EE 313 Analog Electronics Laboratory Term Project Final Report

Optical Wireless Communication System: Photophone

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***Abstract*— This report explains specifications, stages and components used in our EE313 Analog Laboratory Project, Optical Wireless Communication System. This report is prepared to give information about our project.**

***Keywords*—Optical Transmission, Automatic Gain Control, High-pass Filter, Low-pass Filter**

I. INTRODUCTION

In this project, our aim was to transmit an audio signal with the help of an optical transmitter module. To achieve this, we have divided our project into two parts, transmitter and receiver. We have summed our audio signal with a reference signal to show the signal strength. In our design, we have included some special circuit designs such as low-pass and high-pass filters, automatic gain control circuit and power amplifier to drive the speaker. In this report, the specifications, components and stages of the project will be explained. Also, design methodology, simulation results, experimental results, the comparison of the experimental results with the simulation results and explanation of any discrepancies will be given.

II. SPECIFICATIONS AND COMPONENTS

Specifications:
Cut off frequency of the low-pass filters: 3.6kHz
Cut off frequency of the high-pass filter: 10.2kHz
Frequency of the reference signal: 20kHz
Optical transmitter: Red LED
Optical receiver: Photodiode

Components:
Resistors
Potentiometers
Capacitors
BJTs (BC108, BC135, BC136)
Diodes (1N4148, 1N5819)
Op-Amps (LM741)
Breadboards
Red LED
Photodiode
Common Cathode RGB LED
Resistive Microphone
50-ohm Speaker

III. CIRCUIT STAGES

A. Pre-Amplifier Stage

In transmitter part, firstly, speech signal must be converted into electrical signal. We used resistive microphone and its resistance changes with the intensity of our sound. We need to convert this resistance change into voltage. Therefore, we used microphone driver circuit for this reason.

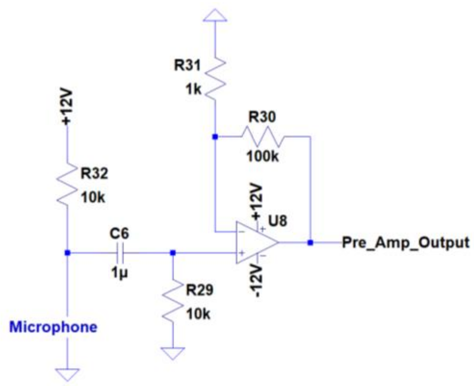

Figure 1: The schematic of the pre-amplifier circuit

As can be seen from Figure 1, capacitor eliminates the DC offset of the microphone and resistor (R4) between microphone and supply creates biasing. Then, amplification occurs under favor of non-inverting amplifier. Gain of this amplifier can be calculated from Formula 1.

$$Gain: A_v = \frac{R_2 + R_3}{R_3} \quad (1)$$

By this formula, our gain is calculated as 101 V/V and our simulation results can be seen in the Figures 2 and 3.

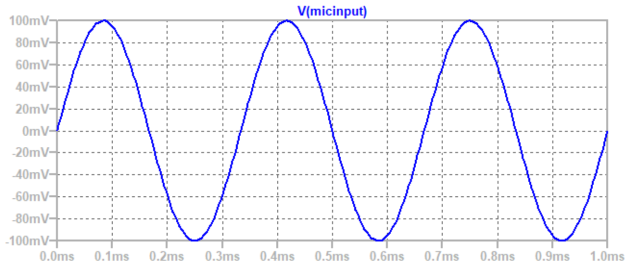

Figure 2: Microphone signal without amplification

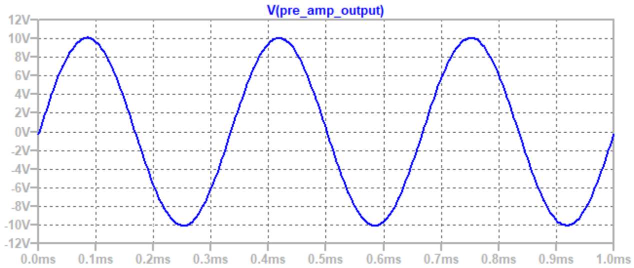

Figure 3: Output signal after amplification

B. Automatic Gain Controller Stage

After microphone driver circuit we constructed automatic gain controller circuit which can be seen in Figure 4 because the output of the microphone depends on frequency and distance. Automatic gain controller adjusts the amplitude of our signal and controls the gain with its feedback mechanism.

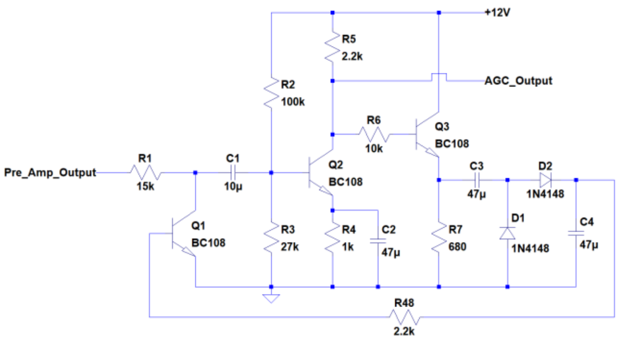

Figure 4: The schematic of AGC circuit

In automatic gain controller circuit, the signal amplification is done by the second transistor, and it operates in common emitter mode. The output taken from its collector side is sent to peak detector, fourth capacitor (C4) controls the base current of first transistor with the voltage on itself. At low signals, the voltage on C4 is small and Q1 draws little current. At high signals, Q1 draws high current and while rising of the voltage on C4, input signal begins attenuating. Thus, our output signal remains relatively constant.

After automatic gain controller, we used a buffer circuit at the output of the AGC which can be seen Figure 5 because connecting AGC to the low-pass filter directly can cause some current leakages.

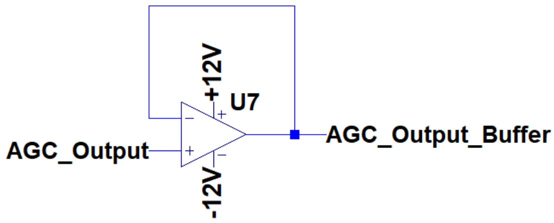

Figure 5: The schematic of the buffer circuit

C. Low-pass Filter Stage

Afterwards, the output signal obtained from the automatic gain control part is sent to the low-pass filter to eliminate the unwanted frequency of the signal. The frequency range of human voice is from 80 Hz to 14 kHz. However, our project only uses the portion of 300 Hz to 3.4 kHz. Thus, we need low-pass filtering to prevent the audio signal and the reference signal from overlapping in the frequency domain. As low-pass filter, we used Sallen-Key low-pass filter which can be seen in Figure 6.

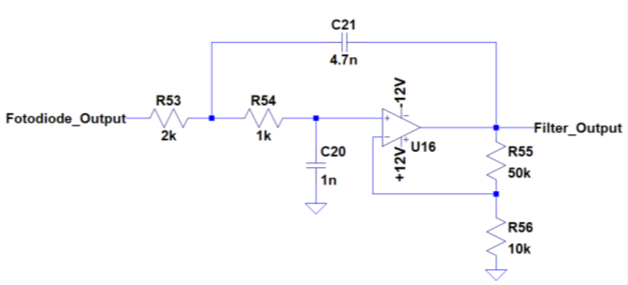

Figure 6: The schematic of the low-pass filter

The properties of the filter are calculated from the Formulas 2 and 3 [1].

$$Gain: Av = \frac{RA + RB}{RA} \tag{2}$$

$$Center\ Frequency: fc = \frac{1}{2\pi\sqrt{R1 * R2 * C1 * C2}} \tag{3}$$

The frequency response of the filter can be seen in Figure 7.

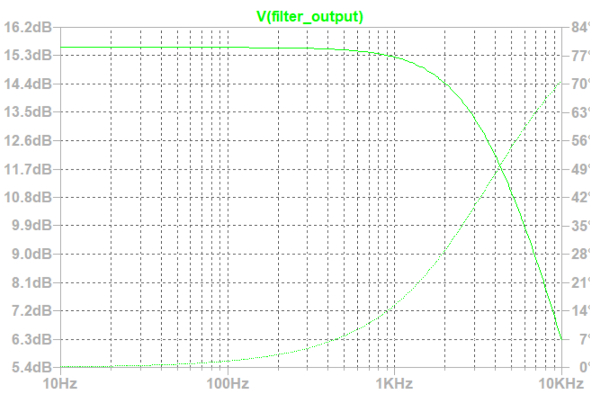

Figure 7: The frequency response of the low-pass filter

Simulated cut-off frequency is 3.6kHz.
Simulated gain is 15.5dB.

During the making of the filter, when we connected the resistances and the capacitors with the simulated values, the filter did not work as we expected. Therefore, we connected potentiometers instead of resistances and changed the resistance values until we obtained the required frequency response.

D. *Transconductance Amplifier Stage*

Then, for summing our filtered signal and reference signal which is taken from signal generator, we used summing amplifier which can be seen in Figure 8. We select the frequency of the reference signal is 20 kHz which is far from filtered signal. Moreover, we add some DC offset to our reference signal from signal generator in order to achieve enough opening voltage for our LED in the transmission part.

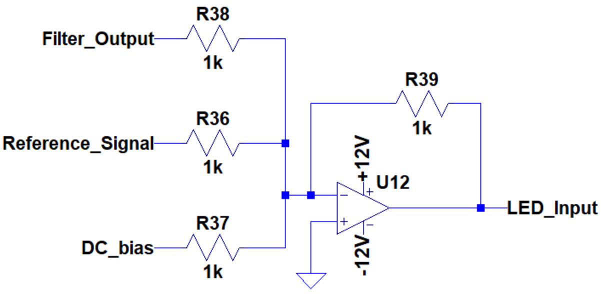

Figure 8: The schematic of the summing amplifier

Electrical signal must be converted into optical signal to transmit the signal to the rest of the circuit, so we constructed a transmitter circuit with using a visible LED. Light intensity of the LED is directly proportional with the current not voltage [2]. Therefore, we need to use transconductance amplifier for this reason. We decided to add transistor part because output current of the op-amp is not enough for LED, thus we got enough current. Design of our transconductance amplifier can be shown in the Figure 9.

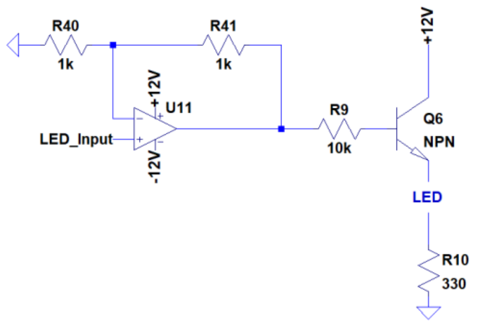

Figure 9: The schematic of the transconductance amplifier

E. *Transresistance Amplifier Stage*

In the receiver part, we used photodiode to convert our optical signal to electrical signal. Again, photodiode is current related component, so we need to use transresistance amplifier which takes current as input and gives output as voltage. The schematic of the transresistance stage can be seen in Figure 10.

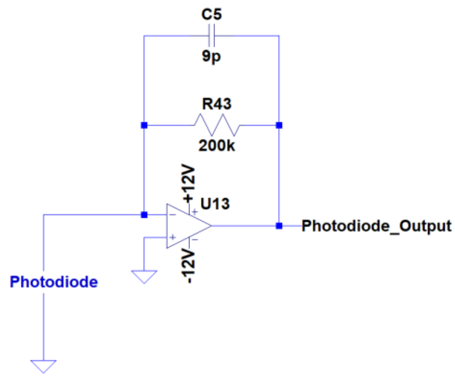

Figure 10: The schematic of the transresistance amplifier

F. *Low-pass Amplifier Stage*

After the transresistance amplifier, the output signal will be sent to low-pass and high-pass filters. The low-pass filter used in this part is the same as the one used in transmitter part. The low-pass filter can be seen in Figure 11.

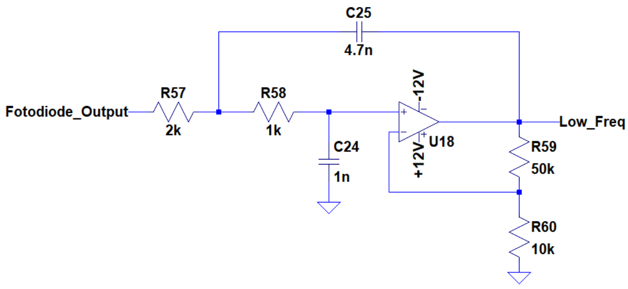

Figure 11: The schematic of the low-pass filter

The frequency response of the filter can be seen in Figure 12.

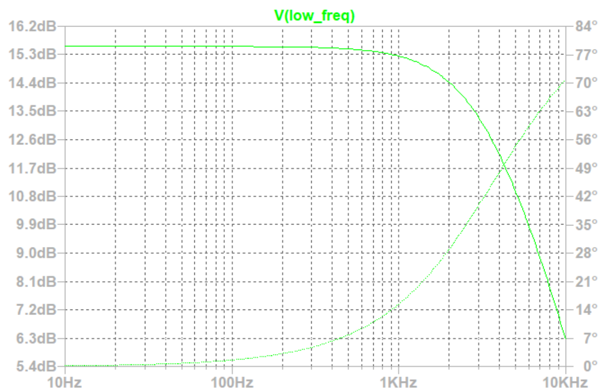

Figure 12: The frequency response of the low-pass filter

Simulated cut-off frequency is 3.6kHz.
Simulated gain is 15.5dB.

G. Output Stage

After low-pass filtering, the original sound signal is obtained. Then, this signal is sent to the output stage. In this stage, power amplifiers with cooling parts are used to drive the speaker because op-amps cannot supply enough current to it. Class AB output stage is used in this part. It is more advantageous compared to class A and class B output stages as it provides high efficiency and low distortion [3]. Output stage circuit can be seen in Figure 13.

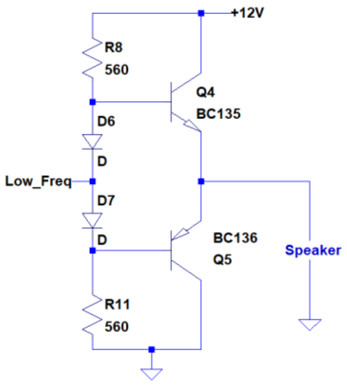

Figure 13: The schematic of the output stage

H. High-pass Amplifier Stage

The output signal obtained from the transresistance amplifier is also sent to high-pass filter. We used Sallen-Key high-pass filter as high-pass filter which can be seen in Figure 14.

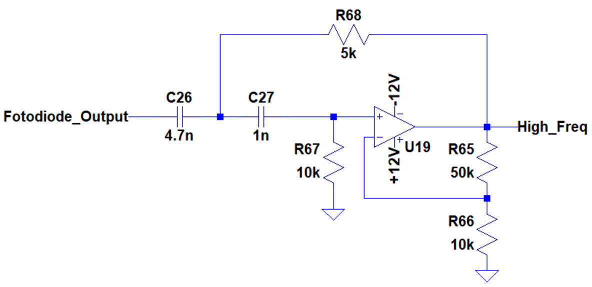

Figure 14: The schematic of the high-pass filter

The properties of the filter are calculated from the Formulas 4 and 5 [1].

$$Gain: Av = \frac{RA + RB}{RA} \tag{4}$$

$$Center\ Frequency: fc = \frac{1}{2\pi\sqrt{R1 * R2 * C1 * C2}} \tag{5}$$

The frequency response of the filter can be seen in Figure 15.

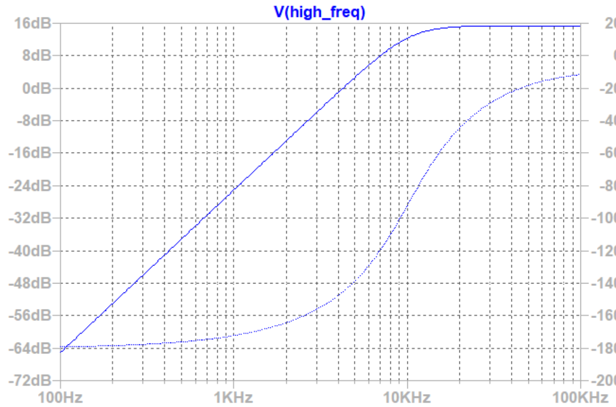

Figure 15: The frequency response of the high-pass filter

Simulated cut-off frequency is 10.2kHz.
Simulated gain is 16dB.

I. RGB Signal Indicator Stage

After the high-pass filter, we need to determine the intensity of the incoming reference signal. As a DC voltage is needed to be compared, high frequency part is sent to the peak detector. After determining its peak value, we compare this value with four different reference voltages as can be seen in Figure 16. Our aim is to light the RGB in a different way in all five cases. We used a common cathode RGB, so the according light will be displayed if the voltage is positive. According to this design, green will light if the voltage is less than Ref2 or higher than Ref4, red will light if the voltage is higher than Ref1, and blue will light if the voltage is higher than Ref3. This way, the RGB will display different colors for different cases as can be seen in Table 1.

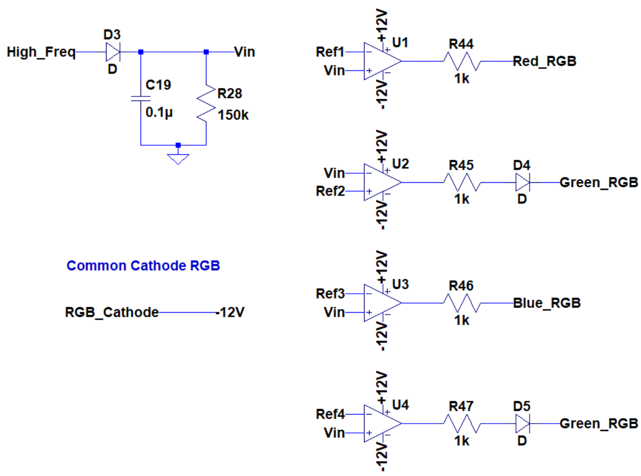

Figure 16: The schematic of the RGB signal indicator part

	Ref1	Ref2	Ref3	Ref4
Green	Green			Green
	Red	Red	Red	Red
			Blue	Blue

Table 1: The colors of the RGB for different cases

IV. COST AND POWER ANALYSIS

Components	Quantity	Price Per Unit	Price
Resistors	30	0,02	0,6
Potentiometers	10	0,69	6,9
Capacitors	12	0,18	2,16
BJTs (BC108, BC135, BC136)	6	2,20	13,2
Diodes (1N4148, 1N5819)	6	0,10	0,6
Op-Amps (LM741)	11	1,12	12,32
Breadboards	4	7,55	30,2
Red LED	1	0,13	0,13
Photodiode	1	6,92	6,92
Common Cathode RGB LED	1	0,96	0,96
Resistive Microphone	1	0,64	0,64
50-ohm Speaker	1	5,33	5,33
		Total Price	79,96

Table 2: Cost analysis of the overall project

The project draws 204mA from +12 voltage source and 74mA from -12 voltage source. Therefore, power is calculated as in Formula 6.

$$P = V * I = 12V * (0.204 + 0.074)A = 3.336\ W \qquad (6)$$

V. CONCLUSION

In this project, we used our theoretical knowledge which we have learned in EE311 and EE313 courses, and we have gained a lot of insight into how analog circuits work properly. While studying on optical wireless communication system, we have had very deep understanding about its working principle. We examined new circuits like transconductance and transresistance amplifiers and learned how they can be used in real life. Also, we have seen how to implement low-pass and high-pass filters in real life, what kind of difficulties we may come across and how to overcome these problems.

However, some parts of our circuit did not work properly. We expected a different result, but we missed out some points and we could not correct them in the remaining time. Despite everything, we are glad to work on this project as it gave us a valuable experience.

The block diagram and schematic of the overall circuit can be seen in Appendix A, B and C.

In conclusion, this project was a very good opportunity for us to use our knowledge and ability of self-learning to design and implement a project. We believe that this experience will be very helpful in our future engineering life.

VI. REFERENCES

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VII. APPENDIX

A. Appendix A

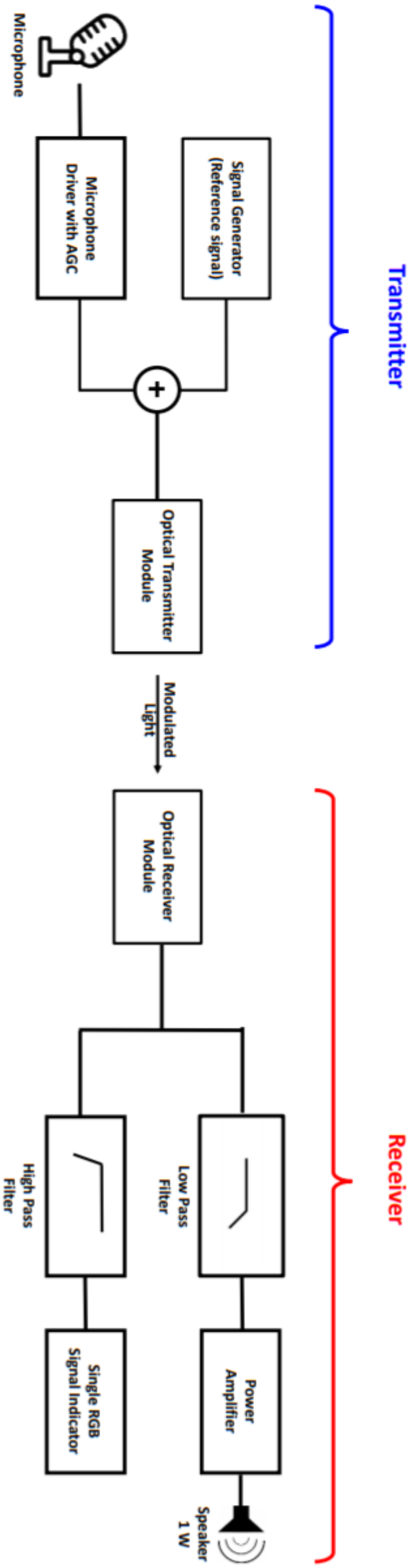

Figure 17: Block diagram of the overall circuit

B. Appendix B

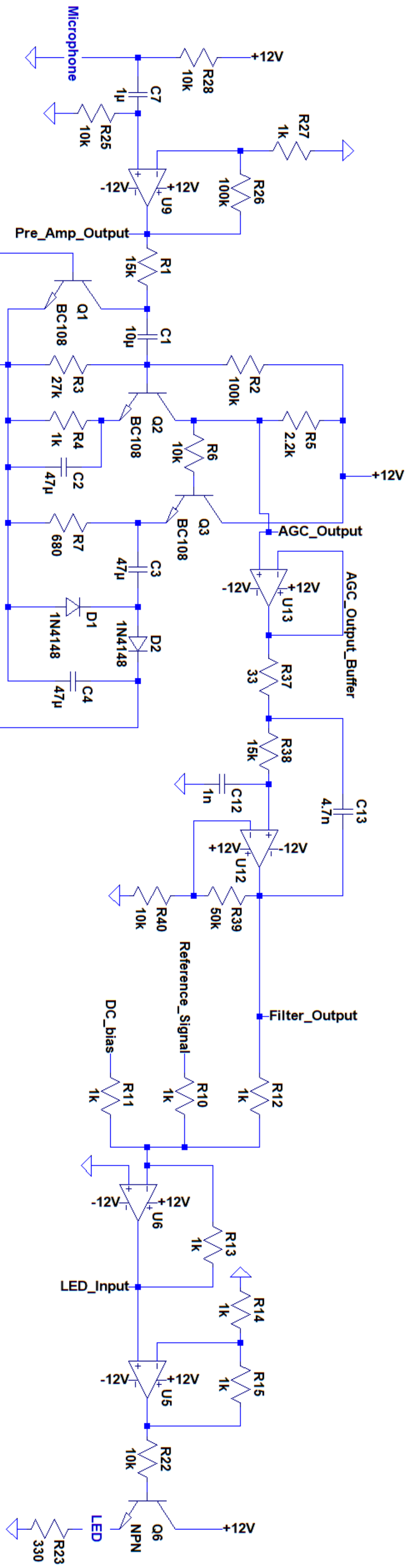

Figure 18: Overall schematic of the transmitter part

C. Appendix C

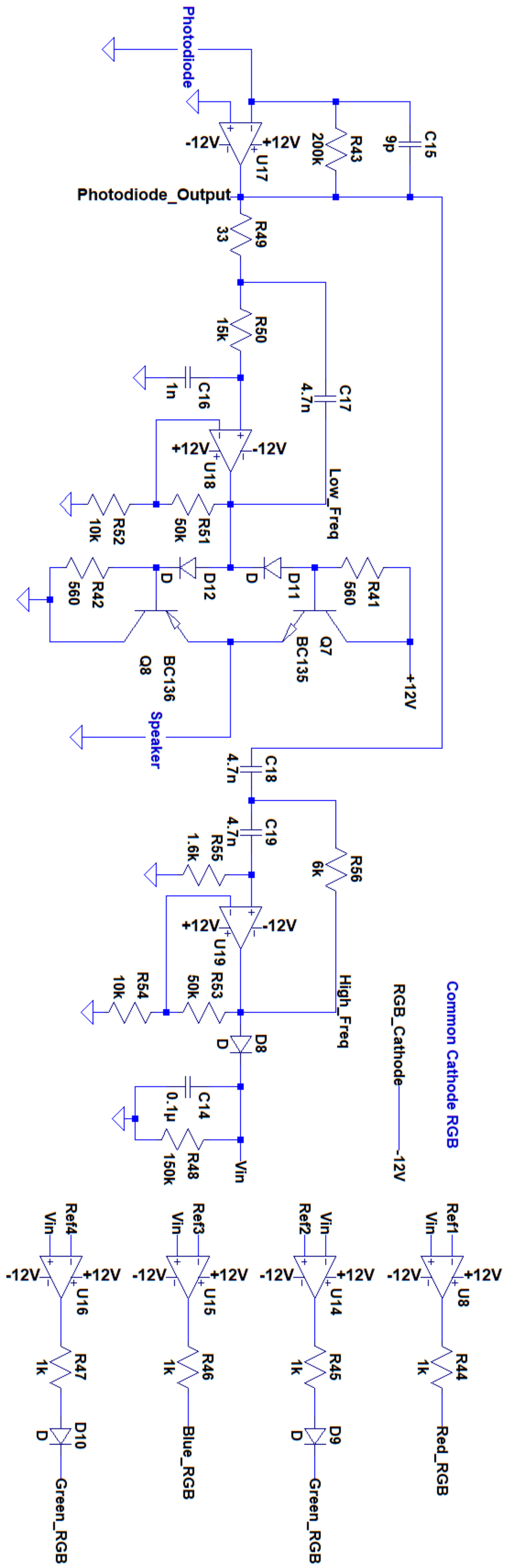

Figure 19: Overall schematic of the receiver part