ECE 110: Introduction to Electronics
Week 12: Final Report

Group Members:

Holly Roach (hollyr2@illinois.edu; 667759534)
Geitanksha Tandon (gtandon3@illinois.edu; 659853977)
Maddie Rydell (mrydell2@illinois.edu; 673790352)
Austin Paull (aapaull2@illinois.edu; 657472559)

Overview:

We ECE 110 students were given a task: to make a car that can run straight using a new concept, instead of using photoresistors, one that runs self-sufficiently with our given battery.

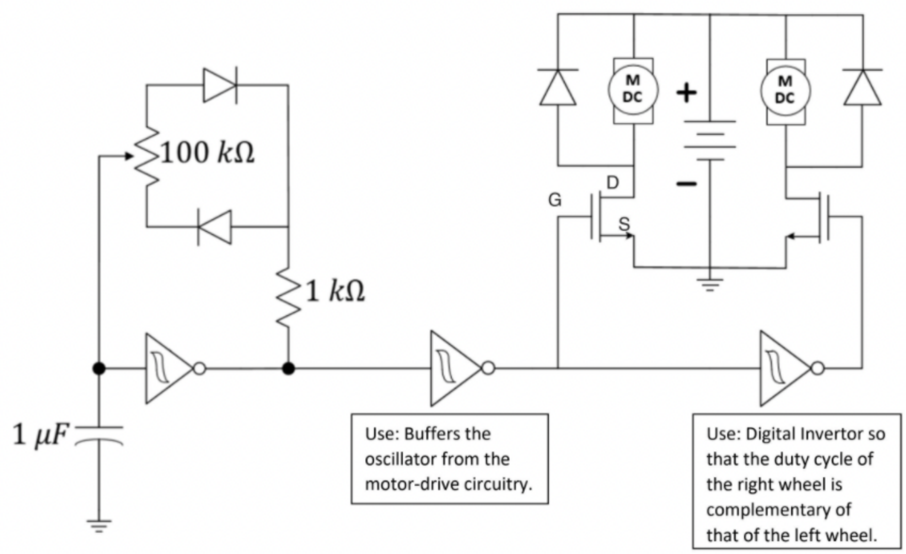


Figure 1: General Design Information
Figure taken from UIUC: ECE 110 Lab Worksheet of Week 10

Now, however, we were given an even bigger task: To make sure that our car was protected with a special "key" in the form of a resistor! The way that we were told to do this was using our crucial components: resistors, comparators, some and logic and of course, our motors.

Design:

We were given the design of the protection system in the form of some components:

Figure 2: General Design Information
Figure taken from UIUC: ECE 110 Lab Worksheet of Week 12

We began by analyzing the content given to us: the Wheatstone bridge and the equation that it was used to derive, and how it would make our values more precise than most other available sources.

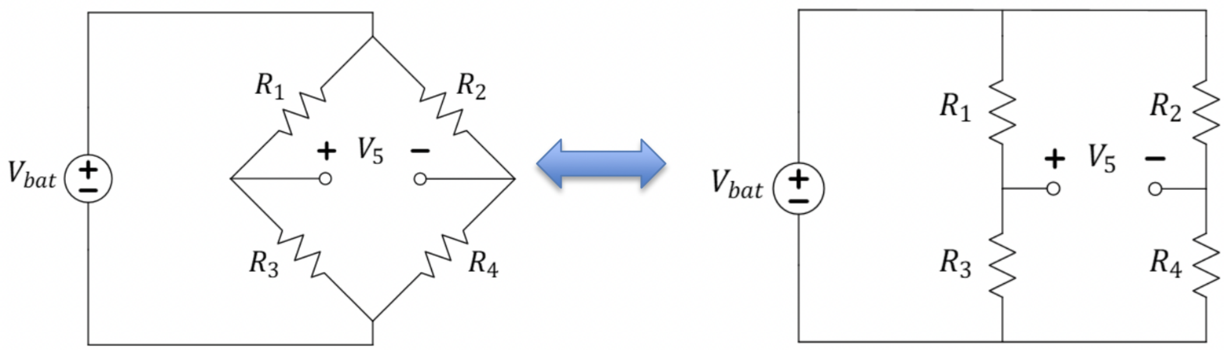
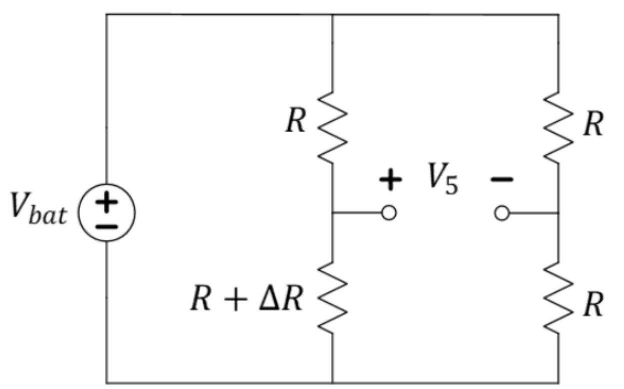


Figure 2: Wheatstone Bridge
Figure taken from UIUC: ECE 110 Lab Worksheet of Week 12

The Wheatstone bridge is different from a voltage divider in the way that it is a network of 4 resistors arranged in a manner that only a specific value of each resistor would let our Wheatstone Bridge work.

$$\frac{R1}{R3} = \frac{R2}{R4}$$

In our case however, our wheatstone bridge is much easier to analyze:



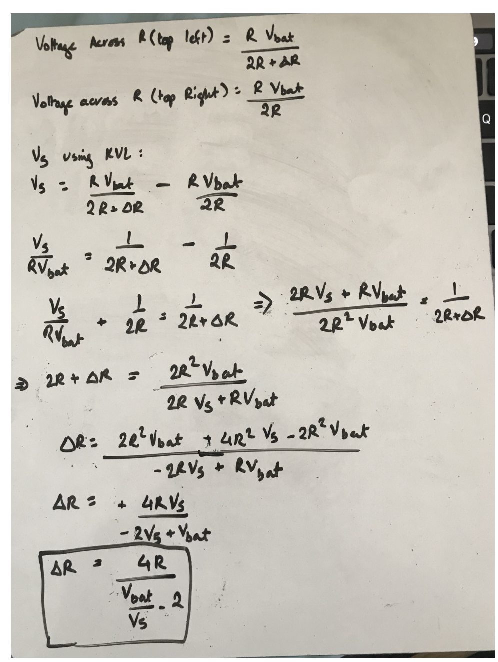


Figure 3: Wheatstone Bridge - Our version
Figure taken from UIUC: ECE 110 Lab Worksheet of Week 12

$$\Delta R = \frac{4R}{\left(\frac{V_{bat}}{V_5} - 2\right)}$$

This was the same equation that they had given us in the lab report, and thus we figured that it was correct.

Then, in our report we were given a diagram that was a simple, redrawn version of our circuit using 3 voltage dividers so far:

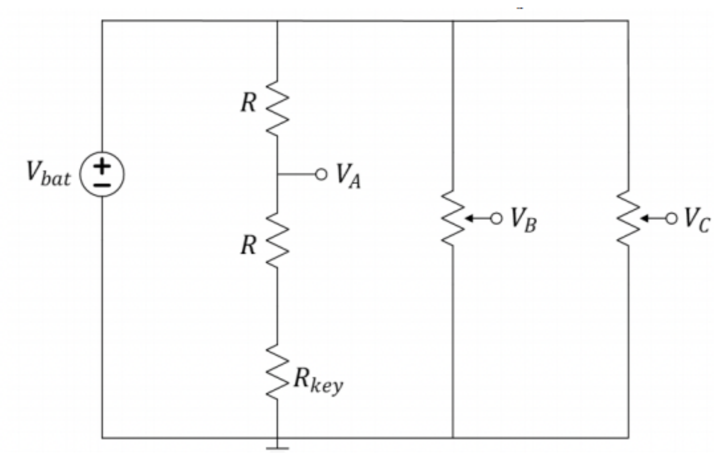


Figure 3: Redrawn Wheatstone Bridge with specific Vb, Vc

Figure taken from UIUC: ECE 110 Lab Worksheet of Week 12

This circuit, however, posed a new challenge. Because we have taken away the simplicity of R, we needed to check the voltages of Vb and Vc, where these two values are in fact potentiometers. This however, was another question: What was the purpose of Vb and Vc anyway? We looked back and realized that we in fact needed a value of R_{key} such that it would make Va come in between our boundary voltages of Vb and Vc, where the top boundary was Vb, and the bottom boundary was Vc. That would give us limits of sorts where Vb>Va>Vc. This meant that we figured out how exactly this circuit functioned!

Given these, our job was now more clear: What value of R_{key} did we want to use? And how would that implicate our design to make it feasible for our potentiometers and Resistors (R)? Luckily, the team of ECE 110 made our jobs a little easier and gave us suggestions:

> **Suggestions**: For your design, choose the potentiometers such that each has an end-to-end resistance near $2R$. Also choose a key, R_{key}, that is at least *five times smaller* than R. Do this by increasing R if necessary.

We got to thinking, and we decided to be a little careful and look at our options, so we lay out all the resistors we had: we knew our limitations were the resistors that we had, because we did not have all the options, so we started to play around with values. We wanted a combination of potentiometers/resistors that were easy to achieve/tune. We decided to try several things: maybe keeping our Rkey as 100 Ohms: That means that our R would need to be 500 Ohms and we did not have enough resistors to make that, and besides choosing a potentiometer value between 100kOhm, 10kOhm, or 1kOhm was difficult, so we went forward with keeping Rkey as

1000 Ohms. This meant that our R values were 5000 which we had enough resistors to make! We decided on keeping that, and realised our potentiometer values needed to thereby be 10KOhms which we also had! With this discovery, we worked on falstad to simulate our circuit and try our resistor combinations. Since our potentiometers are hand tuned, we wanted to use values on the potentiometer marked with the notches (every notch changing the resistance by 10%) so that we could be more exact. Instead of manually checking each potentiometer combination, we checked on Falstad until we landed on a combination of potentiometers/resistors that gave Vb>Va>Vc with Va = 4.9 V, Vb = 5.391, Vc = 4.5 Volts, which were all within 10% of each other.

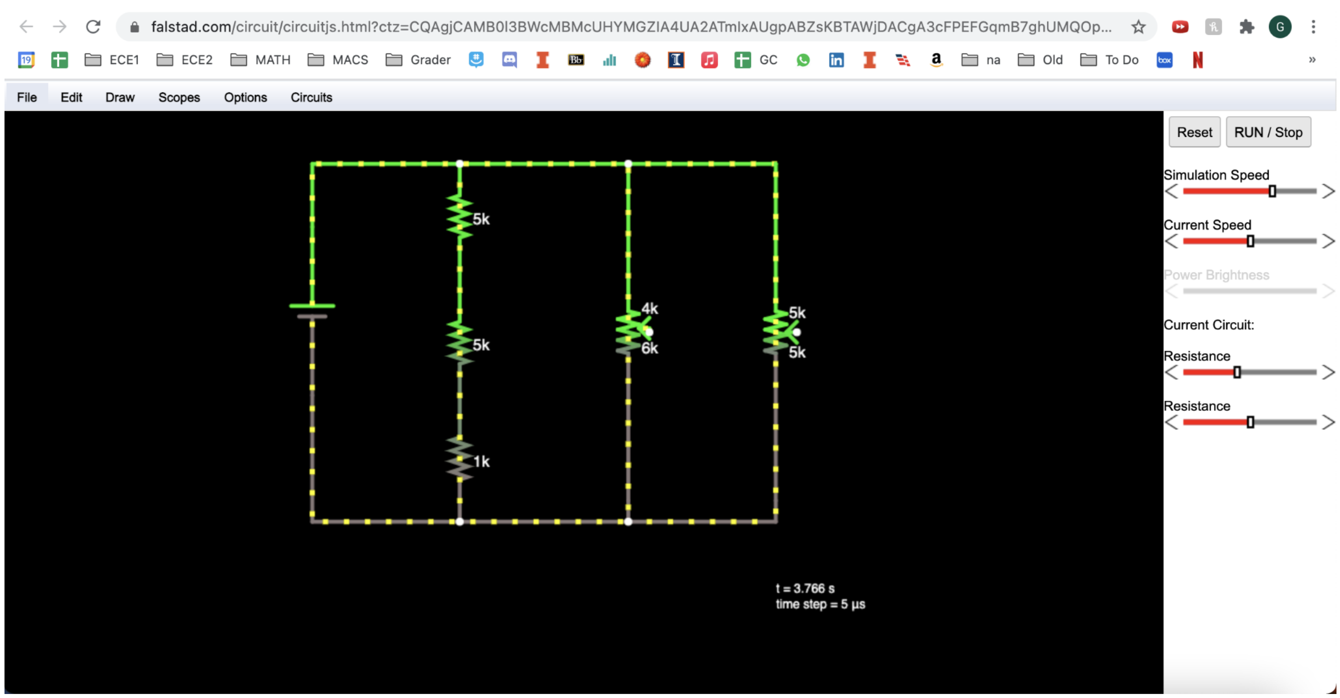


Figure 4: Circuit of the resistor connections

Figure taken by using Falstad for ECE 110 Lab of Week 12 by Lab AB9 Members via https://www.falstad.com/circuit/

Now that we figured out Rkey and R and our potentiometer values, we had a new task: to make our comparator run properly.

First, we had to understand the comparator. When we observe the use of a comparator, we notice that it checks whether the input voltage on it's positive end is more than the input voltage on its negative end. If this is true, then it lets current flow through its output. In our situation, we used 2 comparators. The reason we did so is by noticing that if we want an upper and lower boundary, we would need 2 comparators to check for those boundaries. Thus, we used the first comparator to compare the voltage between Vb and Va, where the positive end of the comparator is connected to Vb and the negative to Va. This means that while the Va voltage is less than the Vb voltage, current will flow. We then used the second comparator to compare the voltage between Vc and Va, where the positive end of the comparator is connected to Va and

the negative to Vc. This means that while the Va voltage is more than the Vc voltage, current will flow. Thus by keeping the values of Vb as 10% more than the ideal Va value and the Vc value as 10% less than the ideal Va value, we get our limitations.
The comparator is something that would check our conditions before: whether Va>Vb and whether Va<Vc using 2 comparators. We decided to take our datasheet (attached here) for our LM311 Comparator and looked at figure 9 in that datasheet:

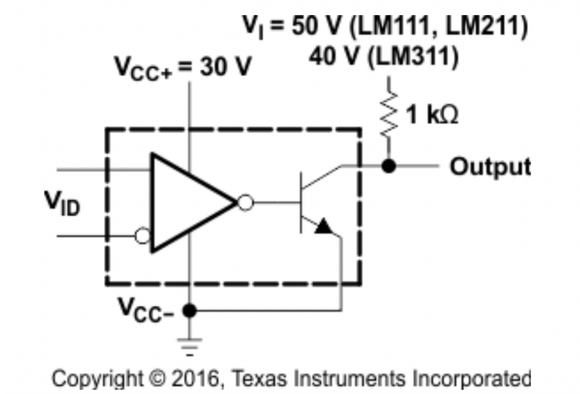


Figure 4: Comparator Internals relevant to our Circuit
Figure taken from TI: https://www.ti.com/document-viewer/LM311/datasheet/parameter-measurement-information#SLCS0078776

This meant that we had to connect our comparator in a way that matched the figure. Once we had our conditions (Va>Vb and whether Va<V) met, the output of the comparator would be high. This could then be used to run our motors. This diagram below is what we used as reference instead of the complicated diagram from the datasheet above:

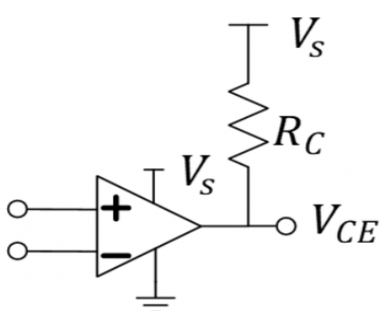


Figure 5: Simple version of our LM 311 Comparator Circuit
Figure taken from UIUC: ECE 110 Lab Worksheet of Week 12
Now that we even had our comparator ready, we just had to get our motors to work! Luckily, the T.A. in our lab was kind and gave us a simple regular motor pathway as shown:

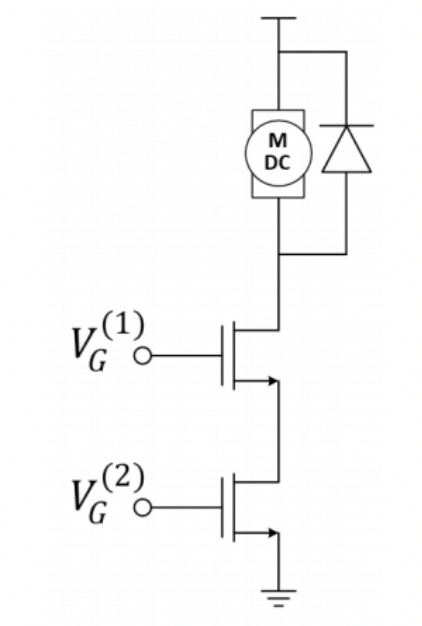


Figure 6: Singular Motor working schematic to be implemented
Figure taken from UIUC: ECE 110 Lab Worksheet of Week 12

All we had to do was duplicate the circuit so it could run the 2 motors we needed as shown below:

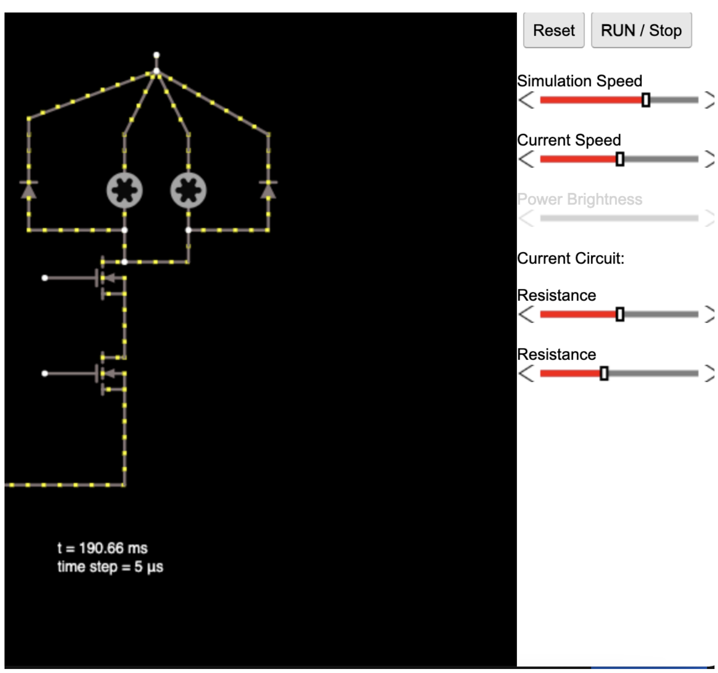


Figure 4: Circuit of the motor / MOSFET connections
Figure taken by using Falstad for ECE 110 Lab of Week 12 by Lab AB9 Members via https://www.falstad.com/circuit/

Finally, we were finished with the components! All we needed to do after this was to bring it all together! We used falstad to check all the information we found and put our circuit together abd we got this:

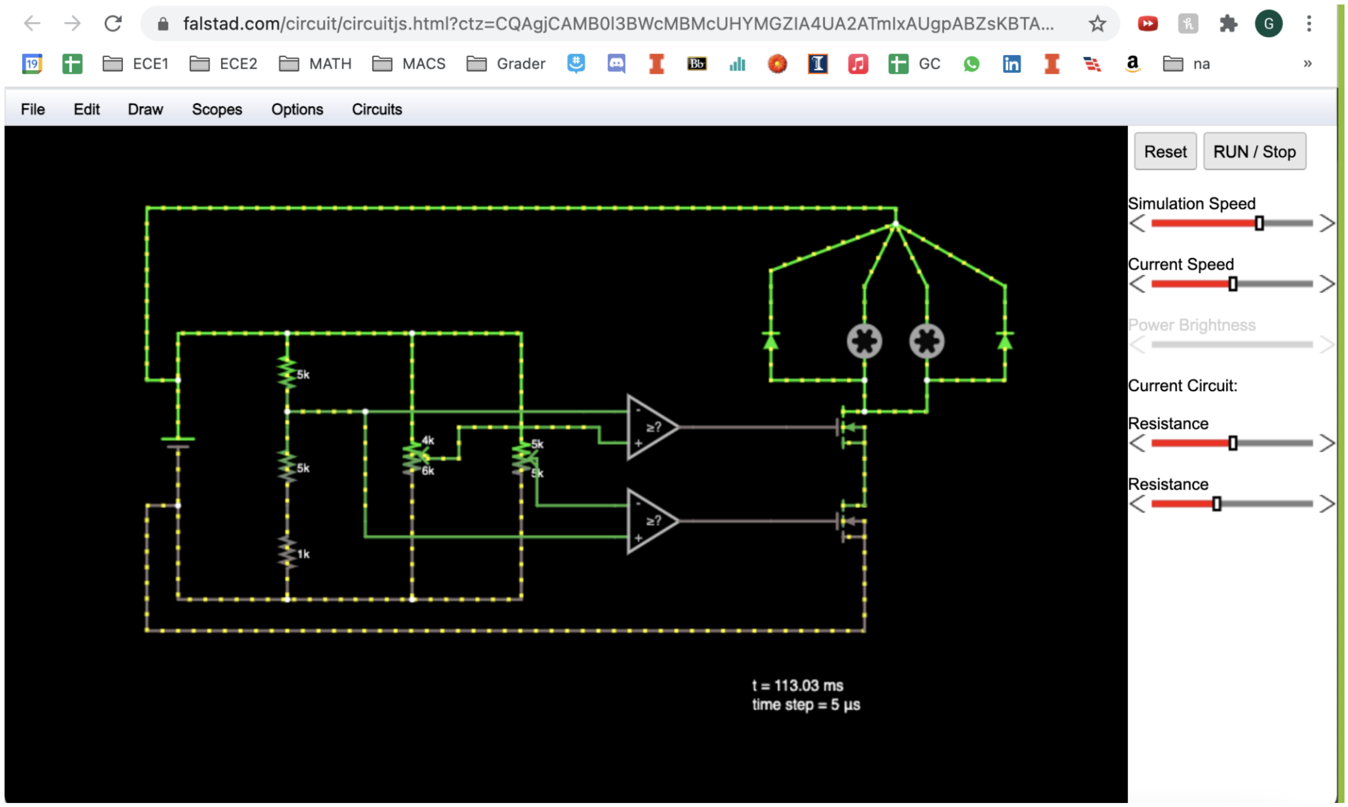


Figure 4: Final Circuit

Figure taken by using Falstad for ECE 110 Lab of Week 12 by Lab AB9 Members via https://www.falstad.com/circuit/

At the end, just to double-check, we recorded our values for Va, Vb and Vc when the circuit was running a) With our key, b) Without our key, c) With a different key (where key is a resistor) as shown below:

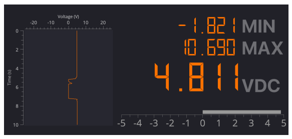
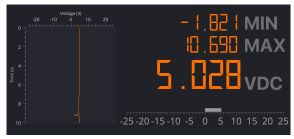
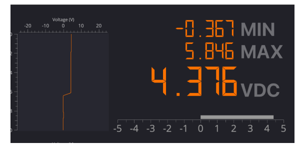
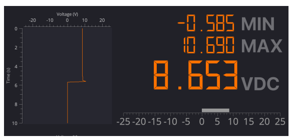
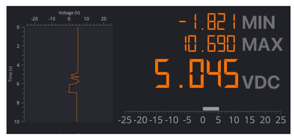
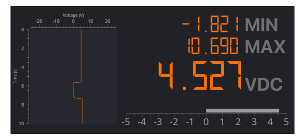
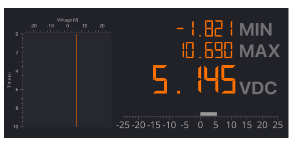
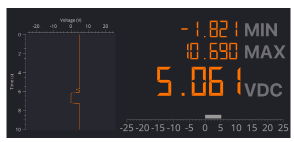
	Va	Vb	Vc	Motors Run?
With Key (1K Ohm Resistor)				Yes
Without Key				No
With a different Key (1.33K Ohm Resistor)				No

Figure 4: Final Values

Figure taken by using Scopy's M2K Voltmeter for ECE 110 Lab of Week 12 by Lab AB9 Members

Since in these cases, the motor only ran when Va was between Vb and Vc, we proved that our circuit works!

Troubleshooting & Validation:

We encountered a variety of issues while implementing the circuit that we simulated using falstad. Minor rookie issues including hooking up the negative wire of the motor to the ground and the positive wire to the drain of a mosfet, when the negative wire of the motor should be connected to the drain of a mosfet and the positive wire connected to power. More minor rookie issues included mixing up the Gates, Drains, and Sources on the mosfets which can be avoided by sketching out a physical circuit on paper with proper labeling.

An extremely useful engineering tool in this process was falstad, where we simulated our circuit. We were able to play around with resistance combinations to find a circuit of resistors/potentiometers that would let Va be within 10% of Vb and Vc. We were able to predict what values we would read for Va, Vb, and Vc when using our M2k by looking at our simulated circuit on falstad. We also used the M2k to narrow down where issues were occurring on our circuit. For example, we could check that Va, Vb, and Vc were as expected, thus narrowing the problem down to the comparators or mosfets. Then we could check that the comparators were giving the correct outputs, thus narrowing the problem down to the mosfets (where we found some rookie mistakes of mixing up the pins). The way we shortened the extent of our search was by looking at the oscilloscope: instead of the correct circuit that was to be displayed like this:

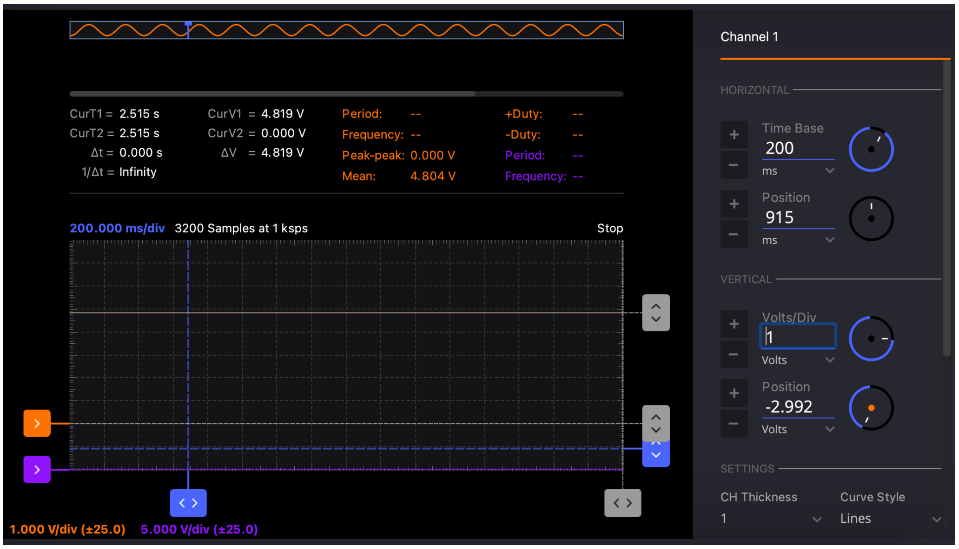


Figure 4: Oscilloscope Values

Figure taken by using Scopy's M2K Oscilloscope for ECE 110 Lab of Week 12 by Lab AB9 Members

Our wave pattern was fluctuating for our MOSFET gate, and so we realized that we had to revisit that section of our circuit.

An unpredictable issue we ran into is that one of our cars was using a battery that was operating at 8 volts instead of 9 volts (found by using the M2k). This caused Va to be lower than expected, and thus fall out of range of Vb and Vc, not allowing the car to run. We resimulated our circuit on falstad using 8 volts, predicted new voltages for Va, Vb, and Vc (which were correct) and were able to get the car to run for the 8 volt battery as well.

Conclusion & Future Work:

We definitely ran into some challenges throughout the entirety of the circuit design process. At the beginning, we were having some trouble understanding how the circuit was going to work and selecting which resistors to use. However, one of our group members remembered using Falstad earlier in the semester, and by building the circuit digitally first we were able to easily collaborate virtually and develop our understanding of what was occurring in the circuit without having to physically build it or do a lot of messy guess and check calculations. This was an example of using our engineering tools where it is important to remember resources and information gained in the past as well as demonstrating resilience when it is originally unclear how to begin a problem. Many of the challenges we encountered (as described in the Troubleshooting & Validation Section) were simply hooking up circuit components incorrectly or not understanding exactly how to connect everything together. However, we were able to look back at datasheets and collaborate as a team in order to determine where things were going wrong for each member of our team. Teamwork and communication were two more engineering tools we demonstrated with this issue as they are going to be crucial to our future endeavors in college and beyond. When building our circuits, we employed many of the components we have learned about in ECE 110 such as comparators, resistors, and potentiometers. Also, we used almost all of the circuit analysis techniques we learned, such as Kirchoff's Voltage and Current Laws, the Voltage Divider Rule, Nodal Analysis, and Thevenin Equivalent Circuits. We also used our M2K measurement equipment and Scopy Software to obtain voltage readings. For a future project, we thought we could combine the activities over the last few weeks to implement a light seeking car that only works when the correct key is inserted. In order to achieve this we would have to implement more circuit components, such as photoresistors, and generally combine our final circuit from weeks 8-10 of the semester with this circuit for our final project. In doing this, the car would run normally before the key is inserted, perhaps like the straight run car from week 10, and then attempt to follow light as soon as the proper resistor is added. We are all excited to utilize all of the knowledge gained throughout the semester in all of our future electronics projects.

Contributions:

Holly Roach:

I had a lot of trouble with the build, so I discussed that during the Troubleshooting & Validation section of the report. I also attended the first Saturday lab with my group to go over the Rc value with the TA's and try to work on the derivations for delta R. I also went to the second Saturday lab to work through some problems that our group had with the derivations with TA's. I came to the final lab with my build completed with the intention of taking measurements but realized there were major errors with my build preventing that (which I talked about during troubleshooting). I participated in and asked questions during group meetings.

Maddie Rydell:

I also attended the first Saturday open lab with my group and worked with them on understanding some of the concepts we were confused on while also beginning to work on our report. I also had trouble with the circuit build, so I attempted to bring a working circuit to our second lab but I had to work on that largely during the lab with the help of my group and TA's. I wrote a lot of the conclusion of the report as well as spent a lot of time working on derivations for delta R, which I also ran into many issues with that I attempted to troubleshoot.

Austin Paull:

While I did not take the lead on either the build of the circuit or the lab report. I helped work through all of the problems we had with the design. I assisted in the construction of our original design on Falstad so we could find our values for Va, Vb, and Vc theoretically before we continued with the actual build and measurements on our breadboard. I participated in the lab and assisted my team wherever needed.

Geitanksha Tandon:

I took on the responsibility of formulating the report based on the rest of my team's work. I worked with my team to figure out the values of Rkey, R and the Potentiometers for the original circuit. I got my circuit to work during the first lab session, so luckily I was able to assist my other team members in finishing their circuits. During the rest of the lab sessions and during the first Saturday extra lab I was finalizing the report, recording the values of Va, Vb, Vc for the 3 conditions of ours, and made sure that my team members were up to par with the work that needed to be done by planning a schedule of sorts for us to keep track.