ECE110 Final Project Report

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May 4th, 2022

Abstract (jacobop2, vverm2, curtiss8, calebs13)

Designing a car that had controllable speed, steering, and a reversing capability required the combination of many circuit components we studied this semester. First, because of the differing voltage requirements of various components, we need to construct a circuit using a Zener diode that converts the 9V battery source to 5V, so all components have the proper voltage. Then diodes are used to logically AND the speed and balance control signals. Then, we used a mic and amplifier chip to create a high voltage output when there is a loud noise. Next, we connected a MOSFET timed circuit in sequence with this mic output, so that when the output was high, the MOSFET gate allowed current to flow, creating a discharging path for the capacitor. This signal then went to the H-Bridge to enable the reverse signal and change the direction of movement. This paper discusses each of these segments in greater detail and investigates how each component works together to create each desired function for our car.

Introduction (jacobop2, vverm2, curtiss8, calebsl3)

Throughout the semester our group has worked on various modules with the goal of understanding circuit components enough to create a car with speed control, turning, and reverse capabilities. Most importantly, the modules regarding speed and balance control, and gates, the h-bridge, the mic, and the MOSFET timed reaction each played a critical role in our car.

First, we had to answer the question of speed and balance control of the two motors. We want to be able to control how fast our car goes, and we cannot have one motor turning faster than the other or else the car will not go in a straight line. We learned in the lab how to use potentiometers to create pulse width modulation (PWM) which allowed us to control the duty cycles of the currents the motor received by tuning potentiometers. This allowed us to control the speed that each motor turned at as well as balance the current each motor received to account for potential differences in manufacturing. To avoid conflicting speed and balance signals, the two had to be combined into one control for each motor. This was achieved by creating AND logic circuits with Zener diodes.

Then, we had to make use of the unique capabilities of a microphone. When the mic receives a loud noise, it produces a high voltage. Unfortunately, on its own, this voltage is often very small. So, we must run the output of the mic through an amplifier chip to give us a high enough voltage to make the MOSFET circuit function as desired. The MOSFET circuit receives the output from the mic. When the output is high (there is a loud noise), the MOSFET gate closes, allowing current to flow from drain to source. This creates a discharging path for the capacitor in the MOSFET circuit, which triggers the discharging process, sending the signal to the H-Bridge. We can control the time that this signal lasts by changing the time the capacitor takes to discharge, which is given by $\boldsymbol{t}$ = RC.

The outputs from the reverse signal and multi signal interfaces then go into the H-Bridge which is our motor controller. Based upon the signals sent by the reverse signal interface the motors go either in the forward or reverse directions and from the multi signal interface the speed of the motors.

Speed and Balance Control (curtiss8)

Two key features of our ultrasonic car are the wheel balance control, which allows for adjustments in speed between the two wheels to either turn or account for manufacturing differences in the motors, and the speed control, which as the name suggests allows us to adjust the speed of rotation of the motors. Using potentiometers, we are able to independently control the amount of current each motor receives. The key part of the balance control is the selectable duty cycle oscillator controlled via a potentiometer. This allows us to fine tune the car such that there is little to no difference in how much voltage is given to the motors. In practice this is done by creating the sub circuit with two Zener diodes, a potentiometer, and three Schmitt triggers as shown in figure 1. The Schmitt triggers allow us to have the upper part of the waveform created by the oscillator to control one motor and the lower part for another, in practice creating 'balance' with the two. The speed control circuit (shown on the right) functions the exact same as the balance control, just without the third inverter. This way both motors receive the same 'speed' input.

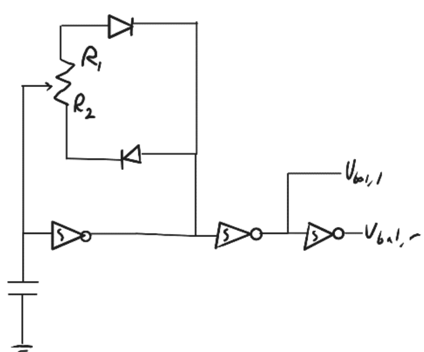

Figure 1: Balance Control sub-circuit

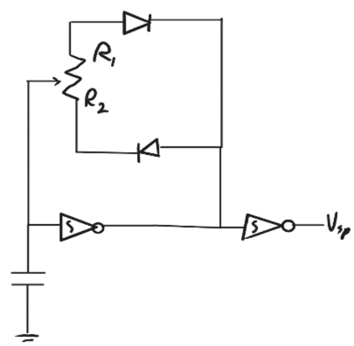

Figure 2: Speed Control sub-circuit

V_1	V_2	V_{out}
0	0	0
0	1	0
1	0	0
1	1	1

Figure 3: AND Gate inputs/outputs

However, we can't have two separate circuits that independently control motor current. For example, if the motor balance was allowing an equal amount of current to each circuit but the speed was allowing none, what happens? We needed some way to combine the respective signals from the balance and speed control into one to control the motor. In comes the AND gate**.** Using AND logic allows us to take both our inputs, the speed and balance control, into consideration when delivering the output to the motor. As shown in the table, the motor will only receive a current when both inputs are supplying a current. To achieve this logic, our group simply used diodes. As shown in figure FILL IN, only V_{bat} is capable of flowing to V_{out}, as our inputs V1 and V2 are blocked by the diodes. When V1 or V2 are much smaller than V_{bat}, all of the current will flow from V_{bat} through either of the diodes into ground. However, if a voltage is being supplied by both of the inputs, some of the current from V_{bat} will instead flow to V_{out}. The more voltage supplied by the inputs, the more voltage will flow through V_{out}. We could use Schmitt Triggers on the output to force the output into logical high and low, however, this is not necessary for proper functionality of speed and balance control in the car.

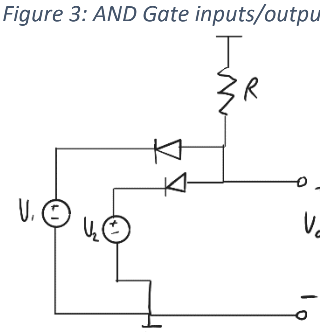

Figure 4: Diode Based AND sub-circuit

MOSEFET Timed Reaction (jacobop2)

One key component required by our car is to have the capability to reverse for a set amount of time. In order to achieve this, we must find a way to first of all send a signal to the motors to reverse them, and second control the length of this signal in order to manipulate the time for which our car reverses. This necessitates the combination of capacitors, a MOSFET, and a Schmitt trigger. The first key component is a capacitor.

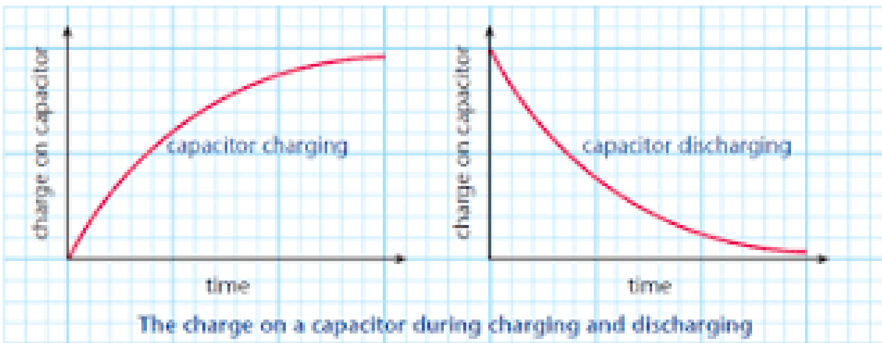

Figure 5: Graphs of a capacitor charging and discharging, respectively

Figure 5 shows the charging and discharging graphs for a capacitor. The rate at which capacitors charge and discharge is given by the time constant, $\boldsymbol{t}$. To calculate the time constant, we use the equation $\boldsymbol{t}$ = RC, where R represents the resistance and C the capacitance. It is important to notice that we can change both R and C and use these values to manipulate the time it takes for the capacitor to discharge. The use of capacitors in the more detailed MOSFET circuit will be discussed later. For now, we will investigate the next crucial component: the MOSFET.

Capacitors give us the opportunity to control the length of the signal sent to the motors. Now, we must use a MOSFET to determine when this signal is sent. As figure 2 demonstrates, each MOSFET has 3 pins: gate, drain, and source. Depending on the voltage at the gate pin, the drain and source pins either act like an open circuit or like a short circuit. In this case, when the voltage at the gate is high, the MOSFET acts like a short circuit, and allows current to flow through the drain and source pins. This ability to use an outside voltage to determine when current is allowed to flow, combined with the time control of capacitors gives us most of the circuit pieces we need to make our car reverse for a desired time. The last piece is the Schmitt trigger inverter. The Schmitt trigger is a simple device that inverts the voltage across its input and output pins, which is useful for balancing the signal sent out of the MOSFET, as well as generation of an oscillator which can be used to test the circuit. Now, with the basic knowledge of these pieces in place, we can look at the full MOSFET timed reaction circuit in figure 7.

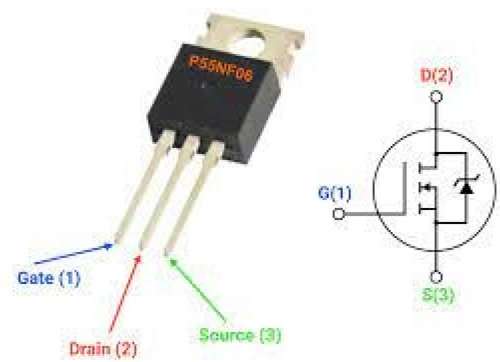

Figure 6: A MOSFET and its pin diagram

Notice the blue line dividing the circuit in two halves. The left side is simply used to generate an oscillating signal which can be used to test the transistor. As the capacitor starts charging at low voltage, the input to the Schmitt trigger is low, meaning the output is high. This creates a voltage difference across the resistor which continues charging the capacitor. Once the capacitor is more charged, the input voltage to the trigger is high, which means the output voltage is low. This causes the capacitor to discharge through the resistor, and this cycle continues, producing the output seen in figure 8.

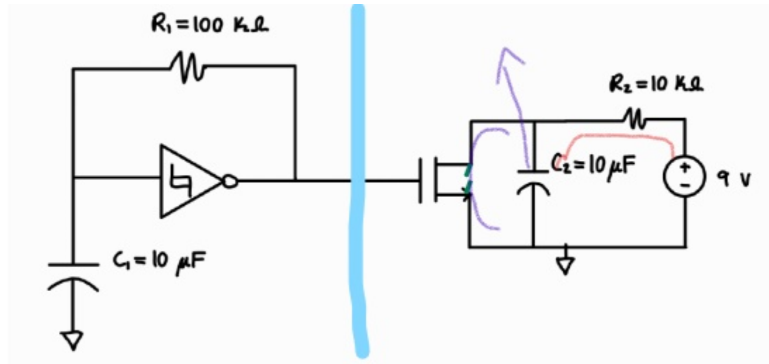

Figure 7: The MOSFET timed reaction circuit

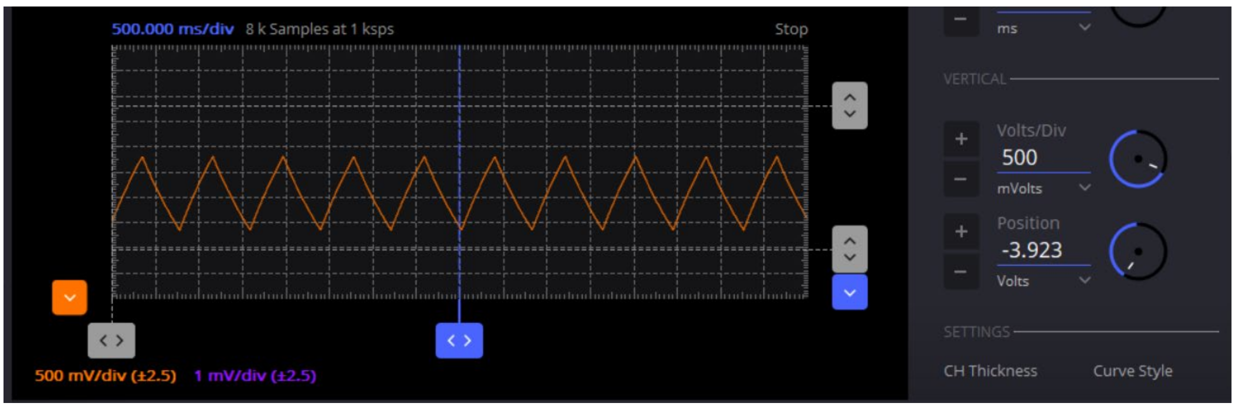

Figure 8: The orange graph shows the voltage across the capacitor in the Schmitt trigger oscillator

As the figure 8 shows, the voltage produced oscillates. This allows us to test our MOSFET reaction by repeatedly triggering the MOSFET to let current flow and seeing how the signal is sent. **NOTE: This oscillator was not part of the actual circuit used in the car!** This is because rather than a constant oscillating signal, we want the signal to be sent only when there is a loud noise. By connecting the MOSFET circuit to the mic output, when the mic hears a loud noise and produces voltage, the MOSFET transistor in the right half of the circuit will close. To understand what happens when this occurs, we must first look at what happens when the MOSFET acts as an open circuit. When the circuit is open, the voltage source is connected to the capacitor across a resistor. This causes the capacitor to charge along the red path as seen in figure 3. Then, when the gate closes, the capacitor is provided with a discharging path (as seen in blue in figure 3). This means that when the mic output is high, the gate closes, and the capacitor discharges, pushing the signal to the h-bridge and then to the motors. So, by using this design, and modifying the time constant of the capacitor, we can control the time that a signal is sent to the motors based on the mic output. With the h-bridge, this signal will briefly reverse the motors, creating the reverse effect that is desired.

Microphone Module (vverm2)

One of the major components of our car is the microphone module, which enables the MOSFET Timed Reaction and our reverse signal. The microphone that we use is an Electret Microphone Capsule which is able to create a small signal when it hears noise, due to the nature of the microphone we have to immediately amplify the signal in order to have less interference. This is because, as said in the introductory paragraphs of the “Microphone with Voltage Amplification” module, “Tiny signal + tiny noises = significant noise interference!” We use the (Texas Instruments LM358) microcontroller as an op amp to provide a voltage gain for the signal sent from the microphone, since the voltage coming from the microphone is extremely small. This amplified signal is sent to the MOSFET Timed Reaction to create the reverse signals that go into our Motor Controller. Though I will not go over the specifics of the microphone module’s functionality it is worth noting that the voltage gain is produced using a feedback resistor and the microcontroller (as shown in the figure 10) which can be shown in the equation $G_V = 100k\Omega/1k\Omega$. This is derived from the equation $G_V = R_{feedback} / R_{in}$ where G_V is the voltage gain in a closed loop (like in figure 10).

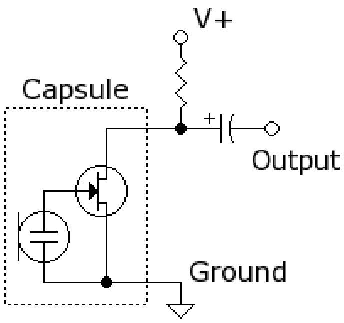

Figure 9: Generic example of an Electret Microphone Capsule

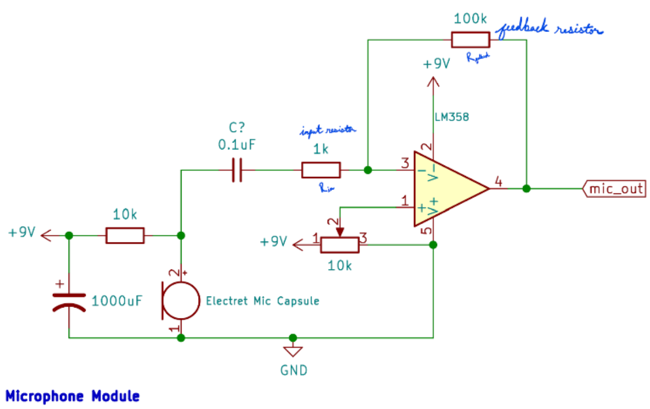

Figure 10: The Microphone Module sub-circuit including the microcontroller and Electret Mic Capsule from our final schematic for the car (labeled)

9V to 5V (DC to DC) Power Converter (calebsl3)

While many components in our various circuits function normally when connected to the 9 V DC power supply that the battery provides, there are some components such as the Schmitt trigger inverters which would break if 9 V was applied to them and require a 5 V DC power source instead. Due

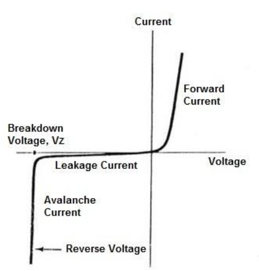

Figure 11: IV curve of a Zener diode

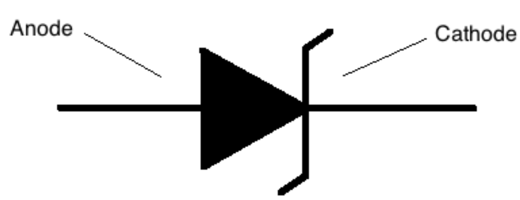

Figure 12: Schematic Symbol of a Zener Diode

to these lower voltage requirements we needed to create a circuit capable of taking a 9 V DC power source and lowering it to 5 V. To achieve this, we constructed a circuit consisting of the 9 V battery, various resistors, a capacitor, and a Zener diode. A Zener diode is a special type of diode that allows for current to flow in either direction once the turn on voltage is reached for its respective polarity. The IV curve and schematic symbol of a Zener diode are shown in figure 11 and figure 12 below, respectively.

Since the reverse-bias turn-on voltage is approximately 5V, placing our circuit components which require a 5V source in parallel with the Zener diode oriented such that the diode is reverse-biased will solve our power conversion problem. Knowing this we can sketch a basic schematic for the circuit which is shown in figure 13. We know that the Zener diode will have a maximum voltage of 5 V across it, and by Kirchhoff's voltage law the sum of any voltage rises and drops in any closed loop of a circuit equals 0 V. Therefore, we need to place a resistor in the circuit to dissipate the other 4V of the 9V battery which is represented by R1 in figure 13. Now the only thing left to figure out is what resistance should be used for the resistive network.

There are two major considerations to consider when choosing a resistor or network of resistors to place here, the maximum power consumption of the resistive network and the value of the resistance of the resistive network. It is given that the total current drawn by all components that

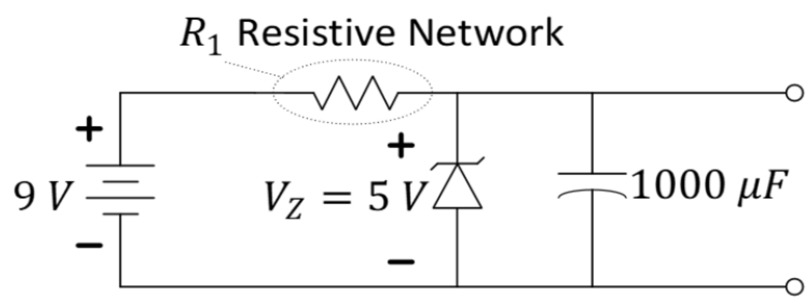

Figure 13: The 9V to 5V Converter sub-circuit

require a 5 V source is 50 mA. Using this current value, we can model all of these components as one resistor placed across the region of the circuit that is currently an open circuit. The resistive load of this resistor has a value of 100 Ω. Knowing this value, we can find the range of values of our resistive network that guarantees the current through the diode is greater than or equal to 0 mA. By using Kirchhoff's Voltage Law on the outer loop, combined with the fact that at the maximum value of R1, the current through the diode will equal 0 mA, it is found that the resistive network must have a total resistance at or below 80 Ω. Now the only thing left to consider is the power that is consumed by each resistor in the network. Each resistor in the network is rated for a maximum of 0.25 W, but to be safe we want the maximum power dissipation of each resistor to be less than or equal to 0.2 W. Using the Falstad Circuit Simulator to simulate a variety of resistor networks, we found that two 47 Ω resistors in series, placed in parallel with a 330 Ω resistor fit

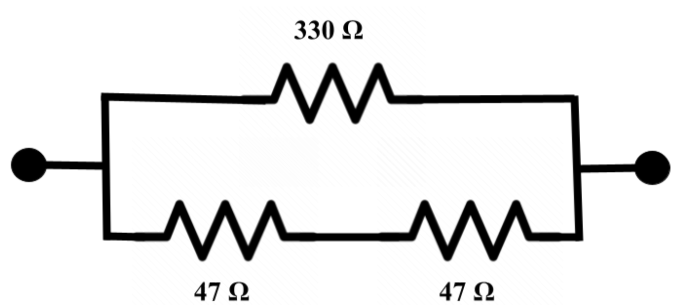

Figure 14: Our resistive network for the sub-circuit in figure 13

all of the requirements quite perfectly (see figure 14). This network has an effective resistance of 73.160 Ω and the maximum power dissipated by a single resistor in the network is 0.07691 W which falls far below the threshold of 0.2 W we set for ourselves earlier. If we wanted to change the number of components connected to the 5 V source, all we would have to do is find the new current drawn by all 5 V components and repeat the calculations above with the new current draw and resistive load values.

H-Bridge Motor Controller (vverm2)

Perhaps the corner piece component of our car is the H-Bridge which acts as a major part of our motor controller. Though not the most complex part of our overall circuit, it is where the entire car comes together. At its base level, the H-Bridge allows our motors to move in both the forward and backward directions by switching the flow of current going through the motors. The simplest form of H-Bridge we can construct (theoretically) is created using four switches as shown in figure 15. When only switches 1 and 4 are on then the motor goes in the forwards direction and when only switches 2 and 3 are on the motor goes in the backwards direction. The reason this happens is because we are using DC motors, due to the nature of DC motors when the current goes in the ‘reverse’ direction the entire part is moving in the direction opposite of what it usually would. We can visualize this (in a basic manner) using Fleming’s left-hand rule for electric motors, which can be compared to Fleming’s right hand. This visual mnemonic helps us see that when current is flipped the “Thrust of Motion”, which can also be called the ‘motion of the conductor’, also flips. So as our H-Bridge changes the flow of current we are also changing the direction of the mechanical force that is being created in the motor.

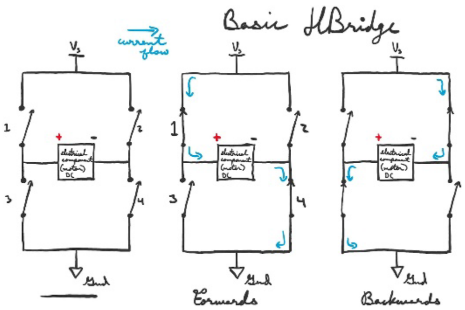

Figure 15: A schematic of the basic form of an H-Bridge

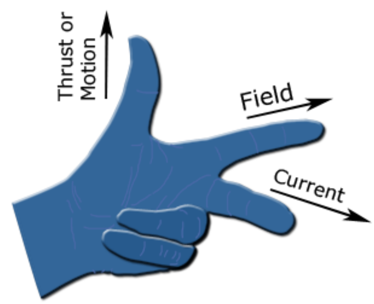

Figure 16: An example of Fleming’s left-hand rule for electric motors being used (field being for magnetic field)

Now that we know how and why an H-Bridge works, we can show how it’s implemented in our car. For the car, we used an IC that was provided to us in the course lab kit which had two H-Bridges on it. The SN754410NE IC has two logic pins as well as an enable pin for each motor, the IC is also

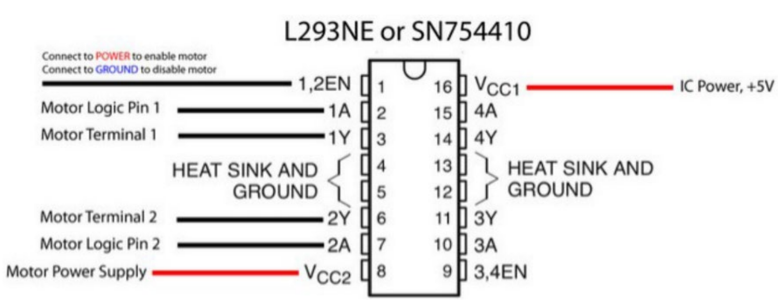

Figure 17: The given trace of the SN754410NE IC used in our car with pin labels

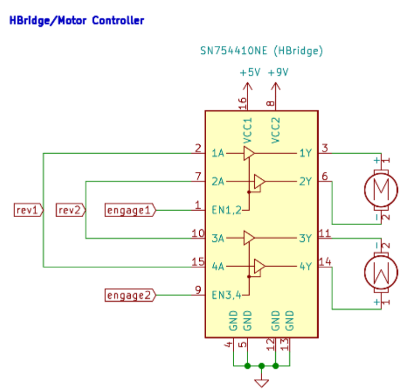

Figure 18: The trace of the SN754410NE IC on our final schematic for the car

interesting in the fact it requires two voltage sources for itself and the motors. For our motors the IC must receive 9 Volts in pin 8 and to power the IC itself it must receive 5 Volts in pin 16. We can get our 9 Volt source from the battery, which is connected to the power rails, however for the 5 Volt source we must take it from our 9V to 5V (DC to DC) Power Converter. Now that we have our power for the IC we must connect it to ground, since we have both motors in our IC we must plug into ground for each motor as well as our IC which is done through 4 pins (pins 4, 5, 12, and 13). Once our power is sorted, we can go and find input for the rest of our pins. The motors are plugged into the motor terminals (in the opposite orientation of each other) and receive the engage and logic signals from H-Bridge and our car can move! Our logic pins determine what direction the motors would be moving, are our two reverse signals from the Reverse Signal Interface. These act as the triggers that flip the switches in the H-Bridge that determine the direction of movement for our car. Our enable pins are filled by the two engage signals from our Multi Signal Interface which tell our motors at what speed they should be moving and keep them from moving differently due to manufacturing differences. The signal received in the engage signals are PWM waves created through the Multi Signal Interface from the Speed and Balance Control, both engage pins receiving the inverse signal. This is so that one, since the motors are in opposite orientations, the motors receive the same amount of voltage and in turn are equal in movement. Altogether the H-Bridge with these input signals comprise the Motor Controller for our car.

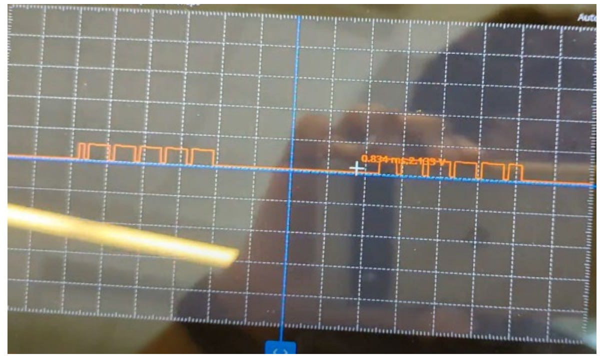

Figure 19: A picture of the PWM wave from the Multi Signal Interface going into the H-Bridge shown on an oscilloscope

Conclusion (jacobop2, vverm2)

Overall, the combination of all the described sub-circuits allowed us to create a car with all our desired functions. The process required us to use many of the skills we developed over the semester. Beginning with the construction of each individual module, we demonstrated our ability to understand circuit schematics and the function of each component (capacitors, transistors, ICs, diodes, etc.). However, it was not enough to simply understand our own module; the assembly of our car forced us to understand how each aspect worked in conjunction with the others. To combine the modules while still maintaining their functionality we had to debug extensively using oscilloscopes and multimeters from Scopy (which was the only thing available to us for such purposes). Putting our skills and knowledge to use, we were able to create our car which had speed control, turning, and reverse capabilities. This project required each group member to gain in depth knowledge regarding their modules and its functions. Additionally, every group member obtained a substantial amount of practice with general circuitry concepts (assembly, debugging, testing, etc.). On a more universal level, we practiced the skills of collaboration and teamwork which we can now apply across every area of our lives. In the future, we will be able to use all of these skills, from knowledge of individual circuit components all the way to teamwork to tackle even more complicated projects and find success in our careers.

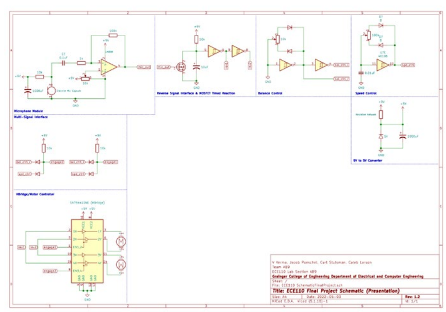

Figure 20: Our full final schematic for the car