IMPORTANT - READ CAREFULLY: Lab questions are now broken into PRE-LAB, LAB, and POST-LAB components. Please go to the EE1305 website and read the lab procedure, and complete all of the PRE-LAB sections, BEFORE coming to the lab.

Pre-Lab - Question 1:
- What is the LMC6484? (Read Procedure 1)
- How many pins does LMC6484 have? How many Op-Amp does it include?
- Describe the pins that are connected to the inverting (-) input, non-inverting input (+), and the output. (see Figure 1)

Pre-Lab - Question 2:
- Draw an Op-Amp Buffer. What does Op-Amp Buffer (or voltage follower) do?

NOTE: For this week's lab, you are individually work for all procedures and everything should be completed by yourself. You are provided with necessary instructions.
Lab – Procedure 1: Follow the procedure 1 on the website. Describe the assumptions that we follow for Ideal Op-Amps. (Please use your own words)

Lab – Procedure 2: Please follow procedure 2 to analyze and build voltage divider with and without an Op-Amp buffer.

- Use Figure 2 to explain what you would expect to measure Ch1+ of the Voltage Divider (Figure 2 - left), and at the output of the Op-Amp (Figure 2 - right).

Solution for Figure 2- left:

\[ V_{ch1+} = \frac{1M\Omega}{1M\Omega + 1M\Omega} \times 5 = ?? \]

Solution for Figure 2- right:

\[ V_{non-inverting \ input \ of \ buffer} = \frac{1M\Omega}{1M\Omega + 1M\Omega} \times 5 = ?? \]

Based on assumption for ideal Op-Amps:

\[ V_{+ \ input \ of \ buffer} = V_{- \ input \ of \ buffer} = ?? \]

Channel 1+ is connected to the output of buffer. The output of buffer is itself connected to inverting input of buffer. Thus:

\[ V_{ch1+} = V_{inverting \ input \ of \ buffer} = ?? \]

- Build the circuit of voltage divider without buffer (Figure 2- left) and fill the table below. Calculate the impedance of analog discovery based on measured voltage at Ch1+.
Solution:

Voltage divider without buffer can be built as shown below. Include the figure of your circuit on your breadboard along with your UTEP ID or your name on a piece of paper.

To calculate impedance of Analog discovery/ADALM2000, just imagine another resistor sits in parallel between ch1+ and ch1- in Figure 2 - left, and the value of this resistor (let’s call it $R_{A−Discovery}$) is the input impedance of Analog Discovery.

Here is the solution of how to calculate $R_{A−Discovery}$:

$$V_{ch1+} = \frac{1\,\Omega \ || \ R_{A−Discovery}}{1\,\Omega \ || \ R_{A−Discovery} + 1\,\Omega} \times 5$$

$$V_{ch1+} \times \left( (1\,\Omega \ || \ R_{A−Discovery}) + 1\,\Omega \right) = 5 \times (1\,\Omega \ || \ R_{A−Discovery})$$

$$V_{ch1+} \times (1\,\Omega \ || \ R_{A−Discovery}) + V_{ch1+} \times 1\,\Omega = 5 \times (1\,\Omega \ || \ R_{A−Discovery})$$

$$V_{ch1+} \times 1\,\Omega = (1\,\Omega \ || \ R_{A−Discovery}) \times (5 - V_{ch1+})$$
\[(1\Omega || R_{A-Discovery}) = \frac{V_{ch1+} \times 1\Omega}{(5 - V_{ch1+})}\]

\[\frac{(1\Omega \times R_{A-Discovery})}{1\Omega + R_{A-Discovery}} = \frac{V_{ch1+} \times 1\Omega}{(5 - V_{ch1+})}\]

\[R_{A-Discovery} = \frac{1,000,000 \times V_{ch1+}}{5 - 2V_{ch1+}}\]

Replace measured value for \(V_{ch1+}\) in highlighted formula to calculate \(R_{A-Discovery}\).

Build the circuit of voltage divider with Op-Amp buffer (Figure 2 - right) and fill the table below.

<table>
<thead>
<tr>
<th>Calculated Voltage at Ch1+</th>
<th>Measured Averaged Voltage at Ch1+</th>
</tr>
</thead>
<tbody>
<tr>
<td>of voltage divider with Op-Amp buffer</td>
<td></td>
</tr>
</tbody>
</table>

**Solution:**
Voltage divider with Op-Amp buffer can be built as shown in below. Include the figure of your circuit on your breadboard along with your UTEP ID or your name on a piece of paper.
Lab – Procedure 3: Follow the procedure 3 on the website to build and analyze the inverting amplifier Op-Amp circuit.

You can built inverting amplifier circuit as illustrated below. Include the figure of your circuit on your breadboard along with your UTEP ID or your name on a piece of paper.

- Take screenshot of the scope data for three different input amplitudes.
- Describe your observations for #3 and #4.
- At what point (amplitude of the waveform) does the output amplitude stop increasing? Does this make sense? Explain

Lab – Procedure 4: Follow the procedure 3 on the website to build and analyze the inverting amplifier filter circuit

You can built inverting amplifier filter circuit as illustrated below. Include the figure of your circuit on your breadboard along with your UTEP ID or your name on a piece of paper.
Include your calculations for the critical frequency.
Use the resistor of 10 kΩ and capacitor of 10 nF to calculate critical frequency.
10 kΩ = 10,000 Ω, 10 nF= 10 × 10⁻⁹

\[ f_c = \frac{1}{2\pi RC} = ?? \]

Include and describe the MATLAB Bode plot (identify fc on the graph) and indicate the type of filter (low pass, high pass, or band pass)

Include plots (screen shot) for step #4, and describe your results relative to the cut-off frequency for this circuit.
Lab Procedure 5: Follow the procedure 5 on the website to build and analyze the photodiode O2 sensor circuit. Put your UTEP ID across your breadboard and take a picture of your UTEP ID (or your name) and final circuit on your breadboard, and include it in your report.

You can build circuit in Figure 5a as below:

- Include your results (using MATLAB) from step 3 including both Ch1 and Ch2 measurements.
Post-Lab – Step 1 Organize all of your Figures and tables neatly in your Word document. Figure caption is placed at the bottom while table caption should be placed on top of the table. For any figure you copy from website, please include reference number at the end of figure caption. Then cite to the website in Reference section of your report.

Post-Lab – Step 2 In a few sentences, answer the following sentences. You can also answer them in your Word doc if you want to type/need more room.

- What did you learn about:
  - LMC6486
  - Op-Amp buffer
  - Inverting amplifier low pass filter
In a few sentences, answer the following sentences. You can also answer them in your Word doc if you want to type/need more room.

- In procedure 2 (Figure 2 - left), explain why the measured voltage at Ch1+ is not match with the expected voltage at Ch1+?

- In procedure 2 (Figure 2 - right), explain why we have not really noticed the effect of the Analog Discovery’s input impedance. Also explain the usefulness of an Op-Amp buffer circuit based on your results. Why would you want to use a buffer?

Post- Lab – Step 4

- Figure below shows the circuits you implemented to measure light intensity through your finger. What is each block called? Use one of the following to describe each stage: Low pass filter, high pass filter, Inverting amplifier low pass filter or buffer.

- Explain the different stages of the circuit.
Post-Lab – Step 5 Include the Figures, add your answers and solutions in this document. Upload this document in the respected folder in the blackboard for grading.