A Lane Adjuster Circuit for Smart Car Applications

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***Abstract*—This document is the final report for a circuit which is constructed for the term project of Analog Electronics Laboratory at Middle East Technical University. It includes a possible solution for the problem, which provides a theoretical background, power analysis of the circuit, an equipment list, cost analysis of the circuit, and some circuit schematics for the circuit design. One can look up Section III for more detailed information about the specifications of the project.**

***Index Terms*—Analog electronics, project, EE313, METU, audio transmission, speaker, microphone**

I. Introduction

Vehicles going autonomously are desired for simple drives and safe trips by the costumers. One of the reasons of choosing autonomous vehicles is to eliminate the human factor that causes accidents in most of the cases. Thus, the vehicle must move completely on its own so that this factor is eliminated. The first thing we need to do is to realize and decide which lane the vehicle should go through in different situations. To illustrate this, we will design a controller circuit for such a small environment in our project. There will be three types of cars, which are ambulance, police car and regular car, in a double lane road. Ambulance must have the highest priority and police car has a higher priority than regular car. Every vehicle has a different sound, it can be called the siren of the vehicle, and we detect which vehicle is approaching from which lane by the siren. At the end, we decide which lane we should be taking.

II. Overall Block Diagram

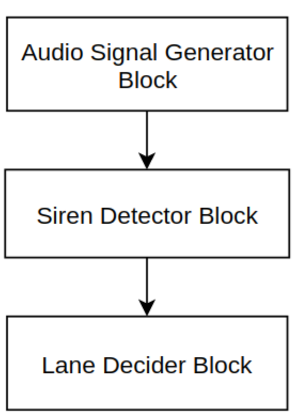

Fig. 1. Overall block diagram of the project

III. Specifications

At the beginning, we are creating three sinusoidal signals with frequencies 2.85 kHz, 2.6 kHz and 2.32 kHz, which stands for ambulance, police car and regular car, respectively. Moreover, we need to tell which vehicle is coming from which lane, which will be decided from the amplitude of the sinusoidal signal, where having a higher amplitude means that it is coming from the right lane. Another thing is a restriction given to us, that is, there are always two vehicles on the lanes and one is coming from the right, and the other is coming from the left. After the signal is created and summed accordingly, we transmit summation of the signals from a speaker to a microphone. Amplification is needed for the signal since it is attenuated and the microphone we use performs poorly. After the amplification, filters do the separation of the signals, here 20 dB attenuation is required for the other frequencies for each channel. For example, filter having center frequency of 2.85 kHz must attenuate the the signal having frequency of 2.6 kHz at least by 20 dB. For the logic unit, ac signal should be converted to DC signal. 8 LED's are used, 2 for lane decider logic, 6 for siren detector logic. Lane decider logic decides whether our car should go left or go right according to the situation. Whereas, in the siren detector logic, there are 3 LED's representing each vehicle and each LED shows whether corresponding vehicle is coming or not. Other 3 LED's represent the lanes of the coming vehicles, right or left. Now, it is time for more detailed information about the sub-blocks of the system.

IV. Analysis of the Circuit

A. Audio Signal Generation

Firstly, we will indicate the lane that vehicles come from with the amplitude of their audio signals. Therefore, we need to be able to obtain two different amplitudes. To do so, we will use two switches for each vehicle. The circuit schematics are shown in Figure 2. Closing only S1 will provide us with 8 V, which we will use to indicate that the vehicle is travelling from the left lane. Closing both S1 and S2 will cause a short circuit and it will instead provide us with 12 V, which we will use to indicate that the vehicle is travelling from the right lane. Finally, not closing any switches will provide us with 0 V and and indicate that type of vehicle is not travelling.

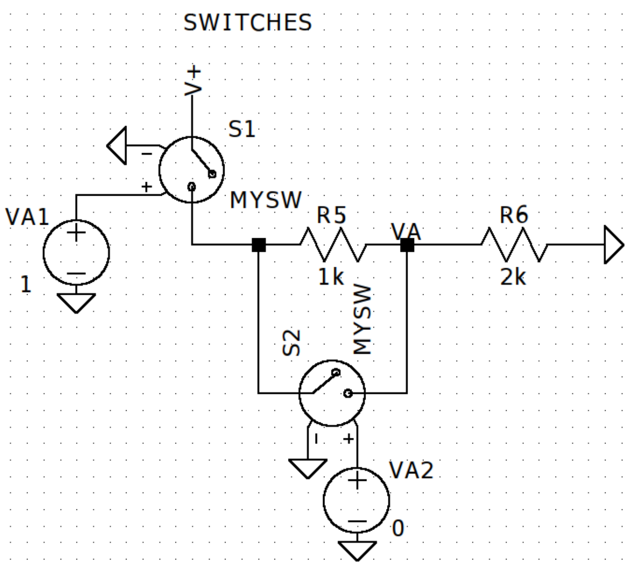

Fig. 2. Creating the road environment by using switches

Secondly, we will indicate the type of vehicle travelling with frequencies. To do so, we determined different frequencies for ambulance, police car and regular car, which are 2.85 kHz, 2.6 kHz and 2.3 kHz, respectively. We will create a sinusoidal wave with determined frequencies and amplitudes to show the type of the vehicle and the lane it travels. We will adjust the amplitude as we mentioned previously. We will use an oscillator to create a sinusoidal wave. Two of op-amp based oscillators are Wien Bridge Oscillator and Phase Shift Oscillator. Alternatively, it is possible to use a Square Wave Generator and filter the signal to obtain a sinusoidal signal. We decided to use an RC Phase Shift Oscillator whose circuit schematics can be seen in Figure 3.

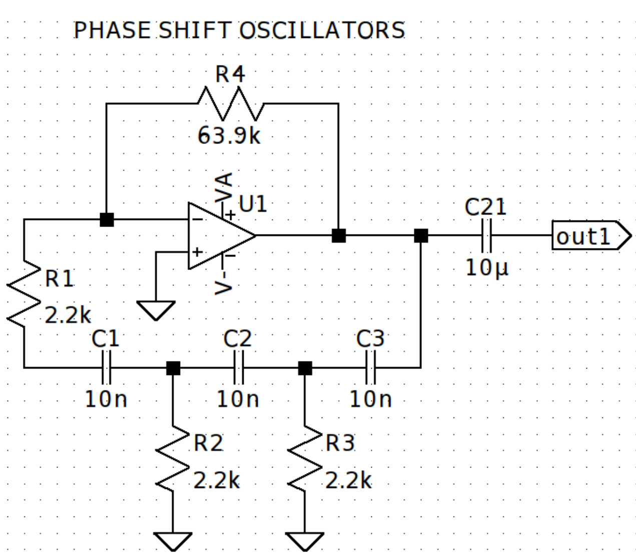

Fig. 3. Phase shift oscillator for generation of a sinusoidal

We will use same capacitors and resistances for ease of implementation. When we select resistances and capacitances as the same, equations becomes much simpler. Oscillation frequency of the oscillator when we use same capacitance and resistor values is given in (1).

$$f_{\text{oscillation}} = \frac{1}{2\pi RC\sqrt{6}} \tag{1}$$

The feedback resistor that is necessary to sustain the oscillation is given as

$$R_4 = 29 \cdot R \tag{2}$$

The RC Phase Shift Oscillator is a combination of RC network and an amplifier. The resistor-capacitor network consists of stages that contains a capacitor and a resistor connected in series. In our oscillator, we cascaded three of these stages where each stage causes a phase shift of 60°, summing up to 180° of phase difference. This phase difference is necessary to obtain a positive feedback. Then, we determined the resistance of our feedback resistor as found in (2), which is necessary for us to obtain a unity feedback loop gain. However, we observed that in practice, the feedback resistance is slightly higher than what we found theoretically. Therefore, we used trimmer potentiometers as feedback resistors to be able to adjust their resistances.

Considering the fact that the most viable method of communication in a traffic environment is sound, it is inevitable for us to use sound waves to transmit the signals we created with phase shift oscillators. To be able to establish a communication between vehicles, we must be able to produce and receive sound signals properly. To produce a sound signal, we need an audio speaker. However, since it is not feasible to create a separate sound wave for each signal, we need to sum the signals. We constructed a summing amplifier to sum the signals up and fed the speaker with the sum of the sinusoidal waves. Also by using a summing amplifier, we are able to acquire the required power rating to drive the speaker, which is shown in Figure 4.

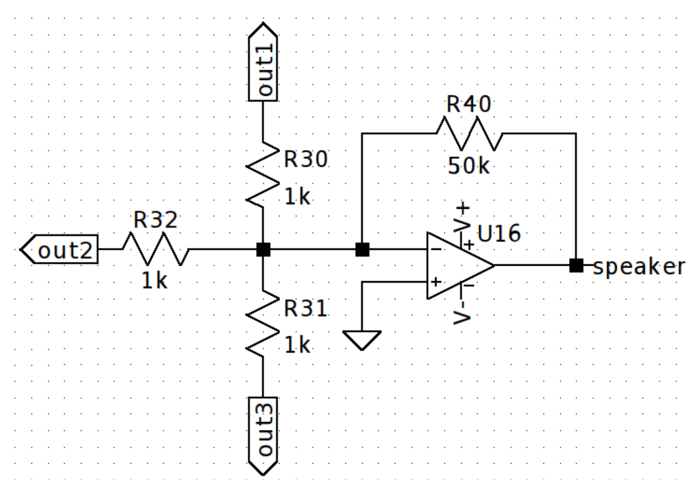

Fig. 4. Summing amplifier circuit for generated sinusoidal signals

Additionally, we would have to use a power amplifier to drive the speaker, if we had a power below 1 W, which was the power rating. We could use Class A or Class AB power amplifiers, since we want our signal to stay intact. In fact, using a power amplifier would have provided us with a better solution. But since using the summing amplifier to amplify our signal was satisfactory, we decided not to use a power amplifier for the sake of compactness.

B. Siren Detection

In this stage, we are to collect the sound waves send by the speaker. We will use an electret microphone, which is a type of capacitance microphone, to collect the sound wave send by the speaker, which is illustrated in Figure 5.

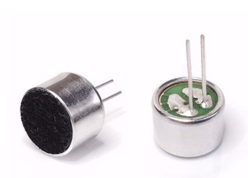

Fig. 5. Electret microphone used in the circuit

Capacitance microphone is a type of microphone that contains a parallel-plate capacitor and makes use of electrostatic forces to receive sound. One side of the parallel-plate capacitor is formed of thin metallic membrane. Capacitance of the parallel-plate capacitor will change because of the vibrations caused by sound waves. Time-varying capacitance will create a time-varying current, which will then create a time-varying voltage.

In electret microphones, the time-varying voltage is used to modulate the gate voltage of a FET, which is used to buffer and amplify the signal. However, the output voltage that electret microphone yields is not sufficient for our applications. Therefore, we need to amplify this voltage. We used the gain amplifier shown in Figure 7 to raise the voltage to a satisfactory level. Biasing of the microphone is shown in Figure 6. To adjust the level, we have added a second amplification stage consisting of a trimmer potentiometer, shown in Figure 8.

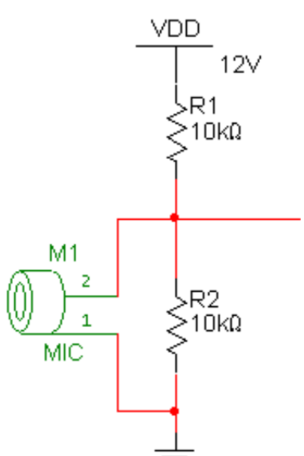

Fig. 6. Biasing of the electret microphone amplification circuit

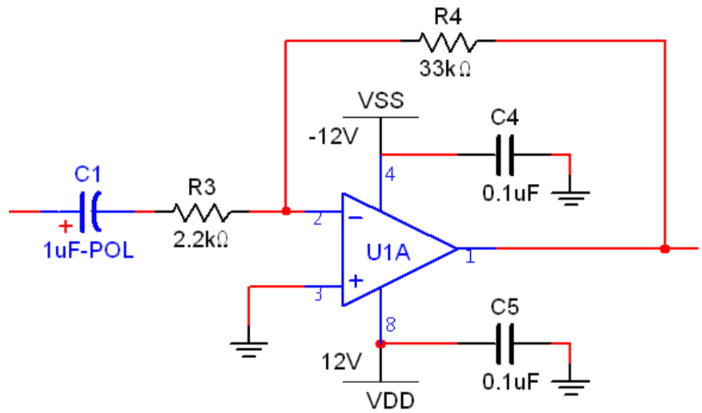

Fig. 7. Electret microphone gain amplification circuit

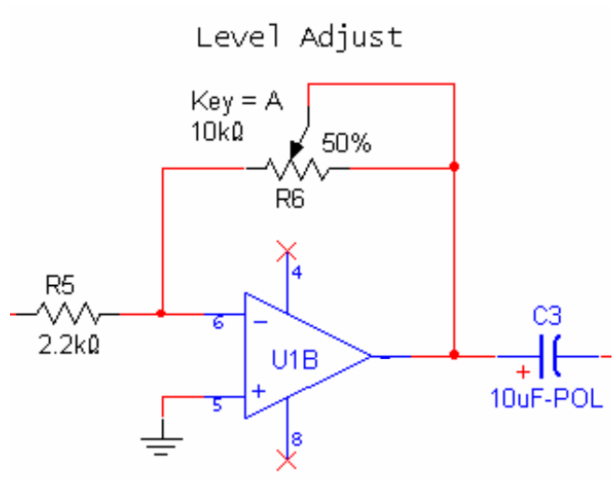

Fig. 8. Level adjuster of the electret microphone amplification circuit

After receiving the signal with the electret microphone and amplifying it, we need to interpret the information that the signal carries to be able to process it. As we discussed before, we determined different frequencies for different types of vehicles. Therefore, in order to determine which type of vehicle are travelling on the road, we must determine the frequencies that the audio signal contains. For this purpose, we need to filter the signal. We will use Multiple Feedback Band-Pass Filters to filter the signals. Circuit schematic of Multiple Feedback Band-Pass Filter can be seen in Figure 9.

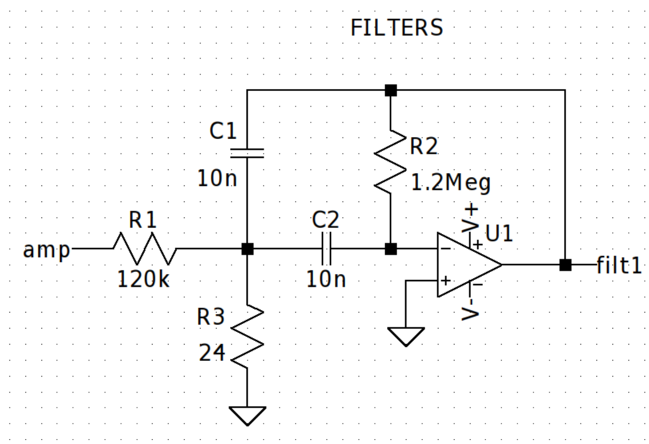

Fig. 9. Band-pass filter circuits for detection of sirens

Transfer function of the filter is obtained and given in (3). Center frequency, quality factor and the gain of the filter at the center frequency is given in (4) and (5).

$$\frac{V_{out}}{V_{in}} = \frac{-\frac{1}{R_1 C}s}{s^2 + \left(\frac{2}{R_2 C}\right)s + \frac{1}{R_2 C^2}\left(\frac{1}{R_1} + \frac{1}{R_3}\right)} \tag{3}$$

$$Q = \pi f_c R_2 C \tag{4}$$

$$K = \frac{R_2}{2R_1} \tag{5}$$

Bode plots of the functions according to the used parameters are given in Figures 10, 11, and 12. As seen from the Bode diagrams, 20 dB attenuation is clearly obtained.

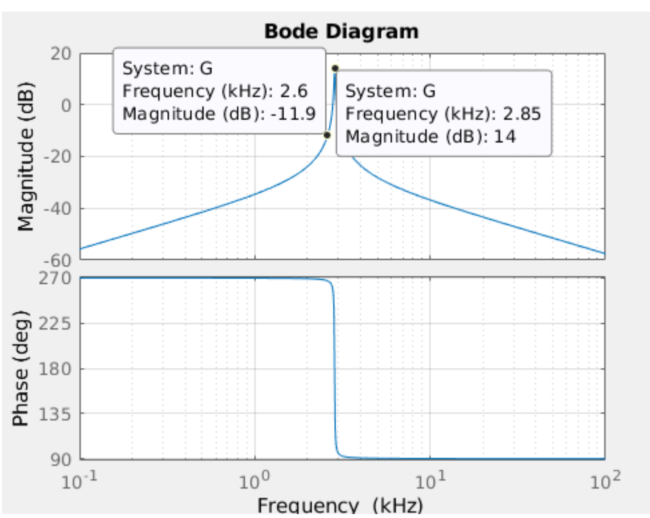

Fig. 10. Bode plot of the transfer function for the filter having 2.85 kHz center frequency

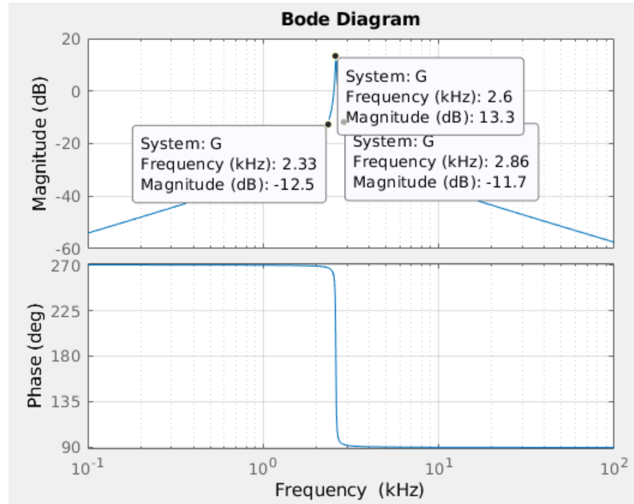

Fig. 11. Bode plot of the transfer function for the filter having 2.6 kHz center frequency

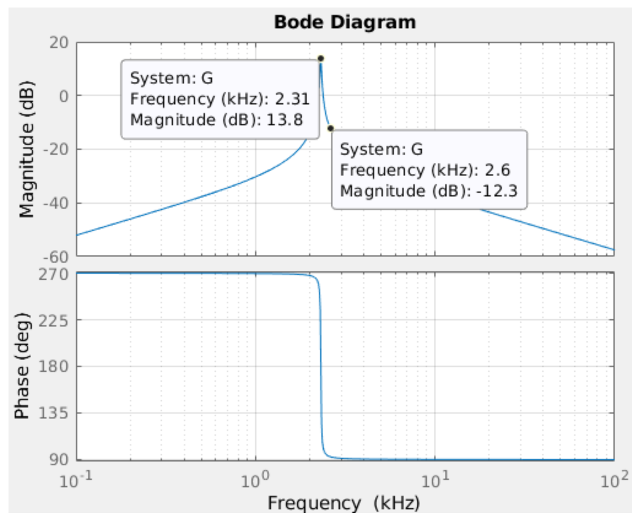

Fig. 12. Bode plot of the transfer function for the filter having 2.32 kHz center frequency

We used three different Multiple Feedback Band-Pass filters designed to have center frequencies as the frequencies we previously determined for the vehicles. We selected the quality factor of each filter to attenuate signals with other frequencies by at least 20dB. We adjusted the gain at the center frequency so that filters will not attenuate the signals with their center frequency.

We now have completely recovered signals we had previously produced and transmitted. We have the necessary information to identify the vehicles coming from behind and which lane should our car use. However, it is inconvenient for us to use AC signals while making such decisions. Therefore, we will use the circuit in Figure 13 to convert ac signals into DC inputs. This circuit is half wave rectifier plus a capacitor and an op-amp is used as a buffer. Half wave rectifier takes the positive side of the sinusoidal signal and then peak is detected by the capacitor.

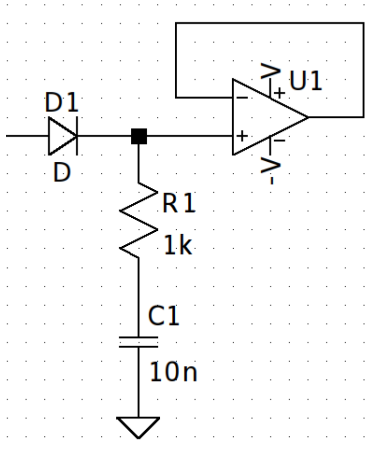

Fig. 13. Circuit for ac-dc conversion

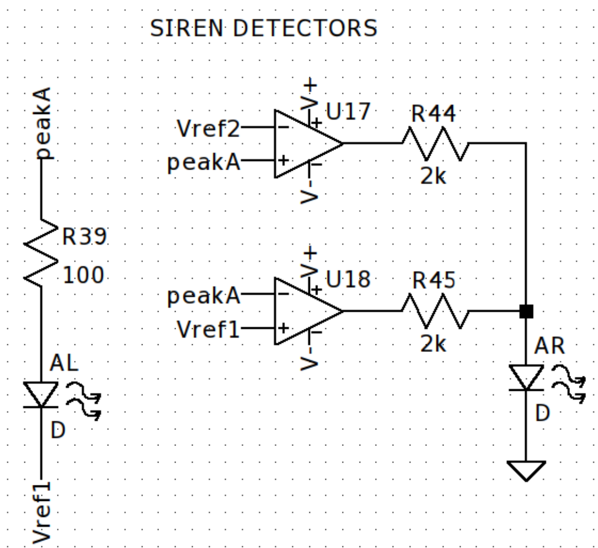

Fig. 14. Indicator LED's for the given situation

We designed a siren detector circuit that visualises the information we obtained from the audio signals. Our siren detector circuit is a logic circuit that determines the lane that each vehicle is on or whether that type of vehicle is actually on the road. This circuit operates by comparing the DC inputs with two reference voltages we determined beforehand. The circuit is shown in Figure 14. The LED on the left determines whether the vehicle is on the road. If the DC input is higher than Vref1, the LED is open, meaning that the vehicle is on the road. The LED on the right determines whether the vehicle is travelling from the left. The DC input is compared separately with reference voltages using comparators as shown in Figure 14. If the LED is open, this means that the vehicle is travelling from the left.

C. *Lane Detection*

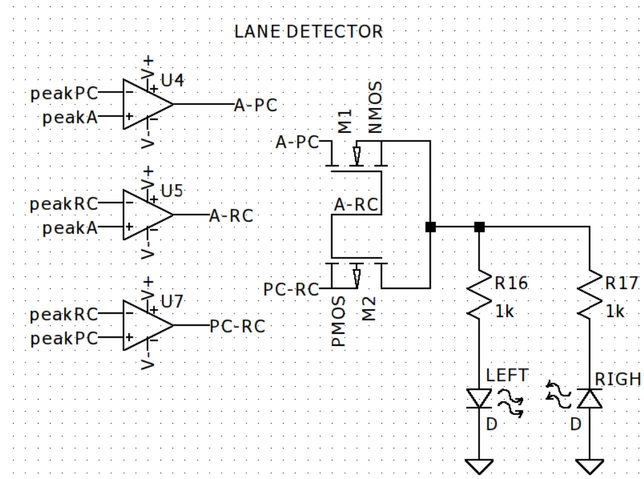

Fig. 15. Lane decider logic circuit

V_A	V_{PC}	V_{RC}	V_{APC}	V_{ARC}	V_{PCRC}	LED
12	6	0	**12**	12	12	**12**
12	0	6	**12**	12	-12	**12**
6	12	0	**-12**	12	12	**-12**
6	0	12	12	0	**-12**	**-12**
0	6	12	-12	0	**-12**	**-12**
0	12	6	-12	0	**12**	**12**

TABLE I
VOLTAGES APPEARING ON THE CIRCUIT FOR ALL SITUATIONS

For this unit, we have found out that if we compare the voltages with each other we see that we ca apply pass transistor logic to the decider. V_{ARC} decides which MOSFET will transmit the signal. If it is high, NMOS allow V_{APC} to pass, if it is low, PMOS allow V_{RCPC} to pass. Note that both of them is never open at the same time. Here we could use CMOS transmission gate, however this is enough or our application.

V. Power Analysis

Fig. 16. Power consumption of the circuit

$$P = V \cdot I \tag{6}$$

For 12 V, power consumption of the circuit is (12.01V)(0.046A)=(0.55246W). Moreover, -12 V has an extra effect, which we forgot to take a picture of. Thus, doubling can be a good approximation. Thus, power consumption of the circuit is about 1.10492 W. It changes according to the speaker operation. But, it is about 1-1.5 W range.

VI. Equipment List

Apart from the equipment used in the laboratory such as multi-meter, oscilloscope, and DC supply, there are components we purchased. The components which are used while constructing the circuit can be listed as:

- LM741
- Switches
- Speaker
- Electret microphone
- LEDs
- Capacitors
- Resistors
- Potentiometers
- Breadboard
- Jumpers

VII. Cost Analysis

Items purchased for the project are listed with their prices in Table VII, 105 TL is out of our pocket.

Item (Number)	**Price (TL)**
LM741 (25)	25
Switch (6)	5
Speaker (1)	10
Electret microphone (1)	5
LEDs (8)	2
Capacitors (Various)	5
Resistors (Various)	3
Potentiometers (Various)	10
Breadboard (3)	30
Jumpers (Various)	10
Total Cost	**105**

TABLE II
COST ANALYSIS

VIII. Project Video and Photography

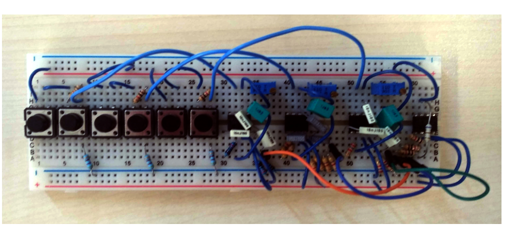

Fig. 17. Audio Signal Generator Block

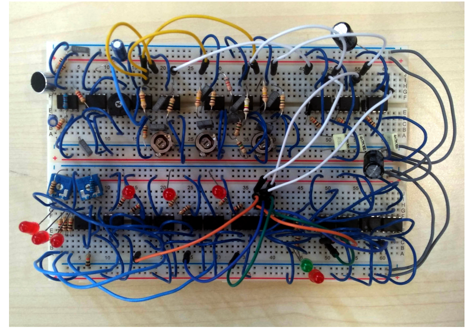

Fig. 18. Siren Detector and Lane Decider Block

IX. Conclusion

In conclusion, we proposed a solution to the problem introduced in the introduction section. We have proposed a method for cars to determine the type of vehicles behind them and the lane they are on. We have designed oscillators for each type of vehicle that we can control the amplitude of the signal they produce. Then, we summed these signals and produced a sound wave to transmit. Afterwards, we received the signal with the help of an electret microphone and amplified it with an amplifier. We have filtered the signal with the filters we designed for each type of vehicle. Then, we converted the ac signals to DC inputs to be able to use them while making decisions. We constructed a logic circuit to visualize the information we obtained from the audio signal and another logic circuit to decide the lane that our car should travel. With its ups and downs, this project improved our knowledge and enabled us to put the theoretical knowledge into practice with all its problems. We learned something thanks to each problem that we faced, and we really wanted to improve our design by solving its challenges one by one and make it real in every second. Although it is not the best design of the electronics world, it served the purpose and can be improved, which provided an insight for us to design more than a lane decider system in future.

References

[1] S. Hamilton, An analog electronics companion. Cambridge: Cambridge University Press, 2007, pp. 403-441.

[2] D. Kaplan and C. White, Hands-on electronics. Cambridge, UK: Cambridge University Press, 2003, pp. 85-125.