Electroencephalograph (EEG)

Final Project Supplementary Information

ELECTRICAL ENGINEERING 40

INTRODUCTION TO MICROELECTRONIC CIRCUITS

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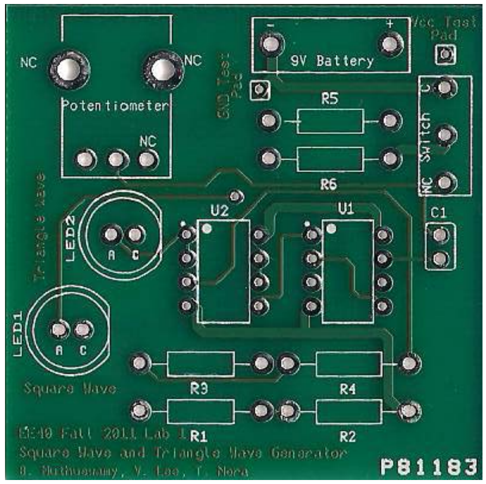
Some Background to the Printed Circuit Board (PCB)

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).

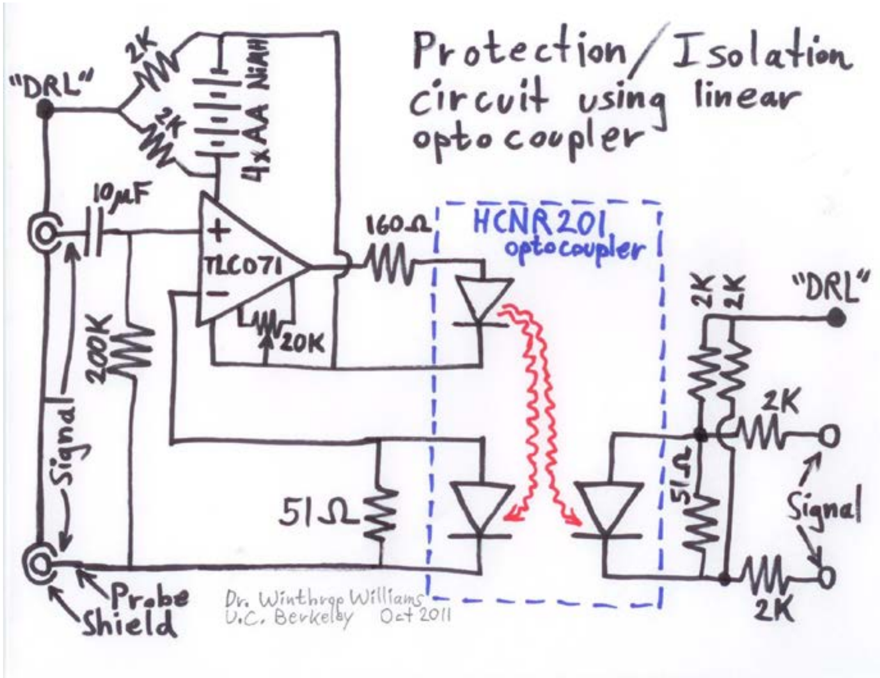
A printed circuit board, as stated early, is simply a mechanical platform which more permanently and reliably implements our circuits. You will notice in the figure below that there are a lot of copper trace lines that interweave the surface. These lines are simply wires that electrically connect different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

Electrode Protection Circuit

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]

Breadboard Prototyping

For Fall 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 bread-boarding 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.

[1] An appropriate lawyer joke would go here

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 Worksheets

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.

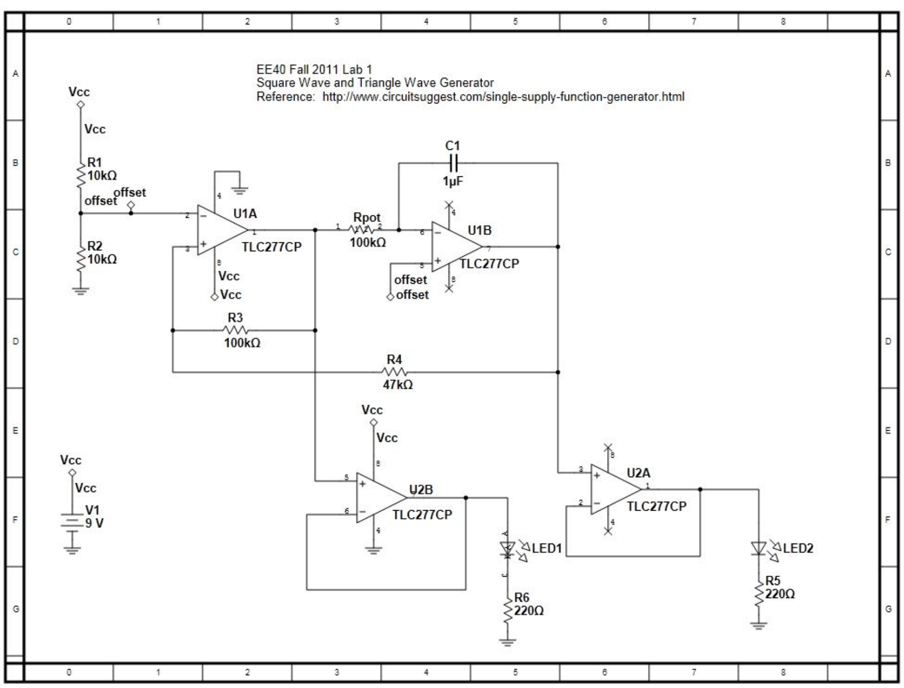
Frequency	Peak-to-peak value of input	Peak-to-peak value of output	Gain/Attenuation Factor	Gain/Attenuation in dB
DC				
1 Hz				
3 Hz				
10 Hz				
30 Hz				
50 Hz				
60 Hz				
70 Hz				
100 Hz				
300 Hz				
1000 Hz				

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[2]

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?

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