

Lab 2 – Audio Amplifier

• GOAL

The goal of Lab 2 is to demonstrate an audio amplifier based on an op amp and totem-pole stage.

• OBJECTIVES

- 1) Observe crossover distortion in a Class B totem-pole stage.
- 2) Measure frequency response of the amplifier voltage gain
- 3) Measure the impedance magnitude of the coupling capacitors
- 4) Listen to some tunes!

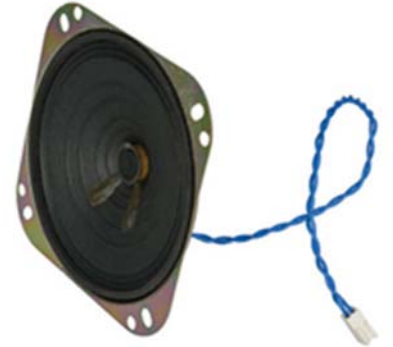


Fig. 1: 16 ohm speaker.

• INTRODUCTION

The overall goal of Lab 2 is to demonstrate an audio amplifier. Yes, you could just purchase an IC chip to do this (e.g. LM386), but it is more instructive to build one with an op amp and transistors.

The overall specifications are the following:

- Voltage gain $|G| = 6$ dB (± 0.5 dB is fine) from 400 Hz to 4 kHz
- Input impedance $Z_{IN} \geq 5$ kohm
- Capable of driving a 16 ohm speaker with 75 mW of power.

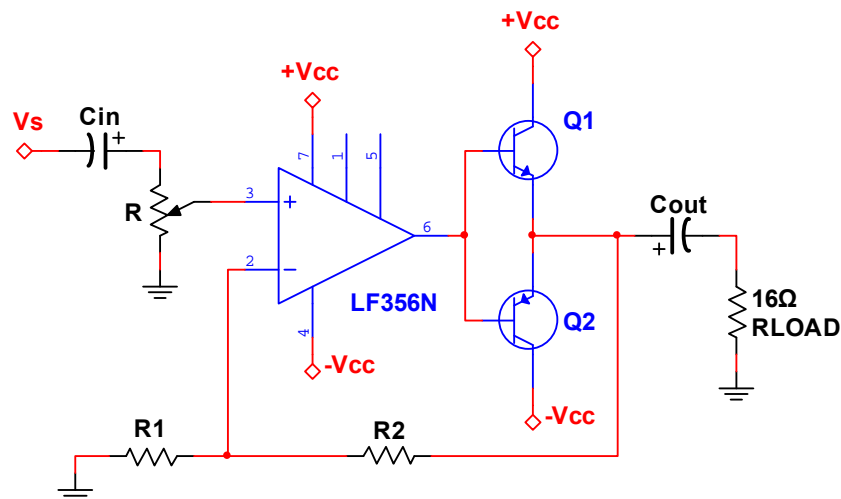


Fig. 2: Non-inverting amplifier op amp with Class B output stage. Volume control is achieved with the potentiometer. At the lowest frequency of interest, the impedances of C_{in} and C_{out} should be no more than $1/10$ of Z_{in} and R_{LOAD} , respectively.

• PART 1: CLASS B PUSH-PULL STAGE

Parts and Materials:

- Lab kit, benchtop power supply, function generator, scope, and probe box (contains banana cables, multimeter probes, etc.)
- 2N3904 (npn) transistor, 2N3906 (pnp) transistor, 16 ohm resistor (brown/blue/black)

➤ Task 1a: Build the Class B push-pull stage (see Fig. 3).

- You must use NEAT and COLOR-CODED wiring on your breadboard:
 - RED = +5V, BLACK = GND, BLUE = -5V, YELLOW = everything else
- Component pin diagrams are in the data sheets on the course website.
- Configure the function generator for a SINE wave at 1 kHz and 2Vp amplitude (High Z output).

➤ Task 1b: Measure crossover distortion (see Fig. 3).

- Attach a scope probe to V_s and another probe to V_{LOAD} .
- Configure the scope in the following manner:
 - Use a coaxial cable to connect the function generator's SYNC output to the scope's EXT input.
 - Set the scope to "External Trigger" by using TRIG MENU >> SOURCE >> EXT
 - Adjust the TRIG LEVEL to about 1V
- Manually adjust the vertical and horizontal scales of the scope to show a couple cycles of the load voltage.
 - Do NOT press the Autoscale button! Buma will deduct 500 points from your grade if he catches you doing this.
 - You should see significant crossover distortion (similar to Fig. 3).
 - **Save both traces for the lab demo** (e.g. use the "swave" command in MATLAB).

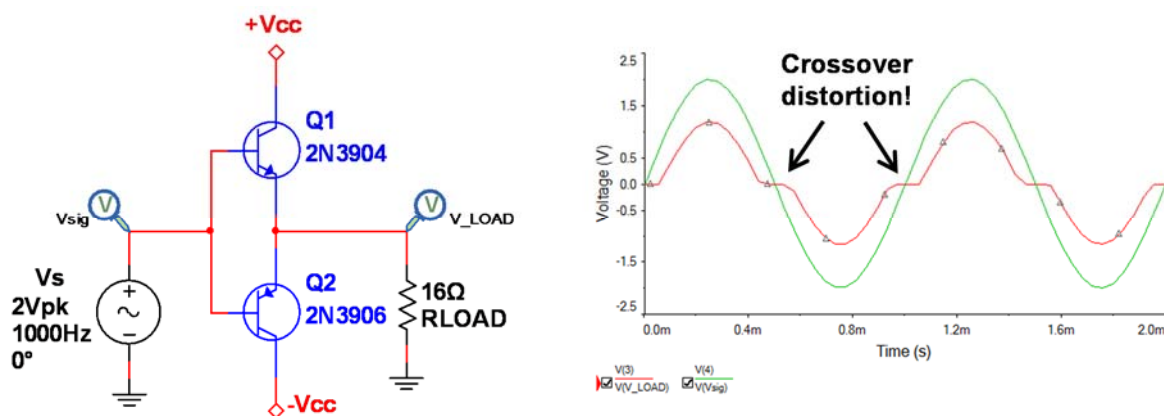


Fig. 3: Class B push-pull stage, where $V_{cc} = 5V$. Your scope measurements should clearly show the crossover distortion.

• PART 2: AMPLIFIER CONSTRUCTION AND TESTING

Parts and Materials:

- Two capacitors for C_{in} and C_{out} : Choose between 1, 4.7, 10, 47, 100, and 470 μF
- 10 kohm potentiometer and two resistor of your choice (for R_1 and R_2)

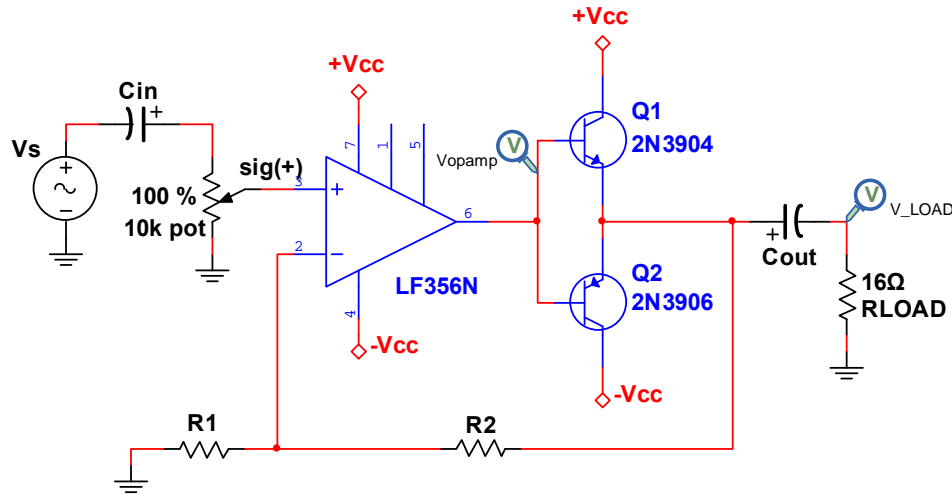


Fig. 4 Non-inverting amplifier op amp with Class B output stage. Volume control is achieved with the potentiometer.

➤ Task 2a: Build your non-inverting amplifier with Class B output stage (see Fig. 4).

- You must use NEAT and COLOR-CODED wiring on your breadboard:
 - RED = +5V, BLACK = GND, BLUE = -5V, YELLOW = everything else
- Component pin diagrams are in the data sheets on the course website.
- Configure the function generator for a SINE wave at 1 kHz, amplitude = 0.5V_{peak}, and High Z output.

➤ Task 2b: Test the volume control.

- Attach a scope probe to the sig(+) input of the op amp (Pin 3 of op amp) and another probe to V_{LOAD} .
- Manually adjust the vertical and horizontal scales of the scope to show a couple cycles.
 - Do NOT press the Autoscale button!
 - Make sure the probes and the scope are both set to 1X!
 - Adjusting the potentiometer should vary the amplitude of BOTH waveforms simultaneously.
 - Leave the potentiometer at the “full” volume setting.
- Adjust the function generator sine wave amplitude until you get $V_{LOAD} = 1.55 \text{ V}_p$ (or slightly higher).
 - This is to make sure you are driving 75 mW into a 16 ohm load.

➤ **Task 2c: Measure the op amp output waveform.**

- Move the scope probe from sig(+) to the op amp output (pin 6). Leave the other probe on V_{LOAD} .
- The Vopamp waveform should have very steep changes when V_{out} has zero-crossings (see Fig. 5).
- Measure the peak-to-peak V_{LOAD} using the CURSORS or MEAS function.
- You know V_S , so you can compute the voltage gain.
- **Save both Vopamp and V_{LOAD} traces for your lab demo** (e.g. use the “swave” command in MATLAB).

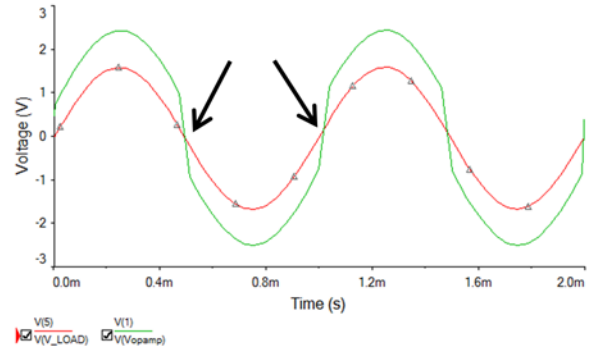


Fig. 5: The arrows show where the op amp output voltage must change abruptly.

➤ **Task 2d: Measure the frequency response of your amplifier gain.**

- For the same V_S amplitude, vary the frequency and use the scope’s MEAS function or CURSORS to measure V_{LOAD} and fill out the table below.

Table I: Power amplifier measurements

Amplifier	
Freq	V_{LOAD}
10 Hz	
20 Hz	
40 Hz	
100 Hz	
200 Hz	
400 Hz	
1 kHz	
2 kHz	
4 kHz	
10 kHz	
20 kHz	
40 kHz	
100 kHz	
200 kHz	
400 kHz	

- V_{LOAD} should show increasingly worse crossover distortion at very high frequencies (e.g. above 10 kHz)!
 - This is due to the limited slew rate of the op amp.

- In MATLAB, make a plot of your measured amplifier gain. It should resemble Fig. 6.
 - Gain should be in DECIBELS.
 - Use the “semilogx” command to display frequency over a log scale.
 - Use the “grid on” command to display the grid lines.
 - An amplifier’s “cut-off” frequency is defined as the frequency where the gain drops by -3 dB. Based on your plot:
 - What is the LOW frequency cut-off of your amplifier?
 - What is the HIGH frequency cut-off of your amplifier?
 - **Save your plot for the lab demo!**

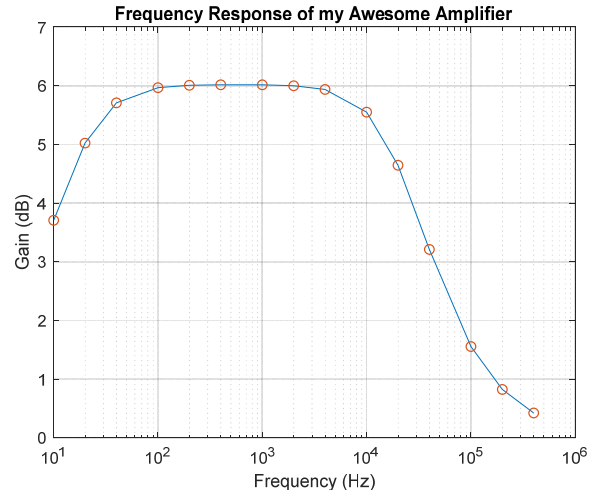


fig. 6: The MATLAB plot of your amplifier frequency response should look something like this. This is a simulated response, so your plot may look very different at high frequencies.

➤ **Task 2e: Measure the impedance magnitude of Cin and Cout.**

We have assumed that Cin and Cout have negligible impedance. Of course, they actually have non-zero impedance that varies with frequency! To make things easier, let’s just focus on the MAGNITUDE of the impedance (more effort is required to measure phase) for each capacitor.

How to do this? One way is to use a multimeter to measure AC voltage across a particular component, as shown in Fig. 7. Based on these measurements, you can determine $|Z|$ for each capacitor.

- Come up with an equation to compute $|Z|$ for Cin.
- Formulate an equation to compute $|Z|$ for Cout.
- Set the function generator sine wave frequency to 400 Hz.
- Make the appropriate measurements to complete Table 2. Use proper voltage range settings for best accuracy!

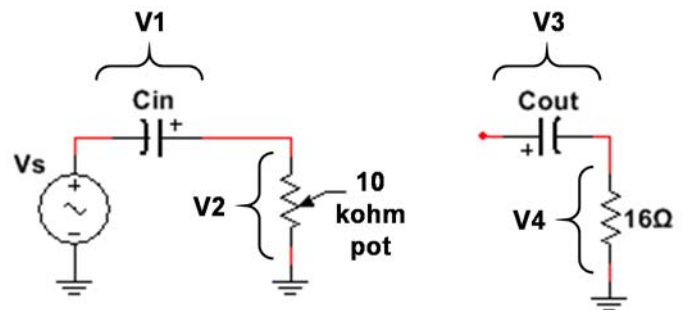


Fig. 7: Set the multimeter to measure AC voltage. Measure V1 and V2 to determine $|Z|$ of Cin. Similarly, measure V3 and V4 to determine $|Z|$ of Cout.

- Does the $|Z|$ for each capacitor decrease with higher frequencies?
- For Cin, is $|Z|$ less than 10% of 10 kohm?
- For Cout, is $|Z|$ less than 10% of 16 ohm?

Table 2: Capacitor Impedance Measurements at $f = 400$ Hz

Frequency	V1	V2	$ Z $ for Cin	V3	V4	$ Z $ for Cout
400 Hz						
1 kHz						
4 kHz						

• PART 3: AUDIO TESTING

OK, now we can finally listen to some sounds! Get a 16 ohm speaker and an audio cable.

➤ Step 3a: Make the following modifications to your breadboard:

- Amplifier input:
 - Remove the function generator from the amplifier input.
 - Connect the audio cable to your breadboard.
 - ❖ The “red” wire goes to your amplifier input (e.g. Cin)
 - ❖ The “copper” wire goes to GND.
 - Insert the audio cable jack into your device (e.g. phone, or laptop, or the desktop computer).
 - Choose your music, or podcast, or whatever.
 - Set the volume on your device to be roughly 50% of maximum.
- Amplifier output:
 - Remove the 16 ohm load resistor.
 - Connect the audio speaker (e.g. to Cout).
 - ❖ You will need two wires to connect the speaker’s two-pin socket to the breadboard.
 - If all goes well, you should hear stuff coming out of the speaker! 😊
 - ❖ Turn the 10 kohm potentiometer to adjust volume as necessary.

➤ Step 3b: Lab Demo.

- Show Buma the following:
 - Measured plot of crossover distortion
 - Measured plot of V_{OUT} and V_{opamp}
 - Plot of the amplifier gain’s frequency response
 - Measured impedance magnitude of Cin and Cout
- Let Buma enjoy the music from your audio amplifier!

(End of Lab 2)