EE313 Fall 2022 Project Work Final Report

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I. Introduction

Our project in the EE313 course aimed to transmit an audio signal via an optical transmitter module. It was divided into two components: the transmitter and the receiver. To measure signal strength, we combined the audio signal with a reference signal. Our design featured circuit designs such as low-pass and highpass filters, an automatic gain control circuit, and a power amplifier for the speaker. This report will give details on the project's specifications, components, and stages. It will also provide information on the design methodology, simulation results, and experimental results, a comparison of the simulation and experimental results, and explanations for any differences.

II. General Structure and Design Philisophy

The general structure is given in Figure 1. Mainly there are transmitter and receiver sides. The transmitter is responsible for the acquisition of the sound signal and processing it to be carried out in the air with light. The receiver is responsible for the extraction of the sound signal from the incoming light, informing the customer about the signal quality, and broadcasting the sound signal to the user.

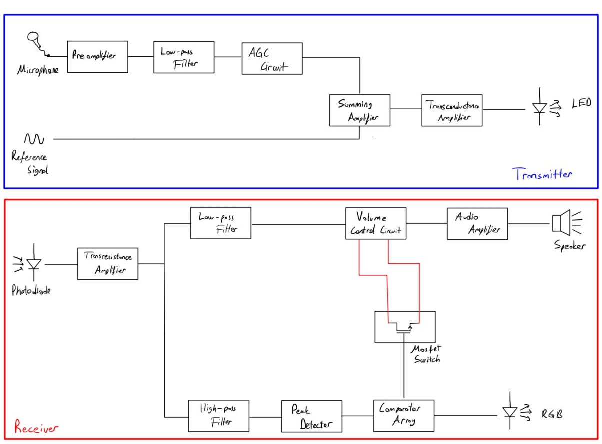

Fig. 1: General Structure

III. Transmitter Side

A. Input and Early Stage Amplification

The microphone functions as a resistor, with its resistance varying based on the audio waves. To turn audio signals into electrical signals, a voltage divider circuit can be employed. However, the resulting output signal is quite weak, making it susceptible to noise. To mitigate this issue, the small signal is amplified using a common source or common emitter amplifier, which results in a less noise-sensitive and more usable voltage range signal. Subsequently, this signal is passed through a low pass filter to separate the human voice for further processing. The schematic of this circuit is given in Figure 2

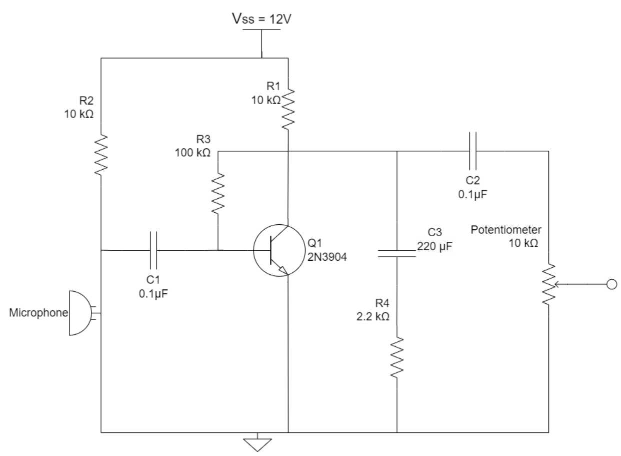

Fig. 2: Microphone and preamplification circuit

The amplification factor can be adjusted from the pot so that the voice level and noise level can be fine-tuned with a proper selection of amplification factors. The construction of this circuit is done on a breadboard, and the design specs are satisfied successfully, as shown in the demonstration. The experimental output of the preamplification is given in Figure 3. The input is a 1khz sine wave sound played from a device.

B. Low Pass Filter

After the preamplification process is completed, the resulting output signal is sent to a low-pass filter to remove any unwanted frequencies. The typical range of

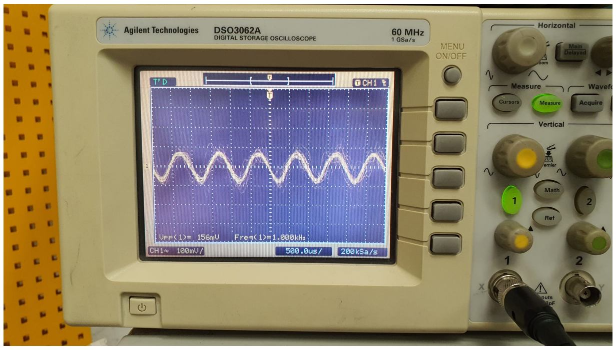

Fig. 3: Microphone and preamplification circuit experimental result.

human hearing is between 20 Hz and 20 kHz, but for this specific project, only the range of 100 Hz to 5 kHz is used. This is done to prevent overlap between the audio signal and the reference signal in the frequency domain. The low-pass filter used in this project is a two-stage Sallen-Key active low-pass filter which is shown in Figure **??** The frequency response of the circuit is given

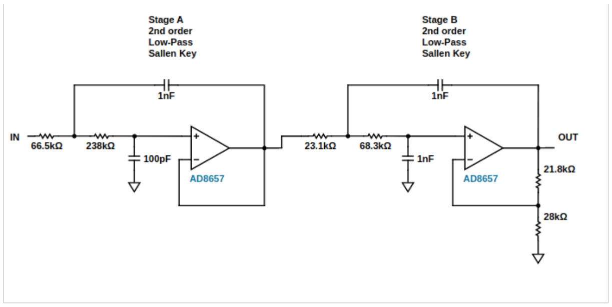

Fig. 4: Active low pass filter.

in Figure 5. The filtering strategy is an accurate decision

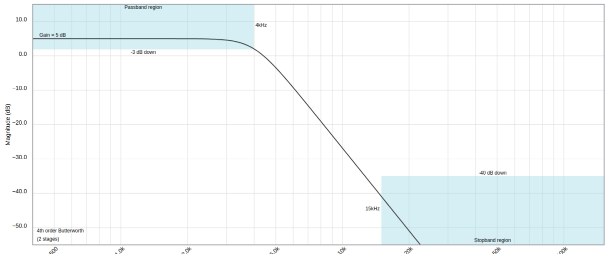

Fig. 5: Active low pass filter frequency response.

as minimal noise is measured from the output.

C. Automatic Gain Control

The automatic gain control circuit given in Figure 6 is designed.

The circuit is composed of three transistors. The first stage (Q2) is a common emitter amplifier with feedback supplied by two other transistors. The second transistor in the common collector configuration is a voltage buffer that takes the amplitude information of the Q2. Then the Q3 works as an active resistor which takes input from a simple peak detector connected after Q3. The simulation was carried out in LTSpice.The input and output characteristics for different amplitudes are given in Figure 7 and 8, respectively. The experimental output of the AGC is given in Figure 9. The input is a 1khz sine wave sound played from a device.

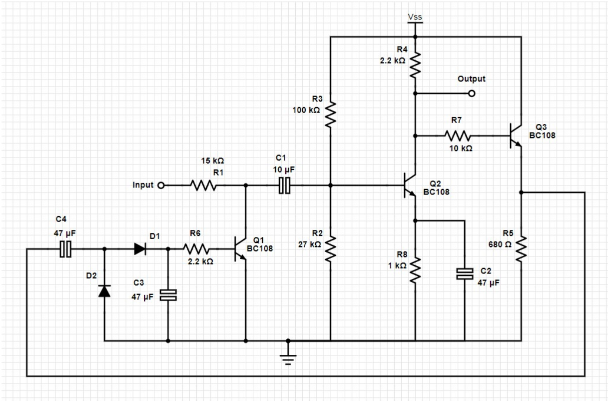

Fig. 6: Automatic gain circuit schematic.

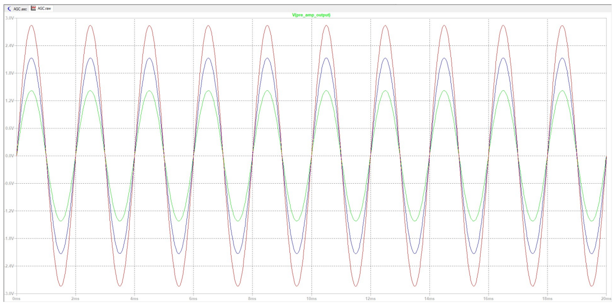

Fig. 7: Automatic gain circuit simulation input.

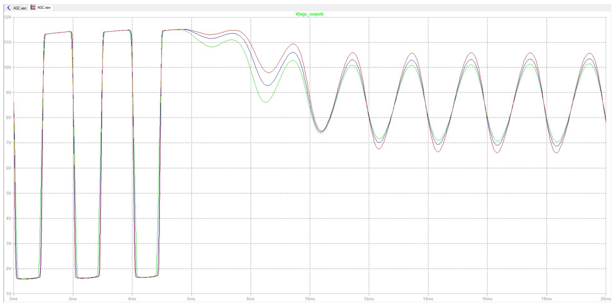

Fig. 8: Automatic gain circuit simulation output.

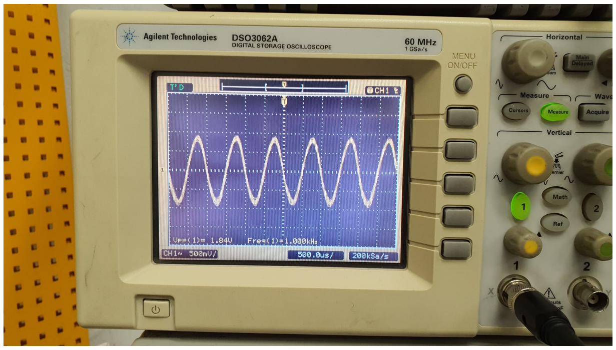

Fig. 9: AGC circuit experimental result.

D. Reference Signal Summation

The constant gain audio signal and the high-frequency reference signal should be summed before transmission. This summation process is thought to be applied by adopting a simple op-amp summing amplifier. The schematic given in 10 is used in a 1 to 1 ratio.

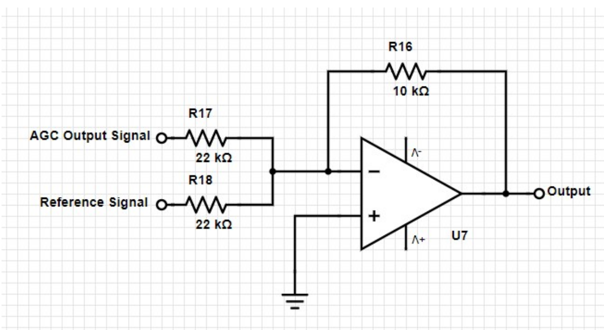

Fig. 10: Summing amplifier.

E. Light Transmission

The decision on the light transmission is made towards using an IR LED. Since the LED's brightness changes with respect to the current passing through it, we needed to convert the signal from voltage form to current form. In order to achieve this, we have utilized a transconductance amplifier given in Figure 11. The circuit is composed of a basic degenerated common emitter configuration with feedback.

As a result of our prototyping process, we constructed the circuit on a breadboard, and the transmitter part of the circuit was successfully operated as expected without any big surprise. The physical structure of our prototype is given in Figure 20 in Appendix.

IV. Receiver Side

As shown in Figure 1, the receiver design has two main branches after the light receiver. Therefore we have investigated them separately.

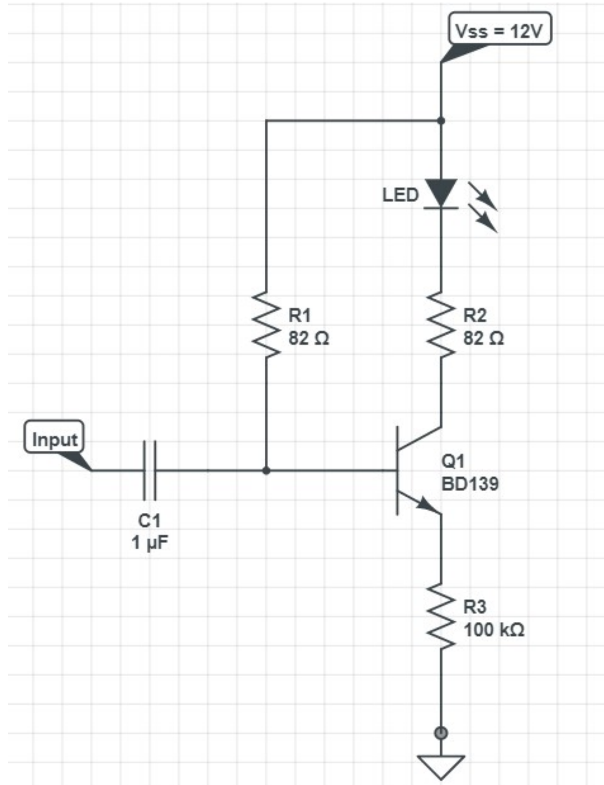

Fig. 11: Transconductance amplifier.

A. Light Receiver

In the receiver section of the system, a photodiode is utilized to transform the optical signal into an electrical one. It is important to note that photodiodes are components that respond to current, so in order to convert the current into a voltage signal, a transresistance amplifier is employed. The design of the transresistance stage can be observed in Figure 12. At the output of the light receiver,

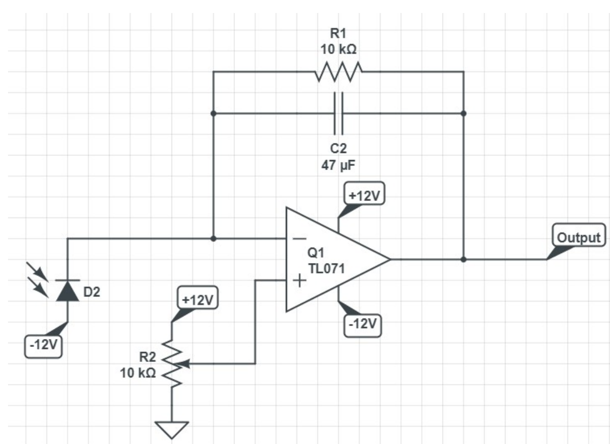

Fig. 12: Photodiode amplifier.

an op-amp buffer is employed for each input of a filter in order to maintain the good signal quality on both inputs.

B. *Voice Signal Path*

1) Low Pass Filter: In order to extract the sound signal from the inside of the incoming signal, a low-pass filter that is explained on the transmitter side is used. The circuit schematic is given in Figure **??**, and the frequency response is given in Figure 5. We have constructed the given circuit, and the experimental result is given in Figure 13. Thus, the intended use of the filter

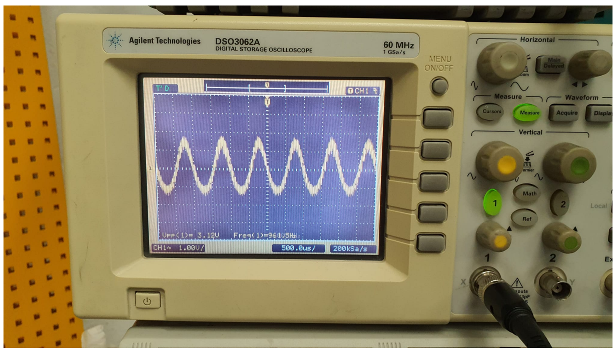

Fig. 13: Experimental response of the low-pass filter at the receiver side.

is achieved.

2) Speaker Driver: After the process of filtering out high-frequency signals, the original sound is obtained. This signal is then sent to the final stage for output, where power amplifiers with cooling components are utilized to power the speaker, as op-amps alone are not capable of providing enough current. The specific type of output stage used in this scenario is known as a Class B output stage, which is more beneficial than Class A and Class AB output stage since it offers a relatively higher level of efficiency. A diagram of the speaker stage circuit can be found in Figure 14. The used topology

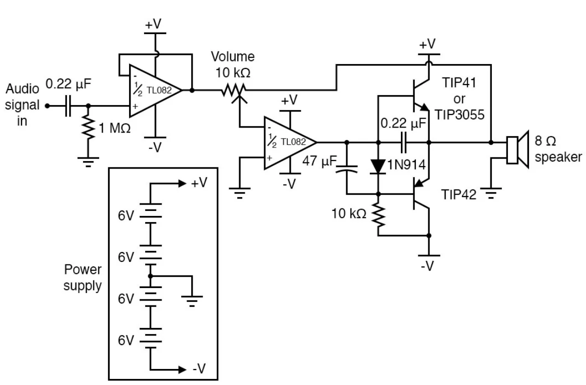

Fig. 14: Class B amplifier.

also allows us to adjust the volume level easily without any compatibility issue or additional tuning for cascading two stages. The physical output of the amplifier is given in Figure 15. That is the same 1kHz signal used in the first stage. As a result of our prototyping process, we

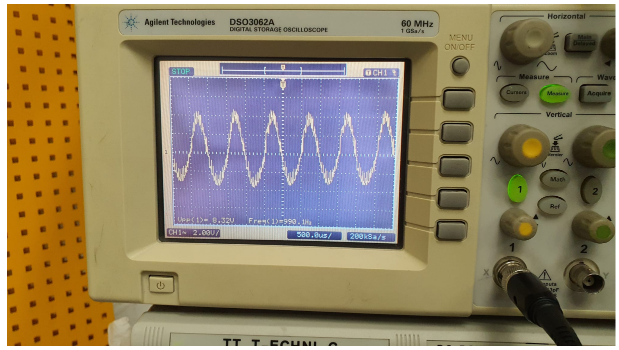

Fig. 15: Experimental response of the speaker amplifier at the receiver side.

have constructed the speaker circuit on a breadboard, and the voice part of the circuit is successfully operated as expected. The physical structure of our prototype is given in Figure 22 in Appendix.

C. *Carrier Signal Path*

1) High Pass Filter: To distinguish the carrier signal from the overall incoming signal. An active highpass filter with Sallen-Key configuration is used. The schematic is given in Figure 16. The frequency response of the

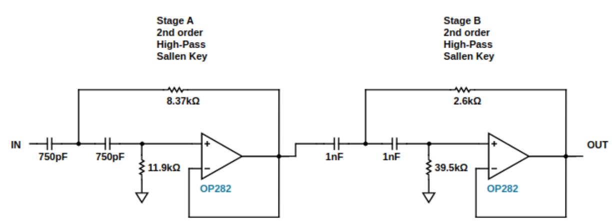

Fig. 16: High pass filter schematic.

highpass filter is given in Figure 17.

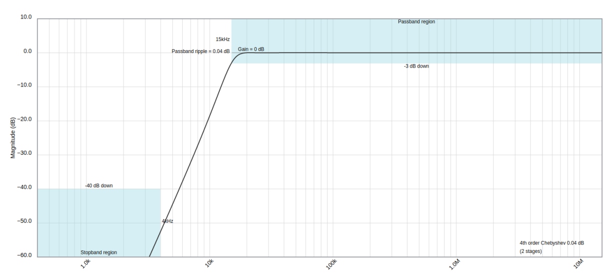

Fig. 17: High pass filter frequency response.

D. *Peak Detector*

To be able to convert the sinusoidal signal coming from the highpass filter to the DC logic levels. So we have utilized a two-stage peak detector which has almost no ripple compared to its DC average. The circuit schematic is given in Figure 18.

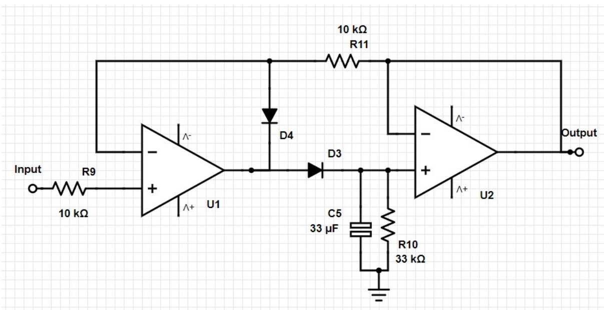

Fig. 18: Peak detector circuitry.

1) Signal Level Indication: At the last stage of the carrier signal pathway, the comparator array composed of op-amps drives an RGB LED to indicate the level of the incoming signal. Figure 19 shows how the configuration works. The scheme of how the signal levels correspond to the colors is given in Table I

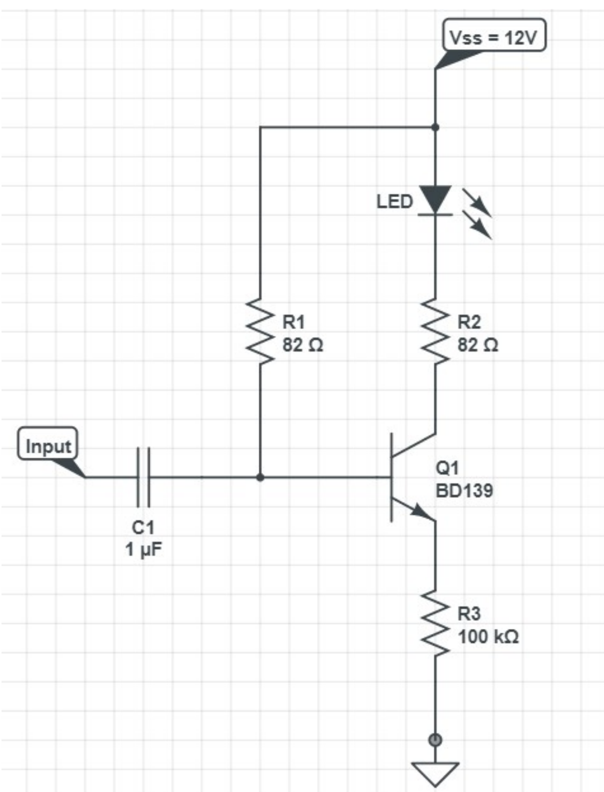

Fig. 19: Comparator array.

TABLE I: the color scheme

Reference 1		**Reference 2**		**Reference 3**		**Reference 4**	
red	*red*	*red*					*red*
	green	*green*	*green*	*green*	*green*	*green*	*green*
					blue	*blue*	*blue*

As a result of our prototyping process, we have constructed the whole receiver circuit on a breadboard, and the receiver part of the circuit is successfully operated as expected. The physical structure of our prototype is given in Figure 21 in Appendix.

V. Conclusion

In this project, we delved deeper into the intricacies of analog circuit design by applying the theoretical concepts learned in our EE311 and EE313 courses. Our focus was on optical wireless communication systems, and through our study of these systems, we gained a comprehensive understanding of their principles of operation. We explored new circuit designs, such as transconductance and transresistance amplifiers, and learned how they could be applied in practical settings. Additionally, we gained valuable hands-on experience in implementing peak detector and speaker driver circuits. As we encountered and overcame any difficulties that arose during the course of the project, we developed a greater appreciation for the complexities and nuances of analog circuit design. Through this project, we were able to enhance our understanding of the fundamental concepts and principles that governed the functioning of analog circuits and gained a deeper understanding of their real-world applications.

Appendix

The physical model of our system is presented in Appendix.

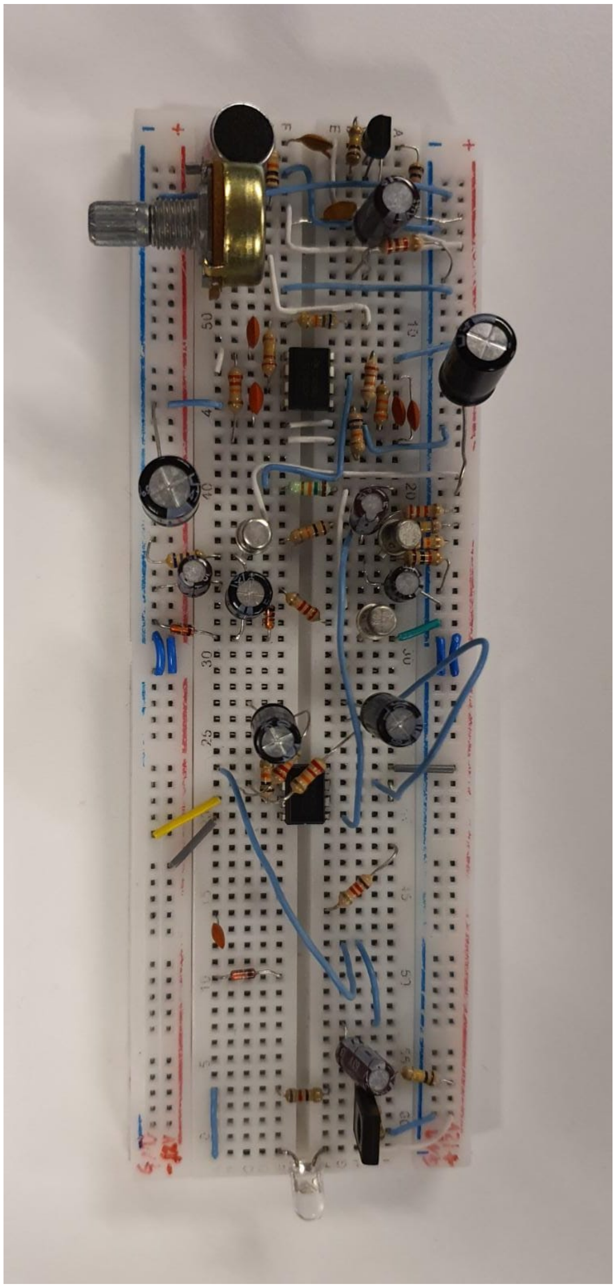

Fig. 20: Transmitter prototype.

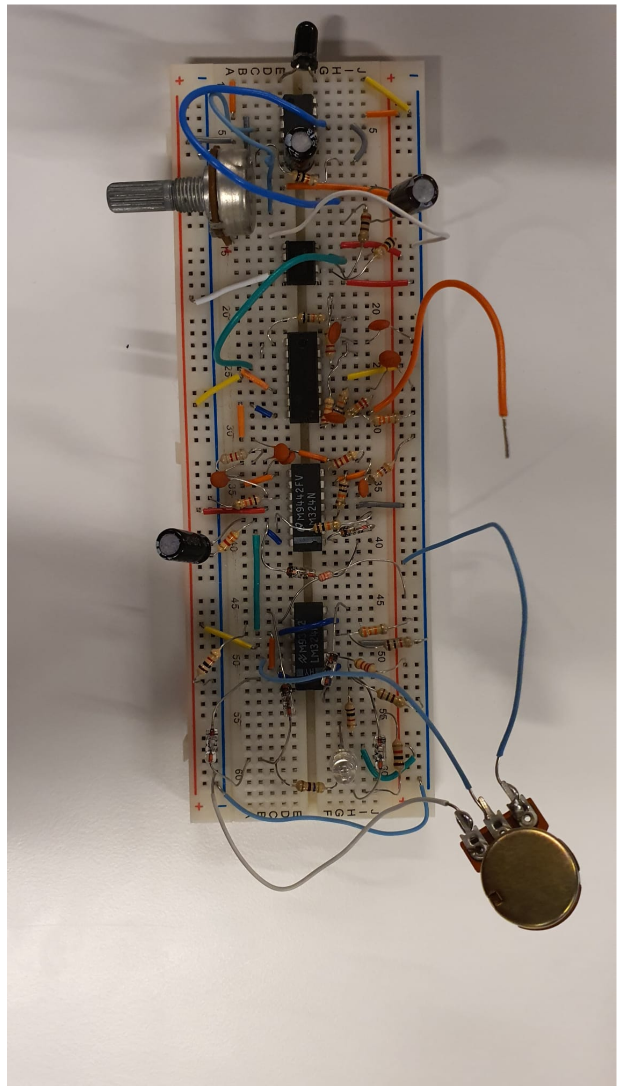

Fig. 21: Receiver prototype.

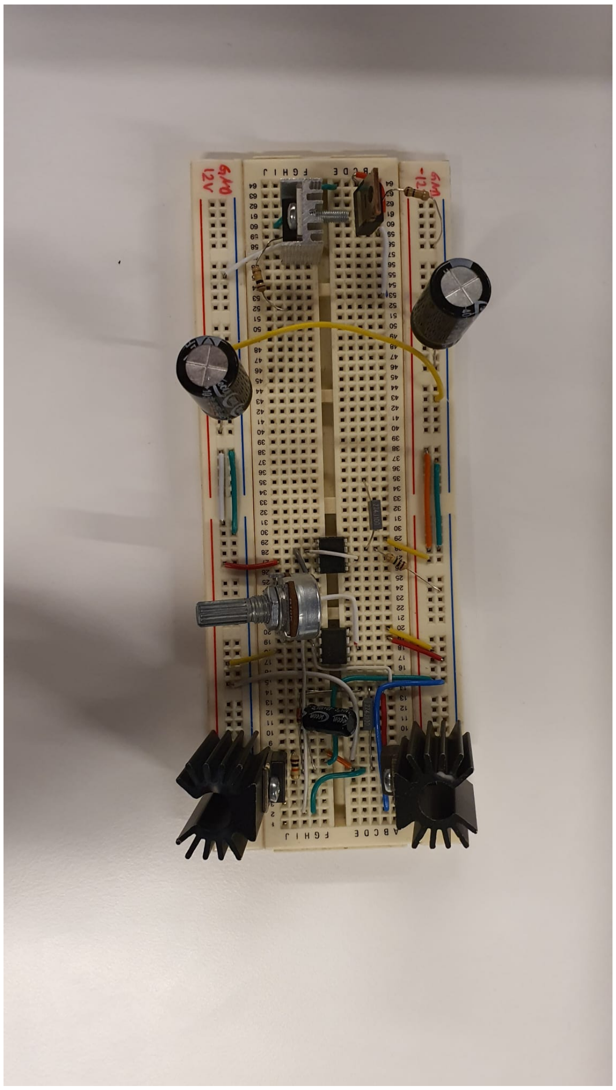

Fig. 22: Speaker driver prototype.