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28.05.2017
Spring 2016

MIDDLE EAST TECHNICAL UNIVERSITY

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

EE214 ELECTRICAL CIRCUITS LABORATORY TERM PROJECT

NOTE CONTROLLED VEHICLE

Term Project Final-Report

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1.INTRODUCTION

In this project, our goal is to design a note controlled vehicle. We are required to control the vehicle by different notes of a flute. For example, the vehicle should turn right when the B note is played and left when the F note is played. For this purpose, we will use a microphone to receive the sound signals and bandpass filters to differentiate the signals. We also will use operational amplifiers to amplify the signal coming from the microphone since it has a very small amplitude. We will use one summing two difference amplifiers to decide which direction the vehicle will go. Finally, we will use motor driver circuits with two BJT transistors to run the motors according to the coming signal.

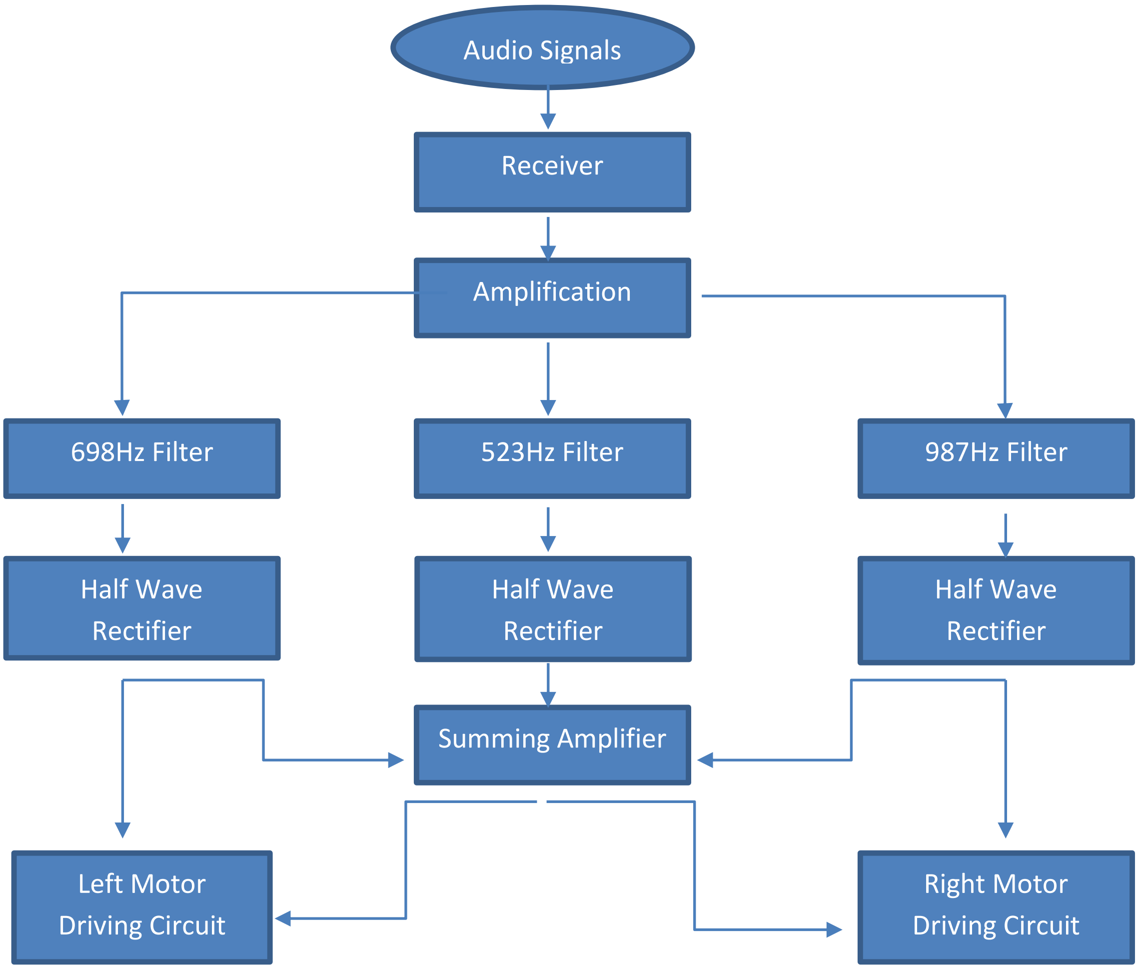

Figure 1 : A general diagram of the project

2.RECEIVER UNIT

In this part, we will use a microphone to receive the sound signals coming from the flute and convert them to voltage values according to the sounds in the environment. We use a voltage source with sine wave since the sound signal coming from the flute is almost a sine wave and there is no microphone in Ltspice. However, the representation of the implemented microphone circuit is shown in Figure 2.

2.1)Obtaining the sound signal

Firstly, we represent the microphone circuit in Ltspice as shown in Figure 2. We used a capacitor in order to block any DC voltage at the output of the microphone in addition to our circuit in the preliminary report. We used the capacitor after we saw a DC offset at the output when we constructed the circuit.

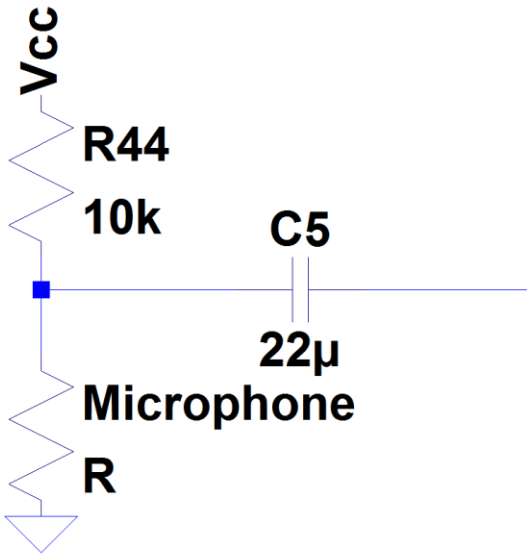

Figure 2 : A representation of the microphone circuit with a voltage source

2.2)Amplification

In this part, we amplify the output of the microphone before the filtering part since it will be easier to filter a signal with large amplitude. For this purpose, we use an operational amplifier as shown in Figure 3.

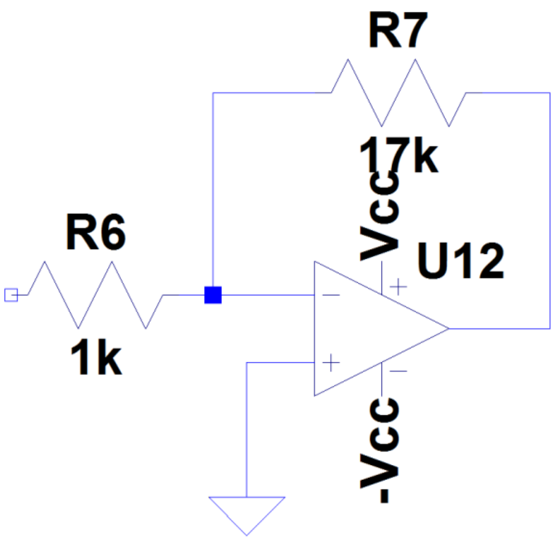

Figure 3 : Amplifier circuit to amplify the output of the microphone

We can obtain the ouput of the op-amp as follows:

$$V_o=-V_{in}*(R_7/R_6) \qquad (1)$$

The minus sine only causes a phase shift of 180 degrees but it has no effect overall. For our case, V_{in} is equal to 0.03sin(wt), R_7=300kΩ and R_6=1kΩ. We get the result as the following when we insert these values into equation (1):

$$V_o=0.02\sin(wt)*17/1=0.34\sin(wt) \qquad (2)$$

Indeed, we get the same result when we simulate this circuit with these values as shown in Figure 4.

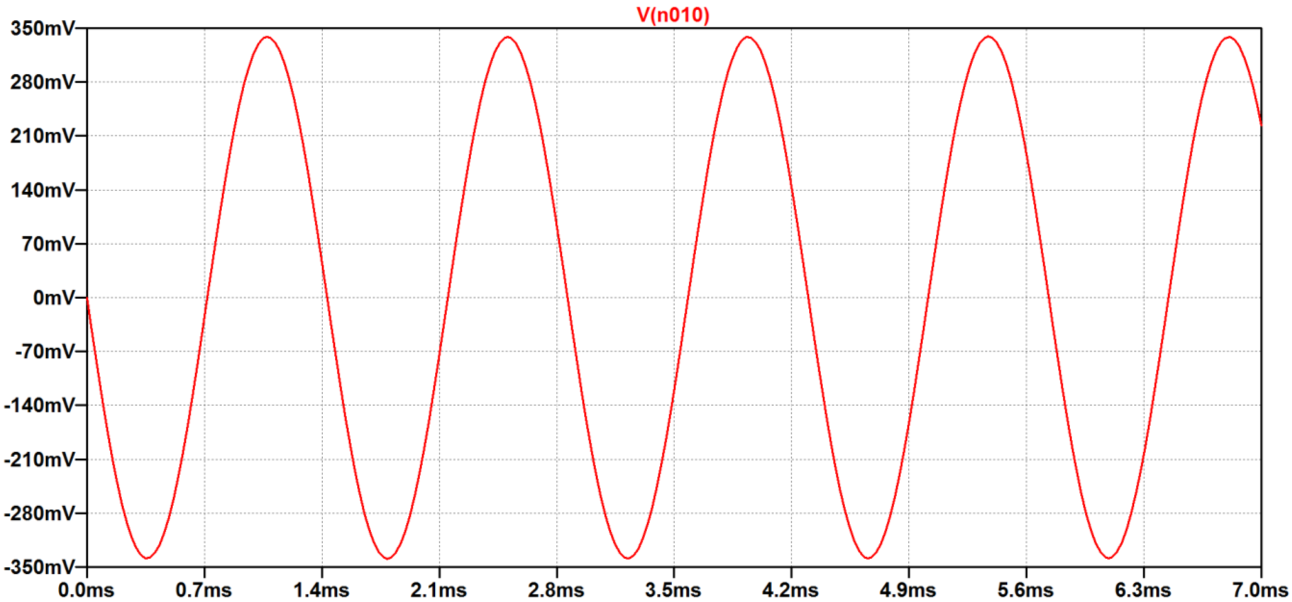

Figure 4: The output waveform of the amplification process.

3)CONTROL UNIT

In this part, we are required to differentiate the various signals coming from the receiver unit and decide what operation to perform according to the frequency of the signal in the decision subunit. Then, we are required to carry out this operation in the function subunit.

3.1)Decision Subunit

i)Filtering the Signals

In this part, in order to differentiate the signals from each other, we use band pass filters. Band pass filters pass the signal with the frequency of interest and stops other signals. We use three filters for three different signals and make each of them second order in order to increase the quality of the filter. The design of our filter are as shown in Figure 5. We use active filters because our frequencies quite low and active filters are better than passive filters at low frequencies. The other reason is to avoid the usage of bulky inductors. We do not need to have high gain since we amplify our signals.

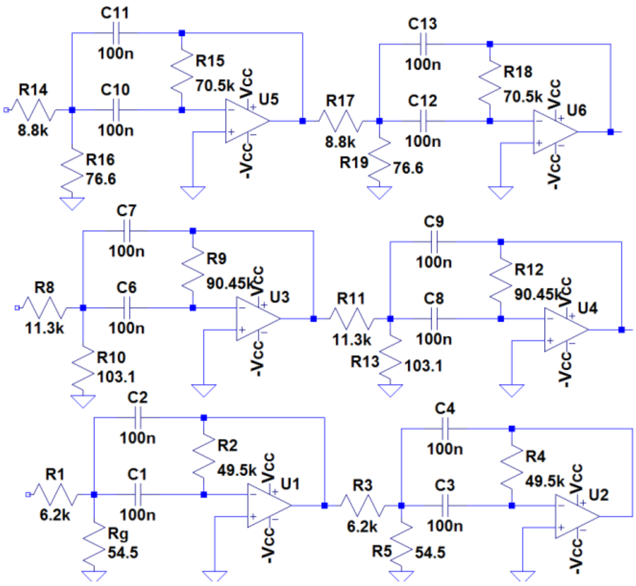

Figure 5 : The circuit diagram of the bandpass filters for 523 , 698, 987Hz

We chose the resistance values according to the predefined properties of the filter such as quality factor, gain and center frequency. We chose the capacitance value 100nF for the sake of simplicity in calculations. The equations for the resistance values are as follows[1]:

$$R_1=Q/(2\pi f_c CG) \tag{3}$$

$$R_g=Q/(2\pi f_c C(2Q^2-G)) \tag{4}$$

$$R_2=Q/(\pi f_c C) \tag{5}$$

Where f_c is the center frequency, Q is the quality factor, G is the gain and C is common capacitance value which is 100nF. We chose the quality factor 15 and the gain 4. We decreased the quality factor to 15 because the resistance values were either too high or too low with Q=100 and it affected the mechanism of the filters. We obtained these resistance formulas by the help of the transfer function which is shown in (6).

$$H(s)=-(R_2R_g/R_1+R_g)Cw_cs/(1+(2R_1R_g/R_1+R_g)Cw_cs+(R_1R_2R_g/R_1+R_g)C^2w_c^2s^2) \tag{6}$$

For the case of 987Hz center frequency, the resistance values are obtained when these properties are inserted into equations (1), (2) and (3) :

$$R_1=15/(2\pi*987Hz*100nF*4)=6.2k\Omega$$

$$R_g=15/(2\pi*987Hz*100nF(2*100^2-4))=54.5\Omega$$

$$R_2=15/(\pi*987Hz*100nF)=49.5k\Omega$$

For the case of 698Hz center frequency, the resistance values are obtained when these properties are inserted into equations (1), (2) and (3) :

$$R_{14}=15/(2\pi*698Hz*100nF*4)=8.8k\Omega$$

$$R_{16}=15/(2\pi*698Hz*100nF(2*100^2-4))=76.6\Omega$$

$$R_{15}=15/(\pi*698Hz*100nF)=70.5k\Omega$$

For the case of 523Hz center frequency, the resistance values are obtained when these properties are inserted into equations (1), (2) and (3) :

$$R_8=15/(2\pi*523Hz*100nF*4)=11.3k\Omega$$

$$R_{10}=15/(2\pi*523Hz*100nF(2*100^2-4))=103.1\Omega$$

$$R_9=15/(\pi*523Hz*100nF)=90.45k\Omega$$

Equations (1), (2) and (3) can be found by obtaining the frequency response of the filters by analyzing the circuit in phasor domain. The output signals of the filters with various frequency values are shown in the following figures.

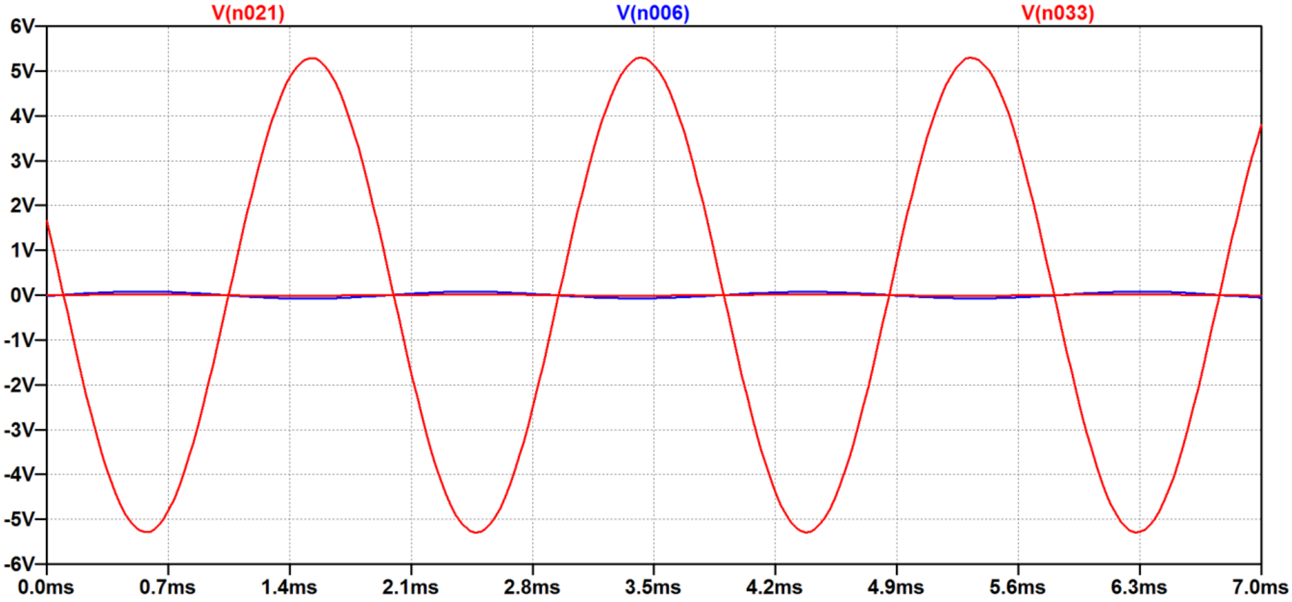

Figure 6 : The output waveforms of the the filters with 523Hz frequency input

As shown in Figure 6, the 698 and 987Hz filters give zero while the 523Hz filter gives a full sine wave with considerable amplitude when a signal with 523Hz frequency is applied as the input.

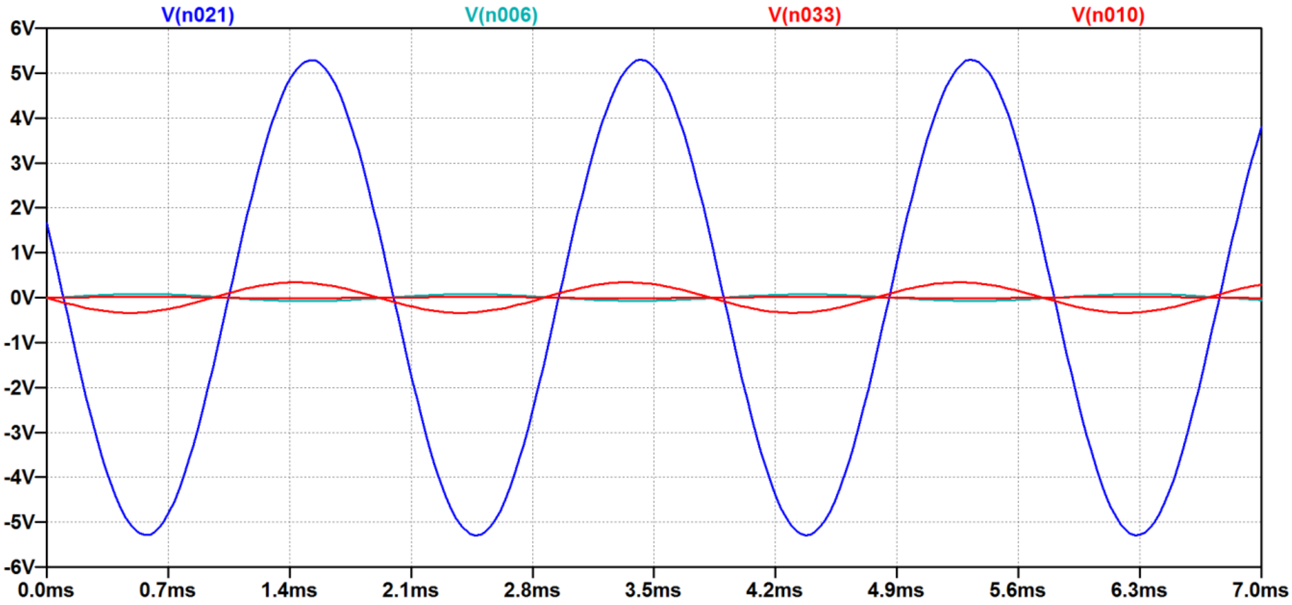

Figure 7 : Input(red:698Hz) and output waveforms of the filters(blue:698Hz filter)

As shown in Figure 7, the 987 and 523Hz filters give zero while the 698Hz filter gives a full sine wave with considerable amplitude when a signal with 698Hz frequency is applied as the input.

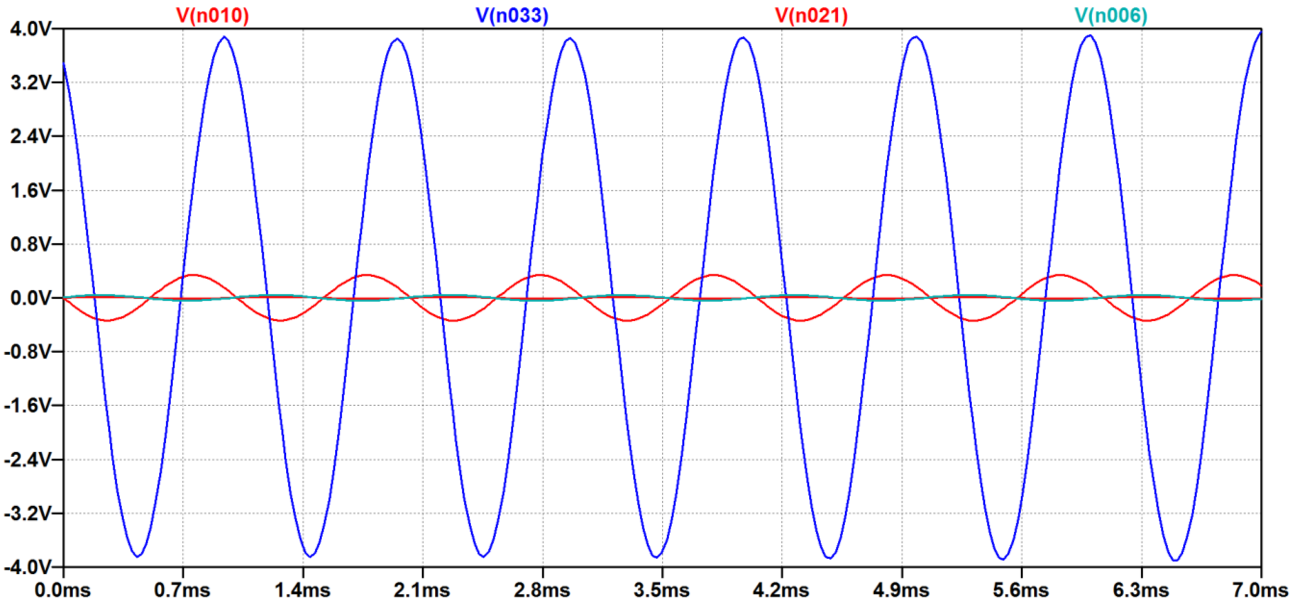

Figure 8 : Input(red:987Hz) and output waveforms of the filters(blue:987Hz filter)

As shown in Figure 8, the 698 and 523Hz filters give zero while the 987Hz filter gives a full sine wave with considerable amplitude when a signal with 987Hz frequency is applied as the input.

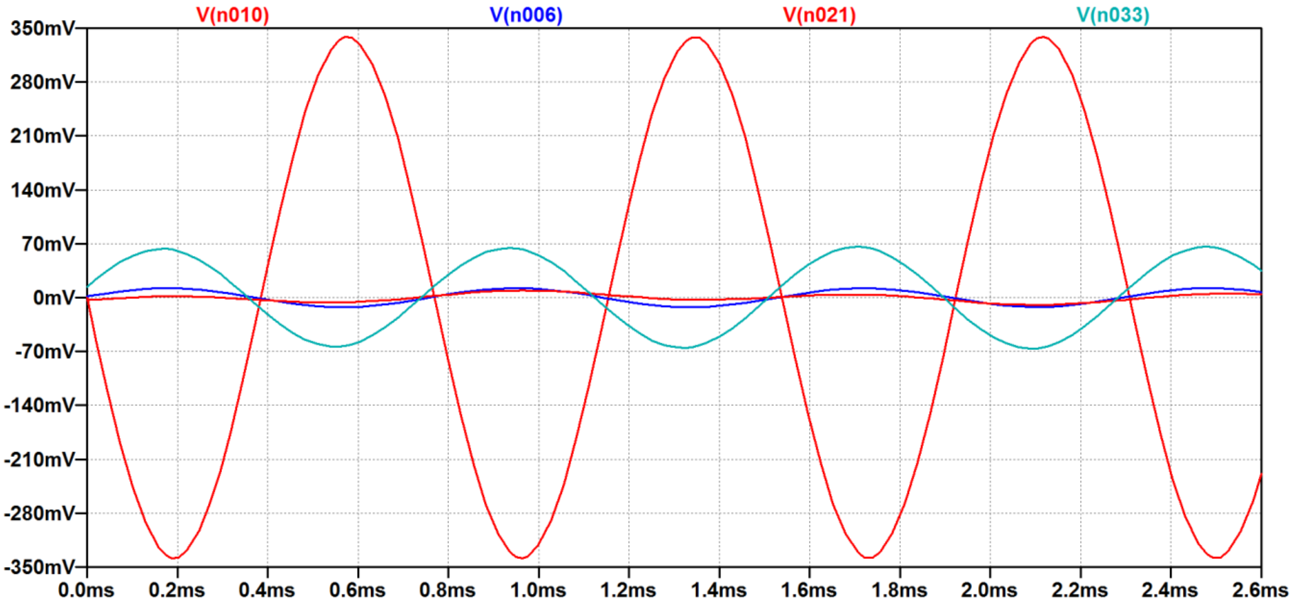

Figure 9 : The output waveforms of the filters and the input(red) with 1300Hz frequency

As shown in Figure 9, all the filters give zero when an arbitrary input with 1300Hz frequency is given.

The HPVEE and MATLAB plots are illustrated in the following figures for each case seperately.

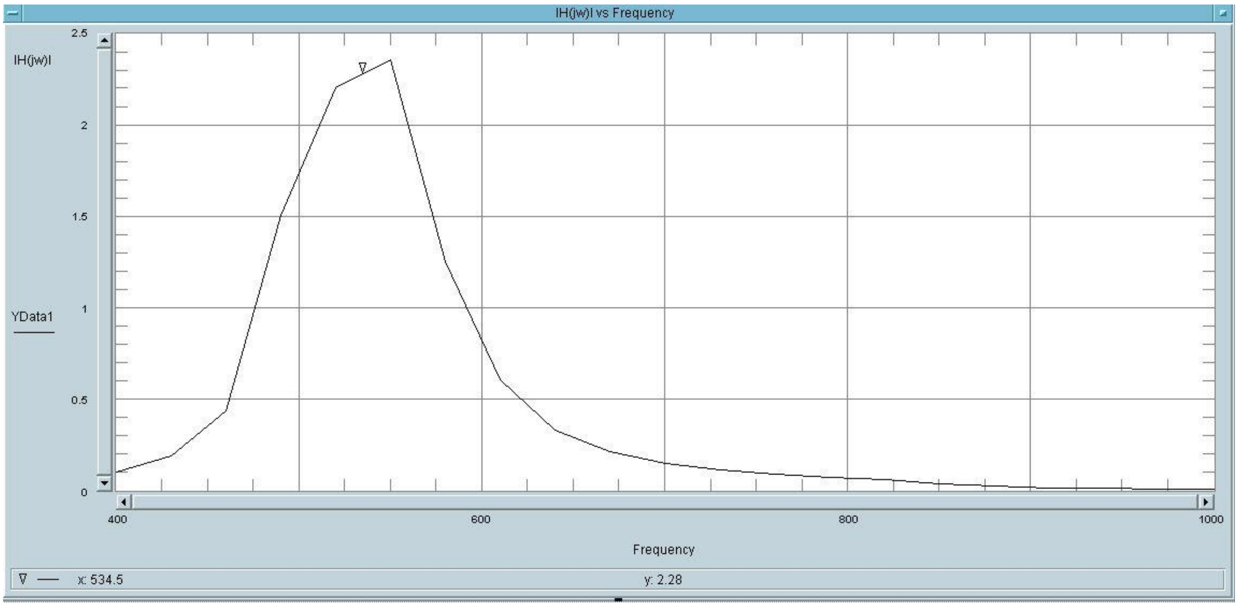

Figure 10 : The magnitude response of the 523Hz filter on Vee

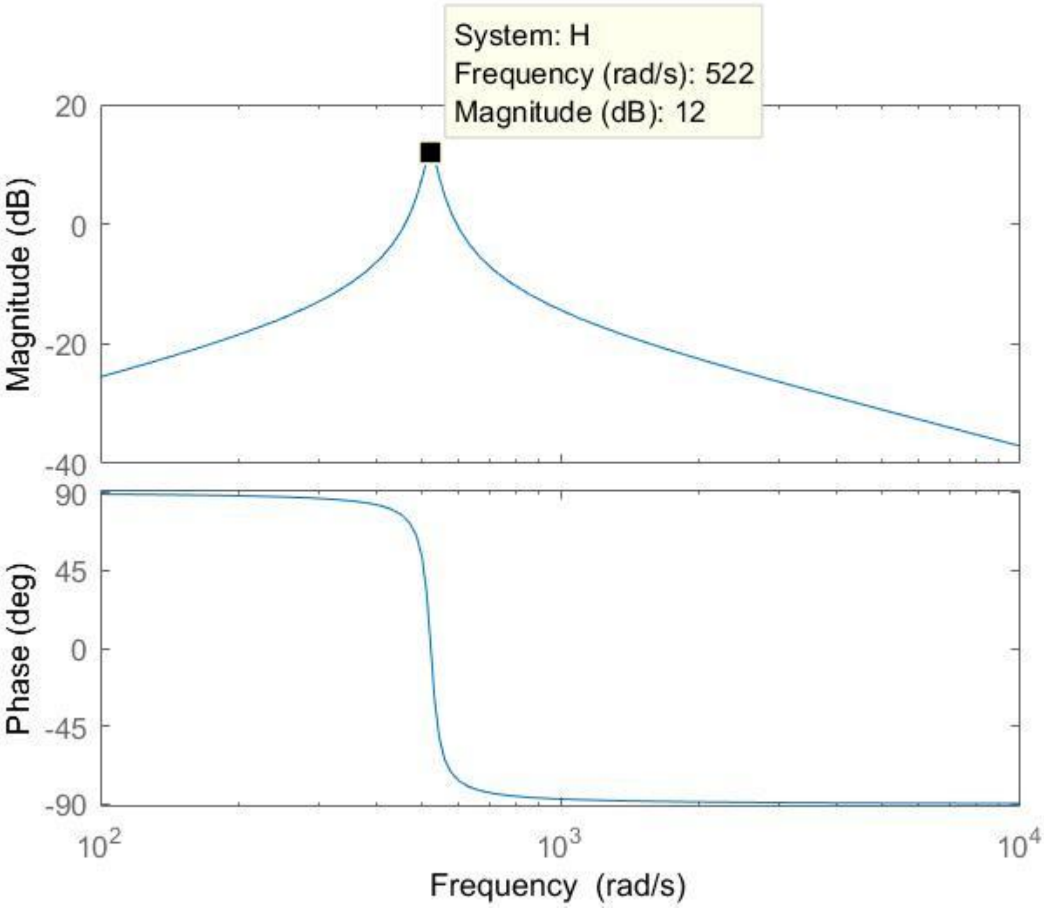

Figure 11 : The frequency response of the 523Hz filter on MATLAB

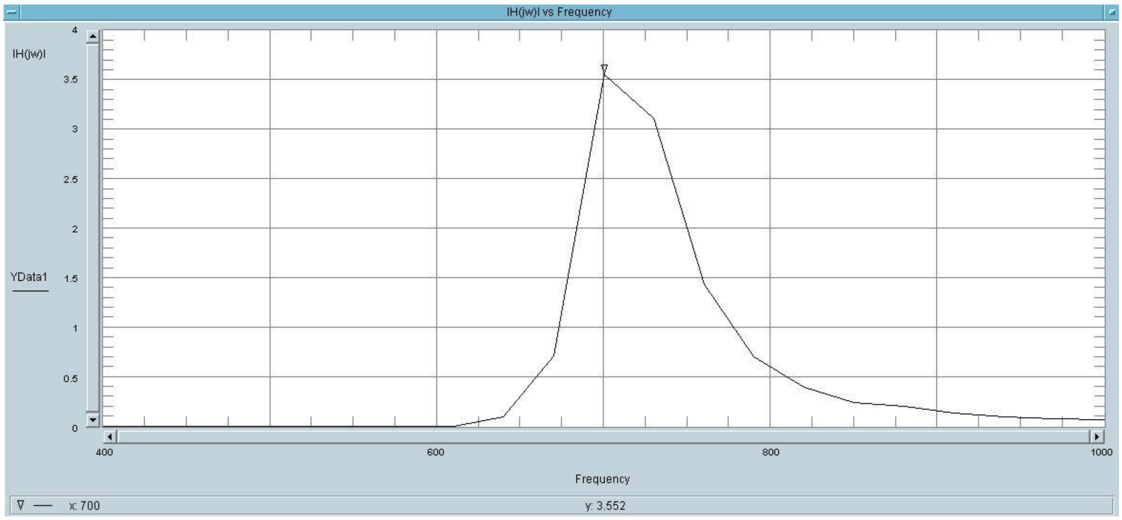

Figure 12 : The magnitude response of the 698Hz filter on Vee

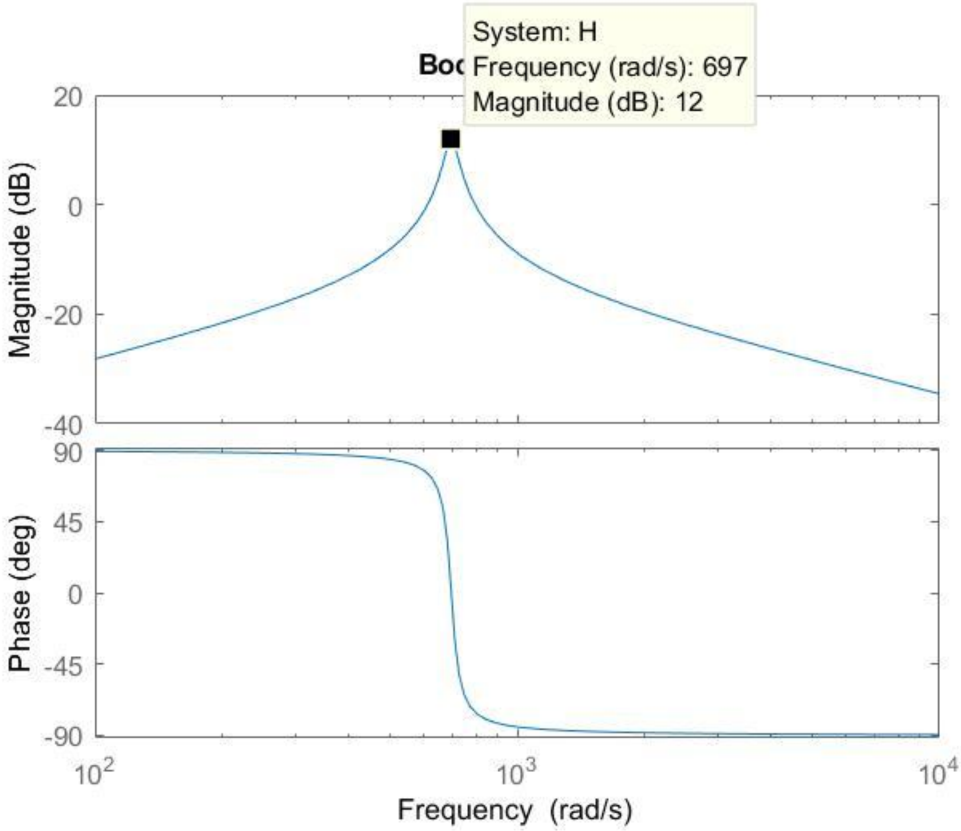

Figure 13 : The frequency response of the 698Hz filter on MATLAB

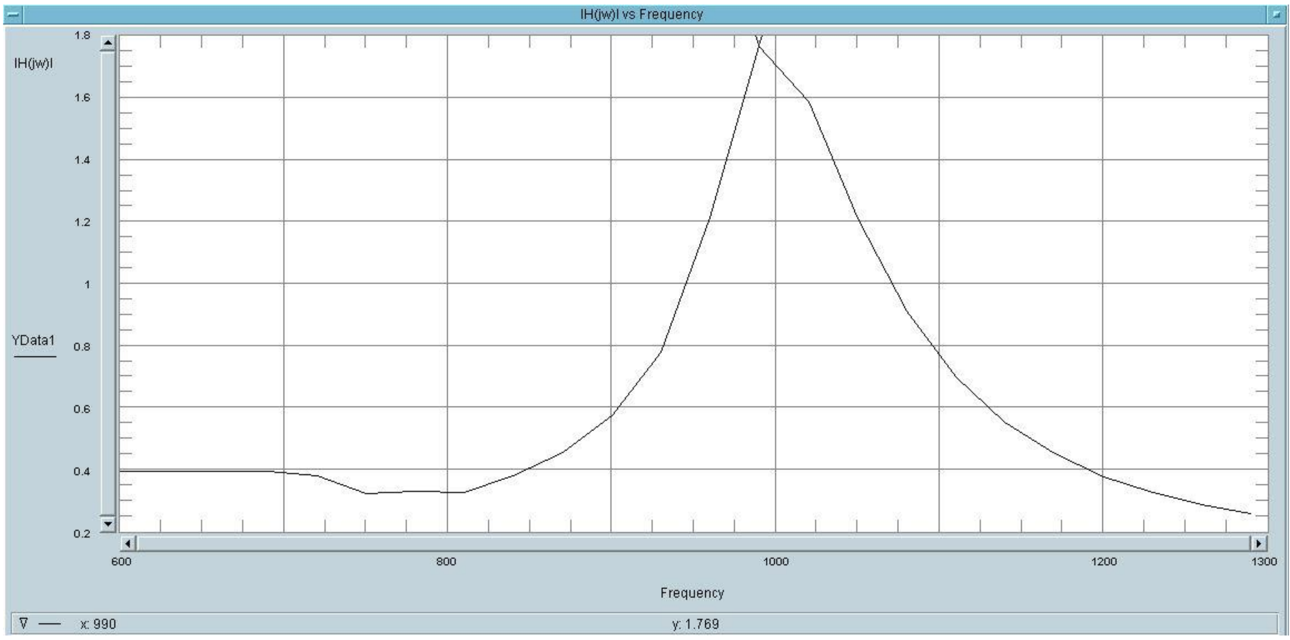

Figure 14 : The magnitude response of the 987Hz filter on Vee

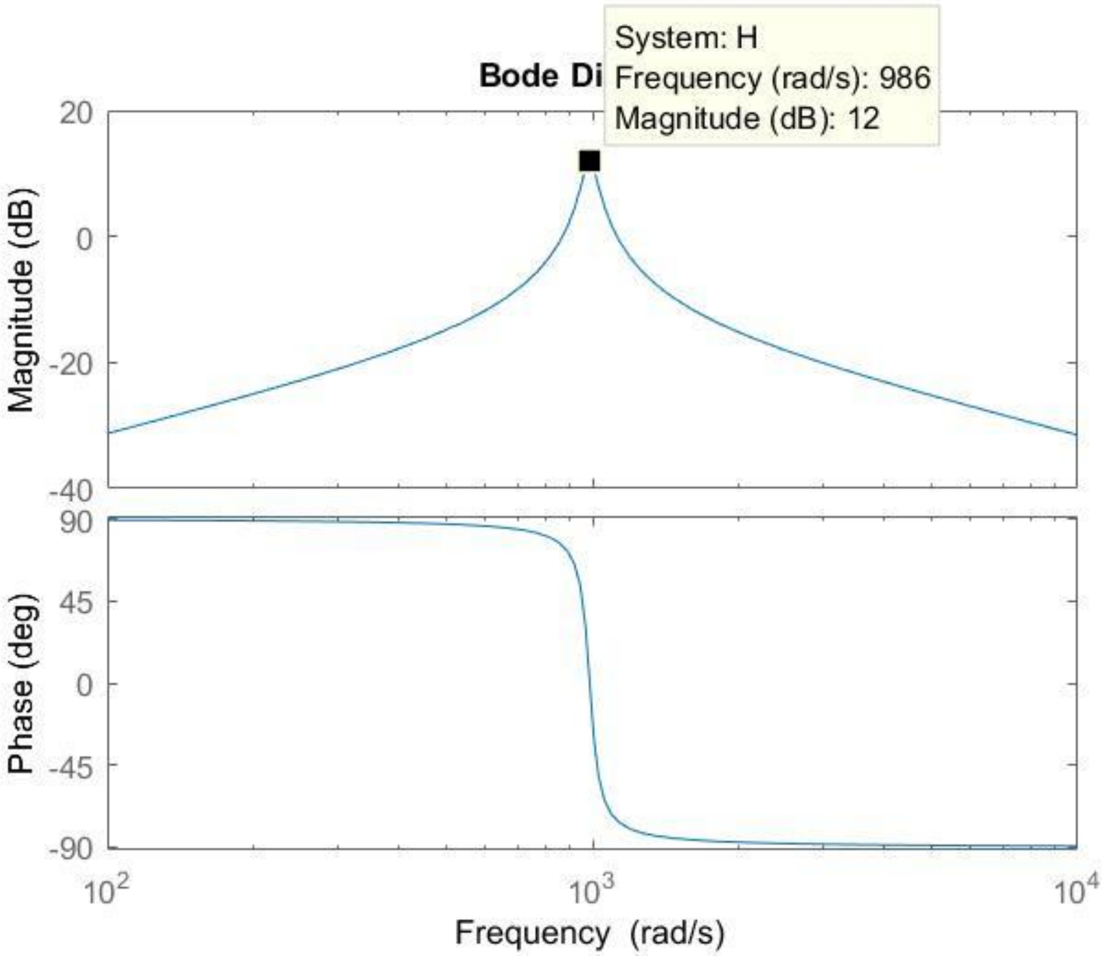

Figure 15 : The frequency response of the 987Hz filter on MATLAB

ii)AC to DC Conversion

In this part, we convert the AC signal coming from the previous part to DC voltage in order to compare the voltages and run the motors. For this purpose we use a half wave rectifier circuit and connect a capacitor in parallel with the resistor. The design is shown in Figure 16.

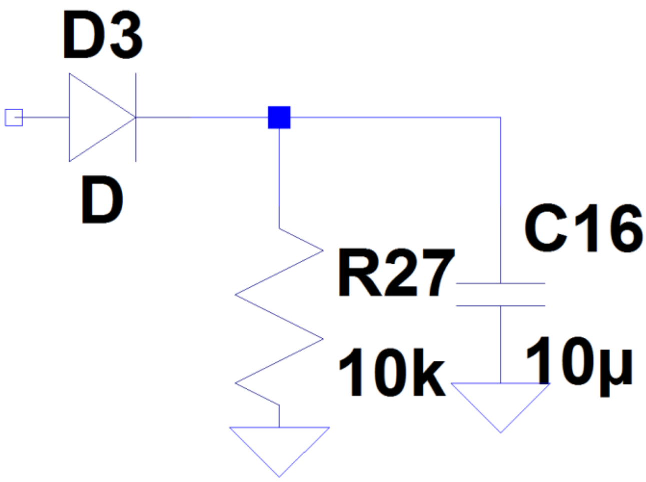

Figure 16 : The half wave rectifier circuit with a capacitor in parallel with the resistor

The purpose of using a capacitor such as shown in Figure 8 is to fix the voltage on a voltage value with a small ripple voltage. When the upper half of the sine wave is flowing through the resistor and capacitor a voltage is formed across the capacitor. The diode does not pass the lower half of the sine wave and the capacitor holds the voltage across its terminals with a little decrease in this period until the sine wave catches up with the voltage value across the capacitor. Therefore, almost a constant voltage is obtained as output with a small ripple voltage. The resistance and the capacitance values are chosen according to the following equation in order to decrease the ripple voltage[2] :

$$V_r/V_i=1/fRC \tag{6}$$

Where V_r is the ripple voltage, V_i is the amplitude of the sine wave and f is the frequency of the sine wave. When we insert the resistance, capacitance and frequency values into equation (6):

$$V_r/V_i=1/(523*10k\Omega*10\mu F)=0.019$$

The ripple voltage in this case is %1.9 of the amplitude of the sine wave which is small enough. The output of the half wave rectifier in this case is as shown in Figure 17.

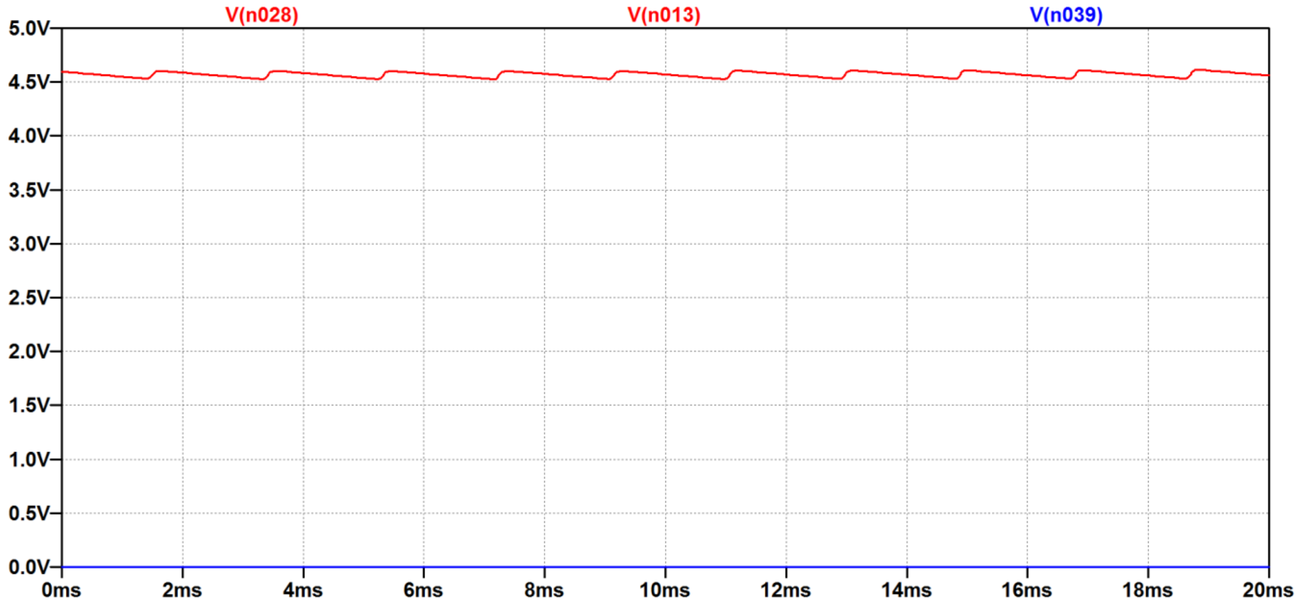

Figure 17 : The output of the half wave rectifier circuit when 523Hz signal is applied

The output is almost constant and the ripple voltage is very small as shown is Figure 17. Also, the other voltage values are zero as expected.

iii)Decoding the information of the previous part

In this part, we will decode the information coming from the previous part. In other words, we will distribute the voltages such that the difference between the sum of all three outputs and the output of the 698Hz filter is greater than the difference between the sum of all three outputs and the output of the 987Hz filter when an input with 698Hz frequency is given i.e. turning left command so that we can give the function subunit necessary information to run the right motor faster than the left motor. The opposite will occur when an input with 987Hz frequency input is given i.e. turning right command. When an input with 523Hz frequency is given the differences will be equal and the vehicle will move forward as expected. The circuit diagram of what is stated above is shown in Figure 18.

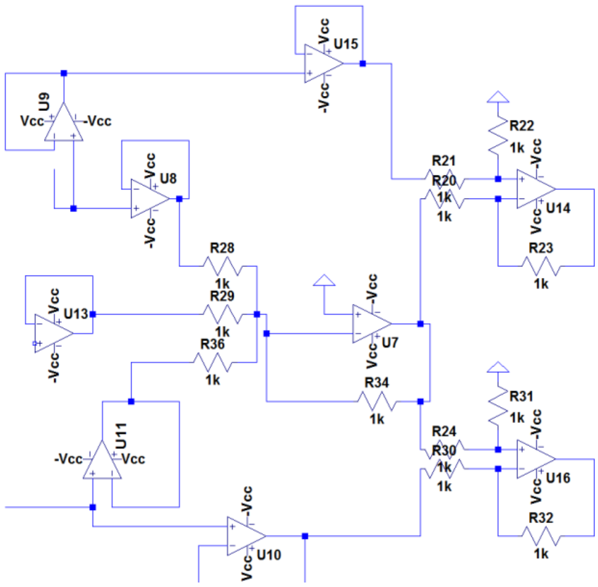

Figure 18 : The circuit diagram for the decoding part of the information

We are adding the three voltages with some gain by using an inverting summing amplifier and we are using buffers in order to isolate the voltages so that they will not affect each other. The output of the summing amplifier is given in the following equation.[3]

$$V_o=-((V_1+V_2+V_3))*(R_{34}/R_{28}) \tag{7}$$

Where V_o is the output of the amplifier, V_1, V_2 and V_3 are the voltages of the left way, straight and right way respectively.

When we insert the voltage values in Figure 9 into equation (7), we get :

$$V_o=((0+4.5+0))*(1/1)=-4.5V$$

The outputs of the summing amplifier, left way and right way parts are as shown in Figure 13 when an input with 523Hz is applied.

Then, we are comparing the outputs of summing amplifier and left and summing amplifier and right filter's output by using difference amplifiers as shown in Figure 12. The difference amplifiers gives a result as shown in (8):

$$V_{oleft}=(V_1-V_o)R_{23}/R_{20} \tag{8}$$

When we insert the voltage values in Figure 17 into equation (8), we get :

$$V_{oleft}=(0-(-4.5)*1k/1k=4.5V$$

$$V_{oright}=(0-(-4.5)*1k/1k=4.5V$$

The outputs of the left and right difference amplifiers are the same therefore the vehicle will move straight when 523Hz input is applied.

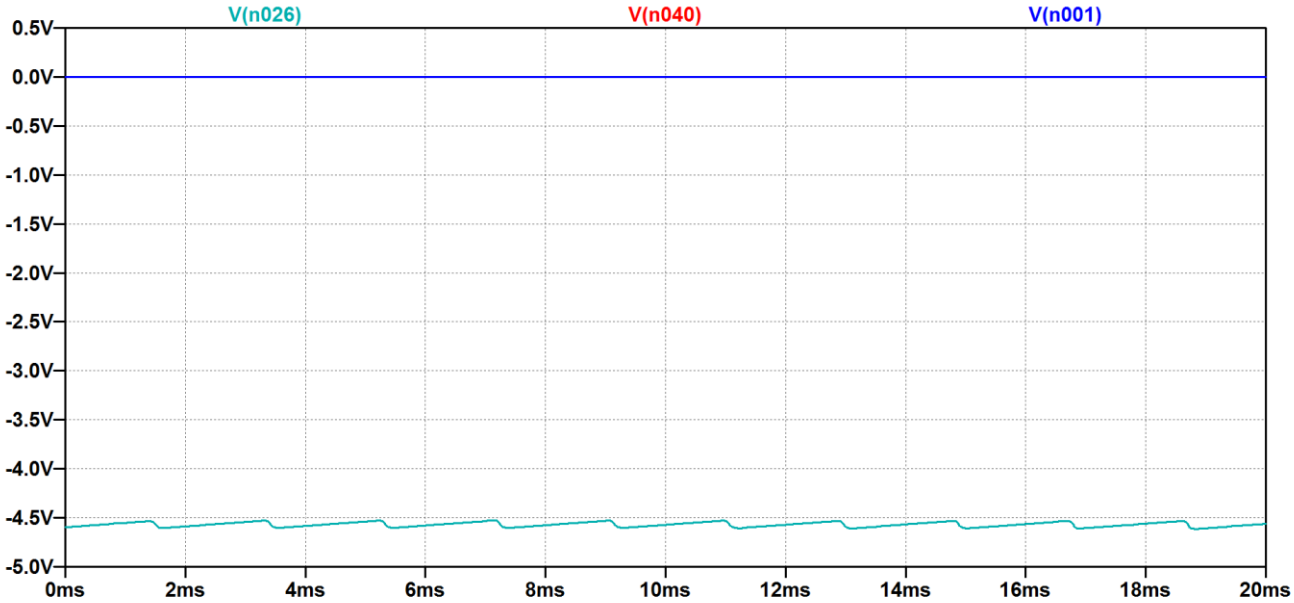

Figure 19 : The output waveforms of the summing amplifier, left way and right way parts

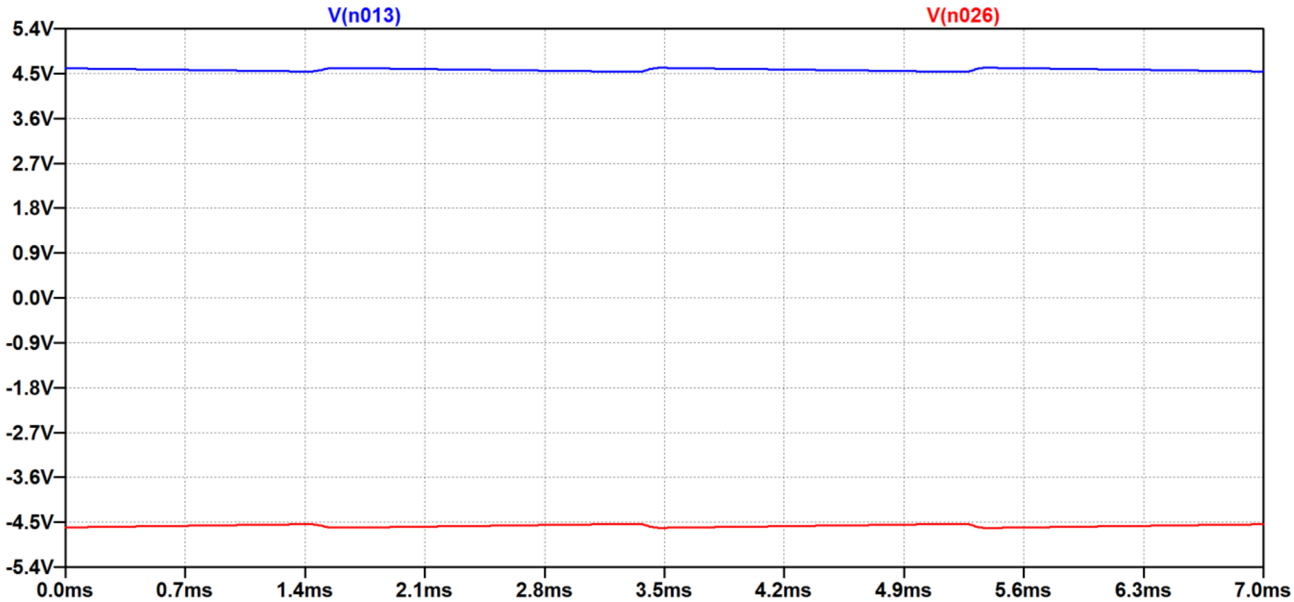

Figure 20 : The output waveforms of the summing amplifier and two difference amplifiers

While the output of the summing amplifier gives around -4.5V Volts the left and right way parts give zero as output as seen in Figure 16 since 523Hz is the forward command and the difference between each of the two is the same as shown in Figure 20. Therefore, the vehicle will go straight.

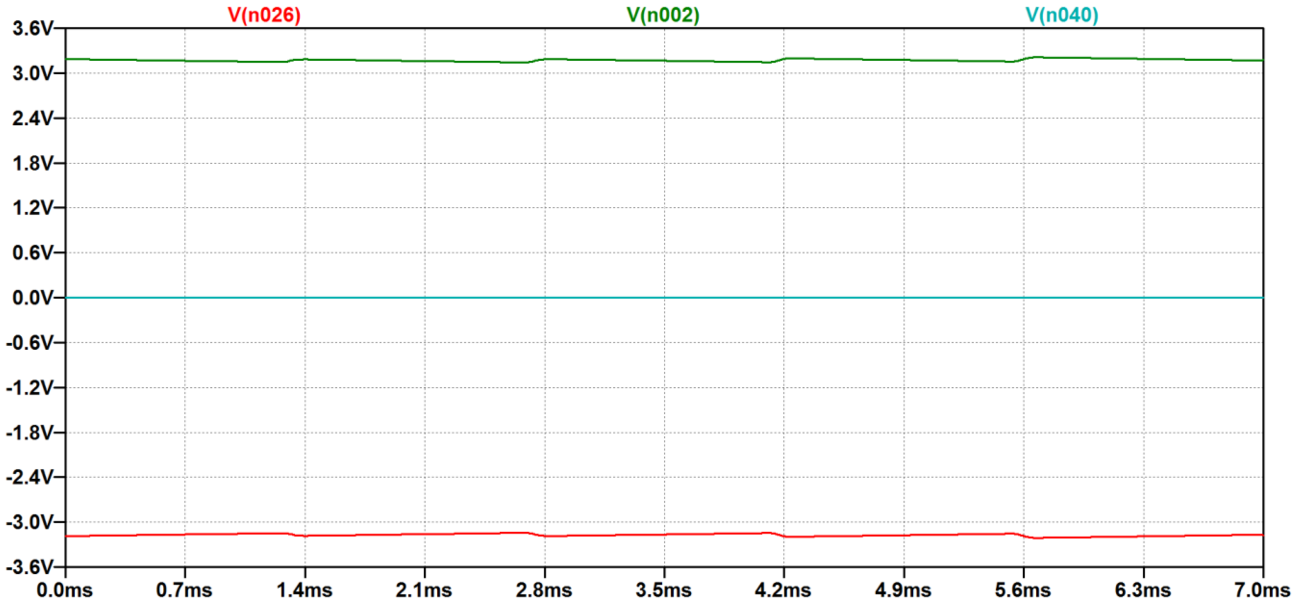

Figure 21 : The output waveforms of the summing amplifier(red),left way(green) and right way

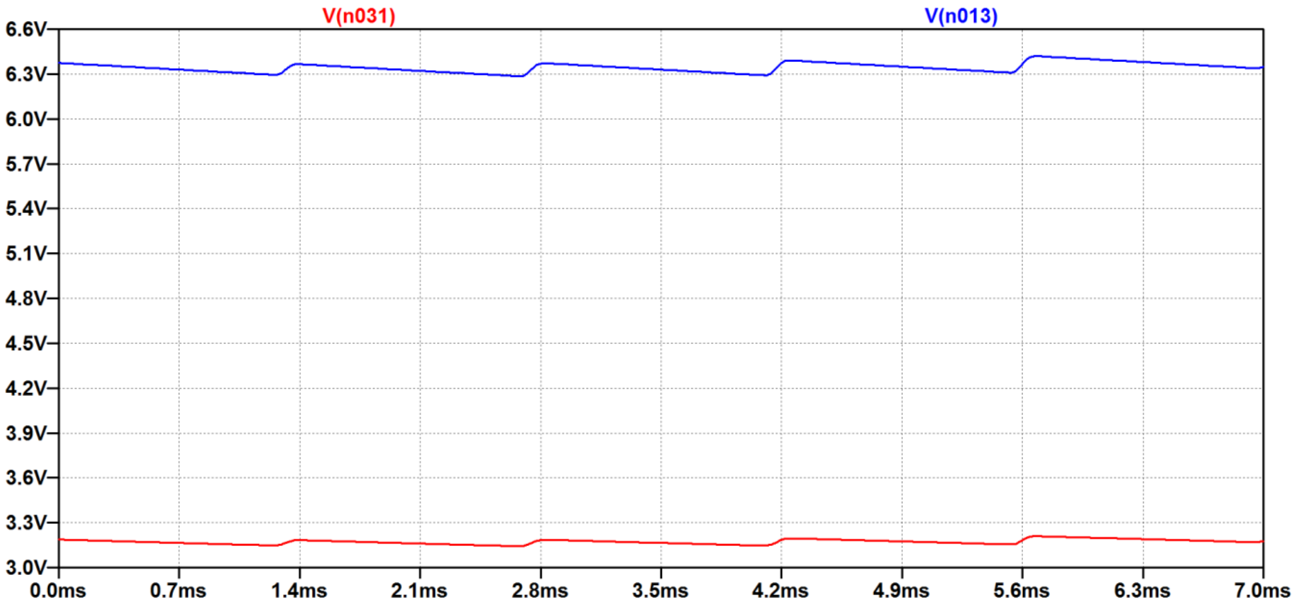

Figure 22 : The output waveforms of the two difference amplifiers

As expected, the output of the left difference amplifier is greater than the other when a 698Hz input is applied as shown in Figure 22. We connect the output of the left difference amplifier to the right motor driver so that the vehicle will turn left. The opposite will take place when a 987Hz input is applied.

b)Function Subunit

In this part, we are required to run the left and right motors according to the information coming from the decision subunit. In other words, the right motor should run faster than the left when the turn left command is given i.e. a signal with 698Hz frequency and vice versa if a signal with 987Hz frequency is given. Finally, the two motors should run at the same speed when a signal with 523Hz freqeuncy is given and they should stop if no note is played or a note other than these three is played.

For this purpose, we will use a motor driver circuit with two BJT transistors. We connect the output of the left difference amplifier to the right motor driver circuit. We connect the output of the right difference amplifier to the right motor driver circuit. Therefore, when the turn left command is given, the voltage across the left motor will be less than that across the right motor and the vehicle will turn left and vice versa if the turn right command is given. When the move forward command is given, the voltages across the right and left motors will be equal and the vehicle will move forward.

We use two BJTs in this circuit configuration to form the opening mechanism and to have large current flowing through the motors since the motors operate with large currents and op-amps can not supply so much current. However, since the motors have small internal resistance, they will require large currents to acquire enough voltage. When large currents start to flow through the BJTs, they will change operation mode and the circuit characteristics will change. We use two transistors to increase the current gain so that there will not be need for large current output from difference amplifier to have large currents flowing through the motors.

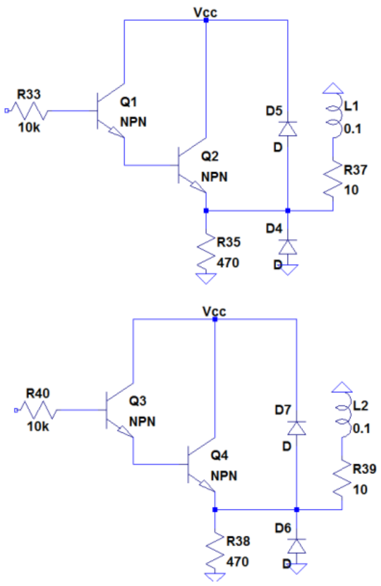

Figure 23 : The circuit diagram of the motor drivers with two BJT transistors

The voltage across the motors will be proportianate to the difference amplifier outputs. The emitter current is proportionate to the base current i.e. the output current of the difference amplifiers.The voltage across the motors for various inputs are given in the following figures.

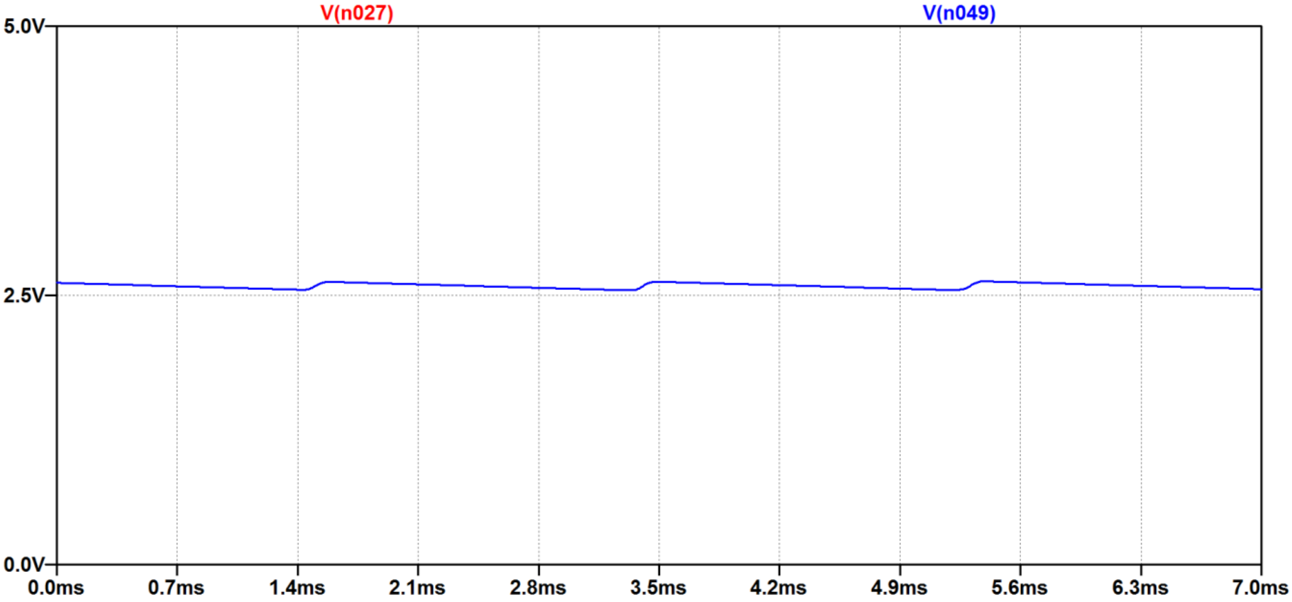

Figure 24 : The voltage across the motors when 523Hz frequency input is given

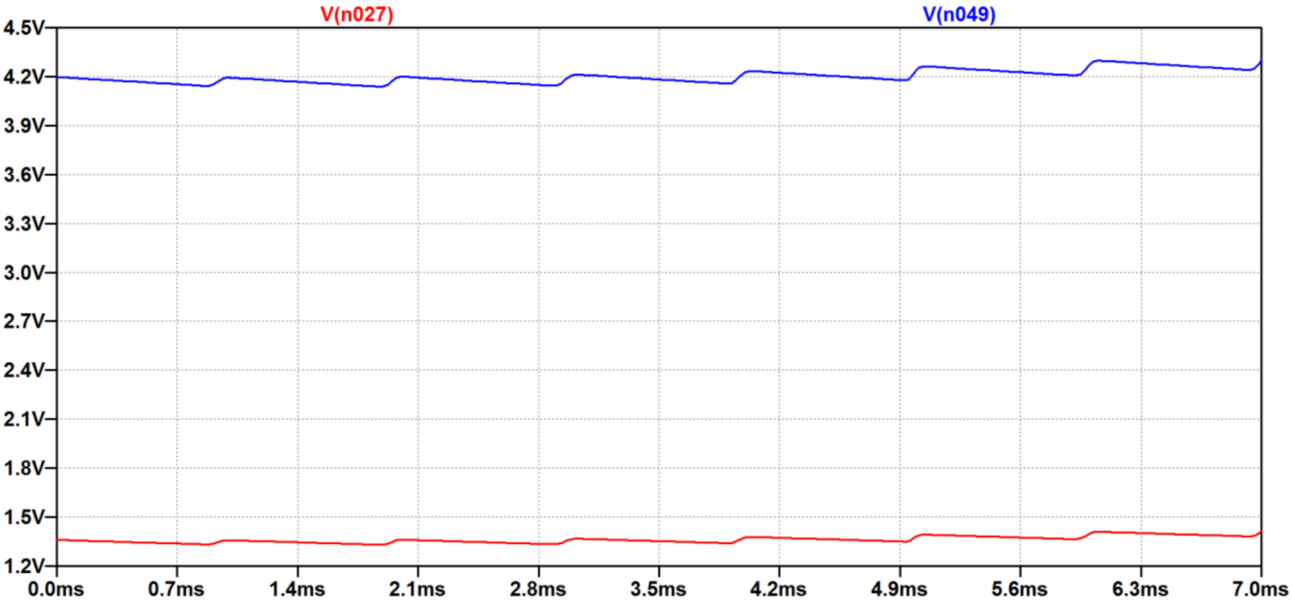

Figure 25 : The voltage across the motors when 987Hz frequency input is given(bigger one is left)

The output stage circuits in the preliminary report did not work in practice because we did not feed the circuit with a voltage supply. The output currents from the op-amps were not enough to drive the circuits.

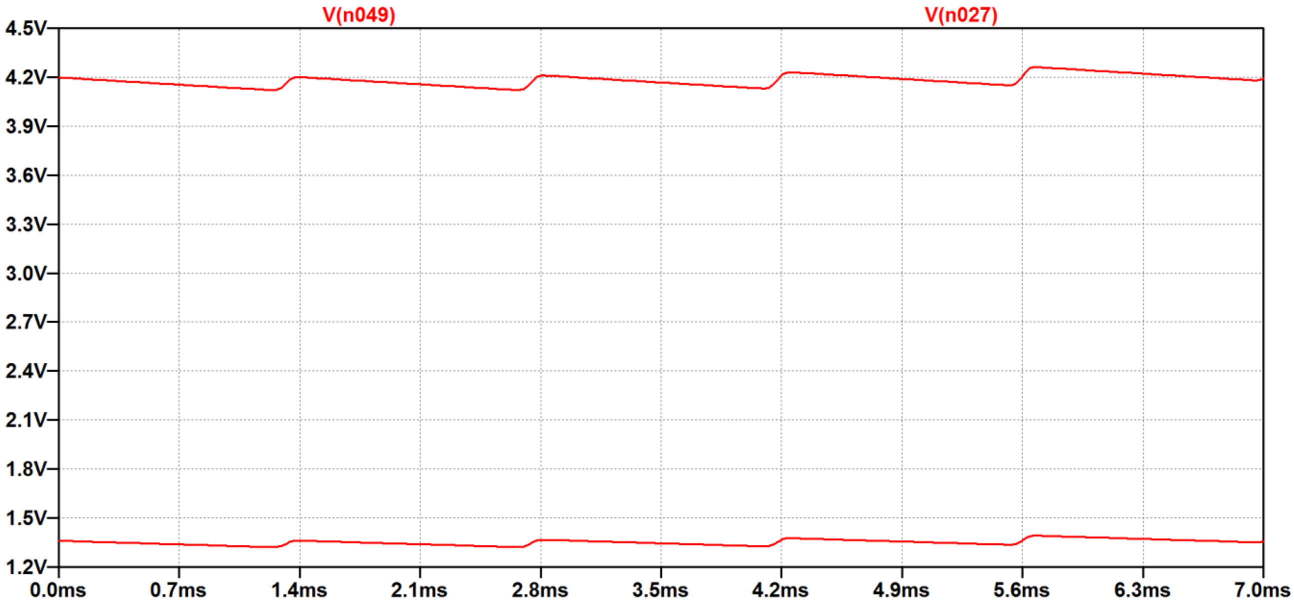

Figure 26: The voltage across the motors when 698Hz frequency input is given(bigger one is right)

As shown in Figure 24, when 523Hz(move forward) input is applied, the two motors move at the same speed. The left motor moves faster when 987Hz(turn right) input is applied as shown in Figure 25. The right motor moves faster when 698Hz(turn left) input is applied as shown in Figure 26.

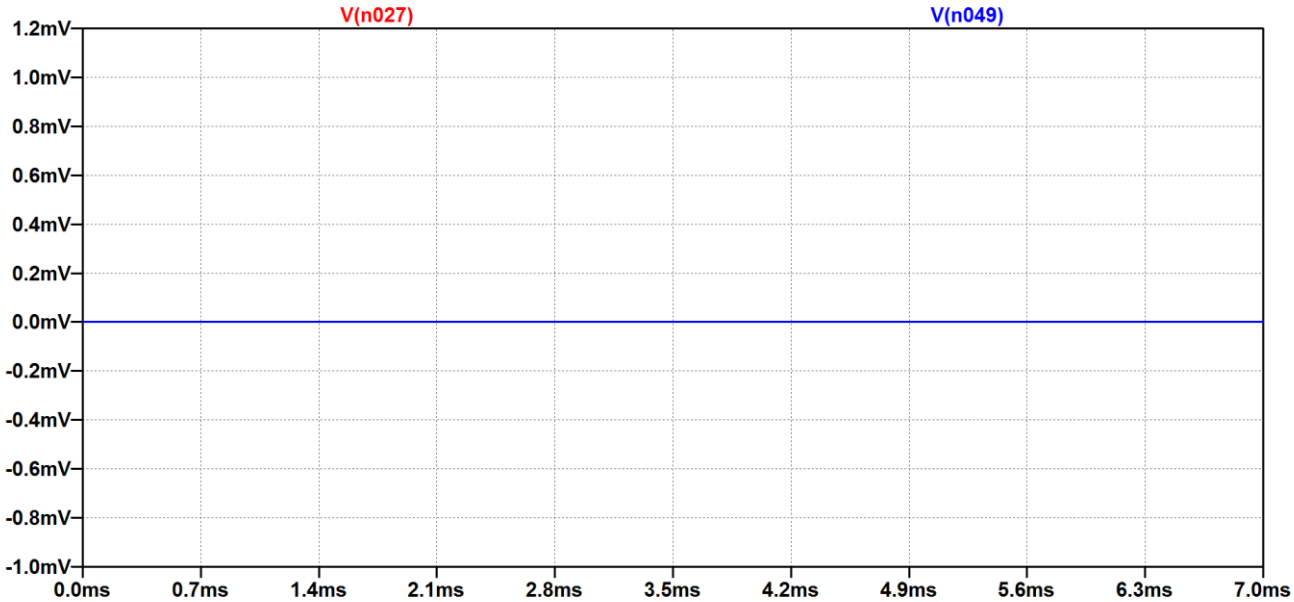

Figure 27 : The voltages across the two motors when an arbitrary input(500Hz) is given

As shown in Figure 22, when an arbitrary input with 500Hz frequency is given, there should be zero volts across both motors thus they will stop.

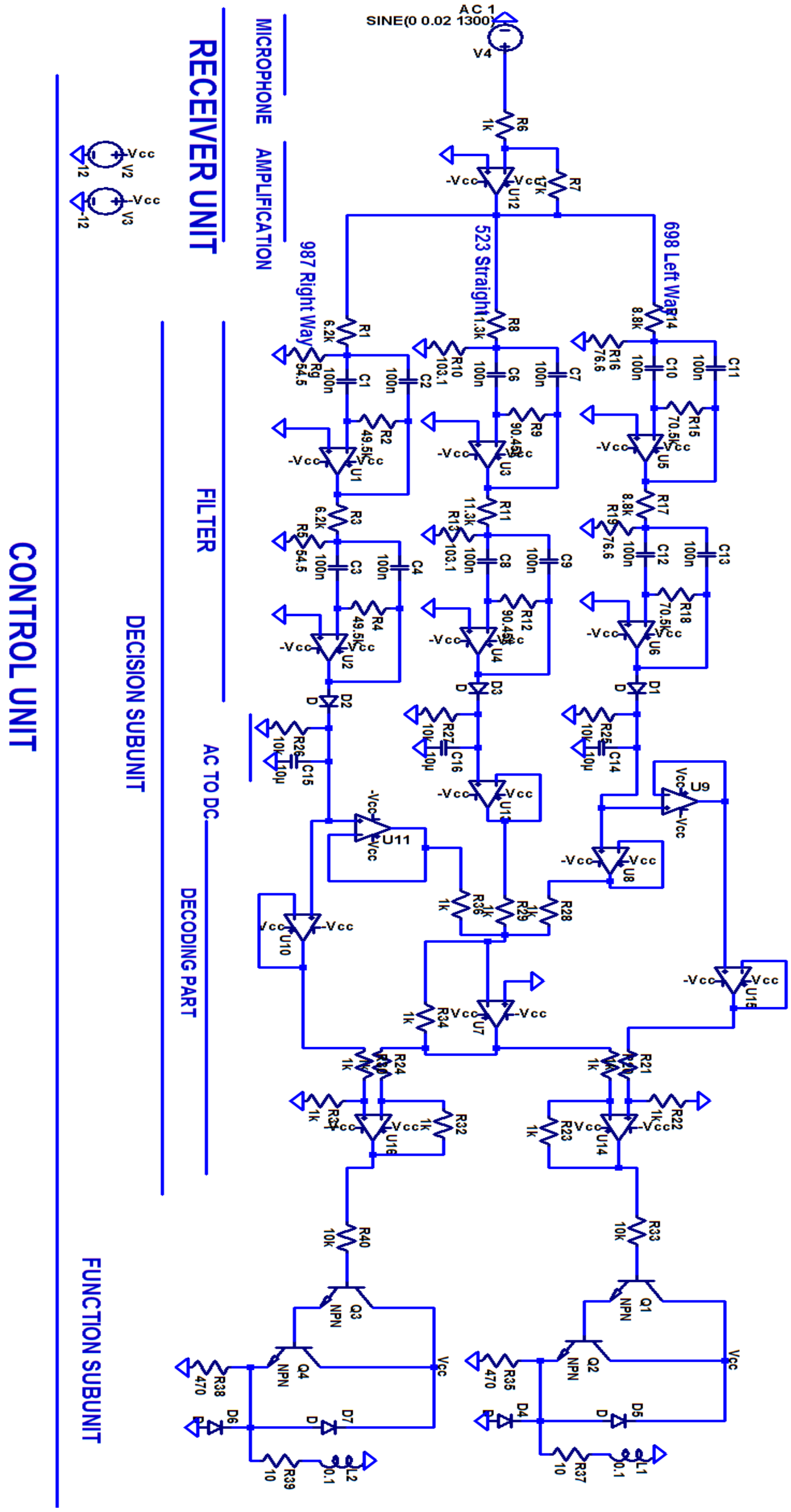

Figure 28 : Detailed circuit schematics of the overall project

Generally, our circuit is designed such that the vehicle will turn left if an input with 698Hz is given and right if an input with 987Hz is given. If an input with 523Hz is given then it will move forward. For this purpose, we used various circuit aplications such as bandpass filters, half wave rectifier, motor driver circuits with two BJTs and op-amps.

4)POWER CONSUMPTION

In order to calculate the power consumption, we measured the currents and voltages on the motors seperately for each case coming from DC supplies.

When the motors move straight (at 523Hz):

P=12V*320mA+(-12)V*(-12)mA=3984mW ≈ 4W

When the motors move right (at 987Hz):

P=12V*257mA+(-12)V*(-12)mA =3228mW ≈ 3.2W

When the motors move left (at 698Hz):

P=12V*278mA+(-12)V*(-12)mA =3480mW ≈ 3.5W

When there is no motor motion:

P=12V*15mA+(-12)V*(-12)mA =324mW ≈ 0.3W

5) COST ANALYSIS

Name of the component	Unit price of the component	Number of components used	Total price
Lm358 Op-Amp	50 kurus	8	4 TL
1N4007 Diode	5 kurus	7	35 kurus
Potentiometer	50 kurus	10	5 TL
Capacitors	20 kurus	16	3.2 TL
Resistors	1 kurus	37	37 kurus
BD135 Transistor	60 kurus	4	2.4 TL
Microphone	2	1	2 TL
Breadboard	7 TL	2	14 TL
Driving Motor	5TL	2	10 TL
Cables	50 kurus per meter	0.5 meter	25 kurus

In total, this project costed us 41.4 TL.

6)CONCLUSION

In conclusion, in this project, we learned how to obtain the output of a microphone and block any DC offset and amplify it. We learned how to construct high quality active bandpass filters to differentiate the signals by their frequencies. We have seen that too high quality filters do not necessarily give good results in real life since the reistance values become too high or too low. We used half wave rectifier circuit to convert AC to DC and used op-amps for various purposes such as amplification, buffer and decision making elements as difference and summing amplifiers. We mainly used what we have learned in the EE214 experiments by doing some changes on some circuits to use them for our circuit such as the motor driver circuit with BJTs. This was a great opportunity for us to implement the knowledge we have obtained in EE214 and improve our technical skills.

REFERENCES

[1] Band Pass Filters. (2011,April 14). Retrieved April 30,2017, from http://www.circuitstoday.com/band-pass-filters

[2] Capacitor Smoothing Circuits & Calculations. (n.d.). Retreived April 30,2017 from http://www.radio-electronics.com/info/circuits/diode-rectifier/rectifier-filtering-smoothing-capacitor-circuits.php

[3] Summing amplifier in inverting and non inverting configurations.Practical summing amplifier circuit. (2011, November 11). Retreived April 30,2017, from http://www.circuitstoday.com/summing-amplifier