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EE 202 Section 1

EEE 202 CIRCUIT THEORY

LAB 5

Software Implementation

In this lab experiment it is expected to design a band-pass filter with some specifications for a 50Ω load resistance. To convenience and use the skills gained in the previous semester, designed band-pass filter will be a Butterworth band-pass filter. The specification of the filter is given below, and frequency response is given in figure-1.

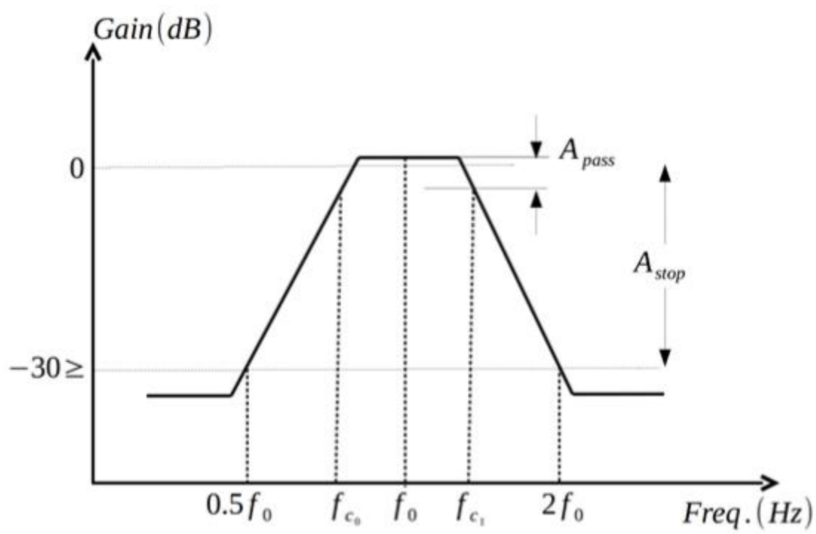

Figure 1: Response of filter to different frequencies

$Central\ frequency$: $1Mhz \leq f_0 \leq 4Mhz$

$Passband\ width$: $f_{c_0} - f_{c_1} = \Delta f = 0.05 f_0$

$Gain\ variation\ in\ the\ passband$: $A_{pass} \leq 3dB$

$Stopband\ attenuation$: $A_{Stop} \geq 30dB$

According to given specifications, first of all the order of the filter must be determined. To determine the order of the filter, transducer gain formula for band-pass Butterworth filter below will be used.

$$G_T = \frac{P_L}{P_A} = \frac{1}{1 + (\frac{f_0}{\Delta f})^{2n} * (\frac{f}{f_0} - \frac{f_0}{f})^{2n}}$$

Let's choose central frequency (f_0) as 3Mhz which is in the range. Pass band width (Δf) becomes 150Khz according to specifications. Now let's determine the order keeping in mind Stopband attenuation (at $f_0/2$ or $2f_0$) is bigger than 30dB.

$$10 * \log_{10}(\frac{P_L}{P_A}) = 10 * \log_{10}\left(\frac{1}{1 + \left(\frac{f_0}{\Delta f}\right)^{2n} * \left(\frac{f}{f_0} - \frac{f_0}{f}\right)^{2n}}\right) \leq -30$$

Simplifying the equation above,

$$\log_{10}\left(1 + \left(\frac{f_0}{\Delta f}\right)^{2n} * \left(\frac{f}{f_0} - \frac{f_0}{f}\right)^{2n}\right) \geq 3$$

$$1 + \left(\frac{f_0}{\Delta f}\right)^{2n} * \left(\frac{f}{f_0} - \frac{f_0}{f}\right)^{2n} \geq 10^3$$

$f_0 = 3Mhz, \Delta f = 150Khz, f = 1.5Mhz \; or \; f = 6Mhz$

$$\left(\frac{6Mhz}{150\text{Khz}}\right)^{2n} * \left(\frac{6Mhz}{3Mhz} - \frac{3Mhz}{6Mhz}\right)^{2n} \geq 999$$

$$(30)^{2n} \geq 999$$

$$n \geq 1.153$$

Since n is bigger than 1.153 let's choose it 2. Therefore, the order of the filter is 2.

Now, to design a band-pass Butterworth filter, first of all a 2nd order low pass filter with cut-off frequency Δf=150Khz must be designed.

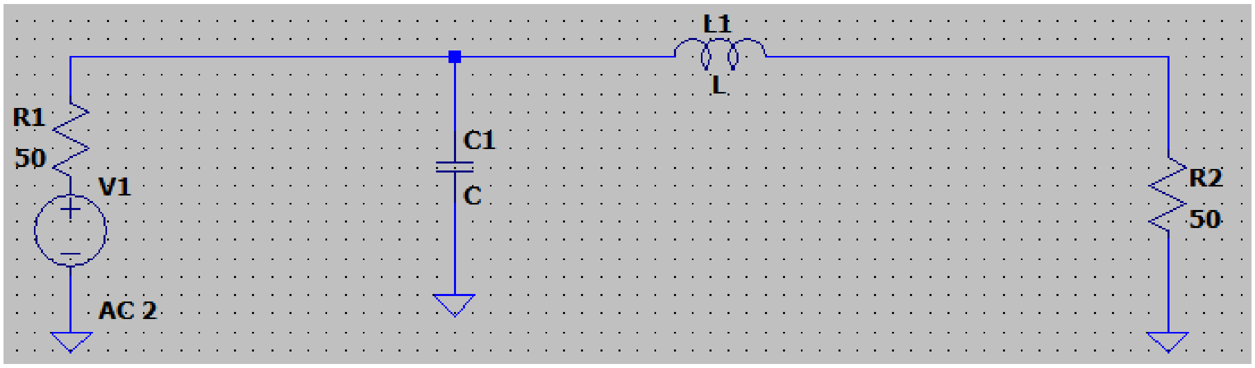

Figure 2: 2nd order low pass filter

The values of C and L must be found. Using the formulas below they can be found easily.

$$C_i = \frac{\mathrm{b_i}}{2\pi \mathrm{R} f_C} = \frac{1.412}{2\pi * 50 * 150Khz} = 29.96nF$$

$$L_i = \frac{\mathrm{b_i R}}{2\pi f_C} = \frac{1.412 * 50}{2\pi * 150Khz} = 74.909\mu H$$

$\mathrm{b_i}$ values are taken from the table below (Table 1).

n	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8
1	2.000							
2	1.4142	1.4142						
3	1.0000	2.0000	1.0000					
4	0.7654	1.8478	1.8478	0.7654				
5	0.6180	1.6180	2.0000	1.6180	0.6180			
6	0.5176	1.4142	1.9319	1.9319	1.4142	0.5176		
7	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450	
8	0.3902	1.1111	1.6629	1.9616	1.9616	1.6629	1.1111	0.3902

Table 1: Prototype values in Butterworth filters according to orders

Now, to design band-pass filter we need to add 2 more component that tune the components at 3Mhz to make the filter's center frequency 3Mhz.

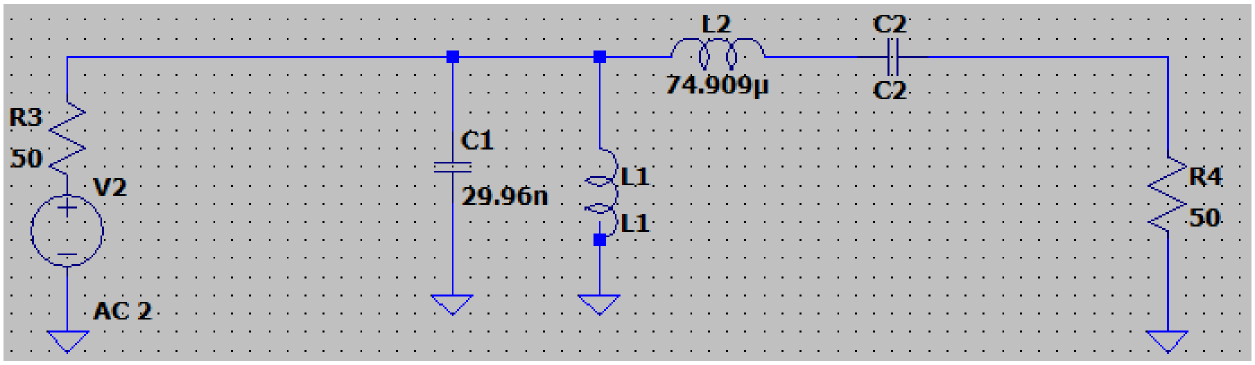

Figure 3: Band-pass Butterworth filter schematic

By tune the components at 3Mhz the unknown valued components will be found.

$$L_1 = \frac{1}{(2\pi * f_0)^2 * C_1} = 93.94nH$$

$$C_2 = \frac{1}{(2\pi * f_0)^2 * L_2} = 37.57pF$$

According to results the final design is given below in figure 4

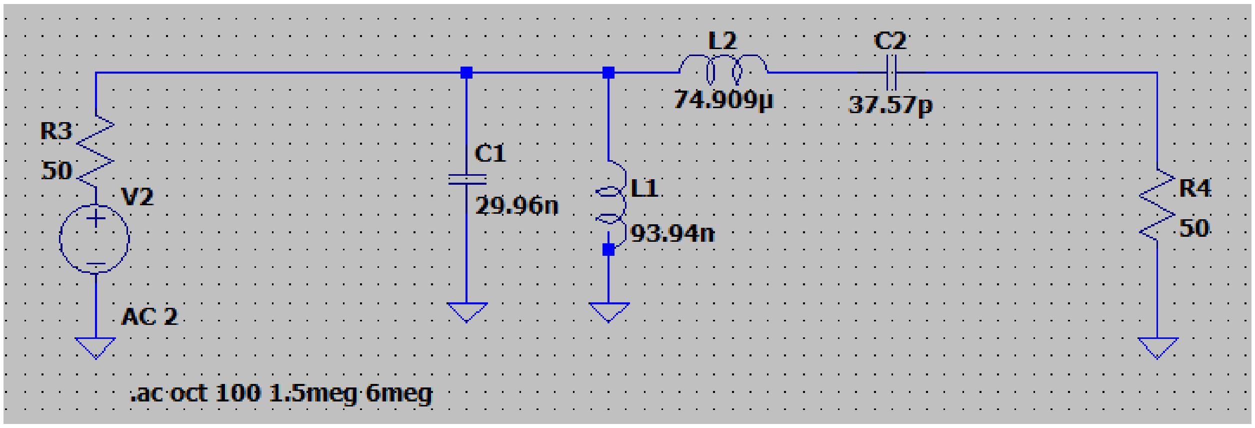

Figure 4: Final Band-Pass Butterworth Filter

The simulation results of the filter in figure 4 are given below.

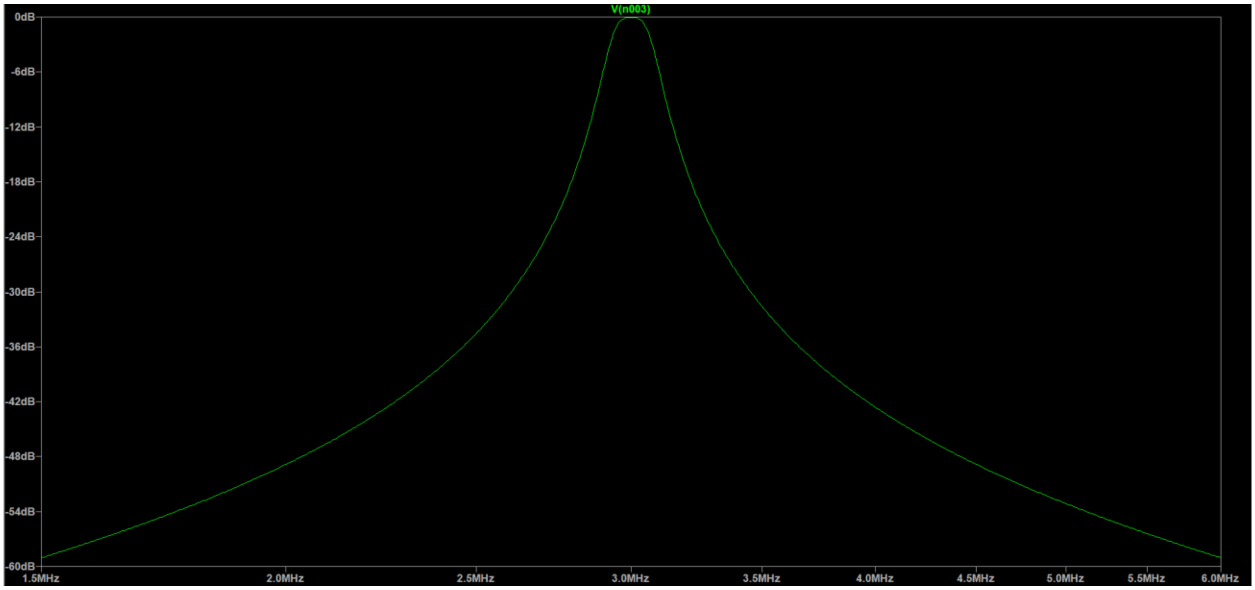

Figure 5: Simulation result in the wanted range

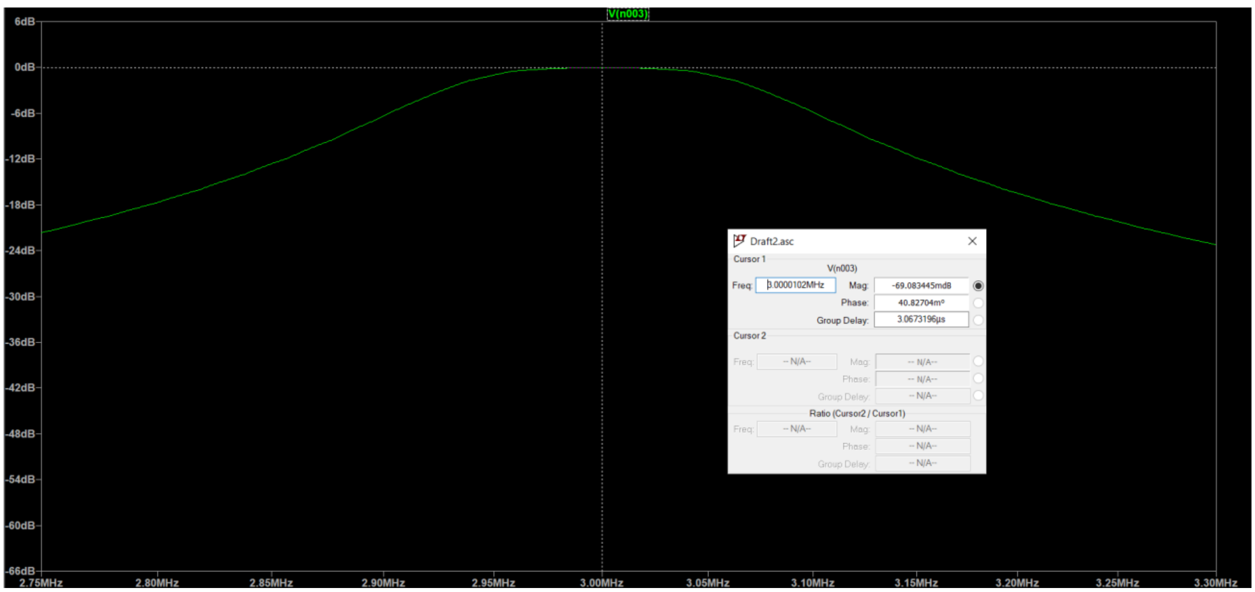

Figure 6: Simulation Result that shows center frequency

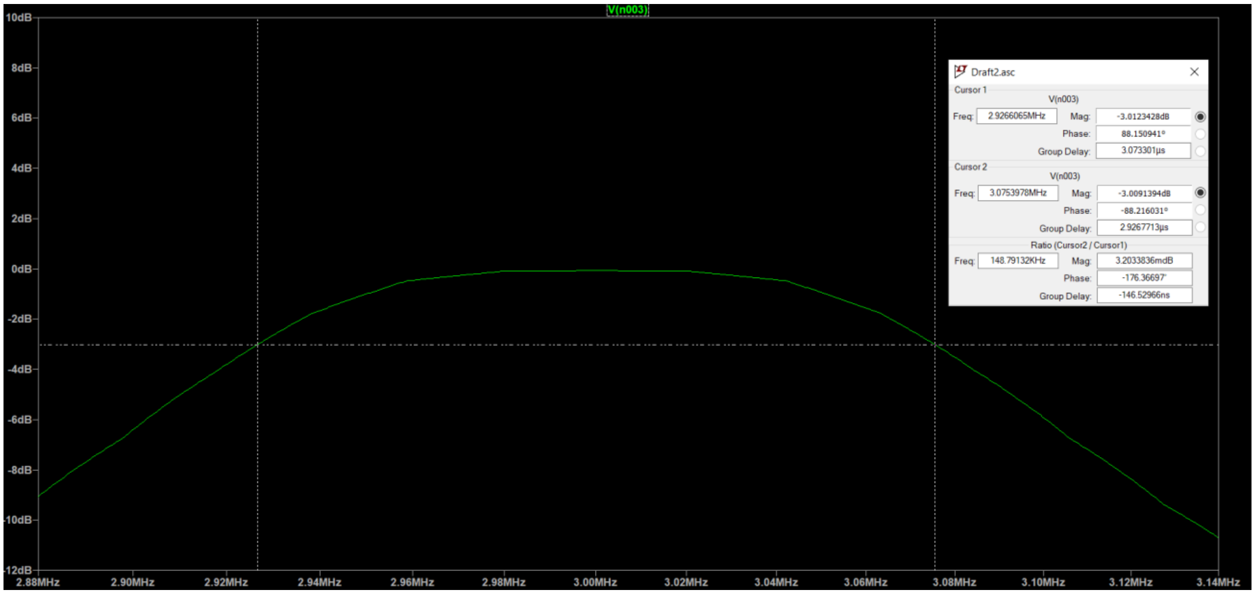

Figure 7: Simulation Result that shows pass-band width and -3dB frequencies

Expected -3dB frequencies were 3Mhz±150Khz/2 = 3.075Mhz and 2.925Mhz.

Hardware Implementation

In the hardware implementation part same filter is used for convenience. Since there is no bode plot function in oscilloscopes, gain is calculated at 10 different frequencies and the results are saved and plotted.

To calculate the gain the formula below will be used at different frequencies.

$$G_{T_{dB}} = 10 * \log_{10}(\frac{P_L}{P_A}) = 20 * \log_{10}(\frac{V_{out}}{V_{in}})$$

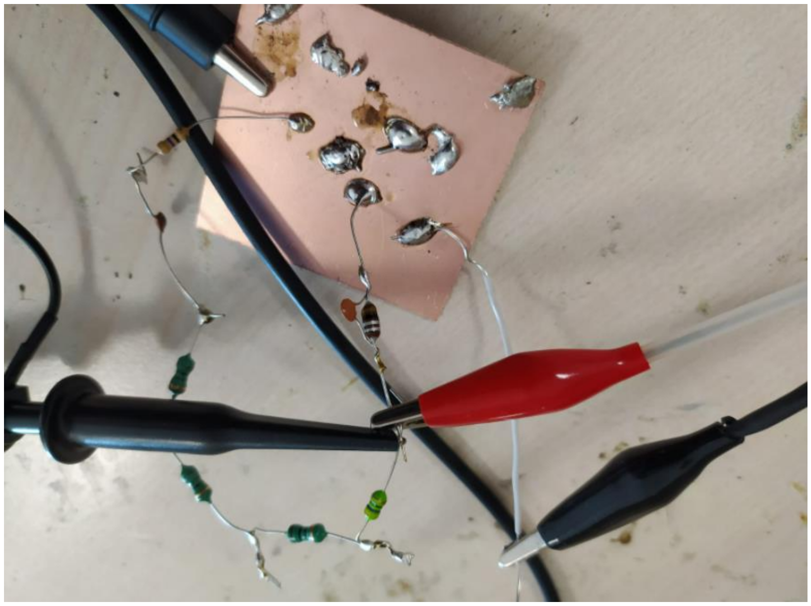

Figure 8: Real Life Implementation of the Filter Circuit

The results of the circuit in Figure 8 in given below for 11 different frequencies.

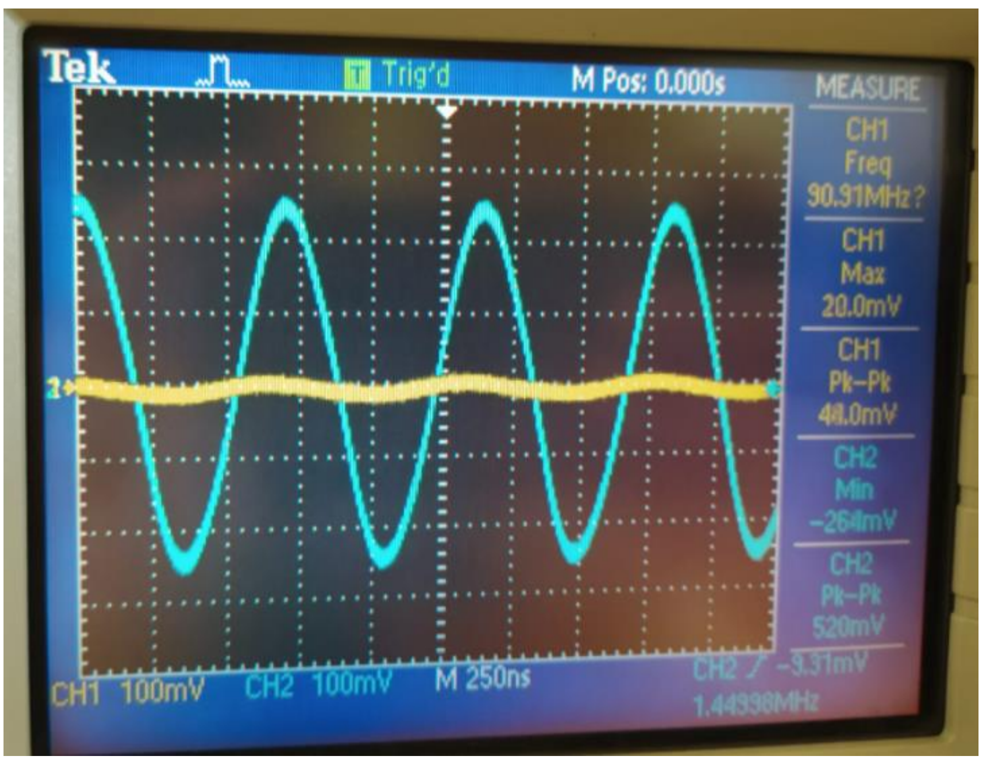

Figure 9: Result of 1.45Mhz input frequency, $f_0/2$

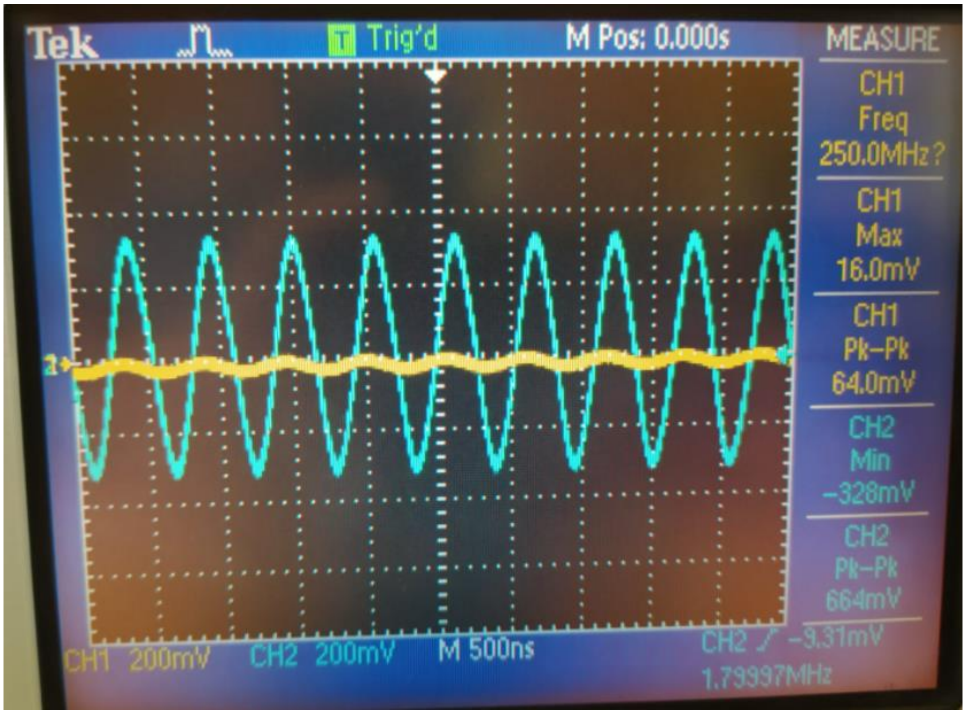

Figure 10: Result of 1.8Mhz input frequency

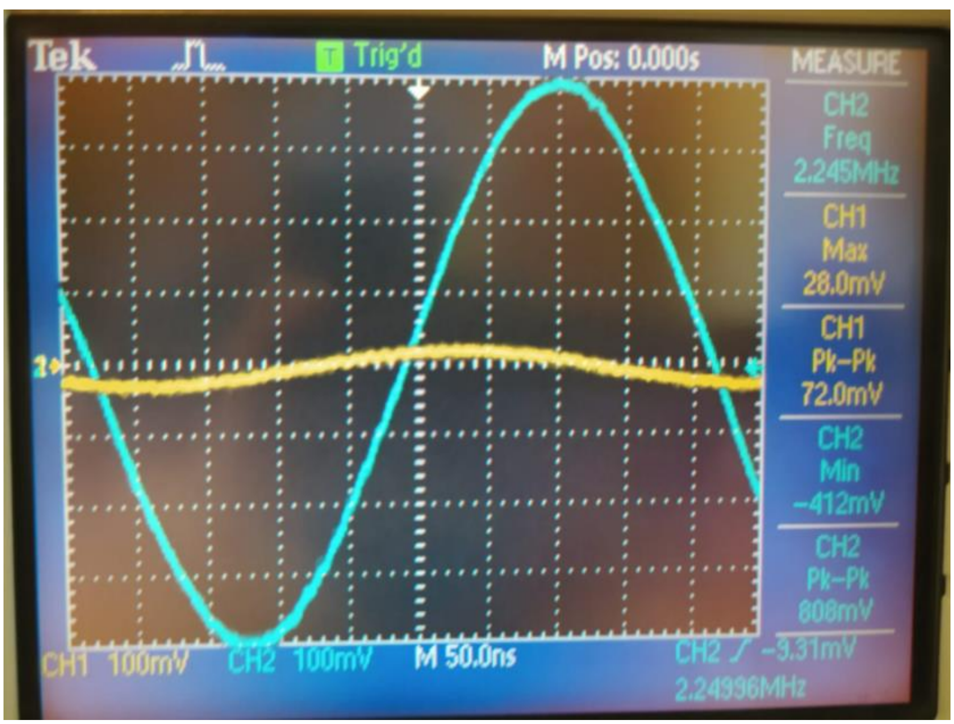

Figure 11: Result of 2.25Mhz input frequency

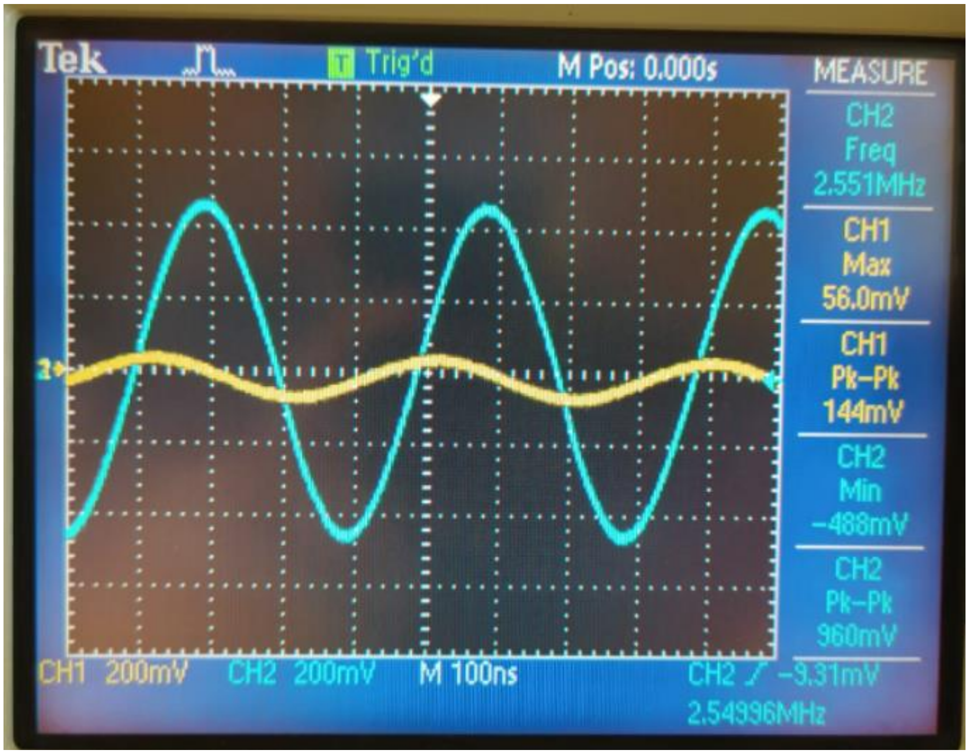

Figure 12: Result of 2.55Mhz input frequency

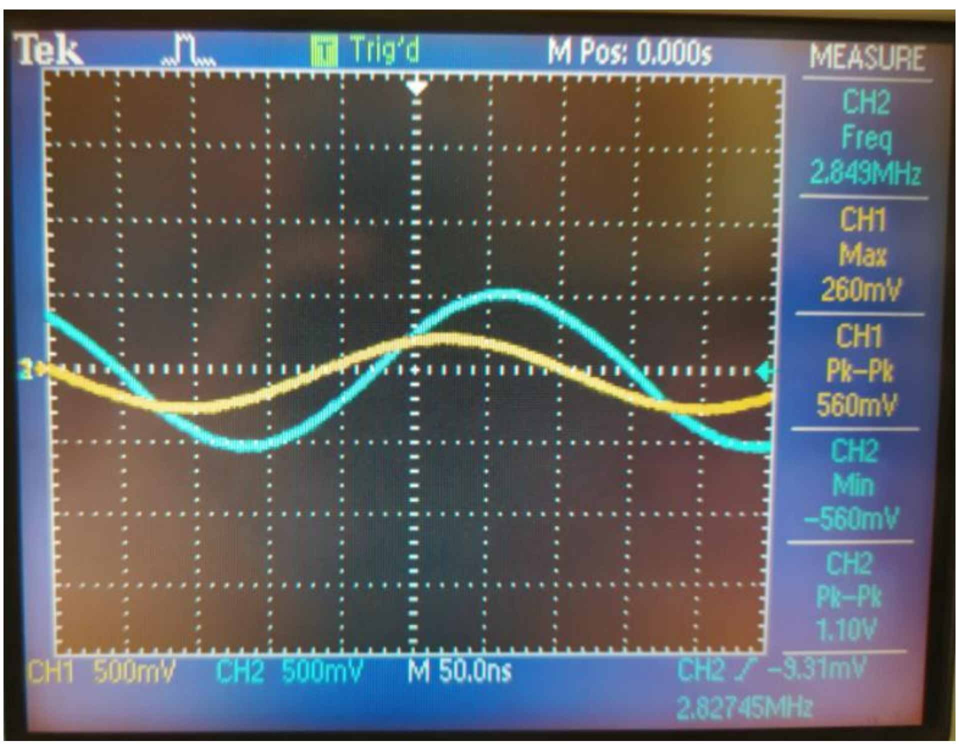

Figure 13: Result of 2.8275Mhz input frequency, -3dB point

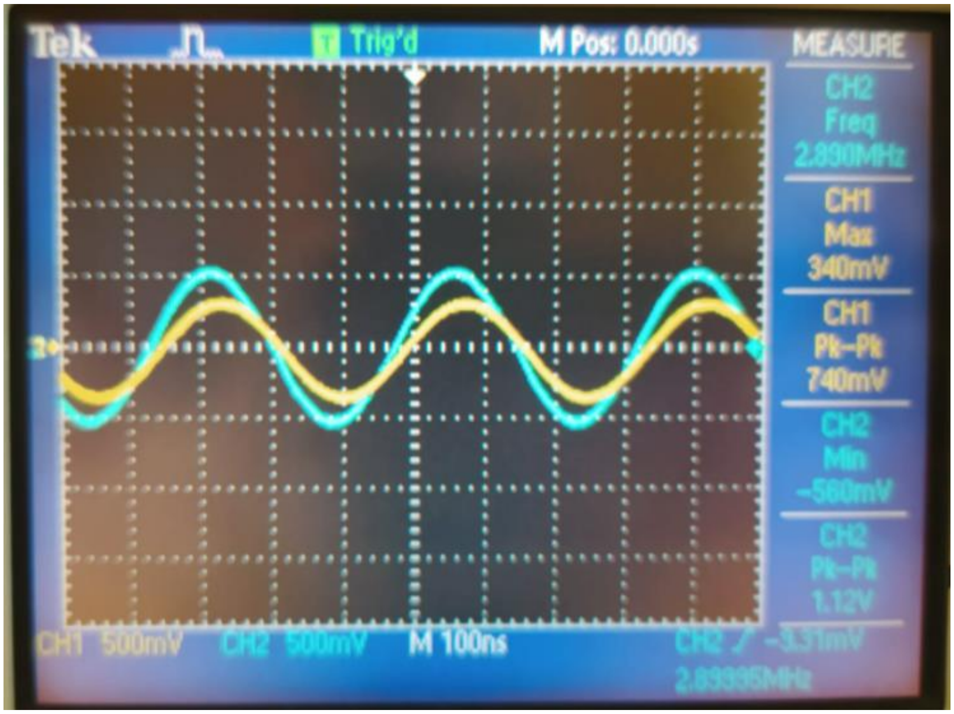

Figure 14: Result of 2.9Mhz input frequency, center frequency f_0

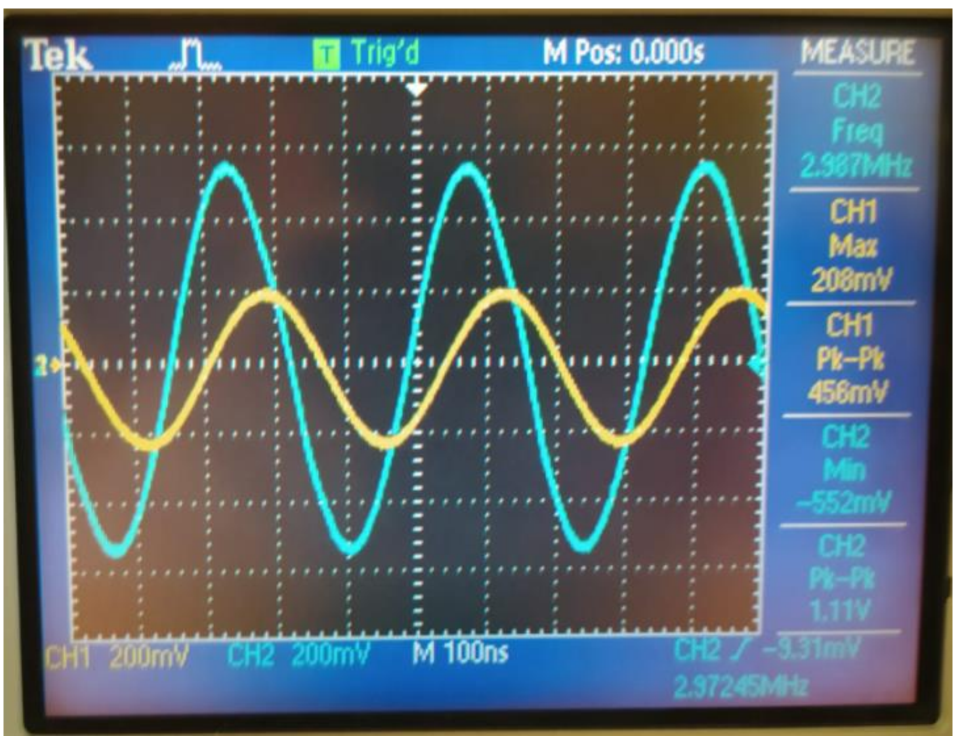

Figure 15: Result of 2.9725Mhz input frequency, -3dB

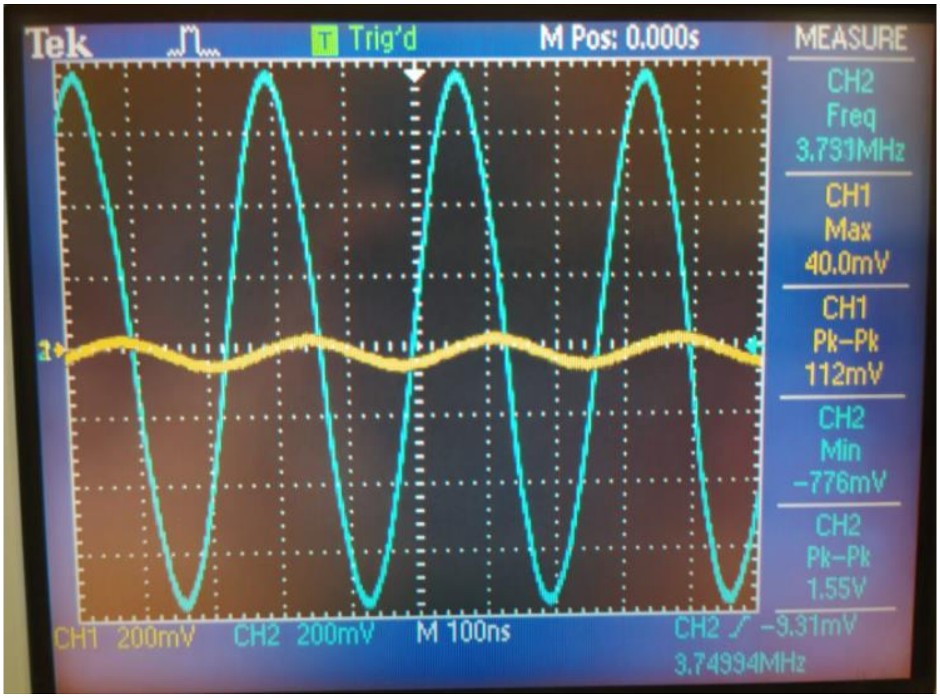

Figure 16: Result of 3.75Mhz input frequency

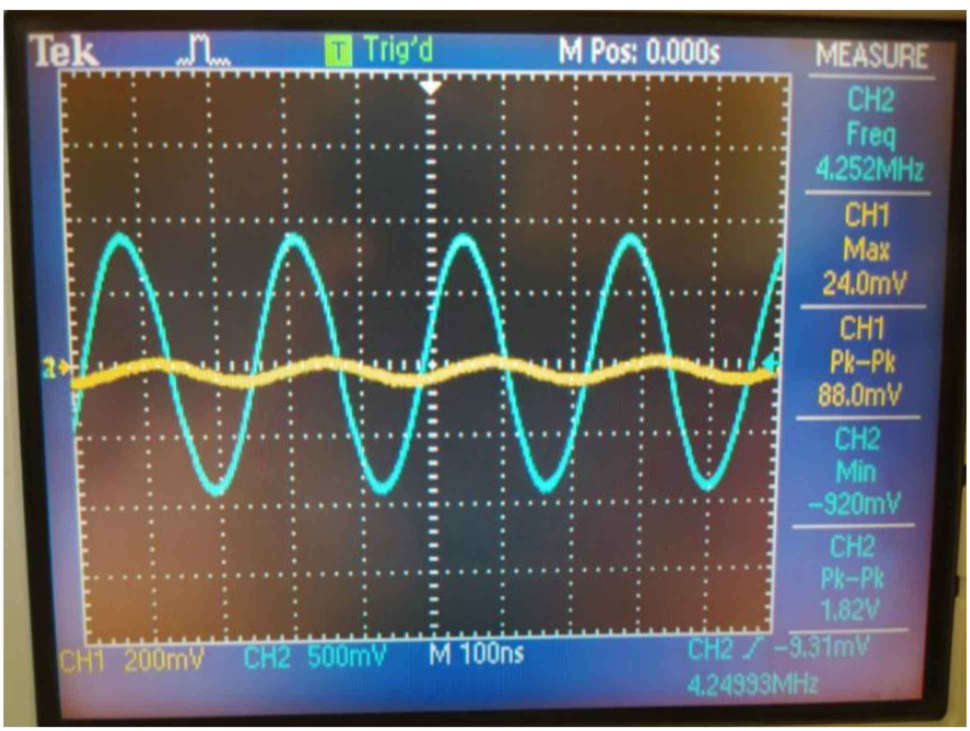

Figure 17: Result of 4.25Mhz input frequency

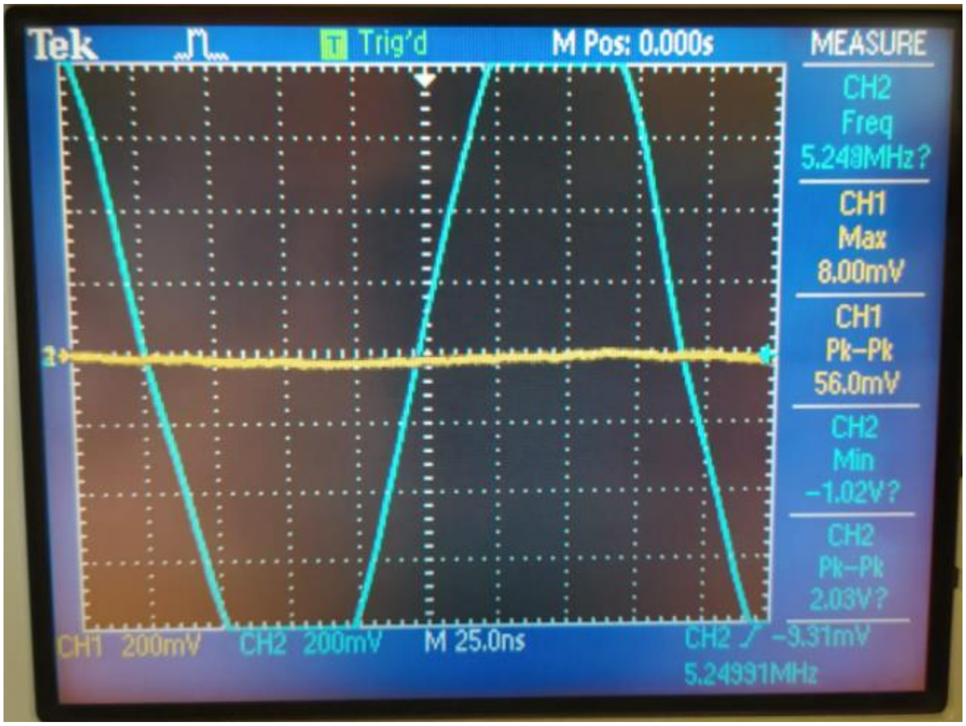

Figure 18: Result of 5.25Mhz input frequency

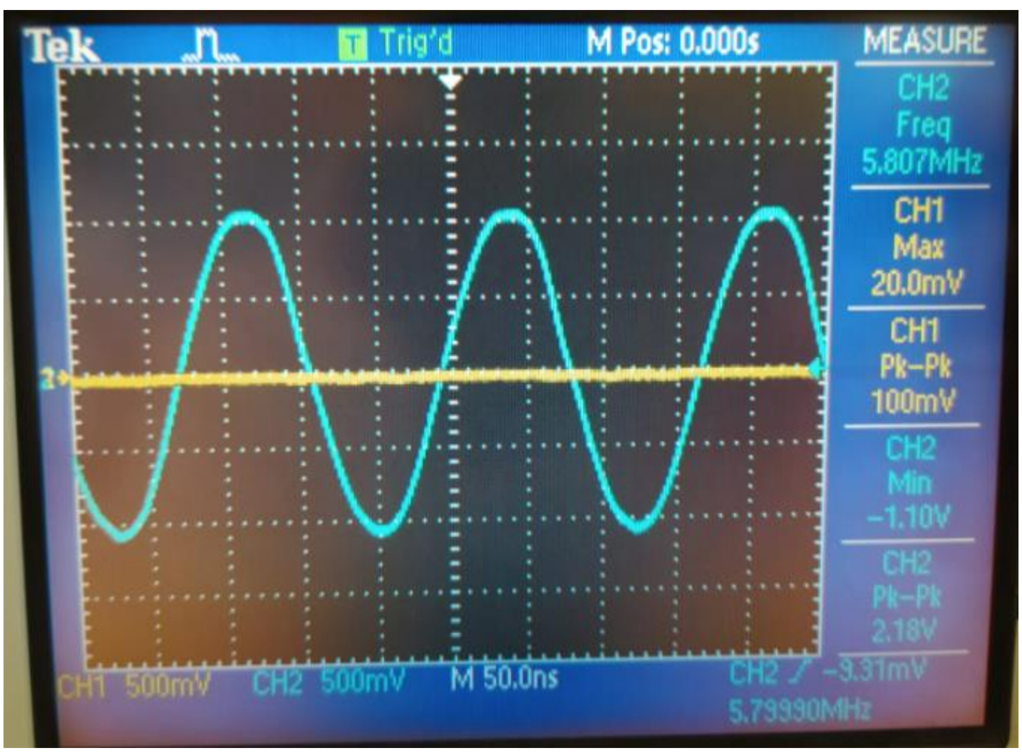

Figure 19: Result of 5.8Mhz input frequency, $2 * f_0$

Frequency	V_{in}	V_{out}	Gain (dB)
1.45Mhz	20mV	260mV	-28.3 dB
1.8 Mhz	32mV	332mV	-20.32 dB
2.55 Mhz	72mV	480mV	-16.48 dB
2.8275 Mhz	280mV	550mV	-5.86 dB
2.9 Mhz	370mV	560mV	-3.6 dB
2.9725 Mhz	228mV	555mV	-7.73 dB
3.75 Mhz	56mV	775mV	-22.82 dB
4.25 Mhz	44mV	910mV	-26.31 dB
5.25 Mhz	28mV	1.02V	-31.22 dB
5.8 Mhz	20mV	1.10V	-34.81 dB

Table 2: Experiment Results Table

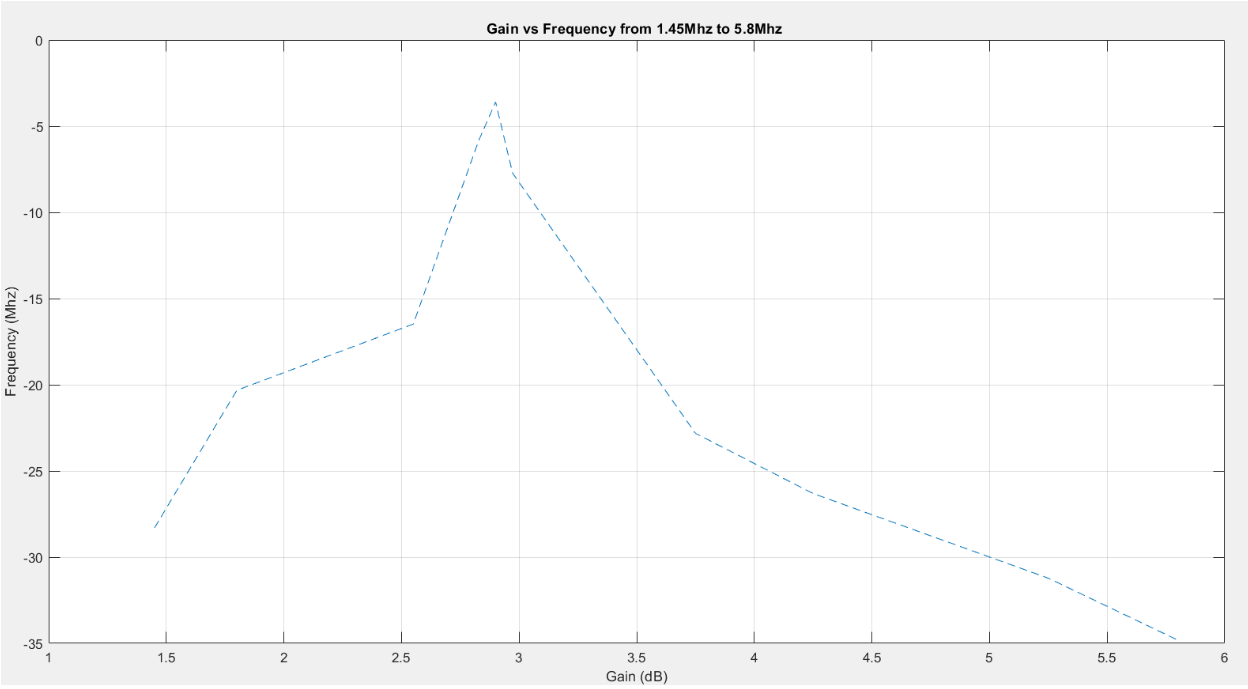

Figure 20: Plot of the obtained results

Conclusion

In this lab experiment filter concepts is investigated by designing a Butterworth band-pass filter. Using the specification in the lab manual the minimum order of the filter is determined and 2^{nd} order filter was chosen for convenience. To design this filter firstly a low pass filter with known cutoff frequency is designed and then some components that tune others at required frequency were added to have a band pass filter. After all this steps, in the software part of this experiment there were almost no error, all the measurement was close to expected values. However, in the hardware lab there were lots of errors. The reasons for those errors are differ. First of all, the used components were not perfect, and they have some error percentage which is in ±10%. With all the components the error percentage becomes bigger and bigger. Even if I tried to choose the components as close as to wanted values, there were still some errors. In addition to that the oscilloscope was not sensitive enough that at small output input it is almost not able to measure the exact values and it gives a noise like signal. Therefore, the results have big errors. Fortunately, the filter concepts is understood even if there were some errors and the filter worked somehow.