ECE 351 Lab 8

In this lab we will verify the operation of inverting and non-inverting amplifiers constructed using Operational Amplifiers. We will also observe the frequency response of these circuits. The frequency response of a circuit answers the question, “How does the gain of a circuit vary with frequency?” All amplifiers have frequency limitations. Use the **741** OPAMP **(and no other)** in the lab and in PSpice. The UA741 is equivalent to the LM741.

VIII.A. Pre-Lab

We will be using the circuits of Figure VIII-1 and Figure VIII-2. These are inverting and non-inverting configurations. We will be investigating each circuit for three different gains. You will have six different designs.

1. Design the inverting amplifier of Figure VIII-1 to have gains of 1, 10, and 100. The smallest value of R_F you should use is10 kΩ. You will have 3 separate circuits. With the available resistor values you may not achieve these gains exactly. Come as close as possible while only using two resistors.

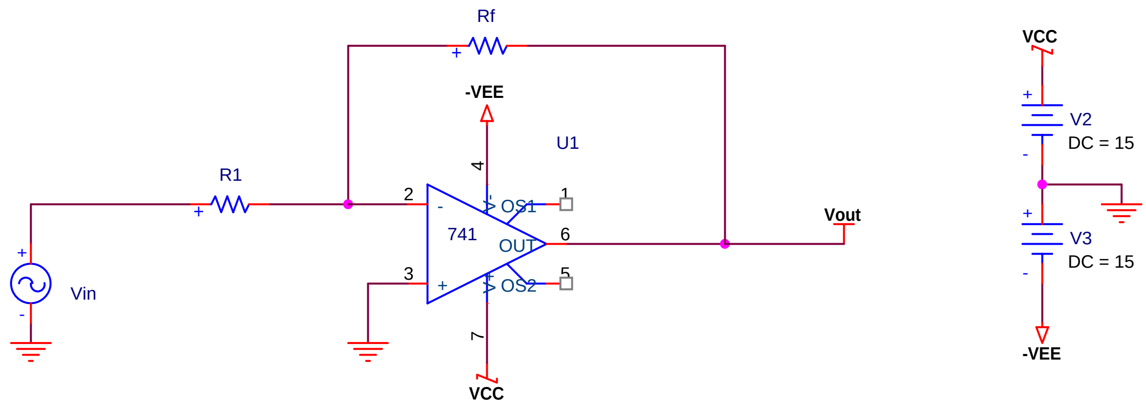

Figure VIII-1: Inverting amplifier.

2. Design the non-inverting amplifier of Figure VIII-2 to have gains of 1, 11, and 101. The smallest value of R_2 you should use is 10 kΩ. You will have 3 separate circuits. Note that for a gain of 1, no resistors are required. A non-inverting amplifier with a gain of 1 is also referred to as a buffer. With the available resistor values you may not achieve these gains exactly. Come as close as possible while only using two resistors.

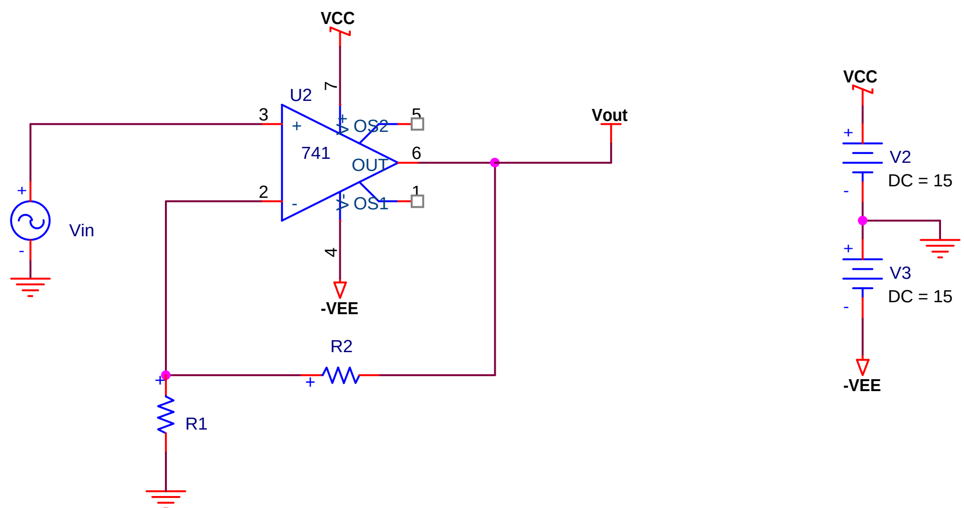

Figure VIII-2: Non-inverting amplifier.

3. Read Sections 5.E and 5.F in the PSpice manual.

4. Obtain plots of gain versus frequency for all 6 circuits. Plot the gain in Decibels (dB) versus frequency for frequencies from 1 Hz to 100 MHz. To plot gain in dB, add the trace dB(V(Vout)) instead of V(Vout). Use the cursors or a goal function to find the low frequency gain and the -3 dB frequency for each value of gain. The -3 dB frequency is the frequency where the gain is down by 3 dB from its maximum value. Remember that gain is the ratio V_{out}/V_{in}, and gain specified in dB is $20\log_{10}(V_{out}/V_{in})$. Fill in the tables below. **Note than when calculating *Gain×Bandwidth* below, the bandwidth is the -3 dB frequency and the gain is not in dB.**

Table VIII-1: Non-Inverting Amplifier

PSpice Simulation Results

Calculated Gain	PSpice Gain (dB)	Pspice Gain (V_o/V_{in})	-3 dB Frequency (Hz)	*Gain×Bandwidth* (Hz)
1				
11				
101				
1001	59.97	996.55	990	986,584

Table VIII-2: Inverting Amplifier

PSpice Simulation Results

Calculated Gain	PSpice Gain (dB)	Pspice Gain (V_o/V_{in})	-3 dB Frequency (Hz)	*Gain×Bandwidth* (Hz)
1				
10				
100				

Note that when you calculate *Gain×Bandwidth*, the gain is **not** in dB.

VIII.B. Non-Inverting Amplifier Laboratory Measurements

Wire the circuit of Figure VIII-2.

VIII.B.1. Gain 1

Use the resistors you chose to achieve a gain of 1.

1. Let V_{IN} be a 1 kHz sine wave. Set its amplitude so that V_o is 1 volt peak-to-peak. Obtain a scope plot that shows that the gain is 1 and that the output is in phase with the input. The plot should use as much space in the scope window as possible.

2. We will now measure the small signal frequency characteristics of this circuit. Make sure that **V_o is 1 volt peak-to-peak or smaller. If the output is not an undistorted sine wave, reduce the input until the output is an undistorted sinewave.** Gain is only measured with small signal outputs. Fill in the Table VIII-3. Note that Table VIII-3 contains several rows where the frequency has not been specified. You must fill in all rows of this table and choose frequencies that will make a nice looking plot. Voltages can be measured as either peak-to-peak or magnitude (center to

peak). Make sure you specifically measure the -3 dB frequency and highlight it in the table. Plot the measured results using MATLAB. On this plot, use MATLAB to place a red star at the predicted –3 dB frequency. You can do this with the command:

```
semilogx(x,y,1e6,-3,'r*')
```

This command plots the measured data contained in variables x and y, and then also places a star at coordinates y = -3 dB, and x = 1 MHz. You will need to change the coordinates of the star for your calculations.

Table VIII-3: Non-Inverting Amplifier - Gain 1
Measured Results

Frequency (Hz)	$\lvert V_o \rvert$ (Volts)	$\lvert V_{in} \rvert$ (Volts)	$\left\lvert \frac{V_o}{V_{in}} \right\rvert$	$\left\lvert \frac{V_o}{V_{in}} \right\rvert_{dB}$
1				
10				
100				
1,000				
10,000				
100,000				
1,000,000				

VIII.B.2. Gain 11

Use the resistors you chose to achieve a gain of 11.

1. Let V_{in} be a 1 kHz sine wave. Set its amplitude so that V_o is 1 volt peak-to-peak. Obtain a scope plot that shows that the gain is 11 and that the output is in phase with the input. The plot should use as much space in the scope window as possible.

2. We will now obtain the small signal frequency characteristics of this circuit. Make sure that **V_o is 1 volt peak-to-peak or smaller. If the output is not an undistorted sine wave, reduce the input until the output is an undistorted sinewave.** Fill in Table VIII-4. Voltages can be measured as either peak-to-peak or magnitude (center to peak). Make sure you specifically measure the 3 dB frequency and highlight it in the table. Plot the measured results using MATLAB. On this plot, use MATLAB to place a red star at the predicted –3 dB frequency.

Table VIII-4: Non-Inverting Amplifier - Gain 11 Measured Results				
Frequency (Hz)	$\lvert V_o \rvert$ (Volts)	$\lvert V_{in} \rvert$ (Volts)	$\left\lvert \frac{V_o}{V_{in}} \right\rvert$	$\left\lvert \frac{V_o}{V_{in}} \right\rvert_{dB}$
1				
10				
100				
1,000				
10,000				
100,000				
1,000,000				

VIII.B.3. Gain 101

Use the resistors you chose to achieve a gain of 101.

1. Let V_{in} be a 1 kHz sine wave. Set its amplitude so that V_o is 1 volt peak-to-peak. Obtain a scope plot that shows that the gain is 100 and that the output is in phase with the input. The plot should use as much space in the scope window as possible.

2. We will now obtain the small signal frequency characteristics of this circuit. Make sure that **V_o is 1 volt peak-to-peak or smaller. If the output is not an undistorted sine wave, reduce the input until the output is an undistorted sinewave.** Fill in the Table VIII-5. Voltages can be measured as either peak-to-peak or magnitude (center to peak). Make sure you specifically measure the 3 dB frequency and highlight it in the table. Plot the measured

Table VIII-5: Non-Inverting Amplifier - Gain 101 Measured Results				
Frequency (Hz)	$\lvert V_o \rvert$ (Volts)	$\lvert V_{in} \rvert$ (Volts)	$\left\lvert \frac{V_o}{V_{in}} \right\rvert$	$\left\lvert \frac{V_o}{V_{in}} \right\rvert_{dB}$
1				
10				
100				
1,000				
10,000				
100,000				
1,000,000				

results using MATLAB. On this plot, use MATLAB to place a red star at the predicted –3 dB frequency.

VIII.B.4. Measured Gain-Bandwidth

Based on your previous frequency measurements, fill in Table VIII-6. Compare the results to PSpice (Table VIII-1). What do you notice about *Gain×Bandwidth*?

Table VIII-6: Non-Inverting Amplifier

Gain Bandwidth - Measured Results

Calculated Gain	Measured Gain (dB)	Measured Gain (V_o/V_{in})	-3 dB Frequency (Hz)	*Gain×Bandwidth* (Hz)
1				
11				
101				
1001				

VIII.C. Gain-Bandwidth

By this time you should realize that *Gain×Bandwidth* is approximately constant for this OPAMP circuit. In general, for any OPAMP circuit you can assume that *Gain×Bandwidth* is constant. A number for the *Gain×Bandwidth = Constant* can be found in all OPAMP data sheets. It may sometimes be given different names but it is a number that is always available. Some common names are *Unity Gain Bandwidth*, *Small Signal Bandwidth*, or *Unity Gain Crossover Frequency*. This number is usually easy to find if you look for units of Mhz.

We will use the *Gain×Bandwidth* product to find the -3 dB frequency of the circuit in Figure VIII-3. Note that the OPAMP is now a TL072. Find the specification of the Unity Gain Bandwidth in the data sheets for the TL072. Calculate the gain for the circuit and use the Unity Gain Bandwidth to find the -3 dB frequency. Measure the -3 dB frequency in the lab and compare the result to the calculated value.

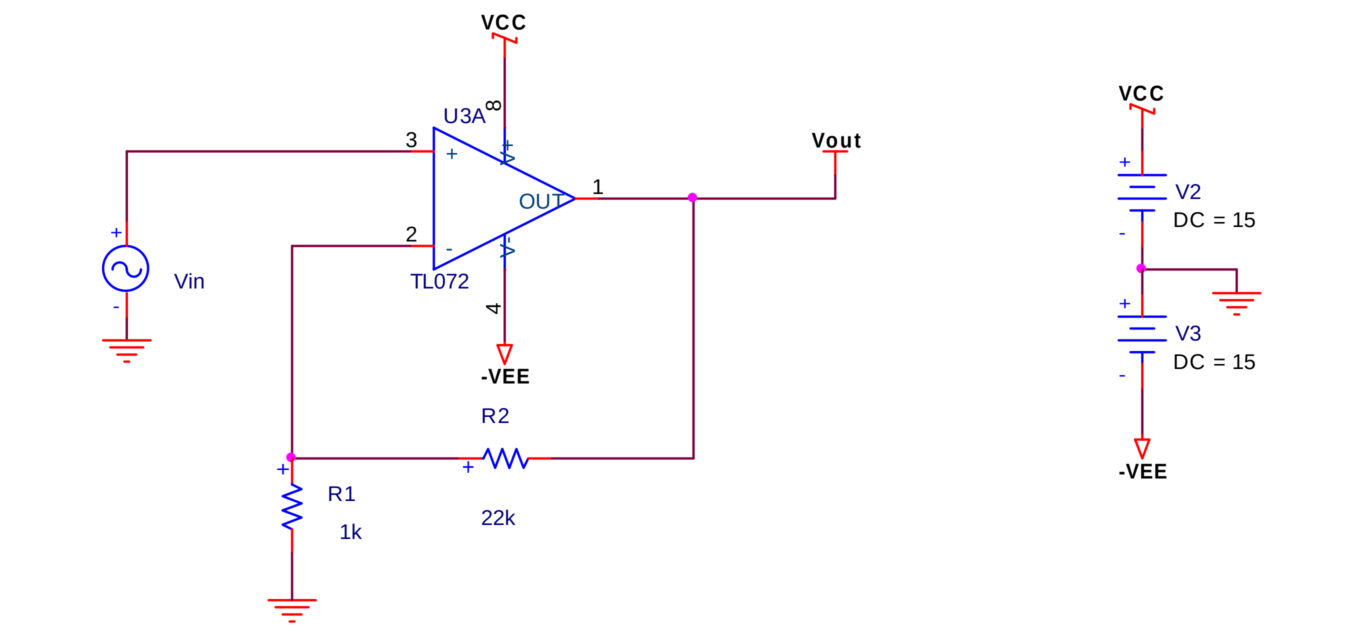

Figure VIII-3: Non-inverting circuit using a TL072 op-amp.