI use a 1 KHz sine wave as the signal. Specify the source that you choose.