Senior Design Project II (BE-4355-001)

A Lightweight Wearable American Sign Language Translation Device

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2. Executive summary

The main goal of this project is to create a lightweight, wearable American Sign Language (ASL) translation device. Currently, over 5% of the world's population lives with a hearing disability. It is estimated that by the year 2050, 1 in every 10 people will have a hearing disability (1). The overall aim of this project is to create a fully functional translation device that will diminish the current communication barrier that exists. Through our research, we found that there are many devices that are currently being developed with similar goals. Many of these devices are glove-based, making them cumbersome to use, as they limit the user's ability to perform everyday life tasks. We attempt to overcome this issue by designing the device to be glove-less with no necessity for it to be connected to any external computers, monitors, or network. It is composed of five wireless fingernails, five wired rings that are connected via thin wires to a wrist-worn central processing unit. The wrist-worn unit is composed of an Arduino Mega, Raspberry Pi, and a 9V battery. These components are encased in a box-like enclosure with a Liquid Crystal Display (LCD) screen and a speaker mounted on the side. The device will achieve hand gesture recognition using 850 nm infrared (IR) light-emitting diode (LED) emitters in the fingernails and rings. The IR LEDs (Light Emitting Diode) in the rings will trigger the IR LEDs in the fingernails and thus turn them on. Each ring will have IR receivers that will be able to measure the intensity of the signals produced by the IR emitters in the fingernails. They will then send this information to the wrist-bound Raspberry Pi to translate it through a trained neural network, which is coded using Python, and produce the corresponding letter to be displayed on the LCD screen and through the speaker. Our produced device will be the 9th generation production. Previous generations of the device relied on digital filtering, which has been proven to hinder the performance of the device as it results in inaccurate translating different gestures. Our novelty is implementing a new analogue filtering system, which aims to fix this issue. We envision having square waveform generators in the fingernail devices and filters in the ring devices. The specifications that we set for this project are that the device should be lightweight (less than 400 g) and not rely on an external computer. The functional specifications are that the device can recognize and translate the ASL alphabet, be at least 95% accurate, be able to differentiate different frequencies, not pose any optical hazard, and have a life span of 4 hours. One of the main specifications is that the device must be below 400 grams, after calculating the final device weight, we measured it to be 375.88 grams, which meets the weight limit. Another criterion is that it must not rely on any external device, which our device meets that standard. The device must, however, be connected to a power source, such as a power bank.

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4. Introduction

4.1 Significance and benefits of the project

American Sign Language is the third most used language in the United States. Across the country, 10 million are hard of hearing and close to 1 million are functionally deaf (2). Furthermore, 2-3 of every 1000 children are born with a detectable level of hearing loss, and 90% of this population is born to hearing parents, thus creating a communication divide within families (3). In a work environment, accommodations for ASL users are minimal to none. Moreover, the deaf awareness training in workplaces has low results. And in the past few years, due to Pandemic it has become more difficult for ASL users to sign and understand their coworkers as interpreters are not always “pinned” during video calls (4)(5).

4.2 Existing similar systems

Currently, there are no ASL translation devices on the market, but there are several institutions and groups that have researched and designed similar devices. These institutions include Cornell University where Electrical and Computer Engineering students designed a wearable glove that uses Machine Learning algorithms to translate signed language into spoken English (6). This prototype uses Spectra Symbol Flex-Sensors to measure how much a finger is bent and a three- axis accelerator and gyroscope to identify the orientation and movement of the hand. The data from the sensors is then analyzed using ATmega1284p microcontrollers and sent to a main PC (Personal Computer) unit and run-in conjunction with a python script and then translated. As a result, their final device had an accuracy of 98%, translating 28 ASL signs, however, these values are dependent on the user's hand size which creates challenges differentiating between certain letters.

Similarly, Michigan State University developed a deep learning-based sign language translation technology implementing Leap Motion for light-based sensing of skeletal joints. In addition to this, the technology uses a recurrent neural network model the spatial structure and temporal dynamics of the extracted ASL characteristics, and a probabilistic framework based on Connectionist Temporal Classification, allowing for both word and sentence level ASL translation of 94.5% accuracy (7). However, this design is different from other translation devices as it does not incorporate any type of glove which other devices lean towards.

4.3 Objectives of the project

The main objective of this device is to narrow the communication gap between ASL and non ASL users by allowing the language to be used and understood between the two parties without the need of an interpreter. This communication barrier makes it hard for ASL users to express themselves and communicate and the reliance on an interpreter would hinder them and may also lead to miscommunication due to human error upon translating. It is also not feasible to carry around a device using a camera and angle it correctly to always interpret hand movements. Thus, this device is non-intrusive, portable, and easy to use across all ages as it does not rely on external computers.

4.4 Distinguishing features of the proposed system compared to existing similar systems

Compared to other devices currently underway, our device aims to occupy less space to leave the user's hand as free as possible leaving the fingertips exposed to allow easy access to touch screen devices, unlike the glove-based devices. This device will implement modulated infrared frequencies for detection of signed hand positions. This information from the IR emitters is then transferred to a system with a trained neural network to identify the corresponding signed letter. Additionally, to achieve the objective of convenience and portability, the device will have wireless fingernails, and rings connected to the wrist component by minimal wires. The device will also rely on an analog system to communicate between the rings and fingernails components as well as filter different IR emitted frequencies.

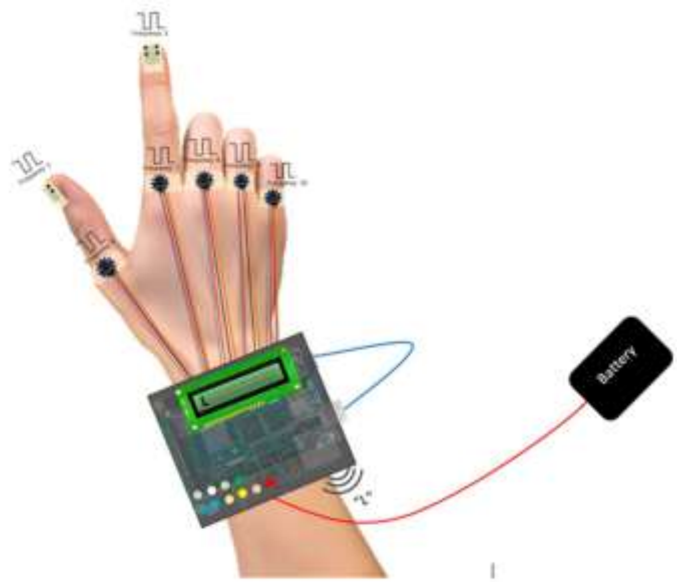


Figure 1. Device components: central processing wrist unit, wired rings, wireless fingernails

4.5 A brief outline of how this written report is organized

The remainder of this report includes detailed information about the project specifications, which includes detailed quantitative functional and physical specifications, the safety and sustainability, as well as any constraints of the device that may be identified. The report will also include detailed design information including the rationale behind it. We will also discuss test results and present simulation results as well as any schematics and computations that were done. We also discuss any fabrication that was done, including building the circuits. Finally, we discuss the project costs and present detailed tables of costs and vendors as well as any laboratories and facilities used.

5.Project Specifications

The device must meet several necessary specifications and safety requirements to operate properly and avoid any safety hazards within the provided constraints.

5.1 Detailed quantitative functional specifications

The main components in the subsystem included breadboards. The three subsystems were waveform generating circuit, detection circuit, and active bandpass filter circuit.

Waveform generating circuit consisted of the following circuit components: 555 Timer, resistors, capacitors, and IR LED. The IR LED was secreting 850 nm light and the IR LED that was used in this circuit was an SMD model. To power the subsystem, voltage supply was used. The voltage values used were 5 V or 3 V. Overall subsystem was designed to function at 5 V because the main CPU unit contains Arduino Mega, and it provides the voltage supply of 3 V or 5 V.

Waveform generating circuit included 555 Timer. The primary function of 555 Timer was to produce square waveforms that oscillate at a specific frequency. To obtain the desired frequency, resistor and capacitor values were changed on the circuit which can be found in Figure 4.

In the above-mentioned circuit, values of resistors R_A and R_B, and the capacitor value of C_2 were the main components in determining the desired frequency. The desired frequencies for this project included 18 kHz, 38 kHz, 56 kHz, 77 kHz, 98 kHz, 114 kHz, and 132 kHz. In the future, a total of 10 or 15 unique frequencies must be generated to account for two to three transponders in each ring. To calculate the unique frequencies' resistors and capacitor values, the following formula was utilized:

$$f = \frac{1.44}{(R_A + R_B) * C_2} \qquad [1]$$

The above formula provided rough values of resistors and capacitor and it did not provide exact values. The next step to obtain the resistors and capacitor values, NI Multisim was utilized to obtain a more approximate value of the resistors and capacitor.

The voltage input for the waveform generating circuit included 3 V and 5 V. The output of the waveform generating circuit was attenuated and the values can be observed below:

Table 1. The voltage values of the waveform generating circuit.

V_{in}	V_{out}
3 V	1.96 V
5 V	2.60 V

The detection subsystem consisted of phototransistor and resistor components. The phototransistor was specified to detect 850 nm and the model that was used for detection subsystem was SMD model. The resistor value that was finalized to be used was 1 MΩ.

To power the subsystem, voltage supply of values 3 V and 5 V were used. The phototransistor needed to be pointed at the IR LED at 90 degrees to be able to detect the emitted signal. The detected signals were very attenuated and the following voltage values were observed for phototransistor detection subsystem:

Table 2. The voltage values of the detection subsystem.

V_{in}	V_{out}
3 V	200 mV
5 V	500 mV

The third subsystem, the active bandpass filter, consisted of the following circuit components: dual Operational Amplifier (op-amp), resistors of different values and capacitors. To power the subsystem, voltage supply was used. The voltage supplied was also 5 V or 3 V as the overall system was designed to function at 5 V as mentioned above.

The main purpose of the dual op-amp in this circuit was to provide isolation between the two sub-filters and amplify the voltage going through the two stages of the bandpass filter (the high-pass filter and the low-pass filter). Furthermore, to obtain filters with the desired bandwidth an online Texas Instruments program was used to get filters that worked with the op-amp available to us. The bandpass filter in Figure 8 was obtained for the 14-22kHz filter but a lot of testing and changing of resistor values was needed to obtain a functioning filter.

To test the functionality of the filter, a waveform generator was used to test the change in voltage at a range of frequencies. Amplification of voltage was expected at frequencies in the bandwidth and attenuation of voltage was expected at frequencies outside the bandwidth. The following results were obtained:

5.2 Detailed quantitative physical specifications

5.2.1 Lightweight

The overall device needs to be lightweight to avoid discomfort when used for extended periods of time. The device should not weigh over 400 grams to allow it to be easy to carry around.

5.2.2 External devices

The device should not rely on any external devices to function. All audio, visual, and data outputs must be independent without the reliance on an external laptop, phone, motor, keyboard, mouse, or network connection. The power system of the device should also not be excessively bulky or large. The device should also be portable.

5.3 Engineering, safety, environmental, and sustainability standards that are applicable and are to be observed

5.3.1 Engineering and safety standards

Over-exposure to IR LED light can cause optical damage to the human eyes. Hence, in the designing of this device, we made sure to adhere to the guidelines set forth by the International Electrochemical Commission's IEC62471 which state that the duration of exposure of the infrared light should be under 10 seconds and the wavelength should be within the 180 nm to 3000 nm range at 1 meter (8). With this in mind, we will implement a TPL 5111 timer in all circuits that will limit the duration of IR LED light exposure to 50ms, and the wavelength emitted will be 850 nm. Circuit building and soldering will play a heavy role in the creation of our device. When working with circuitry, such as exposed wires and running voltage, we complied with standards set forth by the National Institute for Occupational Safety and Health (NIOSH). These standards state that the level of danger of a wearable electronic device is reliant on these factors: voltage/current output of the device that comes into contact with skin, wetness and/or any rupture on the skin, duration of electrical exposure, and the pre-existing health conditions, age, and gender of the user (9). The process of soldering can release toxic fumes and dust that are hazardous and if inhaled can cause occupational asthma or worsen existing asthmatic conditions, as well as cause eye and upper respiratory tract irritation (10). To adhere to both guidelines wore protective clothing and safety goggles and used a soldering fume extractor.

5.3.2 Environmental and sustainability standards

As mentioned before, the fabrication of this device required soldering using lead. This process releases toxic fumes which require proper ventilation and disposal (11). A soldering fume extractor was used during the soldering process and excess solder and any rags used were disposed of in the designated hazardous waste disposals provided in the electrical engineering labs. Components such as batteries, SMD models, and all other electronic components were recycled accordingly in the following facilities:

- Best buy electronic recycling: 1730 Pleasant Pl, Arlington, TX, 76015 (for computers, batteries, and electronics)
- Master fibers, Inc: 2410 W. Division St, Arlington, TX, 76012 (for aluminum, copper, electronics, and plastics)
- Public convenience center in Arlington (for circuit boards, electronic household items)

5.4 Cost constraints

The allocated budget given to us by the Bioengineering Department at The University of Texas at Arlington was $500.00. Due to this project being a generational project, we were able to find many components that we needed, such as breakout boards and jumper cable wires in our lab. Because of this, we were able to reuse many of those components for testing purposes. We needed to buy a few specific components, which will be listed below. Our team also requested access to the Electrical Engineering Lab, which allowed us to use much of their equipment, such as the oscilloscopes, without an extra charge. Overall, we spent $98.63 from our allocated budget. Our mentor, Dr. Yetkin, spent $45.82, that is not included in the amount referenced above as it was spent by Dr. Yetkin and not from the budget we received from the department. The total leftover amount is $401.37.

Table 3. Cost constraints.

Ceramic Capacitor Assortment Kit	$16.99
Resistor Assortment Kit	$12.99
NE555P Timers (12 units)	$9.35
Operational Amplifier Dual Op-amps (50 units)	$6.49
Soldering Kit	$7.48
Soldering Board	$7.98
Soldering Putty	$2.13
Potentiometers	$8.49
Multiplexer Breakout Board	$5.29
Multiplexers (10 units)	$21.42

5.5 Project duration constraints

The project took off in August of 2021, and our team had a goal of completing the project on April 7th, 2022. This would give the team enough time to prepare for innovation day, which took place on April 11th, 2022, as well as finish any presentations required for the class and completing the final report. However, after some extensive testing and research that took place in January of 2022, our team realized that the original plan we had produced in the previous semester was not going to yield the desired results. After performing more research, and with our mentor's advice in mind, the team resorted to proceeding in a different direction. Testing for our new plan was very extensive and took up most of the semester. The reason for this being is our mentor had urged us to not proceed with any fabrication until he approved the testing results, to ensure that the new filtering subsystem would benefit the device.

Requesting access to the Electrical Engineering Lab took a few days, which delayed the start of testing. Another factor that contributed to delayed testing was the process of ordering and receiving parts, which took approximately two weeks. A snowstorm that hit during the semester also hindered our testing progress as campus was closed for a few days. Testing of the circuits continued through our original proposed deadline and concluded on April 21st, 2022.

5.6 Final project schedule

The following Gantt and PERT charts represent the timeline we followed throughout the semester, the tasks carried out, and who was responsible for which task. The charts had to be altered after we realized how much preliminary testing we had to conduct. Previous versions of the chart can be found in the appendix.

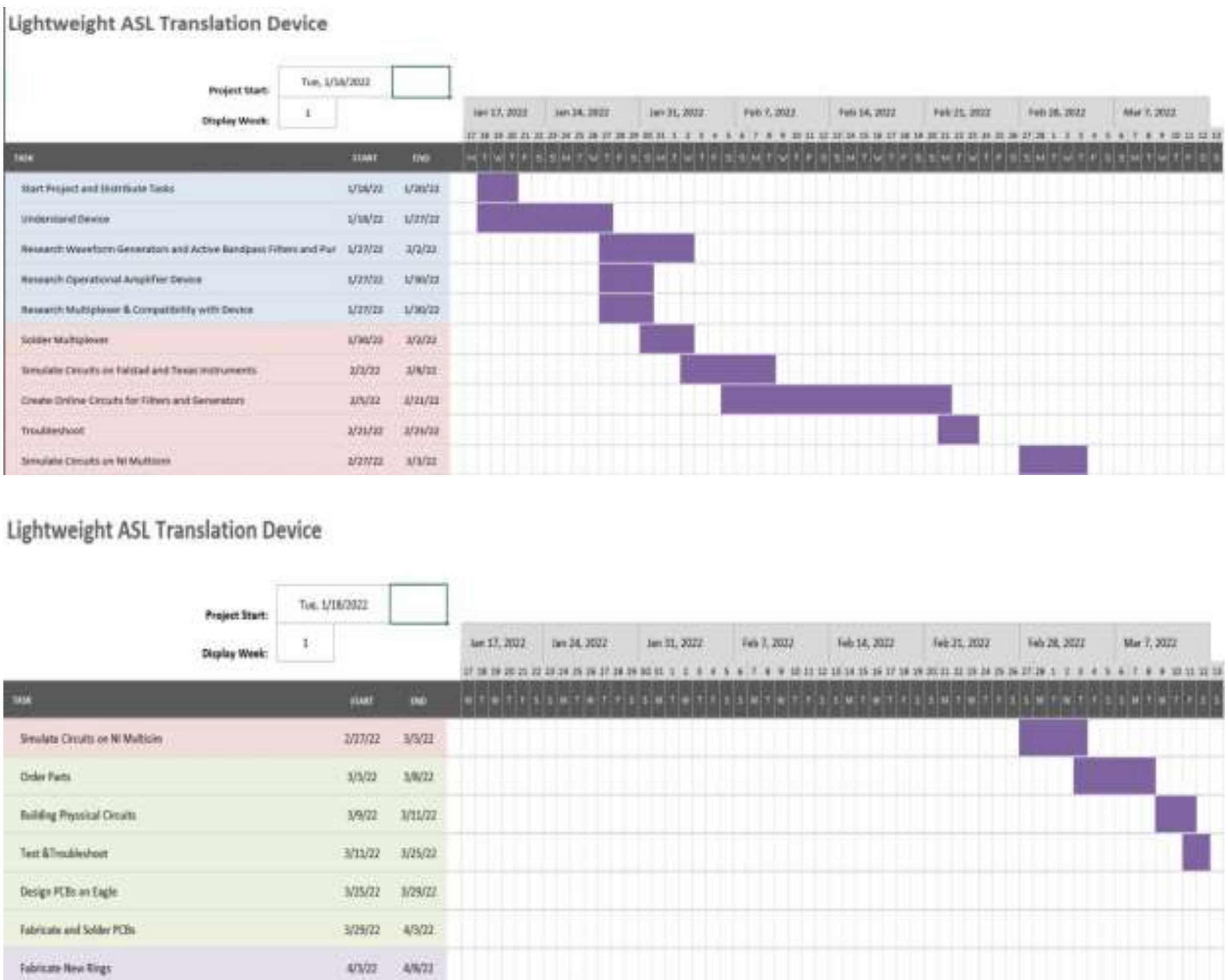


Figure 2. Gannt chart of Spring 2022 semester activities.

Figure 3. PERT chart of Spring 2022 semester tasks

6. Design

6.1 Description of the selected design concept and rationale behind it

The previous generations left a digital system that consisted of fingernails system, ring system, and CPU unit. Most of the system utilized digital components and various codes that performed desired functions like filtering and data acquisition. The shortcomings of the previous generations outweighed the benefits and a new pathway needed to be explored. The current group focused on analog components of the system and started from zero.

The chosen pathway included building fingernail and ring subsystem with chips, resistors, and capacitors. The current group performed testing and troubleshooting throughout the whole time. The main design of the project that was chosen included working with breadboards, perforated boards, measurement tools, and simulation tools.

The circuits that the group started out with included waveform generating circuit, detection subsystem, and active bandpass filters. To test the obtained circuits, simulation was performed using NI Multisim and Falstad online tools. To test the subsystems in real life, the circuits were constructed on breadboards using 555 Timer, operational amplifier, resistors, capacitors, phototransistor, and IR LED.

Simulation tools were advised by the course professor Dr. Behbehani and project mentor Dr. Yetkin, who suggested simulating the subsystems first in the online simulation tools and then build them. The rationale was to analyze if the potential subsystem does work in an online environment and then build it in real life to test it.

The testing in real life was done on breadboards because of flexibility and ease of building the subsystems and obtaining the measurements using measurement tools such as oscilloscope and multimeter.

6.2 Description of major subsystems

The main subsystems of the chosen design consist of waveform generating circuit, detection subsystem, and filter.

The waveform generating circuit utilizes 555 Timer that outputs square waves that have a unique frequency. This unique frequency is obtained by a unique combination of resistors and capacitors. The circuit powers 850 nm IR LED to flash at unique frequency that was mentioned. The IR LED used was in an SMD form.

The detection subsystem consists of the phototransistor detection component that is in SMD model, and it is designed to detect 850 nm IR light. The detection subsystem circuit also utilizes a high value resistor.

Lastly, the active bandpass filter having a bandwidth from 14 kHz-22 kHz was set up on a breadboard using a dual op-amp, a range of resistors and 1nF capacitors. This filter consisted of a high-pass filter in cascade with a low-pass filter, separated by the op-amp. The subsystem was supplied with a voltage of around 5 V for optimal function. This subsystem's purpose was to amplify the voltage of signals at frequencies in the bandwidth range and attenuate the voltage of signals at frequencies out of the bandwidth.

6.2.1 Drawings, schematics and other illustrative means of showing the system and the subsystems for the device

The group focused and created three subsystems overall. Those subsystems are waveform generating circuit, detection subsystem, and active bandpass filter. The diagram of circuits and PCBs of those subsystems will be shown below:

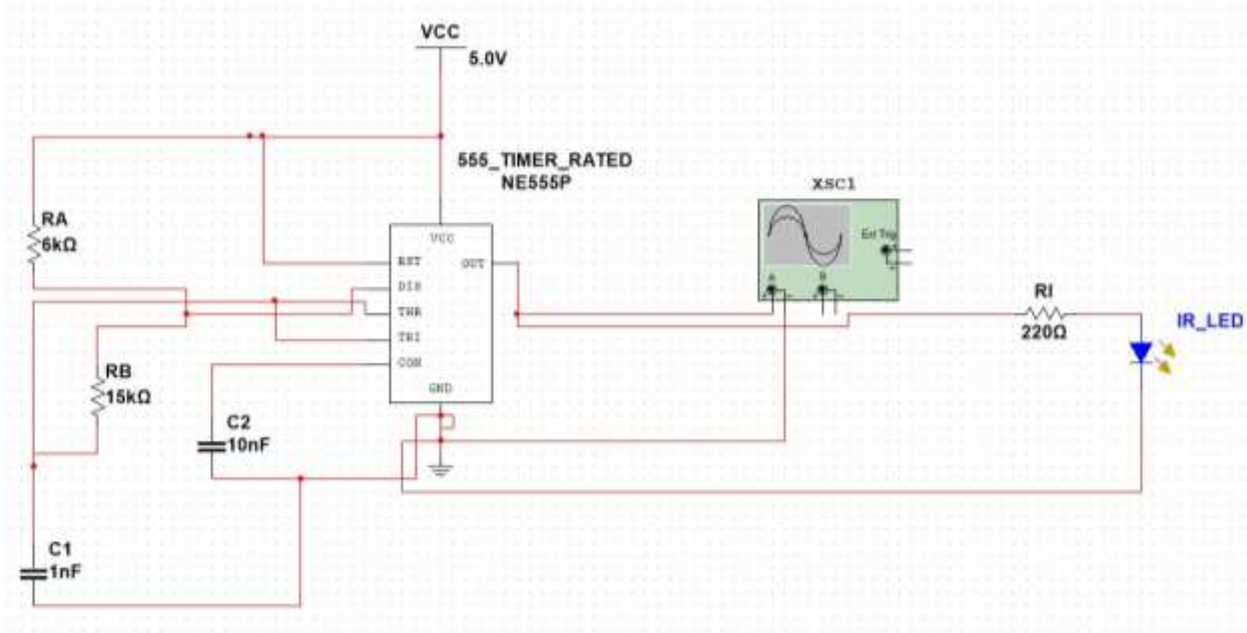


Figure 4. Circuit diagram of waveform generating circuit.

It is worth noting that the resistor values of R_A and R_B as well as capacitor value of C_2 change depending on the desired frequency needed. The voltage supply can also change and is usually either 3 V or 5 V but the final system will utilize 5 V. The above subsystem was built on breadboard and miniaturized into a perforated board as well, which will be discussed later in the report.

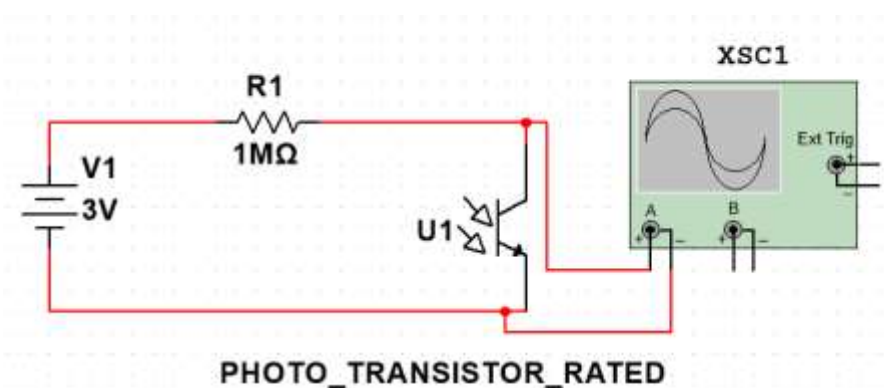


Figure 5. Circuit diagram of detection subsystem.

It is worth noting that the voltage supply could either be 3 V or 5 V but the final system will utilize 5 V. The above subsystem was built on breadboard and miniaturized into a perforated board as well, which will be discussed later in the report.

The following diagrams are the PCB Eagle diagrams of the waveform generating circuit and detection subsystem:

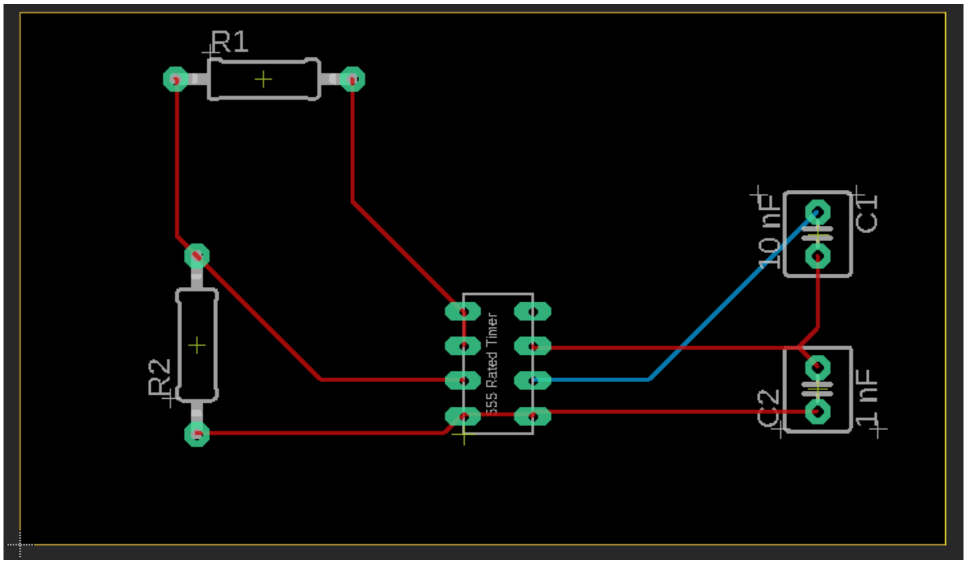


Figure 6. PCB circuit of waveform generating circuit.

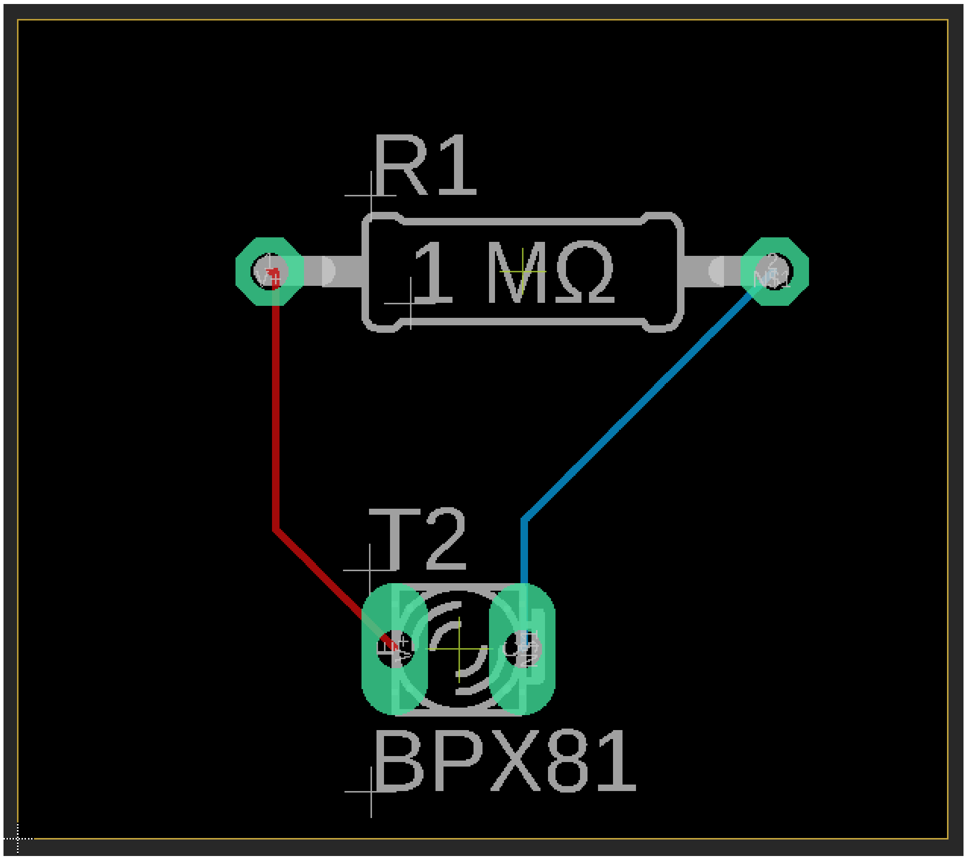


Figure 7. PCB detection system.

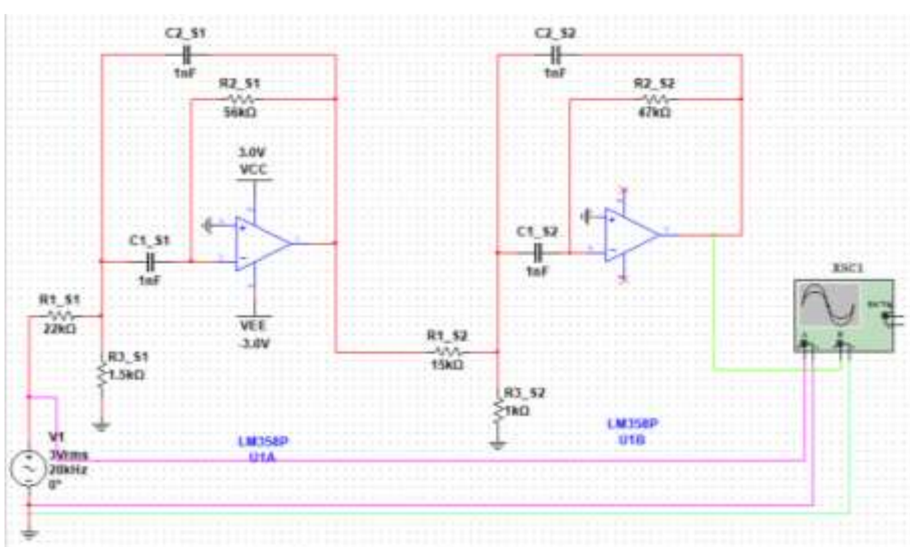


Figure 8. Circuit diagram 14 kHz-22 kHz bandpass filter circuit.

As mentioned previously, the voltage supply could either be 3 V or 5V, but the final system will utilize 5 V. The above subsystem was built on breadboard and miniaturized into a perforated board as well, which will be discussed later in the report.

6.3 Engineering design computations

The three subsystems that were worked on by the group include waveform generating subsystem detection subsystem, and an active bandpass filter.

The main computations carried out for the waveform generating subsystem included figuring out the resistor and capacitor values to obtain desired frequencies. Another computation that needed to be Figured out was the voltage supply that powered the circuit. As mentioned above the frequencies that were decided on include 18 kHz, 38 kHz, 56 kHz, 77 kHz, 98 kHz, 114 kHz, and 132 kHz.

To calculate the unique frequencies' resistors and capacitor values, the following formula was utilized:

$$f = \frac{1.44}{(R_A + R_B) * C_2} \qquad [2]$$

The above formula provided rough values of resistors and capacitor and it did not provide exact values. The next step to obtain the resistors and capacitor values, NI Multisim was utilized to obtain a more approximate value of the resistors and capacitor. The next subsystem is the detection subsystem. The main computational analysis performed focused on input voltage, output voltage and resistor value. The final detection subsystem circuit was represented in Figure 5.

The voltage input applied was either 3 V or 5 V and it was settled that for the final design 5 V will be used for both waveform generating and detection subsystems because the main CPU unit of the device utilizes 5V.

Table 4. The voltage values of the waveform generating circuit.

V_{in}	V_{out}
3 V	1.96 V
5 V	2.60 V

The output voltage of the detection subsystem was very attenuated, and our mentor suggested increasing the resistor values. The subsystem was tested using various resistor R1 values and the following values were recorded:

Table 5. The output voltage values of the detection subsystem using different R1 values.

R_1 (kΩ)	V_{out}
680	15.2 mV
1000	150.0 mV

Following the change of the resistor R1 values the input voltage of 3V and 5V were applied to obtain the output voltage value of the detection subsystem and the values can be observed in the table below:

Table 6. The voltage values of the detection subsystem.

V_{in}	V_{out}
3 V	200 mV
5 V	500 mV

As mentioned earlier, to obtain filters with the desired bandwidth an online Texas Instruments program was used to get schematics of filters that worked with the dual op-amp available to us. Once the circuits were built, some testing was done to see how well the bandpass filters attenuated voltage of frequencies out of the passband and amplified frequencies in the passband. The results showed that the circuit was not accurate, and some adjustments were made using the following equations and calculations were needed, allowing us to achieve the circuit in Figure 8

$$C = C_1 = C_2 \qquad [3]$$

$$k = 2 \cdot f_{center} \cdot C \qquad [4]$$

$$R_1 = \frac{Q}{1 \cdot k} \qquad [5]$$

$$R_2 = \frac{Q}{(2 \cdot Q^2 - 1) \cdot k} \qquad [6]$$

$$R_3 = \frac{2Q}{k} \qquad [7]$$

$$f_{center} = 18\ kHz \qquad [8]$$

$$Q = \frac{f_{center}}{BW} = 2.25 \qquad [9]$$

6.4 Simulation results

The three subsystems that were built and tested for the project included a lot of simulations, failures, and troubleshooting.

The main tools that were used to simulate the waveform generating circuit were Falstad online tool and NI Multisim desktop tool. The following initial circuit of waveform generating subsystem was simulated using Falstad:

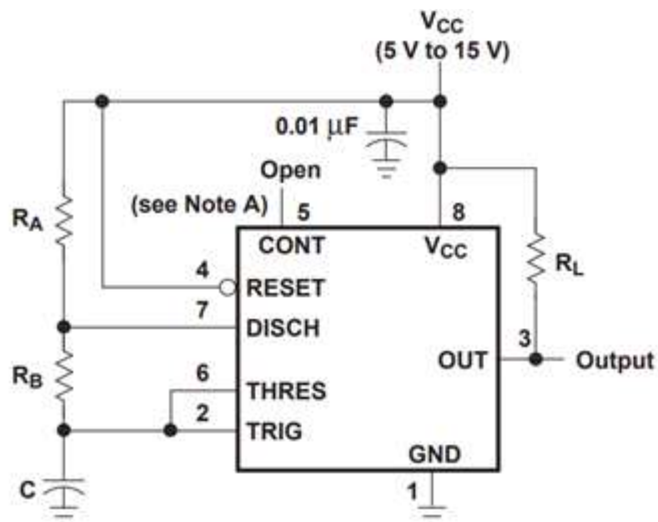


Figure 9. Circuit diagram of initial waveform generating subsystem.

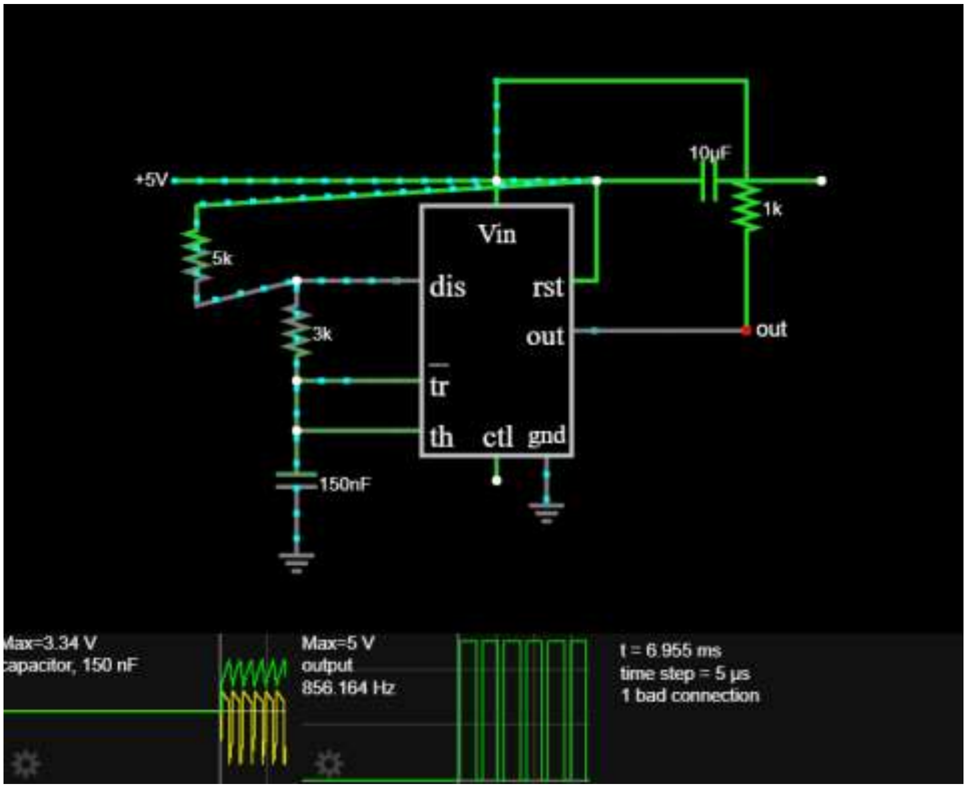


Figure 10. Falstad simulation of the initial waveform generating circuit.

As can be observed from the above simulation, there is a bad connection that does not provide accurate values for the frequency. Troubleshooting was attempted and the results were unsuccessful. Thus, it was suggested by our mentor to try NI Multisim desktop simulation tool. The above initial circuit of waveform generating circuit did not provide any results in the NI Multisim, so a new circuit was researched and simulated. The new waveform generating circuit is represented below:

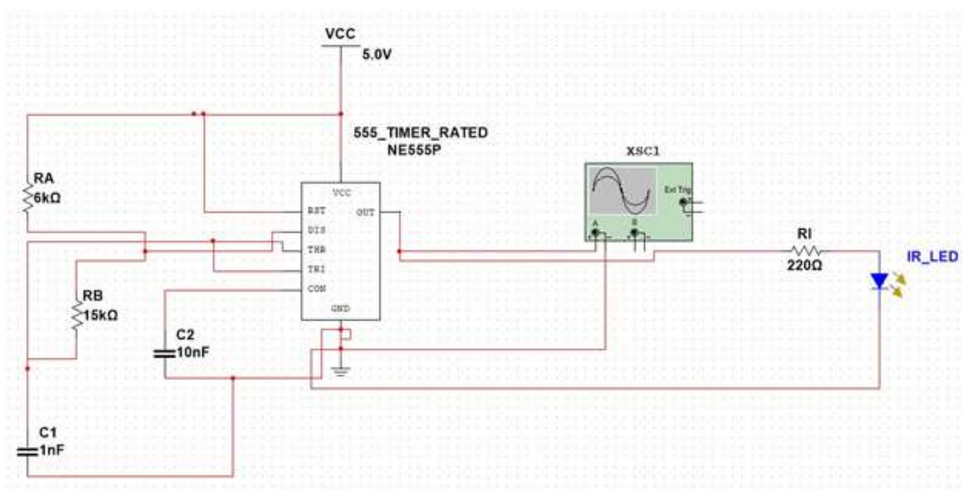


Figure 11. The final waveform generating circuit's diagram.

The above circuit was tested after changing the R_A, R_B, C_1 and C_2 values. When simulated, NI Multisim provided a graph from which the frequency was calculated by utilizing the time stamps for each cycle. An example of the graph from NI Multisim is represented in the following Figure:

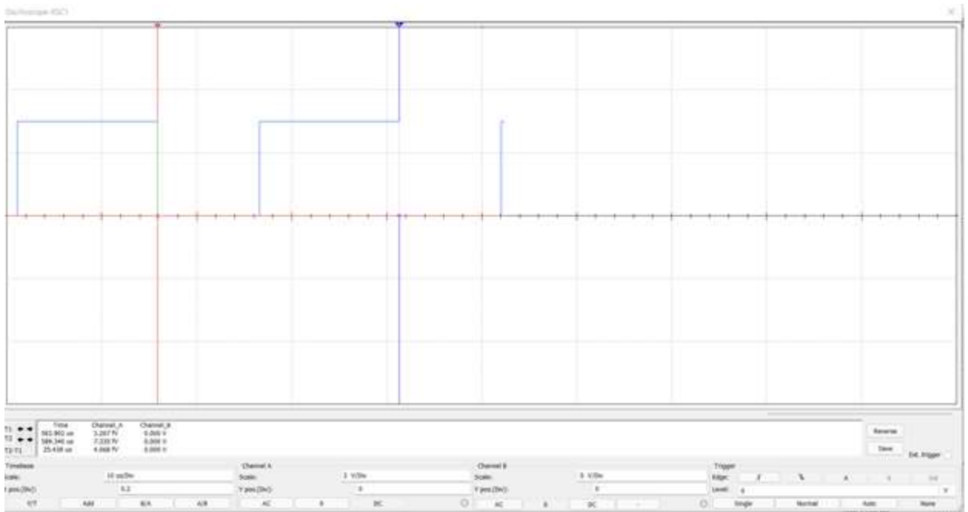


Figure 12. An example of the NI Multisim resulting graph for the waveform generating circuit tested.

The simulated values and the obtained frequencies have been put into the following table:

Table 7. The simulated resistor and capacitor values and obtained frequency values.

Frequency (kHz)	**R_A (kΩ)**	**R_B (kΩ)**	**C_1 (nF)**	**C_2 (nF)**
~8.0	5.1	33	1	10
~16.4	4.7	3	1	10
~25.5	4.7	22	1	10
~72.5	4.7	4.7	1	10
~89.3	4.7	3	1	10
~104.0	3	3	1	10
~101.0	4.7	2.2	1	10
~121.0	3	2.2	1	10

The next step was to test the above obtained resistor values to acquire exact values of the resistors and capacitor to produce square waveforms at desired frequency. The following frequencies were tested, and the resistors and capacitor values were finalized:

Table 8. The final resistors and capacitor values produce the desired frequency of square waveform oscillation.

Frequency (kHz)	**R_A (kΩ)**	**R_B (kΩ)**	**C_1 (nF)**	**C_2 (nF)**
~18	5.1	33	1	10
~38	2.2	15	1	10

The voltage input for the waveform generating circuit included 3 V and 5 V. The output of the waveform generating circuit was attenuated and the values can be observed on Table 4.

The V_{out} values were fluctuating but the values were never high enough for our testing which will be explained when discussing detection subsystem.

Detection subsystem could not be simulated in online tools because online tools lacked IR components. The project utilizes components such as 850 nm IR LEDs and 850 nm SMD phototransistors and the online tools did not have the needed components. When simulating the detection subsystem with different phototransistor components, the result contained no signal, and it was confirmed by our mentor that such models may not work in online environments.

The detection subsystem consisted of SMD model of 850 nm phototransistor and 1 MΩ resistor components. Due to the low output voltage values that were recorded throughout many testing procedures, resistor value of 1 MΩ was utilized for the circuit and following results obtained can be observed on Table 6.

It is possible to observe that the output voltage values are still very attenuated. These values were the highest voltage output values obtained with the resistor value of 1 MΩ. The resistor values less than 1MΩ gave much smaller voltage output values than above.

The attempted simulation of amplifier circuit was challenging in a way that simulation of the amplifier circuit gave promising results but when tested on lab bench using power supply and oscilloscopes the subsystem either failed or got fried.

The following inverting op-amp was built on breadboard and tested:

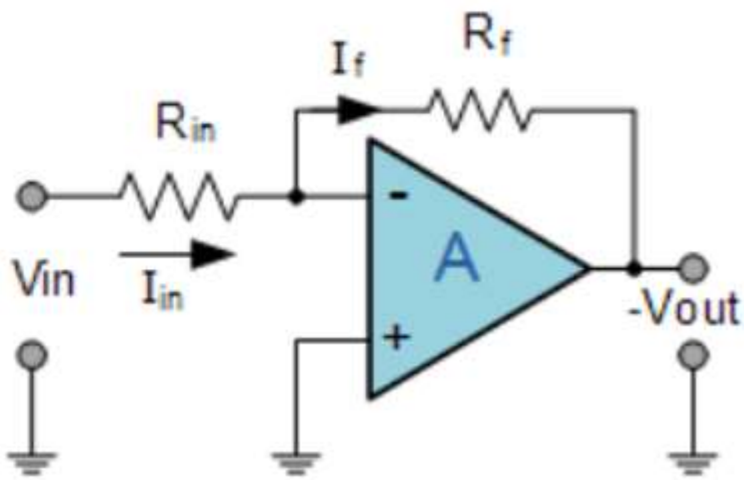


Figure 13. Inverting operational amplifier circuit #1.

Tha above circuit was connected to the detection subsystem circuit and the main purpose was to amplify the signal detected by the phototransistor. More specifically, the purpose was to amplify the voltage signal of the obtained signal. The above circuit has the gain that can be calculated using the following formula:

$$Gain = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}} \qquad [10]$$

Here the R_f and R_{in} were set to be 10 kΩ and 1 kΩ. The calculated gain was -10^3 where the negative means that the output signal will be inverted.

Table 9. The output voltages of detection subsystem with and without amplifier circuit connected.

V_{out} of detection subsystem without amplifier	V_{out} of detection subsystem with amplifier
150 mV	560 mV

The output voltage of the detection subsystem without amplifier served as the input voltage for the amplifier circuit and the gain was calculated to be:

$$Gain = \frac{560\ mV}{150\ mV} = 3.733 \qquad [11]$$

As can be observed from the gain value as well as the output voltage of amplifier circuit that is connected to the detection system, the final values are not amplified properly so new attempts at amplifier circuit were performed.

A new amplifier circuit was simulated first before building it right away like was done with the previous amplifier mentioned above. The following diagram was created using NI Multisim:

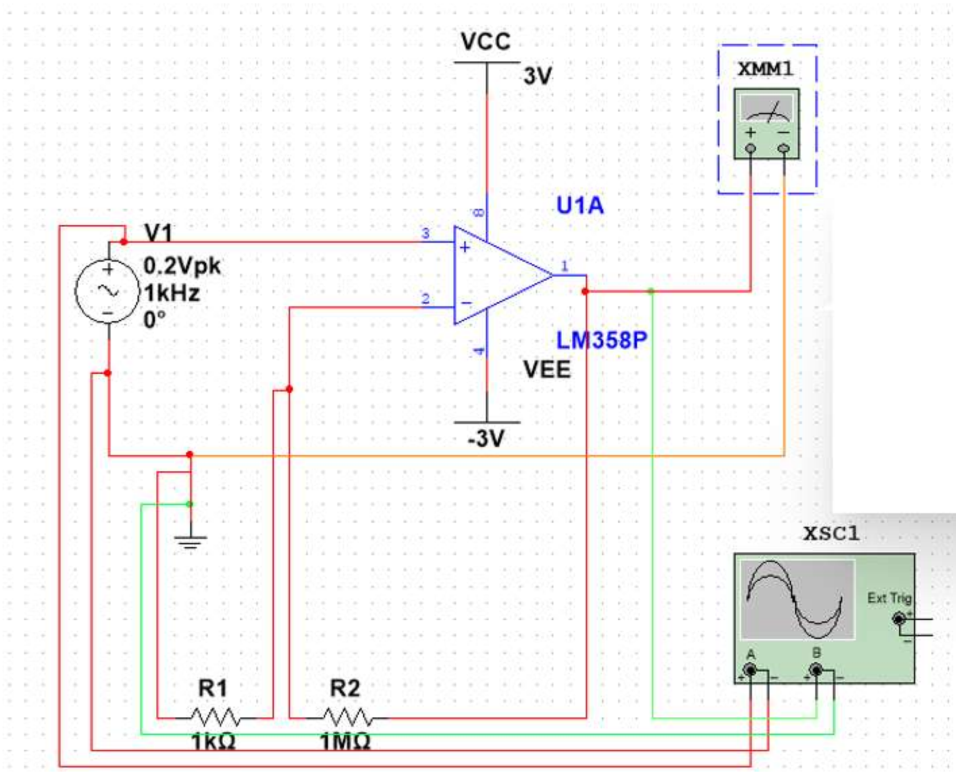


Figure 14. Amplifier circuit #2.

The above circuit contains operational amplifier, resistors, and AC voltage supply. The AC voltage supply was chosen to mimic the signal output of detection subsystem which will act as the AC voltage supply to the amplifier circuit. As can be seen from the circuit, an input voltage of 0.2 V was provided, and the output voltage was 2.187 V. The gain of this computation was:

$$Gain = \frac{2.187\,V}{0.2\,V} = 10.935 \qquad [11]$$

The next step included building the amplifier circuit #2 on a breadboard. The obtained results included no signal when connected the amplifier circuit to the detection subsystem. Researching and building a new amplifier circuit was attempted. The new simulated circuits did not work, provided small gain, or burned. The lack of time and guidance resulted in discontinuation of amplifier circuit research.

To test the 14-22kHz bandpass filter in Figure 8, the filter was supplied with a voltage of 3-5V using a power supply and connected to a function generator. The input and output of the filter were then connected to an oscilloscope to visualize how the signals changed when different frequencies were fed into the bandpass filter.

The 14-22kHz bandpass filter was fed frequencies from 10-30kHz consecutively and the voltage of the bandpass filter was recorded at each frequency, seen in Table 10 and Figure 16 below.

Table 10. The change in output voltage of the 14-22kHz bandpass filter at a range of frequencies.

Frequency of Waveform Generator (kHz)	Amplitude of Function Generator (V_{pp})	Input Voltage of Op Amp (V)	Frequency from filter input (kHz)	Frequency from filter output (kHz)	Vpp of filter input (V)	Vpp of filter output (V)	Amplitude of filter input (V)	Amplitude of filter output (V)
10	3	3	~10	~10	3.4	0.320	3.2	0.320
11	3	3	~ 11	~ 11	4.0	0.264	3.2	0.264
12	3	3	~12	~12	3.6	0.280	3.2	0.152
13	3	3	~13	~13	4.0	0.288	3.0	0.176
14	3	3	~14	~14	3.4	0.366	3.2	0.248
15	3	3	~15	~15	3.4	1.64	3.2	0.840
16	3	3	~16	~16	4.0	1.68	3.2	1.68
17	3	3	~17	~17	4.2	1.72	3.0	1.72
18	3	3	~18	~18	4.2	1.76	3.2	1.76
19	3	3	~19	~19	4.0	1.72	3.2	1.64
20	3	3	~20	~20	3.6	1.68	3.2	1.56
21	3	3	~21	~21	3.6	1.56	3.2	1.44
22	3	3	~22	~22	4.8	1.6	3.2	1.6
23	3	3	~23	~23	3.4	1.52	3.0	1.52
24	3	3	~24	~24	3.4	1.48	3.2	1.48
25	3	3	~25	~25	3.4	0.920	3.2	0.920
26	3	3	~26	~26	4.4	0.800	3.2	0.800
27	3	3	~27	~27	3.8	0.680	3.2	0.600
28	3	3	~28	~28	3.8	0.560	3.2	0.560
29	3	3	~29	~29	4.4	0.520	3.2	0.520
30	3	3	~30	~30	3.8	0.480	3.2	0.480

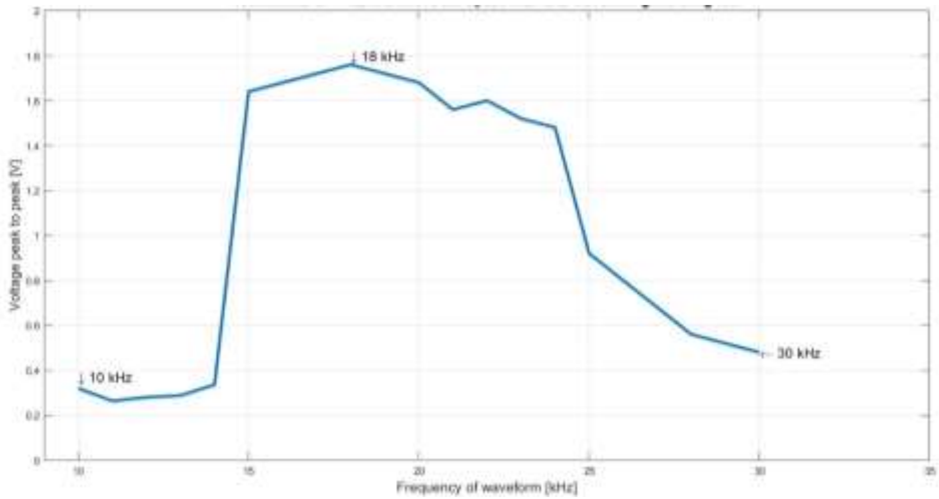


Figure 16. Change in output voltage of 14-22kHz Active Bandpass Filter.

As seen in Table 10 and Figure 16 above, with a 3V voltage supply the voltage output of the filter was attenuated from 10kHz to about 15kHz range, and slightly amplified between 16kHz-24kHz, then attenuated again from about 25kHz-30kHz. Although the voltage was amplified within the bandwidth, we observed uneven distribution of the voltage compared to what was expected. Higher voltage amplification was expected as 3V was supplied, however, the maximum output voltage was approximately 1.76V. Additionally, the bandwidth range calculated was not as accurate as was expected.

To further analyze the results of the 14-22kHz bandpass filter and identify how accurately it was working, the frequency response of the filter was calculated using the voltage transfer function [12] below where $Vout$ is the output signal voltage, Vin is the input signal voltage, j is $\sqrt{\ } -1$ and ω is the radian frequency.

$$H(j\omega) = \left[\frac{Vout(j\omega)}{Vin(j\omega)}\right] \qquad [12]$$

The frequency response graphed in Figure 17 below shows how the gain of the output responds to input signals at different frequencies. The highest gain was at the center frequency (18kHz) as expected, however, the gain still fluctuated and had uneven distribution specifically within the passband. Furthermore, the gain did attenuate as frequencies moved out of the passband.

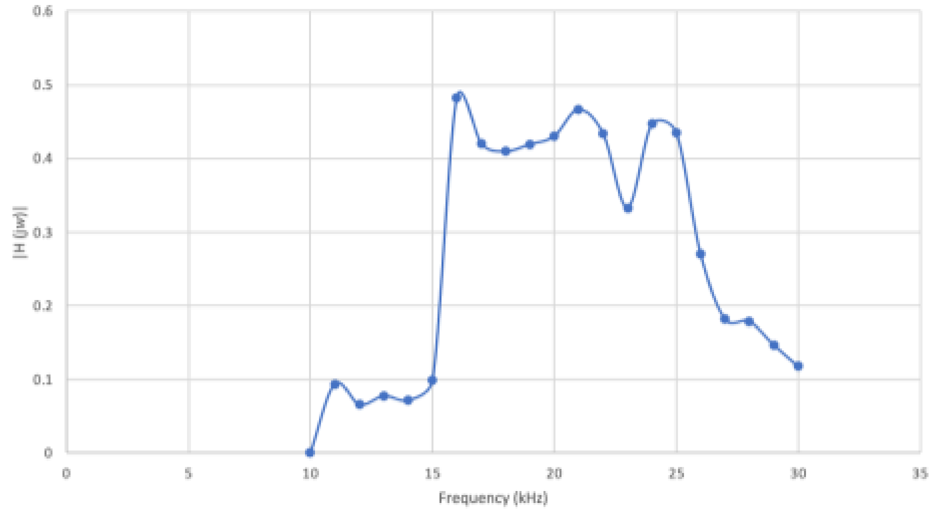


Figure 17. Frequency Response of 14-22kHz Active Bandpass Filter.

6.5 Assessment of chances of success based on the selected design concept and engineering computations and simulations

Due to the team needing the basis of the project midway through the year, additional research needed to be done in the second semester, which lead to us having a delayed start to testing. Our mentor also strictly urged us to not fabricate anything until he approved all testing done. This expanded our testing and troubleshooting phase, thus preventing us from fabricating anything. However, considering all limitations the team faced, our simulations provide a great foundation for future generations to build upon. They show great promise for the future direction of the project in switching to an analog filtering subsystem, rather than the current digital filtering subsystem.

7. Fabrication

7.1 Details of how the device prototype was fabricated

The three subsystems that were fabricated included waveform generating subsystem, detection subsystem, and a bandpass filter. Some of these subsystems needed preliminary fabrication of some SMD models before being fully fabricated.

The initial fabricated model included building the subsystems on breadboard. To build the subsystems on breadboard, a lot of research has been done to find the right circuits. The next step included obtaining parts such as chips, resistors, capacitors, breadboards, wires, and SMD devices.

SMD devices included soldering SMD model IR LED and phototransistor to two wires on each conducting side of the SMD model. The following tools were used to solder an SMD model to wires: soldering iron set, tips, cleaning sponge, metal brass wool, tweezers, soldering wire, and SMD models. The following steps were utilized to solder the SMD models to wires:

1. Use the tweezers to position the SMD model.
2. Set the correct tip on the soldering iron before turning it on.
3. Turn on the soldering iron and smoke absorber.
    a. Set the heating temperature to 350 C.
4. Heat one side of the SMD model for 2-3 seconds.
5. Add some solder onto the heated part of the SMD model.
6. Have the jumper wire ready and heat up the jumper wire ending after placing it on one side of the SMD model.
7. Make sure the wire is not moving and that it is connected correctly.
8. Utilize metal brass wool or cleaning sponge to get rid of the extra solder on the tip of the soldering iron.
9. Repeat the same steps for the other side of the SMD model.
10. Turn off the tools from power supply, clean the bench, and clean hands after finishing the procedure.
11. Test the SMD model to see if it is working.

The breadboard devices were tested and troubleshot for quite some time before the miniaturization was performed. For the miniaturization, perforated boards were used to solder all the components on. The miniaturized subsystems included an 18 kHz waveform generating circuit, detection subsystem, and 14-22 kHz active bandpass filter. Once fabricated, the perforated boards were tested for connectivity using a multimeter to ensure that there was no short circuiting or damage to the subsystems.

Figure 18. Set up for soldering of perforated boards

7.2 Figures, photos, and other forms of illustrations of the device

-The three subsystems that were fabricated included breadboard perforated board prototypes of waveform generating circuit, detection subsystem, and active bandpass filter.

The following are the figures representing breadboard prototypes:

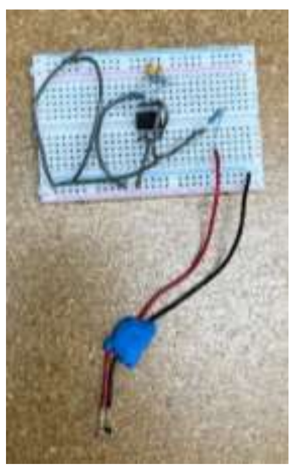


Figure 19. Waveform generating circuit as a breadboard model.

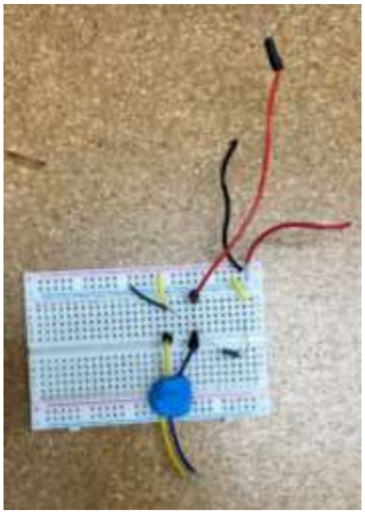


Figure 20. Detection subsystem as a breadboard model.

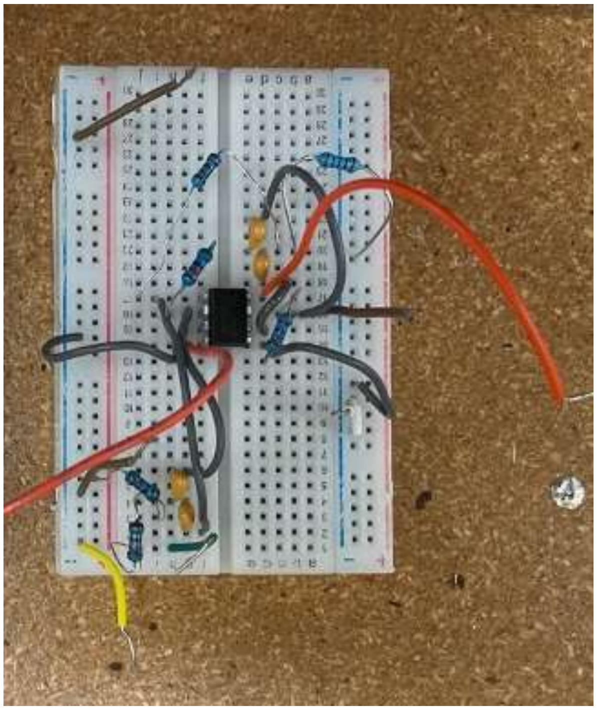


Figure 21. 14kHz-22kHz bandpass filter circuit as a breadboard model.

The following are the figures representing perforated board prototypes:

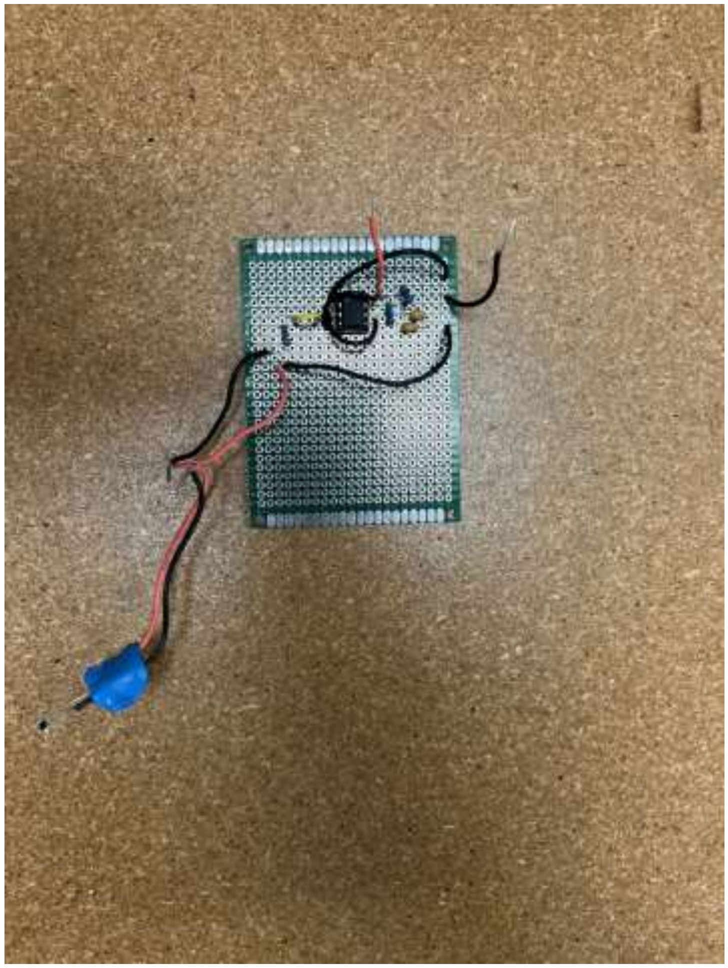


Figure 22. 18 kHz waveform generating circuit as a perforated board model.

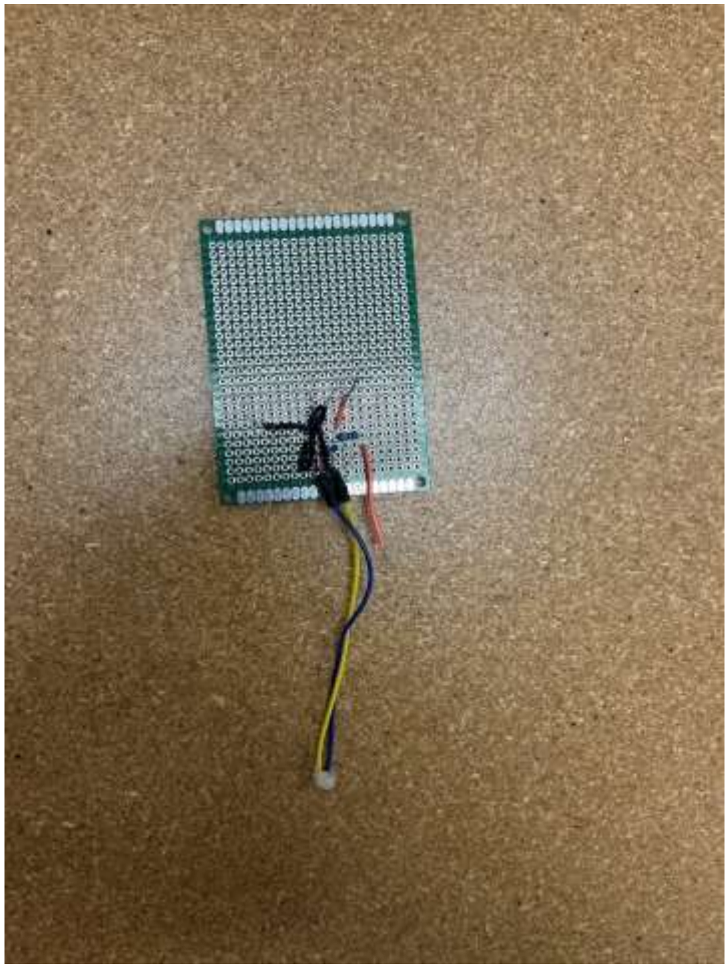


Figure 23. Detection subsystem as a perforated board model.

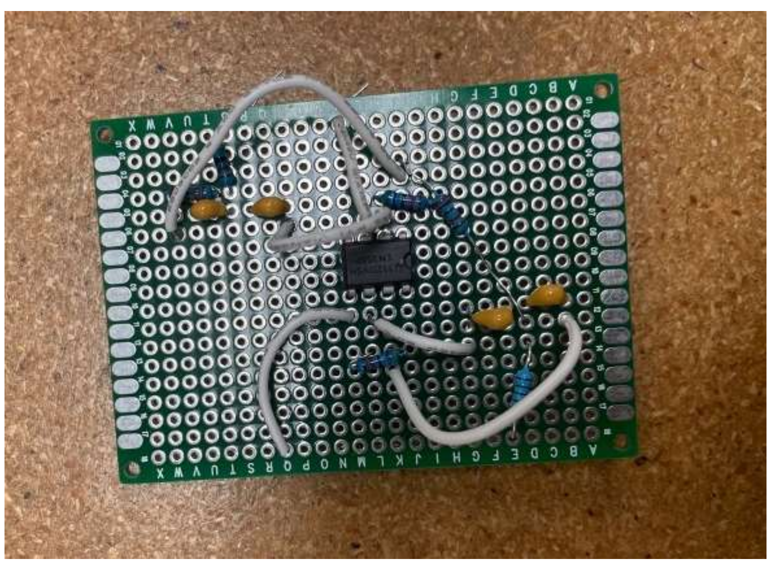


Figure 24. 14kHz-22kHz bandpass filter circuit as a perforated board model.

7.3 Modifications to the design that were needed to achieve the design specifications

The three subsystems that were developed and attempted to improve are waveform generating circuit, detection subsystem, and filter.

The initial waveform generator circuit had challenges that needed to be addressed. Those challenges included the output of the circuit being unstable. This was measured by analyzing the frequency values that were provided through oscilloscope measurements. The frequency values were unstable, and the target frequency was hard to achieve. To address that issue, troubleshooting, research, and simulations were performed. When troubleshooting with a mentor, the issues could not be fixed, and it was decided to do more research about waveform generating circuits that produce a square waveform with a unique frequency. Research has been done and new circuits were simulated. The optimal circuit was found and tested. The new optimal circuit provided a signal that was stable and the frequency values on the oscilloscope did not fluctuate as they used to in the initial circuit designs. Another challenge of the waveform circuit included attenuated voltage output. Due to the limitation of being able to use only up to 5 V, the output voltages were attenuated and hard to work with. Building and testing amplifier circuits were attempted but no successful outcome was achieved.

The following initial circuit was built and tested:

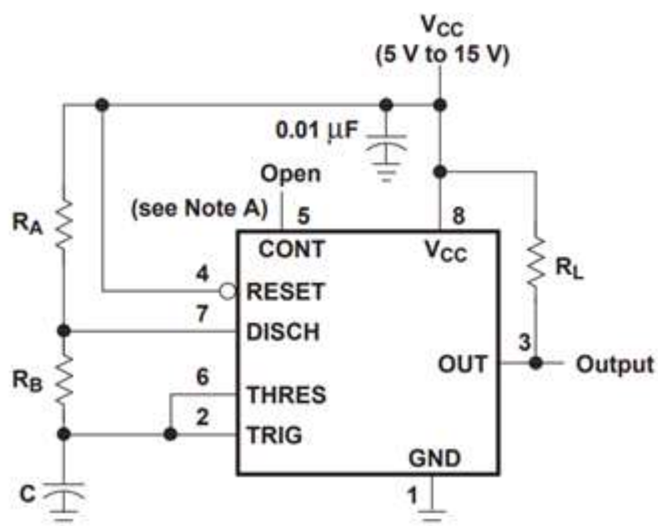


Figure 25. One of the initial testing circuits for the waveform generating system.

The above circuit was one of the initial circuits that was built and tested on to obtain target frequencies of square waveforms on oscilloscope. It was used to test various values of resistors RA and RB and capacitor C to obtain the desired frequency. Below is the representation of the testing performed to obtain a 38 kHz waveform generating circuit:

Table 11. The testing values of R_A, R_B, and C values to obtain desired frequency of 38 kHz on oscilloscope.

RA (kΩ)	RB (kΩ)	C (nF)	Oscilloscope frequency (kHz)	Theoretical frequency (kHz)
5.1	3	0.01	~214.8	12973.0
5.1	3	1	~ 89.4	129.7
5.1	5.1	1	~70.2	94.1
5.1	33	1	~18.8	20.3
5.1	22	1	~26.3	29.3
5.1	15	1	~35.2	41.0
4.7	15	1	~35.6	41.5
3	15	1	~37.4	43.6
2.2	15	1	~38.2	44.7

Theoretical frequency was obtained utilizing the following formula:

$$f = \frac{1.44}{(R_A+2\cdot R_B)\cdot C} \qquad [13]$$

The following values were computed to obtain the desired frequency of 56 kHz waveform generating subsystem:

Table 12. The testing values of R_A, R_B, and C values to obtain desired frequency of 56 kHz on oscilloscope.

R_A (kΩ)	R_B (kΩ)	C (nF)	Oscilloscope frequency (kHz)	Theoretical frequency (kHz)
5.1	5.1	1	~ 70.8	94.1
5.1	5.6	1	~67.3	88.3
5.1	7.5	1	~57.2	71.6
5.6	7.5	1	~56.1	69.9

The obtained voltage values of the above subsystem when tested using oscilloscope are represented below:

Table 13. The voltage values of the above initial 38 kHz waveform generating subsystem.

V_{in}	V_{out}
3 V	720 mV
5 V	1.96 V

The initial detection subsystem had challenges of phototransistor not being able to receive enough voltage due to the resistor values that were used in the circuit. The attempt to fix that problem included troubleshooting using various resistor values. It was found that more voltage was delivered when using 1 MΩ resistor value. Another challenge of the detection subsystem included inability to detect enough of the IR LED's signal due to factors like distance, noise, and attenuation. It was found that the phototransistor of the detection subsystem circuit needs to be parallel and upside down to the IR LED of the waveform generating circuit. The distance at which a distinguishable signal is detected was found to be about 1-2 cm. The next challenge that was faced was the attenuation of voltage signal when measuring voltage output values using an oscilloscope. The attempts to create an amplifier circuit were tried but were unsuccessful.

Regarding the active bandpass filters, a couple approaches were initially explored. One of these approaches included using a single narrow active bandpass filter, whose schematic is seen in Figure 26 below. The problem faced with this approach was that we had trouble obtaining any kind of output that resembled a stable waveform as seen in Figure 27 below despite calculating the specific components to use. The yellow waveform seen is the filters input from a function generator and the blue waveform seen is the filters output. The bandwidth used in this test was 34-42kHz with a center frequency of 38kHz but even at the center frequency, the output of the filter had an amplitude of about 60mV despite being supplied with 5V.

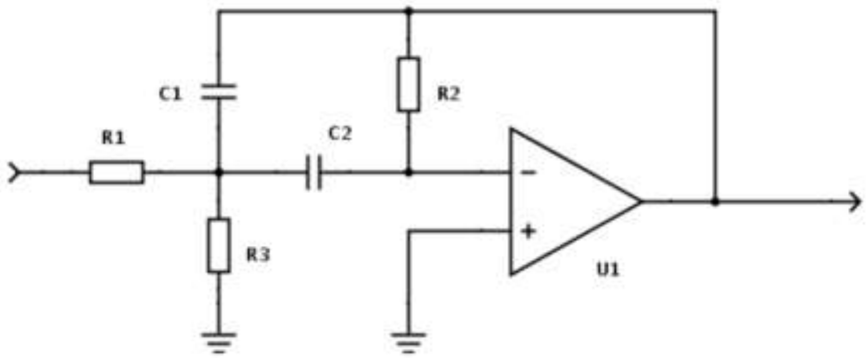


Figure 26. Initial single narrow bandpass filter circuit tested.

Figure 27. Initial testing of single narrow bandpass filter.

Following this approach, we tested a bandpass filter that consisted of two separate narrow bandpass filters cascading to each other known as a wide bandpass filter to distinguish between the high-pass filter and the low-pass filter as seen in Figure 28 below. The bandwidth used in this test was 14-22kHz with a center frequency of 18kHz but even at the center frequency, the output of the filter had an amplitude of about 1V despite being supplied with 5V. With this system some type of filter output waveform was achieved but it had a lot of noise and there was no significant amplification of voltage at frequencies within the bandwidth or attenuation of voltage at frequencies outside of the bandwidth.

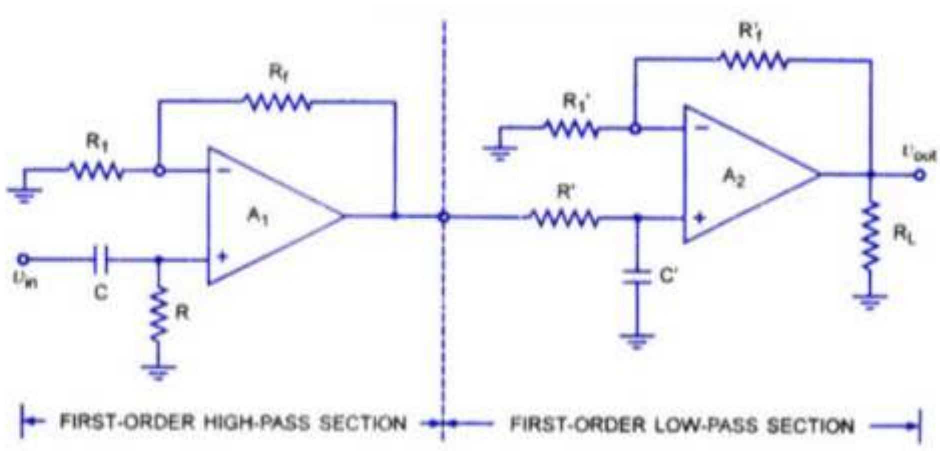


Figure 28. Wide bandpass filter schematic.

Figure 29. Testing of wide bandpass filter.

Taking these tests into consideration, we decided to run trial and error tests with different resistor values to find what would work best. We did this because despite simulating our circuits beforehand and checking that they worked, that did not translate to the physical circuits. This led to the current functioning 14-22kHz bandpass filter as we obtained the following waveforms and results through testing.

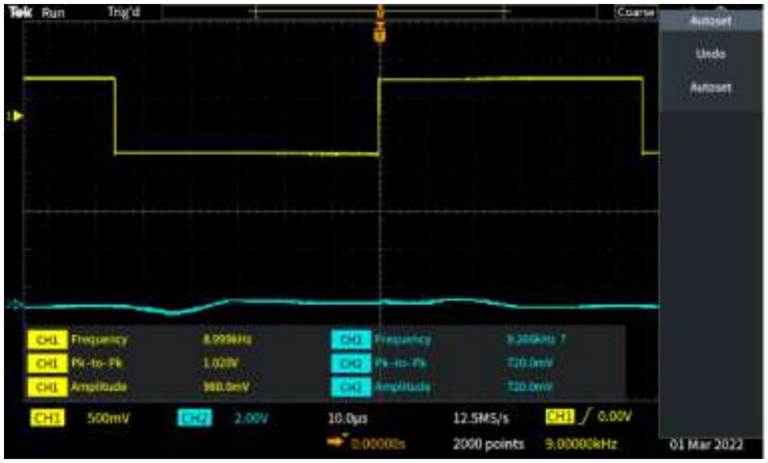


Figure 30. 14-22kHz bandpass filter output with 10kHz input.

Figure 31. 14-22kHz bandpass filter output with 18kHz input.

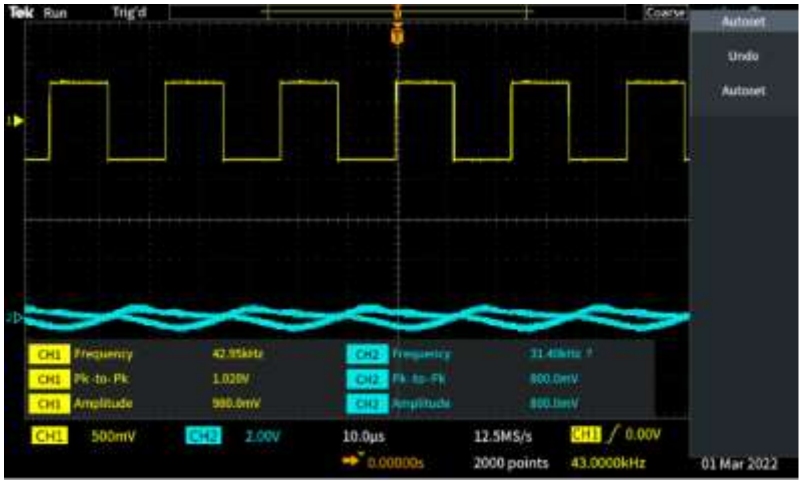


Figure 32. 14-22kHz bandpass filter output with 30kHz input.

As seen in Figure 31 a more defined and amplified signal was achieved at the center frequency compared to previous tests and the voltage of the filter output was attenuated at frequencies outside of the bandwidth as seen in Figure 30 and Figure 32 above. However, despite the positive progress made, the bandwidth of the system was larger than what was calculated as attenuation of voltage was only seen around 10kHz and 40kHz compared to the expected frequencies of 14kHz and 22kHz. This was later improved on in the final filter design by reducing the resistance of R1_S1 and increasing the resistance of R1_S2 in Figure 8.

7.4 Vendors and facilities used

Part	Unit	Price/Unit	Vendor	Contact Information
Ceramic Capacitor Assortment Kit	1	$16.99	Amazon	https://www.amazon.com/
Resistor Assortment Kit	1	$12.99	Amazon	https://www.amazon.com/
NE555P Timers	12	$0.79	Amazon	https://www.amazon.c https://www.amazon.com/ om/
Operational Amplifier Dual Op-amps	50	$0.13	Amazon	https://www.amazon.com/
Soldering Kit	1	$7.48	Amazon	https://www.amazon.com/
Soldering Board	1	$7.98	Amazon	https://www.amazon.com/
Soldering Putty	1	$2.13	Amazon	https://www.amazon.com/
Potentiometers		$8.49	Amazon	https://www.amazon.com/
Multiplexer Breakout Board	1	$5.29	Amazon	https://www.amazon.com/
Multiplexers	10	$1.34	Mouser Electronics	1 (800) 346-6873

Considering this project entailed a great deal of testing, our group contacted the Electrical Engineering Department, and we were able to get access to the electrical engineering lab. Thus, testing was performed at the Electrical Engineering Laboratory at Nedderman Hall.

8. Performance evaluation

8.1 Detailed description of the testing procedures/protocols for determining the physical and functional characteristics of the final prototype

There were two physical specifications for this device: The device should be lightweight and not rely on any external computers. The specification of lightweight was tested by measuring the previous device and its individual components on a scale, the overall device weighed 373.88g. Then the new components to be fabricated were weighed by getting a quote on the newly designed PCBs which will an additional 2g. The specification of external sources was resolved through the addition of the waveform generators and filters. These new additions use an analog system to generate and differentiate different IR LED frequencies which means it does not rely on external computers to function. However, the system will rely on an external 9V battery to operate.

The three subsystems that were tested for functional characteristics include waveform generating circuit, detection subsystem, and the active bandpass filter. Each subsystem has its own breadboard or perforated board setup as have been shown above.

The waveform generating circuit had a 555 Timer with the following pinout diagram:

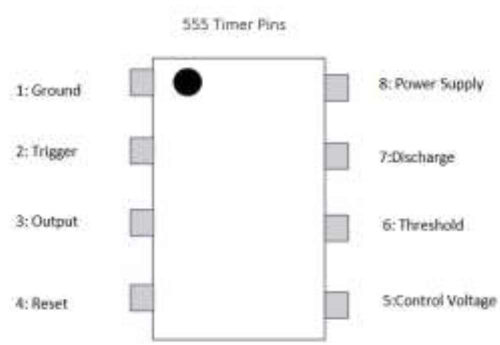


Figure 33. The pinout diagram of 555 Timer used in waveform generating circuit.

As can be observed in the above diagram, power supply needed to be connected to pin 8 and pin 1 needed to be grounded. To measure the output of the subsystem after placing resistors and capacitors as described in the circuit diagram in Figure 4, an oscilloscope was used. Oscilloscope's pins were connected to pins 3 and 1. The output would include a square diagram and measurement variables such as peak to peak voltage and frequency.

The detection subsystem required its own power supply of +5 V and ground pins. The subsystem needed to have a unique setup to be able to detect any signal and to measure the incoming signal. The setup of the detection system and waveform generating circuit are represented in the following figure:

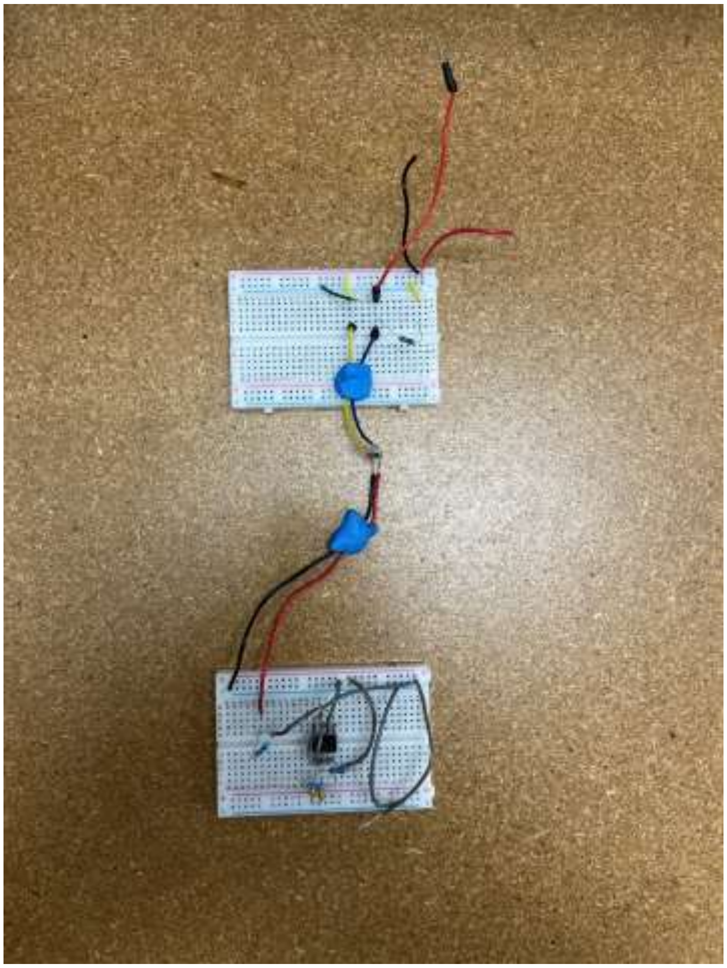


Figure 34. The setup of detection subsystem and waveform generating circuit.

As can be observed from the above setup, where the top breadboard is the detection subsystem with a phototransistor having yellow and black wires that are extended towards SMD model IR LED. The bottom breadboard is the waveform generating circuit where red and black wires that are connected to SMD model IR LED which is placed right below the upside down SMD model phototransistor component. To measure the output signal of the phototransistor oscilloscope was used to plot the obtained signal. Two pins of oscilloscope were connected to the positive pin of the phototransistor and ground. Oscilloscope was used to plot signal as well as obtain measurements such as voltage peak to peak and frequency values. On some occasions when the output of the detection signal was not clear or hard to analyze, Arduino Uno was used to plot the obtained signal.

The active bandpass filter utilized a dual op-amp with the following pin configuration:

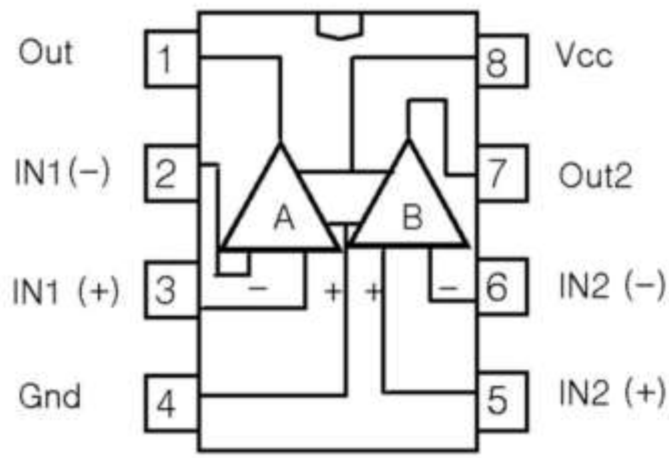


Figure 35. The pinout diagram of dual op-amp used in the active bandpass filter circuit.

The configuration of the dual op-amp pins can be seen in the schematic diagram of the active bandpass filter in Figure 8. However, to test the subsystem, 3-5V were supplied to circuit through pin 8 and the output of the filter was visualized on an oscilloscope connected to pin 7 of the op-amp. Initial testing of the individual subsystem utilized a waveform generator to mimic the function of the waveform generating circuit being designed. The waveform generator was used to supply signals at various frequencies to observe how the 14-22kHz bandpass filter reacted to those frequencies by measuring the change in voltage and calculating the frequency response of the system.

The three subsystems that were worked on independently were finally combined to test the combination of all subsystems. Ideally, this combination of three subsystems would have become the basis of the fingernail and ring system.

The setup of all subsystems included setting the waveform generating circuit with the correct targeted frequency with detection system and connecting the output of the detection system to the active bandpass filter.

The top breadboard in the below figure represents the three different target frequencies achieved by building three waveform generating circuits on the big breadboard. These target frequencies were 10 kHz, 18 kHz, and 30 kHz. The SMD model phototransistor on the detection system was upside down and was placed right above the SMD model IR LED to achieve the data acquisition by phototransistor.

The output of the detection system was fed to the 14-22 kHz active bandpass filter which had a central frequency equal to 18 kHz.

The three subsystems each required their own voltage supply and oscilloscope wires to plot the three output signals from waveform generating circuit, detection system, and 14-22 kHz active bandpass filter.

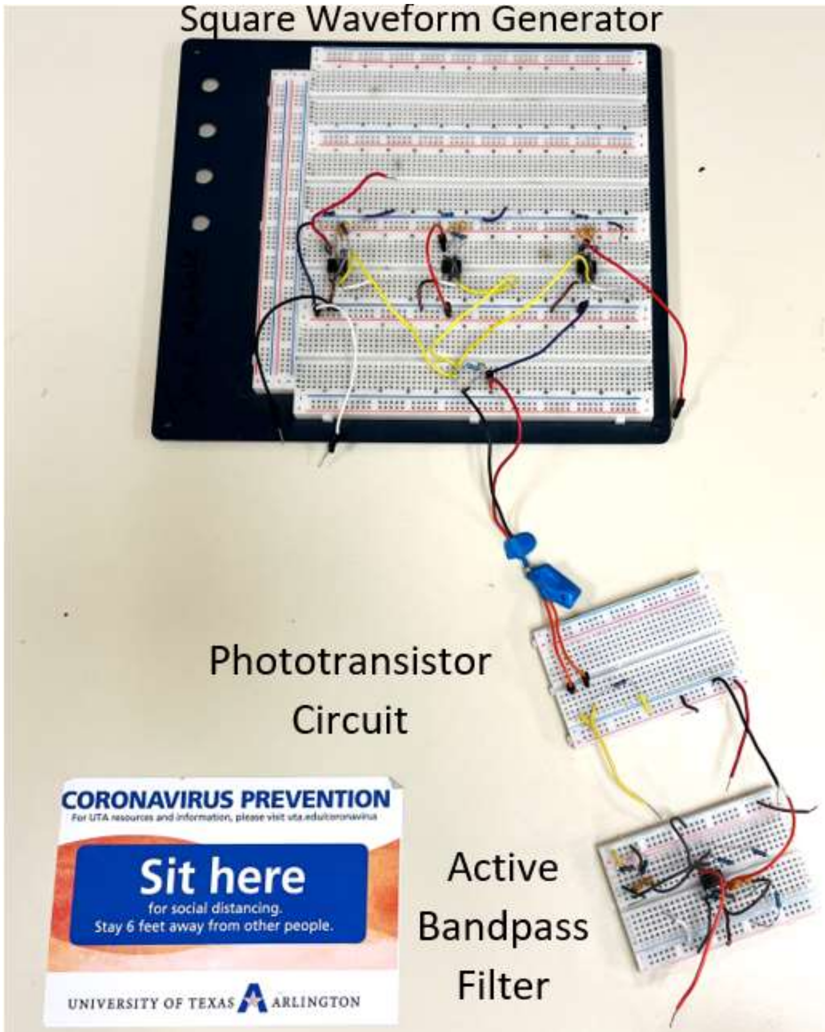


Figure 36. Three subsystems set-up and tested together.

8.2 Results from the performance evaluation tests

The testing procedures of the three subsystems were carried out using multimeter and oscilloscope. Multimeter was used to double check the resistor values and the oscilloscope was utilized to plot the signals and analyze the obtained graphs.

The following graph shows the signals from 38 kHz waveform generating signal and the phototransistor circuits. The signals were plotted on the oscilloscope and the measurements were obtained as well:

Figure 37. Plotted output signals of the waveform generating circuit and detection subsystem.

In the above Figures, the yellow line represents the output signal of 38 kHz waveform generating circuit and the blue line stands for the output signal of the detection subsystem. The setup of these subsystems is like Figure 34.

For the 14-22kHz bandpass filter, as mentioned before, the main objective during testing was to record the change in output voltage of the filter at a range of frequencies to identify whether the filter was accepting and rejecting the desired frequencies. These results are seen in Table 10, Figure 16 and Figure 17, where the change in input and output voltage of the filter was recorded.

8.2.1 Embed video or photos of the evaluation process

The video was uploaded on YouTube and a brief description can be provided.

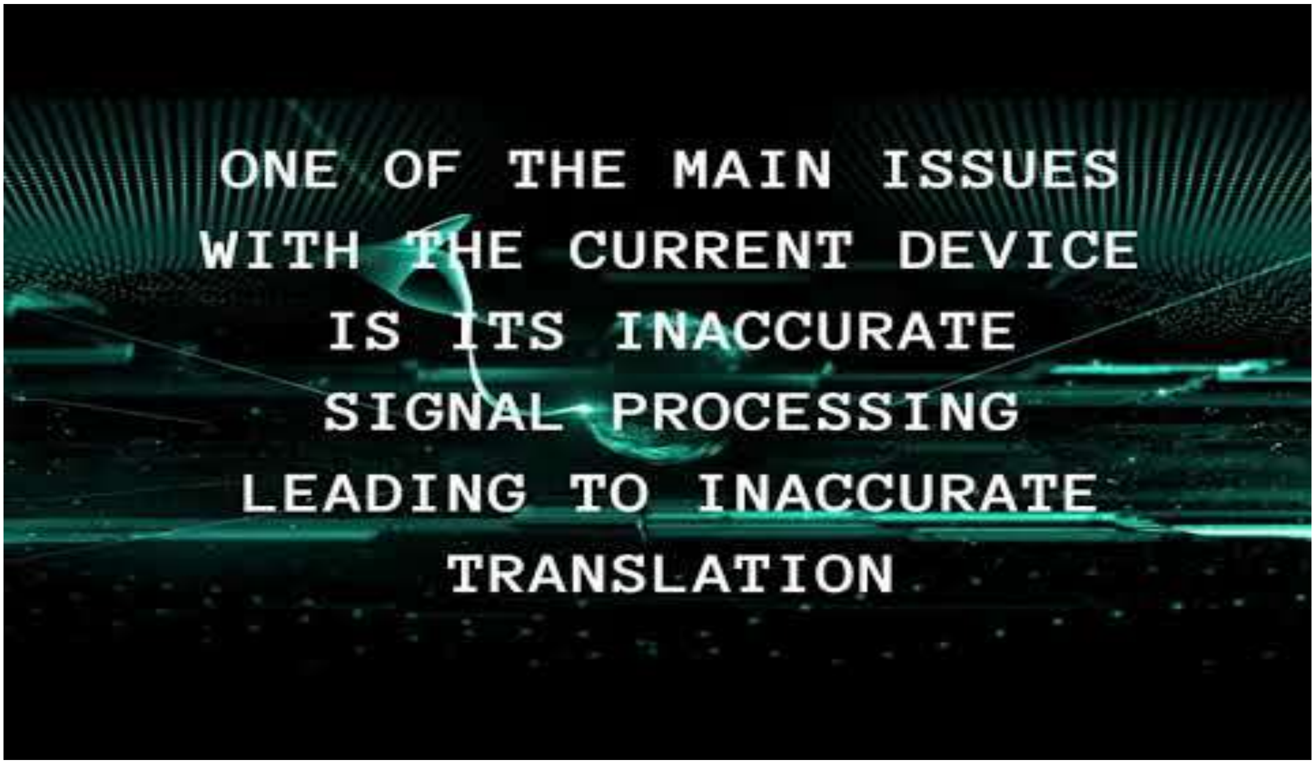
Video 1 shows the testing of our 3 subsystems in their breadboard's models. The three subsystems include an 18 kHz waveform generating subsystem, detection subsystem, and filter. These subsystems' breadboards were connected to power sources as well as oscilloscopes to measure the output signals. The first oscilloscope shows the square waves from 10 kHz,18 kHz or 30 kHz waveform generating circuit in yellow lines and blue lines that are the signal output of the detection subsystem. The second oscilloscope shows the response of the 14-22 kHz active bandpass filter.

Video 2 shows demonstration of fabricated subsystems on perforated boards. Those subsystems are an 18 kHz waveform generating circuit and 14-22 kHz active bandpass filter. The 18 kHz waveform generating circuit shows square waves on the oscilloscope with an approximate measured frequency of 19.34 kHz shown on the screen of the oscilloscope. The demonstration of 14-22 kHz active bandpass filter included showing the signal output at 3 specific frequencies that were supplied to the circuit by the function generator. The yellow line which corresponds to Channel 1 of the oscilloscope provides the visual representation of the function generator’s function. The blue line corresponds to Channel 2 of the oscilloscope and provides output signal of the 14-22 kHz active bandpass filter. The first supplied frequency of 10 kHz resulted in very attenuated signal output. The second supplied frequency of 18 kHz resulted in less attenuated output and the signal has a more defined shape. The third supplied frequency of 30 kHz resulted in another attenuated signal output of the filter.

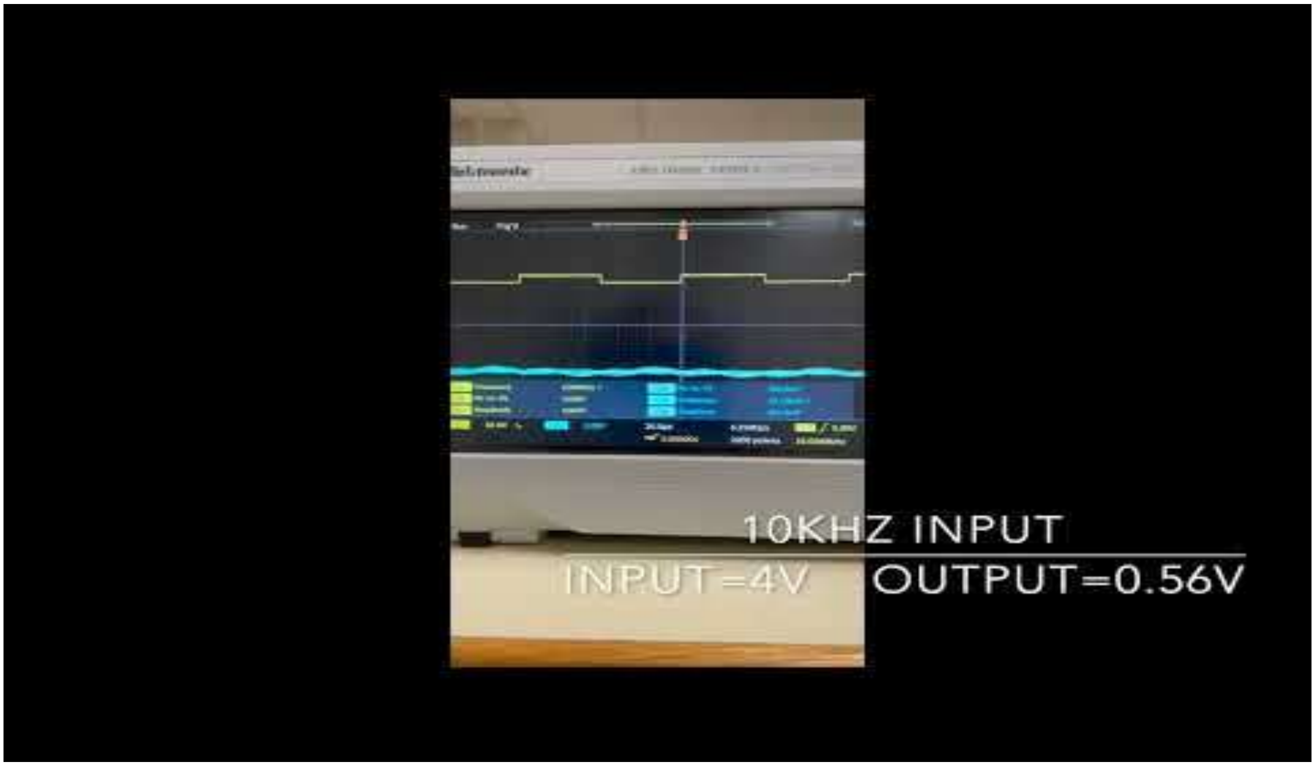
Video 3 shows three different testing that were performed. In the first and second testing setups detection system had phototransistor receiving some type of infrared light signal and the output of the phototransistor was fed to the 14-22 kHz active bandpass filter and the output of the filter was plotted. In the first setup, modulated IR LED was shone at the phototransistor at 18 kHz rate and the output of the phototransistor was fed to the 14-22 kHz active bandpass filter. The outputs plotted on the first shown oscilloscope included the yellow lined output of the waveform generator that made the IR LED shine at 18 kHz in a form of square waves and the blue lined output represents the output of the phototransistor. The second oscilloscope shows the output of the 14-22 kHz active bandpass filter. The second testing setup included shining unmodulated IR LED onto the phototransistor and this setup involves shining an IR LED at close proximity to the phototransistor. All three outputs were shown like the first setup. The third testing setup included feeding DC offset signal with a frequency of 0.1 mHz to the 14-22 kHz active bandpass filter and observing the output signal of the 14-22 kHz active bandpass filter.

The following are the videos to evaluate the process:

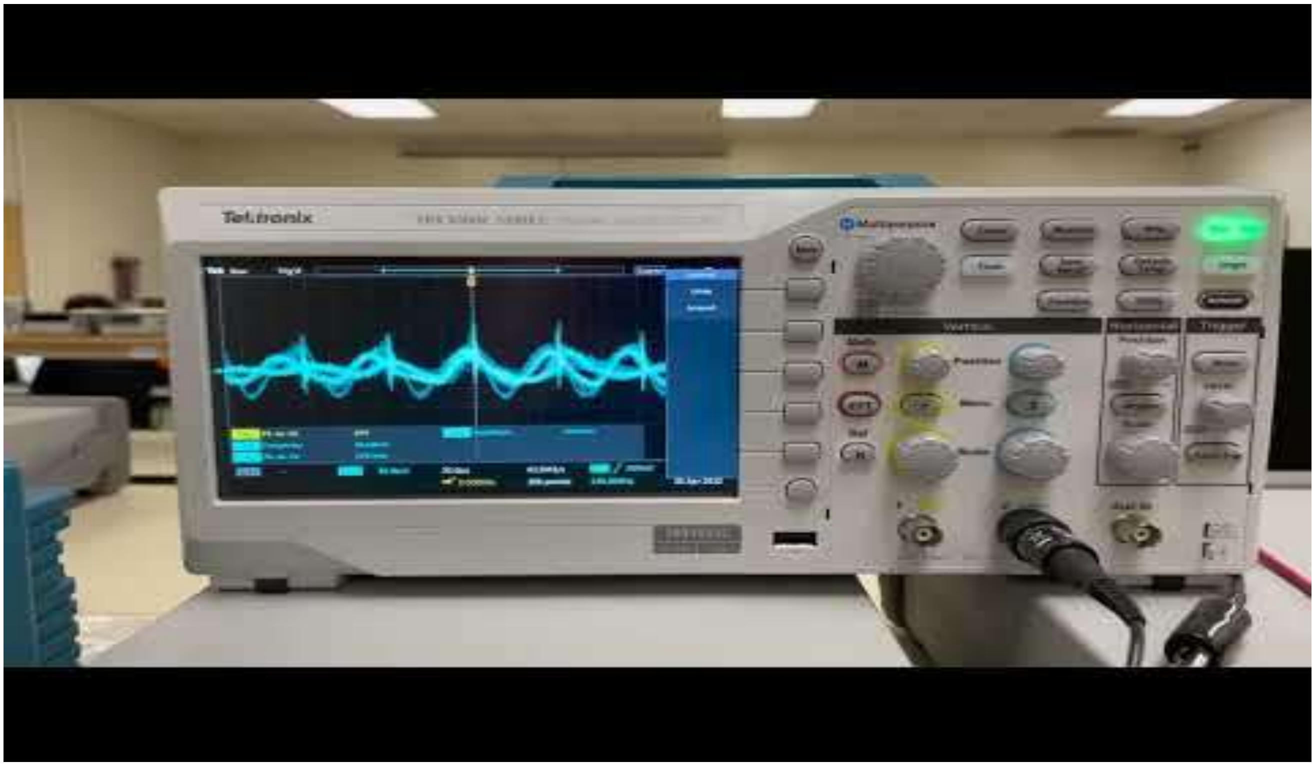
[Video1] Light Weight ASL Translation Device



[Video 2] Perforated Board Components Demonstration



[Video 3] System Demonstration



8.2.2 Show quantitative results obtained from the performance evaluation tests

Quantitative results related to the three subsystems were obtained using oscilloscope. Attempts were made to obtain quantitative results from simulation tools NI Multisim and Arduino Uno but were unsuccessful. The following representation was obtained after performing a successful testing of all three subsystems:

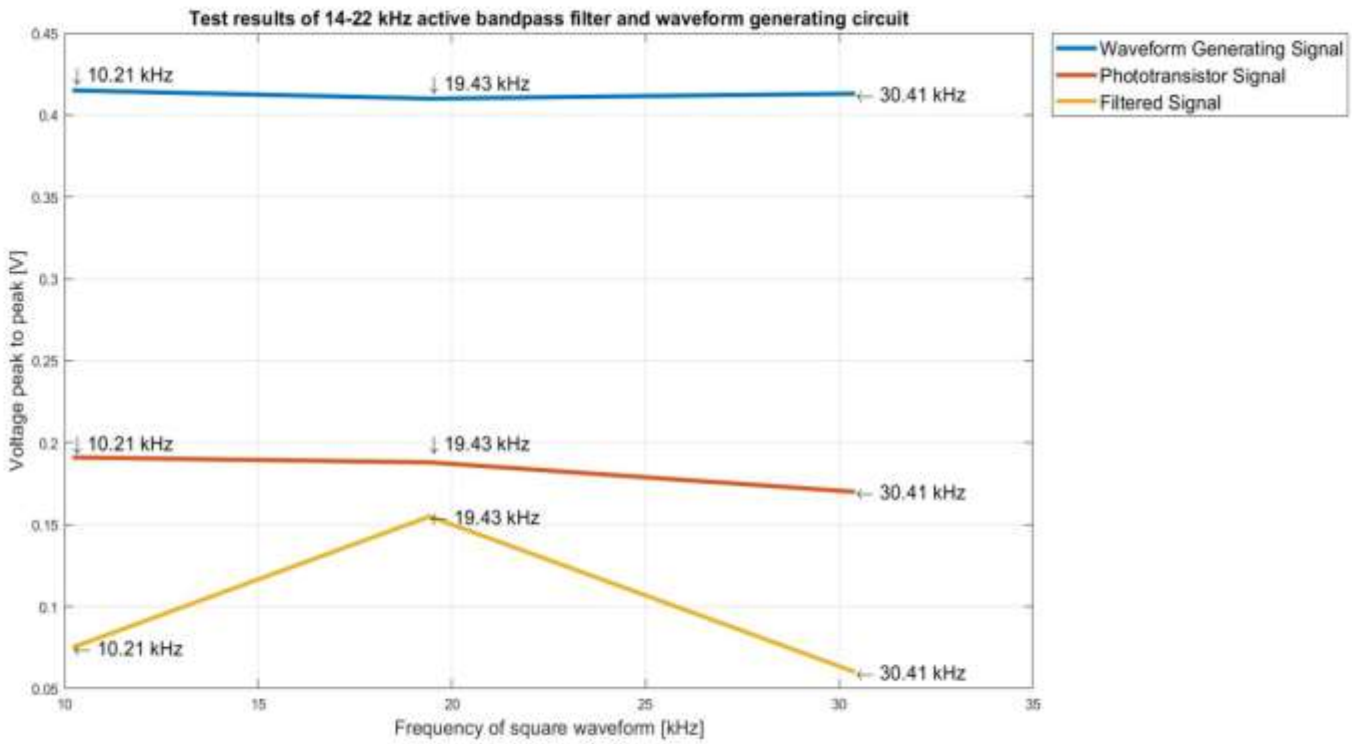


Figure 38. Test results of three subsystems: waveform generating circuit, detection subsystem, filter.

As can be observed from the above figure, three waveform generating circuits were built with the following unique frequencies: 10 kHz, 18 kHz, and 30 kHz. Oscilloscope was used to obtain the exact frequencies which were labeled on the graph. The correct measurements of the unique frequencies were measured to be 10.2 kHz, 19.4 kHz, and 30.4 kHz.

The detection subsystem was set up to detect signals from the IR LED that was powered by the waveform generating circuits and had the output described by the orange line in the above graph.

The 14-22 kHz active bandpass filter was set up to use the output signal of the phototransistor as the input signal for the filter and the output was plotted above in the blue line. The following values can be used as reference for the above graph:

Table 14. The quantitative results of testing three following subsystems: waveform generating circuits, detection subsystem, 14-22 kHz active bandpass filter

Frequency [kHz]	V_{out} Waveform Generating Circuit [V]	V_{out} Detection subsystem [V]	V_{out} 14-22 kHz Active Bandpass Filter [V]
10.2	0.415	0.191	0.075
19.4	0.410	0.188	0.155
30.4	0.413	0.170	0.06

8.3 Analysis of test results

The three subsystems were set up to obtain results of the testing that involved testing all subsystems. The three unique frequencies that were tested were 10 kHz, 18 kHz, and 30 kHz that were produced by three waveform generating circuits. Each waveform generating circuit was set up for the detection subsystem to record the output signal of the IR LED by phototransistor. The 14-22 kHz active bandpass filter was used to test the ability of the circuit to filter out the unnecessary and out of bandwidth frequencies such as 10 kHz and 30 kHz.

The waveform generating circuits were able to produce frequencies that were close to the target frequencies. The 10 kHz waveform generating circuit produced a frequency that was only 0.21 kHz off from the target frequency. The 18 kHz waveform generating circuit produced a frequency that was only 1.43 kHz off from the target frequency. The 30 kHz waveform generating circuit produced a frequency that was only 0.41 kHz off from the target frequency. The detected frequencies and the square waveforms that were produced by the circuit were stable and fixed. The voltage output of these circuits was the highest among the three subsystems but were still small to continue our project.

The detection subsystem was able to detect some signal emitted by the IR LED and the output signal of the subsystem was plotted after obtaining voltage peak to peak values. The voltage values were quite attenuated, and the detection signal did not represent any shape but ideally should have represented somewhat square waveform shape like the waveform generating circuit’s square waveform.

The 14-22kHz filter was able to accept and reject the desired frequencies, however, the voltage output of the subsystem while connected to the entire system was extremely low compared to the individual subsystem testing seen in Figure 16. The highest voltage output achieved was approximately 0.155V close to the center frequency of 18kHz as seen in Figure 38, and the voltage did attenuate as the input frequency changed between 10kHz and 30kHz to approximately 0.075V and 0.06V, respectively.

8.3.1. Quantitative comparison with physical specifications

The previously defined physical specifications were tested and compared to the final device. We defined that the device should be lightweight and not weigh more than 400 g. We measured the previous device and found the wrist CPU weighed 350.43g, the fingernails weighed 12.7g, and the rings weighed 10.7g, meaning the overall device weighed 373.88g. The addition of the waveform generators and filters will add a weight of 2g making the overall device weigh 375.88g. We also defined the device should not rely on any external computers. The device does not rely on any external sources due to the incorporation of a speaker, LCD screen, waveform generator and filters. However, the power supply to the device is an issue, as it cannot function on its own, which is why an external battery source is needed. The battery used is a 9V power bank battery which can be clipped on around the waist.

8.3.2 Quantitative comparison with functional specifications

Three subsystems that were developed and tested included being powered by the voltage supply in the laboratory settings. It is known that the whole device that originally was thought to be built utilizes 5 V maximum voltage and one of the main aspects of the testing was to keep all the power supply at maximum 5 V.

The waveform generating circuit utilized 5 V and the main component of the circuit to get powered was the IR LED. Due to the way the circuit was built with resistors and capacitors, the IR LED received less than 5 V and thus the IR LED blinked at a smaller intensity. The frequency with which it blinked matched the desired frequency. The target frequencies that were set by the team and mentors work well with the overall system and the transponders within ring and fingernail devices.

The detection subsystem utilized 5V power supply and due to the nature of the SMD model phototransistor, the component received less than 5 V and the output signal depended on how strong the IR LED was blinking. Due to the low intensity of the IR LED, the output voltage of the phototransistor was low as well.

Similarly, the 14-22kHz bandpass filter was supplied with 5V to ensure it would function well with the entire system. Despite this, a lot of voltage was lost due to the number of resistors implemented into the wide bandpass filter design. This decreased power supply to the circuit also resulted in a lower voltage output and gain of the filter resulting in less amplification of signals at desired frequencies.

The waveform generating circuit, detection subsystem and filter subsystem utilized 5V, but output voltage was lower than expected. Low voltage will be a challenge for the whole device because Arduino Mega may not be able to work well with such low inputs.

8.4 Needed modifications that were applied to the design/prototype to achieve design specifications

The three subsystems that were developed had multiple prototypes and some were successful. The three subsystems included waveform generating circuit, detection subsystem, and active bandpass filter. Aside from the three subsystems, amplifier circuits were attempted but due to lack of time, the group did not pursue to make the amplifier circuits work.

Waveform generating circuit that was initially built which can be observed on the Figure 9 was very unstable in terms of the frequency of the generated waveform and it was hard to work with such subsystem. Troubleshooting and research gave some ideas that were pursued by the group and a new design utilizing specific component values was simulated on the NI Multisim to see how it works.

The detection subsystem operates by having a phototransistor detect infrared light emitted by the IR LED. The initial prototypes of the circuit were outputting extremely low voltage values. Troubleshooting with the group's mentor was then done which included testing of higher and lower resistor values in the detection system to observe the difference in voltage output.

As mentioned earlier, multiple approaches were taken when designing the active bandpass filter. Once the final design was achieved, the issues faced involved low voltage output and a wider bandwidth range than desired. To address these issues, we made modifications to the subsystem's components, specifically the resistors as mentioned above and explored other components to implement.

8.4.1 Show how the modifications improved the performance of the prototype

As mentioned above, a new waveform generating circuit was simulated and following the simulation, the new circuit was built on a breadboard and further testing showed a more stable waveform and the frequency was not fluctuating as much, staying within 18-19kHz for this system. This helped with ensuring that the IR LED was modulated at a more accurate frequency resulting in a more accurate system as the bandpass filter would be able to filter out more of that frequency as it is the center frequency of the filter.

After troubleshooting the detection system with the group’s mentor, the testing showed that the voltage output increased after increasing the value of the resistor used in the detection subsystem’s circuit. It was decided to use 1 MΩ resistor for the circuit to obtain maximum voltage output from the detection subsystem. Similarly, this improved the system by providing the signal sent to the filter with the highest voltage possible making visualization of voltage amplification or attenuation by the filter easier to identify.

The modifications made to the filter mentioned above helped decrease the bandwidth closer to the desired range of 14-22kHz making filtering of specific frequencies slightly more accurate. However, the modifications did not have much of an impact on the voltage output of the subsystem, hence the suggestion of implementing an amplifier circuit or voltage regulator to future systems as low voltage outputs were still being recorded.

8.5 Assessment of the prototype performance based on the results of the performance tests

Given that the team was pushed to change the direction of the project midway through the year, and work on replacing the previous filtering system with a new analog system, a completely new plan needed to be decided. Thoroughly researching the new system gave the team a delayed start to the project than we had hoped for. After much testing and troubleshooting, one of the subsystems that was worked on, the square wave generator, yielded successful results. However, the bandpass filter system still needs some improvements as does the amplifier circuit. Given the short amount of working time the team had, we were still able to provide an insight as to whether this direction would benefit the future of the device. We believe the testing and troubleshooting done will set a solid foundation for future generations to build upon and improve the functionality of the current device.

8.6 Assessment of environmental impact and sustainability standards of the project

After thoroughly assessing the environmental and the sustainability standards of our project, we have concluded that we met the proper standards that were set early on. All soldering was done in a well-ventilated lab with a fume extractor to eliminate any toxic fumes from the soldering process. All waste materials were properly disposed of in a safe manner in the correct facilities.

9. Summary and recommendation for future improvements

After thorough research and testing, the 9th generation of the American Sign Language Translation Device team decided that it was best for the progress of the device to switch from the previous digital filtering system to an analog filtering system. While the digital system worked and served its purpose of filtering some frequencies, the device still had trouble recognizing different frequencies thus it was having many errors when translating. Due to the advice of our mentor, the team decided an analog filtering system would solve this issue. We also are hopeful the new system will be able to trigger the fingernail devices, which have been an issue with the overall device for many years. We were able to build and miniaturize a 14-22 kHz active bandpass filter, an 18 kHz waveform generator circuit and a detection circuit. We were also able to build a 34-42 kHz bandpass filter, but we were not able to miniaturize it. For the future progression of the project, we would recommend the following: replacing the battery, modifying the active bandpass filters, continuing to build on the amplifier circuit, redesigning the ring and fingernail components, updating the python script, and adding regulators to the op-amp circuit. For the battery replacement, we recommend the 9V power bank be replaced with two 18650 batteries in series. The current battery weighs 187.11g and has a 600mAh capacity so it would only give us 1 hour of battery life. The two 18650 batteries replacement would weigh 90g having a total of 7.4v with 3500mAh capacity which means 5.83 hours of battery life. The modification of the active bandpass would entail shortening the bandwidth range, filtering the out-of-bandwidth frequencies, and amplifying the in-bandwidth frequencies. To continue to build on the amplifier circuit we would recommend further researching the properties of the circuit and simulating and testing the circuit to have an amplified voltage output. To incorporate the new PCBs, we will have to adjust the design of the ring and fingernail components to fit them. The python script for the device will need to be updated. The UTF-8 error needs to be fixed, the reset button code requires debugging, and the FFT portion will need to be removed as it is not a part of the system anymore. Finally, we suggest adding a regulator to the op-amp circuit to maintain the 0-5 V voltage range within the feedback loop so that the circuit does not burn out.

10. Team members' contributions

10.1. Author for each section of the report

Author	Section
R[redacted]	2.0 Executive Summary 4.5 A brief outline of how this written report is organized 5.4 Cost Constraints 5.5. Project duration constraints 6.5. Assessment of chances of success 7.4. A complete list of all parts 8.5. Assessment of the prototype performance based on the results of the performance tests 8.6. Assessment of environmental impact and sustainability of the project 9. Summary and Recommendation for Future Improvements
S[redacted]	5.1. Detailed quantitative functional specifications 6.1. Description of the selected design concept and rationale behind it 6.2. Description of the major subsystems 6.2.1 Drawings, Schematics, and Other 6.3. Engineering design computations 6.4. Simulation results 7.1. Details of how the device prototype was fabricated 7.2. Figures, photos, and other forms of illustrations of the device 7.3. Modifications to the design that were needed to achieve the design specifications 8.1. Detailed description of the testing procedures/protocols for determining the physical and functional characteristics of the final prototype 8.2. Results from the performance evaluation tests

	8.3 Analysis of test results 8.3.2. Quantitative comparison with functional specifications 8.4. Needed modifications that were applied to the design/prototype to achieve design specifications 8.4.1 Show how the Modifications Improved Performance of the Prototype 8.5. Assessment of the prototype performance based on the results of the performance tests 9. Summary and Recommendation for Future Improvements
Mahri [redacted]	3. Table of Contents 4.2. Existing Similar systems 5.1. Detailed quantitative functional specifications 6.1. Description of the selected design concept and rationale behind it 6.2. Description of the major subsystems 6.2.1 Drawings, Schematics, and Other Illustrative means of Showing System and Subsystems for the Device 6.3. Engineering design computations 6.4. Simulation results 6.5. Assessment of chances of success 7.1. Details of how the device prototype was fabricated 7.2. Figures, photos, and other forms of illustrations of the device 7.3. Modifications to the design that were needed to achieve the design specifications 8.1. Detailed description of the testing procedures/protocols for determining the physical and functional characteristics of the final prototype

	8.2. Results from the performance evaluation tests 8.2.1. Embedded video or photos of the evaluation process 8.2.2 Show Quantitative Results Obtained from the Performance Evaluation Tests 8.3 Analysis of test results 8.3.2. Quantitative comparison with functional specifications 8.4. Needed modifications that were applied to the design/prototype to achieve design specifications 9. Summary and Recommendation for Future Improvements
R[redacted]	1. Title Page 2.0 Executive Summary 4.1. Significance and benefits of the project 4.3. Objectives of the project 4.4. Distinguishing features of the proposed system compared to existing similar systems 5.0 Project Specifications 5.2. Detailed quantitative physical specifications 5.3. Engineering, safety, environmental, and sustainability standards 5.6. Final project schedule 8.1. Detailed description of the testing procedures/protocols for determining the physical and functional characteristics of the final prototype 8.3.1. Quantitative comparison with physical specifications 9. Summary and Recommendation for Future Improvements 10. Team Members Contributions 11.0 Acknowledgements

10.2 Main contributors for project aspects

Contributor	Aspect
R[redacted]	Researching Previous Device Ordering Parts Researching Alternative Routes Creating and Organizing Presentations for Class Leading Innovation Day Preparation Creating Innovation Day Poster
S[redacted]	Bandpass Filters Research Bandpass Filters Simulation Bandpass Filters Construction and Fabrication Troubleshooting Systems Creating Innovation Day Poster
Mahri K[redacted]	Waveform Generator Research Waveform Generator Simulation Waveform Generator Construction and Fabrication NI Multisim Simulation Troubleshooting Systems Creating Innovation Day Poster
R[redacted]	Researching Alternative Routes Learning and Executing Soldering Eagle PCB Designing Creating and Organizing Presentations for Class Leading Innovation Day Preparation Creating Innovation Day Poster

11. Acknowledgements

11.1 Acknowledge the people who assisted your team in completing the project

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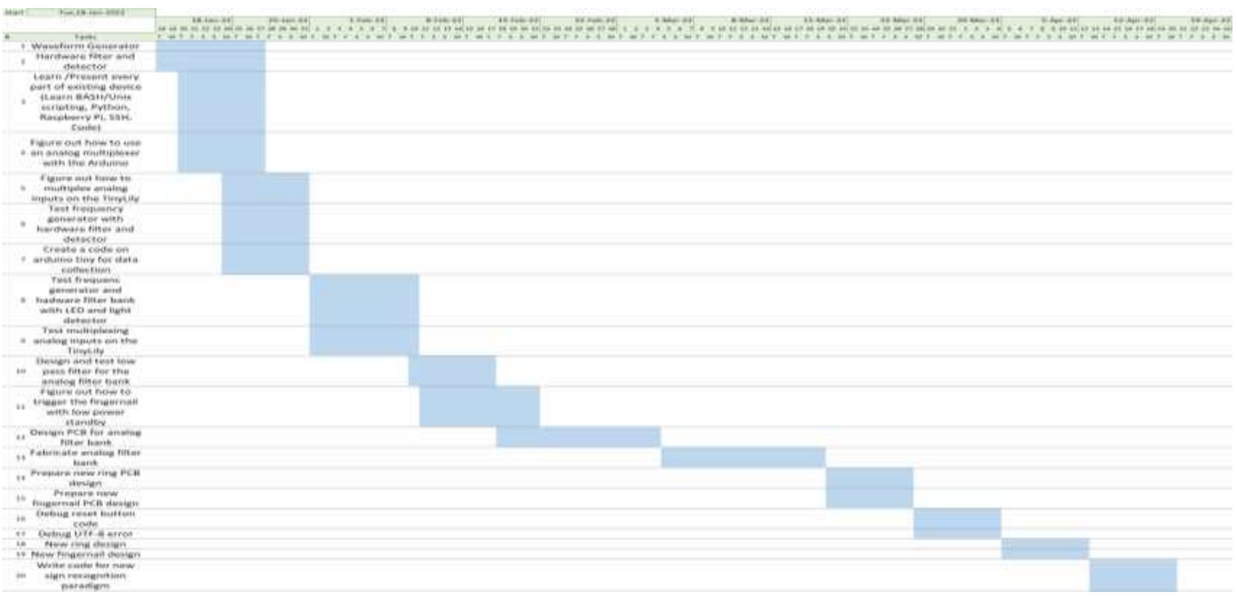
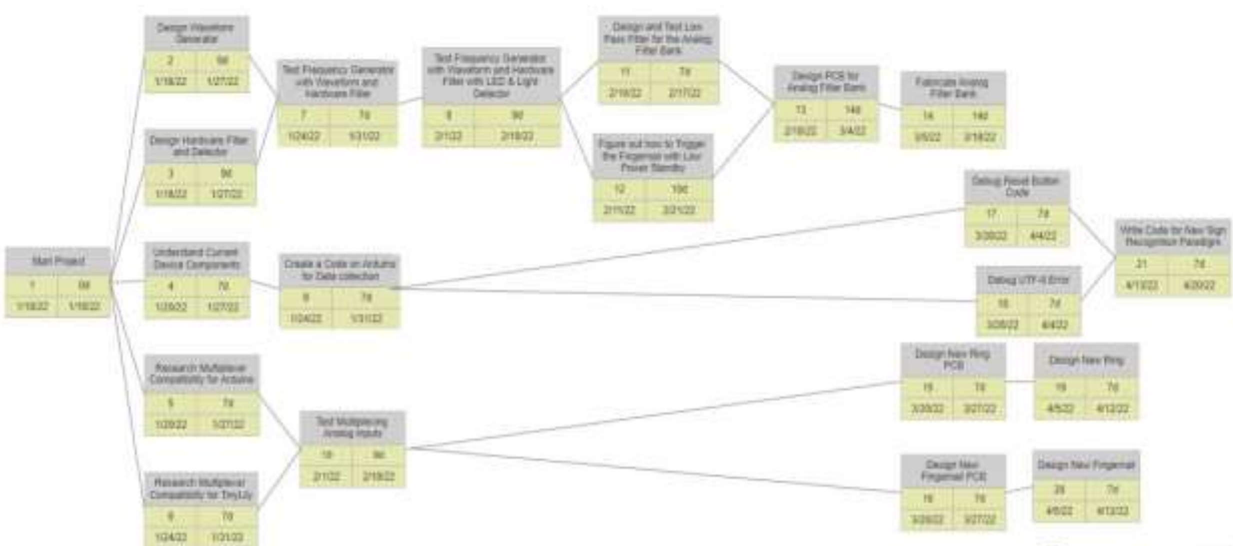
12. Appendix

Previous Gantt Chart:



Previous PERT Diagram:



13.References

1. “Deafness and Hearing Loss.” *World Health Organization*, World Health Organization, https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss#:~:text=Over%205%25%20of%20the%20world's,will%20have%20disabling%20hearing%20loss.

2. Demographics –. (2021, January 12). Gallaudet University. https://www.gallaudet.edu/office-ofinternational-affairs/demographics/deaf-employment-reports/

3. Mitchell, R. E. (2005). How Many Deaf People Are There in the United States? Estimates From the Survey of Income and Program Participation. Journal of Deaf Studies and Deaf Education,

11(1), 112–119. https://doi.org/10.1093/deafed/enj004

4. Davies, J. (2021, November 18). ‘Second-class citizens:’ Hard-of-hearing employees frustrated by lack of accessibility in remote and hybrid working. Digiday. https://digiday.com/media/second-class-citizens-hard-of-hearing-employees-frustrated-by-lack-of-accessibility-in-remote-and-hybrid-working/

5. Lempka, C. (2019). Employees Who are Deaf or Hard of Hearing: Perceptions of Workplace Accommodations. Ursidae: The Undergraduate Research Journal at the University of Northern Colorado, 5(2).

6. Lin, M. R. V. (2010). *ECE 4760 Sign Language Glove*. Copyright (c) 2013 Monica Lin, Roberto Villalba.
https://people.ece.cornell.edu/land/courses/ece4760/FinalProjects/f2014/rdv28_mjl256/webpage/

7. DeepASL: Enabling Ubiquitous and Non-Intrusive Word and Sentence-Level Sign Language Translation. (2017). *Proceedings of SenSys ’17*. Published.

8. Safety of Laser Products - Part 9: Compilation of Maximum Permissible Exposure to Incoherent

Optical Radiation (IEC/TR 60825–9). (1999, October).

9. WORKER DEATHS BY ELECTROCUTION A Summary of NIOSH Surveillance and

Investigative Findings (No. 98–131). (1998, May). U.S. DEPARTMENT OF HEALTH AND

HUMAN SERVICES.

10. Lead Soldering Safety. (2022). UC San Diego. https://blink.ucsd.edu/safety/occupational/hazard-control/lead-

soldering.html#:%7E:text=Soldering%20with%20lead%20(or%20other,and%20upper%20respiratory%20tract%20irritation.

11. Lead Solder. (2018, May 7). Environment, Health and Safety. https://ehs.unc.edu/environmental/fact-sheets/lead-solder/