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Course Code: EEE202

Section: 02

Experiment Number: 05

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Lab 5 Report

Software Implementation

Introduction:

The goal of this experiment is designing a band-pass filter with center frequency between 2MHz and 5MHz. The load resistor value should be 50Ω. Passband width is equal to $0.05f_0$. The gain variation in the passband should be less than 3dB. Lastly, the stopband attenuation must be greater than 30dB. Requirements for the experiments are also shown in the figure below.

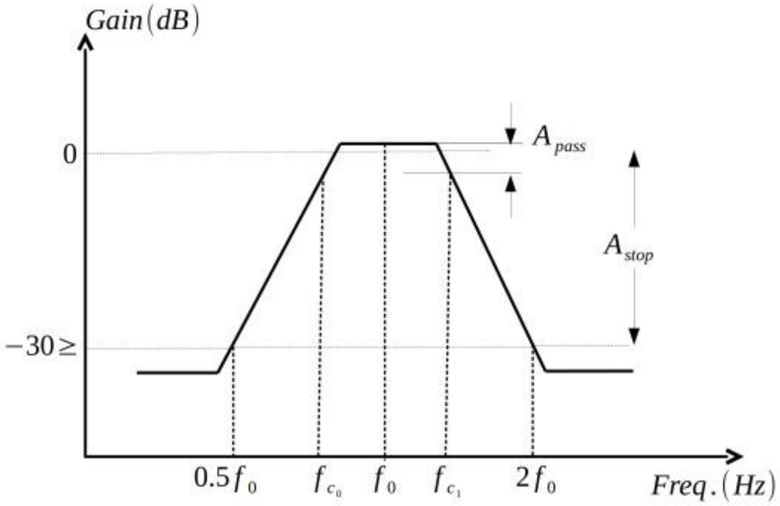

Figure 1: Frequency response of the filter

Central frequency: $2Mhz \leq f_0 \leq 5Mhz$
Passband width: $f_{c_1} - f_{c_0} = 0.05 f_0$
Gain variation in the passband: $A_{pass} \leq 3dB$
Stopband attenuation: $A_{stop} \geq 30dB$

Figure 1: Design requirements

Analysis:

The center frequency (f_0) is chosen as 3MHz. Therefore the bassband gain is equal to $0.05f_0(\Delta f) = 150kHz$. A Butterworth band-pass will be desinged, the order of the circuit is determined as 2 regarding the complexity and accuracy of the circuit. Looking at the table below, the b_i values are chosen as 1.4142.

$$b_1 = 1.4142$$

$$b_2 = 1.4142$$

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: Butterworth filter coefficient table

In order to create a Butterworth band-pass filter, first a low pass filter must be designed. A LPF includes a serial inductor (L_1) and a parallel capacitor (C_2). The designed schematic of LPF can be seen in the below figure.

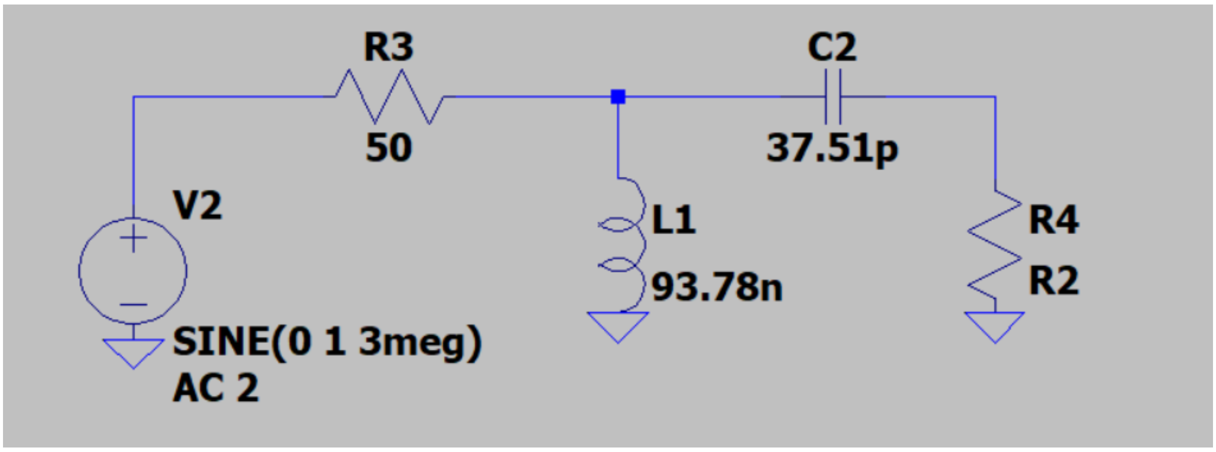

Figure 2: Schematic of LPF

After that, these capacitor and inductor's have to be matched. Therefore, a series capacitor (C_1) is connected to the inductor (L_1) of LPF, and a series inductor (L_1) is connected to the capacitor (C_2) of LPF. The schematic of the circuit can be seen in the below figure.

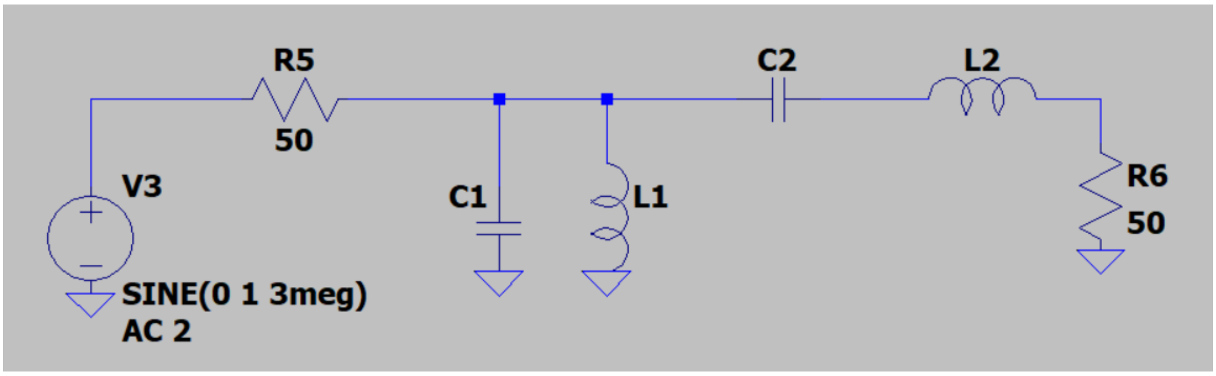

Figure 3: Band-pass Filter Design

The formulas for L_1 and C_2 are given in the equations below:

$$L_1 = \frac{b_1 * R_L}{2\pi * \Delta f}$$

$$C_2 = \frac{b_2}{2\pi * \Delta f * R_L}$$

Inserting the values $\Delta f = 150kHz$, $b_1, b_2 = 1.4142$, and $R_L = 50\Omega$, desired inductor and capacitor values are reached.

$$L_1 = \frac{1.4142 * 50}{2\pi * 150 * 10^3} = 93.78\,nH$$

$$C_2 = \frac{1.4142}{2\pi * 150 * 10^3 * 50} = 37.5\,pF$$

To calculate the remaining capacitor values, the equtions below will be used:

$$L_i = \frac{1}{(2\pi * f_0)^2 * C_i}$$

$$C_i = \frac{1}{(2\pi * f_0)^2 * L_i}$$

From these equations, L_2 and C_1 values are calculated as below.

$$L_2 = 75.03\,\mu H$$

$$C_1 = 30\,nF$$

The last form of the circuit is given in Figure 4.

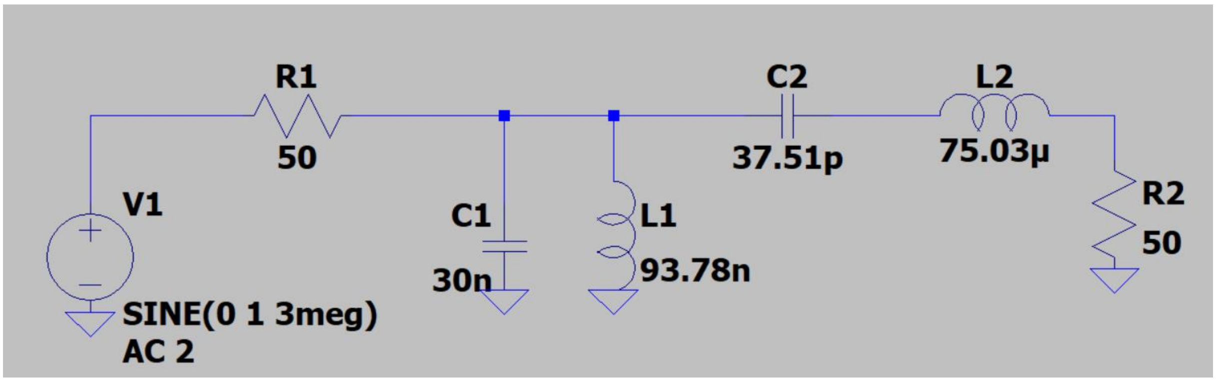

Figure 4: Designed Circuit

Simulations:

At 3MHz, the gain is turned out to be -69 mdB, which is inside the boundary of the design requirement $Gain \leq 3dB$. Figure 5 shows the result.

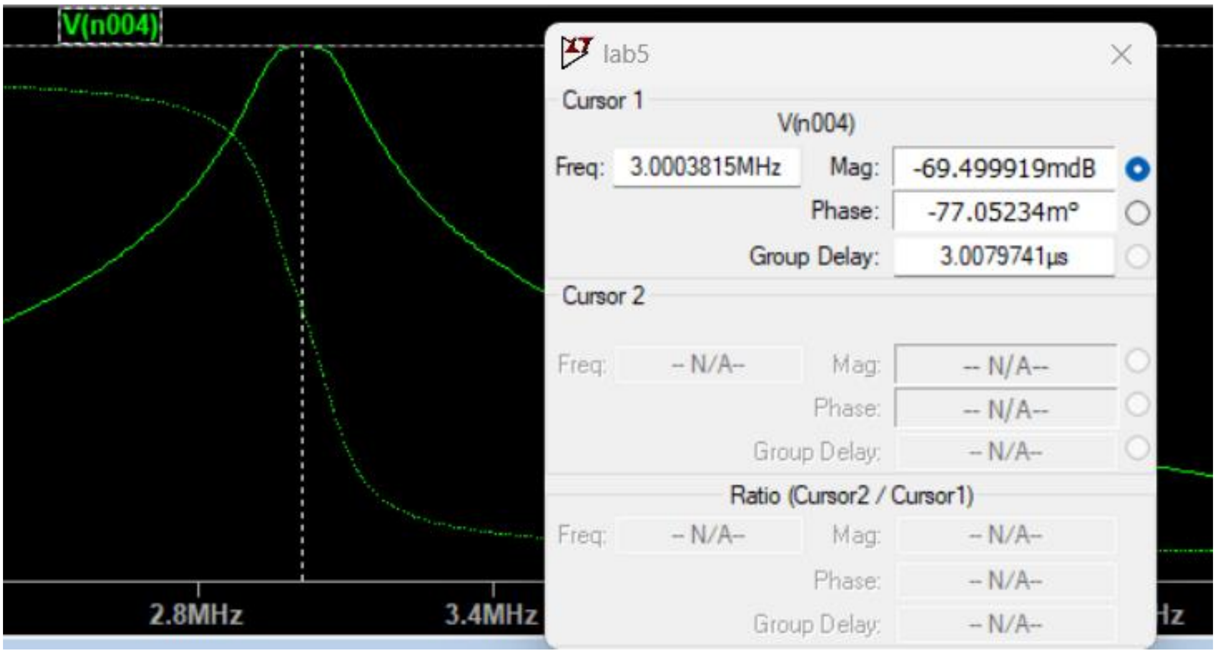

Figure 5: dB gain at center frequency 3MHz

Earlier, the passband width is calculated as 150kHz. From this, corner frequencies are calculated as below:

$$f_{c1} = (3 - 0.075)MHz = 2.925\ MHz$$

$$f_{c2} = (3 + 0.075)MHz = 3.075\ MHz$$

At corner frequecies, dB gain must be equal to -3dB.

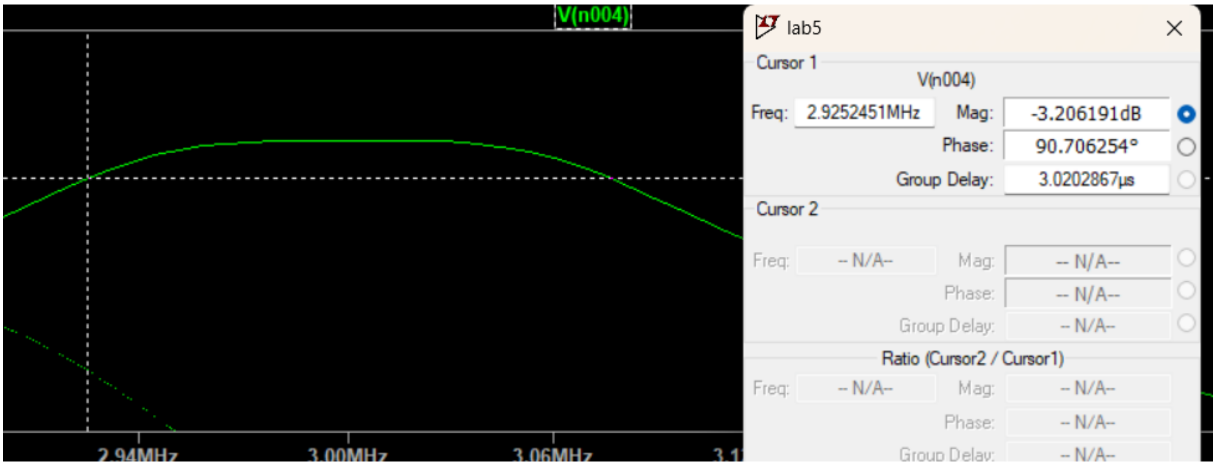

Figure 6: dB gain at f_{c1} = 2.925 MHz

Gain at 2.925 MHz turned out to be -3.21 dB.

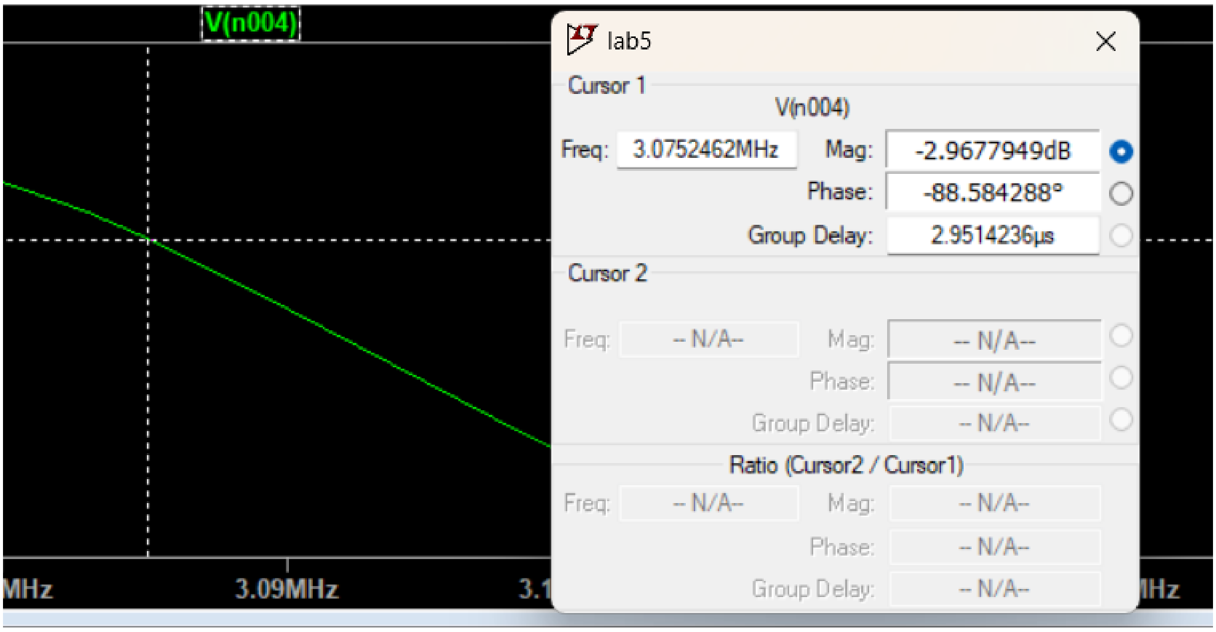

Figure 7: dB gain at f_{c2} = 3.075 MHz

Gain at 3.075 MHz turned out to be -2.97 dB

The last 2 points of the requirements of the lab are $0.5f_0$ and $2f_0$, which are 1.5 MHz and 6 MHz. Gain at these frequencies can be seen in the following 2 figures. (Figure 8-9)

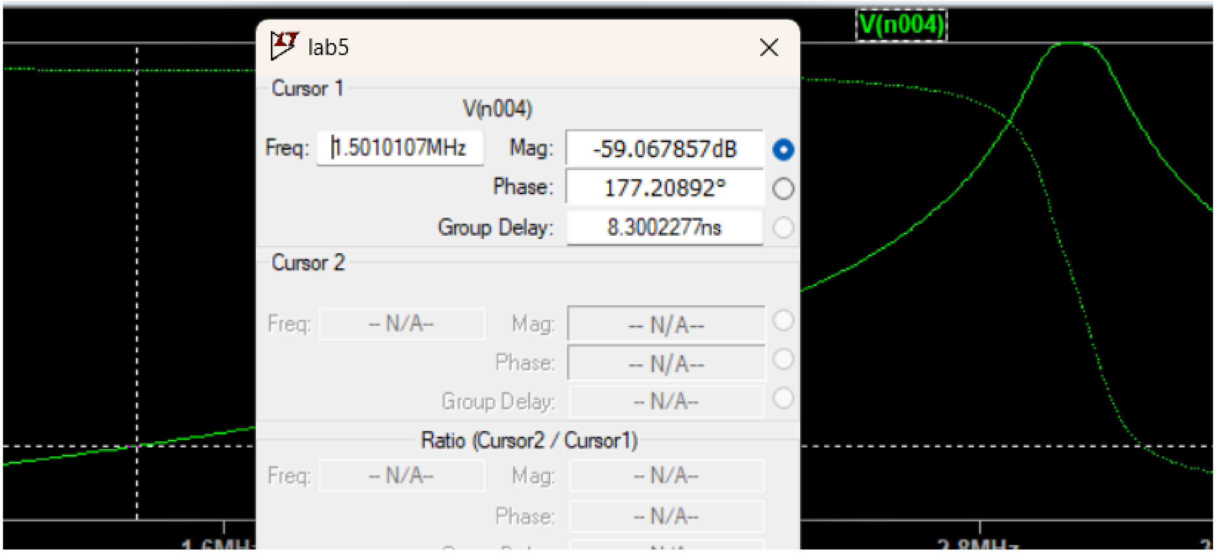

Figure 8: Gain at 1.5 MHz

Gain at 1.5 MHz turned out to be -59.06 dB.

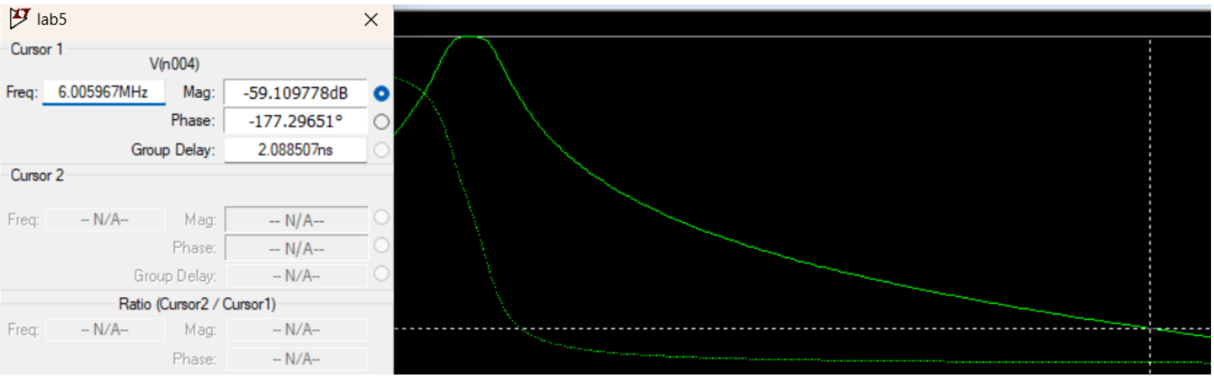

Figure 9: Gain at 6 MHz

Gain at 6 MHz turned out to be -59.11 dB.

	$0.5f_0$	f_{c1}	f_0	f_{c2}	$2f_0$
Frequncy (MHz)	1.5	2.925	3	3.075	6
Design requirements (dB)	≤-30	≤-3	0	≤-3	≤-30
Software Results	-59.06	-3.21	-0.069	-2.97	-59.11
Percentage Error	-	6.54%	-	1.01%	-

Table 2: Software Results and Error calculations

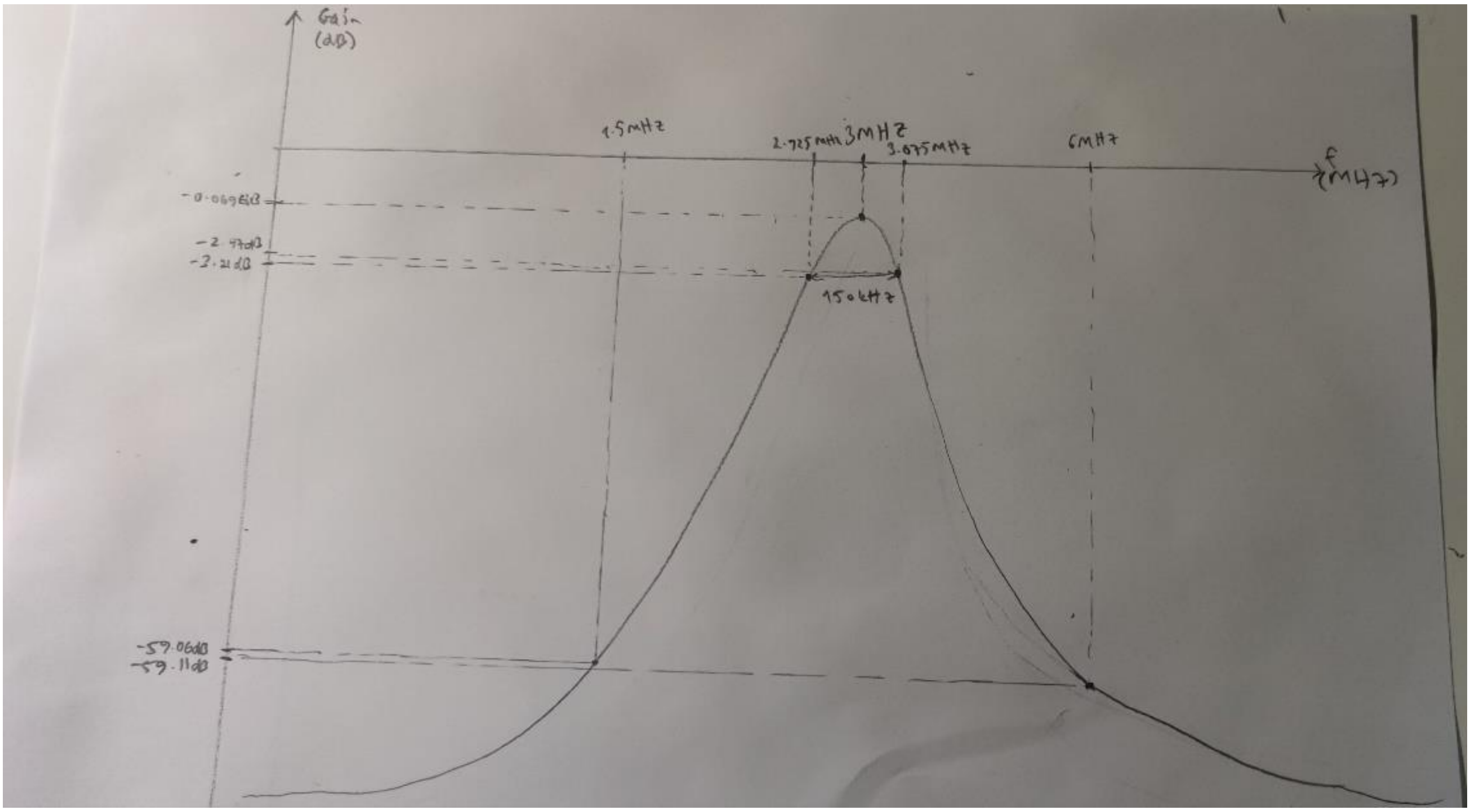

Figure 10: Bode plot of the designed band-pass filter

Hardware Implementation

Unfortunately, I cannot get the desired results for the circuit that I designed in the software implementation. Therefore I cannot provide any information about hardware implementation of the circuit.

Conclusion:

The experiment's purpose is designing a band-pass filter with a center frequency in the range between 2MHz and 5MHz. The bandwith must be equal to $0.05f_0$ where f_0 is the center frequency. Butterworth filter design is chosen for the implementation of the circuit, and order of 2 is chosen regarding the complexity of the circuit. The circuit is designed in two steps: first is designing a LPF, and then matching the inductor and capacitors with serial connections to them.

The results in software part turned out to be similar to the design requirements of the circuit with a slight error included. The errors may caused by the experimenters lack of sensitivity while using the cursor in LTspice. I think the reason I cannot achieved desired results for hardware parts are inability to use the exact same calculated inductor and capacitor values. I tried to design 2 more different circuits however I still cannot get the desired dB gain results.