Middle East Technical University

Department of Electrical and Electronics Engineering

EE214 Electrical Circuits Laboratory
Term Project

Note Controlled Vehicle
Final Report

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1 Introduction

Remote controlled vehicles are the devices that can be controlled by remotely by controller. These kind of devices are very popular among kids, adults, hobbiest and engineers. These devices consist of two main parts, namely, vehicle and controller. As the name suggests, controller is the part that controls the device by remoting and the device is the part driven by controller. Cars, ships and planes are the most popular examples of this concept.

In this project, out purpose is to build a remote controlled car. The car will be controlled by notes of the flute which are C5($\sim$ 525Hz), F5($\sim$ 700Hz) and B5($\sim$ 990Hz). The car will take input with an electret microphone. The output of the microphone, however, is too small. It needs to be amplified. Then, to determine input frequency three bandpass filters are needed with center frequencies 525Hz, 700Hz and 990Hz. While doing so, the amplitudes of the signals are adjusted to fit into resulting design. After filtering, a comparator will be used. One input will be the DC converted filter output, other will be the cutoff amplitude of the filter. Lastly, two OR gates and four current amplifier will take place to drive wheels, namely, motors.

2 Analysis of the Circuit

Our circuit can be analysed mainly in five parts:

1. Remote Controlling and Receiver Unit
2. Filter Unit
3. Decision Unit
4. Action unit

Throughout all analyses, please note that, $VsatP$ will represent $+12V$ and $VsatN$ will represent $-12V$, unless otherwise stated in the text*(Figure 1)*.

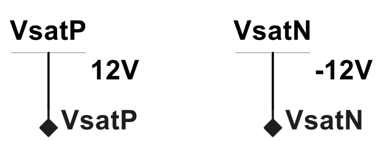

Figure 1: VsatP & VsatN values.

2.1 Remote Controlling and Receiver Unit

In this project we will use a flute to control the car. There are three actions to be achieved, namely, going forward, turning right and turning left. Three different notes will be assigned for each action C5, B5 and F5, respectively. The relevant information can be seen in *Table 1*.

Note	Frequency(Hz)	Direction
C5	523.25	Forward
F5	698.46	Left
B5	987.77	Right

Table 1: Frequencies and Remoting Directions of the used notes.

On the other hand, we shall adapt this remoting input to the circuit. For this purpose, we will use an electret microphone. Electret microphone contains a time-varying capacitor and a JFET or FET inside. So, we need to feed this transistor to get output. However, this is not enough. We need to amplify the signal further with an opamp. But before going amplifying the signal, we shall remove possible dc offsets and noises by a passive high pass filter. The whole structure can be seen *(Figure 2)*.

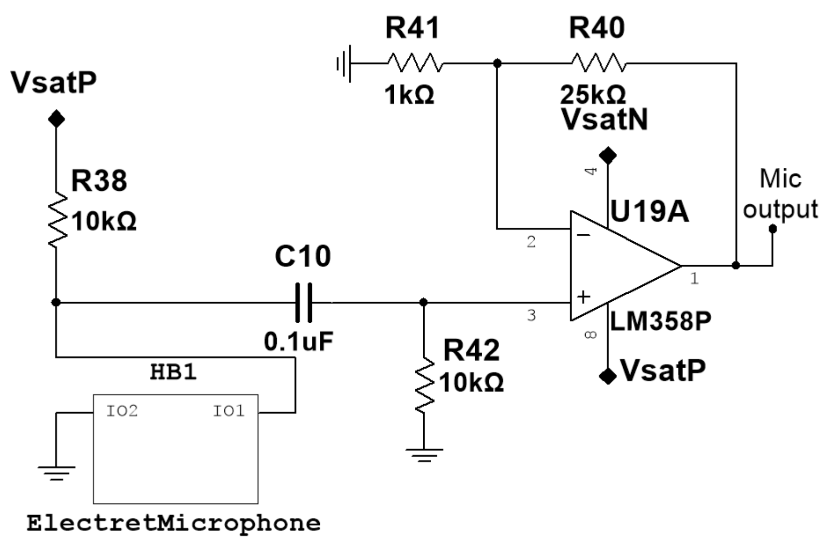

Figure 2: Electret microphone setup.

With simple node analysis in the frequency domain, the cutoff frequency of the passive high pass filter can be found as

$$f_c = \frac{1}{2\pi R_{42} C_{10}} \tag{1}$$

If we take $R_{42} = 10k\Omega$ and $C_{10} = 0.1\mu F$, cutoff frequency f_c can be found as

$$f_c = \frac{1}{2\pi 10k\Omega 0.1\mu F} \approx 159Hz \tag{2}$$

This frequency is pretty good for blocking dc offset and noise.

Let's look at how opamp $U19A$ behaves. If we apply node analysis on the opamp by assuming linear operation region

$$V_{out} = \frac{V_{in}(R_{40} + R_{41})}{R_{41}} \tag{3}$$

If we take $R_{40} = 25k\Omega$ and $R_{41} = 1k\Omega$, output voltage will be

$$V_{out} = \frac{V_{in}(25k\Omega + 1k\Omega)}{1k\Omega} = 26V_{in} \tag{4}$$

which ends up almost $\sim 0.5V$ as the output voltage.

2.2 Filter Unit

The purpose of this part is to filter unwanted signals coming from the microphone and to detect the input frequency. To do so, we will use active bandpass filters. Bandpass filters allow signal to pass within specific range. There will be three active bandpass filters since we have three car directions. We have adjusted the output of the microphone such that it is $\sim 0.5V$. In this stage we will also amplify the signal up to $\sim 10V$ while filtering it. The used bandpass filter can be seen in *Figure 3*. Please note that values indicated in the *Figure 3* are for detection of 700Hz signals.

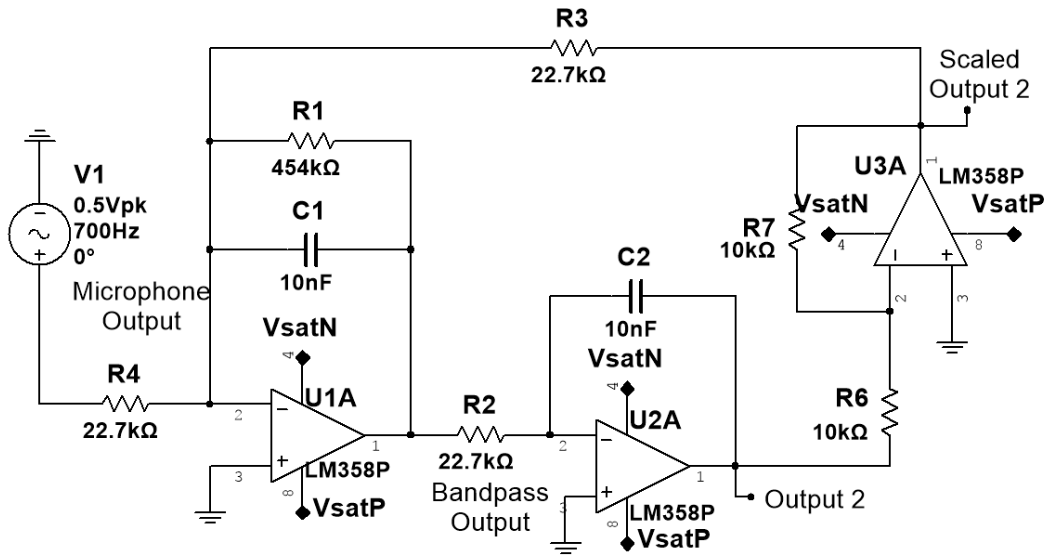

Figure 3: Active Bandpass Filter.

Now let us analyze this circuit in the s-domain. We will assume that bandpass output is the output of $UA1$ and this output will be called V_{BP}. The outputs of $UA2$ and $UA3$ will be called V_{A2} and V_{A3}, respectively. Let's call microphone output as V_{mic}. All opamps are assumed to be in linear operation region.

KCL at the inverting input of $UA1$ gives

$$\frac{-V_{mic}}{R_4} - \frac{V_{BP}}{R_1} - sC_1V_{BP} - \frac{V_{A3}}{R_3} = 0 \tag{5}$$

KCL at the inverting input of $UA2$ gives

$$\frac{-V_{BP}}{R_2} - sC_2V_{UA2} = 0 \tag{6}$$

KCL at the inverting input of $UA3$ gives

$$\frac{-V_{UA2}}{R_6} - \frac{V_{UA3}}{R_7} = 0 \tag{7}$$

If we combine equations (5), (6) and (7) and do some cumbersome algebra, we can find transfer function $H(s)$ as

$$H(s) = \frac{V_{BP}}{V_{mic}} = \frac{sR_1R_2R_3C_2}{s^2R_1R_2R_3R_4C_1C_2 + sR_2R_3R_4C_2 + R_1R_4} \tag{8}$$

One more step yields $H(s)$ as

$$H(s) = \frac{V_{BP}}{V_{mic}} = \frac{-s\frac{1}{R_4C_1}}{s^2 + s\frac{1}{R_1C_1} + \frac{1}{R_2R_3C_1C_2}} \tag{9}$$

Please note that V_{BP} is an inverted sine wave. However, this doesn't imply any significant problem for us since sinusoidal waves oscillate between positive and negative values.

For the sake of simplicity and $\tau = RC$ considerations, we shall take $R_2 = R_3 = R = R_4$ and $C_1 = C_2 = C$. Then $H(s)$ reduces to

$$H(s) = \frac{V_{BP}}{V_{mic}} = \frac{-s\frac{1}{RC}}{s^2 + s\frac{1}{R_1C} + \frac{1}{R^2C^2}} \tag{10}$$

From this equation we can find the bandwidth parameter(Q), center angular frequency(ω_0) and H_0 (gain at $\omega = \omega_0$). The formulas can be seen in the following equations as

$$Q = \frac{R_1}{R} \tag{11}$$

$$\omega_0 = \frac{1}{RC} \tag{12}$$

$$H_0 = \frac{-R_1}{R} \tag{13}$$

We need to set center frequencies (f_0) to the values indicated in *Table 1*, respectively. The corresponding f_0, H_0 and Q can be found in *Table 2* for relevant center frequencies .

$f_0(Hz)$	Q	H_0	C (F)	R(Ω)	$R_1(\Omega)$	$R_6\&R_7(\Omega)$
525	20	-20	10n	30.3k	606k	10k
700	20	-20	10n	22.7k	454k	10k
990	20	-20	10n	16.07k	321.515k	10k

Table 2: Frequencies and Remoting Directions of the used notes.

The simulation result for filtering actions can be seen in *Figure 4*. A superposition of 990Hz, 700Hz and 525Hz with 0.5V was supplied as the input and all filters amplified their center frequencies up to 8.2V which is pretty good. The modifications are done in lab environment to correct them.

Figure 4: Filtering Action.

On the other hand, magnitude response of bandpass filters could be observed in the following figures. Agilent VEE, MATLAB and MULTISIM was used to get the graphs. All graphs are pretty close to eachother. However, Agilent VEE and MULTISIM has some shifts in frequencies and decrease in gains. They are due to unideal measuring techniques and components. They will be adjusted in the lab environment to get close values to ideal ones.

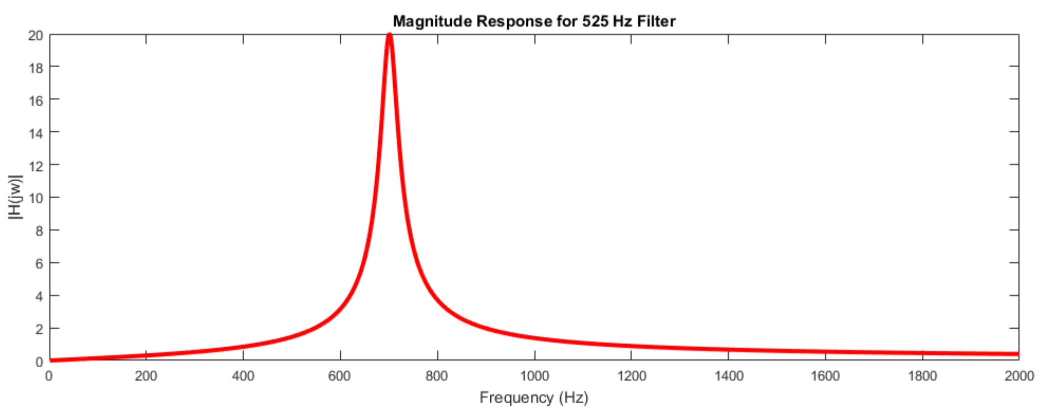

Figure 5: 525 Hz Bandpass Filter in MATLAB.

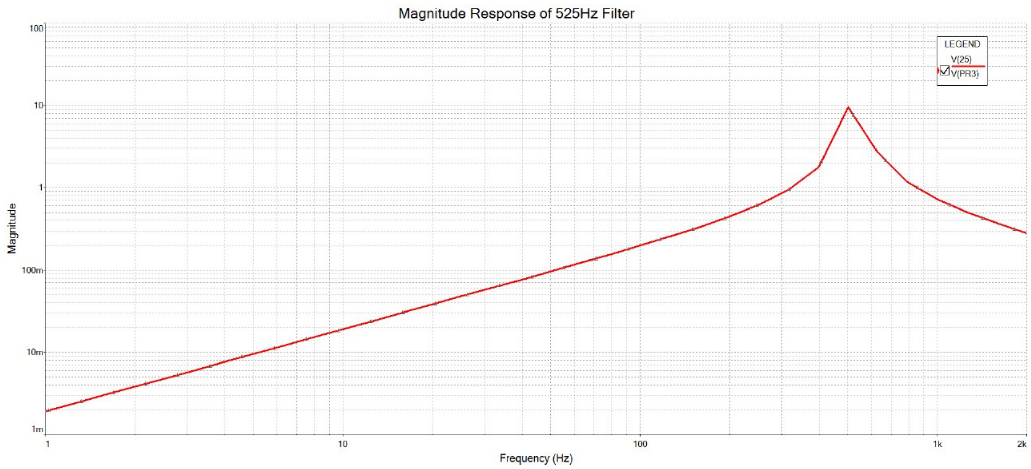

Figure 6: 525 Hz Bandpass Filter in MULTISIM.

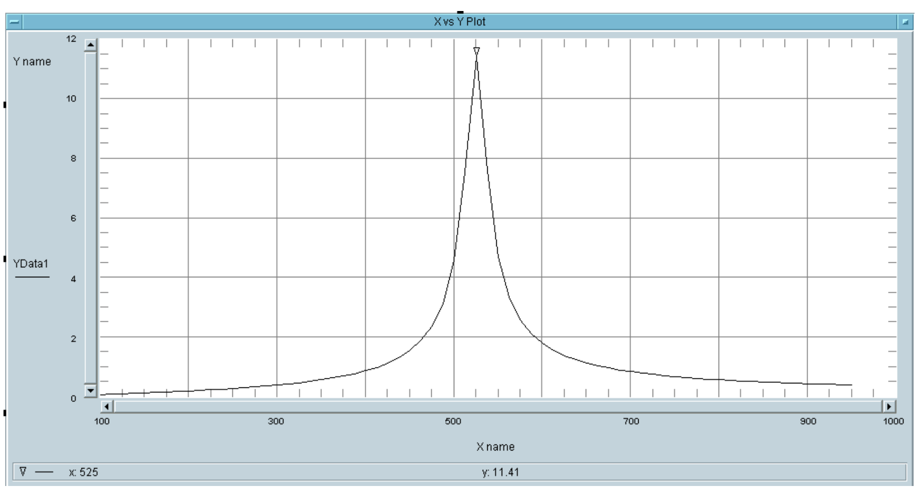

Figure 7: 525 Hz Bandpass Filter in Agilent VEE.

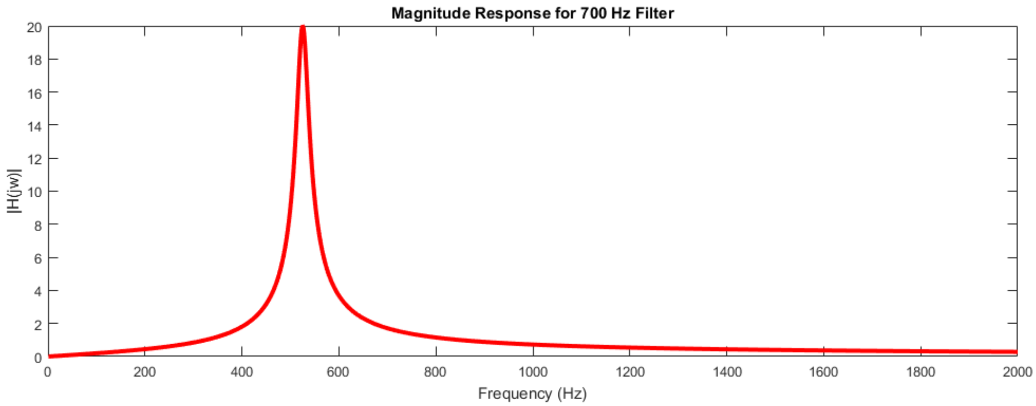

Figure 8: 700 Hz Bandpass Filter in MATLAB.

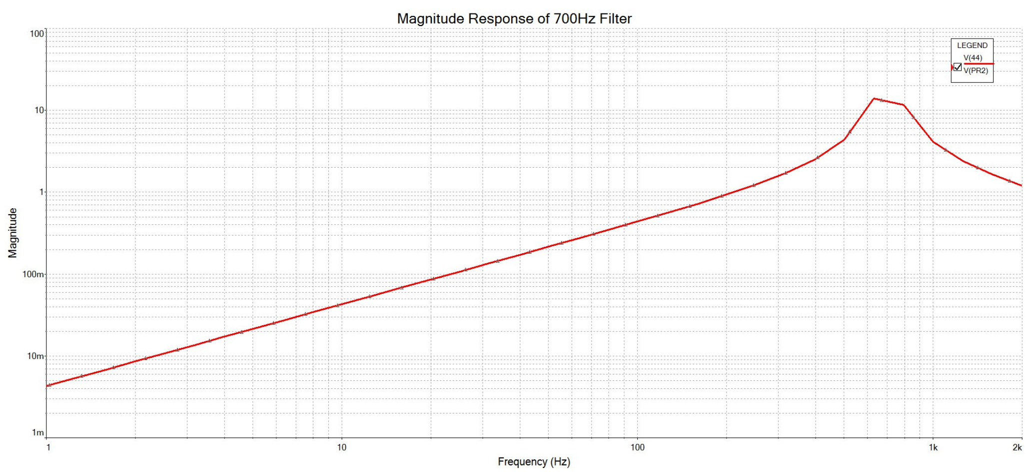

Figure 9: 700 Hz Bandpass Filter in MULTISIM.

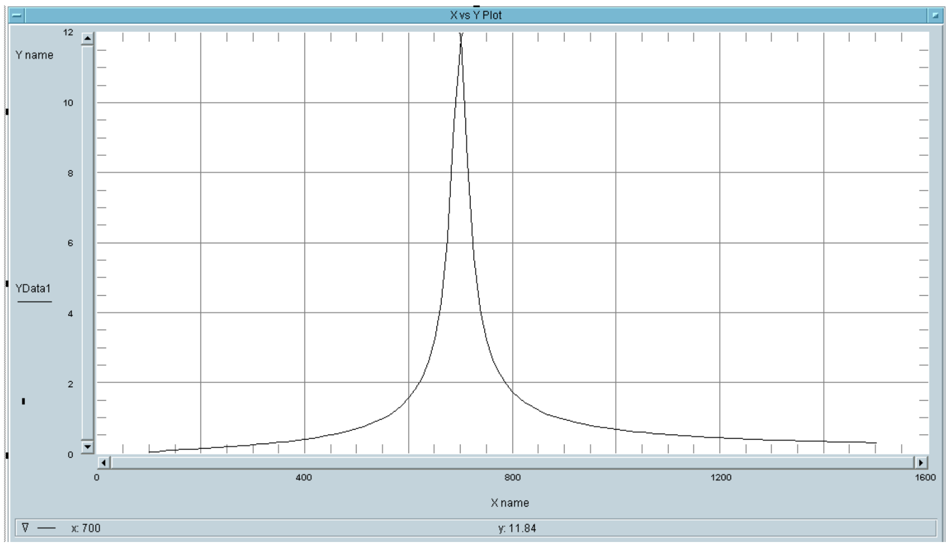

Figure 10: 700 Hz Bandpass Filter in Agilent VEE.

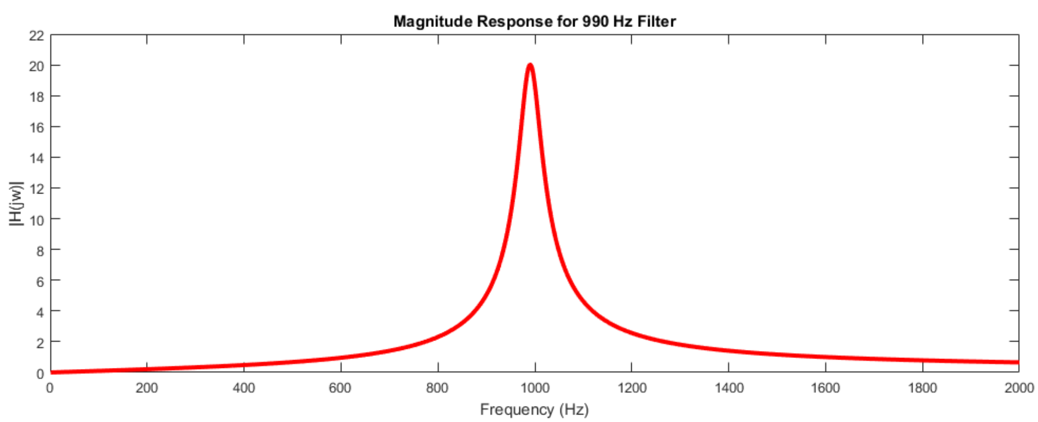

Figure 11: 990 Hz Bandpass Filter in MATLAB.

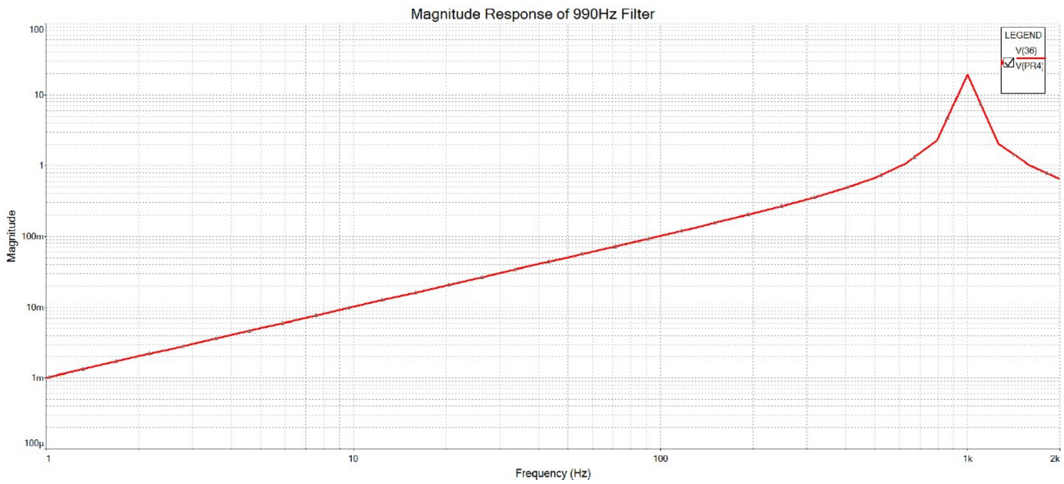

Figure 12: 990 Hz Bandpass Filter in MULTISIM.

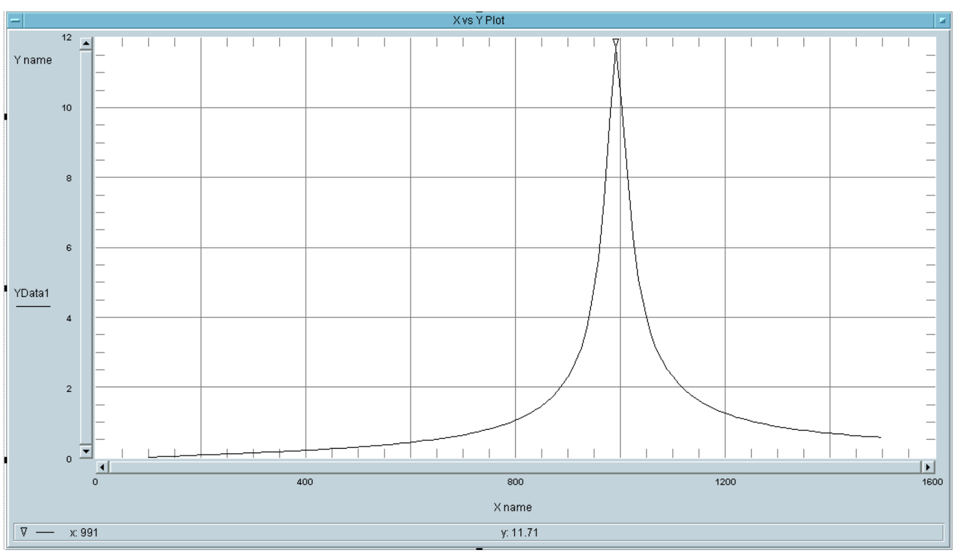

Figure 13: 990 Hz Bandpass Filter in Agilent VEE.

2.3 Decision Unit

In this part, our purpose is to analyse the output of the bandpass filters and to decide which wheels to work. For this purpose, there are mainly three parts that are:

1. Sinusoidal Rectifier
2. Comparator
3. OR Gate

2.3.1 Sinusoidal Rectifier

The purpose of this part is to convert sinusoidal output of the filters to DC signal in parallel with our design considerations. To achieve this, an half wave rectifier is used with parallel resistor and capacitor combination. The circuit structure can be seen from *Figure 14*. The diode, D_1 in the circuit is used to eliminate negative cycle signals. The R_9 and C_7 is chosen such that the ripple voltage is low enough and time constant RC is feasible. Please note that DC output voltage will be at most 9.3V since opening voltage of the diode is $\sim 0.7V$. The output signal of this rectifier can be seen in *Figure 15* when the incoming signal is a sinusoidal.

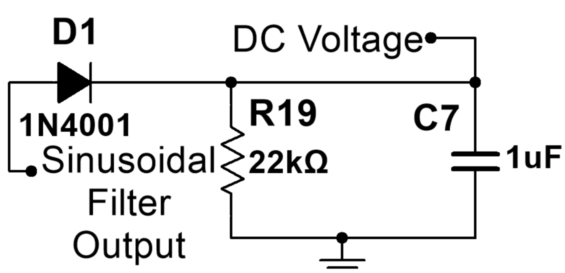

Figure 14: Rectifier Circuit Diagram.

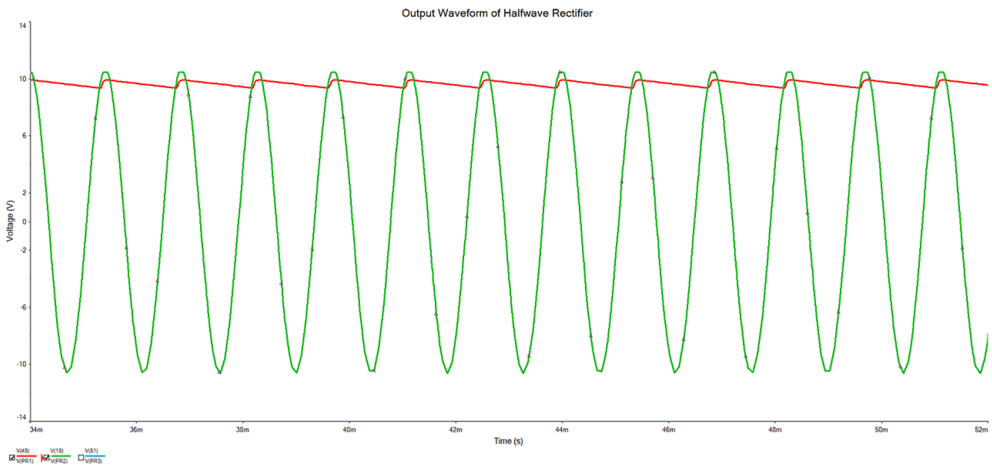

Figure 15: Output of the Rectifier Circuit

2.3.2 Comparator

The purpose of this part is to eliminate the amplified signals that are below the cutoff frequency. Suppose that, 525 Hz signal is applied to the microphone. 525 Hz filter will surely amplify it to the 10V. However, we shall make sure the input signal is within the bandwidth of the filter. The voltages of cutoff frequencies are 7.07V. We shall make a comparison between rectified DC value of the filtered signal and cutoff voltage. For this purpose, a basic comparator circuit is used. We send rectified DC voltage to the noninverting input of $U13A$ and V_{cutoff} to the inverting input. $U13A$ will output $+12V$, if $V_{cutoff} < V_{DC}$. However, if $V_{cutoff} > V_{DC}$, $U13A$ will output $-12V$. The comparator can be seen in *Figure 16*.

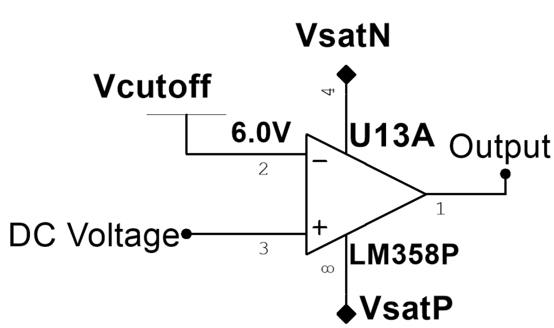

Figure 16: Comparator Circuit.

2.3.3 OR Gate

We know that one wheel must turn slower than the other if 700 Hz or 990 Hz signal is applied. For our design considerations, we decided to use two OR gates. Comparator output of 525 Hz filter will be common in both gates, however, 700 Hz and 990 Hz signals will be in different OR gates. OR gate outputs high if one of the inputs is high. If both of them are low, it outputs low. We will have a better understanding about this part while studying *Action Unit*. One of the OR gates could be seen in *Figure 17* and in *Table 3*, operation of the OR gate is listed. In addition, the *Figure 18* and *Figure 19* shows the output of the OR gate when high& low and low& low voltages are applied to the gate, respectively.

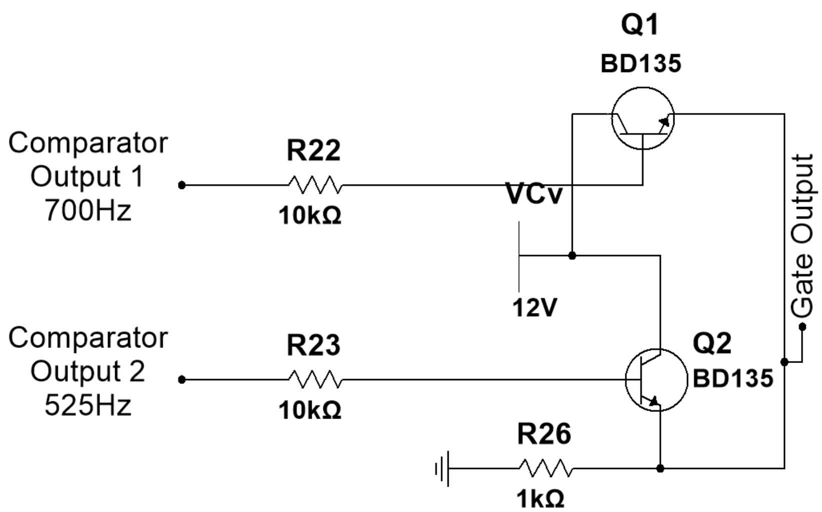

Figure 17: OR Gate Structure.

Input 1	Input 2	OR gate Output
High	High	High
High	Low	High
Low	High	High
Low	Low	Low

Table 3: The working principle of the OR gate.

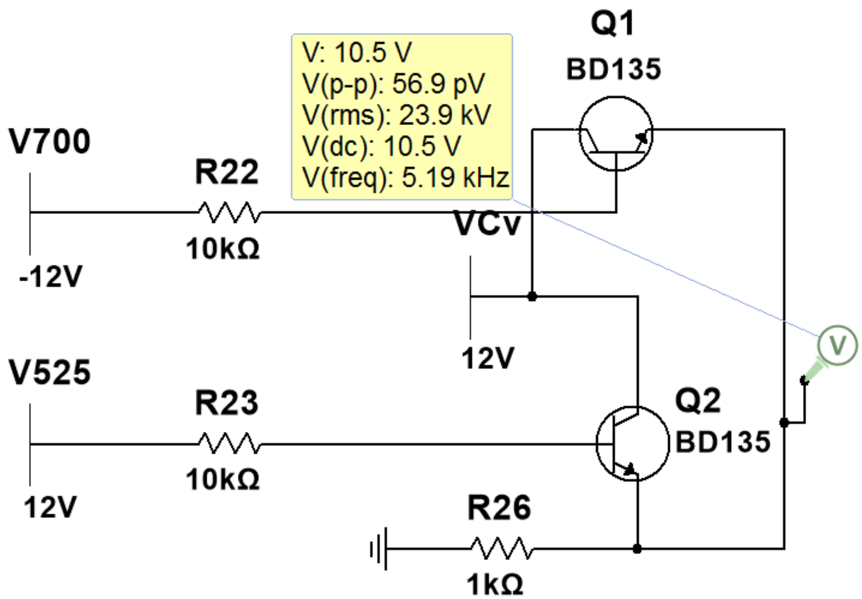

Figure 18: Output of OR Gate when high&low voltages are applied.

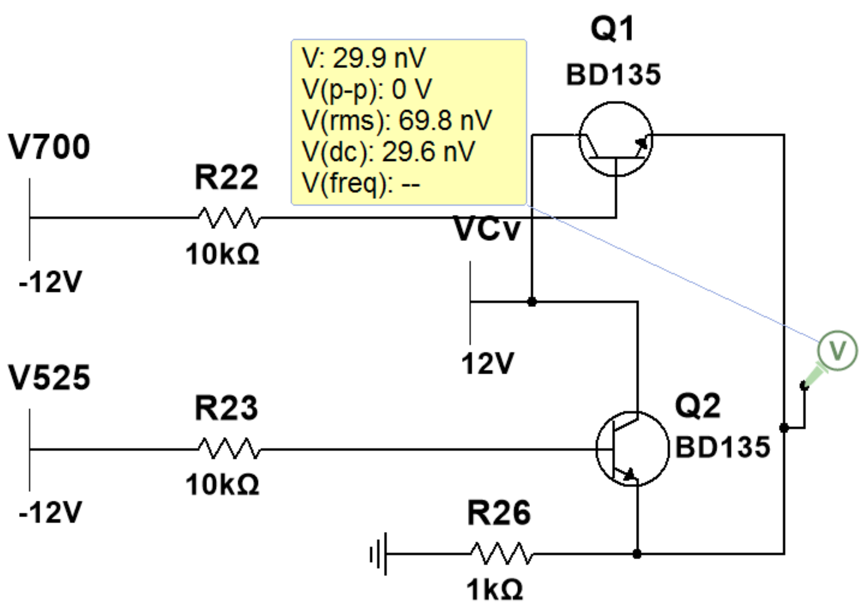

Figure 19: Output of OR Gate when low&low voltages are applied.

2.4 Action Unit

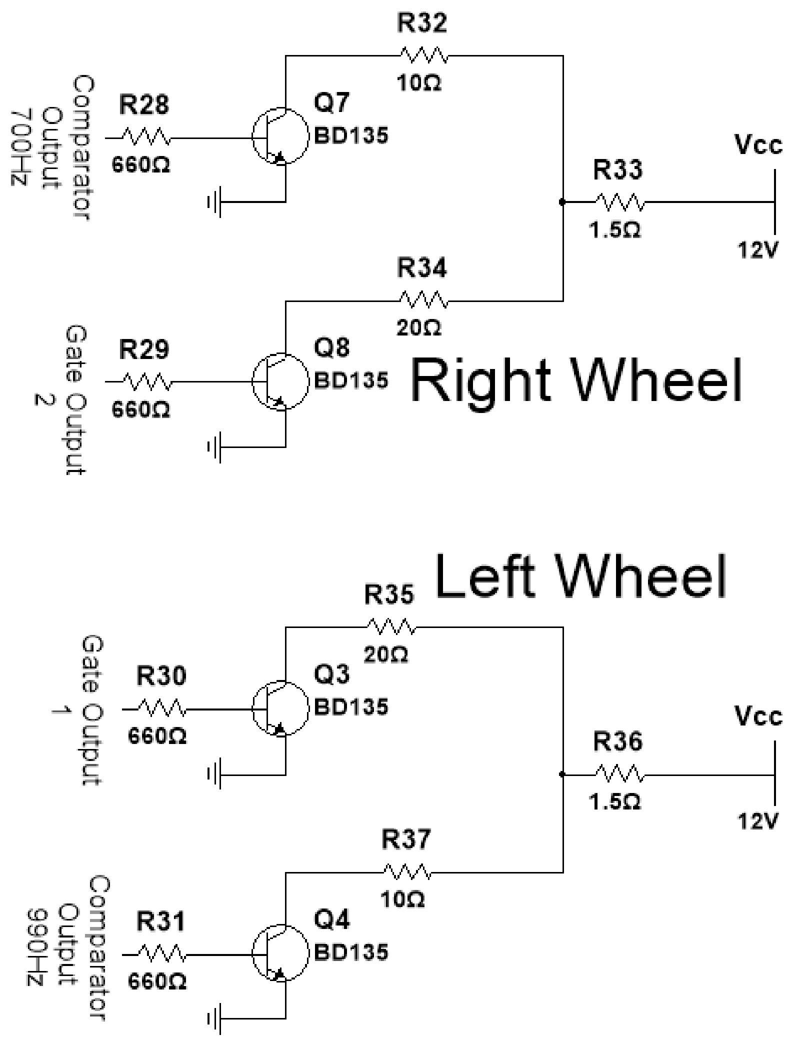

Figure 20: BJT Current Amplifiers and Wheels.

In this unit, we will turn the wheels. But, please note that if we want to turn right or to the left, one of the wheels must turn faster according to turning direction. To do so, we have four BJT current amplifier setups. Two of them provides higher current amplification than the rest two. The reason is to be able to make one wheel faster than the other. The circuit can be seen in *Figure 20*. In the *Figure 20*, we have modeled wheels as $R_{33}\&R_{36}$

resistors.

The working principle of this circuit is pretty simple. Let us assume that we want to turn the car to the right. We will apply 990 Hz signal. That means comparator of 990 Hz filter will output +12V while two other filter comparators will output -12V. Remember that these comparator outputs will go to OR gates. One of the or gates will output low, since both of the inputs are low. But the other OR gate will output high, since 990 Hz comparator will supply +12V. We shall send this high output to the R_{29}. This will make right wheel to turn. However, the left wheel must also turn and faster than the right. To do so, we will send the output of the 990 Hz comparator to the R_{31}. Please note that the transistor $Q8$ will have lower current gain than the transistor $Q4$, due to difference resistances of R_{34} and R_{37}. In *Figure 21*, it could be seen that car will turn to the right. And in *Figure 22*, the car will go forward clearly.

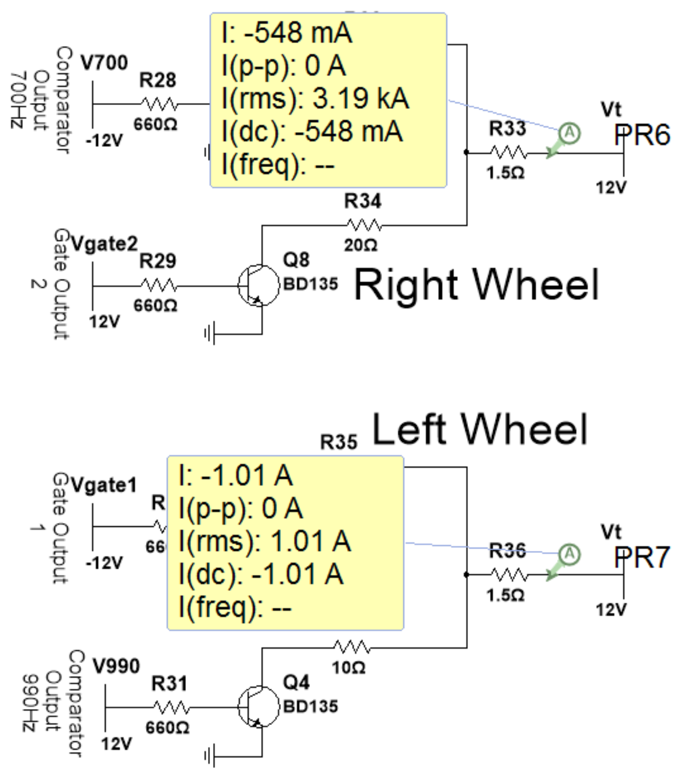

Figure 21: BJT Currents and Wheels while 990 Hz applied.

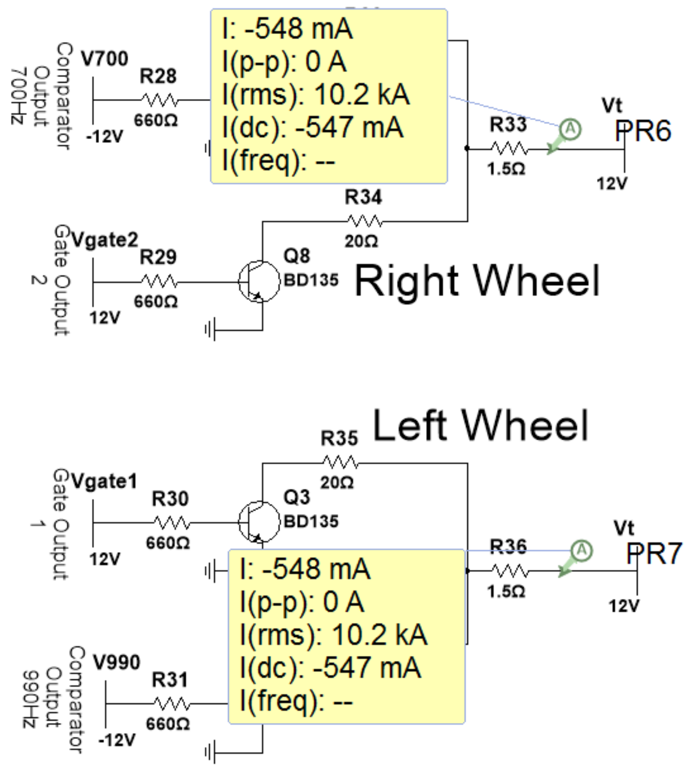

Figure 22: BJT Currents and Wheels while 525 Hz applied.

3 Power Consumption

Even though not all parts of our design worked, the power consumption of the working parts are given *Table 4*. Please note that *Action Unit* didn't work. Thus, the power consumption is considerably low.

	Voltage(V)	Current(A)	Power(W)
Positive Supply	12	0.122	1.464
Negative Supply	-12	0.026	0.312

Table 4: Power consumption of the design.

4 Cost Analysis

Various circuit components are used while constructing each sub-circuit. Since our design has changed in compared to preliminary report, used components and their values are not the same. The datas are tabulated in *Table 5*. Couple of components burnt during the project and their cost isn't included in the table.

	Number of used	Unit Price (TL/unit)	Cost(TL)
Various Resistors	33	0.021	0.693
Potentiometers	13	0.50	6.50
Capacitors	6	0.0665	0.399
1N4007 Diode	3	0.049	0.147
LM358 Opamp	12	0.39	4.68
BD135 Transistor	8	0.39	3.12
Heat Sink	2	0.85	1.7
DC motor	2	3	6
Breadboard	5	8	40
		TOTAL	63.239

Table 5: The cost analysis of the whole project.

5 Circuit Overview

The circuit overview can be seen in *Figure 24* and *Figure* **??**.

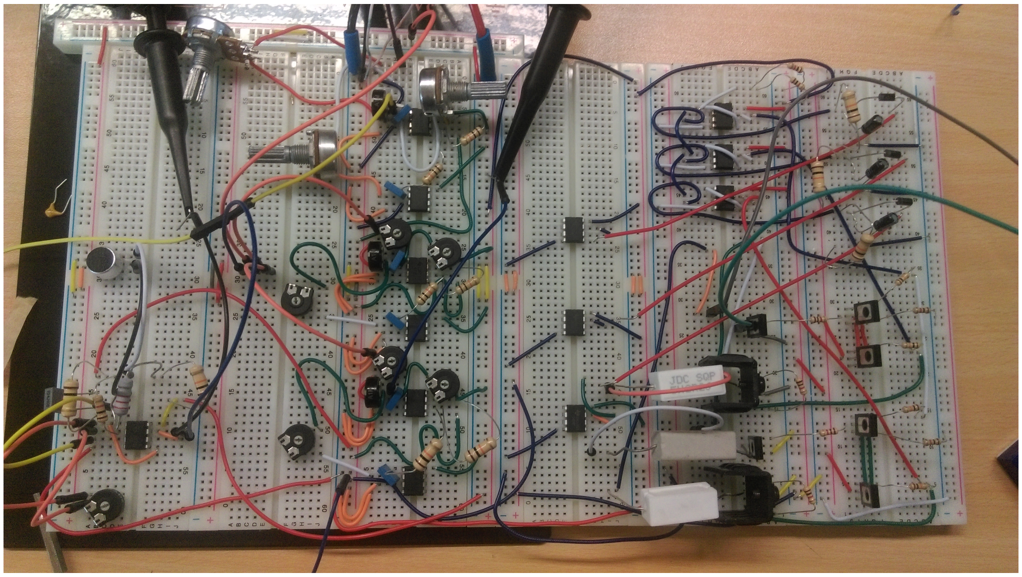

Figure 23: The circuit overview on breadboard.

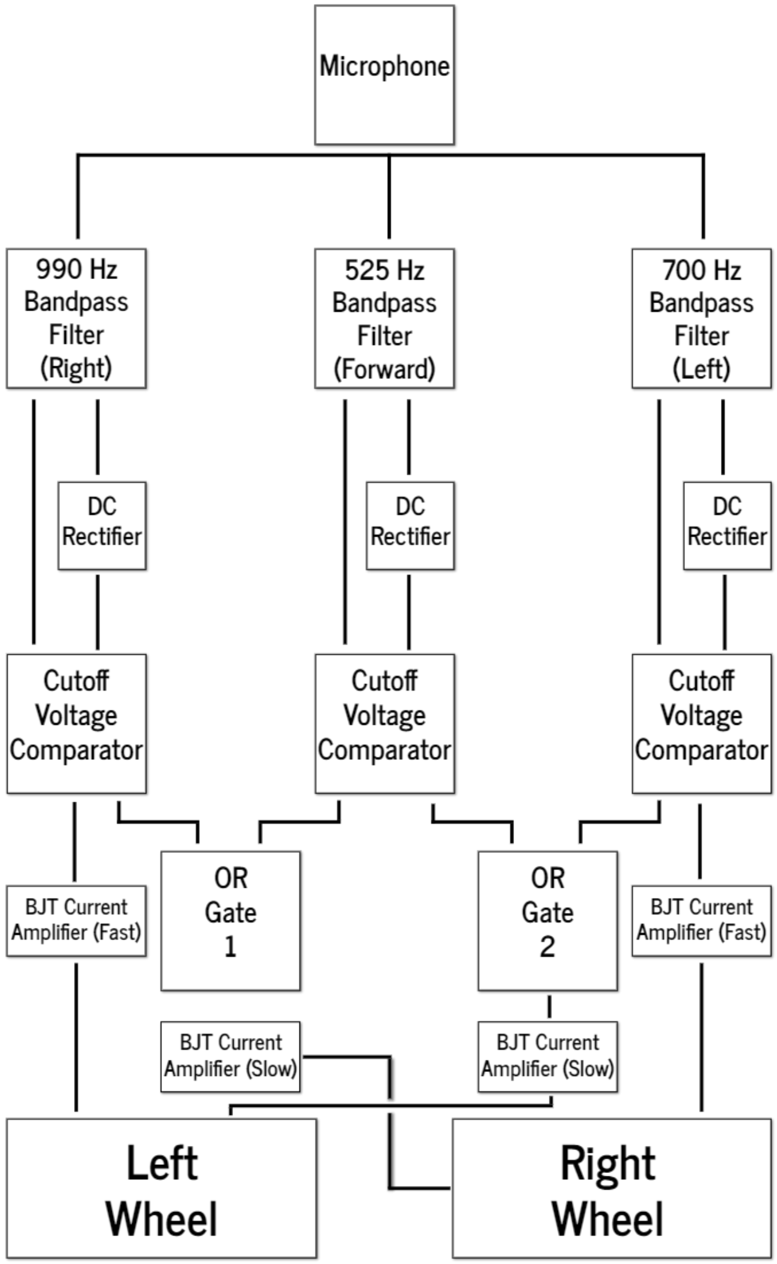

Figure 24: The circuit overview with block diagrams.

6 Conclusion

Throughout the designing and building processes, we have learnt many things about electret microphone, like, biasing, killing DC offset, removing noise, amplifying. Also, worked a lot on bandpass filters and some usage areas of operational amplifiers and bipolar junction transistors. In the very beginning of our project we have tried different techniques of biasing the electret microphone, our final decision model was both able to bias the microphone and amplify the output signal for us. Later on, we have faced quite unique problems while building ideal bandpass filter for our project. To overcome this problem, we had to design several types of filters and build them repetitively and that was the most frustrating part of this project. However, at the end we have observed almost ideal bandpass filters as in *Figure 7*, *Figure 10* and *Figure 13*. We had troubles in OR Gates. We couldn't realize problem with them, so we failed at the OR Gates, which is was one of the key points in the decision unit. Nevertheless, we have acquired the significance of developing new concepts and visionary perspective when building and designing the project.