Lab 5

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Section: 2

Purpose:

The purpose of this lab is to design a bandpass filter for a 50 Ohm load resistor with a center frequency between 1 and 4 MHz, with a bandwidth of 0.05 times the selected center frequency. In addition, the gain variation in the passband will be less than or equal to 3 dB and the stopband attenuation will be greater than or equal to 30dB. (*Figure 1*)

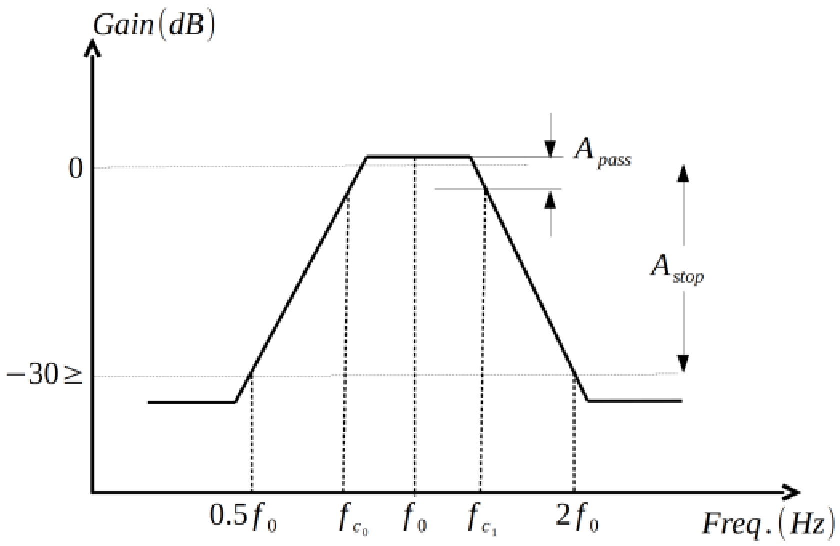

Figure 1: Frequency response of the filter

Methodology:

The bandpass filter is a combination of low pass and high pass filters. Therefore, the circuit diagram contains the circuit of high pass and low pass filters. In this case, second-order and 4 MHz center frequencies were selected to design the bandpass filter and the design was made accordingly.

Simulation Part:

To design a Bandpass filter first, it needs to be designed Low pass filter in which the cut-off frequency (f_c) must be equal to the bandwidth (Δf) of the Bandpass filter. Then replace every series and parallel element with a tuned LC circuit at the center frequency (f_0). The steps can be seen above.

f_0 = 4 MHz

$\Delta f = f_c = 0.05 \times f_0 = 0.05 \times 4.10^6 = 200\ kHz$

Lowpass filter with $\Delta f = f_c$ = 200kHz (*Figure 2*) :

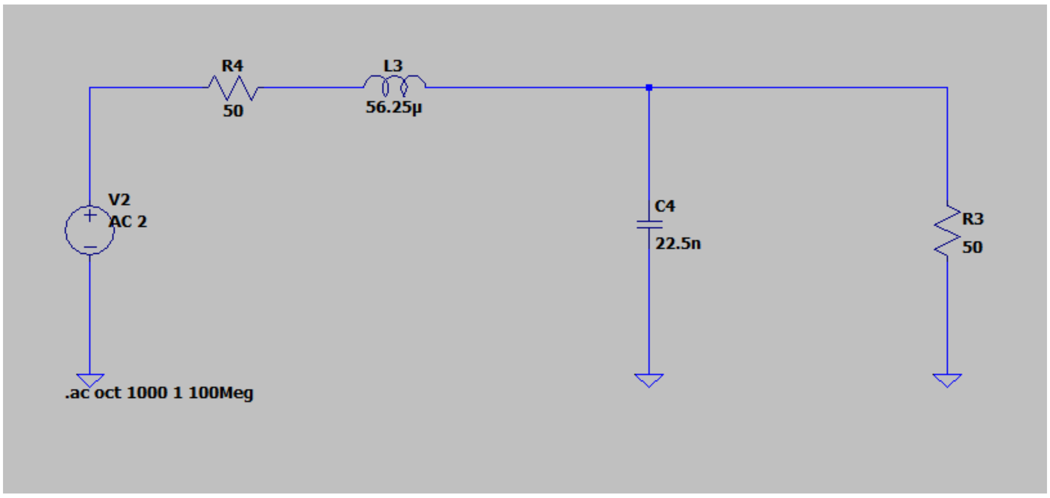

Figure 2 – Lowpass Filter Configuration

$$L_1 = \frac{b_1 * R}{2\pi f_c}$$

$$C_2 = \frac{b_2}{2\pi f_c * R}$$

Where bi = 2sin($\frac{(2i-1)\pi}{2n}$) and its values can be found in the following table. (*Figure 3*)

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

Figure 3 – Coefficients of Butterworth Filter

By using bi, f_c, R values can be reached:

$$L_1 = \frac{1.4142 * 50}{2\pi * 200 * 10^3} = 56.25\ \mu H$$

$$C_2 = \frac{1.4142 * 50}{2\pi * 200 * 10^3} = 22.5\ nF$$

Tune in at f_0 = 4 MHz :

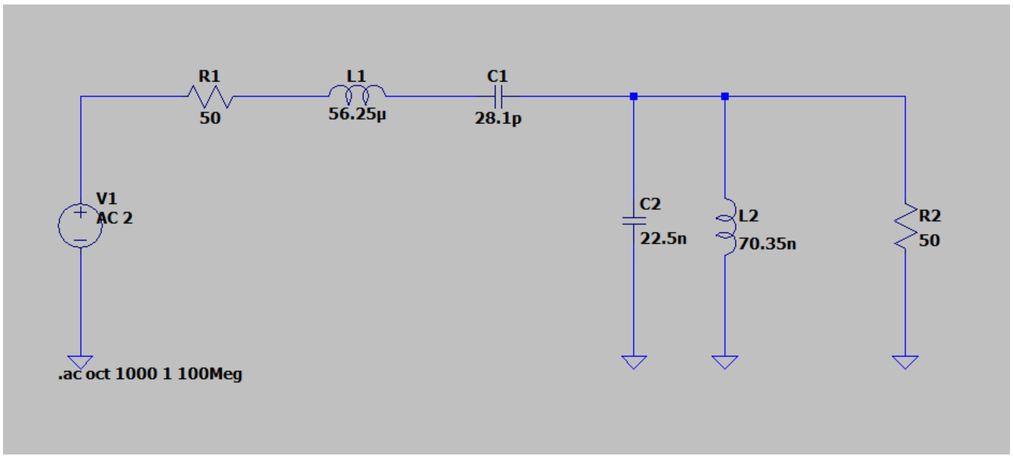

Figure 4 - Bandpass Filter Configuration

In order to tune it, it will be used :

$$C_1 = \frac{1}{{w_0}^2 * L_1}$$

$$L_2 = \frac{1}{w_0 * C_2}$$

With using w_0, C_2, L_1 values it can be reached:

$$C_1 = \frac{1}{(2\pi * 4 * 10^6)^2(56.25 * 10^{-6})} = 28.1\, pF$$

$$L_2 = \frac{1}{(2\pi * 4 * 10^6)^2(22.5 * 10^{-9})} = 70.35\, nH$$

Hardware Part:

2 Vpp is given as input voltage. Then, two 100-ohm resistors were connected in parallel to create a 50-ohm source resistor, and the toroid with an A_L of 4.3 nH/t^2 was wound 4 times for the 70.35 nH inductor. 56.25 μH inductor is obtained by connecting two inductors with 10 and 47 micro-henry units in series. 27 pF capacitor was used instead of a 28.1 pF capacitor and a 22 nF capacitor was used for the 22.5 nF capacitor. Then, in order to evaluate the performance of the bandpass filter 5 and more frequencies are given and the gains obtained in the passband and center frequencies were found.

The Gain can be calculated by using the formula below :

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

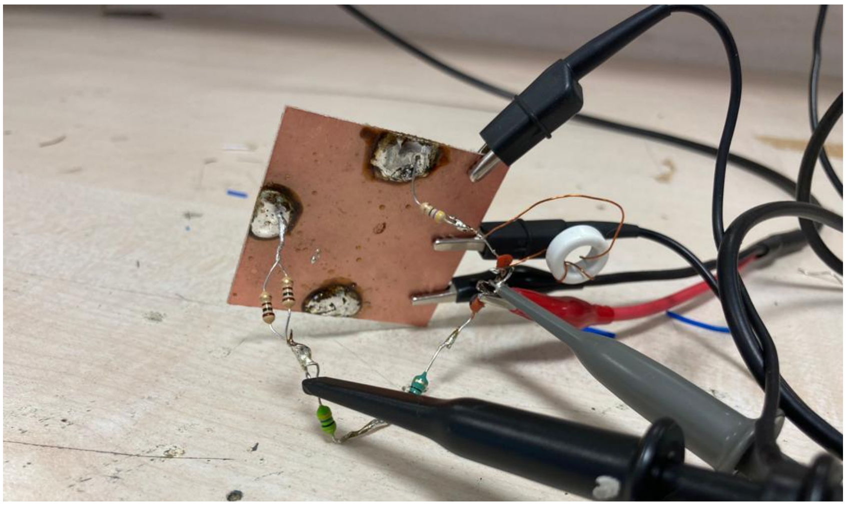

Figure 5 - Hardware Implementation

Results:

Simulation Part:

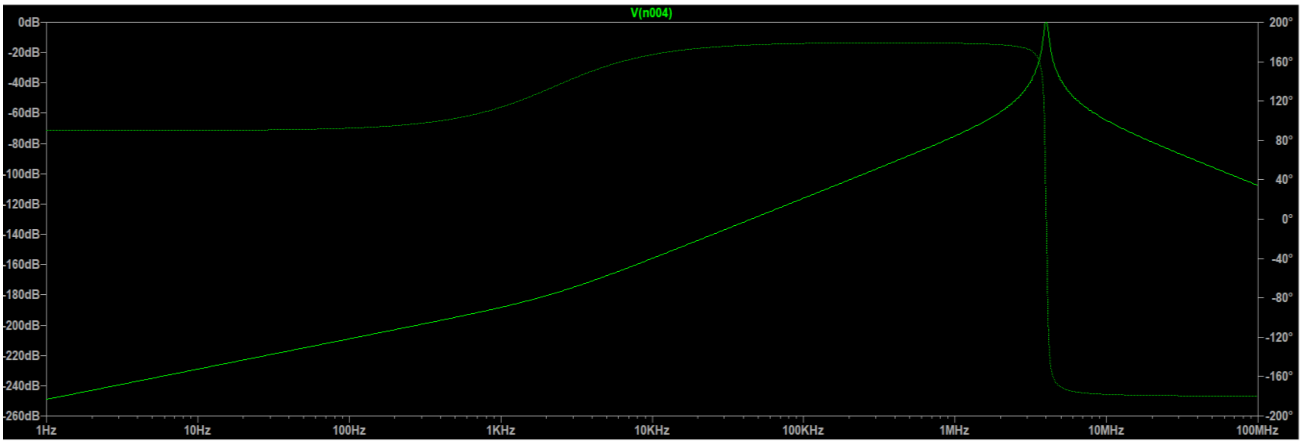

Figure 6 - Overall Result

The frequency at which the Gain is maximum :

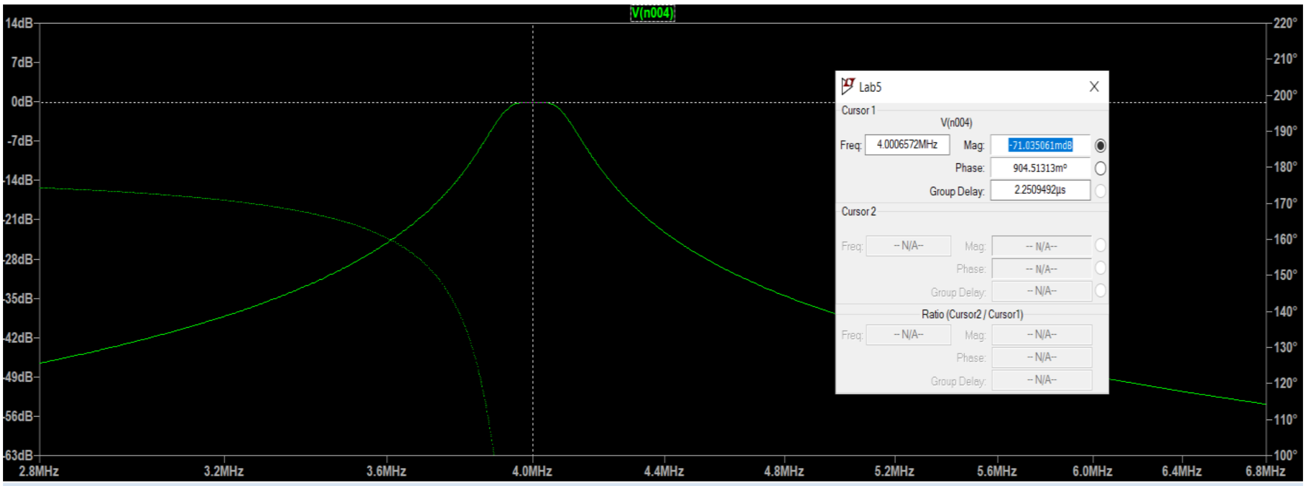

Figure 7 - Gain is Maximum (f_0)

Since it is known that Apass ≤ 3dB the f_{c0} and f_{c1} values are below :

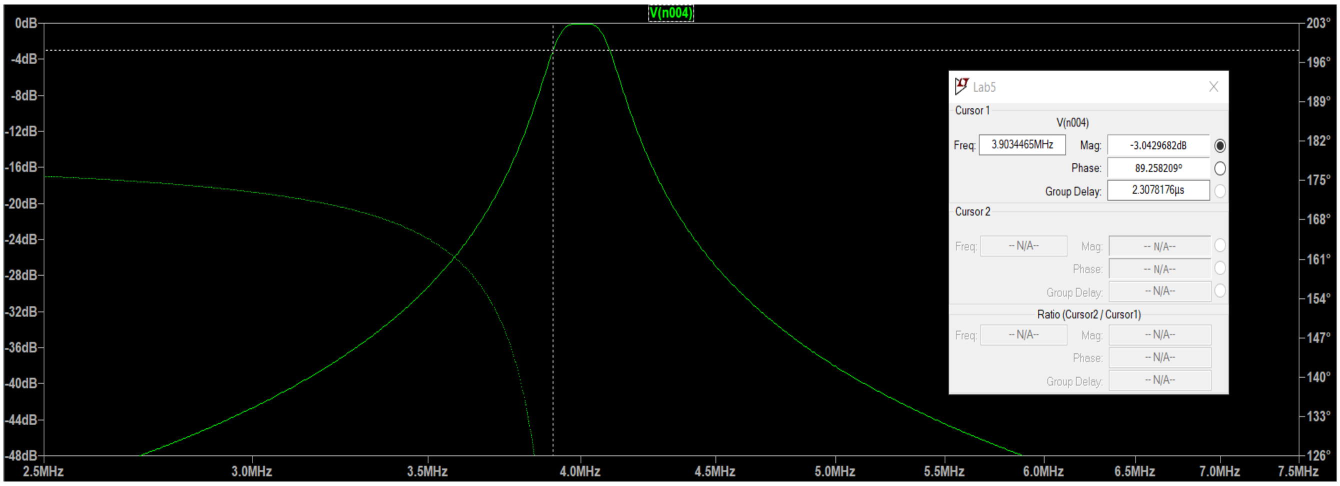

Figure 8 – (-3db) Gain at f_{c0}

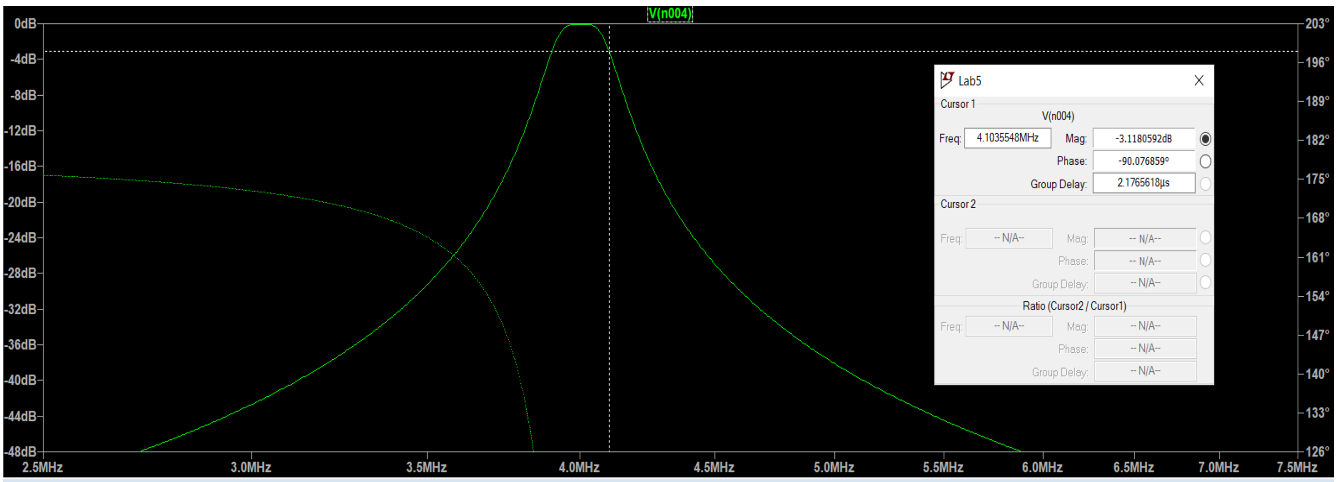

Figure 9 – (-3db) Gain at f_{c1}

The Stopband attenuation must be more or equal (Astop ≥ 30dB), therefore $\frac{f_0}{2}$ *and* $2f_0$ values are below:

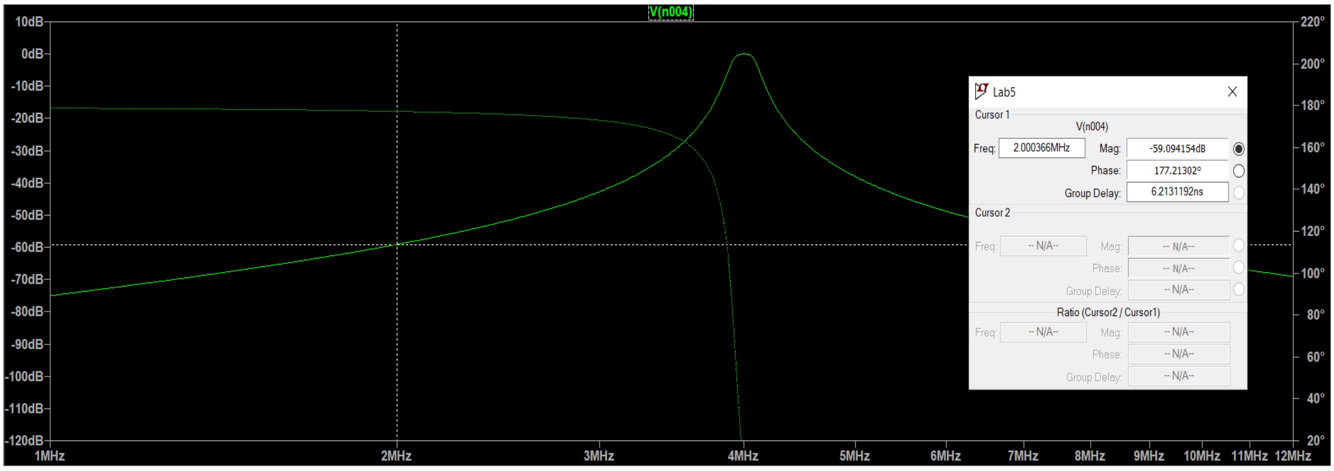

Figure 10 – Gain at Frequency $\frac{f_0}{2}$

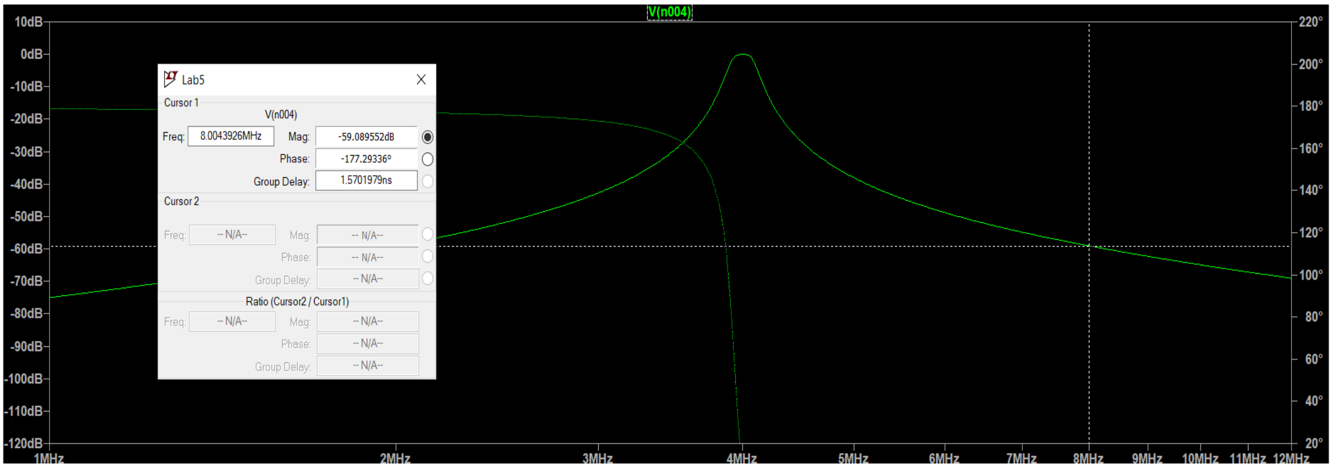

Figure 11 – Gain at Frequency $2f_0$

Table 1 – Important Frequencies and their Gain Values

	f_0	$\frac{f_0}{2}$	$2f_0$	f_{c0}	f_{c1}
Fequency	4.0006572 MHz	2.000362 MHz	8.0043926 MHz	3.9034465 MHz	4.1035548 MHz
Gain	-71.035061 mdB	-59.094154 dB	-59.089552 dB	-3.042962 dB	-3.1180592 dB

Hardware Part:

About 20 different frequency values were taken for the hardware part. The reason why so many frequency values were observed was to draw a more accurate Gain - Frequency graph. These frequency values and gains at these values are as follows:

Table 2 – Hardware Frequency – Gain Table

Frequencies	Gain
4 .2 MHz	-9.707875614
4.1 MHz (Hardware f_{c1} $value$)	-7.103760565
4 MHz (Given f_0 $value$)	-4.349678884
3.9 MHz	-2.624303364
3.8 MHz	-7.455939466
3.94 MHz (Hardware f_0 $value$)	-2.321285785
7.88 MHz (Hardware $2f_0$ $value$)	-32.9760679
1.47 MHz (Hardware $\frac{f_0}{2}$ $value$)	-31.70053304
3.83 MHz (Hardware f_{c0} $value$)	-7.319416052
4.05 MHz	-7.487633961
3.85 MHz	-6.654888177
4.01 MHz	-6.654888177
7.9 MHz	-32.22029668
7.86 MHz	-32.9760679
7.6 MHz	-32.17586748
8 MHz (Given $2f_0$ $value$)	-32.22029668
2 MHz (Given $\frac{f_0}{2}$ $value$)	-26.84845362
2.2 MHz	-27.87150407
1.90 MHz	-27.82752478
1.5 MHz	-29.11863911
1.37 MHz	-30.54400238
3.87 MHz	-6.020599913
3.89 MHz	-4.997549464

As it can be seen instead of the chosen frequency of 4 MHz, the maximum gain is when the frequency is 3.94 MHz.

Special frequency values and Vin and Vout values at these frequency values are as follows :

At 4 MHz :

Vin = 2.72 V   Vout = 1.46 V

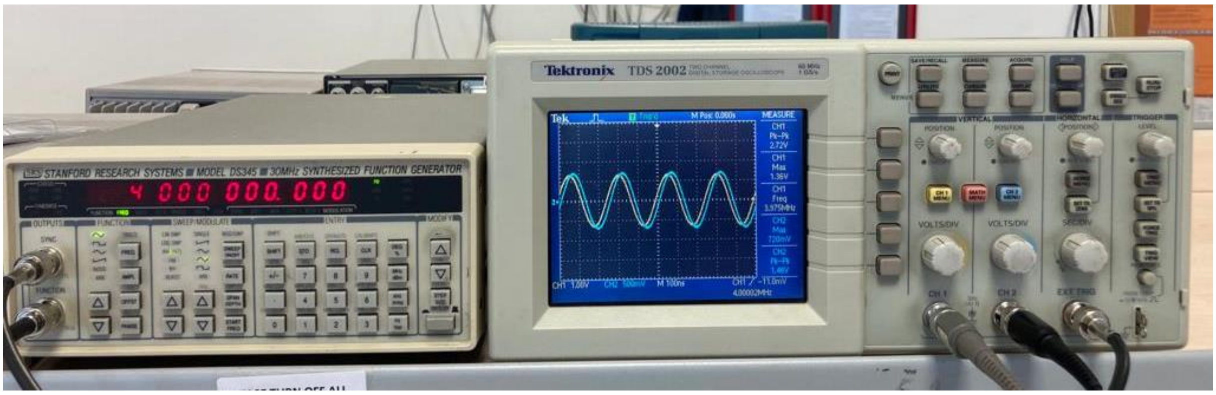

Figure 12 – At 4 MHz

At 2 MHz :

Vin = 3.96 V   Vout = 120 mV

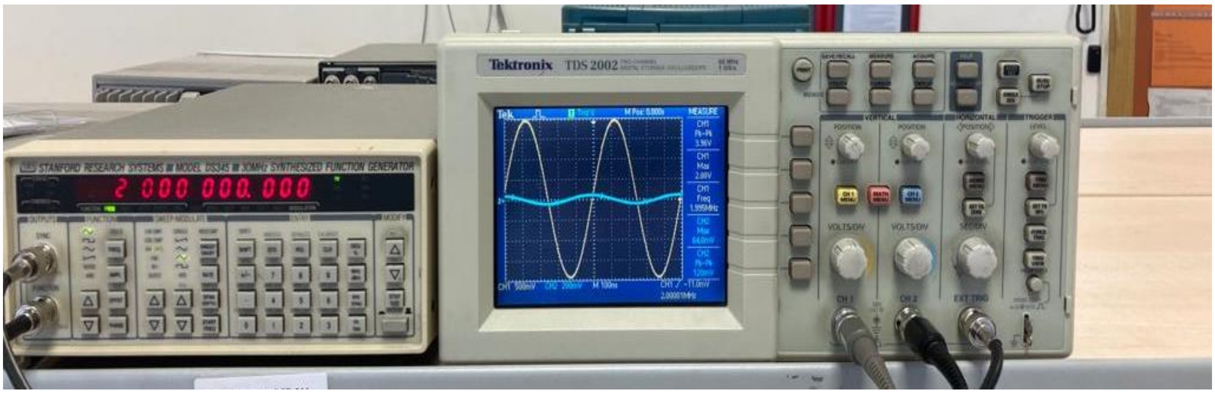

Figure 13 – At 2 MHz

At 8 MHz :

Vin = 3.58 V   Vout = 96.0 mV

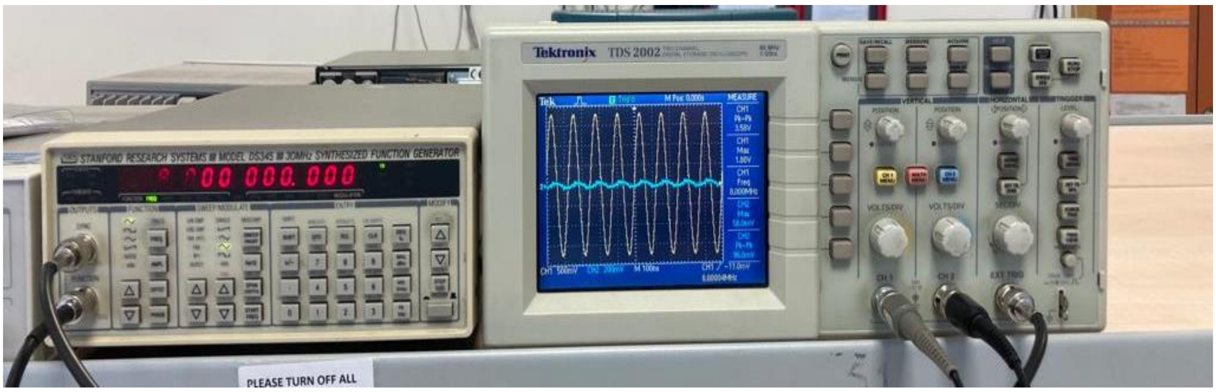

Figure 14 – At 8 MHz

At 3.94 MHz :

Vin = 2.38 V   Vout = 1.76 V

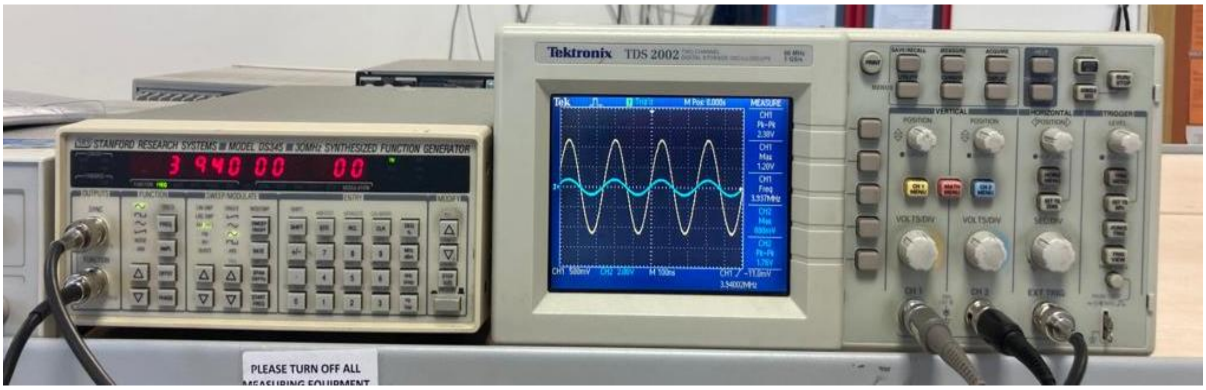

Figure 15 – At 3.94 MHz

At 1.47 MHz :

Vin = 4.00 V   Vout = 104 mV

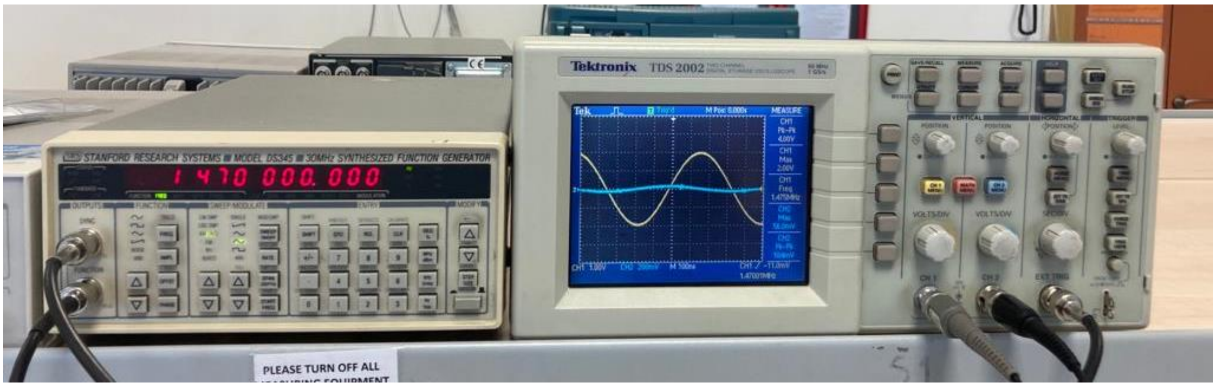

Figure 16 – At 1.47 MHz

At 7.88 MHz :

Vin = 3.92 V   Vout = 88.0 mV

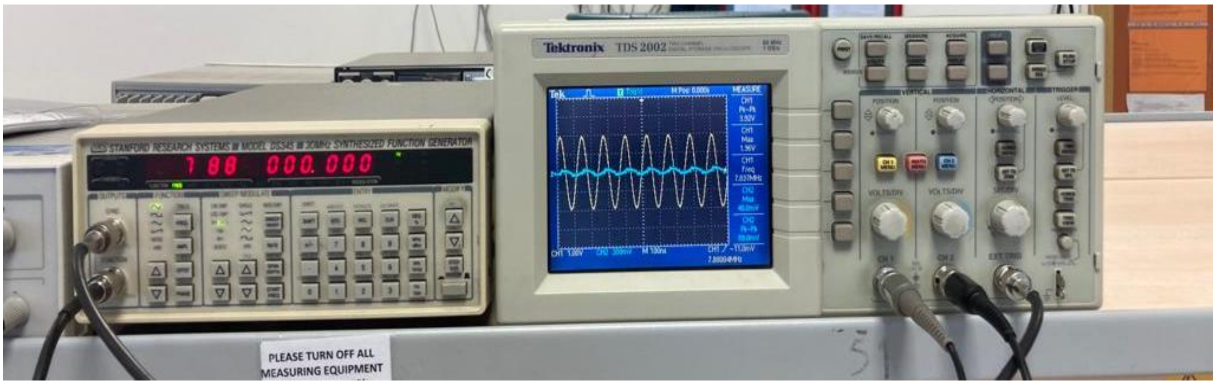

Figure 17 – At 7.88 MHz

It is known that Apass ≤ 3 dB. At 4 MHz we have a -4.35 gain. If -3 dB is added to -4.35 dB, we have f_{c1} and f_{c0} which are approximately -7.35 dB. The formula f_{c1} - f_{c0} = 00.5 f_0 is used to approximate the values of f_{c1} and f_{c0} .

$$f_{c1} - f_{c0} = 0.05 \times f_0 = 200\ kHz$$

It can be round $f_{c1} = 3.83\ MHz$ and $f_{c0} = 4.1\ MHz$ which their gain values are as follows :

At 3.83 MHz :

Vin = 2.88 V Vout = 1.24 V

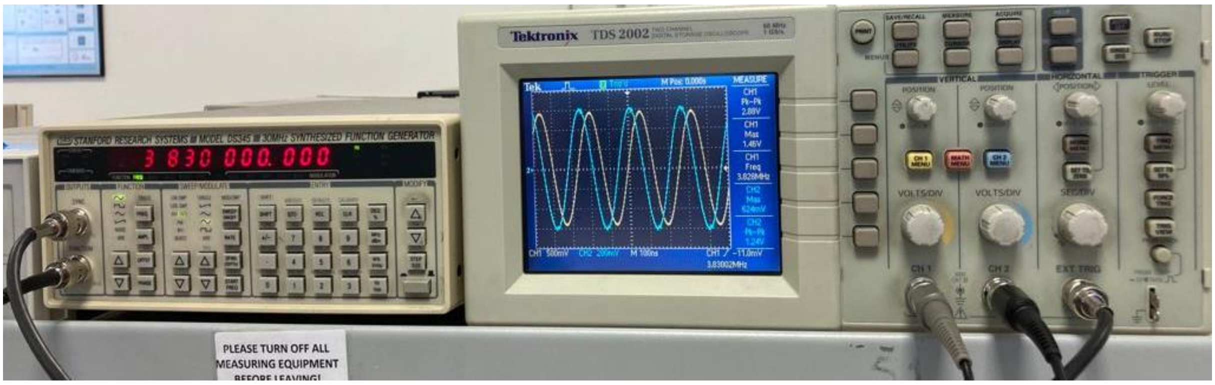

Figure 18 – At 3.83 MHz

At 4.1 MHz :

Vin = 2.90 V Vout = 1.28 V

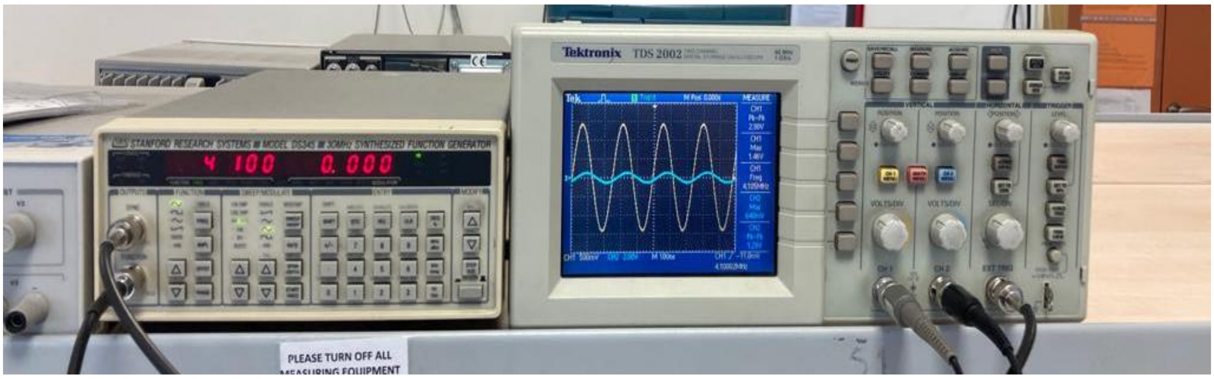

Figure 19 – At 4.10 MHz

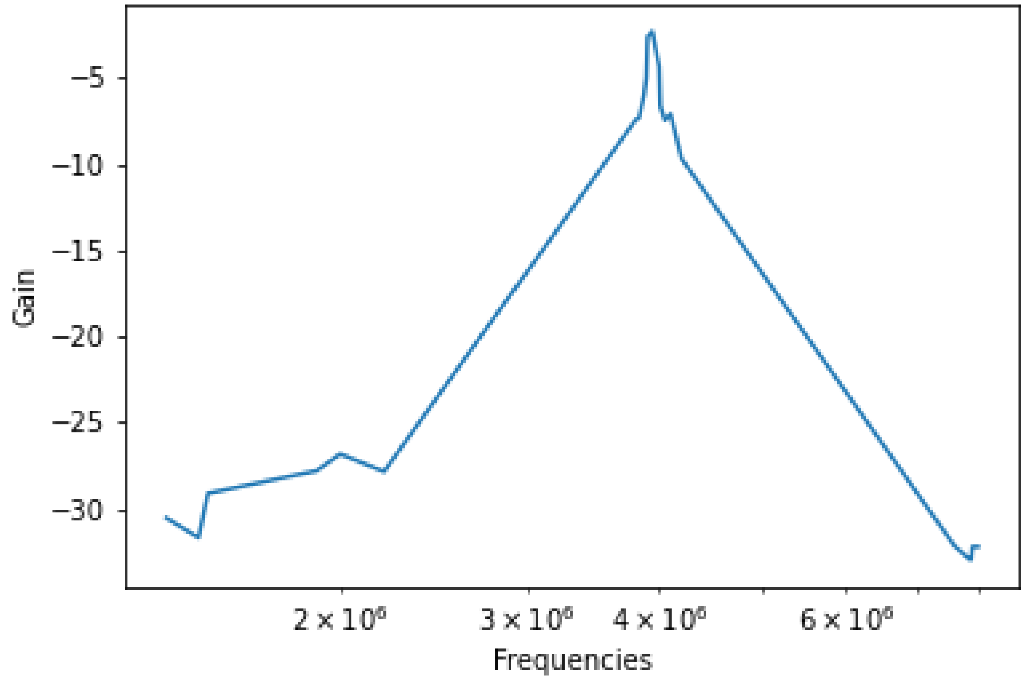

Figure 20 – Gain vs Frequency Graph

Conclusion:

In this experiment, it is designed a bandpass filter with given specifications. The Butterworth filter is chosen to design the bandpass filter. My bandpass filter was the second-order filter. The reason why I picked the second-order is I get more accurate results by using fewer components. In the simulation part, there were nearly no mistakes, and the second-order filter met all of the requirements. My results were predicted, as I had nearly identical results with the theory. However, in the hardware part, since I winded the 70.35 nH inductor myself, an error was observed between 5% and 8% in the f_c and f_0 values. In order to eliminate this, a lower value resistor could be replaced with a 50-ohm load resistor or manufactured inductors can be combined to make desired inductor value instead of winding and a more accurate result could be obtained. Also, it can be collected more than 30 frequency data to plot a more accurate graph. To sum up, I learned to design a bandpass filter both in LTSpice and lab environment.