Final Design Report: A Speed and Balanced Controlled Clap-Reverse Car

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Abstract (Team)

Throughout this course, we have studied techniques for turning environmental stimuli and translating them into electrical signals which can be used to control a small robotic car. These skills have culminated in our final project, a car with wheel speed and balance control which reverses when a clap occurs. The methods we use in this project (that we have learned throughout this lab) can be adapted for many different applications, which can address a multitude of differing stimuli with unique responses.

Introduction (Team)

Throughout ECE110, we have explored many aspects of obtaining stimuli and converting them into electrical signals that can be used to produce responses. Previous labs, like the Cloud Detector and the Light Seeking Robot have used light stimuli to produce a reaction, be it turning an LED on or causing the wheels to turn on a car. The Straight-Run Car with Speed Control provided lessons in concepts such as pulse-wave modulation and logical ANDs in order to create multi-signal interfaces, both of which are standard in robotics for dealing with things like manufacturing differences in motors.

In order to accomplish our assigned objective of creating a speed and balance-controlled car which reverses for a period of time after a clap, we essentially utilized strategies from previous labs to handle a more complex stimuli and response. Much of the nuance of the project came with the challenges associated with collecting stimuli (i.e. needing to amplify the microphone capsule's voltage) and connecting the technologies together (i.e. ensuring that each component got the correct Voltage where and when it needed to). This technical report documents the decisions we made to address these challenges and complete the car.

1. Power Source: 9-Volt-to-5-Volt DC Converter (ralphn2)

Most of the electronic devices used in our final project are compatible with a 9-volts power source which we can acquire from a 9-volts battery. However, Some electronic devices such as the ultrasonic sensor in our lab kit are designed to work with a maximum voltage supply below the 9-volts battery that we have in our lab kit. Specifically, the motor controller circuit that we designed for the speed and balanced controlled clap-reverse car requires a 5 volts power source for its logic power (V_{CC1}). We utilized a zener diode in order to design a 9-volt-to-5-volt dc converter so that we can supply the right voltage supply for each circuit that we designed for our project.

The zener diode is a special diode that allows current to flow in either direction once a turn-on voltage (zener breakdown voltage) has been applied in that polarity. Although the forward-bias turn-on voltage of a zener diode is typical to that of a normal diode, the reverse-bias turn-on voltage can be designed to take on different turn-on voltage for different applications.

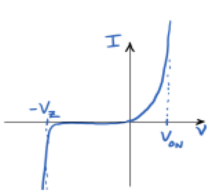


Figure 1.1 : Zener Diode I-V Characteristics Curve (source)

Unlike a normal diode, when a reverse voltage is applied to the zener diode, the voltage across the diode remains constant at its breakdown voltage (5 volts in our design) and will not suffer damage when applied a reverse voltage of high magnitude. Figure 1.1 shows the zener diode I-V characteristics curve where it can be observed that the voltage across the zener diode is constant at its breakdown voltage in either current direction (-Vz or Von).

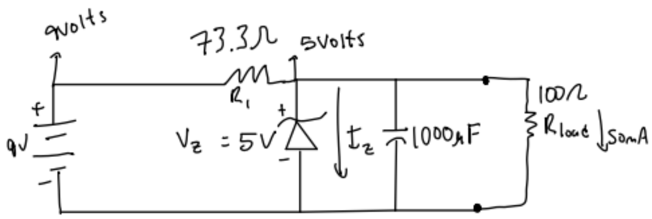


Figure 1.2: 9-volts-to-5-volts dc converter circuit design

Figure 1.2 represents the design that we implemented for our 9-volt-to-5-volt dc converter (reference). We connected a zener diode with a breakdown voltage of 5 volts in reverse bias to an input voltage source of 9 volts which is the 9-volt battery that we use to power most of our circuits for the project. The zener diode behaves as a battery during ON state, hence, as long as it receives its breakdown voltage of 5 volts in that polarity, a change in input voltage or in load resistance will not change the output voltage across the zener diode. Thus, the zener diode provides constant voltage across load. We used the voltage output supplied from the zener diode, which is 5 volts, to power our balance and speed control circuit.

When utilizing the zener diode, we can adjust the current that flows through the load by adjusting the resistance from the resistive network (R1), which is connected in series with the input voltage (9-volts battery), as shown in figure 1.2 in order to provide sufficient current for load. In our design, we used a resistance of 73.3 Ω for our resistive network (R1) by connecting three 220 Ω resistors in parallel so that a current of 50 mA is provided to the load. How much current we need to provide to the load depends on the current draw of the electronics that we will use in that load.

2. Multi-Signal Interface(lorenzo9)

For our final project, we wanted to be able to control the speed of the car and we wanted to make sure the car is able to move in a straight line. In order to do that we implemented a speed control and a balance control signal generation. We implemented a logical AND gate, to handle this complex motor response. Both signals need to provide high voltage to get a motor response.

The speed of the motors is a very important task for this project. There are many ways in order to control the speed of the motor, but the best one suited for this project was using pulse width modulation. We first learned about Pulse Width Modulation during our week 8 lab and pre-lab. Information that we provide below about the duty cycle and the oscillations, were referenced from the lab document "Pulse-Width Modulation using Diode Magic". We are essentially modifying the duty cycle of a pulse of a square wave signal. This method is efficient because we are able to control the frequency of high voltage pulses to the motor, instead of lowering or increasing the current flowing to the motor using a current limiting resistor. If the frequency of pulses is lower then there is more time between pulses which will seem like the wheels are spinning at a slower rate. Then when the frequency of the pulses is high there will be very little time between pulses and it will be like the motor is receiving the full supplied voltage. In order to control the frequency of the oscillator will be to change the RC time constant of the discharging and charging paths of the capacitor.

First of all we need to build the oscillator using a schmitt trigger, a resistor, and a capacitor. This oscillator will make our square wave pulses. The schmitt trigger will invert the input signal which will cause the capacitor to charge and discharge effectively making an oscillation. We then place a resistor between the output and input of the trigger to control the time of charging or discharging.
In order to change the frequency of these pulses we put a potentiometer in place of the resistor. Different resistances for the charging and discharging cycles of the capacitor will allow for a change of duty cycle. Then we also have to put a diode at each side of the potentiometer to differentiate the charging and discharging cycles. Then we can change the resistance for each path in order to affect the duty cycle (https://courses.engr.illinois.edu/ece110/sp2022/content/labs/Experiments/C_RC_PWM.pdf).

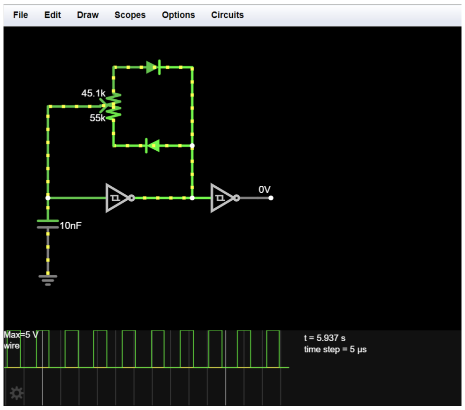


Figure 2.1: Falstad Simulation of a basic oscillator

For our final circuit we used the speed and balance generator circuits from the "Straight-Run Car with Speed Control" week 10 lab, and information that is discussed below about the PWM wheel balancer with speed control was referenced from this lab. The generators used the above mentioned pulse width modulation. It is important for the balance control to use PWM because the fabrication of motors is inconsistent, and most of the time even if the same voltage is applied to the motors, they will run at different speeds. This will cause the car to change direction from a straight line. Therefore we can send the pulses into each motor, but one of them will be inverted so that we can find the equilibrium where both wheels are running at the same speed ("Straight-Run Car with Speed Control").

Discussion about the logical AND gate below was referenced from the "Straight-Run Car with Speed Control" and the "Diode-based Logical And" labs. Now we need to control both of the signals that are being sent to the motor. To do this we are taking inspiration from the MOSFET AND gate that we made in the "Straight-Run Car with Speed Control" lab. We still needed to use the logical AND gate to control both of the signals, but instead we used diodes to implement the gate. Two diodes are used for each of the wheels, one takes the signal for the speed and one takes the signal for the balance for that wheel. When a high voltage is applied to both of the diodes, then there will be no voltage drop across the resistor so the high voltage will be sent into the double inverting schmitt triggers to clear up the signal and make a clear logical one. Both the signal for the speed and balance must be high in order for the output of the AND gate to be high, or logical one. In any other case where the voltage is low for either of the speed or balance, there will be a drop across the resistor and current will be able to flow through the diode to ground and a low voltage will go into the double inverting schmitt triggers which will cause the AND gate to output a low voltage, or logical zero ("Straight-Run Car with Speed Control", "Diode-based Logical And").

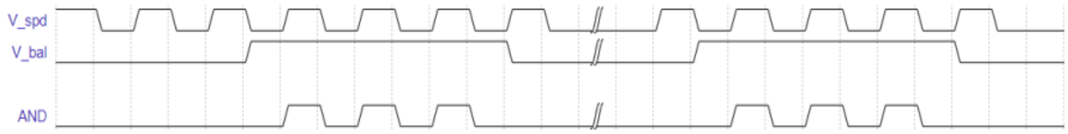
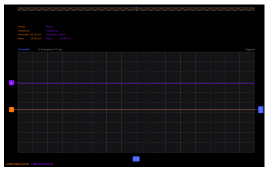
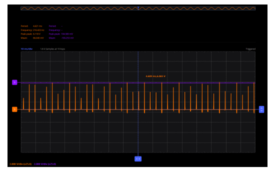
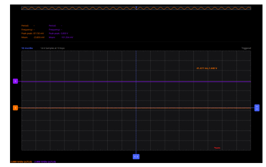
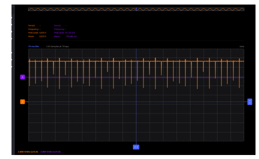


Figure 2.2: Waveform for speed, balance, and AND gate.

 Figure 2.3: Speed and balance off	 Figure 2.4: Speed on and balance off	 Figure 2.5: Speed off and balance on	 Figure 2.6: Speed on and balance on

Above you can see sample duty cycles of the speed and balance signals from the "Straight-Run Car with Speed Control" lab. The AND output is only high when the signals for both of the signals are both high and is low the rest of the time ("Straight-Run Car with Speed Control").

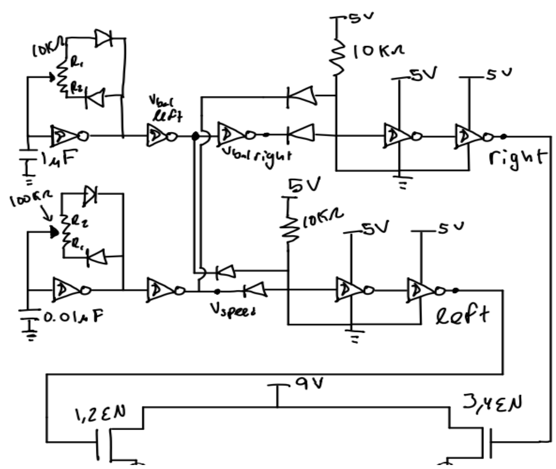


Figure 2.7: Final circuit for the speed and balance generation, and the diode based and going to H-bridge (discussed in section 5).

The final circuit that we used for this project was one where the speed and balance signals were generated with a PWM based oscillation which is then sent into a diode based AND which combines both of the signals. The output of the AND gate will depend on whether or not the speed and balance signals are high. Finally the ANDed signal for each wheel will be sent into the enable bits of the H-Bridge. The rest of the implementation of how the H-Bridge will handle the ANDed signal will be discussed later in the report. It is also important to note that this section of the circuit is all powered by 5 volts.

3. Reverse Signal Generation: microphone with voltage amplifier (ralphn2)

The input for our speed and balanced controlled clap-reverse car was accomplished by utilizing an elecret microphone capsule to detect sound created by a clap. The electret microphone capsule produces a response from ordinary sounds measured in the milivolts or tens-of-milivolts range. These voltages are small enough that typical electronics circuits would not capitalize them. Hence, we utilized the LM358 to amplify the output voltage from the microphone capsule. (reference)

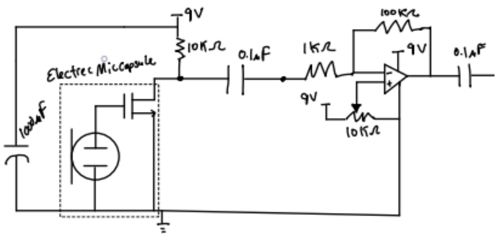
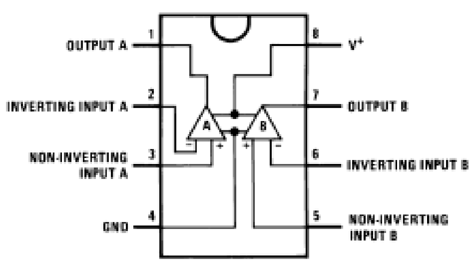


Figure 3.1: Microphone with voltage amplifier circuit design

With reference to the "Microphone with Voltage Amplification" module from our ECE 110 lab, we designed a circuit that amplifies the voltage from the microphone by a factor of 100 by using a 1 $k\Omega$ resistor in the negative input of the LM358 as shown in figure 3.1 and a 100 $k\Omega$ resistor as a feedback resistor from the output of the LM358 to the negative input. A voltage gain of the amplifier would be 100 which could be derived from this formula: $Gv = 100\ k\Omega\ /1\ k\Omega = 100$

With this, we can increase the amplification of the voltage received from the microphone by increasing the gap or difference between the resistor going in the negative input and the feedback resistor from the output to the negative input of the LM358 and using a capacitor with a larger capacitance. However, a larger amplification would increase the sensitivity of the mic which is not suitable for our experiment as the sound of the wheel is loud enough to be picked up by the microphone and generate a signal to reverse the wheel of the car whereas our goal is for the mic to only detect a clap from our hands. We referred to the LM358 datasheet to determine the pin configuration and function as shown in figure 3.2 below.



PIN			TYPE[1]	DESCRIPTION
NAME	D/P/LMC	YPB		
OUTA	1	A1	O	Output, channel A
–INA	2	B1	I	Inverting input, channel A
+INA	3	C1	I	Non-inverting input, channel A
GND / V–	4	C2	P	Ground for single-supply configurations. Negative supply for dual-supply configurations.
+INB	5	C3	I	Non-inverting input, channel B
–INB	6	B3	I	Inverting input, channel B
OUTB	7	A3	O	Output, channel B
V+	8	A2	P	Positive supply

Figure 3.2: Pin configuration and function of the LM358 (Source)

Signal Types: I = Input, O = Output, I/O = Input or Output, P = Power

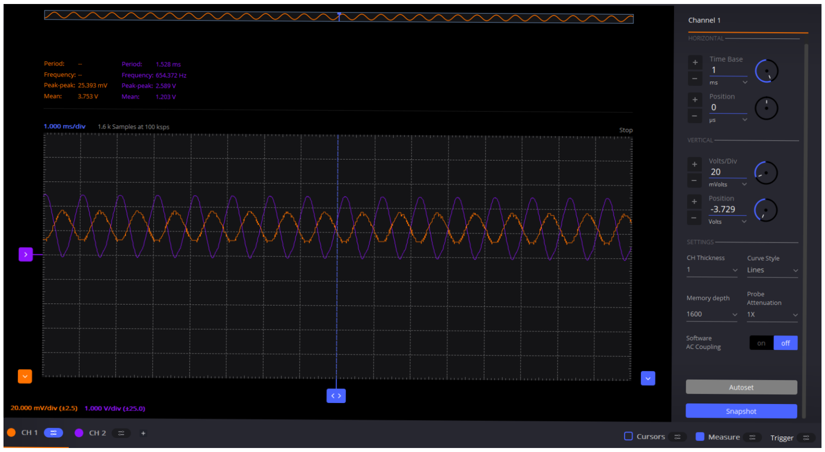


Figure 3.3: M2K voltage measurements before (orange) and after (purple) amplification from the LM358 when using a tone generator to play a constant tone into the microphone. Notice that the peak-to-peak Voltage after amplification is about 100 times that of the original signal, which aligns with our predicted amplification..

Figure 3.3 compares the voltage between 2 different points in our circuit design when the microphone picks up a constant tone from a tone generator. The orange signal is the voltage measured at a point in the circuit after the 0.1 μF capacitor and before the 1 $k\Omega$ resistor (before amplification) whereas the purple signal is the measured voltage of the output of the LM358 at a point after the 0.1 μF capacitor. From the peak-to-peak measurement shown in figure 3.3, we could see a voltage amplification of 100 from 25 Millivolts to 2.5 Volts which shows that our circuit design does its intended behavior.

For our design, we used a potentiometer of 10 $k\Omega$ to act as a voltage divider so that the positive and negative input of the LM358 each get a 4.5 volts supply. Since the circuit is powered by a 9-volts battery, by tuning the potentiometer to about half, we will get roughly 4.5 volts on both the positive and negative input of the LM358. This is because shifting the voltage at the positive input of the LM358 will also raise the voltage of the negative input according to the properties of the LM358 operational amplifier which could be referred from the datasheet. Furthermore, since capacitors resist large fluctuations in voltage, (they need time to charge and discharge) we used a 1000 μF (electrolytic) capacitor across the battery to eliminate voltage changes that could develop on the power rails.

Simply explained, when sound from a clap is detected by the microphone, the signal from the microphone will be amplified through the LM358 and then later used as an input for the reverse signal interface circuit from the 0.1 μF capacitor which is connected to the output of the LM358 (amplifier) as shown in figure 3.1.

4. Reverse Signal Interface (cbmello2)

The reverse signal interface serves as an intermediary controller for the signal produced by the electret microphone, and serves essentially to create a processed timed-reaction that dictates the disruption of the standard motor functioning. Standard motor functioning is defined as the base behavior of the motor as dictated by the multi-signal interface and motor controller (more on that next section). The microphone signal disrupts the standard motor functioning, leading to a temporary change in the balance signal through the generation of a reverse signal, as explained in the last section. The signal generated by the microphone with the voltage amplifier, however, doesn't dictate in any way the duration of the standard motor functioning disruption, and therefore needs to be delegated to a time-reaction interface so that the signal can be processed to perform the desired behavior. In other words, we need to use the reverse-signal to generate a controlled timed-reaction to perform the sought motor behavior.

To perform the behavior described above, we used a combination of Schmitt-Trigger Inverters to clean the microphone signal, a passively charging capacitor to control the timed-reaction, and a MOSFET transistor to delegate the reverse-signal disruption signal and sent it to the motor controller. This designed can be referenced to the "MOSFET Switching Circuit" module, with the added feature of signal clearing.

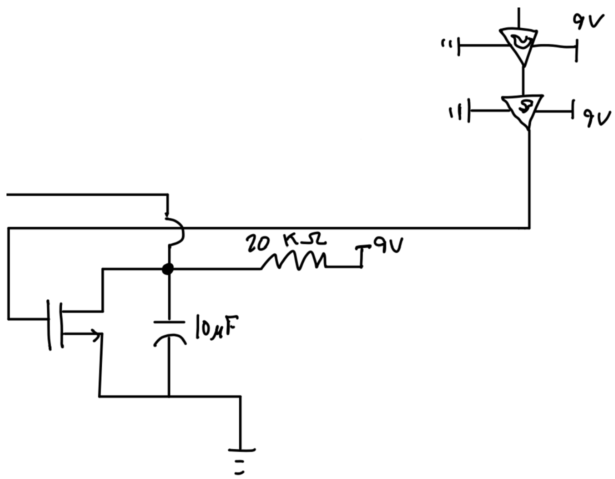


Figure 4.1: Signal processing a timed-reaction through MOSFET switching and Schmitt-Trigger Inverter signal clearing circuit design.

The first section to understand about this circuit is the one located at the top-right corner of the design diagram, which connects directly to the reverse signal generated by the microphone and voltage amplifier.

The microphone generated reverse signal is a spike that lasts as long as the sound that produces it, and therefore can't account by itself the necessary duration of the timed reaction of the disruption of the standard motor functioning. The barrier here is to clearly detect the microphone signal without having to deal with continuous in-between voltages in an analog wave.

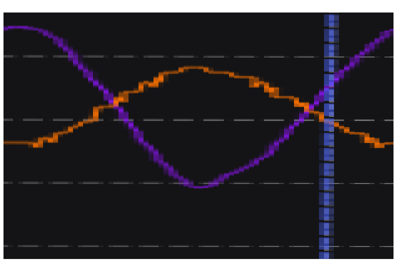


Figure 4.2: Single spike in the reverse-signal generation circuit generated by a tone generator.

As demonstrated by the voltage spike, this signal not only has a low-voltage section but a peak section. However, the in-betweens might make the detection of a disruptive noise too sensitive (or not enough) to correctly assess whether or not a disruptive signal should be detected. The necessity to make this signal clearer also becomes evident when considering the 30N06L MOSFET transistor offset voltage of 2.5V (as specified by the model's datasheet), which caps the amount of voltage that will be recognized as an ideal reverse signal. The way we clean up the signal is by using the same method used in the multi-signal interface previously in this report: two CD40106BE Schmitt-Trigger Inverters. The output signal will be of the same general logic as the input, but the in-between signals will be cleaningly divided into high and low states.

After this signal is successfully detected by the MOSFET (and it has a voltage >25), the MOSFET will serve as a switch, closing the circuit containing a 10 microfarad capacitor. The function of this capacitor is to discharge in a timed reaction once the offset voltage is detected by the MOSFET and the circuit is closed. To have the capacitor charged before the circuit closes so that for the instant it is signaled to discharge it already holds the necessary charge, we have a passive charging closed circuit that will keep the capacitor always charging as long as the MOSFET doesn't change the path of least resistance by closing the circuit. The reason the capacitor is iterating with the passive-charging right part of the circuit when the MOSFET switch is open and starts to discharge once the left section of the circuit is closed, is that the left section has less resistance than the passive-charging one due to the 20 Kiloohm resistor between the source and the drain of the MOSFET.

Once that signal is detected by the capacitor, it will discharge directly into the motor controller, and be used to change the standard motor functioning to reverse the motion of the motor temporarily. The time will be dependent on the t_{fall} of the capacitor.

5. **Motor Controller** (mhv4)

Motor control for the speed and balanced controlled clap-reverse car was accomplished using a Texas Instruments SN754410NE Quadruple Half-H Driver IC chip (the datasheet for which can be found here). This chip contains two H-bridges that allow control of the direction of the motor using MOSFETs.

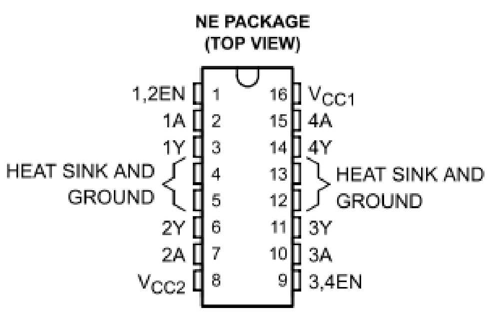


Figure 5.1: The Pin labelings for H-bridge (Source).

Pin (Left Wheel)	Pin (Right Wheel)	Function
1Y (3)	3Y (11)	Positive motor terminal (The + side of each motor is connected to its respective side).
2Y (6)	4Y (14)	Negative motor terminal
1A (2)	4A (15)	FORWARD logic pins. When this signal is high, the BACKWARD logic pins are low and the car moves forward.
2A (7)	3A (10)	BACKWARD logic pins. When this signal is high, the FORWARD logic

		pins are high and the car moves backward.
1,2 EN (1)	3,4 EN (9)	ENABLE pins for the left and right wheel respectively.

Pin	Function
4, 5, 12, 13	Heatsink and Ground. Connected to the common ground of the 9V source for the entire project.
V_{CC1} (16)	Logic Power. Connected to 5V clipped source from Zener Diode module.
V_{CC2} (8)	Motor Power. Connected to 9V power supply.

Figure 5.2: The meanings of each pin label in the context of the project.

The motor terminals (which are connected to the motors according to Figure 2) on the H-bridge supply the Voltage Source (and should be ~~9V, as the pin 8, V_{CC2} is connected to the only 9V voltage for the chip) to the motors when either the FORWARD or BACKWARD signals are high. These signals are inverses of one another, meaning FORWARD is only high when BACKWARD is low and vice versa. The FORWARD logic pins are connected to the inverted microphone signal (discussed earlier) and the BACKWARD pins are connected to the non-inverted microphone signal. When FORWARD is high, current flows from the positive terminal of each motor to the negative terminal, creating a forward-moving behavior. When BACKWARD is high, current flows from the negative terminal of each motor to the positive terminal, creating a backward-moving behavior.

The ENABLE pins allow for speed and balance control, as the ANDed signal of each wheel is connected to its respective ENABLE pin. When the ENABLE pins are low, both wheels do not turn, regardless of the status of the logic pins. The ENABLE pins are connected to their respective outputs from the Diode AND for each wheel.

Pins 4, 5, 8, 12, 13, and 16 are self-explanatory as either Voltage source connections (which are managed by our Zener 9V-to-5V module discussed in section 1) or ground connections. Their functionality and connections are documented in figure 2 and need no further explanation.

When the ENABLE pins are both high, before a clap is detected, FORWARD is high since the microphone module's output is 0, meaning the car advances because current is allowed to flow from V_{CC2} to ground going from + to - through the motor.When a clap occurs, the microphone of the Reverse Signal Generator detects the clap and its output becomes HIGH for the duration of its delayed reaction (discussed earlier), meaning the BACKWARD signal is high and the car reverses because current can flow from V_{CC2} to ground going from - to + through the motor.

We verified this behavior through using the MK2 in order to measure the Voltages of the logic pins under different speed and balance control conditions for the left wheel.

Speed (logic)	Balance (logic)	1A (2) (logic)	Pin 1Y Motor +Terminal (V)	Behavior
0	0	0	-0.05	Wheels do not turn
0	0	1	-0.05	Wheels do not turn

0	1	0	-0.06	Wheels do not turn
0	1	1	-0.06	Wheels do not turn
1	0	0	0.09	Other wheel turns quickly backward (not the wheel with the MK2 measurements)
1	0	1	0.09	Other wheel turns forward
1	1	0	0.42	Wheel turns quickly backward
1	1	1	2.91	Wheel turns quickly forward.

1	BAL	1	2.51	Wheels turn at same rate FORWARD.
1	BAL	0	0.43	Wheels turn at same rate BACKWARD.

Figure 5.3: This table shows the data for the left wheel.1Y was measured relative to ground. The first 8 cases are tuned close to potentiometer extremes with the final 2 being recorded with the wheels balanced at full speed. Potentiometer tunings that produce a high signal are denoted as a logic 1 with a low signal as a logic 0. BAL denotes a balanced balance control signal between both wheels. When 1A is low, a clap has been detected and the timed reaction is occurring.

The data collected verifies the function of not only the H-bridge module but also the Diode-based AND. Notice that neither wheel turns when Speed logic is low, as it is the shared signal between the two wheels. Furthermore, when all balance is given to the other wheel, the measured wheel does not turn. This is the intended behavior for speed and balance control.

Regarding the H-bridge, these data values also make sense, as the ENABLE bit translates the ANDed signals from speed and balance control into the intended behavior. The FORWARD state shows a high relative voltage across the motor and the BACKWARD state shows a low one (because the high voltage is on the negative terminal in the BACKWARD state). These measured values support the intended function of the h-bridge motor controller.

The only possible deviation from expectations occurs in the voltage measured for the FORWARD state on the 1Y pin. This voltage is distinctly lower from 9V. We believe this deviation to be somewhat caused by poor battery performance due to using an older 9V battery that had been in use since the beginning of the semester. The intended behavior still occurs, even with this deviation.

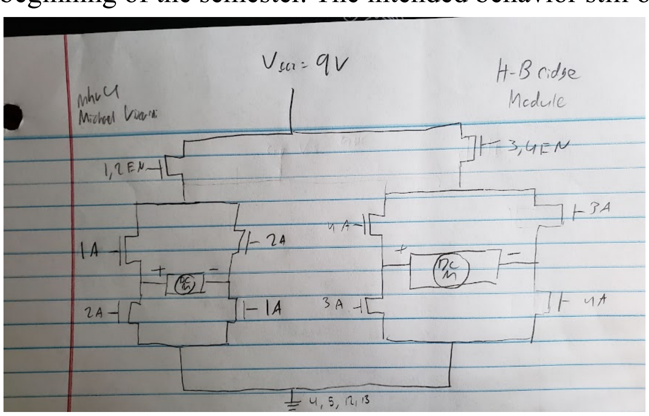


*Figure 5.4: A model used to define the behavior of the H-bridges. Notice that the ENABLE pins are depicted as gates for the sake of model simplicity, but this is not necessarily true. The Enable pins allow precise control (using the earlier-discussed potentiometers within the speed and balance control modules) of how much Voltage is supplied to each motor. This model holds absolutely true when on corner cases, though, as when either ENABLE pin is 0V, there is no path for current to flow from V_{cc2} to ground. Notice, too, that the logic pins also control where and when current is allowed to flow. Assuming both ENABLES are high, when FORWARD is high (1A/4A), current can flow from V_{CC2} to ground going + to - through the motor. The opposite is true for when BACKWARD is high (2A/3A). V_{cc1} is not depicted because it is a Voltage supply that powers internal IC components that control the logic of the H-bridge chip, and can be left abstract considering V_{CC1} should not affect behavior. It is essentially connected in parallel from 5V to ground.

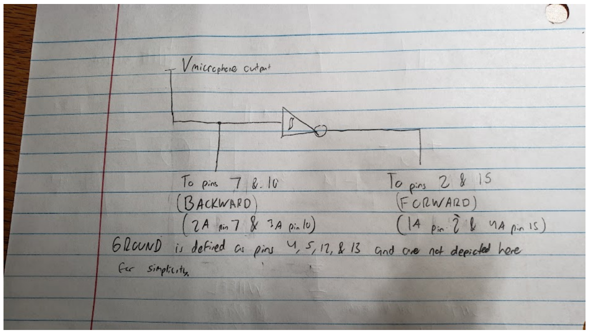


*Figure 5.5: The connections of logic pins from the microphone output. Notice that Ground is not depicted because Ground/Heatsink is pins 4, 5, 12, and 13 and can be seen in figure 3's schematic.

*Both figures 5.4 and 5.5 are also seen on the Final Circuit Schematic, but are included in this section in this form to ensure clarity.

<u>Conclusions and Further Direction</u> (Team)

Each of the previous sections discusses circuits which provides different purposes that each team member has built. By combining the circuits together, we were able to create a fully functional speed and balanced controlled clap-reverse car. The generated speed and balance control PWM signals are ANDed together using a Diode-based AND. This new ANDed signal is connected to the H-bridge's ENABLE pins, which allows for speed and balance control in tandem with the reversing behavior. The microphone/amplifier allows for the detection and translation of sound into electronic signals, which go on to trigger a MOSFET delayed response. An inverted form and a non-inverted form of this microphone output are connected to the H-bridge logic pins, creating the intended reversing behavior. The project utilizes a 9-volt battery to supply power to the circuits whilst employing a Zener 9V-to-5V to supply 5 volts to components which require 5V to operate safely.

Regarding further direction, this final project contains many skills that can be applied to real-world engineering applications. For example, take a robotic vacuum car like a roomba. These types of vacuums move forward until they bump into something that prevents their movement. It can be inferred that the technology that controls said vacuum is somewhat similar to our lab, but with a different stimulus and different responsive behavior. Just as our car turns around when a clap is detected, a roomba turns or reverses when a wall is detected. The fact of the matter is that, through our clap-reverse car and ECE110 as a whole, our group has learned how to detect and respond to stimuli with circuitry, something very important to electronic design and robotics.