Project Overview
There are two kinds of circuits that need to be built for the headphone amplifier project.
1) A power circuit
2) Two amplifier circuits
You will build one of each of these circuits on a breadboard and test it before assembling the circuit on the printed circuit board. Since the two amplifier circuits are identical, you will only need to put one of these on the breadboard.

Project Schedule

<table>
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<th>Week</th>
<th>Activity</th>
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<tr>
<td>Thursday April 11</td>
<td>Breadboard and test the power circuit. Breadboard and begin testing the amplifier circuit. Homework: Derive an equation for the amplifier circuit</td>
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<tr>
<td>Thursday April 18</td>
<td>Finish testing the amplifier circuit. Derive an equation for the amplifier circuit. Practice soldering (if time) Homework: Rough draft of paper due next week.</td>
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<tr>
<td>Thursday May 2</td>
<td>Lab Practical; draft returned</td>
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<tr>
<td>Wednesday May 8, 5:00 PM</td>
<td>Final Draft of report</td>
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If your first draft is not turned in on time, you will not get any feedback and you will loose one half letter grade on your final report. If your final report is late you will lose one letter grade per day it is late.
The power circuit
Most operational amplifiers work off of +/- power supplies relative to a ground. The amplifier that we have chosen will run off of a wide range of voltages: anywhere from +/- 2.5 to +/-18V. We are going to use a single 9 Volt battery and turn it into a +/- 4.5 V power supply using the circuit shown below.

- **SW** is a switch.
- **RLED** is a 24.3kΩ resistor to limit the current through the LED.
- The diode is a blue LED that turns on when you close the switch, so you know the circuit is on. The direction of the LED matters! Be careful when you wire it.
- There is one capacitor labeled C1. It is 470µF, and it is an electrolytic capacitor. This means that it is polarized and it matters which way you put it in the circuit. If you put it in backwards, it will explode. Capacitors C4 are the very small yellow ones. These are 0.1µF ceramic caps. Capacitors on the power supply are there to filter unwanted noise. (Think back to the diode lab 5.)
- Notice the input to this circuit is a 9V battery. There are two outputs relative to the ground, +4.5 V and -4.5V.
- **U2** is rail splitter chip TLE 2426. Read about it and find out what it does. Don’t wire it backwards.

1) Build the power circuit on a breadboard.
2) Measure the input and the two outputs of the circuit. Make sure you measure the outputs as precisely as possible. Perhaps use the 4 digit multimeter. You could also use the oscilloscope, AC coupled, to see how much noise is on the output.
3) In your report talk about the role of each component in this circuit.
The Amplifier Circuit

Overview

Each headphone speaker gets its own amplifier as shown in the circuit diagram below. So for your actual amplifier you will need two of these. For testing purposes we will only build one on the breadboard.

- $C_2$ is a 1$\mu$F capacitor (gray).
- $R_2$ is a 100 k$\Omega$ resistor.
- $R_3$ is a 2.05 k$\Omega$ resistor.
- $R_4$ is a 10 k$\Omega$ resistor.
- $R_5$ is a short—0$\Omega$. You do not need it.
- $POT$ is a 10 k$\Omega$ potentiometer. Use the one supplied.
- $RB = 24$ k$\Omega$ and $CB = 0.068$ $\mu$F are a bass boost.
- The operational amplifier you will be using is the OPA2134. It is a dual amplifier with two sets of inputs and two outputs. The pinout for the OPA 2134 is shown above.
Theory of the circuit

1) It will be easier to characterize this circuit if you know a little bit about what to expect. One way to derive the output of the circuit is to think of the circuit as three different modules hooked together in series. Remember the rule of impedances. In your report you should convince me that this is a legitimate way to proceed.

2) What does the red circuit do? Calculate $V_{out red}/V_{in}$ for this circuit.

3) What does the blue circuit do? Calculate $V_{out blue}/V_{in blue}$.

4) What does the green circuit do without $RB$ and $CB$? With $RB$ and $CB$? What functionality do $RB$ and $CB$ add? Use the golden rules of op-amps and Ohm's law to derive an equation for $V_{out}/V_{in green}$ for this circuit. HINT: You can treat all of the stuff in the feedback branch of this circuit as $Z$ and calculate the impedance of this separately to make the derivation less cumbersome.

5) Recognizing that $V_{in blue}=V_{out red}$ and $V_{in green}=V_{out blue}$, find $V_{out}/V_{in}$ for the entire circuit. You will probably want to find the complex conjugate of each part first.

6) It is useful to plot the behavior of each of the three parts of the circuit separately to see how they behave. Put the equation for each circuit into a program like excel, and plot $V_{out}/V_{in}$ as a function of frequency for the range 1 Hz to 20 kHz. For the red circuit choose two resistance values that total 10 kΩ to model this circuit. Why was this range of frequencies chosen? Next plot the product of the three circuits as a function of
frequency. I suggest you link to the circuit values separately so that you can vary them. For example, what happens when RB and $Z_{CB}$ go to zero?

**Characterizing the circuit**

1) **Build the entire amplifier circuit.**

   Instead of using the potentiometer on the breadboard, I suggest you build the circuit on the right with two fixed resistors that total 10,000 Ω. Try the following two combinations $(R_A, R_B) \rightarrow (2000 \ \Omega, 8000 \ \Omega)$ and $(8000 \ \Omega, 2000 \ \Omega)$.

2) **Characterize the circuit using a sine wave from your function generator** as an input to the circuit. You should make sure that the amplitude of the input sine wave is small enough so that your amplifier isn't causing the signal to clip. Measure the output and the input over a range of frequencies from 1 Hz up through 20 kHz. **Make sure that your oscilloscope is DC coupled.** AC coupling introduces a high pass filter to remove the DC signal and will alter your low frequency measurements. Measure at least three data points per decade of frequency. This will give you at least 12 data points. This is your primary data, so make sure that you are careful, and that you collect enough data to make a very nice graph.

3) Repeat the characterization of the circuit using the $(5000 \ \Omega, 5000 \ \Omega)$ with $C_B=0.01 \mu F$.

4) **What is the purpose of R2, C2?**

5) **How does the gain work?**

**MATCHing resistors**

So that you hear the same thing in each ear, you will want to MATCH the resistors between the two amplifier circuits. You will want two $R_2$, two $R_3$, two $R_4$ and two $R_B$ that are matched. If the resistors aren’t matched, the headphone speakers will sound different, so it is critical that the resistors have the same value. We are starting with 1% metal film resistors, but we can do better. You will use a 4 digit multimeter to choose resistors that have the same value as measured by the meter. You may need to measure 20 or more resistors before you find two that
match. I suggest you take out a blank sheet of paper, and each time you measure a resistor, write down the resistance, and put the resistor on top of it. You can, and should, do this in groups. One person could do one resistor value.

Report

Introduction: give a context for audio amplifiers in general and headphone amplifiers specifically. You should be able to find out something about the CMOY amplifier. You will need references here!

Theory: Show the circuit diagrams, and explain what each circuit is supposed to do. Be specific. Explain the function of each resistor and capacitor. Show the equation for each part of the amplifier circuit (red green and blue). Derive the equation for Vout/Vin for the amplifier circuit, and show the total equation for the circuit that results from the product of the three pieces. Don’t forget to justify the choice to derive the behavior of Vout/Vin for each part of the circuit separately and then put them together.

Procedure: Explain what values are chosen for the circuit elements, and how you characterized the circuits. What measurements did you make and how did you make them? Don’t forget to include circuit diagrams.

Analysis: Explain the choice of R2 in combination with C2 and its purpose. Where does the gain come from for the amplifier. Show your data and explain what each part of the circuit actually does. Here you will include all of your plots. Link them to the theory. It would be useful to plot the data and the theory together. Don’t forget to explain the power circuit. If you can explain the choices for particular values of circuit elements you should do that here. There is lots of information on the internet about this particular amplifier that you may find helpful. There are lots of values in this circuit that could be varied. While it takes too much time to change each one individually and measure it, it isn’t that hard to change a value in the theory and see how it changes the plot. You should do this for RB and CB as well as R3 or R4. Use your theory equation to make graphs to show how changing these values changes the circuit response as a function of frequency.

Conclusions: Does the amplifier behave as expected? Justify your answer with your theory and data. What are some modifications that you might be able to make to improve or change the performance?