Antje Ihlefeld
Nima Alamatsaz

LAB 3

NJIT
BME 301

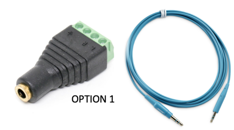
Non-inverting Amplifier

Open your extra lab kit and check that you have all of the parts listed below.

1 Parts

1. 1x Audio Input Jack 3.5 mm

   + 1 male-2-male audio cable



Audio-In + m2m

2. 1x Audio Speaker


Speaker

3. 1x breadboard (solderless)


Breadboard

4. 40x jumper wires


Jumper Wires

5. 1x 9V battery

9V Battery

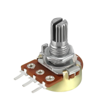
6. 1x 9V battery snaps


Battery Snaps

7. 1x LM386N op-amp chip


Op-Amp LM386N

8. 3x potentiometer 10$k\Omega$


Potentiometer

9. 1x 10Ω resistor


10Ω resistor

10. 2x 10$k\Omega$ resistors


10$k\Omega$ resistor

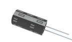
11. 1x 1000μF capacitor

1000μF capacitor

12. 1x 100μF capacitor

100μF capacitor

13. 2x 10μF capacitor



10μF capacitor

14. 3x 0.1μF capacitor

0.1μF

15. 1x 0.033μF capacitor

0.033μF

16. 1x 470pF capacitor

470pF

---

2 Before we start...

Please keep in mind safety and sustainability. The pins of op-amp chips bend easily and often irreversibly, rendering the chip useless! That said, the pins sometimes don't quite fit into the breadboard or won't come out.

Trick 1: If the pins won't fit into your breadboard, place the chip on its side flat on the table. Then, by gently rotating the black plastic piece toward the table, bend just the lower pins (those flat on the table). Avoid touching the upper pins (those suspended in air). Ask if in doubt.

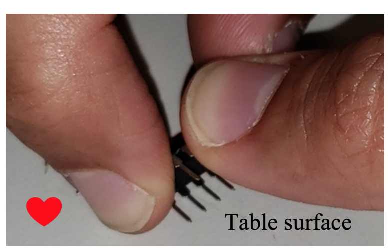


Figure 1: Op-amp legs break easily.

Trick 2: When you need to detach your op-amp from the breadboard, please don't use your fingers. Instead, use lever motion via screwdrivers as shown below on the right.

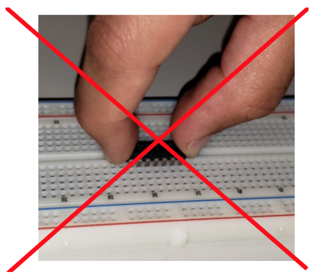


Figure 2: Op-amp legs break easily.

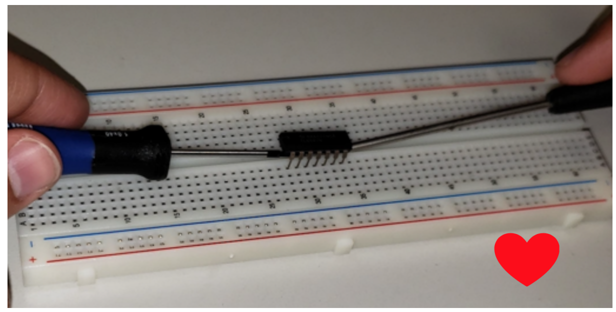


Figure 3: Use screwdrivers to lift up.

Your op-amp is already mounted on the breadboard for you, with pin 1 in $e8$. You should not need to remove it for this lab.

An Operational Amplifier, or op-amp for short, is a device that amplifies the voltage difference between its two input pins by a giant number (usually 10^5 or 10^6). Op-amp circuits always include external feedback components such as resistors and capacitors that shape the output. Today we'll verify our theoretical knowledge of how resistors affect the amplifying function of op-amps. We'll learn to use the LM386N chip and turn it into a non-inverting amplifier. We will then use this circuit to build an audio amplifier that can connect to your phone or laptop.

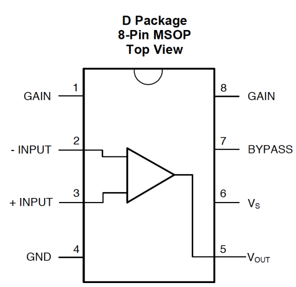


Figure 4: Pin configuration of the LM386.

Remember the non-inverting op-amp from class? Here it is again, with its input-output function:

$$v_{out} = \left(1 + \frac{R_1}{R_2}\right) v_{in}.$$

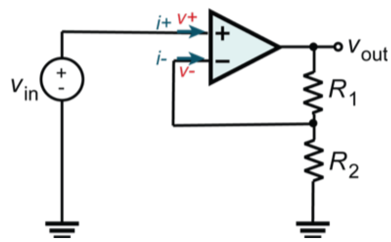


Figure 5: Non-inverting amplifier.

Today we will use the LM386 to build an audio-amplifier.
Input: voltage trace, e.g. of music or speech mono recording
Output: sound

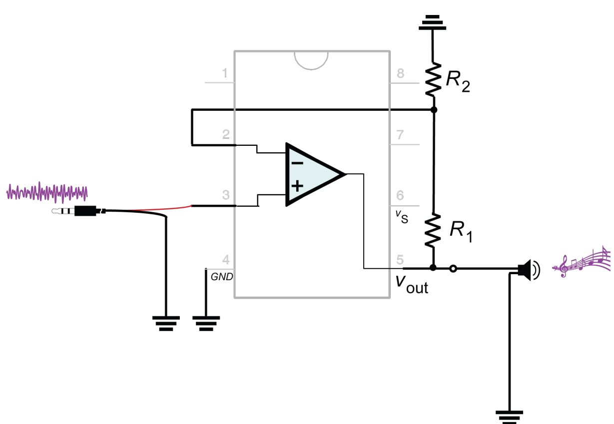


Figure 6: Simple audio amplifier. Can you spot the non-inverting op-amp configuration?

This lab guides you towards building a fully functional audio-amp. We have taken every step to ensure intended functionality of the audio-amp. However, by nature of remote instruction, we cannot guarantee it. Please be advised:

If you don't follow instructions correctly and accidentally send a voltage into the audio plug of your laptop or phone then this might damage the audio chip of the device.

Connecting the audio-amp to your personal devices is optional and at your own risk.

3 Building a non-inverting op-amp

3.1. Bring on your *Google* game to find the datasheet for our LM386 on the internet. Skim through the datasheet and look for a schematic like the one in Figure 4. Have a close look at the actual LM386N. Do you see the tiny circular indentation on top of one end? Based on that indentation, the schematic in the datasheet tells you what number each of those pins is.

3.2. Next, let's figure out what else we need. Today we'd like to amplify the input voltage v_{in}. We are given 2 resistors with $R = 10k\Omega$.

What gain can we achieve with these resistors in the inverting configuration?

3.3. Let's build the circuit. Grab your breadboard with LM386, the two $10k\Omega$ resistors, and the jumper wires.

3.4. Next you are going to connect wires from the LM386 to what will be the source supply (V_S^+ or just V_S) and GND. Figure out where on the LM386 V_S and GND are located and connect both to an appropriate power rail. *Hint: using red jumper wires for connecting to V_S and blue or black wires for ground will help you keep things straight. This coloring convention is usually followed in most electrical circuits.*

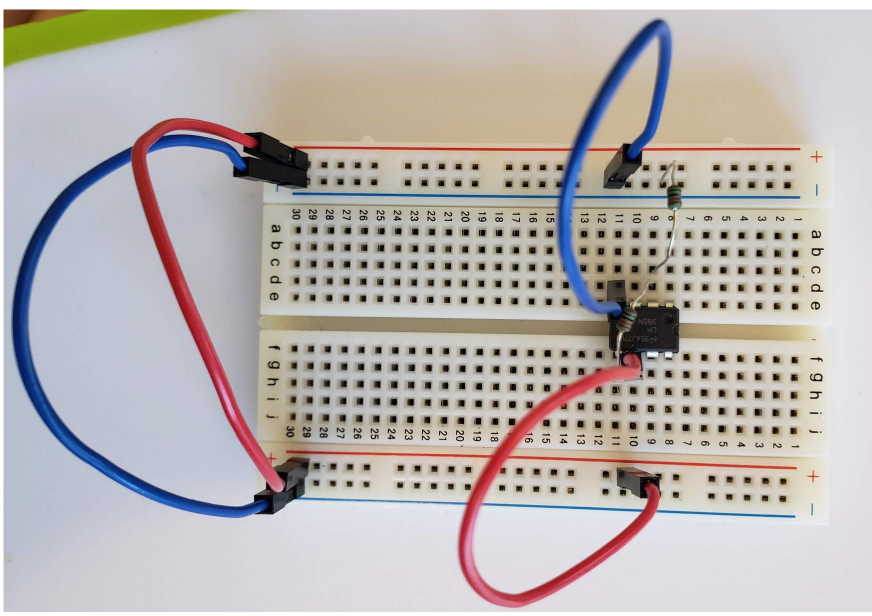


Figure 7: Housekeeping: Connect the top and bottom power rails (blue = ground). This will help you with keeping the circuit assembly organized.

3.5. Without using jumper wires, position R_1 and R_2 according to the non-inverting op-amp configuration (Figure 6). *Since R_1 connects v_{out} to v^- you can carefully push it in across the LM386, without needing jumper wires*.

3.6. Stick an orange jumper wire into v^+, and a second orange wire into a GND rail (two wire ends will poke into the air). This is to remind you where v_{in} will be.

3.7. Take two jumper wires (e.g., one green and one black) and a pair of scissors. Cut off the black pin on one end. Then gently move your scissor around the insulation at about 0.5 inches away from the wire end. Using light pressure from your scissors, finger nails + black magic pull off the insulation. If you have a wire stripper at home, even better - but scissors work just fine. For further help, check out this link: https://www.instructables.com/id/Stripping-Small-Jumper-Wires/

3.8. Take a moment to connect the loudspeaker to the stripped jumper wires. In the ideal world, you'd solder the connections. Today you'll gently twist the stripped wires instead, as shown in Figure 8.

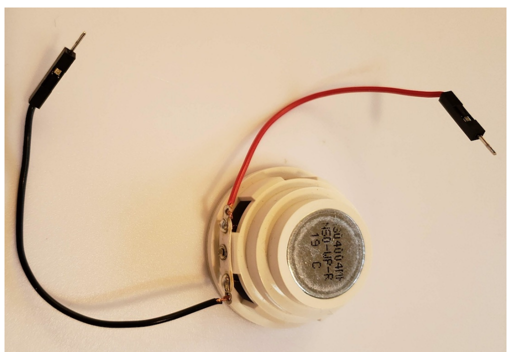


Figure 8: Back View of the Loudspeaker.

Note: The Front of the loudspeaker has a silver membrane. Avoid touching it for it breaks easily. The Back of the loudspeaker has a magnet with black numbers printed on it. The magnet is necessary for loudspeaker function, but that's a topic for another day. On the back you will find two terminals with holes in them. Not very convenient to use this with our breadboard, is it? We want to connect these terminals to our stripped jumper wires so that we can use the loudspeaker with our breadboard. Take the stripped end of one jumper wire, stick it through one hole, bend it back and twist to secure it to the terminal. Repeat for other terminal.

3.9. Now connect one speaker wire to v_{out} and the other speaker wire to a GND power rail. See Figure 9.

3.10. Connect the battery snaps to the 9V battery. Eventually, you will connect both battery snap wires to the power rail. For now, I recommend you connect just the red one and leave the black one unconnected.

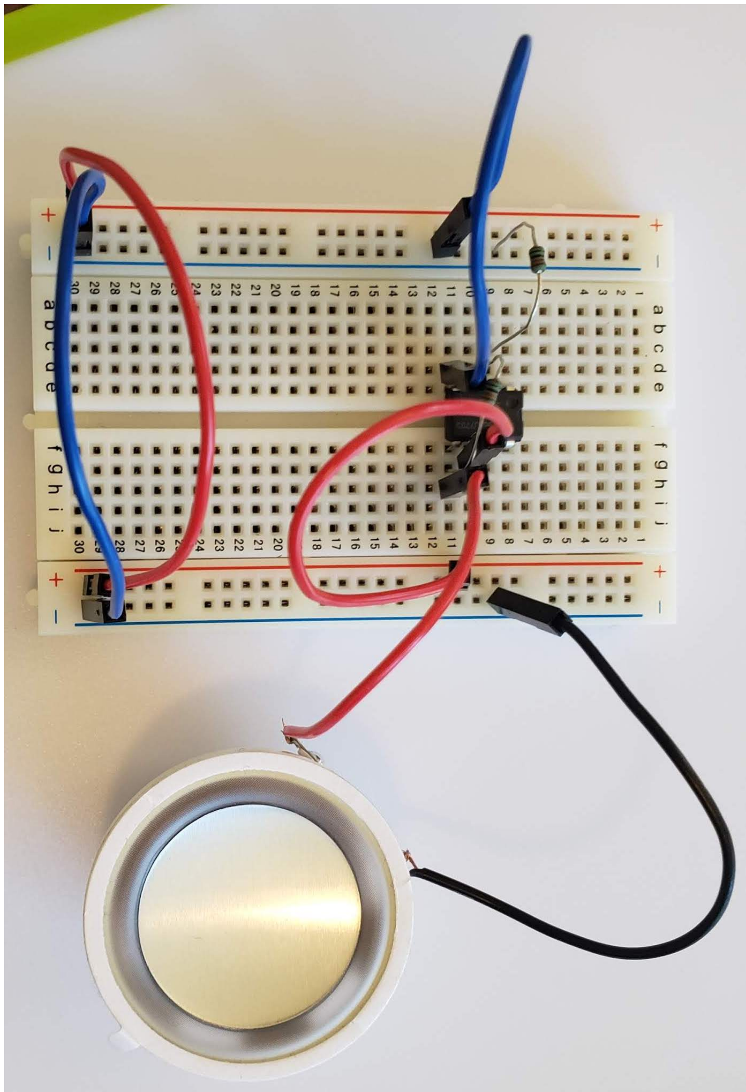


Figure 9: Connect speaker to the circuit.

Congratulations! This is your vanilla non-inverting op-amp circuit. You could already use this to play music, but before we do this, since we don't have any oscilloscope handy to verify that it works properly, let's use our ears instead and take one more safety step to make sure everything is working as it should.

Snap a photo of your circuit and include it in your lab report. Label the following voltages in your photo: v_{in}, v_{out}, V_+, R_1, and R_2.

4 Alien Attack! Multivibrator

Next, we will modify our non-inverting op-amp circuit so that it generates an audible frequency.

Briefly, when air molecules swing at a frequency between $20Hz$ to $20kHz$, your ears convert these vibrations into neural events in your brain. Therefore, the energy becomes audible, creating the percept of *sound*.

To generate a frequency inside the audible range, we will deploy a new trick (without tracking through the circuit arithmetic): By applying a positive feedback loop onto our op-amp, we will force the op-amp to continuously oscillate between two states: 1) a high v_{out} and 2) a low v_{out}. The result is a square wave time series, like the one in the figure below:

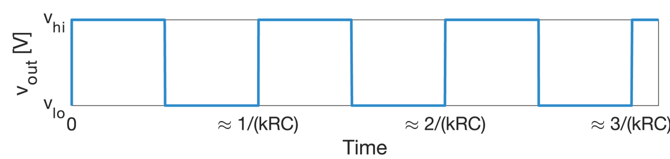


Figure 10: Multivibrators have a characteristic on/off output signal at $f \approx \frac{1}{kRC}$.

This kind of circuit is called multivibrator. It switches between *on* and *off*, *on* and *off*, *on* and *off*, etc. Since this response pattern is caused by a positive feedback loop, this is also referred to as *astable* multivibrator.

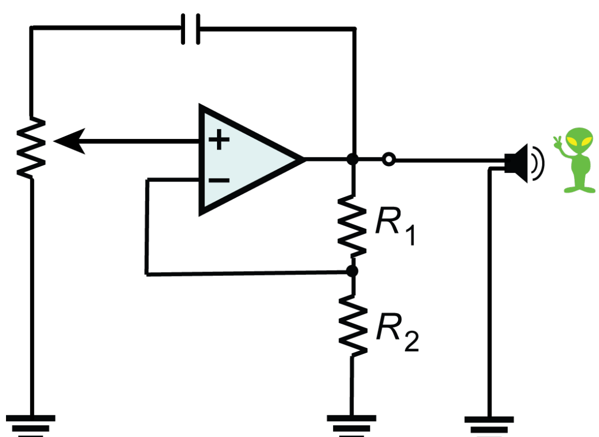
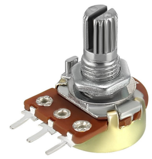


Figure 11: Here is the schematic for the multivibrator circuit we are going to use.

This circuit resonates at a frequency of $\approx \frac{1}{kRC}$ as you are about to verify, where R and C are the resistance and capacitance between v^{+} and v_{out}, respectively.

Meet a new protagonist: the potentiometer, called *pot* for short.


Potentiometer

A potentiometer has three terminals. The total resistance between the two outer terminals always equals the nominal resistance of the pot (here: $10k\Omega$. The resistance between each outer terminal and the middle terminal depends on how you position the knob. Thus, a potentiometer can be used either as a voltage divider (by using all three terminals and treating the middle terminal as the node between two resistors in series) or as a variable resistor (by using only one outer plus the middle terminal, ignoring the second outer terminal). You can read more here: https://en.wikipedia.org/wiki/Potentiometer

4.1. Assemble the circuit in Figure 11 by adding one pot (easiest if the knob points toward the outside) and one $0.1\mu F$ capacitance (plus jumper wires) to your circuit.

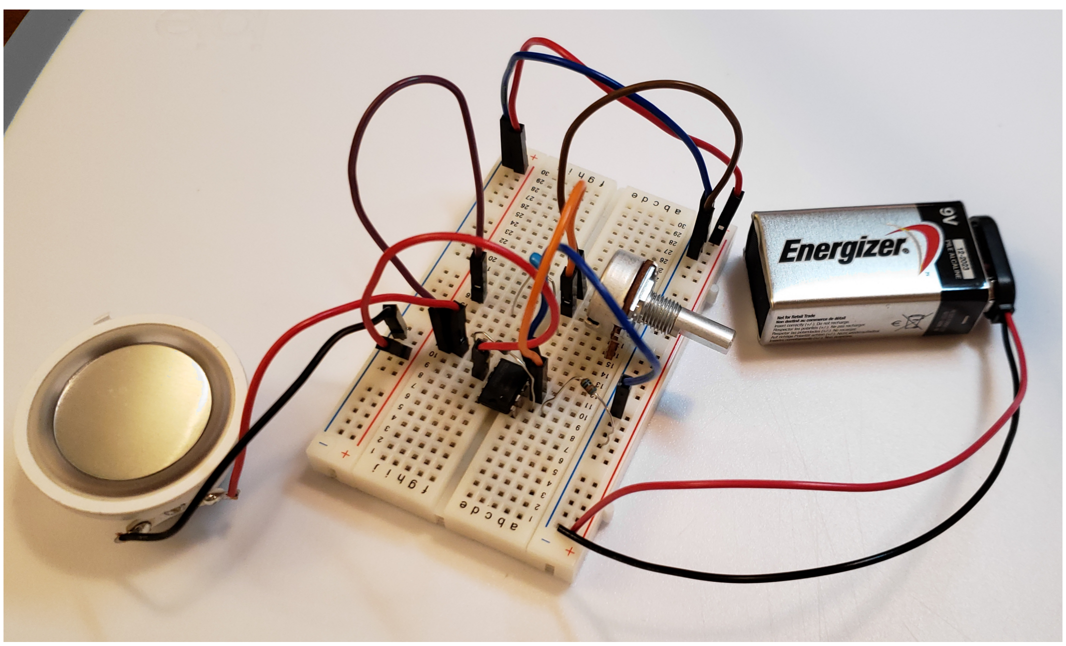


Figure 12: Your circuit should look somewhat like this one.

4.2. If you did it right, your circuit is about to generate some sound (make sure that it doesn't bother the people around you). Plug the black battery snap cable into a GND rail.

4.3. Now turn the knob on the pot (all the way down, all the way up).

What do you expect to hear? What do you hear? Comment on it. Snap a photo for your lab report.

4.4. Disconnect the battery (unplug the black wire). Replace R_1 with the 10Ω resistor. Turn the knob on the pot again.

What do you expect to hear? What do you hear? Comment on it. Snap a photo for your lab report.

4.5. Disconnect the battery (unplug the black wire). Replace R_1 again with the $10k\Omega$ resistor. Remove the $0.1\mu F$ and replace it with a $10\mu F$. Turn the knob on the pot again.

What do you expect to hear? What do you hear? Comment on it. Snap a photo for your lab report.

5 Building an Audio Amplifier

The following sections are optional (but honestly a lot of fun) and quite safe – but we are cognizant of the fact that not everyone will feel comfortable with experimenting with their laptop/phone audio outputs.

5.1. From the Lab 3 module on *Canvas* download the sound file `n1.m4a`. *Irony alert: We have copied this particular tune from youtube to lift your spirits, please ignore the poor audio quality.*

5.2. Take the audio input jack (otherwise called 3.5mm terminal block) and use a small screwdriver or a sharp knife to open up two of the screws labeled as R and $\perp$. Insert two jumper wires inside the opened slot under the screws, and tightly close the screws again. See Figure 13.

5.3. Use the male-to-male audio cable to connect to the audio input jack. See Figure 14.

5.4. If you did not get the alien sound to work (i.e., section 4 incomplete) please do not proceed and contact one of the instructors or peer mentors for guidance (we don't want you to damage your audio port).

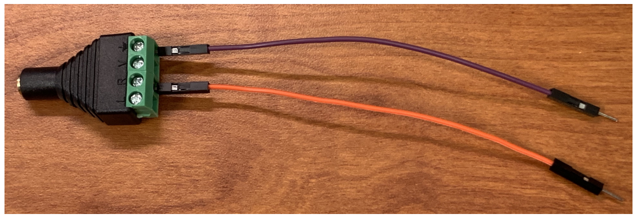


Figure 13: Connect jumper wires to R and ⏚ terminals.

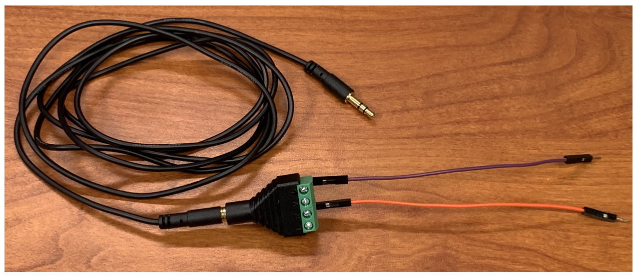


Figure 14: Connect the male-to-male audio cable to audio input jack.

5.5. If you did get the alien sound to work in section 4, it's time to have some fun. First, remove the capacitor and pot from your circuit.

5.6. Start your favorite audio player (e.g., QuickTime). Or you could do it in Matlab as follows:

```
[y, Fs] = audioread('n1.m4a');
a = audioplayer(y, Fs);
playblocking(a);
```

Turn up your regular computer speakers so that the sound is audible.

5.7. Plug the male-to-male audio cable into your audio port (where you would normally plug in headphones). Connect one of the jumper wires to a GND rail and the other wire to v_{in}. This should play your sound through the speaker.

5.8. Replace R_2 with a pot and you can dial it to change the loudness of the music. Cool, right?

6 Active Low-Pass Filtering

As a final cool improvement in your capability to play audio through a speaker, we would like to implement an audio equalizer! Well, not as advanced as the ones professional audio devices have, but we would like to add an active low-pass filter to our circuit in order to filter out the higher frequencies of the sound. The fun part is, you could "hear" a low-pass filter in action and better understand how it works!

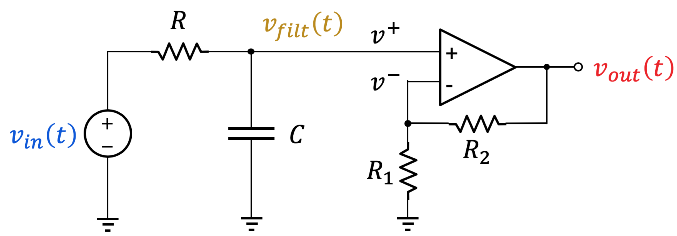


Figure 15: Active low-pass filter.

In order to see the effect of low-pass filtering on the audio played through speaker, we need to have an easily varied cut-off frequency, and so we have to replace the resistor with a potentiometer. Let's use the same $10k\Omega$ potentiometer from the previous section and call it R_1. For C_1 lets use a $0.1\mu F$ capacitor. For having a better sounding speaker, we connect a $C_2 = 0.1\mu F$ capacitor and a $R_2 = 10\Omega$ resistor in series between v_{out} and GND, and a large $C_3 = 1000\mu F$ capacitor between v_{out} and the speaker. These elements act as stabilizer for the amplifier output to speaker, filtering out high frequency noise and removing the DC offset of the signal. Finally, in this section, instead of using feedback resistors like a regular non-inverting op-amp, lets use the special feedback pins of LM386 for maximum audio amplification. Connect a $C_4 = 10\mu F$ capacitor between pins 1 and 8 (with negative pin of the capacitor to pin 8).

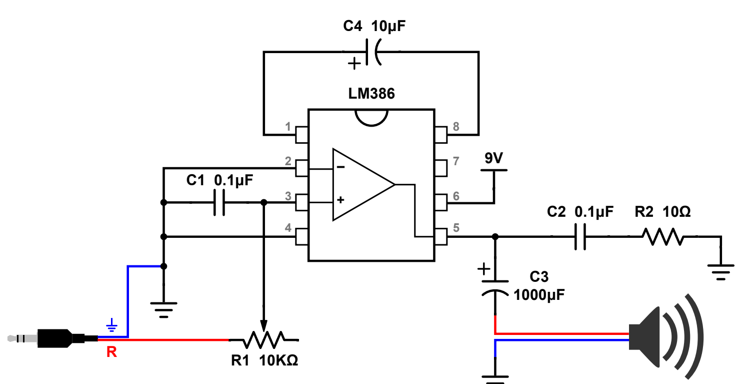


Figure 16: Audio amplifier with active low-pass filter.

Use the pictures below to guide you on how to assemble the circuit.

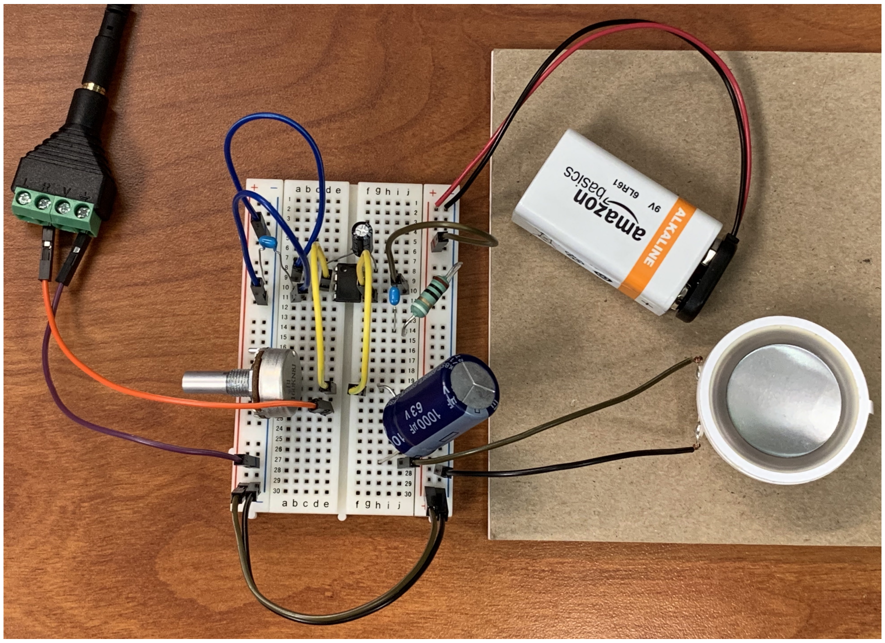


Figure 17: Overview of the active low-pass circuit with all connections.

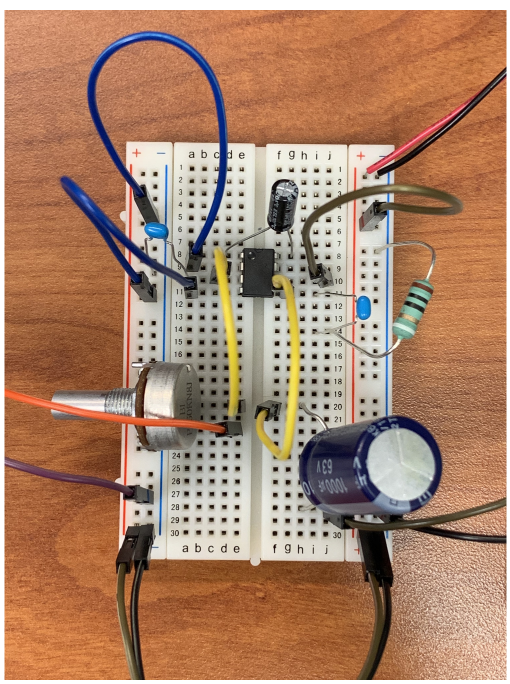


Figure 18: A closer look at the circuit should guide you on how to assemble it.

Verify all your connections by going through this check list:

1. Pin 1 of LM386 should be in hole e8 of breadboard
2. Connect Pin 2 of LM386 to GND: wire from a9 to - rail on the left
3. Pin 3 of LM386 via $C_1 = 0.1\mu F$ capacitor to GND: capacitor from a10 to - rail on the left
4. Pin 3 of LM386 to middle pin of R_1 potentiometer: wire from c10 to e20
5. Pin 4 of LM386 to GND: wire from a11 to - rail on the left
6. Pin 5 of LM386 to + pin of $C_3 = 1000\mu F$ capacitor: wire from g11 to f20
7. Pin 5 of LM386 to $C_2 = 0.1\mu F$ capacitor: capacitor between i11 and i14
8. Pin 6 of LM386 to $V_S = 9V$: wire from j10 to + rail on the right
9. Pin 7 of LM386 not connected to anything
10. Pin 8 of LM386 connected to pin 1 of LM386 through a $C_4 = 10\mu F$ capacitor: - pin of capacitor in g8 and + pin in d8
11. $C_2 = 0.1\mu F$ connected to GND via $R_2 = 10\Omega$: resistor from j14 to - rail on the right
12. $C_3 = 1000\mu F$ connected to speaker: - pin of capacitor in h28 and + wire of speaker in j28
13. The - wire of speaker in the - rail on the right
14. 2 wires connecting + and - rails of the right and left side together
15. The R wire of the audio cable connected to the side pin of potentiometer: wire to e22
16. The ⏚ wire of the audio cable to the - rail on the left
17. Potentiometer $R_1 = 10k\Omega$ in a18, a20 and a22
18. Red wire of the battery to + rail on either side of breadboard
19. Black wire of battery to - rail on either side of breadboard

Some words of encouragement: if you actually manage to get your circuit working on the first try, you are a master circuit builder! Assembling these circuits is not a trivial job and it usually requires multiple checking of all connections.

6.1. Considering R_1 can vary from $10k\Omega$ to 0Ω, calculate what would be the range of the low-pass filter's cut-off frequency?

6.2. Set the potentiometer at somewhere in the middle, and connect the audio plug to your computer. Start playing a music with your favorite audio player. Are you able to hear the music? Try adjusting your computer volume for a reasonable audio quality.

Record a few seconds of video of your circuit in action and submit it along with your report.

6.3. Rotate the potentiometer clock-wise all the way to the end while listening to the music.

Record a few seconds of video as your changing the potentiometer. How does the sound change? Explain why.

6.4. Rotate the potentiometer counter-clock-wise all the way to the other end while listening to the music.

Record a few seconds of video as your changing the potentiometer. How does the sound change? Explain why.

6.5. Finally, here are instructions on how to take this project further. Your kit will allow you to build all audio circuits on this page: https://www.circuitbasics.com/build-a-great-sounding-audio-amplifier-with-bass-boost-from-the-lm386/