EE100 Final Project Guide

Before I begin, many thanks to the EE40 team (Prof. White, Michael Case, Abhijit Davare, Matthew Leslie, Cheuk Chi Lo, Marghoob and Bruno) from Fall 2004 for designing this project. They wrote an excellent guide for this project. This guide for EE100 is based on part 1 and part 2 of their guide.

1. Objective

In this project, you get to design a stereo tone-controller. In other words, the circuit will amplify the base and/or treble for a two-channel stereo system.

2. Prelab

1. Please bring a real audio source – a discman, walkman, iPod, MP3 player, laptop etc. to the lab so you can test your design. Try to place as many components on the breadboard **BEFORE** coming to lab.
2. Read the material on Active Filters from the reader.
3. **WORD OF ADVICE: BUILD CLEAN, NEAT CIRCUITS.** Use the shortest wire possible, use the power rails on your board instead of stringing 12 V and ground everywhere, and be methodical when you wire so that you (and your GSI) can make sense of it. For instance, use red for power, black for ground and blue for signal. Figure 1 shows one half of my tone controller. Notice how all the wires are almost parallel to the breadboard. Also notice how I have added user interface elements– the switch and LED.

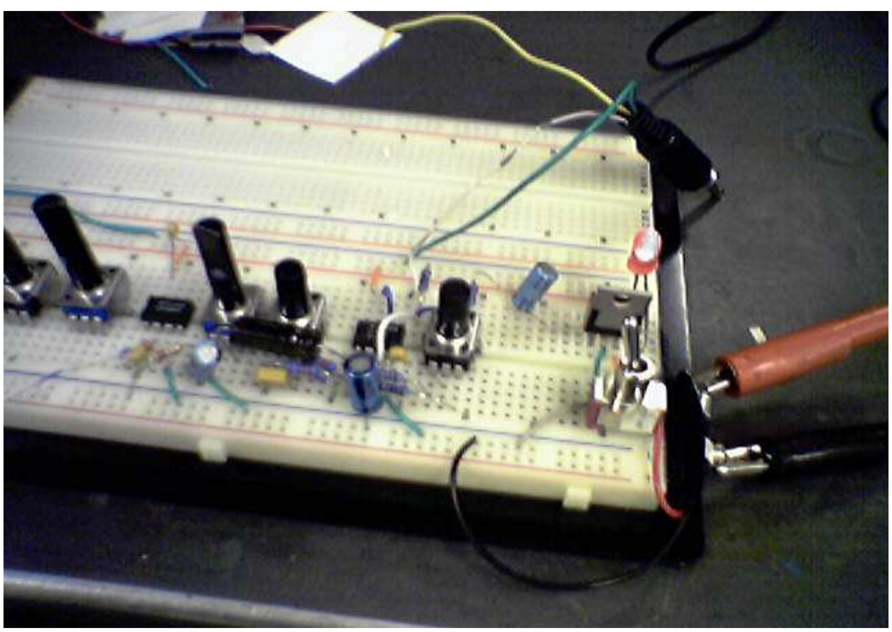


Figure 1. One half (right speaker) of my tone controller circuit

3. System Block Diagram

A block diagram of your tone controller is shown in figure 2.

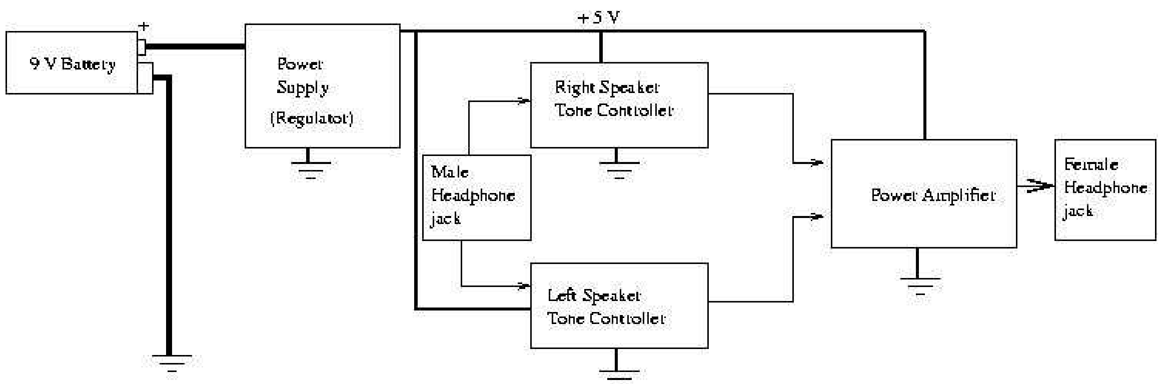


Figure 2. System block diagram

The power supply for your system is a 9 V battery than you can buy from any electronics store/supermarket. The power supply system is to provide a constant 5 V supply to the electronics. This is because a real 9 V battery does not provide a steady 9 V supply. The regulator tries to make sure the 5 V supply is constant. Of course, as time goes on, the battery starts dying and the regulator cannot maintain the voltage. In my case, when the LED starts dimming, that means I need a new battery! A non-mathematical explanation of how the regulator works is given in section 4.

The tone controller is the heart of the above circuit. The left tone controller is the exact same circuit as the right. The tone controller is an op-amp voltage follower followed by an op-amp active filter that can filter the base or the treble regions of the frequency spectrum. A non-mathematical explanation of how this circuit works is given in section 5.

Why do you need the power amplifier stage? The answer: your op-amp tone controller cannot provide enough current to drive any speaker. Speaker resistances are usually 8 or 32 ohms. Your op-amps may be able to provide 10 mA of current on a good day! This is not enough to drive the speakers at all and you will end up blowing your op-amps.

This is where the power amplifier comes in. The power amplifier simply transfers the input from the op-amp tone controller to the speakers, but it can generate a lot of current for driving the speakers.

Overall, the cost of the above system is around $10. You can find the datasheets for all the chips (ICs) in your reader.

4. Block Diagram Component 1: Power Supply

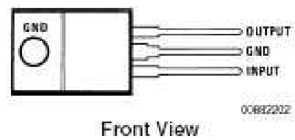


Figure 3. The LM2940CT-5.0 9.0 V to 5.0 V voltage regulator. The 5.0 V suffix indicates the regulator outputs 5 V.

Figure 3 shows the top view of the voltage regulator you will be using. A linear voltage regulator can be thought of as two variable resistors. V_{out} is obtained from V_{in} through a voltage divider. Refer to figure 4.

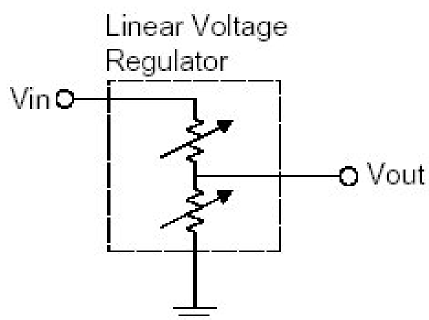


Figure 4. A simple voltage divider between V_{out} and V_{in}.

However, the regulator adjusts V_{out} when V_{in} changes using internal feedback.

5. Block Diagram Component 2: Tone Controller

The tone control circuitry is shown in figure 5. **NOTE: I HAVE NOT INCLUDED THE VOLTAGE FOLLOWER IN FIGURE 5.** The input from your male headphone jack should go to the voltage follower. The output of the voltage follower should go to the tone controller. Details can be found in section 7. Important parts of the circuit are highlighted (source: http://sound.westhost.com/dwopa2.htm)

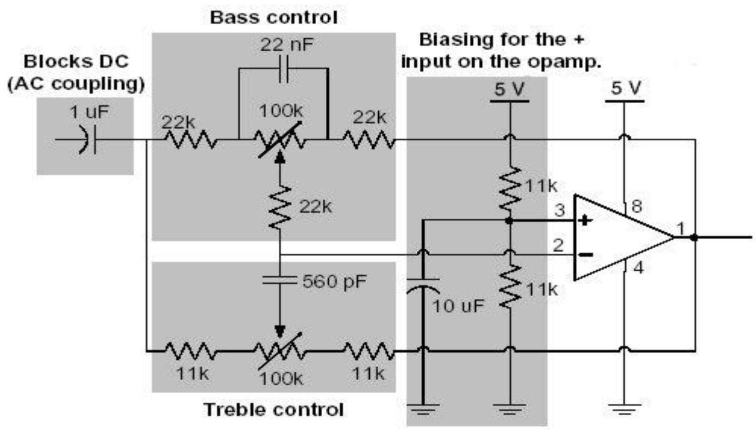


Figure 5. The tone controller

You will be using the LMC6482 opamp, the pinout is given in figure 6 for your convenience.

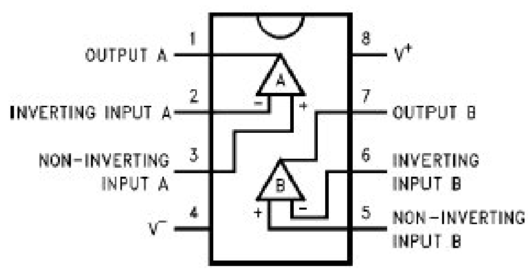


Figure 6. The LMC6482 pinout (top view)

The tone control circuitry is rather complicated. However, a "feel" for the circuit is more than enough. As a rule of thumb, it is always a good idea to have a "feel" for anything before you build it! This gives you an intuition for what to look at if something goes wrong and you need to debug. It also makes the whole process much more fun.

The positive input to the LMC6482 is simply half the power supply due to the 11k resistors. The 10 uF capacitor seen at the positive input merely keeps the node stable (free of AC variations). The purpose of the 1 uF capacitor at the input is to block any DC component of the audio signal . DC voltages do not contain any information about sound and therefore are unnecessary. The rest of the passive components are involved in the feedback path. The key to understanding the bass and treble gains lie in the potentiometers.

If our input signal is very low in frequency (bass), the top potentiometer controls the gain because the 22 nF capacitor appears as an open (use the impedence formula for a capacitor to verify this). Therefore our input signal simply divides inside the potentiometer. Note that for low frequencies, the 560 pF capacitor is effectively an open and does not feed the signal through to the bottom potentiometer.

If our input signal is very high in frequency (treble), no voltage appears across the top potentiometer because the 22 nF capacitor appears as a short. However, the bottom potentiometer divides the input signal and feeds it through the 560 pF capacitor (which now appears as a short) to the input. So for high frequencies the gain is controlled by the bottom potentiometer.

6. Block Diagram Component 3: Amplifier Stage

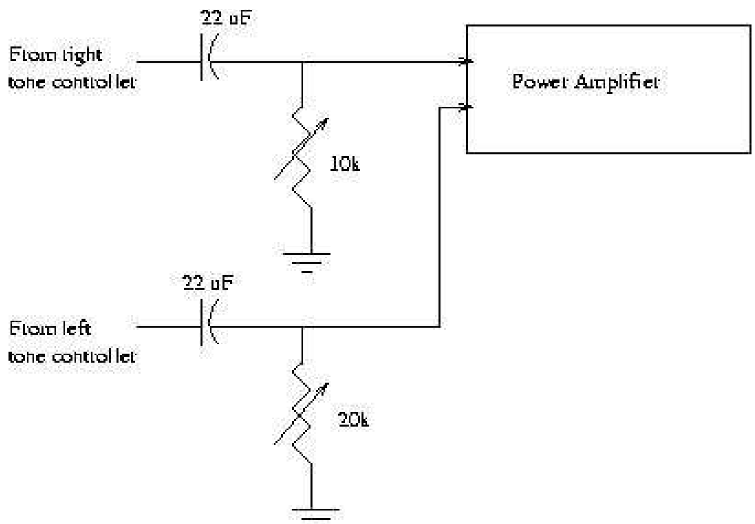


Figure 7. The gain stage + power amplifier

Before the signal goes to the power amplifier, we add an extra gain stage. This is basically your "volume control" knob. The block diagram of the power amplifier is shown in figure 8. The pinout (top-view) is shown in figure 9.

Values for the components in the power amplifier are: C_i = 20 uF, R_f = R_i = 20 k, C_b = 0.1 uF, C_o = 220 uF. If you are interested in knowing why we chose these values, please talk to your TA.

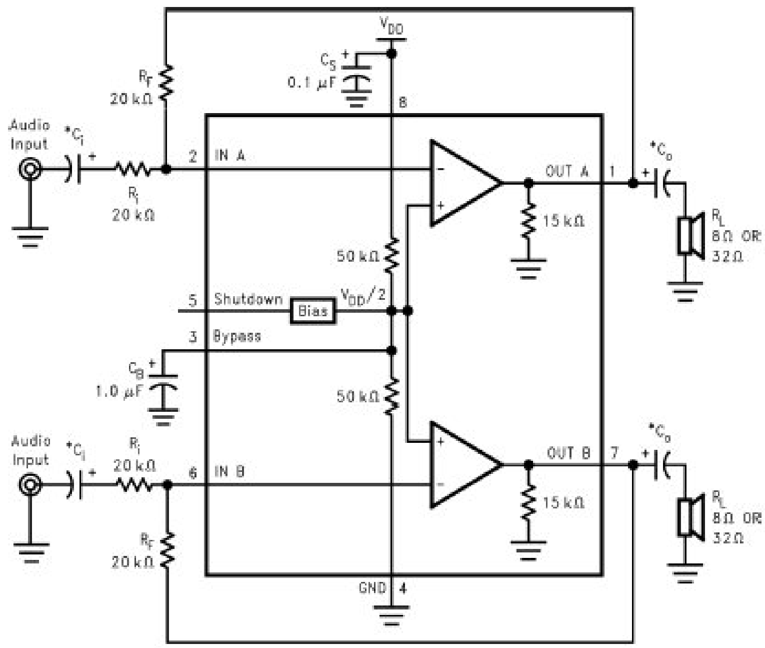


Figure 8. A block diagram view of the power amplifier.

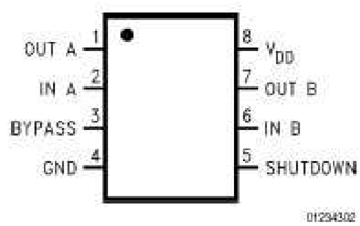


Figure 9. Power amplifier pinout.

7. Building the Circuit

a. Guidelines

i. As said earlier: build clean, neat circuits.

ii. You will need to solder wires onto the male head phone jack since it cannot be hooked up to the breadboard directly. Figure 10 shows the results of soldering wires onto the male head phone jack. In order to solder the wires, unscrew the plastic covering. There will be three pins, the longest one is ground. Your TA will demonstrate soldering in lab.

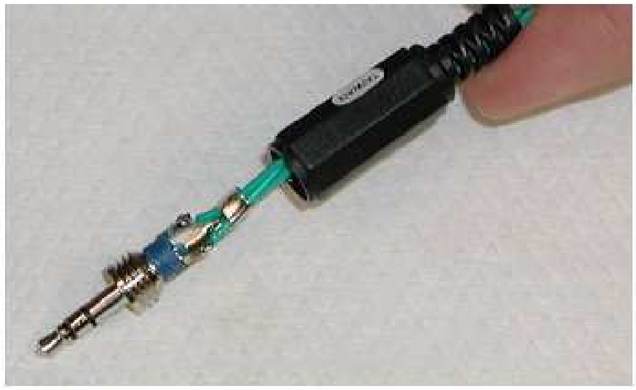


Figure 10. A soldered male headphone jack.

iii. Do not forget voltage follower before tone control circuitry and the gain stage before the power amplifier.
iv. Think about positions of the pots, they are the biggest components in your circuit.
v. You can test the individual blocks in your circuit (power supply, tone controller etc). DO NOT however connect the tone controller directly to the female headphone jack. You will blow up the LMC6482 op-amps. They cannot provide enough current, this is precisely the reason for using the LM4880 power amplifier.

b. Parts List

Once you get the project kit from the TA, please make sure the following components are present in your kit. If anything is missing, talk to your TA immediately.

Miscellaneous	Power Supply	Tone Controller	Gain stage + Power Amplifier
Male Headphone jack x 1	LM2940CT-5.0 x 1	LMC6482 x 2	LM4880 x 1
Female Headphone jack x 1	0.1 uF input filter cap. x 1	22 nF x 2	22 uF x 2
Breadboard x 1	22 uF output filter cap. x 1	560 pF x 2	20 uF x 2
		10 uF x 2	20k x 4
		1 uF x 2	0.1 uF x 2
		100k pot. x 4	220 uF x 2
		22k x 6	10k pot. x 2
		11 k x 8	

Table 1. Parts list for the project

8. Project Report

After you build the circuit and verified its operation, neatly **TYPE** a summary of your results (1 per group). The report should address three areas:

1. **Problems encountered and how you solved them**
2. **A bode magnitude plot of the system.** Recall that a bode diagram plots both the magnitude and phase of the transfer function. We are interested only in the magnitude since as humans we can't "hear" phase differences! Also recall that the transfer function of a circuit is simply a plot of the output voltage divided by the input voltage for a range of frequencies. We could simply plot V_{out}/V_{in} or we could plot the same thing in decibels ($20.\log(V_{out}/V_{in})$). In the case of an audio circuit, it is more meaningful to plot the transfer function in decibels since this directly relates to the change in volume.

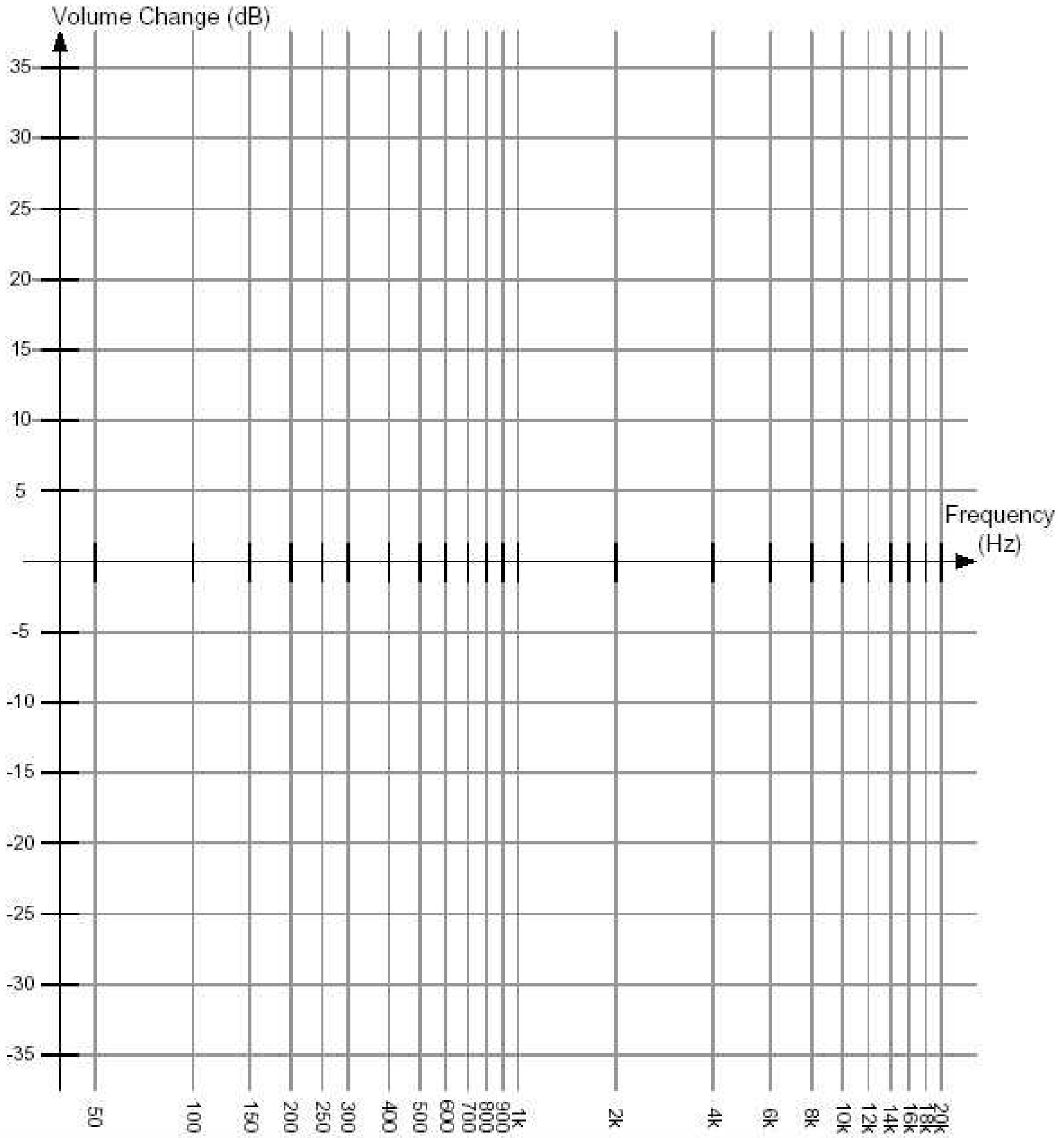
Set the treble, bass and volume knobs to something interesting. Now disconnect your audio player and headphones. Connect the signal generator in place of your audio player (use either left or right male headphone jack). Use 100 mVpp, 0 V offset. Connect two oscilloscope probes, one at the input and the other at the output (use either output from the power amplifier). Use the oscilloscope to measure the peak voltage at both the input and the output. Fill in the template on the next page.

If you are really ambitious, you can use LabVIEW to automate the process. Download RCCircuit.vi from http://www-inst.eecs.berkeley.edu/~ee100/LabVIEW/labs/labs.html Instead of the oscilloscope at the output, connect the multimeter. Set the correct GPIB addresses of the function generator and multimeter in RCCircuit.vi. Set the correct range of frequencies to sweep as well. The VI works by setting a known frequency (it uses 1 Vpp as amplitude of the function generator output, thats ok) from the list, measuring the AC voltage at the output using the multimeter and plotting the result.

3. **Conclusion.** Please also tell us if you enjoyed this experience, how the project can be improved etc.

Frequency (Hz)	V_{in}	V_{out}	20 log(V_{out}/Vin)
50			
100			
150			
200			
250			
300			
400			
500			
600			
700			
800			
900			
1k			
2k			
4k			
6k			
8k			
10k			
12k			
14k			
16k			
18k			
20k			

Table 2. Magnitude response data


Volume Change (dB)
35
30
25
20
15
10
5
-5
-10
-15
-20
-25
-30
-35
Frequency (Hz)
50
100
150
200
250
300
400
500
600
700
800
900
1k
2k
4k
6k
8k
10k
12k
14k
16k
18k
20k