Enter the names and SIDs for you and your lab partner into the boxes below.

Name 1		SID 1	
Name 2		SID 2	

Sensor Interfaces

A very frequent scenario when designing electronic circuits: you need some sensory input, e.g. temperature. You found a sensor (e.g. a thermistor) that converts the actual temperature into an electrical voltage. The next step is to interface the sensor to the rest of your system, typically a computer (microcontroller). Figure 1 shows the setup.

Usually the output of the sensor is a small voltage in the milli- or micro-Volt range (for a full-scale signal), while the rest of the electronic system (e.g. the computer) expects much larger signals, typically around a Volt. For example, the scale we built earlier generated output signals that were only a few milli-Volt. To overcome this mismatch we need some kind of interface between the sensor and the computer (or whatever we would like to connect the sensor to), as illustrated in Figure 2 on the next page.

Sensor interfaces can perform many functions. Here we focus on the task of gaining up the signal to appropriate amplitude. Specifically, we want the interface to perform the function

$$v_2 = A_v \, v_1 \tag{1}$$

where A_v is the voltage gain. For example, if $A_v = 21$ and $v_1 = 7.2\,\text{mV}$, $v_2 =$ ☐ 1 pt. 0

We will build the sensor interface out of operational amplifiers. To test it, we need an input, and something to verify the output. We could use the scale constructed in an earlier lab for the input, but this would require us to wire up that circuit again. Moreover, if we encounter problems, we would have to determine if they are due to the interface or the sensor—not always a trivial issue.

A better solution is to synthesize an appropriate input v_1 with reliable and well characterized (that's why it's expensive) laboratory equipment to test our amplifier circuit. Once we are satisfied with the result we can combine building blocks (and test again). Tackling circuits one-by-one in this fashion significantly simplifies our task and speeds up our work.

We will use the signal generator to simulate the sensor and the oscilloscope to verify the output from our sensor interface.

Signal Generator and Oscilloscope

Download the manuals for the oscilloscope and signal generator and read the quick start and overview guides. Program the signal generator to produce a 1 kHz sinewave with $V_s = 2.1\,\text{V}$ zero-to-peak amplitude. Connect the signal generator to the oscilloscope as shown in Figure 3 on the following page. Observe the sinewave on the oscilloscope display. What is the zero-to-peak amplitude? Note: the answer is not V_s!

predicted		1 pt. 1
measured		1 pt. 4

If you just cannot get this right, reread the guide for the function generator. Feel free to play in the lab with different settings of the function generator, e.g. higher frequency signals. Even test equipment is not "ideal" when used outside its specifications (which the manual explains, although in rather technical terms).

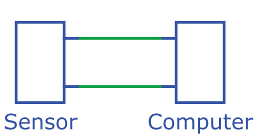


Figure 1 Sensor connected to an electronic system (e.g. a computer).

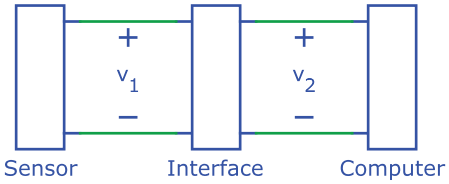


Figure 2 Sensor interface.

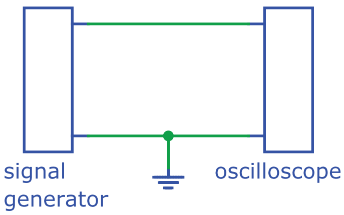


Figure 3 Signal generator connected to oscilloscope.

Operational Amplifier

Let's check out the operational amplifier before designing a more complex circuit. This way we are sure the part is working and we get all connections right (e.g. supplies!) without wasting a lot of time debugging a complex setup.

Download the datasheet of the LMC6482M/AM[1] operational amplifier. We are using the part in a 8-pin dual-in-line package. Find the following specifications from the datasheet:

Specification	Answer	Points
Pin number of the positive supply, V^+		1 pt. 2
Maximum supply voltage, $V^+ - V^-$		1 pt. 3
Minimum supply voltage, V^+		1 pt. 4
Maximum input current, I_B		1 pt. 5
Minimum junction temperature, T_j [C]		1 pt. 6
Maximum junction temperature, T_j [C]		1 pt. 7
Minimum (over temperature) large signal voltage gain A_v, sourcing into $R_L = 2\,\mathrm{k}\Omega$, V^+ (unitless)		1 pt. 8

Figure 4 shows the circuit diagram for an inverting amplifier based on the LMC6482. The inputs of the unused opamp OP2 are grounded, a good precautionary measure that prevents the part from accidentally turning on or even oscillate and interfere with other devices.

Signals are often bipolar (i.e. can assume both positive and negative voltage values). Since the amplifier output cannot possibly swing below the supply, both positive and negative supply voltages V_{dd} and V_{ss} are usually needed, as indicated in the diagram. To avoid clutter, the supplies are often omitted from circuit diagrams. Do not forget to connect them in practice, as the circuit will obviously not work without.

Mark the pin numbers for all connections of the operational amplifier (you will find them in the datasheet) in the circuit diagram and build your circuit on a protoboard. Verify all connections before applying power. If the part gets hot, check if the supply is connected backwards. Choose $V_{dd} = V_{ss} = 5\,\mathrm{V}$, $R_1 = 1\,\mathrm{k}\Omega$ and R_2 such that $v_o/v_i = -10$.

[1] In the actual lab you may get a compatible but different part. Submit the specifications for the LMC6482M/AM, but check into the differences if you get another part in the lab, especially the pin numbering.

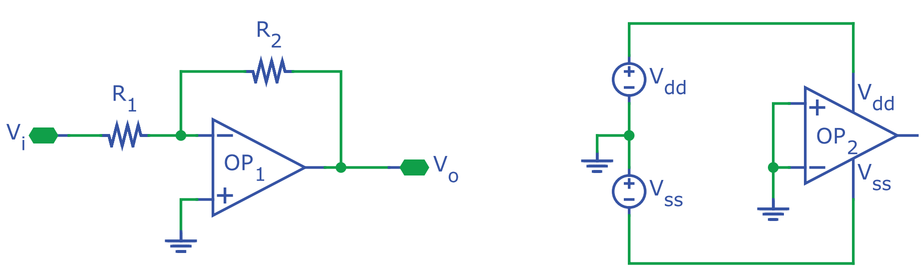


Figure 4 Inverting amplifier circuit diagram (left) and power supply connections (right).

$R_2 =$ ☐ 1 pt. 9

Program the function generator for a sinusoidal output at 1 kHz and 200 mVzero to peak amplitude. Using the oscilloscope, verify that $v_o / v_i = -10$. This is most easily accomplished by setting the input of the oscilloscope for the channel displaying v_o to inverting and its gain to half that of the other channel. Then adjust the vertical position such that the two outputs coincide.

Experiment with other inputs (increased signal amplitude, frequency, and different waveforms). Summarize your observations:

4 pts. 5

Show your setup to the assistant.

Positive Feedback (Schmitt Trigger)

What would happen if you inverted the connections at the input of the operational amplifier in Figure 4 on the preceding page, i.e. connected the resistors to the positive input and ground to the negative input?

Imagine that initially $v_i = v_o = 0\,\text{V}$. In practice we can never observe this state since even a slight disturbance of v_i results in a voltage across the input terminals of the operational amplifier that will be amplified and appear at the output v_o. Ideally the output voltage in this case is infinite, in practice it is limited by the supply voltage, V^+ or V^-, depending on the sign of the disturbance.

Assume that $v_o = V^+$ initially[2]. If we now decresase the input voltage v_i (i.e. make it negative), the voltage across the operational amplifier input decreases. For $v_i = V_{\text{th}}^-$ the amplifier input becomes negative and consequently the output changes to $v_o = V^-$.

Calculate the V_{th}^- for $R_1 = 9.2\,\text{k}\Omega$, $R_2 = 3.4\,\text{k}\Omega$, and $V^+ = -V^- = 6.5\,\text{V}$.

$V_{\text{th}}^- =$ ☐ 2 pts. 10

The operational amplifier stays negative until v_i is increased to

$V_{\text{th}}^+ =$ ☐ 1 pt. 11

Obviously this behaviour is not desired in an amplifier but can be quite useful in circuits that control a device that can only assume one state, e.g. an automatic door should be either open or closed but not oscillate between these two states. The technical term for this connection is "positive feedback" and the circuit is called Schmitt Trigger.

What is the value of R_2 such that $V_{th}^+ = 2.9\,\text{V}$ for $V^+ = -V^- = 5\,\text{V}$. Use $R_1 = 10\,\text{k}\Omega$.

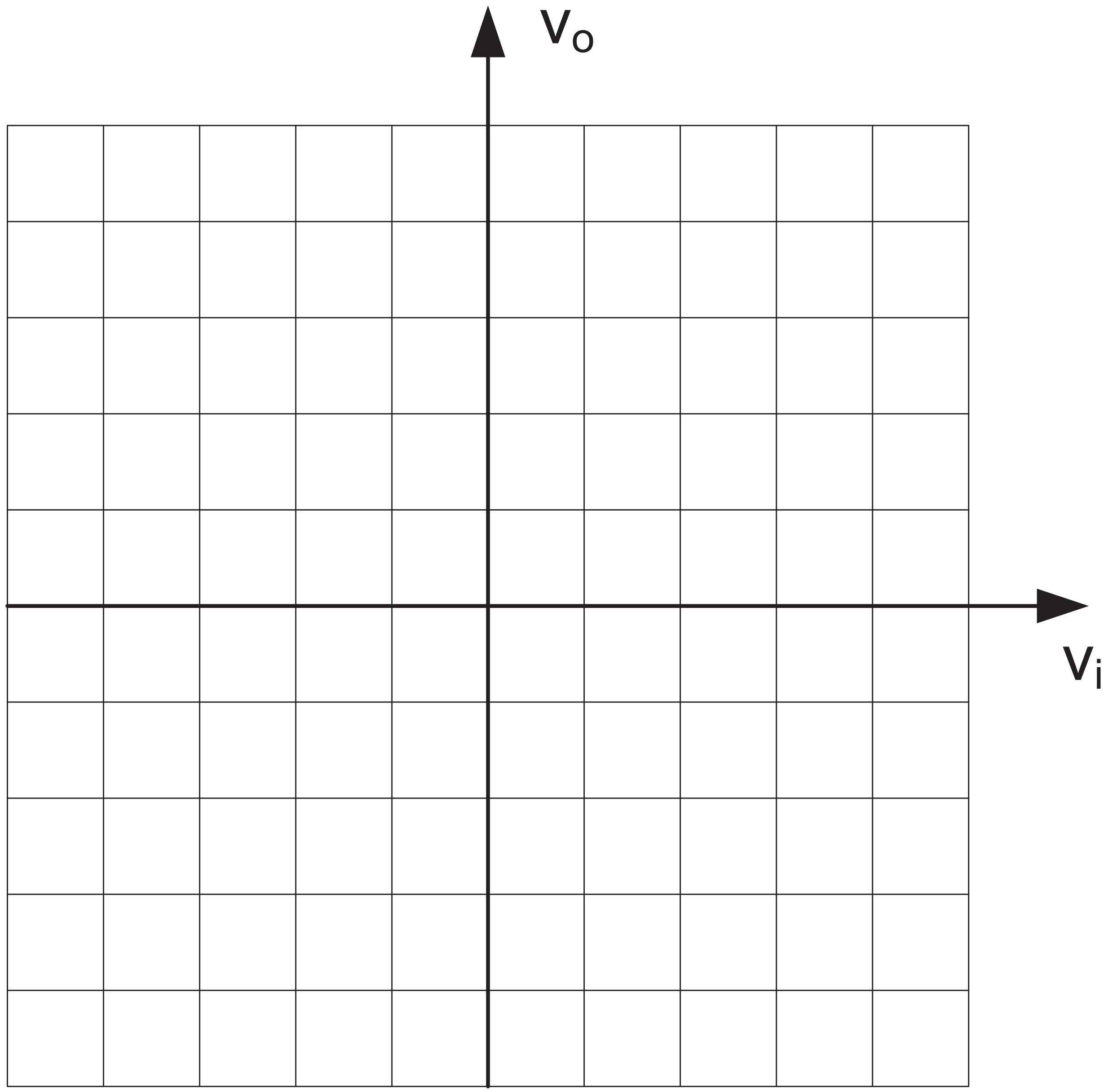
$R_2 =$ ☐ 1 pt. 12

[2] In practice v_o will be less than the supply voltage by an amount that depends on the design of the operational amplifier and is specified in its datasheet. For simplicity we ignore this in our analysis.

Use the closest available resistor in the lab.

Graph the input/output characteristics of the operational amplifier in the chart below for negative and positive feedback for v_i starting at V^- and increasing to V^+ and vice-versa. Indicate the direction with an arrow on your traces. Note that trace for increasing and decreasing v_i differ for positive feedback.

Add your measurement results in the same graph (use a different color).



Audio Amplifier

Now you are ready to design a sensor interface. We also connect a speaker to the output so we can listen to the output in addition to examining it with the oscilloscope (Figure 5 on the next page). We use the function generator to “simulate” the sensor as before, but add an adjustable 100 kΩresistor (potentiometer) in series with its output to mimic the often high and varying output resistance of practical sensors.

Capacitor C_1 blocks direct current from passing through the speaker, preventing it or the amplifier from overheating. Do not worry if you are not familiar with capacitors, they will be covered in a later lab. Just build the circuit exactly as shown in the diagram, paying special attention to polarities. If the capacitor explodes (they really

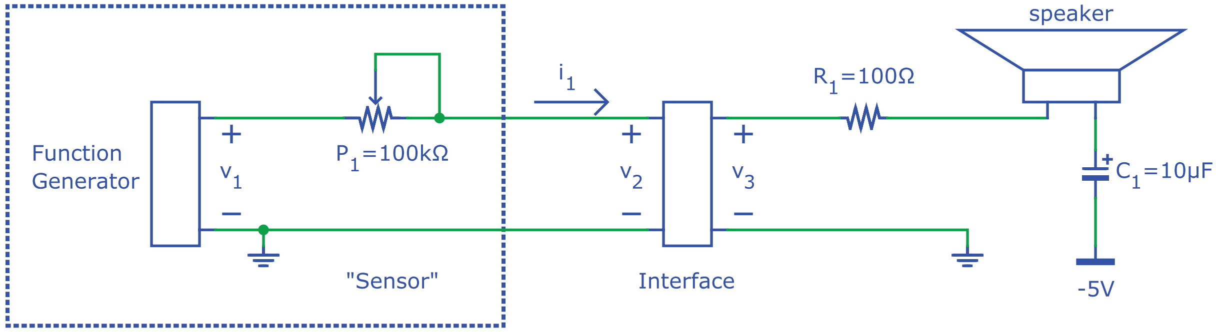


Figure 5 Sensor interface with audio output.

do this), you have connected it incorrectly. You have been warned!

Your objective for designing the sensor interface is for the gain $Av = v_3/v_1 = 7$ regardless of the setting of potentiometer P_1, i.e. the resistance of P_1 can be set to any value between $0\,\Omega$and $100\,\mathrm{k}\Omega$ without A_v changing. For this to be possible, you need to design the sensor interface such that its input current i_1 is (virtually) zero. Some amplifier configurations have this property, others do not. Select an appropriate one. Draw the circuit diagram in the space below. Include all component values and indicate values of all supplies. Mark pin numbers for operational amplifiers in your diagram.

Use the LMC6482 for your design. It is not optimal for this purpose since it cannot drive low resistance loads and hence needs the $100\,\Omega$ series resistor (standard speakers are $\approx 8\,\Omega$). Add an output stage (e.g. LM386 or LM4951) to get increased volume.

1 pt.
7

Verify your circuit, initially setting the function generator to a 440 Hz sinusoidal output with amplitude 0.5 V. Check that v_2 and v_3 are undistorted sine waves (disconnect the speaker to investigate any problems you might have). Then verify that the amplitudes of v_2 and v_3 are independent of the setting of the potentiometer (make sure it's connected correctly as shown in the diagram).

Now check different waveforms. Can you hear the difference between 440 Hz and 880 Hz? What about 10 kHz? Square- and sawtooth waveforms? At very low frequencies you may be able to see the membrane of the speaker vibrate, especially if you put a light weight (paper clip or corn of rice) on top.

Demonstrate your circuit to the assistant and show that the output amplitude is independent of the potentiometer setting.

Password:

EE 42/100 Lab 3 Operational Amplifiers

Prelab Summary

Name:____

SID: ____

Answers

0.____

1.____

2.____

3.____

4.____

5.____

6.____

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