EE313 Term Project Report: Design of an Optical Wireless Communication System

Anar Abdullayev and Emir Yusuf Özen
Middle East Technical University, anar.abdullayev_01, emiryusuf@metu.edu.tr

***Abstract* – The optical wireless system is made up of two subsystems, namely transmitter and receiver. In such a system, the voice signal in converted to electrical signal, and it is transmitted via light (visible, infrared or ultraviolet) to the receiver side. In the receiver, the transmitted light signal is converted back to electrical signal and outputted to the speaker.**

Index Terms – AGC Design, Filters, Optical Transmitter and Receiver, Signal Level Indicator

INTRODUCTION

The aim of this project is to design Photophone, which is an optical wireless communication system. First, voice signal is given as the input to the system through microphone where microphone driver circuit should be constructed. Since this signal will have very low amplitude, a preamplifier circuit is required. For having stable amplified input, automatic gain control (AGC) circuit is designed. Then comes the multiplexer stage where high frequency signal from signal generator is added to the input. The summed signal will be an input to the laser and received by a phototransistor by using transconductance and transresistance amplifiers. The output of the phototransistor will pass through low-pass and high-pass filters in order to separate mixed signal into voice signal (low frequency) and reference signal (high frequency). While the output of the low-pass filter will be fed to the speaker by passing through the power amplifier circuit, that of high-pass filter will determine the strength of the signal by turning on the RGB LED with different color based on the output of the comparator circuit.

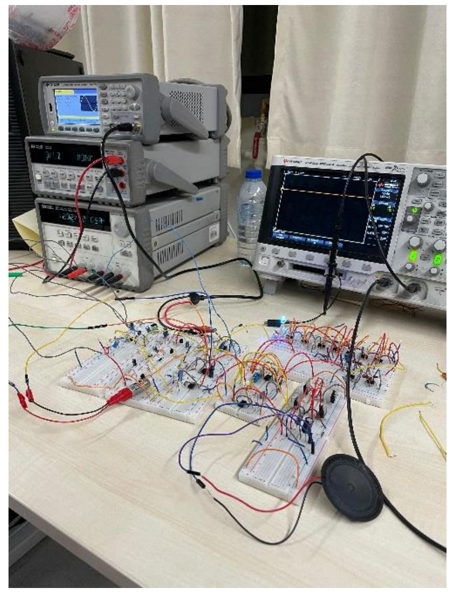

Figure 1: Final Design

PREAMPLIFIER

As mentioned in Introduction, since the output of the speaker is too low to work on, we needed to design a preamplifier by using a simple common emitter amplifier in series with buffer as shown in Figure 2:

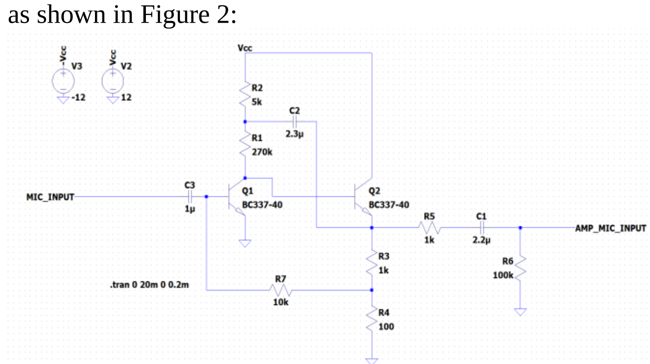

Figure 2: The Schematic of Preamplifier

The output of the preamplifier is provided in Figure 3 below:

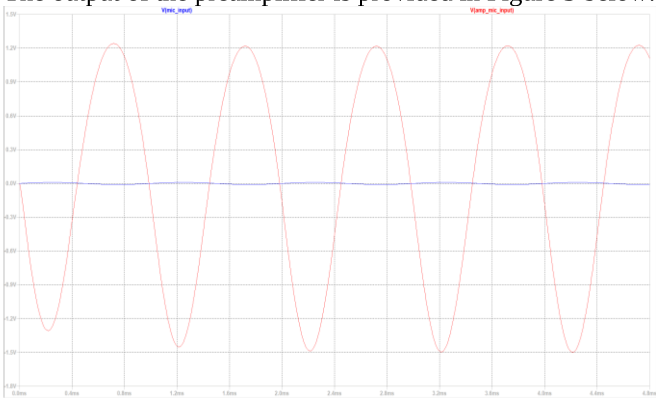

Figure 3:The Output of Preamplifier

AUTOMATIC GAIN CONTROL

- **Reason for using AGC:** The amplitude of sound signal is varying dependent on the distance and the frequency which might lead to clipping at the output. Such a case is not desired therefore we need to design an automatic gain control circuit in order to adjust the gain according to its input to give stable output.
- **Design:** Our design again includes common emitter as main amplifier in series with BJT volage buffer.

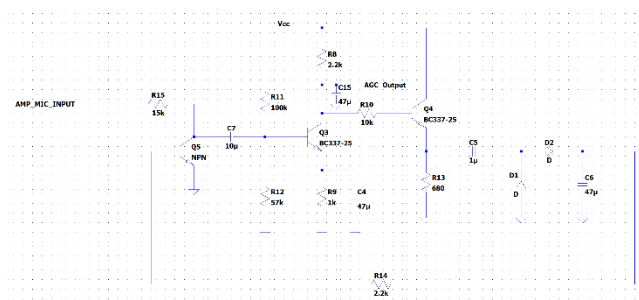

Figure 4: Schematic of AGC

However, this time we added Q5 as seen in Figure 4 which acts as a voltage regulated resistor. The input of AGC goes through the voltage division between R15 and Q5. If the input is high, voltage drop over Q5 decreases which in turn reduces the gain of the overall system or vice versa: if the input is low voltage over Q5 increases, increasing the gain.
The simulation results can be seen in Figure 5 and 6:

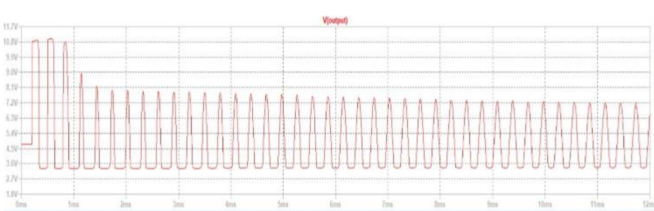

Figure 5: AGC output for 10mV

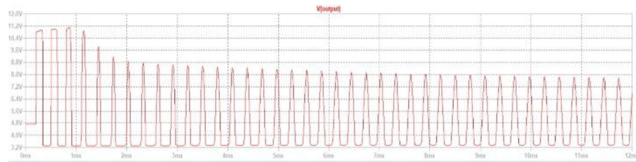

Figure 6: AGC output for 20mV

- **Design Consideration**: At first, there was clipping at the output of AGC circuit in real life observations. We figured out that this due to the high gain we get from the preamplifier stage. In order to solve this, we connected POT instead of R1 in Figure 1 to find the best suitable gain value for which we do not see clipping at AGC

MULTIPLEXER

It was required to sum low frequency sound signal with high frequency reference signal which will bbe given by signal generator. As a reference signal, we used 2.5Vpp and 15kHz frequency. In order to add them, we simply used summing Op-Amp configuration as shown in Figure 7:

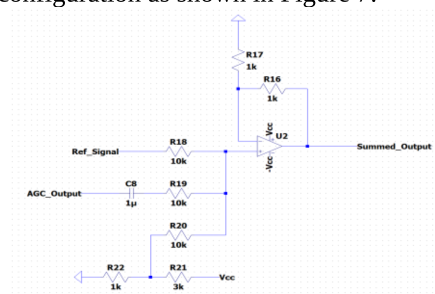

Figure 7: Multiplexer

As it can be seen from Figure 4, we also added DC voltage to the summation. This is for driving the laser which generally acts as a diode and does not let negative voltages pass through it. So we gave DC bias in order to carry all the voltage information above 0V.

TRANSMITTER AND RECEIVER

I. Transmitting with Laser

For driving the laser, one need to convert voltage information to current since laser acts as a diode. For this purpose, we used Op-Amp in transconductance configuration as seen in Figure 8:

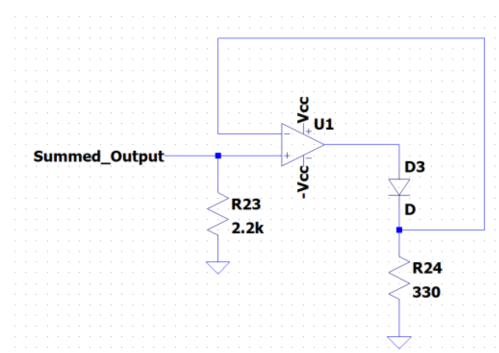

Figure 8: Transconductance Amplifier: Laser Driver

II. Receiving with Phototransistor

For receiver side we tried photodiodes and phototransistors, and it was observed that for our configuration phototransistor works best. To get voltage information back and drive the phototransistor, we designed transresistance amplifier again using Op-Amp as can be seen from Figure 9:

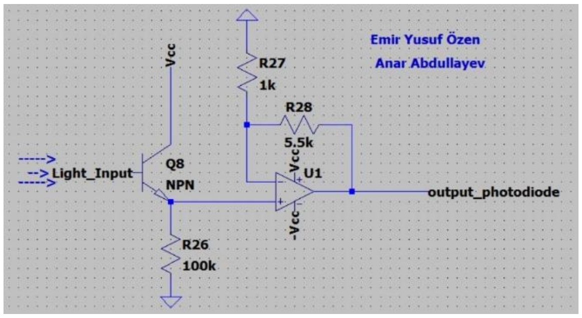

Figure 9: Phototransistor Driving Circuit

FILTERS

Once our multiplexed signal is received at phototransistor, we need to demultiplex the low frequency and high frequency signals by using corresponding filters. In general, we used Butterworth filters and chose the order as 3 since they are more representative of ideal filters.

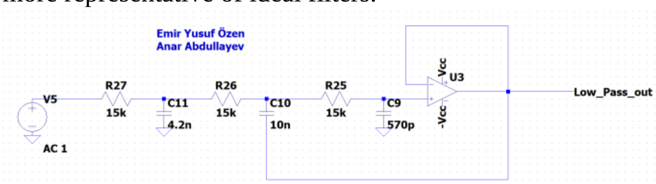

Figure 10: Low Pass Filter

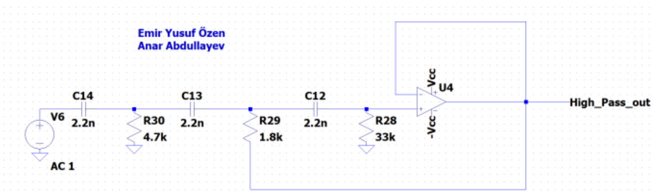

Figure 11: High Pass Filter

Simulation results for Figure 10 and 11 are given in Figure 12 and 13 respectively:

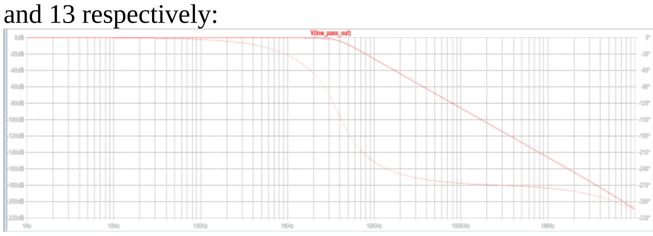
Figure 12: Simulation Result for Low Pass Filter

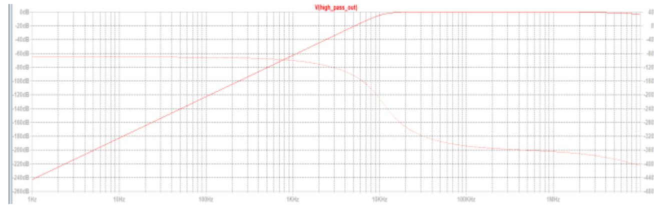
Figure 13: Simulation Result for High Pass Filter

In the Analog Lab, we also made real life analysis of filters by using BenchVue:


Figure 14: BenchVue Results for Low Pass Filter


Figure 15: BenchVue Results for High Pass Filter

As it can be seen from the results that our gain is 0 dB corresponds to gain of 1 V/V. The low pass filter has the cut of frequency of 3.4 kHz, and the cutoff frequency for high pass filter is 10 kHz.

POWER AMPLIFIER AND SPEAKER

To supply desired watt to speaker, signal coming from low pass filter must be amplified. Also impedence matching is needed. Since it is realy smal signal, we must use kind of

We designesignald Class AB which is combination of Class A and Class B amplifiers. Thanks to that, Class AB amplifier has lower distortion(prevents the crossover distortion) than Class B and has higher efficiency than Class A so it does not suffer from poor efficiency or high distortion. Class AB have push-pull configuration which is npn-pnp complimentary pairs. We used TIP41-A and TIP42-C which are power transistors. In order to obtain desired gain, we need higher current flow through the transistors and this can be achieved by using power transistors. Left side of amplifiers which we designed corrsponds to buffer. Moreover, we solved opening voltage problem of transistors which cause crossover distortion by using resistors. Generally this problem solved by using diodes but we designed that circuit and it worked very well. Another important design consideration is transistor must be matching.

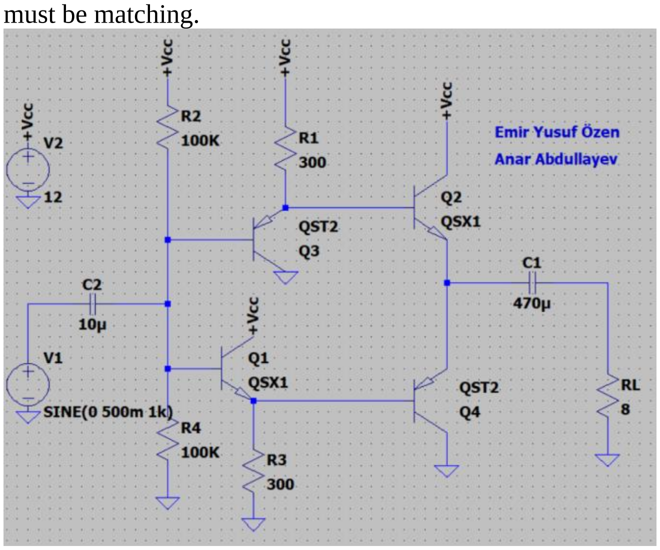

Figure 16: Schematic of Power Amplifier

Peak Detector

We constructed Peak Detector Circuit since we have AC voltage waveform coming from high pass filter and we must convert it to DC voltage waveform which will be common input in the next stage signal level indicator .

We constructed Peak Detector Circuit since we have AC voltage waveform coming from high pass filter and we must convert it to DC voltage waveform which will be common input in the next stage signal level indicator.

While designing peak detector circuit, firstly we consider simplest peak detector design which is series connection one diode and one capacitor. Since voltage drop across the diode occurs problems to detect peak values, we used super-diode which has not voltage drop across the diode and consist of one diode and one op-amp an done capacitor. Also, we connected Rin in order to discharged capacitor when diode is not conducting and we add buffer between Rin and super-diode. Still it has not finished because when diode is not conducting Op-Amp goes to negative saturation and that limits the operating frequency range of peak detector. This problem avoided by using modified peak detector as you can see in Figure 17:

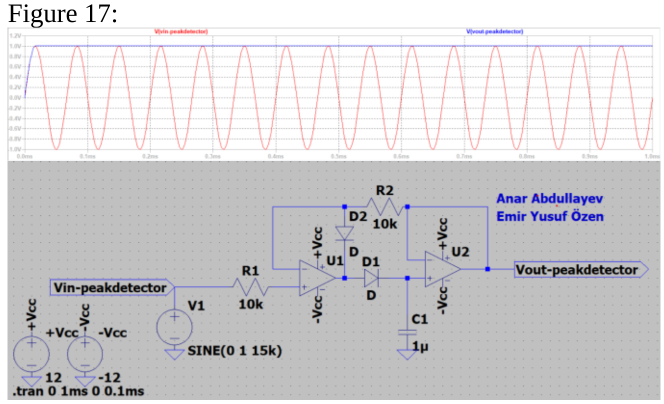

Figure 17: Schematic and Simulation of Peak Detector Circuit

Signal Level Indicator

To evaluate strength of the signal coming from high pass and then peak detector, we used comparator op-amps. We used voltage division on reference signal(it is +5V for us) by using five equal resistors and we obtained 5 different voltage values of that signal. All of these different signals go to the inverting port of the comparators. Input of Non inverting port of comparators are the same which is the signal coming from high pass and peak detector. We design comparator circuit to obtain 3 different signals since RGB led four legs and three of them connected these 3 different signals outputs in order to indicate strength of the high pass signal by using different color combinations (No Signal: Green, Weak Signal: Cyan, Moderate Signal: White, Good Signal: Magenta, Excellent Signal: Blue) and also other cathode leg connected to the ground. We used cathode RGB since we have postive voltage value and it is matching with the direction of diodes as you can see in Figure 18:

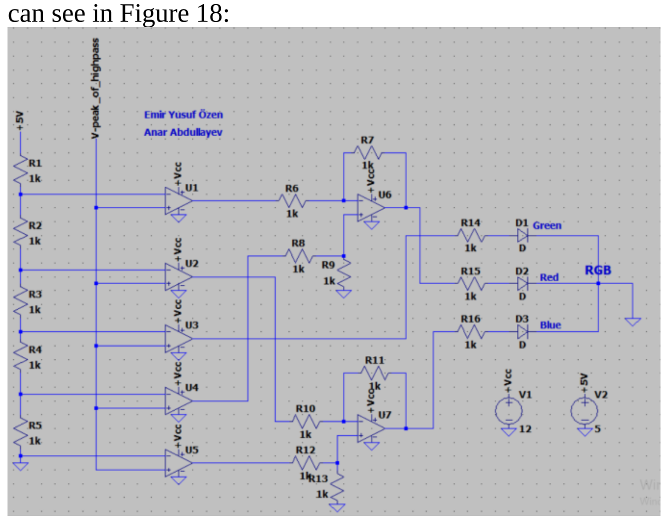

Figure 18: Schematic of Signal Level Indicator

Conclusion

By way of conclusion, we explained how Photophone design works by providing both simulation and real life results.

In general, we spent more time on receiver side than transmitter one. Transmitter unit worked successfully without much problem.

In the receiver side, most of our time was spent on the power amplifier and signal level indicator.

Overall, the demo was successful.

References

[1] Storr, W. (2016, April 29). Class AB Amplifier Design and Class AB Biasing. Basic Electronics Tutorials. https://www.electronics-tutorials.ws/amplifier/class-ab-amplifier.html

[2] Teja, R. (2024, July 11). Butterworth Filter Circuit Design and Applications. ElectronicsHub. https://www.electronicshub.org/butterworth-filter/.

.