Lab 4: Analysis of the Stereo Amplifier

Objectives

In this lab exercise you will use the power supply to power the stereo amplifier built in the previous lab. You will then analyze the frequency response of the stereo amplifier. The idea of filtering signals will be presented in an auditory manner in order to give another means of observing the output of a circuit. You will also determine the resistance and inductive reactance (imaginary part of impedance, which is positive) of a typical speaker.

Pre-Lab Instructions

Calculations

1. The simplified schematic for one channel of the stereo amplifier constructed in the previous lab is shown in Figure 1.
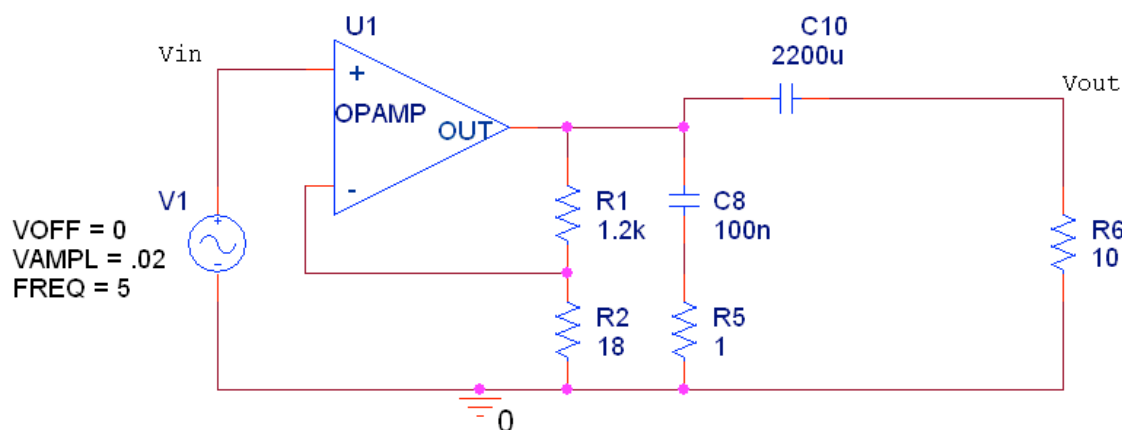

Figure 1: Simplified Schematic for One Channel of the Stereo Amplifier

(a) In PSpice, simulate the circuit and measure the frequency response (gain and phase) for the different values of the frequency f (i.e., $v_i(t) = \cos(2\pi f t)$).

Frequency	|Vout/Vin|	Phase Shift (degrees)
5Hz		
10Hz		
100Hz		
1,000Hz		
10,000Hz		

(b) Print the waveforms for the case of $f = 5$Hz and $f = 1,000$Hz. Also print out the schematic for any one frequency value. (**NOTE: your name must appear in the filename of all circuit and waveform printouts!**)

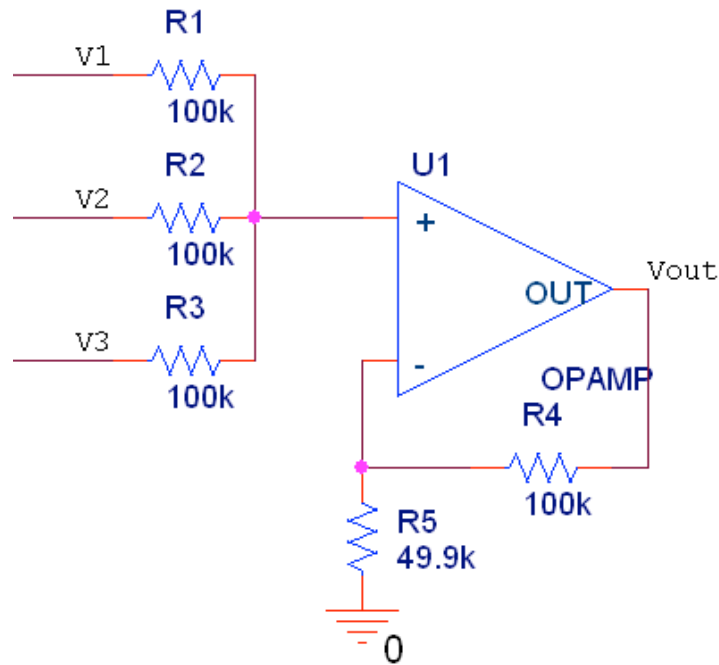2. A summer-circuit is shown in Figure 2 below:

Figure 2: Summer-Circuit

(a) Derive the equation for the output voltage as a function of the three input voltages. The only tools you should need for this calculation are nodal analysis, Ohm's Law (in the form of a voltage divider made up of R4 and R5), and the ideal op-amp rules: No current goes into the + or – terminal, and the voltage difference between those two terminals is zero. Also, comment on why you think this circuit is known as a "summer."

Vout = _____

3. (a) In PSpice, simulate the summer-circuit shown in Figure 3 (using a bias point analysis, as opposed to a time domain analysis), and print the circuit with the bias voltages displayed on every node (simply click the "Enable Bias Voltage Display" button in the toolbar after performing the bias analysis). N.B., you should not print a waveform for this part, just the schematic with the bias voltages displayed.
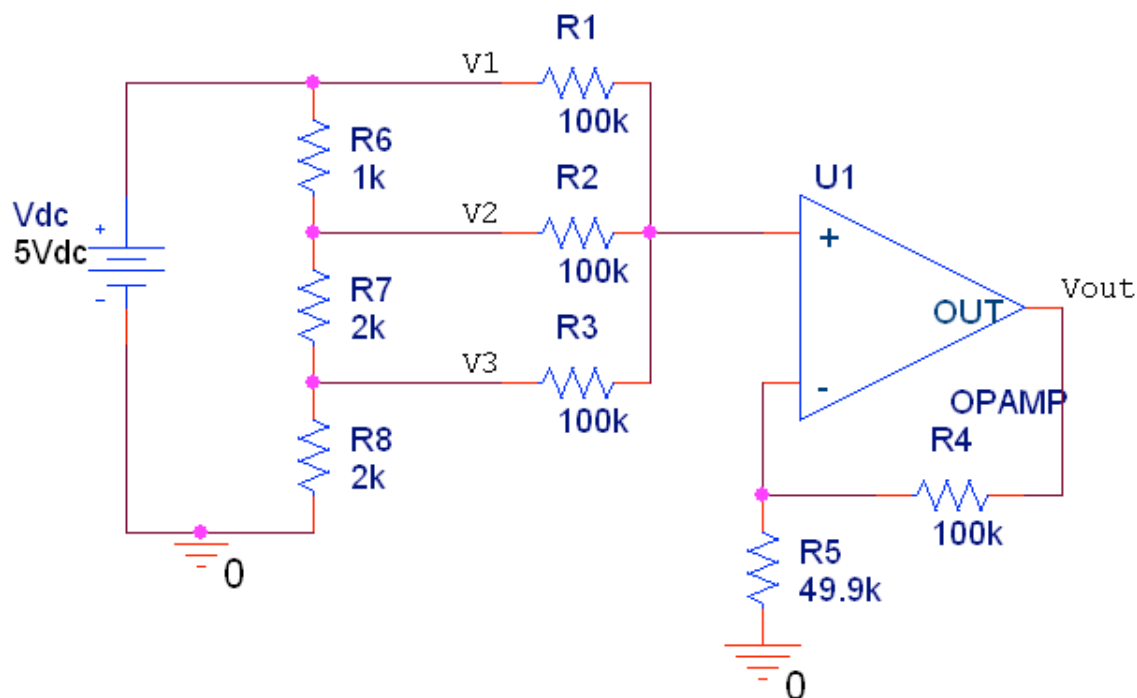

Figure 3: Summer-Circuit with Input Voltages Defined

(b) The voltage source Vdc and resistors 6 through 8 are nothing more than a voltage divider (since an op-amp has a very high input impedance, and thus draws very little current through resistors 1, 2, and 3). Derive the DC values of voltages 1, 2, and 3, and using the equation for the output of this summer-circuit previously obtained, check to see that the bias voltage calculated in PSpice is correct.

V1 _____

V2 _____

V3 _____

Vout _____

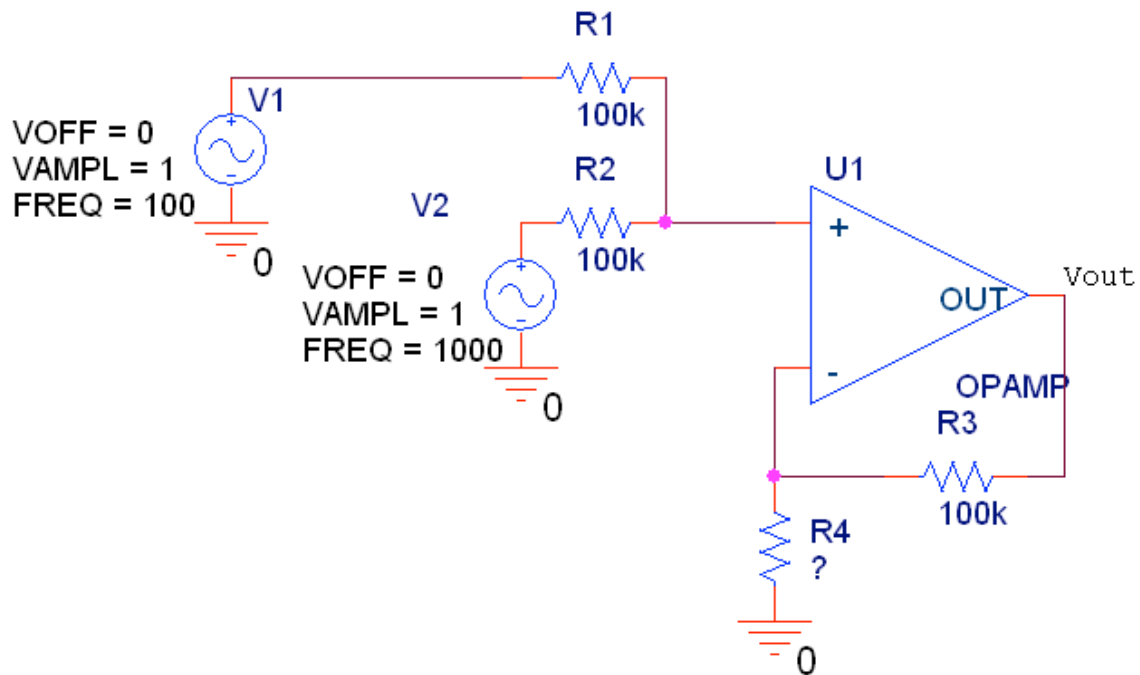4. A summer-circuit with only two inputs is shown in Figure 4:

Figure 4: Summer-Circuit with Two Input Voltages

(a) If the desired output is to be Vout = V1 + V2, what must R4 be?

R4 _____

(b) Once you have chosen the value of R4, perform an AC (PSpice) analysis of the circuit, and print out a waveform showing both the inputs and the output.

5. We will now attempt to filter the output to isolate the lower frequency (100Hz) and attenuate the higher frequency (1,000Hz) using a low-pass filter. We will then do the opposite using a high-pass filter. First, the filters must be designed to accomplish the task for these specific frequency values.

(a) Determine the value of Rload in the low-pass filter of Figure 5 such that the gain at 1,000Hz is 0.1, then choose the resistor value from the table of standard resistors closest to this value.
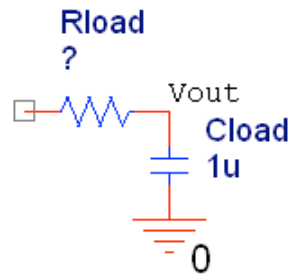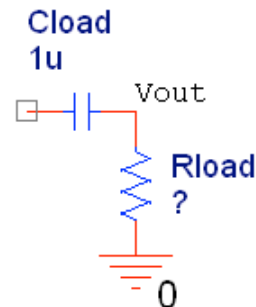

Figure 5: Filters Used to Filter the Output of the Summer-Circuit

Rload (low-pass)   _____

Rload (chosen)   _____

(b) For the resistor value chosen above, calculate the gain of the low-pass filter at 100Hz and 1,000Hz.

Av (low-pass, 100Hz)   _____

Av (low-pass, 1,000Hz)   _____

(c) Determine the value of Rload in the high-pass filter of Figure 5 such that the gain at 100Hz is 0.1, then choose the resistor value from the table of standard resistors closest to this value.

Rload (high-pass) _____

Rload (chosen) _____

(d) For the resistor value chosen above, calculate the gain of the low-pass filter at 100Hz and 1,000Hz.

Av (high-pass, 100Hz) _____

Av (high-pass, 1,000Hz) _____

(e) With these resistor values chosen, add each filter to the output (one at a time) to the output of the circuit shown in Figure 4. Print out both the schematic and the resulting waveform, showing the inputs and the filtered output, for both the low-pass filter and the high-pass filter. For an example of how to attach the filters, see how the low-pass filter is attached in Figure 6:
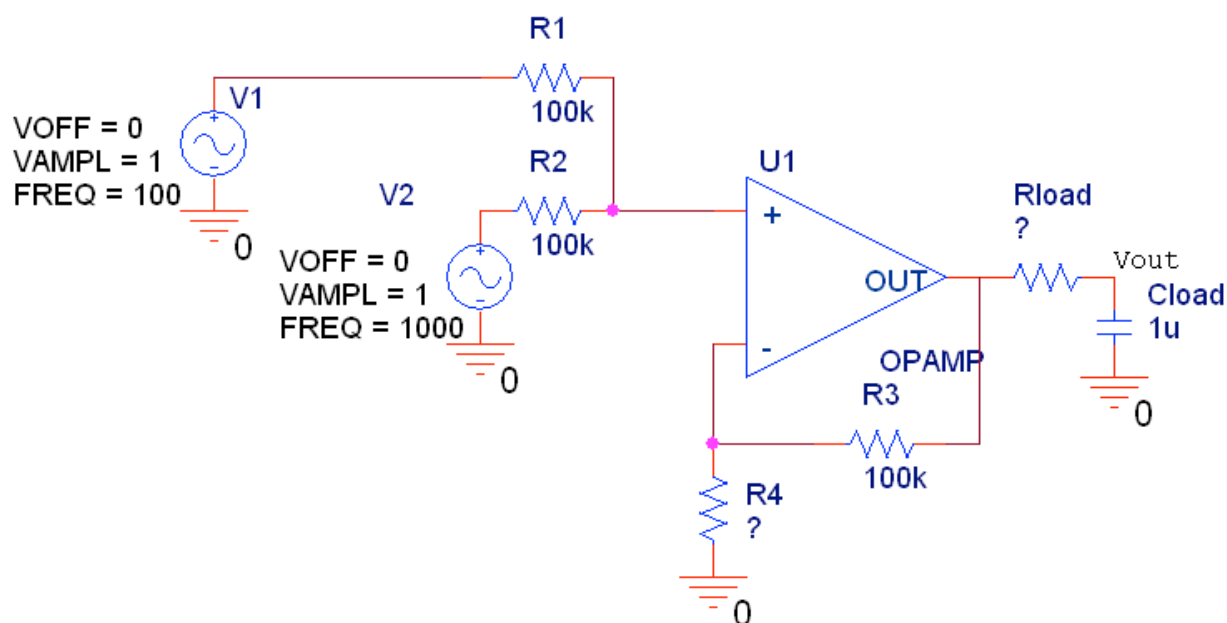

Figure 6: Example of How the Filters Should be Attached

In-Lab Instructions

Part One: Frequency Response of the Stereo Amplifier
 1. Set the power supply you built in the previous lab to 12V (as measured on the digital multimeter), and then unplug the power supply. Attach the outputs of the power supply to the input voltage terminals (V+ and GND) on the stereo amplifier. Connect a 4V peak-to-peak sine wave at 5Hz from the function generator to the input of the voltage divider (Vin) as shown in Figure 7. The output of this will be the input into the first channel (IN1) of the stereo amplifier (the ground from the function generator should be connected to the INPUT GND terminal). Connect a 10Ω, 10W resistor across the output of the stereo amplifier (i.e., from OUT1 to the output ground).
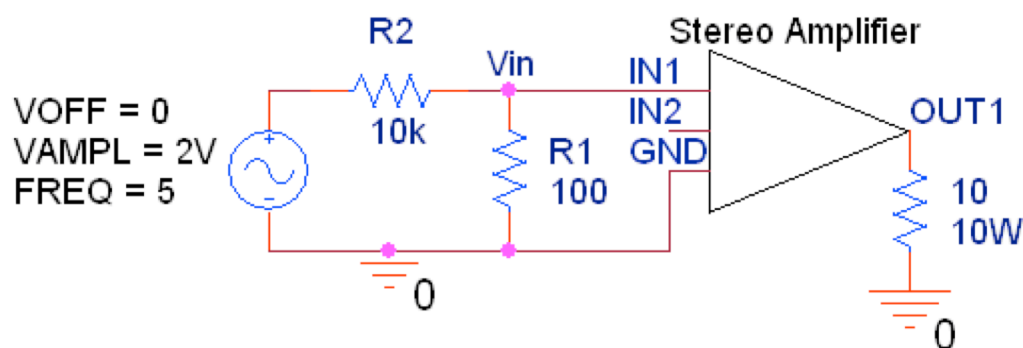

Figure 7: 100 to 1 Voltage Divider

 The 4V peak-to-peak (2V amplitude) sine wave from the function generator will result in approximately 40mV peak-to-peak at the node labeled "V_{IN}" in Figure 1 of the pre-lab. Therefore, only measure the 4V signal on the scope, and assume that the voltage going into the stereo amplifier is 40mV at the same frequency and phase as the 4V signal.

 Plug in the power supply and make the following measurements for the frequencies shown below. V_{OUT} is the voltage across the 10Ω, 10W resistor, and V_{IN} will always be 40mV (assuming the function generator is set to 4V). For phase shift (degrees) use: $\phi = t_{p-p} * f * 360$

Frequency	$| V_{OUT} / V_{IN} |$	Phase Diff (V_{OUT} and V_{IN})
5Hz		
10Hz		
100Hz		
1,000Hz		
10,000Hz		

2. Based on your measurements of V_{OUT}, predict what you think the current through the 10Ω resistor will be. Measure this current using the multimeter, then compare your predictions with your measurements.

Predicted value: _____

Measured value: _____

Percent error: _____

Part Two: Summer-Circuits and Filters
      1. Construct the circuit shown in Figure 3 (pg. 3). Make the following DC measurements of the circuit on the digital multimeter. Have the TA verify that the output is as expected.
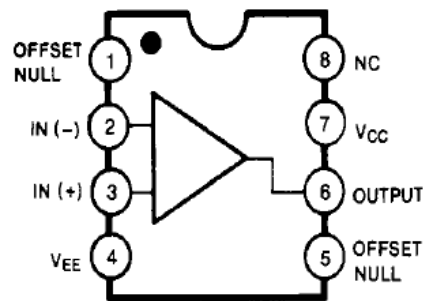

Figure 8: Pin Layout of the LM741 Op-Amp

NOTE: Set V$_{EE}$ to −15 V and V$_{CC}$ to 15 V.

V1   _____

V2   _____

V3   _____

V$_{OUT}$ _____

TA initials _____

      2. Construct the circuit shown in Figure 4 (pg. 4), using the value of R4 chosen earlier. The two different voltage sources will have to come from two different function generators. The resulting waveform may not stabilize on the oscilloscope, so the run/stop button may have to be pressed to see the output waveform. You should see a 100Hz signal with a 1,000Hz signal imposed on top of it. Have the TA check the signal on the screen.

TA initials _____

Reduce the amplitude of each input voltage to zero and make sure the VOLTS OUT button is pushed in on the function generator (limiting the output to 0-2V, as opposed to 0-20V). Connect the output of the op-amp to the input of your stereo amplifier. Connect a speaker to the output channel of the stereo amplifier. Turning up the amplitude on each function generator (very slowly, so as to not blow out the speaker), you should hear both the 100Hz signal and the 1,000Hz signal. Get both amplitudes to be about the same (using your ear to measure the relative amplitude of each signal). Have the TA listen to the output.

TA initials _____

(Optional: push the sweep button in on the function generator, and experiment with the "sweep rate" and "sweep width" for some interesting sounds.)

Disconnect the output of the op-amp from the input of the stereo amplifier. We will now try to filter the output so that we only hear the low-frequency signal (using the low-pass filter). Then we'll remove the low-pass filter and add the high-pass filter so we hear just the high-frequency signal.

Measure the capacitance of a 1μF capacitor using the RLC meter. Compare your measurement to the expected result.

Measured value: _____

Percent error: _____

Construct the low-pass filter shown in Figure 5 (pg. 5) using the resistor found in the pre-lab in series with the 1μF capacitor. Connect the output of this filter to the input of the stereo amplifier. You will hear mainly the 100Hz signal, although the 1,000Hz is still discernible (though greatly attenuated). The 100Hz signal is also slightly attenuated.

Construct the high-pass filter shown in Figure 5 using the 1μF capacitor in series with the resistor found in the pre-lab. Connect the output of this filter to the input of the stereo amplifier. You will hear mainly the 1,000Hz signal.

Have the TA verify that the filters are working as expected.

TA initials _____

Part Three: Determining Speaker Impedance

      1. A speaker can be modeled as a resistance in series with an inductor. In order to determine the resistance (R_{SP}) and the inductance (L_{SP}), two separate experiments will be conducted. First, it should be noted that an inductor behaves as a short circuit at very low frequencies (i.e., DC). We can then set up a DC voltage divider to find the speaker's resistance, R_{SP}. (NOTE: The 2Ω resistor in Figure 9 is actually five 10Ω, 10W resistors in parallel. Ask the TA where to find these resistors.)
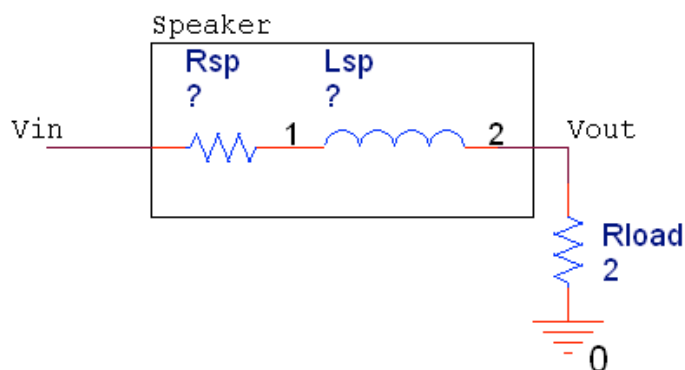

Figure 9: Voltage Divider for Determining R_{SP} and L_{SP}

Derive the equation for V_{OUT}/V_{IN} as a function of ω (since $Z_L = j\omega L$):

$$V_{out}/V_{in} = \underline{\hspace{5cm}}$$

      Connect 1V from the breadboard to the input voltage. Measure the output voltage. Using the above equation, solve for R_{SP} (hint: $\omega = 0$ for DC).

V_{OUT} \underline{\hspace{2cm}}

R_{SP} \underline{\hspace{2cm}}

      Next, we will find the impedance of the speaker. Connect the function generator directly to an oscilloscope probe. Set the frequency to 100kHz, and the amplitude to 2V peak-to-peak.

Now use the function generator as the input for Figure 9. Use one oscilloscope probe on the input, and another on the output. Calculate the value of L_{SP} in two different ways. First, use the phase shift between input and output voltage along with the equation for V_{OUT}/ V_{IN} found above. Secondly, use the gain from the input to the output voltage (as read off the oscilloscope) and the equation above.

L_{SP} (from phase shift calculation) _____

L_{SP} (from gain calculation) _____

When you have completed the lab, sign and print your names below and have the TA initial next to each name.

TA

_____   _____

_____   _____

Skills Assessment (5pts)

Everybody must demonstrate that he/she can perform certain lab skills, as described below.

Fill in your names in the spaces provided. A TA will initial the appropriate space when a skill has been successfully demonstrated.

	Name #1	Name #2
	_____	_____
1. Demonstrate how to supply first 5V and then 12V with the DC power supply on the lab bench.	_____	_____
2. Demonstrate how to use the RLC meter to measure capacitance and inductance.	_____	_____
3. Predict the measured current through a given resistor with a known sinusoidal voltage across the resistor.	_____	_____
4. Demonstrate how to check that a resistor will not overheat (i.e., the expected current will keep the average power below the resistor's rating).	_____	_____
5. Demonstrate how to build a single-loop circuit and measure the current in it with the multimeter.	_____	_____