LABORATORY 5

Operational Amplifier

Guide

Integrated operational amplifiers — op amps for short — became widely available with the introduction of the µA709 designed by the legendary Bob Widlar in 1965. This part was rapidly superseded by the 741 which has better performance and is still in wide use. Today well over a hundred different versions of op amps are available. Op amps are arguably the most widely used analog circuit components. The ideal op amp (Figure 1) produces an output that is the difference $V_{i+} - V_{i-}$ of its inputs gained up by infinity. Practical op amps deviate from this ideal somewhat. For example, the gain of the op amp we are using in this lab is only about two million. In many applications these deviations from ideality do not introduce significant errors. Real operational amplifiers of course must be connected to a power supply which to reduce clutter is often not shown in the schematic diagram.

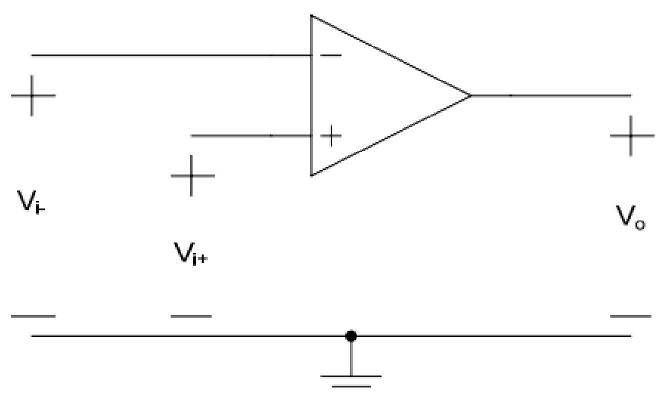

Figure 1 Ideal operational amplifier

Although an amplifier with infinite gain does not appear to be particularly useful, using only few extra components op amps can be configured to perform a very wide range of tasks and find almost universal application in interfacing sensors to other electronic circuits. In this laboratory we will focus on amplification and buffering, two tasks operational amplifiers excel at. We will also design the electronics for a pH (acidity) meter.

Before reading on please download the datasheet for the LMC6482 from the course page. It contains a lot of information such as the supply voltage and temperature range over which the amplifier can be used. Like most datasheets this one also has a section on applications with many circuit suggestions. Datasheets are usually a very valuable source of information and I recommend that you make it a habit to check them out, at the minimum to get the connection diagram of the device.

Reference

- UC Berkeley, course EECS100, Spring 2011.

Lab5 Report

Name ______________________ TA Checkoff ______________________

Teammate ______________________ Score ______________________

In this laboratory we will be using the LMC6482 from National Instruments. An 8-pin package contains two identical operational amplifiers (check the datasheet for the pinout). You can use either op amp in these experiments. It's always a good idea to tie unused inputs to a known potential (e.g. ground) to avoid excessive power dissipation or other problems, but for this laboratory you probably will get by with just ignoring the unused part. **We will power the operational amplifiers from ±5V (i.e. V-=-5V and V+=5V) in all experiments described in this laboratory and will not show the supply connections in schematics**. Note that the operational amplifier has no dedicated terminal for ground.

1. Open-loop Operation

a) Let's first check that the operational amplifier is working and indeed has a very large gain. Set up the circuit below and adjust the potentiometer such that $V_{out} = 0$V. It's unlikely that you in fact will be able to do this because of what?

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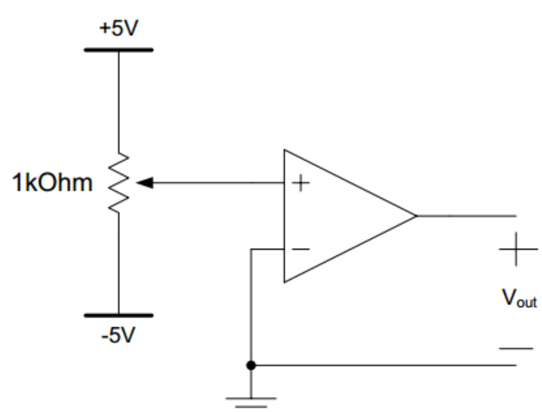
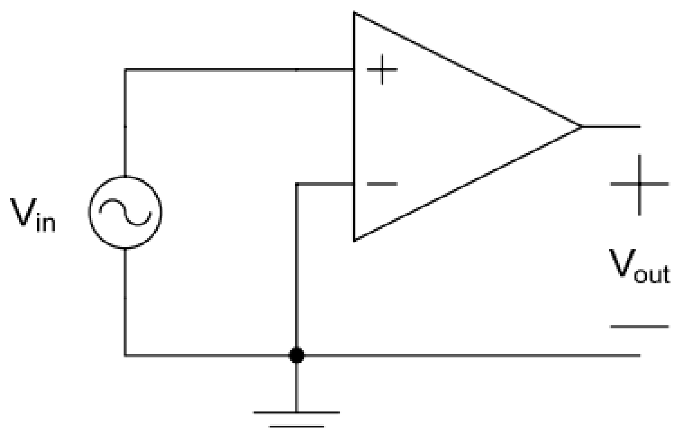
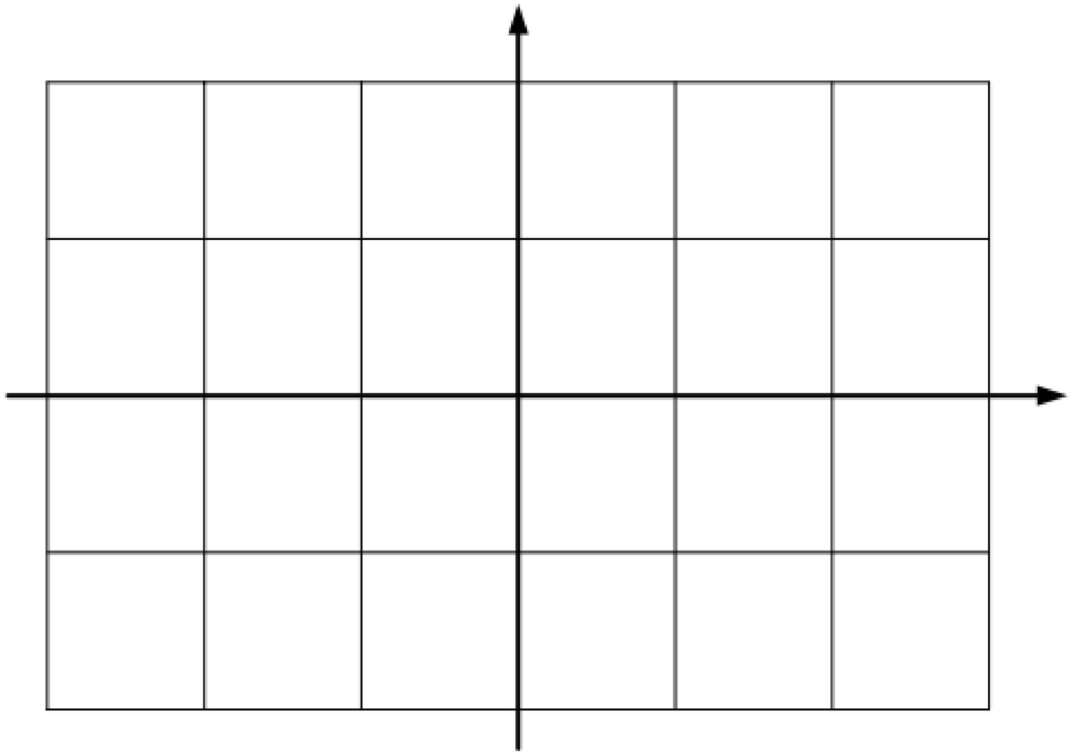


Explain:

b) Draw the open loop V_{out} versus V_{in} characteristic of the operational amplifier.

- Draw the expected V_{out} versus V_{in} characteristic on the plot and copy the plot to your prelab.
- Turn on the oscilloscope.
- Change the scope to XY mode. (Ask your TA if you don't know how to do it.)
- Set the function generator to sine wave output at 80 Hz with 80 mV peak to peak amplitude.
- Label the axes (variable, units, ticks) in the graph below and show the measured result in a different color than the expected result.





Label the axis variables and units!

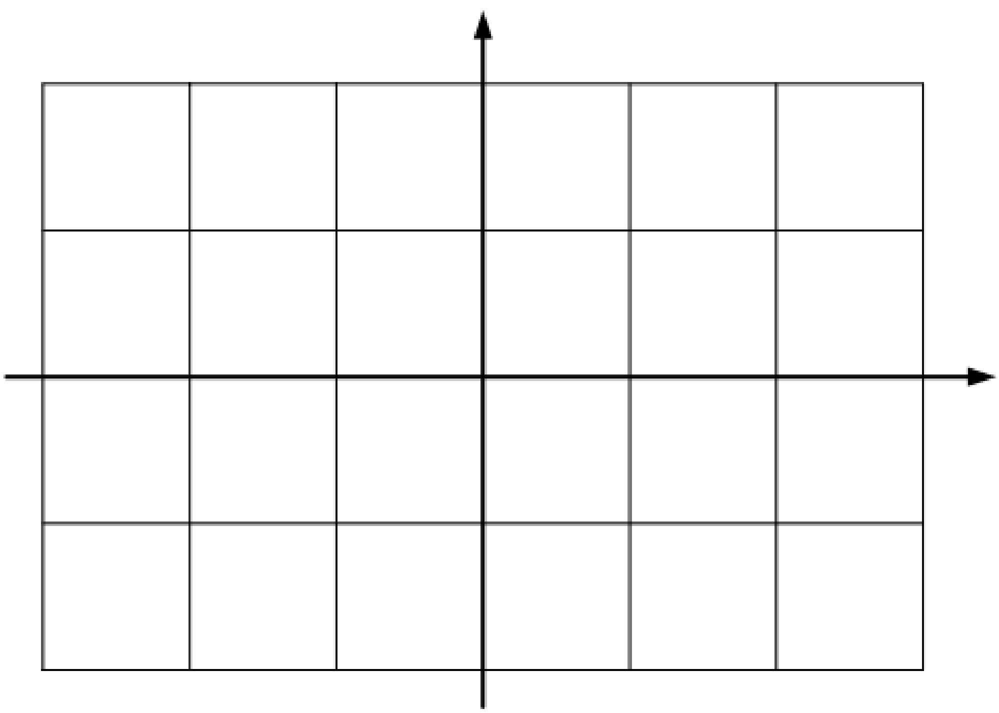
Explain discrepancies:

2. Positive and Negative Feedbacks

Most practical op amp circuits use feedback to set the gain to an accurate and reasonable value. This works very well – provided that the feedback is connected correctly. Please draw a positive feedback circuit and a negative feedback circuit using op amp as $|gain| = 1$ in your prelab.

__/10pt

- Simulate (Use Multisim) and measure V_{out} versus V_{in} for both circuits.
- Setup a 500Hz and 6Vpp sine wave and plot the output as a function of the input.
- Attach your simulation plot to your prelab and copy to the plot below.
- Build the negative feedback circuit which you have simulated and generate the XY plot just as you did in part 1.
- Copy your measured results to the plot below.
- Explain what's happening and summarize your result in the graph.



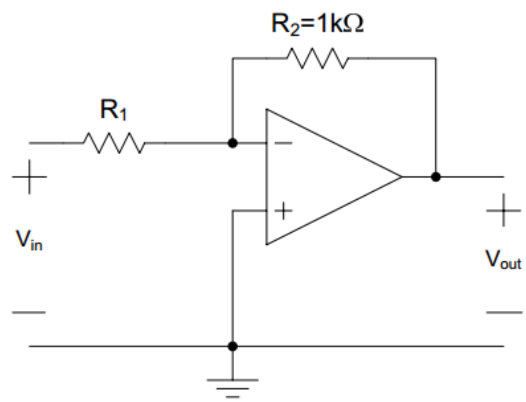
Explanation and summarize:

3. Voltage Gain

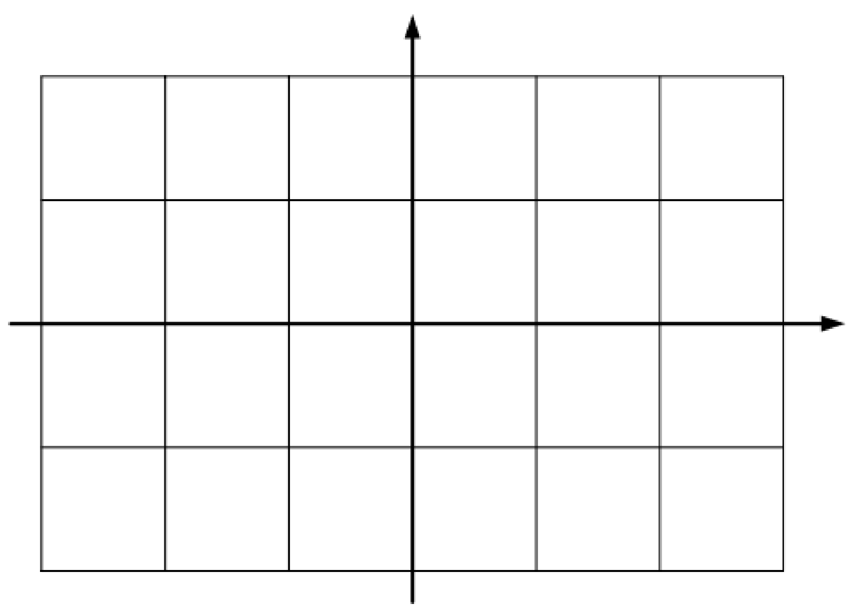
Now let's use the operational amplifier with feedback as shown below. What is the value of R_1 that results in a gain $V_{out}/V_{in} = -4$?

__/14pt

Value for R_1 **:** _______Ω



- Calculate the expected V_{in} to V_{out} relationship and plot to your prelab.
- Simulate (Use Multisim) and measure V_{in} to V_{out} relationship with V_{in} a 1kHz 3V peak to peak sine wave.
- Measure the V_{in} to V_{out} relationship using the XY plot on the oscilloscope with a 1kHz, 3V peak to peak sine wave.
- Include your measured result below.
- Explain any discrepancies.



4. Buffers

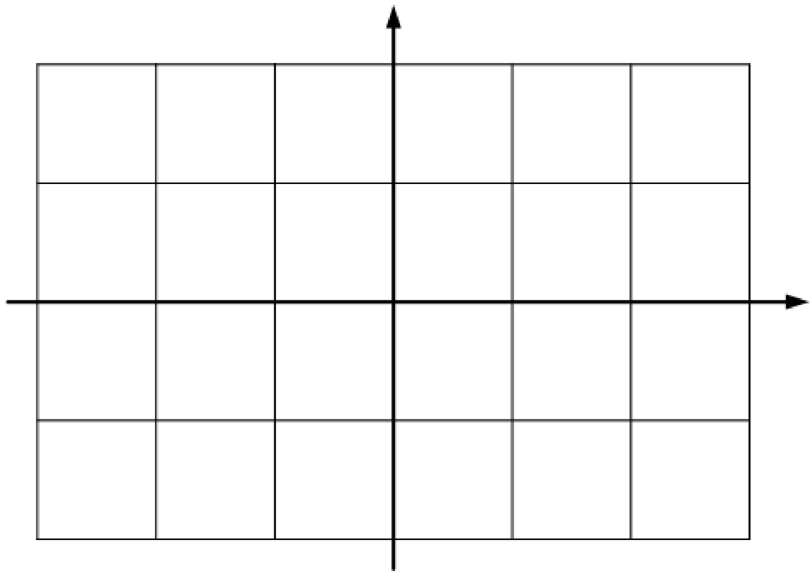
In the previous experiment you had to take the $50\,\Omega$ output resistance of the function generator into account to get the correct gain. This is possible when the output impedance is known. However, often the output impedance of a source (often a sensor) is not known and may even vary from part to part or with temperature. The problem with the inverting amplifier configuration is its finite input resistance, R_1. Noninverting gain stages have infinite (or nearly infinite) input resistance. Since no current is flowing, the value of the source resistance does not matter for the gain.

Circuit diagram for a non-inverting amplifier. Label the resistors (including Rs)

__/14pt

Diagram:

- Build the above circuit with R_s =1.2kΩ.
- Set V_{out}/V_{in} =11, choose the smaller of the gain setting resistors to be equal to 1.2kΩ.
- Record the value of the other gain setting resistor below and on prelab report
- Measure the IO characteristics of the amplifier using the XY plot on the oscilloscope with a 2kHz, 1V peak to peak sine wave.
- Record the measurement below.



Measurement

The value of the other gain setting resistor:____

5. <u>Electronic Interface for a pH Sensor</u>

In this part you will design the electronic circuits for a pH sensor. The pH is an important for characterizing acidity. You can read up on it e.g. on the Wiki (http://en.wikipedia.org/wiki/PH).

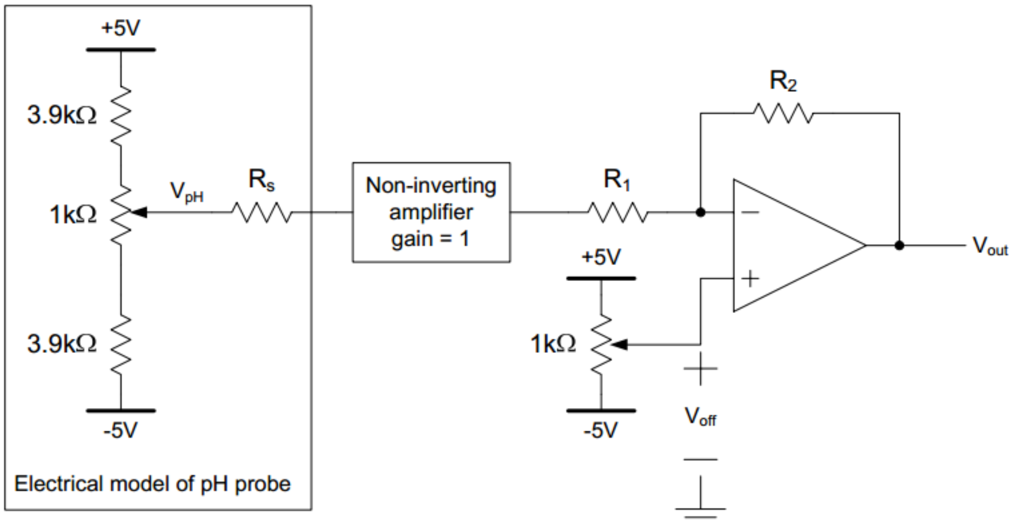
The pH of a fluid is measured with an electrode and produces a voltage according to the following equation (standard Ag/AgCl pH probe at $25^{\circ}C$):

$$V_{pH} = -(pH - 7) \times 59.16 \frac{mV}{pH}$$

The table below gives a few examples for pH and electrode voltage V_{pH} :

pH	V_{pH}	V_{out}
0	414.12mV	0V
4	177.48mV	0.8V
7	0	1.5V
14	-414.12mV	2.8V

One of the challenges is that the output resistance of pH electrodes is very high and variable, typically in the range of $R_s = 50\text{M}\Omega \cdots 500\text{M}\Omega$. You are to design an amplifier that produces $V_{out} = pH/5$ from V_{pH}. The diagram below shows the conceptual circuit:



To develop our circuit we will not actually work with acids and electrodes but instead simulate the behavior with a circuit that has the same electrical behavior. The amplifier consist of a non-inverting stage with gain one followed by an inverting amplifier.

- First derive an expression for $\frac{V_{out}}{V_{pH}}$ as a function of R_1, R_2, and V_{off}
- Find appropriate values for these components such that $V_{out} = pH/5$ from V_{pH}. Choosing the nearest available values for R_1 and R_2 in the kOhm range.
- You may have to combine several resistors or add a potentiometer in series with R_1 to get a sufficiently accurate value for the gain.
- Use Multisim to verify your circuit with Rs=1MΩ in your prelab.
- Test your circuit with Rs=1MΩ.
- Plot V_{out} versus V_{pH} in the range V_{out} =0 … 3.5V.

Although real pH electrodes have higher Rs, we use these smaller values in the laboratory since it is difficult to get reliable results on with higher valued resistors on solderless breadboards.

__/22pt

Calculated value for R_1 : _____ kΩ

Calculated value for R_2 : _____ kΩ

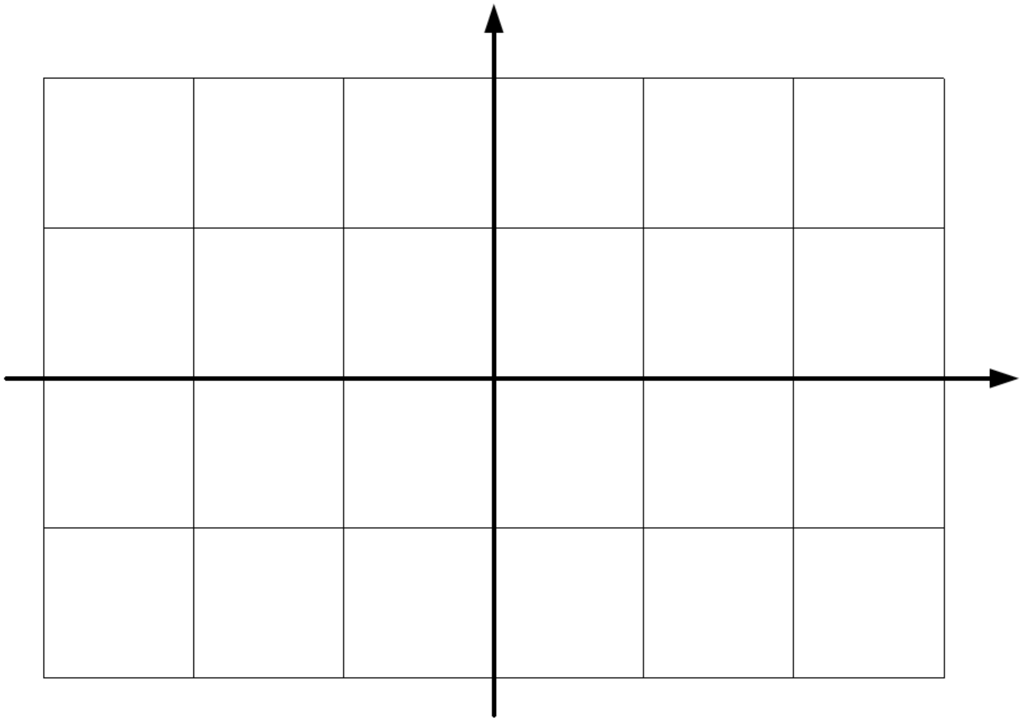
Calculated value for V_{off} : _____ V

Simulated V_{out} vs V_{pH}:

V_{out}	V_{pH}

Measured V_{out} vs V_{pH}:

V_{out}	V_{pH}



TA check off for the working circuit__________________

Prelab : ____of 30 Pt.

Report : ____of 70 Pt.

Total： ____of 100 Pt

Lab 5 Prelab

Name ____________________ TA Checkoff ____________________

Teammate ____________________ Score ____________________

Read Your Report First and You Will Get How to Finish Your Prelab!!

1. Open loop Operation

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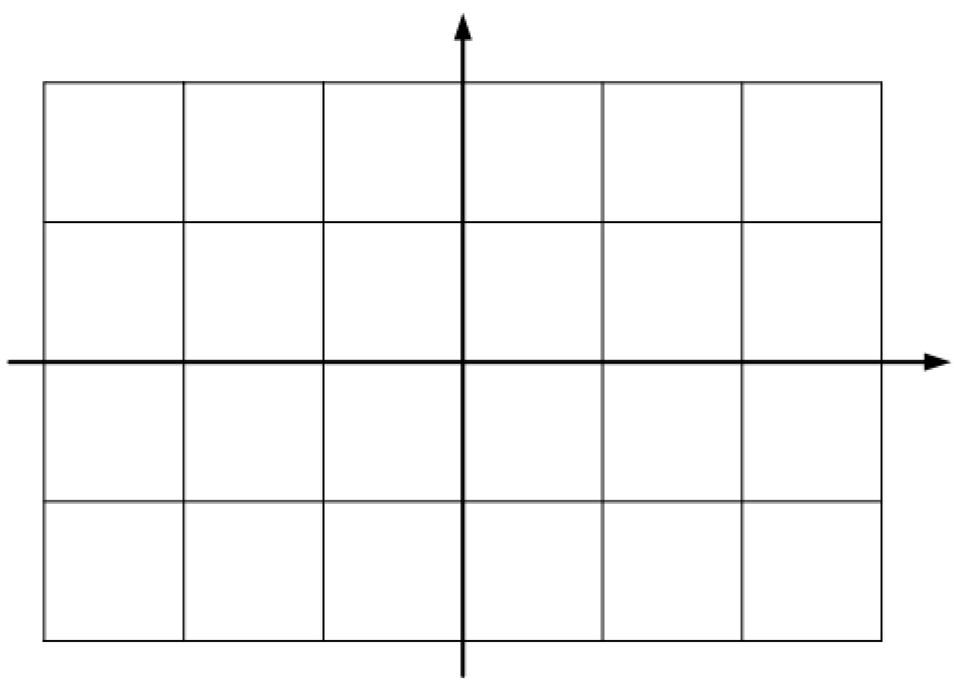


Label the axis variables and units!

2. Positive and Negative Feedback

Draw your positive circuit and negative circuit. Attach your simulation schematic and plot:

__/6pt

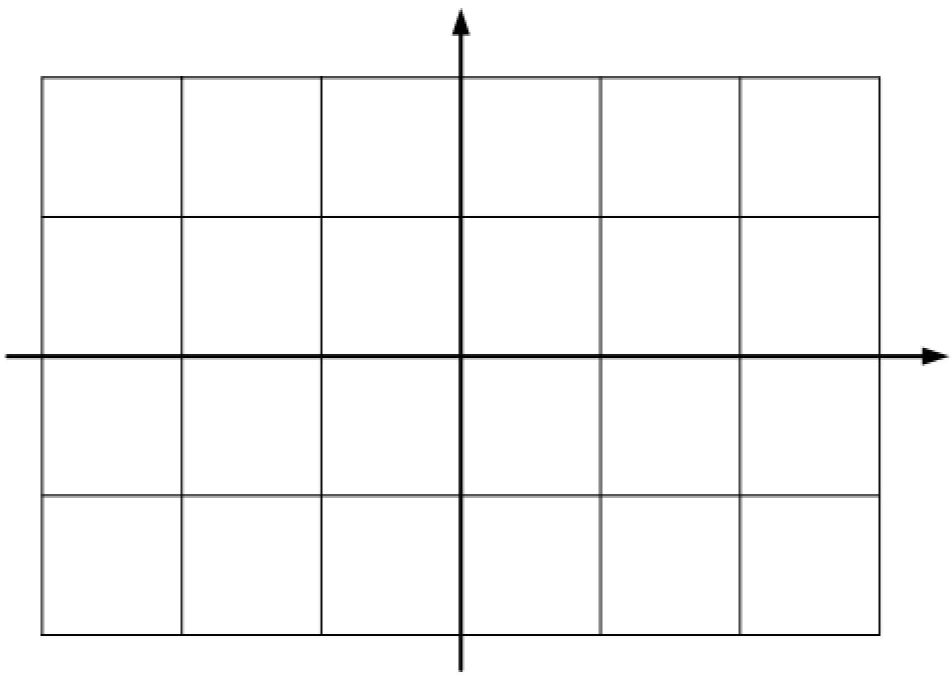
3. Voltage Gain

What is the value of R_1 that results in a gain $V_{out}/V_{in} = -4$?

Value for R_1 : ______ Ω

__/6pt

Your calculate V_{in} to V_{out} relationship and your simulation results. And attach your MultiSim circuit schematic.



4. Buffers

Circuit diagram for a non-inverting amplifier. Label the resistors (including Rs)

__/6pt

Diagram:

5. Electronic Interface for a pH Sensor

Calculated value for R_1: ______ kΩ

Calculated value for R_2: ______ kΩ

Calculated value for V_{off}: ______ V

__/6pt

Simulated V_{out} vs V_{pH} :

V_{out}	V_{pH}