EE214 ELECTRONIC CIRCUITS LABORATORY
2021 – 2022 SPRING TERM PROJECT
FINAL REPORT

Kemal Atacan Mucukgil 2443588 - Onur Emirhan Çon 2304384

Abstract – In this project report, first of all, a short introduction is made in order to explain the goal of the project. After that; the block diagram is shown, circuit sub-block diagrams are shown, circuit sub-block operation principles are explained, and formulas used in the project are given, simulation results and the test results are provided and compared. Second, selection of the equipment is explained. Third, power consumption of the circuit is mentioned. Finally, comments and conclusions are made

Introduction

The aim of this project is to design a circuit that generates sinusoidal signals at different frequencies, sums these frequencies, filters the desired frequency and plays the received signal with a speaker. This project will be implemented in 3 sub-blocks: transmitter unit, receiver unit and speaker unit. In the transmitter unit, 12 sinusoidal signals with different frequencies will be generated and summed up. In the receiver unit, the signal with the desired frequency will be filtered and all the other signals will be suppressed. The receiver unit is tunable with potentiometers in order to filter different frequencies. After the filtering is done, the obtained signal will be passed on to the speaker unit to be played. The speaker unit will contain a speaker and its driver circuit. In this project OP-AMPs, resistors, capacitors, transistors, potentiometers and speakers are used.

Some of the design specifications for this project

- In the transmit unit 12 different frequencies (1 kHz, 2 kHz, 3 kHz, 5 kHz, 6 kHz, 7 kHz, 9 kHz, 10 kHz, 11 kHz, 13 kHz, 14 kHz and 15 kHz) are generated.
- In the receiver unit, the magnitude difference of the desired channel to other channels should be at least 10 dB.
- The channel adjustment should be provided by adjusting at most 2 POTs.
- The speaker unit outputs the desired frequency channel at audible levels.

Design Formulation

As mentioned above, this project consists of three main parts. In this section, these parts are going to explained.

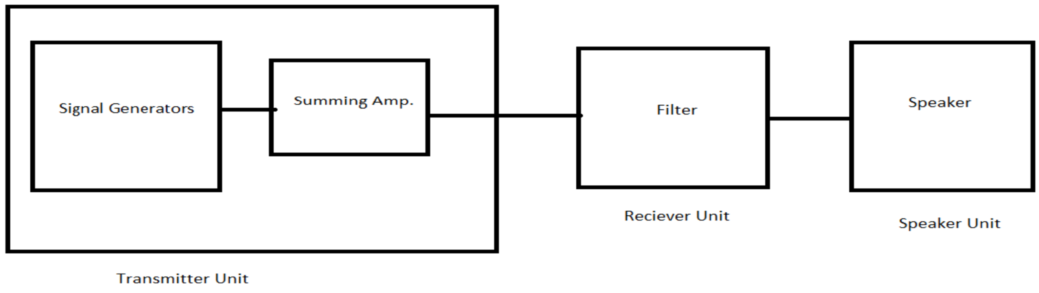

Figure 1: Block diagram of the circuit

The Transmitter Unit

The purpose of the transmitter unit is to generate 12 different sinusoidal waves which have 1, 2 3, 5, 6, 7, 9, 10, 11, 13, 14 and 15 kHz frequencies. Since a square wave consist of sinusoidal waves, we decided to generate square waves. General formula of a square wave is given below.

$$\begin{aligned} x(t) &= \frac{4}{\pi}\sum_{k=1}^{\infty}\frac{\sin(2\pi(2k-1)ft)}{2k-1} \\ &= \frac{4}{\pi}\left(\sin(\omega t)+\frac{1}{3}\sin(3\omega t)+\frac{1}{5}\sin(5\omega t)+\ldots\right), \qquad \text{where } \omega = 2\pi f. \end{aligned}$$

Equation 1

As can be seen from the Equation 1, 1 kHz square wave include the odd frequency sinusoidal waves which are 1, 3, 5, 7, 9, 11, 13 and 15 kHz and 2 kHz square wave includes the even frequency sinusoidal waves which are 2, 6, 10 and 14 kHz. Therefore, we decided to generate and sum 1 and 2 kHz square waves.

In order to generate the square waves, we used the square wave generator circuit which is shown below.

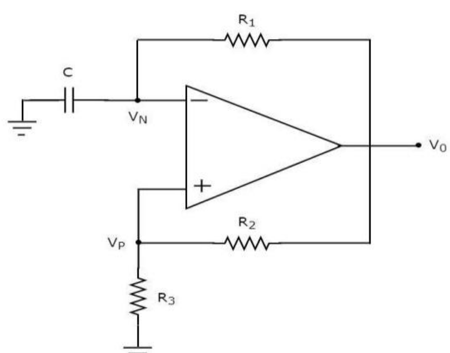

Figure 2: Square Wave Generator

The circuit shown in Figure 1 generates square waves with the frequency

$$f = \frac{1}{2RCln(\frac{2R3 + R2}{R2})}$$

Equation 2

To simplify the Equation 2, we need to choose the R2 = 1.16R3 which makes the ln term 1. So, we chose the R2 = 12 kΩ and R3 = 10 kΩ. As a result, the Equation 2 is simplified to

$$f = \frac{1}{2RC}$$

Equation 3

We used 6.8 nF capacitors therefore the R1 values for 1 and 2 kHz are calculated as 73.5 kΩ and 36.7 kΩ respectively. In order to adjust to frequencies precisely, we used 100 kΩ pots as R1. Since the square wave generator generates the signal with large peak to peak amplitude (from -sat to +sat) we divide the square waves. After the division, we sum the square waves and transmit the final signal to the receiver unit with the help of op-amp buffer. Final schematic of the transmitter unit and the simulation results are given below.

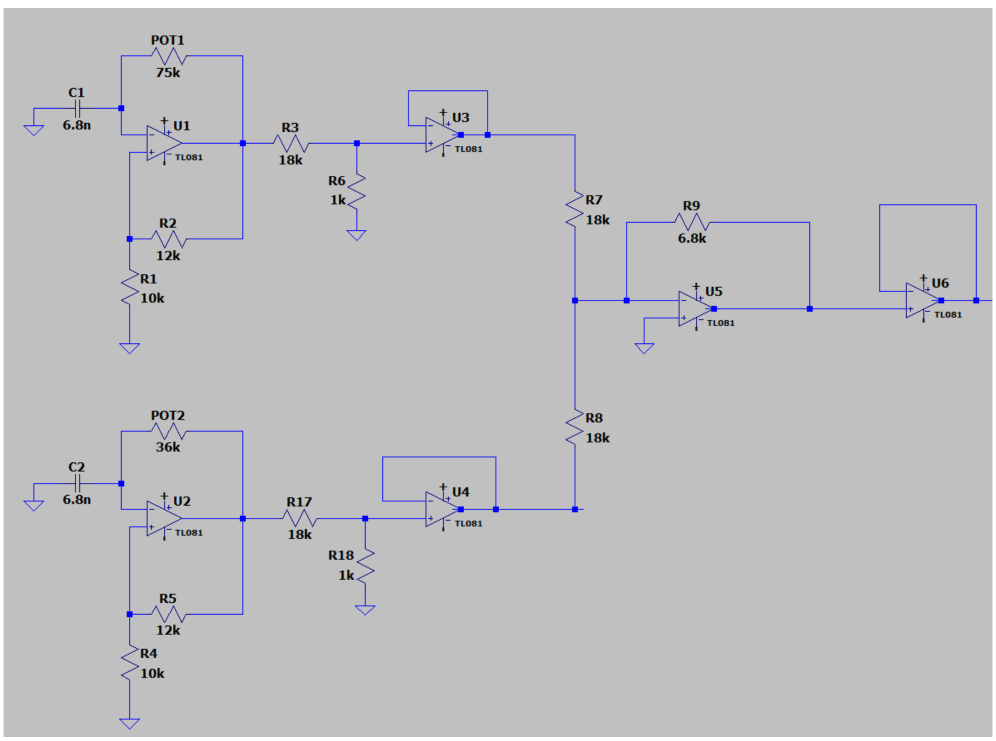

Figure 3: Schematic of the Transmitter Unit

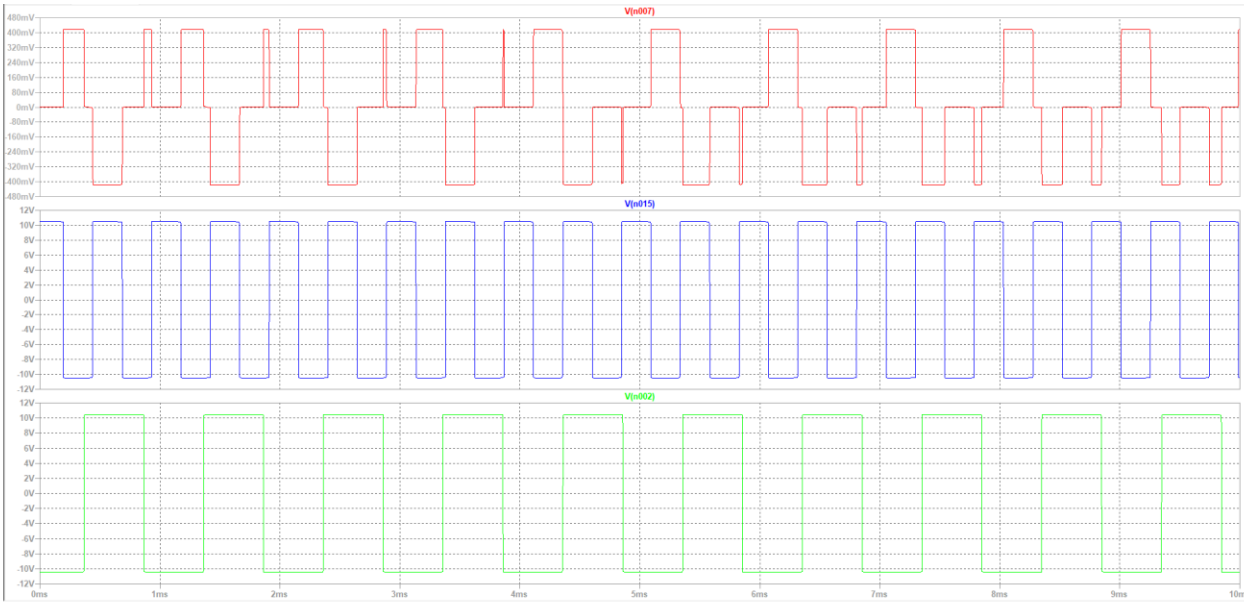

Figure 4: Output of the 1 kHz Generator (Green), 2 kHz Generator (Blue) and the Summing Amp (Red)

The Receiver Unit

In the receiver unit, the sinusoidal signals generated in the transmitter unit will be filtered in order to obtain the desired signal. For this purpose, we have to use a filter circuit and for this project a KHN biquad(second-order) filter will be used. This type of filter can give low-pass, band-pass and high pass outputs at the same time.

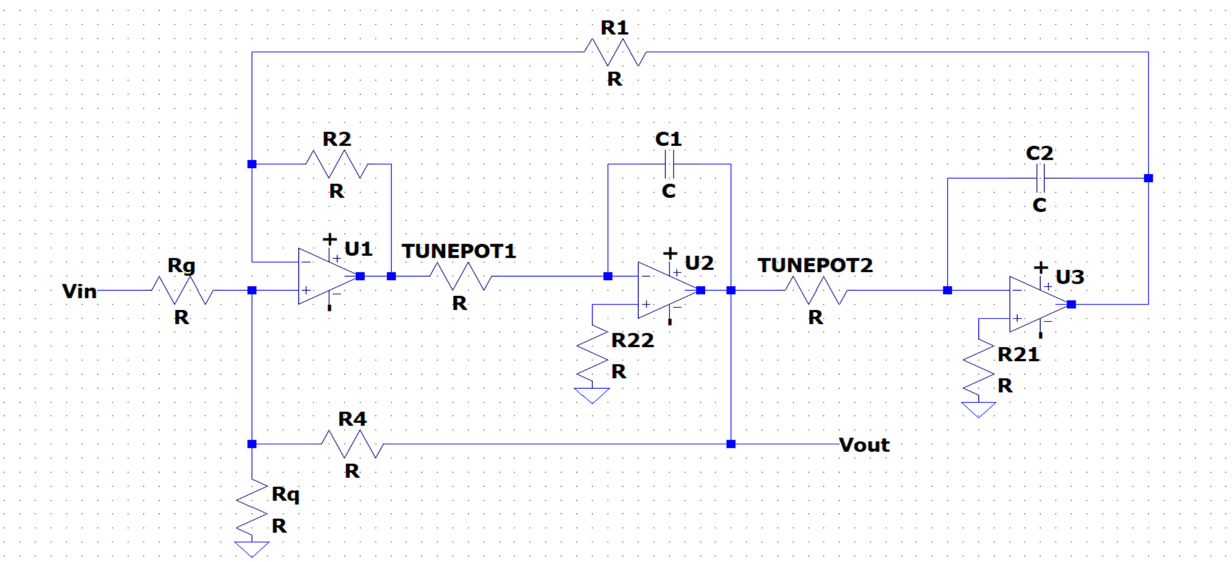

Figure 5: KHN Biquad filter

The first OP-AMP acts as a summing amplifier and its output is high-pass output. The second OP-AMP acts as an integrator and its output is band-pass output which is the one we will use. The third and the last OP-AMP also is an integrator and its output is low-pass output. We use this filter type because it can provide Q (quality factor) values higher than 10 and the center frequency (the frequency we are trying to filter) can be adjusted independently from the Q value. In order to adjust the center frequency, we need to change the values of two potentiometers; TUNEPOT1 and TUNEPOT2. To simplify the design process and find the necessary component values easily, we can make the following assumptions;

$$TUNEPOT1 = TUNEPOT2 = Rf$$

$$C1 = C2 = C$$

$$R1 = R2$$

After making these assumptions we can find the center frequency and the Q value by making the following calculations.

$$Fc = \frac{1}{2\pi(Rf)C}$$

Equation 4

$$Q = (1 + \frac{R4}{Rq})(\frac{1}{2 + \frac{R1}{Rg}})$$

Equation 5

The resistors R22 and R21 are used for bias compensation and their values can be chosen as equal to R1 and R2.

For our circuit we chose a Q value of 11.33. The reason why we didn't choose a higher Q value is that Q value of 11.33 is good enough for the 10db suppression and high Q values tend to make the circuit unstable and cause unwanted oscillations instead of filtering. After choosing our Q value we then chose R1, R2 and Rg as 1kΩ as. Choosing Rg the same value as R1 and R2 further simplifies the equation and leaves us with the equation

$$11.33 = \left(1 + \frac{R4}{Rq}\right)(\frac{1}{3})$$

Equation 6

After finding this equation for simplicity's sake we chose Rq as 1kΩ and the R4 value was calculated as 33 kΩ.

For this project we were tasked with filtering 1k, 2k, 3k, 5k, 6k, 7k, 9k, 10k, 11k, 13k, 14k, 15kHz signals. So our maximum center frequency will be 15kHz and our minimum center frequency will be 1kHz. To determine the potentiometer value, we will use we first need to determine the value of the capacitor and for this circuit we used 15nF capacitors. After determining the capacitor value, in order to find the potentiometer value, we will look for the highest theoretical resistance value for Rf using the Equation 4 and that is 10610Ω for 1 kHz center frequency. Since the highest possible resistance value is around 10 kΩ we used a 15 kΩ POT for Rf (TUNEPOT1 and TUNEPOT2). Final design of the circuit and simulation results for different POT values are given below.

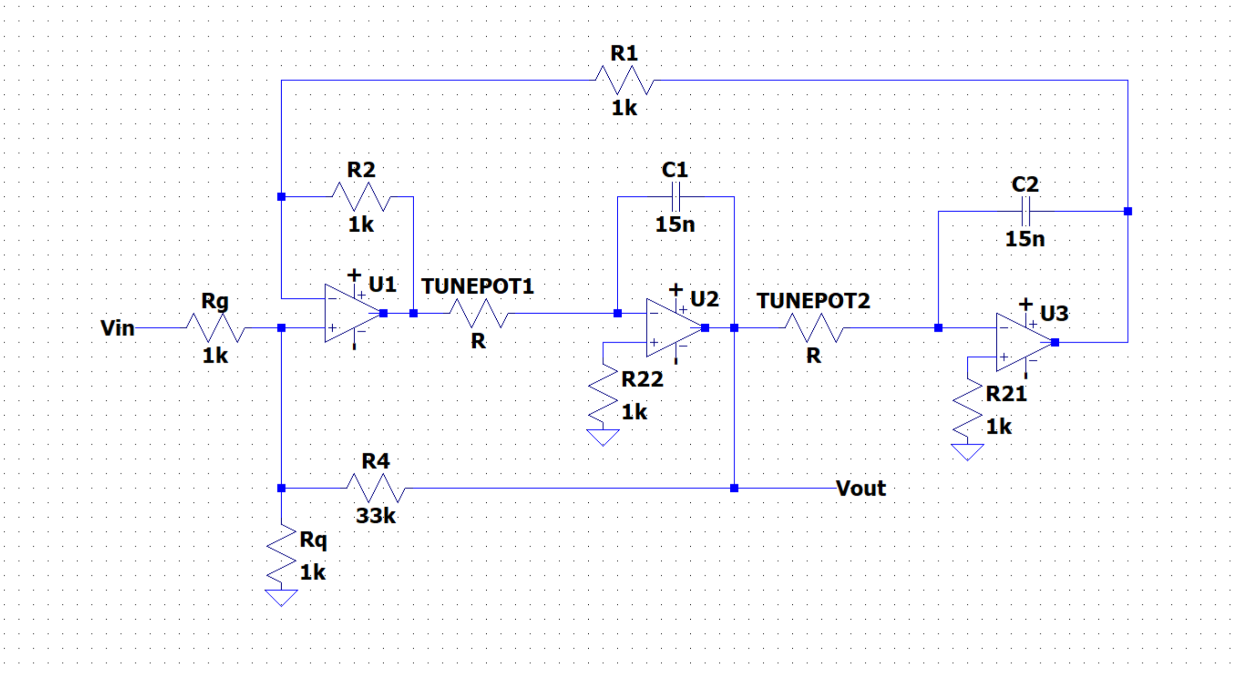

Figure 6: The receiver unit after the design is complete

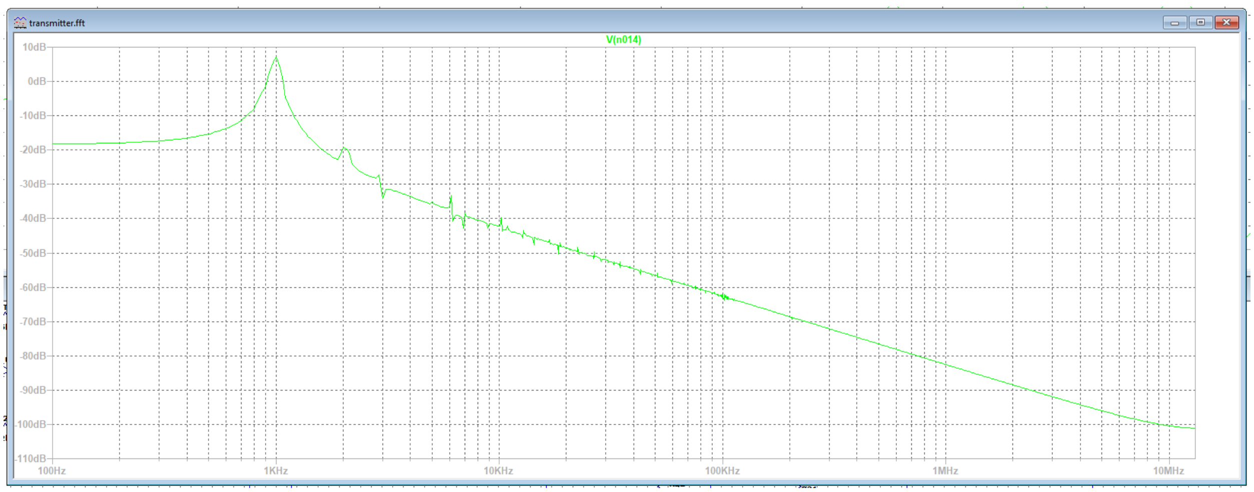

Figure 7: FFT of the output when Rf=10610 Ω and Fc=1kHz

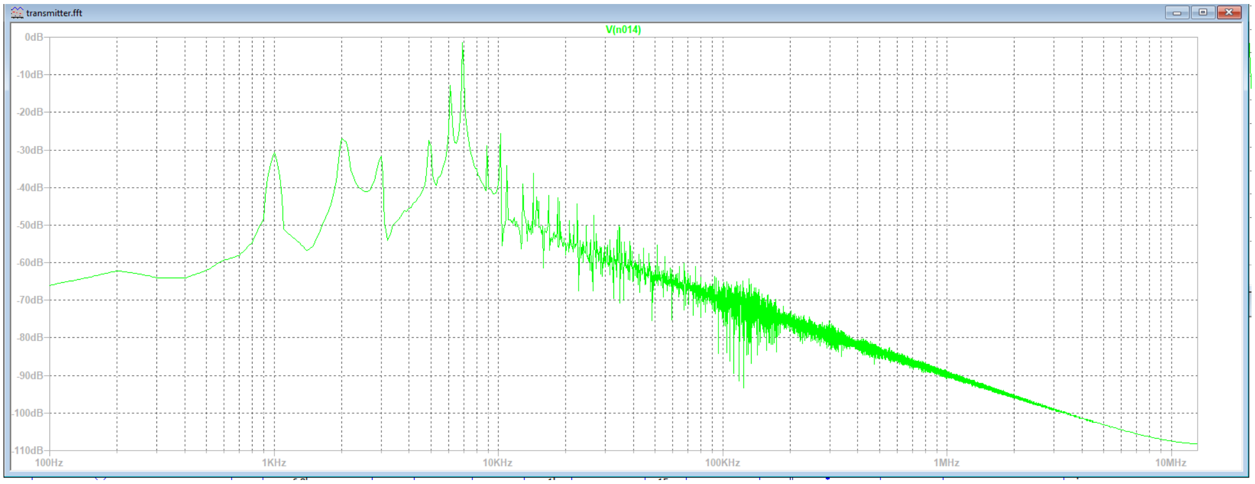

Figure 8: FFT of the output when Rf=1515 Ω and Fc=7kHz

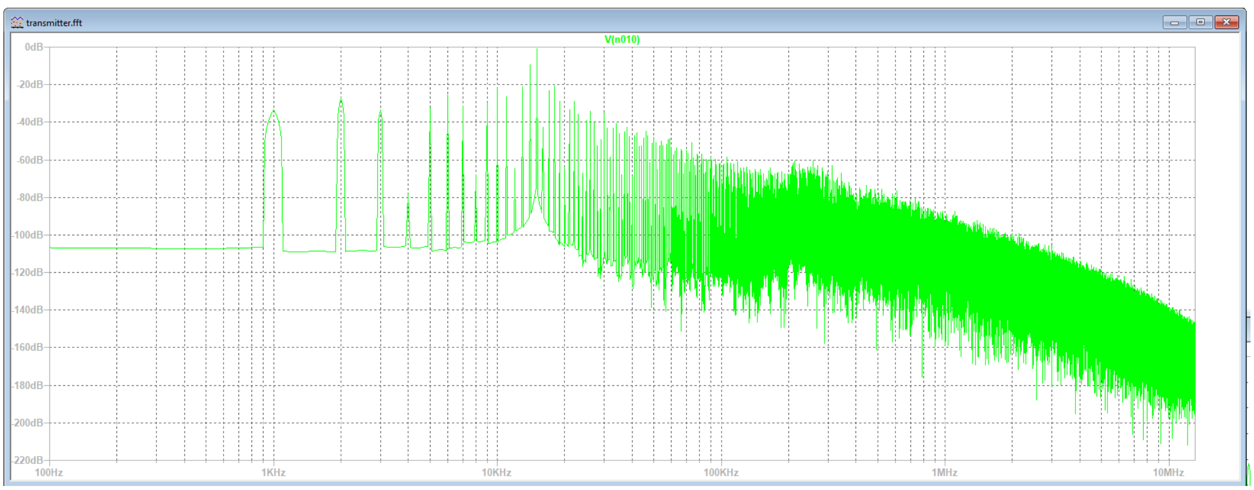

Figure 9: FFT of the output when Rf= 707Ω and Fc=15kHz

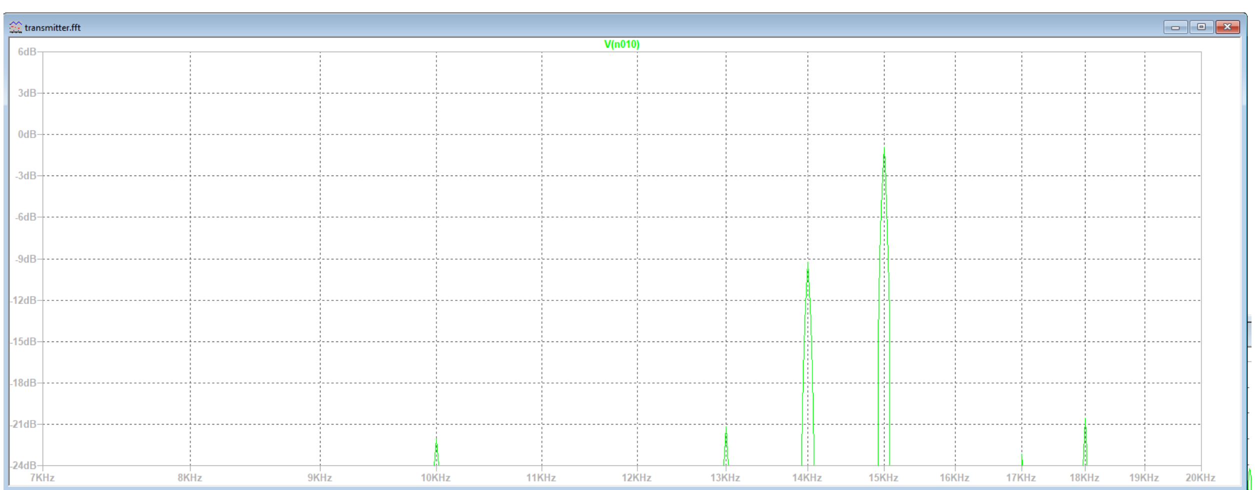

Figure 10: Zoomed in FFT of the output when Rf= 707Ω and Fc=15kHz

From these simulation results we can see that the receiver unit is working as intended and filtering the sinusoids according to the design specifications.

The Speaker Unit

The project requires an audio output. In order the get the audio output we design the speaker unit. Since speakers have very low resistance (nearly 5-10 Ω), directly connecting the speaker to the output of the receiver unit is fails. Therefore, a driver circuit is needed. We used a BJT amplifier circuit, which matches the impedances. The resulting circuit is given in the following figure.

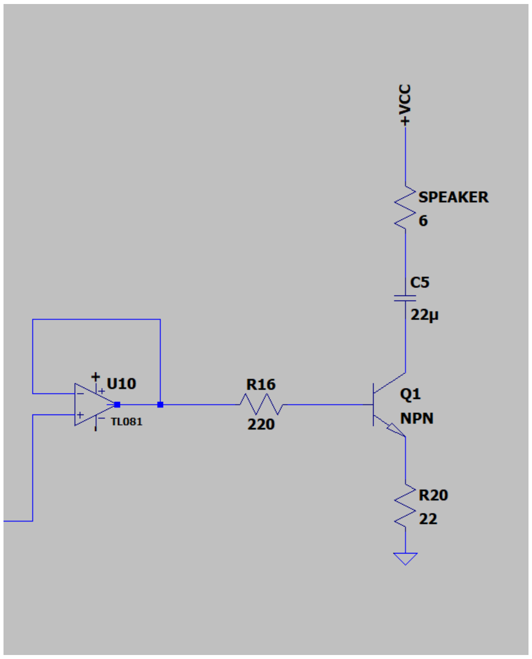

Figure ….: Speaker Unit

Selection of the Equipment

All resistors are 0.25W standard resistors since none of the resistors needed to carry high current.

Trim pots are used in square wave generators. Because once they are adjusted, they don't get affected from outside easily.

10 kΩ double pot is used in filter because we needed 2 pots which have adjustable resistance between 700 Ω and 10.6 kΩ. Adding 680 Ω resistance to the pot we get an adjustable resistance between 680 Ω and 10.68 kΩ. Moreover, using double pot has saved us from trying to adjust two different pots to the same value.

Nonpolar capacitor used for transmitter and receiver unit, and polar capacitor is used for speaker unit because finding them is easy.

TL081 op-amps are used for transmitter unit since they are fast op-amps which enables us to get square waves with higher slew rates.

Since TL081 is expensive, LM741 is used for the rest of the circuit.

BC546 is used as NPN transistor since it is very cheap and easy to find.

6 Ω 0.5 W speaker is used in speaker unit.

Cost Analysis

Resistors and jumpers are not included to this cost analysis since they are very cheap, and we already have them.

- Trim Pot 2x5 TL = 10 TL
- Double Pot 1x10 TL = 10 TL
- Speaker 1x10 TL = 10 TL
- BC546 1x1 TL = 1 TL
- Capacitor 5x1 TL = 5 TL
- TL081 6x10 TL = 60 TL
- LM741 4x5 TL = 20 TL
- Breadboard 2x25 = 50 TL

Overall Cost = 166 TL

Power Analysis

While testing the circuit at the laboratory, we arranged the -25V supply to -12V and +25V supply to +12V. We recorded the output currents from the power supplies as 10 mA and 280 mA respectively. As a result, the total absorbed power from the circuit P = (12*10) + (12*280) mW = 3.5 W.

Comment and Conclusion

In this project we were able to complete the task and design a circuit that generates and sums 12 sinusoidal waves, filters the sinusoidal wave with the requested frequency and plays the tone with the help of a speaker. The circuit we made is similar to a FM radio in the sense that this circuit is able to filter and play a specific frequency from a range of frequencies. While making this project we faced a series of challenges. To overcome these challenges, we had to follow a different line of thought than what we have previously done in the lab sessions as in this project we were asked to design every part of this circuit from scratch unlike in lab sessions where we were given clues about how to proceed with the task. So we had to analyze the design task part by part and then combine all the sub-parts. This turned out to be a really valuable experience. To determine the component values we used both theoretical calculations and simulation programs and when constructing the circuit in lab we made some corrections because of the errors caused by unideal experimenting conditions. We have completed and presented the project.