YOUR NAME:	YOUR SID:
YOUR PARTNER'S NAME:	YOUR PARTNER'S SID:

Score: ___/100

Electroencephalograph (EEG)

Final Project Part 1: Design and Simulation

ELECTRICAL ENGINEERING 40

INTRODUCTION TO MICROELECTRONIC CIRCUITS

University Of California, Berkeley

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Lab Contents:

Final Project Overview and Objectives

For your final project we will be building an electroencephalogram (EEG) and putting it on a PCB much like the board you soldered for the first lab. We will be working our way up to completing the PCB for the rest of the semester and it will be imperative that you do not miss critical deadlines such as fabrication.

In this project we will design, simulate, layout, manufacture, and solder, a complete printed circuit board. Since this is your final project, obviously we will be using a significant portion of what you learned in previous labs about various circuit components and analysis techniques. Therefore, if you're a little rusty on some of the things we did in previous labs; it would be a good idea to brush up on what you do not feel comfortable with because you essentially built most of the modules already in previous labs.

As with all other labs, we will start with design considerations and parameters, and simulate our circuit in Multisim. After the design process, we will prototype our design in the lab before we actually get to the manufacturing process. Once we verify that our design works in the lab, we will transfer our design to a **p**rinted **c**ircuit **b**oard (PCB) layout CAD tool that pairs with Multisim called Ultiboard (don't worry you already have this). Once we prepare our design on the PCB CAD software, we will export our design to a PCB manufacturing company and get your board manufactured. Finally, once the board arrives, we will solder the components to the PCB and we're done!

This may seem a little overwhelming at first, but relax, we will try to make this as painless as possible ☺.

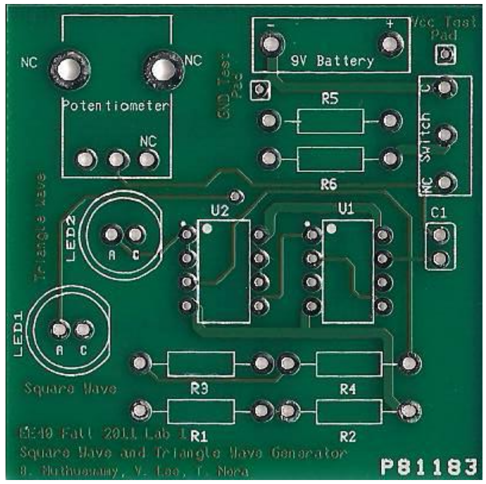
Some Background to the Printed Circuit Board (PCB)

So why are we even bothering to design and make a printed circuit board? What exactly is a printed circuit board and why on earth are we making the final project a printed circuit board?

You may have noticed in lab that breadboards are unwieldy, and are not exactly the most reliable platforms to assemble and present a functional circuit on. You probably have already experienced first-hand how annoying it is to put all your components on the breadboard and realize your circuit is not working. At this point you probably have picked up a fragile object and threw it at a wall…

One of the practical aspects of having a printed circuit board is that it eliminates the loose wires that make the breadboard annoying to deal with. On a printed circuit board, the loose connections will be replaced with copper traces which we will solder as we've seen in Lab 1. Removing a soldered connection is clearly not a trivial task and but having components soldered to the board makes our lives easier.

Another reason we are requiring a PCB as your final project is simply because it is so ubiquitous in our daily lives. Printed circuit boards are found in virtually every electronic device and range from simplistic designs such as the one we encountered in Lab 1, to incredibly complicated designs that are used for computer motherboards. As a result, PCBs form the mechanical platform of all of our electronic applications.



PCB from Lab 1

The printed circuit board is therefore a tool in the electrical engineer's arsenal and it is important to at least understand the methodology and reasoning behind the process of producing one (it's also cool because you get to take home a toy).

A printed circuit board, as stated early, is simply a mechanical platform which more permanently and reliably implements our circuits. You will notice in the figure below that there are a lot of copper trace lines that interweave the surface. These lines are simply wires that electrically connect different parts of the circuit.

You may also notice that there are quite a few holes where the wires seem to just terminate. These holes are called **vias** which indicate that the wire has crossed over to another layer of the board.

This brings us to another important property of printed circuit board. Printed circuit boards are composed of a number of layers. Depending on how complicated our circuit implementation is, we may require more than two layers to route all of the appropriate electrical connections. More layers correlates to higher manufacturing costs, so, in our effort to keep costs low, we want to route our boards as efficiently as possible – a.k.a. minimize wasted board space.

Project Parameters

Now that we have a good feel for what a printed circuit board is, let's consider our project specifications. Below are the project specifications that your design for you PCB must meet along with any metrics of evaluation. Each module of the project is covered in detail in the next section.

Design Specifications

- Your PCB must contain all of the modules required for the EEG
- You must use an instrumentation amplifier built from discrete components with appropriate gain
- The instrumentation amplifier must have adjustable gain
- Any other amplifier stage must also have adjustable gain
- You must use a +/- 5 V regulators to obtain +/- 5 V from the 9 V batteries.
- You must have coupling and decoupling capacitors in appropriate parts of your circuit
- Your board must have a PWM test signal generator output for you to test your circuit

- Your test signal generator must output a test signal on the order of $\sim 10^{-6} V$ to $10^{-5} V$ and be able to adjust the frequency between $10 Hz$ and at least $100 Hz$
- You must have voltage followers where necessary

Part Specifications

The following parts are available for your design. You will be provided a kit with these parts at the beginning of the prototyping phase provided that you have a schematic ready to build. You will not receive the kit if you do not complete the schematic beforehand. Kits will be distributed one per group. It is your responsibility to figure out how these components work. Look at the datasheets.

- 4 x TLC277CP Dual Operational Amplifier
- 1 x LM7805 +5V Regulator, 1x LM7905 -5 V regulator
- 1 x $10k\Omega$ potentiometer (for instrumentation amplifier gain control)
- 4 x 50k 1% tolerance resistors (for instrumentation amplifier input stage and gain stage)
- 2 x 500k 1% tolerance resistors (for instrumentation amplifier input stage and gain stage)
- ~~2 x 50k resistors (for active driven right leg)~~
- ~~2 x 5M resistors (for current limiting the active driven right leg circuit)~~
- 1 x 1M resistor (for filtering)
- 1 x 100k resistor (for filtering)
- 1 x $5k\Omega$ potentiometer (for gain control in active low pass filter)
- 2 x 10 ohm resistors (for notch filter)
- **2 x $20k\Omega$ resistor (for notch filter)**
- 2 x $247k\Omega$ resistor (for notch filter)
- 1 x 1 uF capacitor (for filtering)
- 1 x 0.01 uF capacitor (for filtering)
- **2 x 0.22 uF capacitors (for filtering)**
- 2 x 10 uF capacitors (for filtering)
- Header pins for test pad connections
- 4 x 8 pin DIP sockets for each of your 8 pin chips

Printed Circuit Board Layout Specifications

- Your layout be no larger than 3 inches wide by 3 inches long
- Your layout may only use circular vias
- All pads must be circular; this means no rectangular or square pads
- Your layout must use IC packages that have the same type of through-hole pads
- Your layout must incorporate test pads at key points in your design
- All components on your printed circuit board must be appropriately labeled with component number (such as “R5” for resistors and “C2” for capacitors).
- Your layout may NOT use surface mounts components
- Your name and your partner’s name, and lab section should be clearly marked on your PCB in a legible manner
- Power traces for supplies and ground must be 40 mils wide
- Your traces and pads must satisfy a minimum of 14 mil clearance with other components
- Using the Autorouter is prohibited. It also does not corretly autoroute consistently so if you do, you probably will lose points

- When you solder the board, you must solder the sockets before putting in the IC chips to avoid heat damage to the chips

Performance Specifications

- Your test signal must output a waveform within the correct order of magnitude and appropriate frequencies
- All excess high frequency noise must be adequately attenuated
- You should have a spike at $10Hz$ on the frequency spectrum and a strong DC component
- You will NOT under any circumstances test this device on yourself (we're not going to supply you electrodes anyways)
- The circuit should perform completely off the $9V$ battery

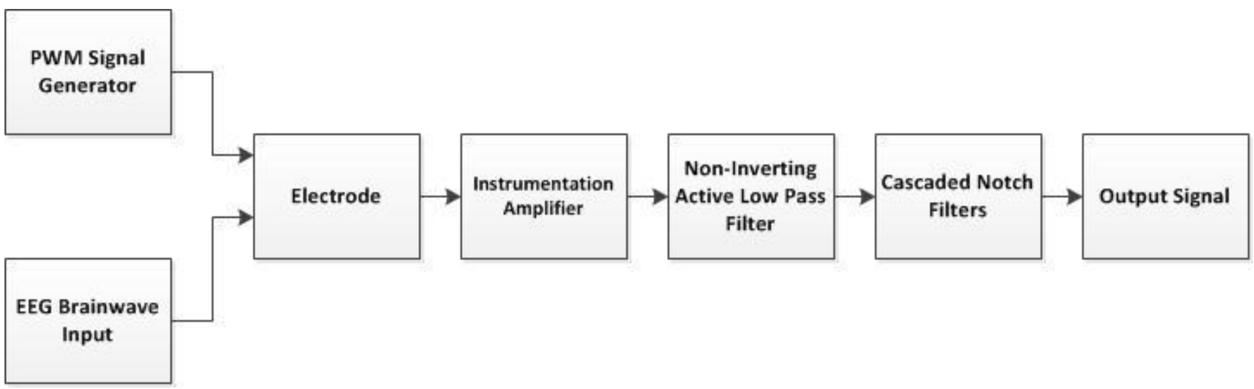
Due Dates for this Project

- The deadlines for this project are as follows:
  - Schematic Design and Simulation: **Due Week of March 26**
  - Printed Circuit Board Layout: **Due Week of April 8th**
  - Final Soldered Board, Demonstration, and Lab Write Up: **Due Week of April 30th**
- You must meet all deadlines for this project ON TIME
  - if you miss the deadline for any of these items you may not finish the project on time
  - if you miss the deadline for the Printed Circuit Board Layout you may receive a zero for the project

Design Phase

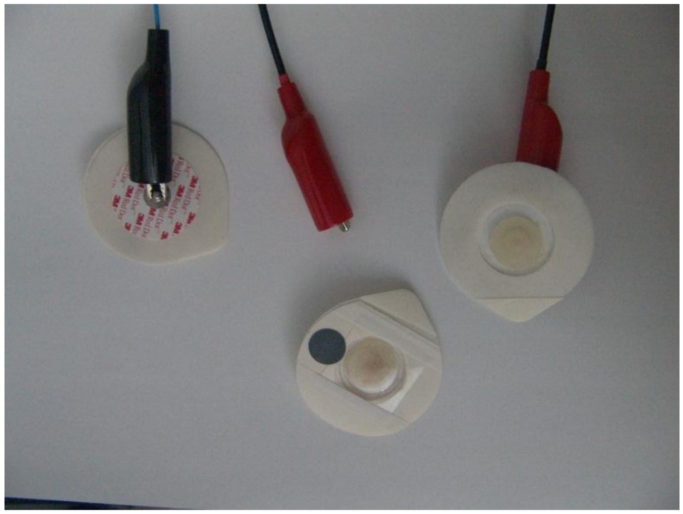
Before we begin any sort of prototyping and PCB layout, we want to design the circuit and do a design analysis. Our EEG will either take a brainwave signal or a PWM test signal. Because the signal is so weak ($10^{-6}V$), we're going to have to amplify the signal by several orders of magnitude in order to apply appropriate signal processing. Therefore, we will first send our signal through an instrumentation amplifier. However, we might not be able to get adequate gain with just one amplification stage. In addition, having several adjustable amplification stages will allow us to have higher resolution in amplification.

At this point, our EEG should have amplified our signal enough to apply filters and various signal processing techniques. As mentioned before, the main signal components of the brainwave signal that we want to capture is around $10Hz$. In addition, we also have to eliminate any signal noise that we may have picked up. Since noise is usually a high frequency component, and we are looking for a low frequency component, we will apply a low pass filter to extract the brainwave signal. We should than be able to take the output signal and display it on an oscilloscope.



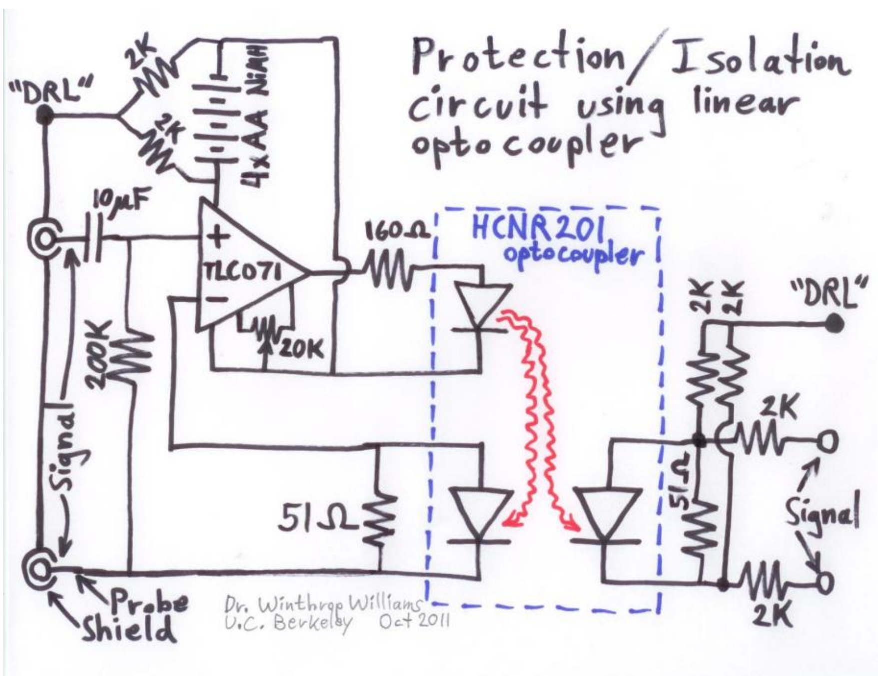
The Electrode

We will be providing you the electrodes to test with after you finish the board. Every group will NOT receive an electrode; we will have a set that we will use for testing and you will return these after testing. ABSOLUTELY at any time, do not test the EEG on yourself. Use the PWM test signal generator that we build in the testing section to test your circuit.



Electrodes

To ensure that our unfortunate test subjects are protected from electrical shock due to questionable PCB designs, our electrodes will be equipped with protection circuitry so that testing will be safe. For those of you who are interested, the schematic of the protection circuit is given below. Basically what it will do is ensure that when we test your circuit on us, we don't get zapped.



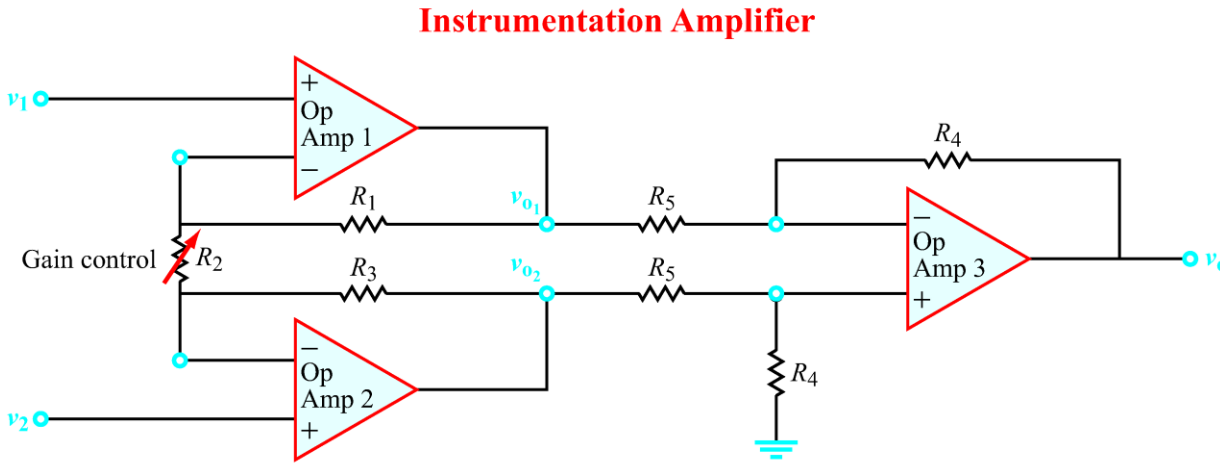
Luckily we have already built these electrodes for you and eliminated most of the issues associated with these problems. Again, we will not be providing electrodes for you to take home since they are expensive and we don't feel like dealing with the paperwork to make it legal.[1]

[1] An appropriate lawyer joke would go here

The Instrumentation Amplifier Stage

Since the signal strength we are processing is on the order of $10^{-6}V$, we have to apply an incredibly high gain in order to bring it into a range that we can process the signal. Recall in lab 4, we used an instrumentation amplifier which can be configured to have high gain.

The instrumentation amplifier that you encountered is lab 4 is shown below:



In the space provided below, prove that the gain of the instrumentation amplifier is given by:

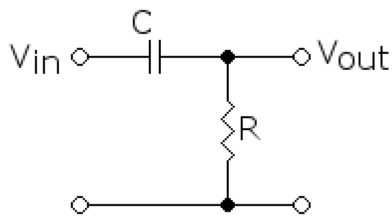
$$v_o = \left(\frac{R_4}{R_5}\right)\left(\frac{R_1 + R_2 + R_3}{R_2}\right)(v_2 - v_1)$$

In addition, choose reasonable values such that the instrumentation amplifier has a gain of ~1000 using a $10k\Omega$potentiometer. Provide all relevant calculations that prove your values satisfy the specifications. Show the Multisim simulations and measure the gain in the simulation. (Set V_1 to ground, and V_2 a ~10 Hz AC signal with the voltage amplitude in the order of $10^{-6}V \sim 10^{-5}V$. The supply voltage of OpAmp is $\pm 5V$.)

Score:__/15

DC Block

Following the voltage follower, we will need to put in a DC block. Remember, the signal that we are processing is being amplifier from a microvolt signal strength and the brain wave signal component that we want to read is around $10Hz$. Thus, to clean things up a little bit, we can apply a high pass filter with a very low cutoff frequency which can easily be done by a resistor and capacitor shown below.



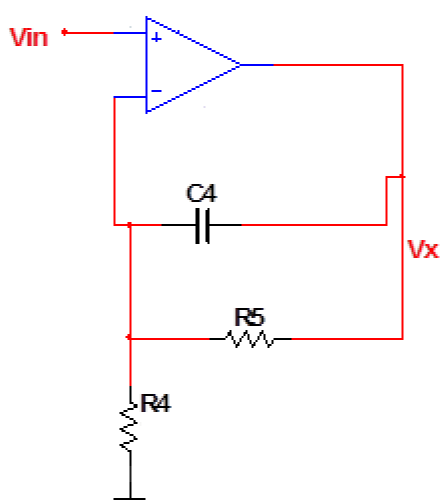
High Pass Filter DC Block[2]

For our circuit we will be using the DC block with a cut off frequency of $\sim .16Hz$. For this we will be using a $1\mu F$ capacitor and $1M\Omega$ resistor.

The Non-Inverting Active Low Pass Filter

So at this point, we've done quite a bit of amplification and signal fluffing, but haven't really amplified the signal enough nor filtered out all of its undesired components. As discussed earlier, the frequency that we want to see from our EEG lies around the $\sim 10Hz$ range so we have to extract that from our amplified signal. So let's stop piddling around and do that.

First, we're going to throw a low pass filter at our signal. For our application, we're going to use a non-inverting active low pass filter which is shown below:



[2] http://en.wikiversity.org/wiki/RL_Circuit

You're probably sick of deriving Bode plots but we're going to make you do it anyways (it may be helpful when we analyze the next filter).

In the space provided below, show that the gain of the non-inverting active low pass filter and cutoff frequency is given by the following:

$$\text{Gain} = 1 + \frac{Z_2}{R4} \text{ and } \omega_c = 1000 \text{ rad/sec}$$

Z_2 is the impedance of C4 and R5 in parallel. Before you begin a mathematical derivation of the gain, think about the circuit above. What is the capacitor's impedance at low frequency (DC?) and high frequencies (ω_c → infinity)? This should give you an idea of why the circuit is a low-pass filter. Plugging in values for different angular frequencies and computing the change in gain will also help you understand the circuit more. Remember that the cutoff frequency above is in rad/sec, not Hertz!

In addition, draw the Bode plot and label any relevant points in terms of the given variables. Finally, choose values for your passive components such that the cutoff frequency ω_c is 1000 rad/sec and the DC gain is 100. Show the MultiSim simulation to confirm your results. The supply voltage of the op-amp is $\pm 5V$.

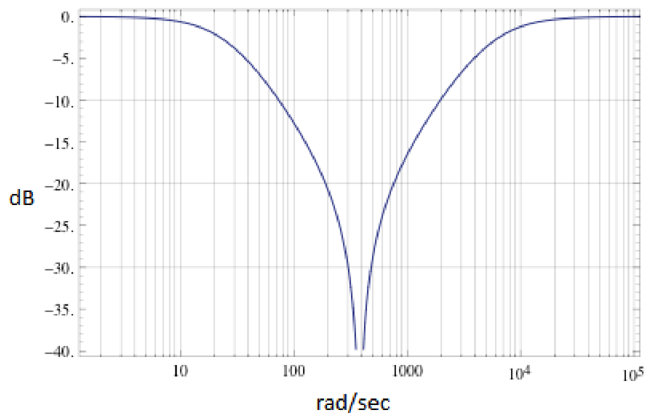
Score:__/15

The Notch Filter

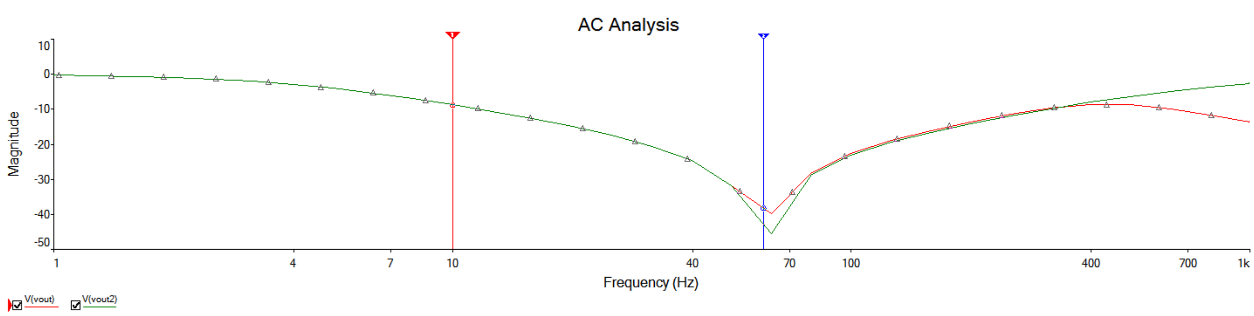
So the low pass filtering was nice, but it doesn't really give us exactly what we want. Remember that EEG signals are on the order of $\sim 10^{-6} V$ which means that the amount of noise we have to deal with is fairly annoying. Our active low pass filter did attenuate many of the higher frequencies but it is limited to a $-20 dB/decade$ dropoff.

In order to fine tune our signal, we are going to apply a cascade of notch filters to eliminate some $60 Hz$ noise.[3] The 60Hz noise is due to the electrical power lines. Once again, since our circuit is dealing with such low voltage signal, we need to consider this electrical interference.

For those of you who don't know what a notch filter is, don't panic. Basically a notch filter passes all frequencies except for a narrow range and is called a notch filter because its frequency response looks like it has a "notch" in it. The plot below is the theoretical plot of the magnitude response of our notch filter from Mathematica.

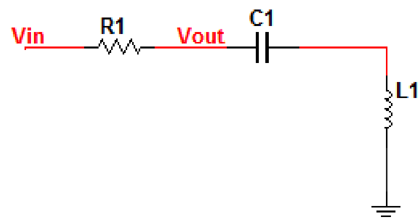


As you can see from the magnitude plot above, a notch filter is ideal for killing any particular undesired frequency such as the $60Hz$ component we wish to eliminate. The same notch filter magnitude plot is shown below in MultiSim.

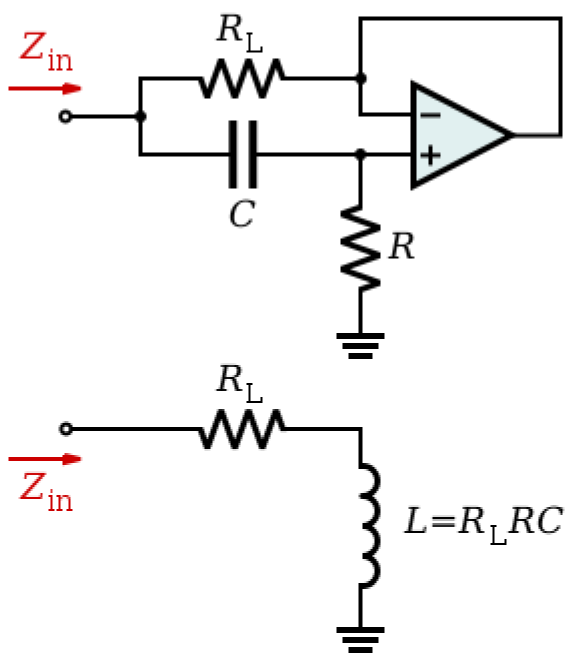


[3] Yes, notch filters are actually used outside of EECS20/120

Notice in MultiSim we have *two* magnitude plots. The reason is that one of the magnitude plots belongs to the notch filter realization shown below.



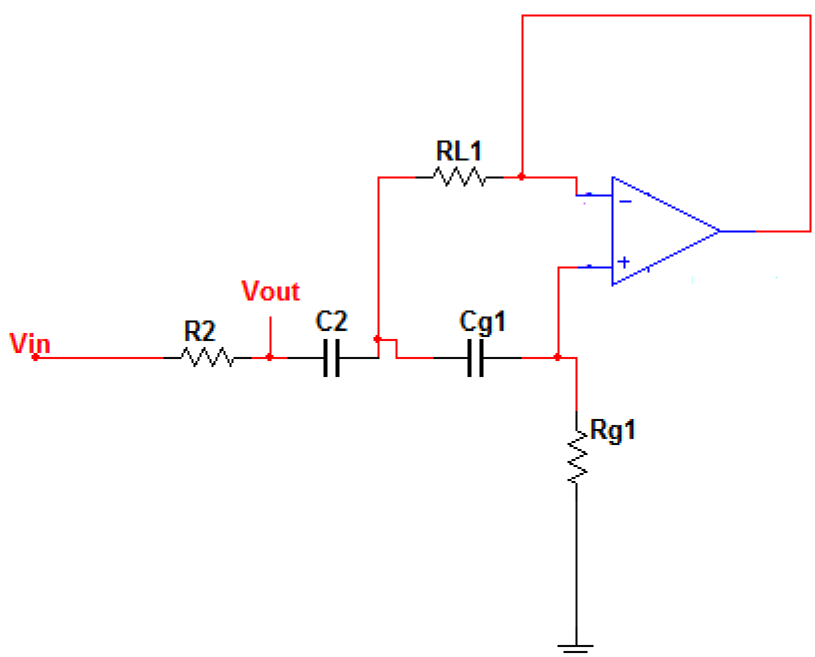
Note we are using the impractical value of 26.5 H for our inductor! So, how did we get a practical circuit close to our theoretical performance? The answer is the gyrator, a circuit that "inverts" impedances. Consider the circuit shown below (from Wikipedia).



First, prove below that the op-amp gyrator circuit above has $Z_{in} = R_L + j\omega R_L RC$

Score:__/15

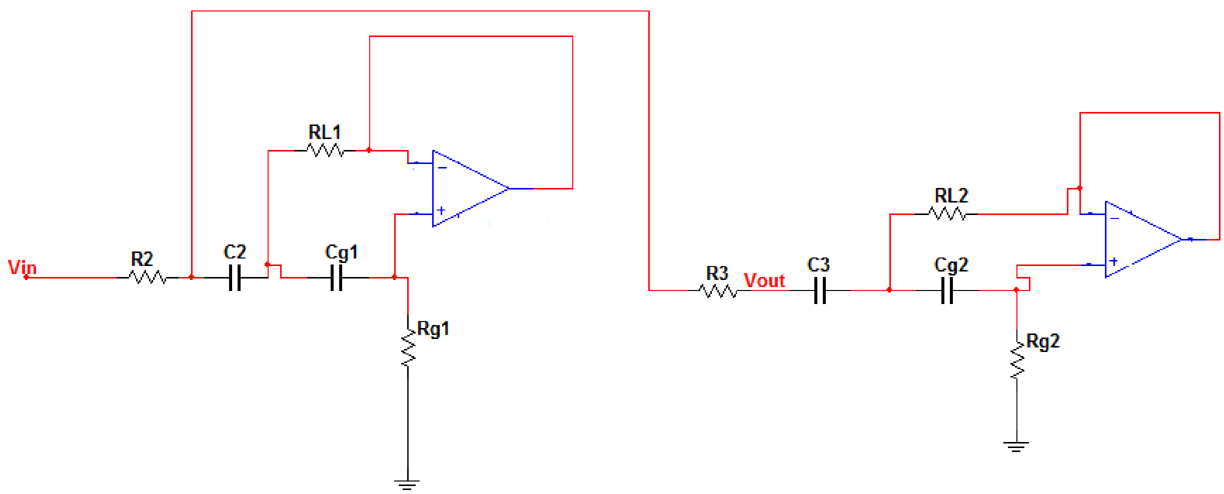
In our usage of the gyrator for our notch filter, we will use the following variation:



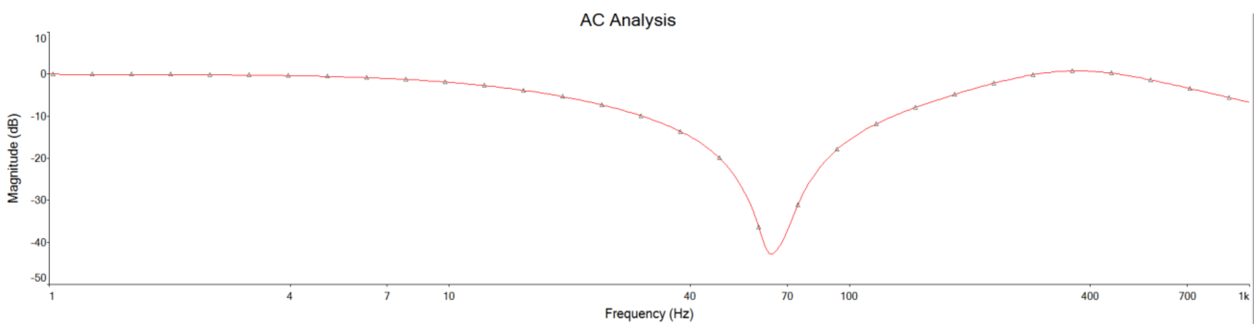
Derive the transfer function of the circuit above. Use RL1 = 10 ohms, Cg1 = 10 uF and remember that the inductor you are simulating is 26.5 H. Choose R2 = 20k, this should help you solve for C2 and thus you should be able to draw a magnitude Bode plot. Show YOUR OWN MultiSim simulation results to confirm your Bode plot. Make sure they agree with our previous STANDARD simulation results from MultiSim. The supply voltage of OpAmp is $\pm 5V$.

Score:__/20

Note that in our application, we are going to cascade two notch filters (we're going to kill the $60Hz$ frequency twice for good measure). The implementation for this portion of the circuit is shown below.



The bodeplot for the cascaded notch filter is shown in the following.



Powering Your Circuit

To power your circuit, we will be using two 9V batteries to provide $\pm 5V$ power supplies to your circuit. In order to do this, we will be using $\pm 5V$ regulators. The regulators in question are the LM7805 and LM7905 regulators. In the space below, look at the datasheet for these components and draw the circuit diagrams showing how to connect them. Clearly indicate where the 9V battery goes and where the $\pm 5V$ output is.

Score:__/5

Output Signal and Testing

Once we have finally finished processing the signal in the lab, we are going to send it to an oscilloscope so that we can actually see the EEG signal. To test your signal, we will be using the oscilloscope to perform a fast Fourier transform to see the frequency components of the signal you processed. Everyone's signal will look different but generally you will end up with a strong DC component and weaker spike around $10Hz$.

Unfortunately, we cannot let you test the EEGs on yourself and we don't have enough electrodes to go around. However, recall that we did design a pulse width modulation square wave generator to provide a test signal. This will be the primary means for you to test and debug your signal when you prototype.

What you need to do…

Your task is to complete the rest of the EEG design, put everything together, and simulate it in Multisim. We recommend that you draw a rough draft on a spare sheet of paper so that you have a good idea of where you are going when you start to place components in Multisim.

One important consideration that we will need to observe when we use Multisim for our project schematic, is to use non-virtual components (we will see why later). So how do we know if we are using a virtual or non-virtual component?

When you open the Select a Component window, virtual components will have a blank in the field Footprint manufacturer/type. You can still place these components but Multisim will display them as a black outline.

Non-virtual components will appear with a blue outline when placed on the schematic design and the Footprint manufacturer/type field will not be empty. Don't worry about the GND and Vcc nodes appearing with a black outline. These components are not physical circuit components but node connection abstractions.

Make sure to **attach a copy of your working schematic and simulation results** to this lab report**. Show that your simulation results meet the design specifications described above**.

Your GSI Signs Here **(30 points)**

In addition, you will need to get your schematic checked off below by your GSI in order to get your parts kit.

You will not have to consider the following when completing the design of your circuit since we have already accounted for them in the modules presented above:

- Bypass Capacitors – to prevent voltage sags and mediate the effect of abrupt current draw fluctuations
- Buffers – to match input and output impedance between different modules
- Output Resistors – to match output impedance

We also recommend that you build and test your circuit in modules. This will increase the chances that you will be able to catch errors and debug your design.

Also **use clean wiring in your schematic** because it makes it easier for us and for you to trace your circuit. **We will refuse to help groups** that do not wire their circuits cleanly. This is a fairly large circuit and if you don't wire things neatly, you will be hopelessly confused and proceed to throwing fragile objects.

Tips on Simulation and Testing…

- To test your circuit in the simulator you will have to generate an oscillating signal using an AC voltage source or something equivalent. Make sure that this source is set to a microvolt level signal ranging from around a few $\mu V - 100\ \mu V$. Unfortunately since our lab instruments won't be able to generate such low voltage signal we will have to use something else when we actually build and test our circuit (we'll worry about this later though…).
- When you do put your circuit in the simulator, make sure that you build it modularly and that each part of the circuit is clearly identified. This is to help you and to help us quickly debug your schematic should there be any obvious problems. You may want to label each module on the circuit with a short description.
- When you are simulating your entire EEG circuit, you may need to set the DC Convergence Limit to 2000 and Transient Convergence Limit to 1000 if you end up getting convergence errors.
- Make liberal use of the virtual multimeters, probes, scopes, and Bode Plot analyzers that Multisim provides you. These are the primary ways you will be able to tell whether your simulation is actually working or not. Make sure to probe key points in your circuit like between critical modules and check to see if the outputs you are reading match with what you expect.

Prototyping Phase

For Spring 2012, we have decided that since these circuits are individually very similar to circuits you have built in previous labs, **we are not going to require you to prototype your circuit on a breadboard**. Your PCB layout tool can compare your layout with the schematic you made in MultiSim to verify that it will function the same, and as you have experienced in the past many errors in breadboarding happen simply due to loose connection, which are generally a non-issue when working with a soldered PCB, so we wanted to spare you that agony. However, this section of the project document has been left in as guidance in debugging your projects in case things go wrong.

Now that you have your schematic ready to go, it is now time for you to actually build your circuit.

Some of you may be tempted to throw everything on the breadboard at once and test functionality at the end. This is not a methodical approach to a project of this scale. If your circuit doesn't work, the error could be anywhere in your circuit. Furthermore, you may have made multiple errors which could be anywhere in your circuit.

Therefore, we recommend that you build your circuit in modules. This will enable you to test the functionality of each module and minimize the time you spend looking for bugs before moving on.

The order in which you build the circuit is entirely up to you. The key part of the process is testing functionality and debugging, since one mistake usually cripples the entire circuit.

In the following sections, we will provide you with some basic ways to test if your circuit module is working properly.

Before you start building up your circuit, we'd like to offer some basic tips:

- **Set current limits** on your power supplies. $P = IV$ means if you make a mistake and run too much current through your operational amplifier, timer, hand, etc. you will destroy it. The current limit is a failsafe mechanism that will limit the maximum current and eliminates the risk of breaking your components. ASK YOUR GSI IF YOU DON'T KNOW HOW TO SET IT.

- When you get stuck**, don't disassemble your circuit until you've verified it's a design problem**. We know sometimes it's tempting to take apart your circuit and try again without taking a closer look at what might be wrong. It might be something simple such as a loose wire or bad power supply. Make sure to check these before deciding to take apart your circuit.

- **Use clean wiring**. This enables other people such as your GSI to help you debug your circuit. If your wiring is a mess, it's harder to trace your circuit and takes more time for us to help you out. Your wires should also not be more than an inch or two above the board. **We will refuse to help groups that do not use clean wiring.**

- **The multimeter and oscilloscope are your friends.** If your circuit is not working, the first thing you should do is measure, measure, and measure, to find out where and what the problem is. Trace the entire signal path starting from the source and try to identify where the error is starting.

Testing Tips

As mentioned before, you should be building you circuit in modules and effectively testing each module before you continue your prototyping. Testing each module for functionality is critical as it will help you isolate bugs to a smaller portion of your circuit and fix them. Below are a few tips on how to test each of your circuit modules in isolation.

Note, however, that when you finally go to test the entire circuit, you will want to use 9V batteries since bench supplies have a strong $60Hz$ noise component. We recommend that once you get to that pont in the testing, that you use the voltage regulators and batteries to produce the supplies.

The Instrumentation Amplifier Stage

- Recall from lab 4, we used the instrumentation amplifier to detect extremely small fluctuations in voltage difference. Similarly, to test that your instrumentation amplifier has adequate gain, you will probably want to supply it with some known input voltage from your power supply and probe the output to see if you are in fact getting the desired gain. Be careful of saturation when making this measurement.

- When you fire up your instrumentation amplifier, if things are getting hot, make sure that you connected power supplies to your operational amplifiers correctly. If your resistors are getting hot, you probably want to use a higher value resistor.

- Make sure to supply your circuit with ± 5 volts since that is what we'll be using in the actual circuit.

- If you're not getting a signal at all, you probably want to double check that everything is connected correctly. If you're wiring is bad, fix it before pulling over a TA.

- Test your circuit and fill in the table below.

Frequency	Peak-to-peak value of input	Peak-to-peak value of output	Gain/Attenuation Factor	Gain/Attenuation in dB
DC				
1 Hz				
3 Hz				
10 Hz				
30 Hz				
100 Hz				
300 Hz				
1000 Hz				

- Set the frequency of the input AC signal to be 10 Hz, and amplitude in the order of $10^{-6}V \sim 10^{-5}V$. Adjust your potentiometer, what is the range of the gain you can achieve?

The Active Low Pass Filter Stage

- We recommend using a function generator as your input to this module and testing the output with an oscilloscope. This way you can sweep a range of frequencies on the function generator and see if your filter kills and passes the correct ranges of frequencies.

- Use the peak-to-peak measurement option on the oscilloscope to make sure you are obtaining the correct amplification or attenuation at the correct frequencies.

- Make sure you send in the test signal at the correct node in the circuit and appropriate nodes are grounded.

- Again we recommend using a function generator and running a sweep of the frequencies to ensure the frequency response is correct and using the peak-to-peak measurement option on the scope to check amplification and gain.

- You can also test this module for gain using a constant voltage signal and measuring the output with a DMM since a DC voltage corresponds to $\omega = 0$. Since this is a low pass filter stage, make sure you are getting maximum amplification at $\omega = 0$.

- Test your circuit and fill in the table below.

Measured cut-off frequency fc =

Frequency	Peak-to-peak value of input	Peak-to-peak value of output	Gain/Attenuation Factor	Gain/Attenuation in dB
DC				
1 Hz				
3 Hz				
10 Hz				
30 Hz				
100 Hz				
300 Hz				
1000 Hz				
fc				

- Set the frequency of the input AC signal to be 10Hz, and amplitude in the order of $10^{-3}V \sim 10^{-2}V$. Adjust your potentiometer, what is the range of the gain you can achieve?

Notch Filter Stage

- Again we recommend using a function generator and running a sweep of the frequencies to ensure the frequency response is correct and using the peak-to-peak measurement option on the scope to check amplification and gain.

- You can also test this module for gain using a constant voltage signal and measuring the output with a DMM since a DC voltage corresponds to $\omega = 0$.

- For the notch filter, we really only expect frequencies in a very narrow region to be killed, so make sure that you don't "miss" that frequency band in your sweep.

- Test your circuit and fill in the table below.

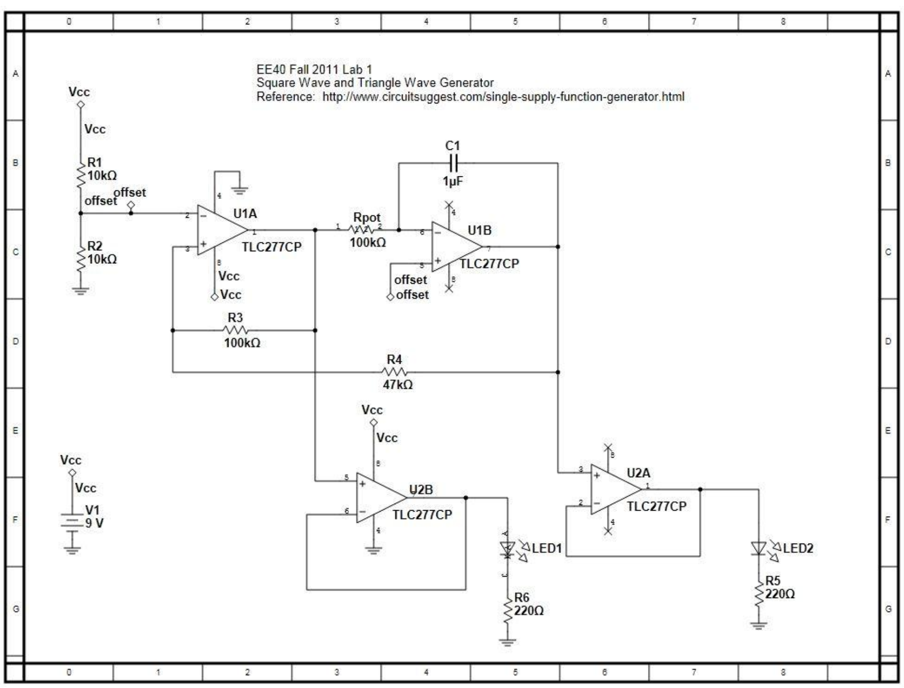
Frequency	Peak-to-peak value of input	Peak-to-peak value of output	Gain/Attenuation Factor	Gain/Attenuation in dB
DC				
1 Hz				
3 Hz				
10 Hz				
30 Hz				
50 Hz				
60 Hz				
70 Hz				
100 Hz				
300 Hz				
1000 Hz				

The Final Test Circuit

Once you have assembled all of the modules, and tested them, you are ready to put the whole thing together and finish the final test. Unfortunately we can't just use the function generator to shove the microvolt level signals we need to simulate. So how can we test our circuit?

Recall in lab 1 and lab 5, we assembled a relaxation oscillator that generated a square wave and triangle wave $\sim 10Hz$. So for our test circuit, we are also going to use… a relaxation oscillator (surprise!...).

As a quick refresher, here is the oscillator circuit again:



Square Wave and Triangle Wave Oscillator[4]

[4] Note that values will not be the same for your test signal source

In our application for lab 1 and 5, the output voltage signal was on the order of ~ 1 volt. This is clearly several orders of magnitude too big to simulate the microvolt brain wave signal we want. So to nerf our signal down to the desired level, we will throw an amazing voltage divider to the output of the oscillator ($1M\Omega$ and 100Ω). This will reduce the signal by an order of 10^4which will bring it down to about the $\sim 10 - 100\mu V$ level which is what we want to simulate.

As a final test for your circuit, build the relaxation oscillator and configure it so that it outputs a square wave with peak to peak magnitude of $\sim 10\mu V$.

Hook up the output of the oscillator to your EEG and probe the output of your EEG with your oscilloscope. On your oscilloscope, you should be able to take the Fourier Transform which will show you the frequency content of the signal.

Verify that it is what you expected and that you do not have any extraneous frequency bands of noise. You may also want to adjust the frequency of your oscillator to sweep frequency bands to ensure that your EEG circuit rejects the appropriate frequencies, especially the $60Hz$ electrical interference.

Final Testing

Once you have confirmed your EEG circuit is working properly, you should gather some data. Make sure to have your oscillator circuit hooked up to your EEG and the scope displaying the output.

Based on your measurement, fill in the following table for the whole EEG circuit.

Frequency	Peak-to-peak value of input	Peak-to-peak value of output	Gain/Attenuation Factor	Gain/Attenuation in dB
DC				
1 Hz				
3 Hz				
10 Hz				
30 Hz				
50 Hz				
60 Hz				
70 Hz				
100 Hz				
300 Hz				
1000 Hz				

Set the frequency of the input AC signal to be 10Hz, and amplitude in the order of $10^{-6}V \sim 10^{-5}V$. Adjust your potentiometers, what is the range of the gain you can achieve?