EENG 385 - Electronic Devices and Circuits
Lab 7 – Audio amplifier
Lab Handout

Objective

The objective of this lab is to study the configure, use and analyze, the audio amplifier on the Audio board.

Audio Amplifier:

The heart of the audio amplifier is shown in the schematic shown in Figure 1.

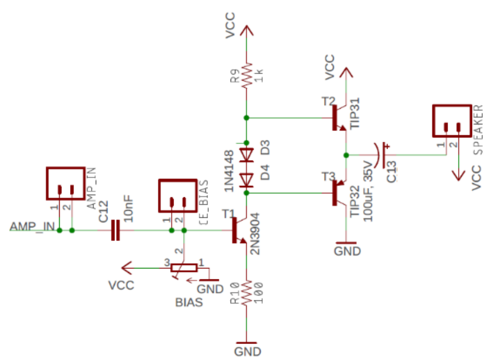

Figure 1: The core of the audio amplifier consists of a voltage gain stage followed by a current gain stage.

The output stage consists of a pair transistors T2 and T3 each in the common collector configuration. In the configuration shown in Figure 1:

- The base of T2 is 0.7V above the emitter.
- The base of T3 is 0.7V below the emitter

When an NPN and PNP transistor are arranged as shown in Figure 1, they are said to form a push/pull pair. The term alludes to the manner in which the pair pull the speaker towards VCC or push it towards GND. When we analyze the individual transistors in the push/pull pair we will refer to them as emitter followers. The output of the push/pull pair should be centered at 4.5V so that the output voltage can swing as far as possible before hitting either rail.

Compute the emitter follower base voltages:

1) In order for the output of the push/pull pair be 4.5V, what should you set the base voltage of transistor T2 to?

2) In order for the output of the push/pull pair be 4.5V, what should you set the base voltage of transistor T3 to?
3) What is the voltage difference between the voltages found in question 1 and 2?
4) What is the voltage drop across the pair of diodes D3 and D4?

Common Emitter Theory:

Transistor T1 in Figure 2 is configured as a common emitter. The base of T1 is the input and the collector is the output. Both the input and output voltages are measured with respect to the emitter terminal; thus, the emitter is in common with both the base and collector.

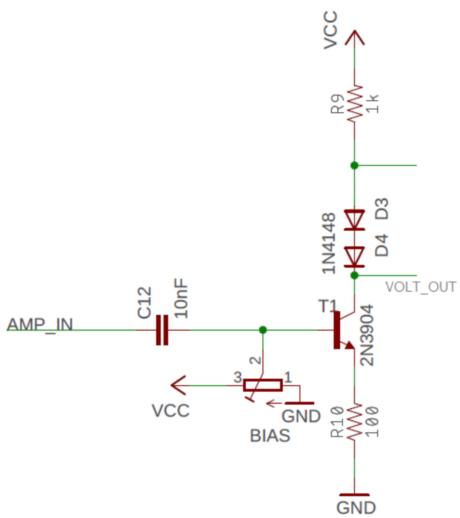

Figure 2: The common emitter stage of the audio amplifier.

The AMP_IN signal in Figure 2 comes from our audio source (your phone or computer). Capacitor C12 removes the DC component from the audio signal and passes along an AC signal centered at 0V. The audio signal output of the capacitor is added (via superposition) to the bias voltage supplied by the potentiometer. You need to adjust the bias voltage so that the base of the push/pull pair are set to the voltages you calculated in questions 1 and 2 above. In other words, in the absence of an AC signal source, you need to:

- Set the collector of transistor T1 (which is connected to the base of transistor T3) to the voltage you computed in **Compute the emitter follower base voltages** question 2.
- Set the anode of diode D3 in Figure 2 (which is connected to the base of transistor T2) to the you computed in **Compute the emitter follower base voltages** question 1.

Now you will use this information to adjust the bias voltage of the common emitter stage.

Compute the common emitter bias voltage:

1) Find I_C so that the base of T2 is 5.2V where VCC = 9V.
2) Find V_E assuming that I_E is equal to I_C
3) Find V_B, your value should be close 1V.

Let's use this information to configure the bias voltage on the audio board. To do this you need a brief introduction to the audio cable and jack.

I hope that this comes as no surprise, but when you put on a pair of headphones to listen to music, your left and right ears hear slightly different audio. This is called stereo sound and is done to produce a more realistic and pleasing sound. The audio board was designed to interface to stereo audio sources, so will have left and right audio signals, called channels.

The left side of Figure 3 shows the structure of the audio cable you will use to connect the audio source from your phone or a computer to the audio board. The audio board connection is made through the audio jack shown at right in Figure 3. The metal tip of the audio cable has 3 electrically isolated rings, each with the purpose shown. When you insert the metal tip into the mating audio jack, see AUDIO_JACK_3.5MM at right in Figure 3, the ground ring connects to ground on the audio board, while the left and right audio channels connect to the 2 pins on the audio jack that have red tracks leaving them. Each audio channel goes to one of the two AUDIO_IN pins. Unless you are dealing with a mono audio source (an audio source with a single channel), it does not matter which audio channel you amplify. In other words, it does not matter which of the AUDIO_IN pins you send to the audio amplifier stage.

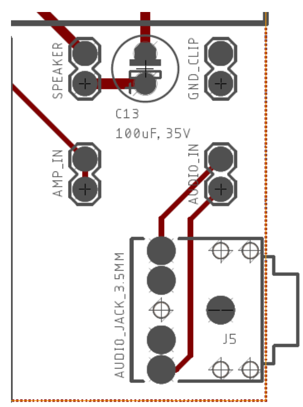

Figure 3: A 3-pole TRS cable Audio cable and the

Follow these steps to properly configure the inputs of the audio board

- Apply power through the barrel connector or the connectors adjacent to the jack.
- Connect a jumper between the AUDIO_IN and AMP_IN. If you are using a stereo source, it does not matter which AUDIO_IN pin you connect to (see Figure 3). Both AMP_IN pins are tied together, so it does not matter which AMP_IN pin you connect to.
- Connect the speaker to the pair of SPEAKER pins (adjacent to the 100uF electrolytic capacitor).
- Go to the large cabinet in the northwest corner of Brown 304 (the tall one with lots of blue and grey pull drawers). Grab a small screwdriver from the "SMALL SCREWDRIVER" drawer.

- Use a DMM or oscilloscope to measure the voltage on CE_BIAS plated through holes. Since both holes are connected, it does not matter which one you measure from. Make sure to ground reference your measurement to one of the GND connections.
- Properly configured, your setup should look like Figure 4. Only then should you power up your audio board.
- Adjust the CE_BIAS to the value you computed in step 3. This value should be around 1V.

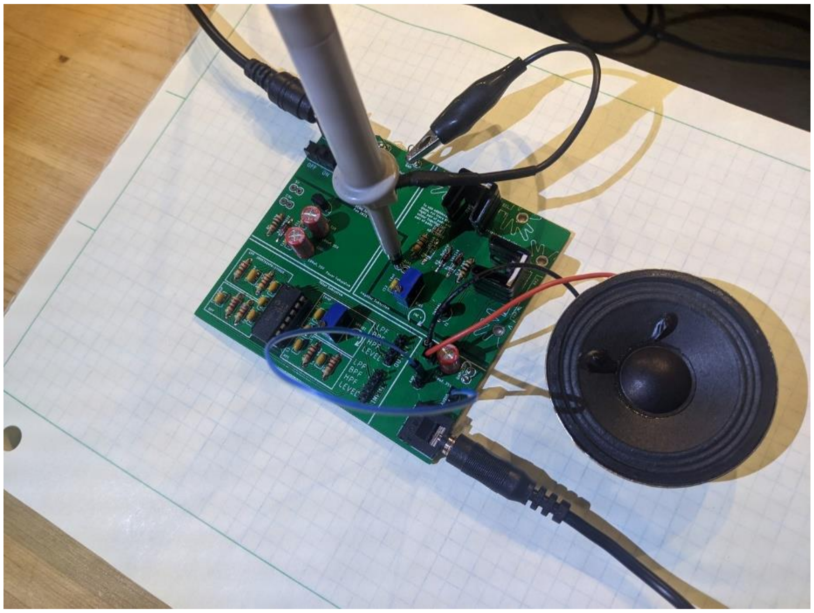

Figure 4: The audio board connected to a signal source and speaker.

Once you have everything setup as shown in Figure 4, enable the audio output of your signal source and listen the to the output, enjoy.

Now let's dig into the amplifier using the framework shown in Figure 5. This figure is an abstract version of Figure 1 and describes how the signal is mathematically manipulated. This information is critical in understanding how to improve the quality of the audio output.

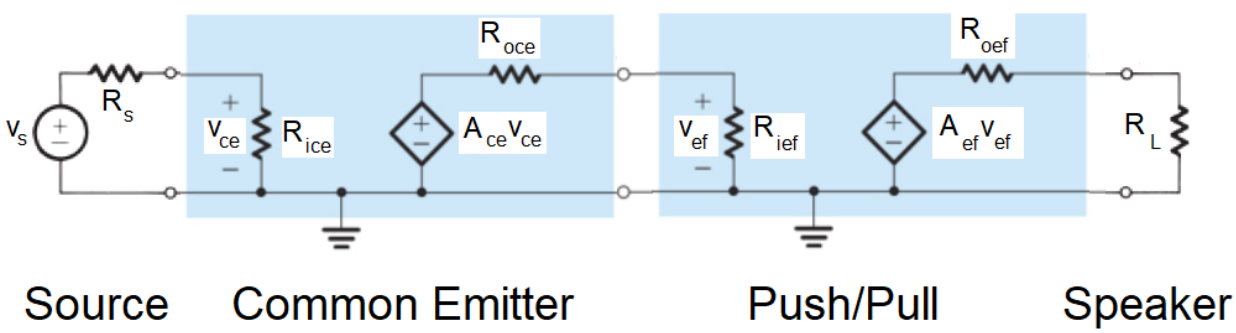

Figure 5: The audio input to the Audio board goes through a common emitter configuration to amplify the voltage of the signal and then onto a push/pull pair to amplify the current before being sent out to the speakers.

Our task is to put values to the variables in Figure 5 and put them into Table 1. You will do this by a combination of observation and computation.

Table 1: Model parameters for the cascade amplifier shown in Figure 5.

	Rin	Rout	Voltage Gain
Source	N/A	R_s =	N/A
Common Emitter	R_{ice} =	R_{oce} =	$A_{ce} = \Delta V_C / \Delta V_B$ =
Emitter Follower	R_{ief} =	R_{oef} =	$A_{ef} = \Delta V_E / \Delta V_B$ =
Speaker	$R_L = 8\Omega$	N/A	N/A

Let's start with the attributes of the common emitter amplifier. Please note that this analysis ignores important details that will be added in class. That said, these details do not significantly effect the analysis, in part because of the component values used in the Audio board.

Compute the input impedance of the common emitter stage - R_{ice}. You will need to reference Figure 2 during this analysis.

1) What is the relationship between ΔV_B and ΔV_E?
2) Use Ohm's law to describe the relationship between ΔV_E and ΔI_E.
3) Solve the previous equation for ΔI_E and replace ΔV_E with ΔV_B from equation 1.
4) Write down the relationship between ΔI_E and ΔI_B? Hint, it's a bad parameter.
5) Equate equations 3 and 4 using ΔI_E.
6) Solve equation 5 for $\Delta V_B/\Delta I_B$, this is the input impedance of the common emitter. Insert this value into the R_{ice} cell of Table 1.

Compute the output impedance of the common emitter stage - R_{oce}. You will need to reference Figure 2 during this analysis.

7) Use Ohm's law to describe the relationship between ΔV_C and ΔI_C.
8) Solve equation 1 for $\Delta V_C/\Delta I_C$, this is the output impedance of the common emitter. Insert this value into the R_{oce} cell of Table 1.

Compute the gain of the common emitter stage - A_{ce}. You will need to reference Figure 2 during this analysis.

1) What is the relationship between ΔV_B and ΔV_E?
2) Use Ohm's law to describe the relationship between ΔV_E and ΔI_E.
3) Solve the previous equation for ΔI_E.
4) Replace ΔV_E in equation 3 for the relationship found in equation 1.
5) Use Ohm's law to describe the relationship between ΔV_C and ΔI_C. Note the sign!
6) Since $\Delta I_E = \Delta I_C$, replace ΔI_C in the previous equation with ΔI_E.
7) Substitute ΔI_E from equation 4 into equation 6.
8) Let $\Delta V_C/\Delta V_B$, be the gain. What is the gain of our amplifier? Insert this value into the A_{ce} cell of Table 1.

Common Emitter Measurements:

Let's take a break from this analysis and take some measurements from the Audio board. This will allow us to see how they compare to the values you've just calculated. We will measure the performance of the common emitter in

To do this configure your oscilloscope as follows. Note, connecting the channel 2 probe to the collector of transistor T1 is tricky and <u>should be performed with the Audio board powered off!</u> You can try to hook the cathode lead of diode D4, trying not to bend the probe hook. Or you can connect directly to the collector of transistor T1 (my preference) while avoiding have the scope hook short out to the adjacent lead of the transistor. Note the collector of T1 is the lead at the bottom of the board - closest to capacitor C13.

Horizontal (scale)	500us
Ch1 probe	CE_BIAS (base of transistor)
Ch1 (scale)	200mV/div
Ch1 (coupling)	DC
Ch2 probe	Cathode of diode D4 or Collector of transistor T1
Ch2 (scale)	1V/div
Ch2 (coupling)	AC
Trigger source	1
Trigger slope	↑
Trigger level	0V

Feed the audio input with a 1000Hz tone. My favorite is from the YouTube video <u>The Ultimate Test Tone -Ten hours of 1000 Hz Sine Wave</u>. Turn up the video and PC volume to their maximum, do not connect the speaker for the first 3 questions.

1) Screen shot your input and output waveforms. Center the input on the lower half of the oscilloscope display and center the output in the upper half. Use the Acquire function to smooth out the waveforms. Consider using the measurement tool.
2) From your oscilloscope trace, how many degree out of phase is the output (collector) with respect to the input (base)?
3) Using the data on the oscilloscope, record the amplitude of the input and output waveforms. Form the ratio of the output over the input to determine the gain of the common emitter. Make sure to include the phase difference (negative sign). Note, you will need to know the input and output amplitudes in a later step.

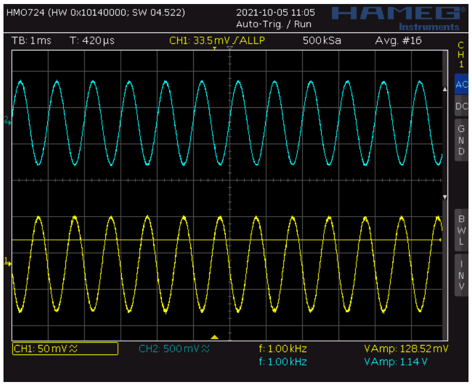

Figure 6: Oscilloscope capture of an unloaded common emitter input and output - no speaker attached. FYI.

Now connect the speaker to the Audio board and make the following measurements. <u>For reasons that will be made clear later, do not alter the amplitude of the input waveform.</u> In other words, do not adjust the sound level.

4) Screen shot your input and output waveforms. Center the input on the lower half of the oscilloscope display and center the output in the upper half. Use the Acquire function to smooth out the waveforms and get better measurements.
5) From your oscilloscope trace, how many degree out of phase is the output (collector) with respect to the input (base)?
6) Using the data on the oscilloscope, record the amplitude of the input and output waveforms. Form the ratio of the output over the input to determine the gain of the common emitter. Make sure to include the phase difference (negative sign). Note, you will need to know the input and output amplitudes in a later step.

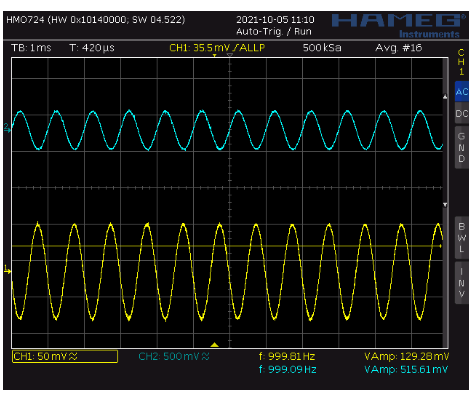

Figure 7: Oscilloscope capture of a loaded common emitter input and output – 8 Ω speaker attached. FYI.

You will notice that the gain is reduced by about ½ when the speaker was attached. This should come as a surprise since the speaker is not directly attached to the common emitter stage. So how could the presence of the speaker possibly effect the common emitter stage?

To understand this interaction, you need to look at Figure 5. To start, note that the output voltage from the common emitter V_{ef} in Figure 5 is the collector voltage that you measured with the oscilloscope. In Figure 5 this voltage is formed from the dependent voltage source $A_{ce}\,v_{ce}$ being divided between R_{oce} and R_{ief}. In the next section, you will find that the presence of the speaker (modeled as R_L) effects the value in R_{ief}.

Emitter Follower Theory:

We now return our attention to the cascade amplifier of Figure 5 and fill in the Table 1. We will focus on the push/pull output stage formed by a pair of emitter followers. I've made some changes to the push/pull circuit shown in Figure 1 to produce the circuit shown in Figure 8.

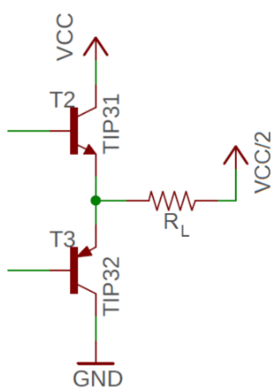

Figure 8: The push/pull output stage of the audio amplifier consists of a pair of emitter followers.

I made the changes going from Figure 1 to Figure 8 are valid and 7made to simplify the analysis process. For example, since this is a small signal analysis (we are looking at changes in values e.g. ΔV_B) we will ignore the 100uF capacitor C13 in Figure 8 because the capacitor appears as a short at audio-frequencies. The speaker is rated as an 8Ω load, represented by R_L – please use R_L in the subsequent analysis. Finally, focus on the NPN transistor, T2, in Figure 8 when answering the following questions.

Compute the input impedance of the emitter follower - R_{ief}. You will need to reference Figure 8 during this analysis.

1) What is the relationship between ΔV_B and ΔV_E?
2) Use Ohm's law to describe the relationship between ΔV_E and ΔI_E. Call the resistance of the speaker R_L.
3) Solve the previous equation for ΔI_E and replace ΔV_E with ΔV_B (using the relationship in equation 1)
4) What is the relationship between ΔI_E and ΔI_B? Hint, it involves a bad parameter.
5) Equate equations 3 and 4 using ΔI_E.
6) Solve equation 5 for $\Delta V_B/\Delta I_B$, this is the input impedance of the emitter follower. Insert this value into the R_{ief} cell of Table 1.

Compute the output impedance of the emitter follower – R_{oef}. You will need to reference Figure 8 during this analysis.

1) Use Ohm's law to describe the relationship between ΔV_C and ΔI_C. Call the resistance of the speaker R_L.
2) Solve equation 1 for $\Delta V_C/\Delta I_C$, this is the output impedance of the emitter follower. Insert this value into the R_{oef} cell of Table 1.

Compute the voltage gain of the emitter follower - A_{ef}. You will need to reference Figure 8 during this analysis.

1) What is the relationship between ΔV_B and ΔV_E?
2) Solve equation 1 for $\Delta V_E/\Delta V_B$, this is the voltage gain of the emitter follower. Insert this value into the A_{ef} cell of Table 1.

Emitter Follower Measurements:

Let's return to a question we posed earlier, how can the presence or absence of the speaker effect the output of the common emitter amplifier stage? You now have all the data to answer this question.

1) Use the information from Table 1 in Common Emitter Theory to assign values to:
   R_{ief} =
   R_{oce} =
2) Use the information in the Common Emitter Measurements section to assign values to:
   V_{ce} = V_{ef} = No speaker $R_L = \infty\Omega$.
   V_{ce} = V_{ef} = Speaker $R_L = 8\Omega$.
3) Write an equation for V_{ef} in terms of $A_{ce}V_{ce}$, R_{ief} and R_{oce} using voltage divider.
   V_{ef} =
4) Substitute the values for $A_{ce}V_{ce}$, R_{ief} and R_{oce} you found in steps 1 and 2 into the equation 3.
   V_{ef} =
5) Determine v_{ef} with no speaker attached, let $R_L = \infty\Omega$. Let $\beta = 100$.
   V_{ef} =
6) Determine v_{ef} with a speaker attached, let $R_L = 8\Omega$.
   V_{ef} =
7) Repeat the calculation in step 6 but substituting the value of $A_{ce}V_{ce}$ with the value of V_{ef} you measured with no speaker attached. This is reasonable, because when you measured V_{ef} the load resistor was the oscilloscope which has a very high impedance when compared to R_{oce}.
   V_{ef} =

Turn in:

Make a record of your response to numbered items below and turn them in a single copy as your team's solution on Canvas using the instructions posted there. Include the names of both team members at the top of your solutions. Use complete English sentences to introduce what each of the following listed items (below) is and how it was derived.

Audio Amplifier

Steps 1 – 4

Common Emitter Theory

Steps 1 – 19

Common Emitter Measurements

Steps 1 – 6

Emitter Follower Theory

Steps 1 – 10

Emitter Follower Measurements

Steps 1 – 7