Bilkent University
EE202-002 Lab 5 Report:
Bandpass Filter

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Purpose:

This lab aims to design a band-pass filter with given specifications for 50Ω load resistance.

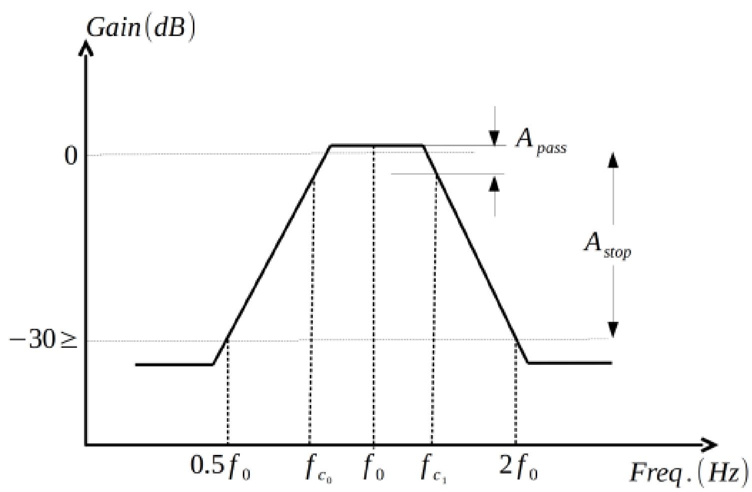

Figure 1: Frequency response of the filter

Central frequency: $3Mhz \leq f_0 \leq 6Mhz$
Passband width: $f_{c_1} - f_{c_0} = 0.05f_0$
Gain variation in the passband: $A_{pass} \leq 3dB$
Stopband attenuation: $A_{stop} \geq 30dB$

Figure 1: Specifications

Methodology:

To design a bandpass filter, it is necessary to apply two steps according to the information learned in the EEE211 course. First, a Butterworth LPF must be designed; secondly, an LC circuit tuned at the center frequency must replace each series and the parallel element.

In the circuit to be designed, 4.7MHz (f_0) is selected as the center frequency, so the bandwidth is obtained as 235Khz (Δf), and the corner frequencies are 4.58MHz and 4.82MHz. Since it is desired to be smaller than -30dB at twice the center frequency, that is, at 9.4MHz (f), the order of the filter to be designed, which fulfills this and other specifications, is determined by the following equations.

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

$$10 * \log\left(\frac{P_L}{P_A}\right) \leq \ -30dB$$

$$10 * \log\left(\frac{1}{1 + (\frac{4.7 * 10^6}{235 * \ 10^3})^{2n} * \ (\frac{9.4 * 10^6}{4.7 * 10^6} - \ \frac{4.7 * 10^6}{9.4 * 10^6})^{2n}}\right) \leq \ -30$$

$$n \ \geq 1.11$$

As a result of these equations, n is obtained as 2, so second-order Butterworth LPF will be used for bandpass filter design. Capacitor and inductor values for this design are found with the following equations.

$$C_i = \frac{b_i}{2\pi * \Delta f * R} \qquad\qquad L_i = \frac{b_i * R}{2\pi * \Delta f}$$

The b_i values in these equations are determined according to the table below.

n	b_1	b_2	b_3	b_4	b_5
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

Figure 2: Butterworth Low Pass Filter Coefficients

When bandwidth, resistance, and coefficient values are put in place,

$$C_1 = \frac{1.4142}{2\pi * 235 * 10^3 * 50} = 19.15\ nF$$

$$L_2 = \frac{1.4142 * 50}{2\pi * 235 * 10^6} = 47.89\ \mu H$$

As a second step, after obtaining the capacitor and inductor values required for the low pass filter, two LC circuits tuned at the center frequency will be designed with these values. Inductor and capacitor values required for LC circuits are obtained with the following equations.

$$L_1 = \frac{1}{(2\pi * f_0)^2 * C_1} \qquad C_2 = \frac{1}{(2\pi * f_0)^2 * L_2}$$

When center frequency, capacitor, and inductor values are put in place,

$$L_1 = \frac{1}{(2\pi * 4.7 * 10^6)^2 * 19.15 * 10^{-9}} = 59.88\ nH$$

$$C_2 = \frac{1}{(2\pi * 4.7 * 10^6)^2 * 47.89 * 10^{-6}} = 23.94\ pF$$

Software Lab

The general view of the designed circuit is as follows.

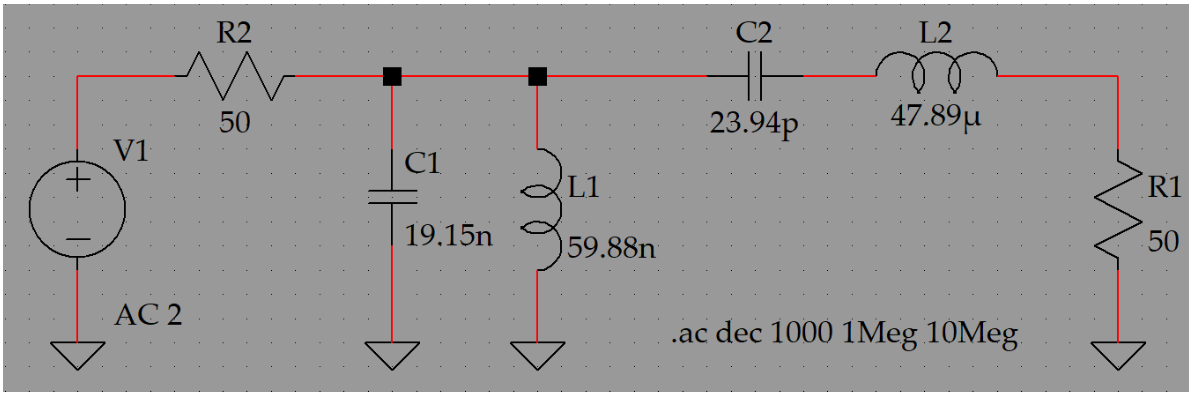

Figure 3: The Bandpass Filter Circuit

Results

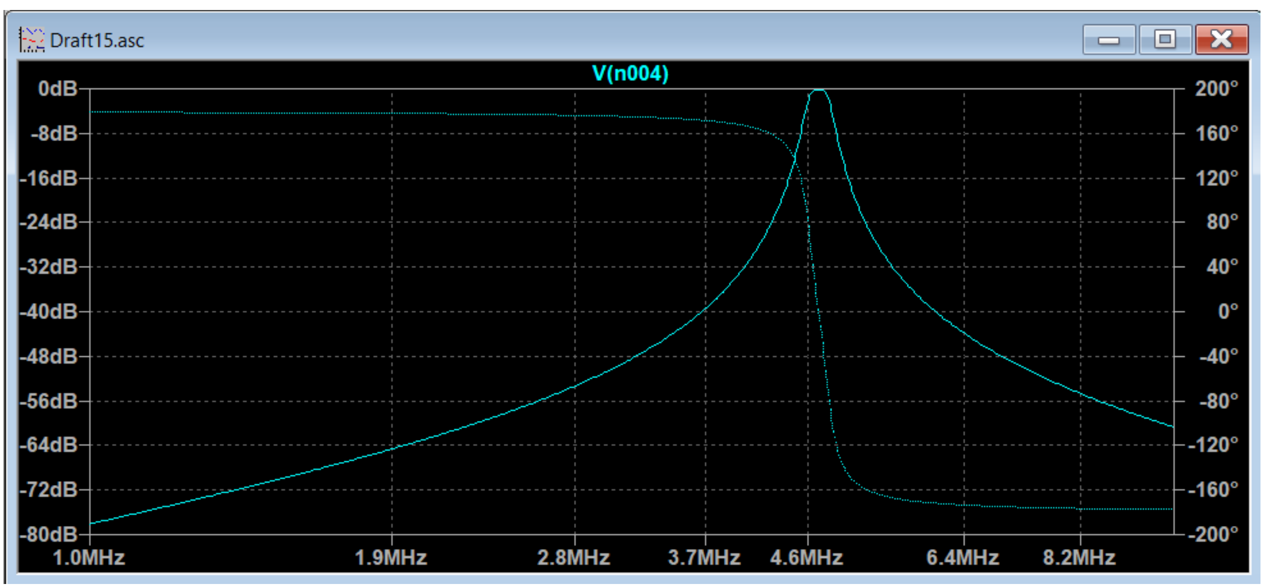

Figure 4:The Frequency Response Plot

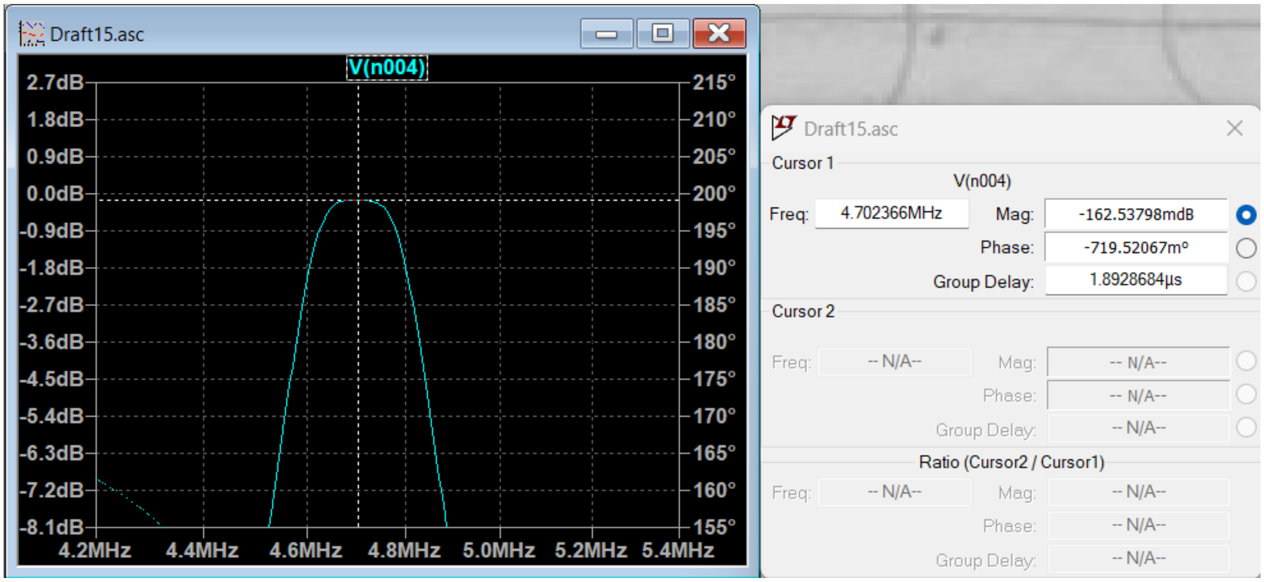

Figure 5: The Center Frequency (f_0)

The center frequency is 4.7MHz, as expected.

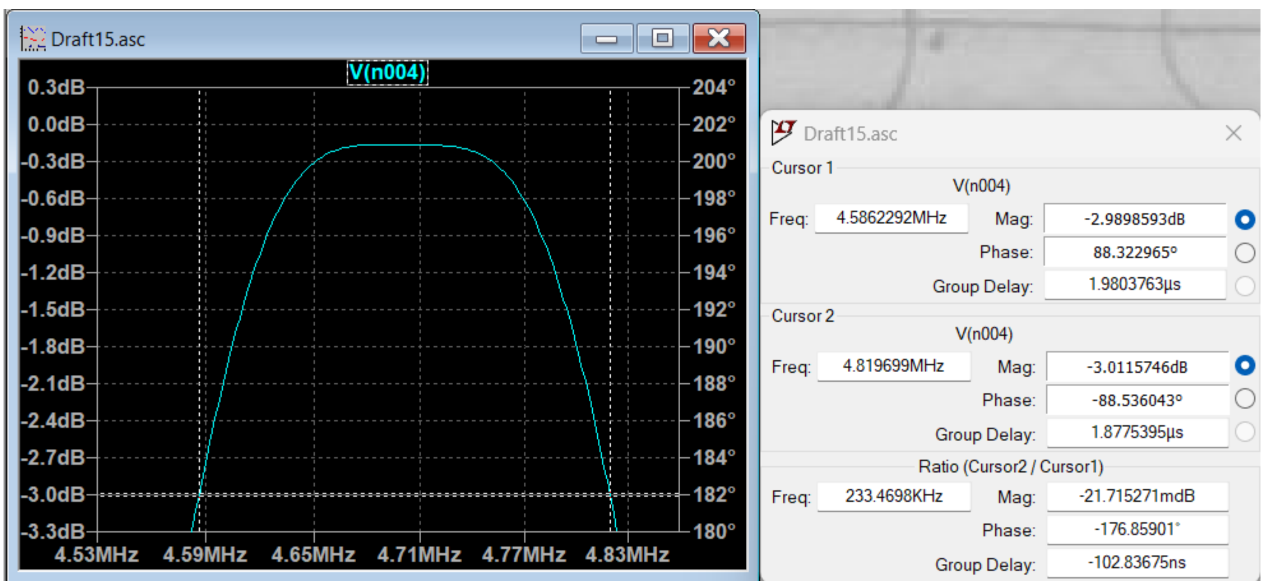

Figure 6: The Bandwidth (Δf)

The bandwidth is 233.5kHz with a 0.63% error. Corner frequencies are 4.59MHz and 4.81MHz with less than 1.00% error.

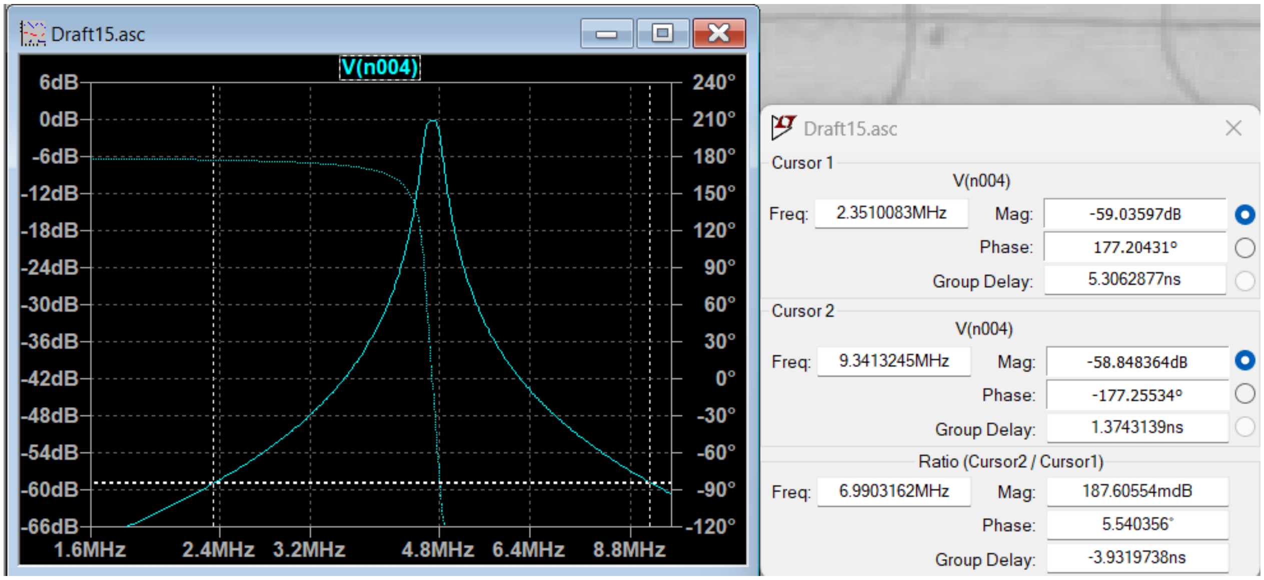

Figure 7: The Stopband Attenuation (f_0/2 and 2 f_0)*

The stopband attenuation is higher than 30 dB.

Bandpass Filter	Specifications	Software Result
Central Frequency	**3MHz < f_0 < 6MHz**	**4.7MHz**
Bandwidth	**0.05 * f_0 = 235kHz**	**233,5kHz**
Stopband Attenuation	**> 30dB**	**59dB**

Table 1: The Specifications and Software Results

The designed bandpass filter is suitable as it fulfills all the requirements.

Hardware Lab

For the hardware part for L_1, two 100nH inductors are connected in parallel. For other components, the closest values to the software part are used.

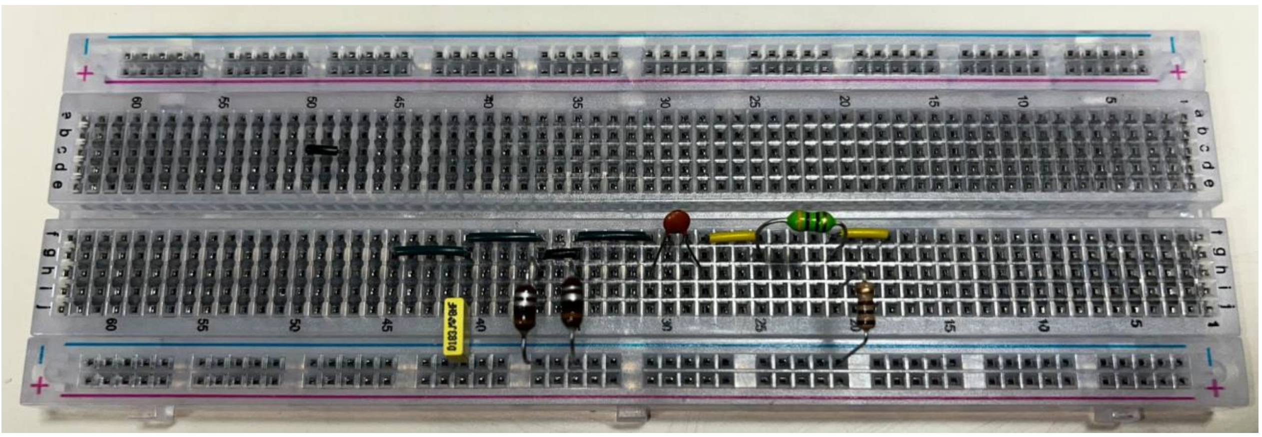

Figure 8: The Bandpass Filter

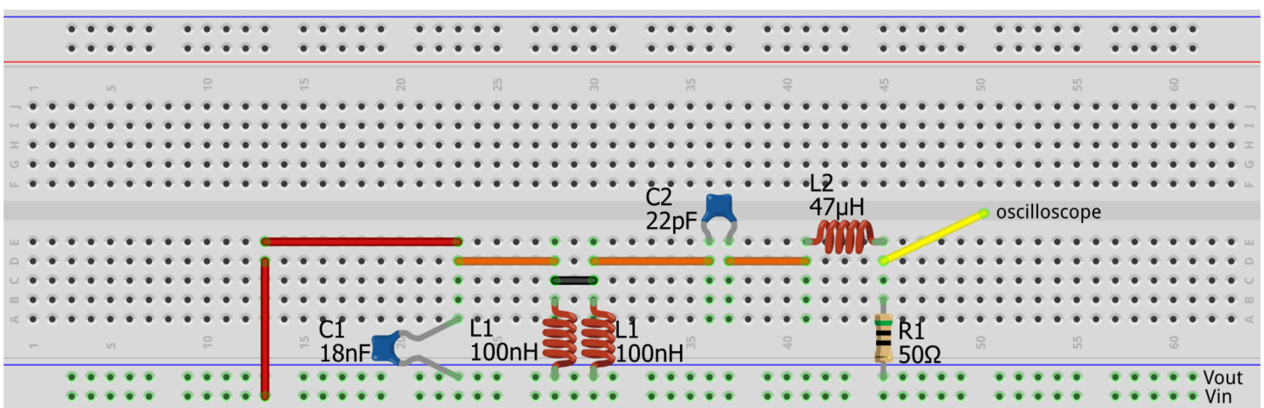

Figure 9: The Schematics of Bandpass Filter

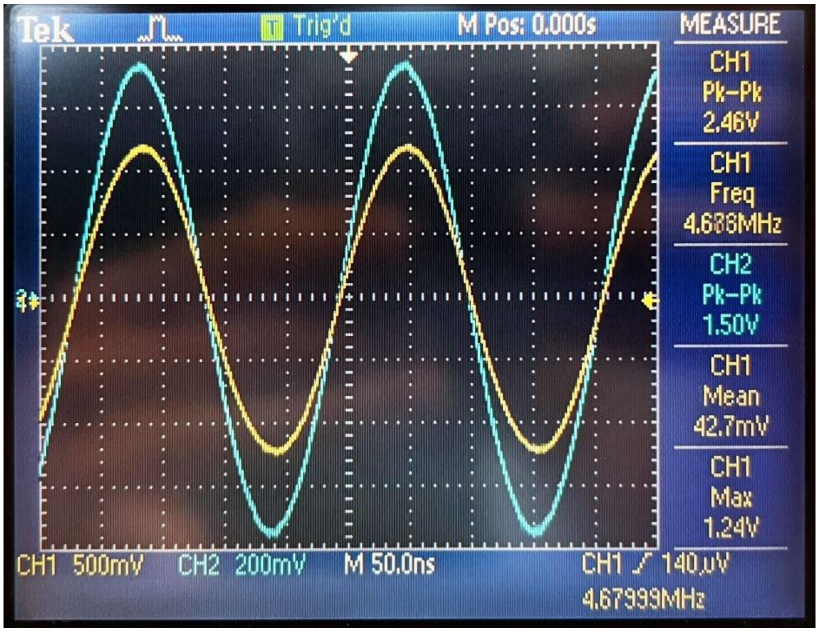

Figure 10: The Center Frequency (f_0)

Center Frequency	Expected Result	Hardware Result	Error
$\boldsymbol{f_0}$	4.7MHz	4.68MHz	0.42%

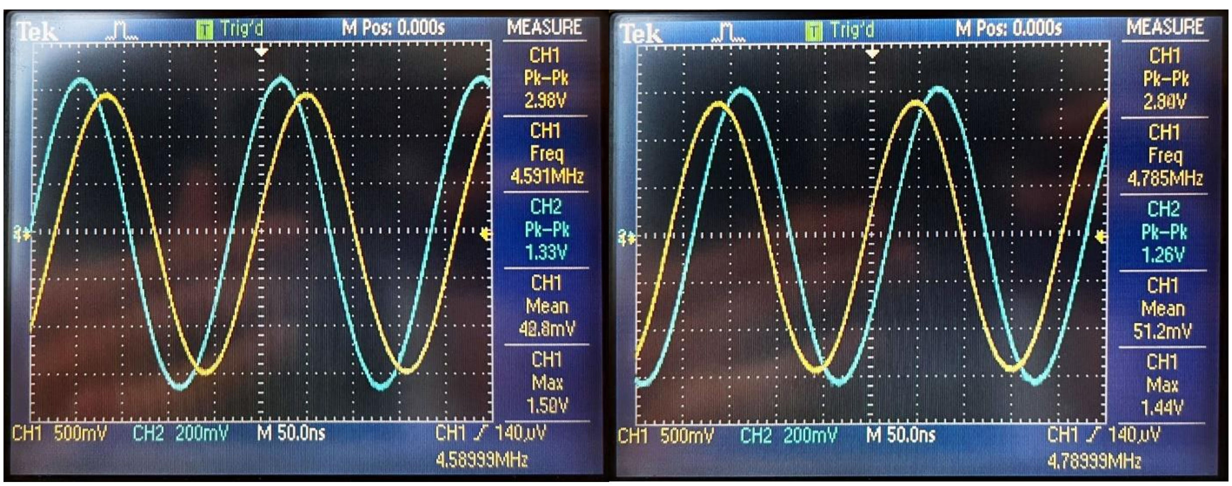

Figure 11: The Corner Frequencies

Corner Frequencies	Expected Result	Hardware Result	Error
$\boldsymbol{f_{C0}}$	4.58MHz	4.59MHz	0.22%
$\boldsymbol{f_{C1}}$	4.81MHz	4.79MHz	0.41%

Figure 12: The Stopband Attenuation ($f_0/2$ and 2 f_0)*

When the gain is calculated using the following equation

$$20 \log\left(\frac{V_{out}}{V_{in}}\right) = Gain\ in\ dB$$

- The gain is -4.3dB at f_0 = 4.7MHz
- The gain is -7.3dB at f_{C0} = 4.59MHz and f_{C1} = 4.79MHz
- The Bandwidth is $f_{C1} - f_{C0}$ = 200kHz
- The gain is -31.74dB at $f_0/2$ and -33.23dB at 2* f_0

More measurements were made at ten different frequencies to draw a frequency response plot, and the gain was calculated. The obtained values are given in the table below.

Frequency(MHz)	**Gain(dB)**	**Frequency(MHz)**	**Gain(dB)**
4.43	-13.19	**4.73**	-5.13
4.48	-11.50	**4.78**	-7.06
4.53	-9.59	**4.83**	-9.11
4.58	-7.50	**4.88**	-11.28
4.63	-5.45	**4.93**	-12.95

The following frequency response plot is drawn with these values and the important frequency values obtained before.

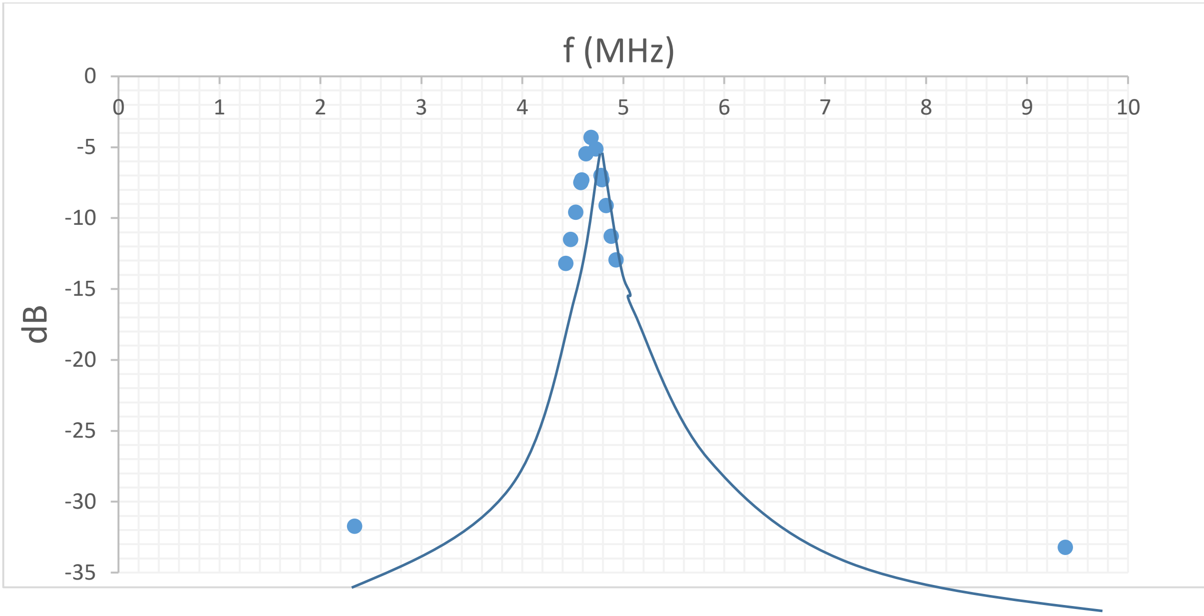

Figure 13: The Frequency Response Plot

Conclusion

This lab aimed to design a band-pass filter that satisfies the requirements for a 50 ohm load resistance. According to the information learned from the EEE211 course, firstly, the Butterworth low pass filter was designed to obtain the bandpass filter. After determining the appropriate order and center frequency, necessary equations were used, and Butterworth LPF was obtained. As a second step, the capacitors and inductors in this filter were replaced with LC circuits tuned at the center frequency. As a result of all these steps, a bandpass filter with a center frequency of 4.7MHz was obtained. The measurements of the designed circuit were made on LTSpice, and then this circuit was implemented on the breadboard. The values of the circuit simulated in the software part and the value of the circuit implemented on the breadboard in the hardware part were compared with the expected values , and tables were created. The designed circuit fulfilled the specifications specified in the software and hardware parts. The bandwidth, 235KHz in the software part, was measured as 200kHz in the hardware part. This difference is excepted because the approximate values of the components are used in the hardware part. The other errors below 1.00 % occurred due to imprecise component values and the material quality or sensitivity of the oscilloscope, signal generator, and breadboard. In summary, thanks to this lab, the design stages of the bandpass filter were learned, and the filter circuits were practiced.