Software Report Lab 5
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EEE202-03

Software Lab 5

Introduction

This software lab assignment consisted of designing a band pass filter. It was given that our band-pass filters should have a center frequency (f_0) between 1MHz and 6MHz. The load resistor should be 50Ω. Furthermore, the 3-dB bandwidth should be equal to 0.05*f_0. The pass-band loss of the filter should be less than 6dB. The rejection of of the output of the filter should at least 30dB for 0 < f < 0.5f_0 and 2f_0< f < 5f_0. The expected output can be seen below.

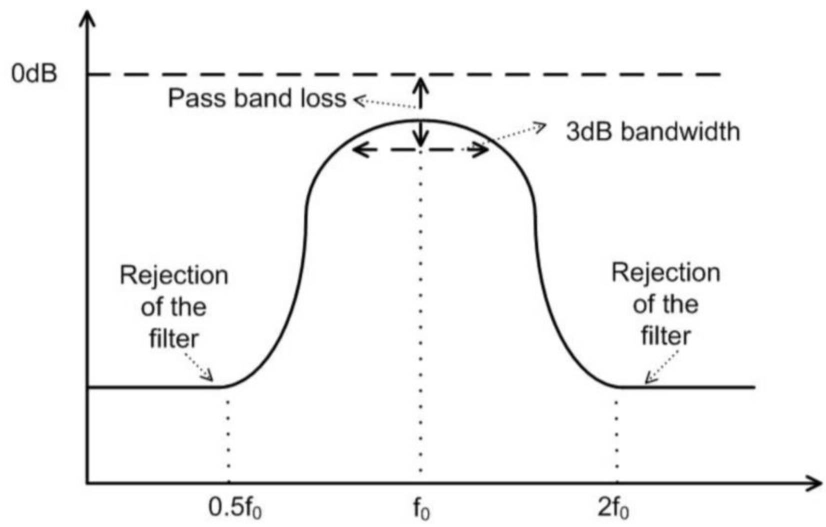

Figure 1: Filter Response

This software report investigates a way to obtain the desired band-pass filter, which will be abbreviated as BPF throughout the report. Then the concluded design will be simulated on LTSpice and the results will be discussed.

Hence, the first process is to select the center frequency that we will be working with. The center frequency (f_0) is chosen as 2Mhz. Hence, the 3-dB bandwidth (Δf) becomes;

$$\Delta f = 0.05 * 2MHz = 100kHz$$

However, there are some important concepts that must be investigated before starting on the structural process. In order to design a BPF, we need to understand how to design Butterworth Filters. One significant detail, I have decided to build a second order Butterworth filter as it is the optimal number when efficiency is concerned. Furthermore, there are two main steps of designing a Butterworth BPF.

1. First, we design a second order low pass filter (LPF), which consists of a serial inductor and a parallel capacitor. Note that the low-pass filter's 3dB cutoff frequency should be equal to Δf.
2. Then, we need to match the capacitor with inductor and vice versa. The capacitor should be in series with the inductor and the capacitor should be in parallel with the inductor. The inductance and capacitance values of these components van be found with the equations below

$$C_1 = \frac{1}{(2\pi f_0)^2 . L_1}$$

$$L_2 = \frac{1}{(2\pi f_0)^2 . C_2}$$

Design and Analysis

Now executing the first step, we need to design a Butterworth LPF. In order to, we need to use the following relations to find the needed inductance and capacitance values.

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

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

We have knowledge of all of these unknowns except the coefficients b1 and b2. These values are to be found from the table that has already calculated values namely "Prototype Element Values in Butterworth LPF".

Order	R_S	C_1 a_1	L_2 a_2	C_3 a_3	L_4 a_4	C_5 a_5	L_6 a_6	C_7 a_7
1	1.0	2.0000						
2	1.0	1.4142	1.4142					
3	1.0	1.0000	2.0000	1.0000				
4	1.0	0.7654	1.8478	1.8478	0.7654			
5	1.0	0.6180	1.6180	2.0000	1.6180	0.6180		
6	1.0	0.5176	1.4142	1.9319	1.9319	1.4142	0.5176	
7	1.0	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450

As our aim is to build a second order LPF, b1 and b2 are both equal to 1.41421. Now we can calculate C1 and L2.

$$L_1 = \frac{b_1 R_L}{2\pi.\Delta f} = \frac{1.41421 * 50}{2\pi.100.10^3} \approx 113\mu H$$

$$C_2 = \frac{b_2}{2\pi R_L.\Delta f} = \frac{1.41421}{2\pi.50.100 * 10^3} \approx 45nF$$

Since we have obtained the required information on designing the LPF, we can implement it on LTSpice and see the results. The implemented circuit can be found below.

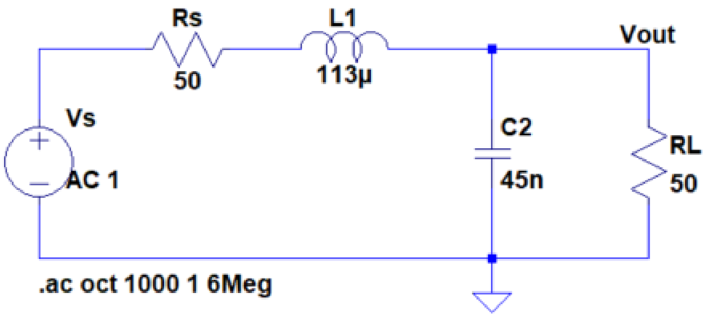

Figure 2 – The LPF Circuit Schematic

AC simulation of the circuit is also down below.

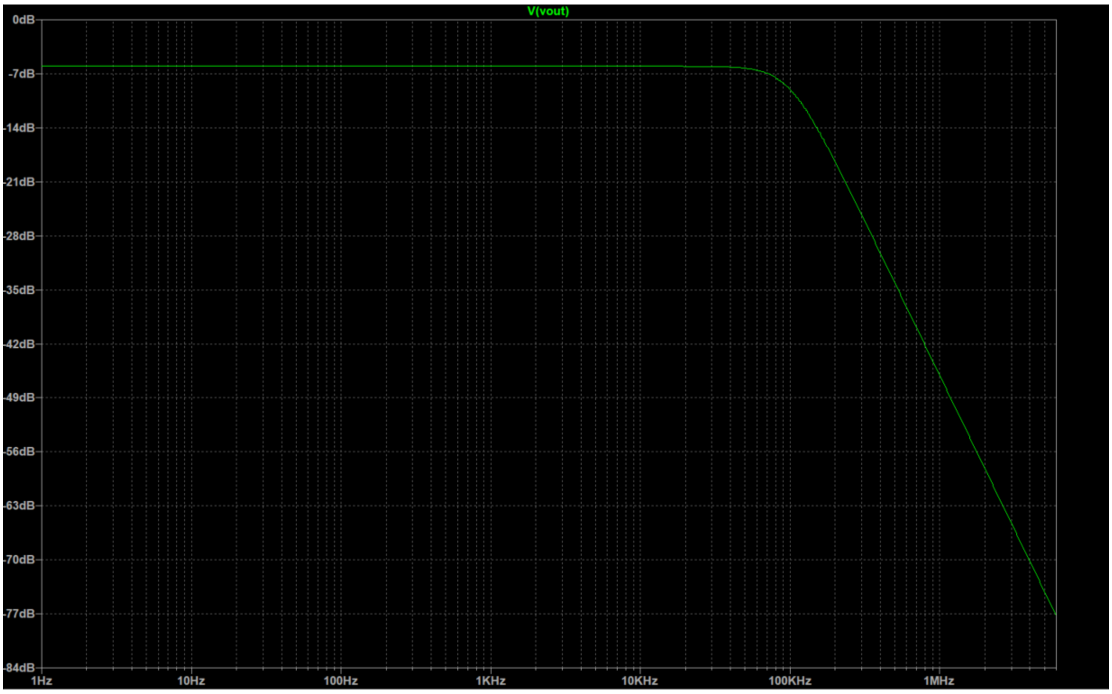

Figure 3 – LPF AC Analysis

As we want to see the exact 3dB cutoff frequency, we use cursers to give it a closer look which can be found down below.

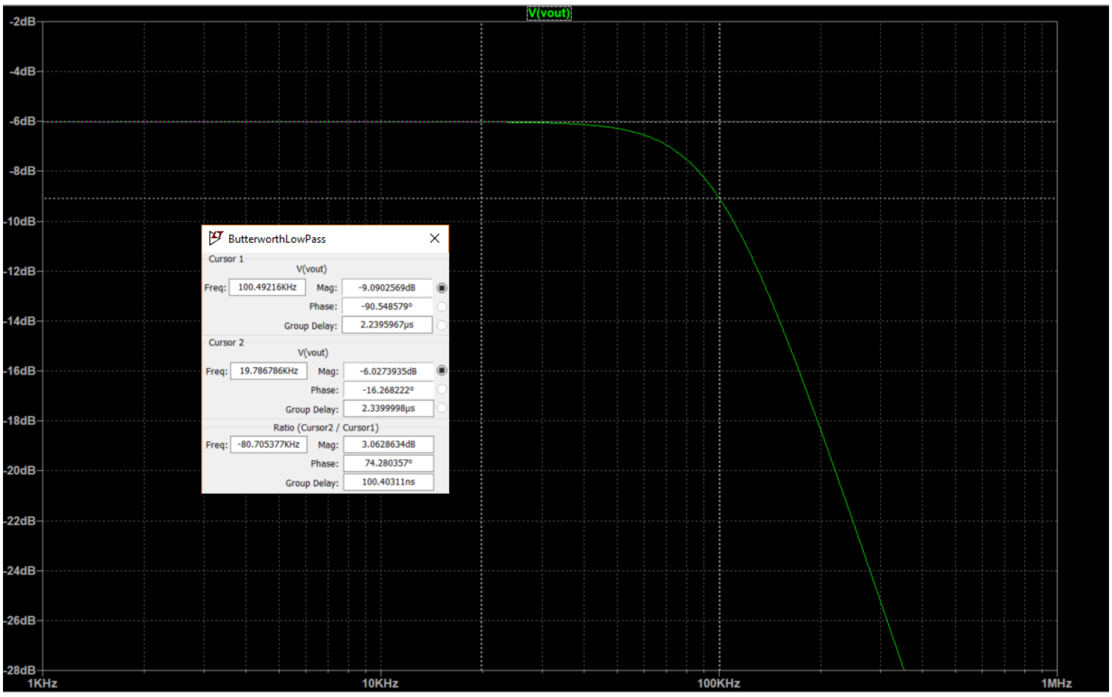

Figure 4 – LPF 3dB Cutoff Frequency

As it is seen from Figure 4, the 3dB cutoff frequency is 100.49216kHz, which is nearly 100kHz, as it is the expected value. Since the design of the LPF is finished, we move onto the second step and add the inductors and capacitors to resonate the circuit on 2Mhz center frequency. However, we first need to obtain the inductance and capacitance values that can be found down below.

$$C_1 = \frac{1}{(2\pi f_0)^2 . L_1} = \frac{1}{(2\pi . 2.10^6)^2 . (113.10^{-6})} \approx 56pF$$

$$L_2 = \frac{1}{(2\pi f_0)^2 . C_2} = \frac{1}{(2\pi . 2.10^6)^2 . (45.10^{-9})} \approx 141nH$$

With the use of these values, we have completed the data collection. The next stage is to put the BPF on test by simulating it on LTSpice. The drawing is given below.

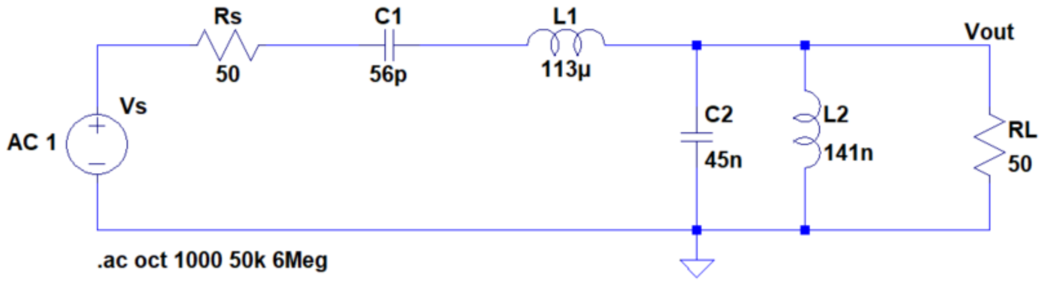

Figure 5 – The BPF Circuit Schematic

As it can be seen, we simulated the circuit from 50kHz to 6MHz to see the range in full resolution. To do, we have used an AC source with 1V amplitude. The AC analysis simulation of the BPF is given below.

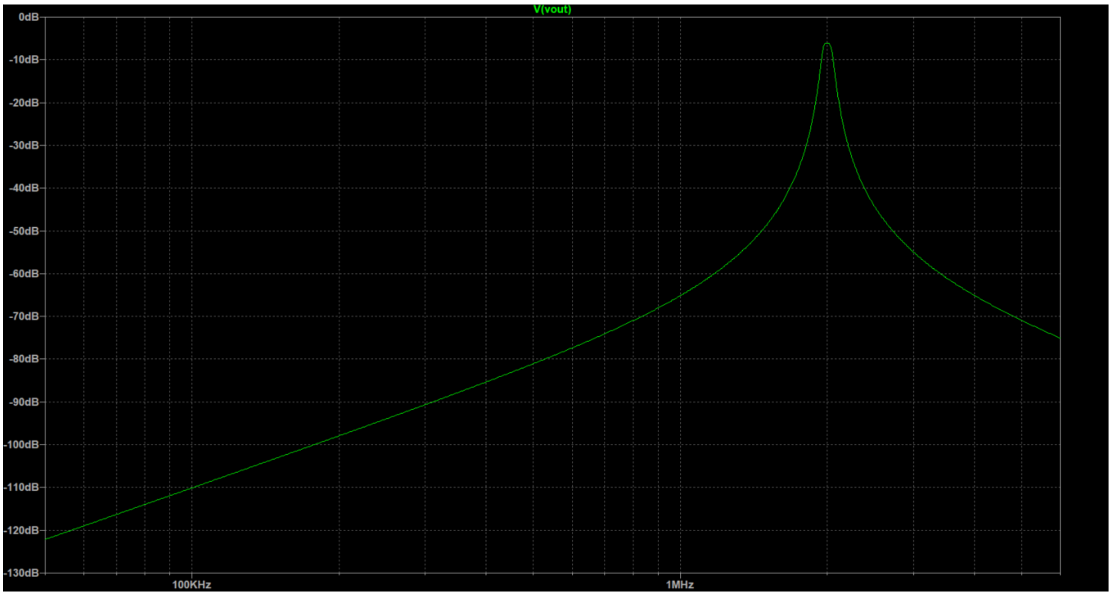

Figure 6 – The BPF AC Analysis

In general, the circuit looks like the expected graph, as this is the graph of the output voltage. However, in order to find if the experiment was a success or not, we should check whether the given criteria in the assignment is matched. First criteria states that the 3-dB filter bandwidth should be equal to $0.05f_0$, 100kHz while the second criteria states that the pass-band loss of the filter should be less than 6 dB. Finally, the third criteria states that the rejection of the filter should be at least 30 dB for 0 < f < 0.5f_0 and 2f_0< f < 5f_0. In order to observe these, we use the cursors and zoom in the function

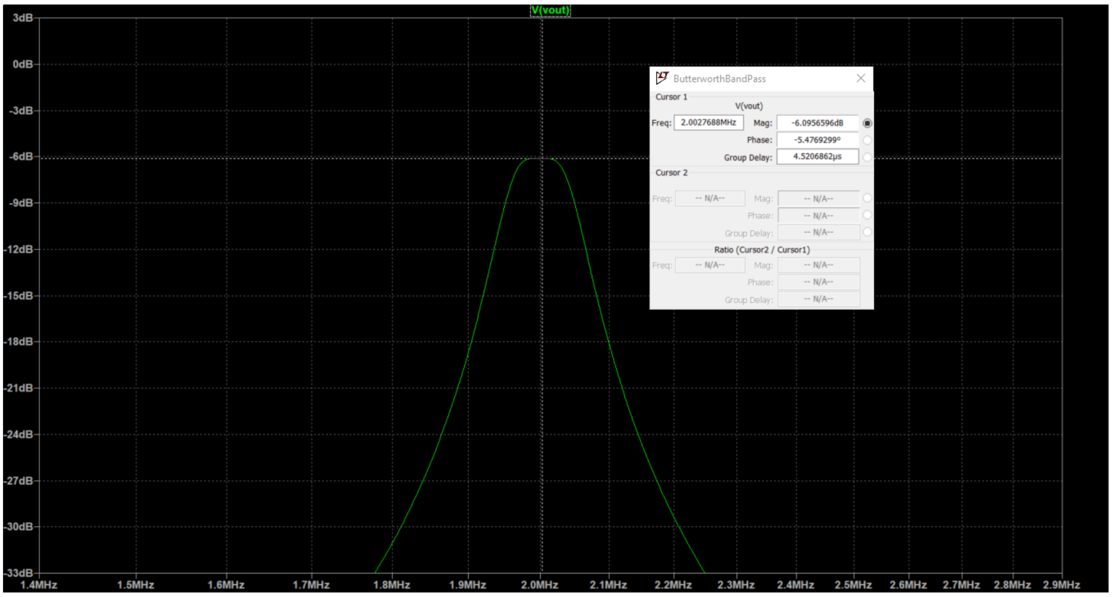

Figure 7 – Peak Zoom of Figure 6

As we can read from the screen, the pass band loss of the filter, which is 6.095dB, is nearly equal to 6dB. The following picture uses the cursors to find the 3dB bandwidth.

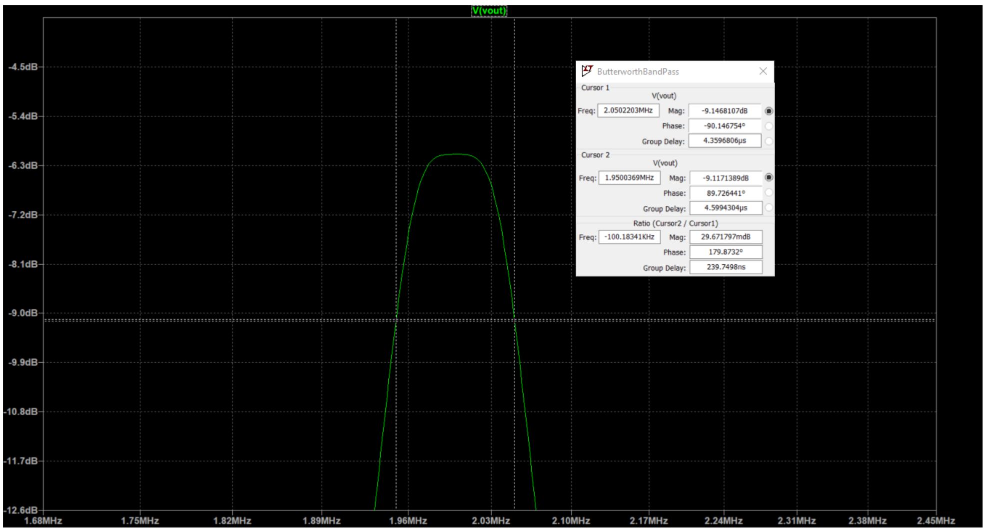

Figure 8 – The 3dB Bandwidth Analysis of Figure 6

From this picture, we can read that the 3dB Bandwidth is equal to 100.1834kHz which is nearly equal to the 100 kHz that we wanted to see. Therefore, we can say that the circuit fulfills the first two criteria. Then, we need to check the third which is the rejection of the filter. The figure shows the two cursors placed on $0.5f_0$ (1MHz) and $2f_0$ (4MHz) as these are the maximum values these voltages can get in the assigned intervals.

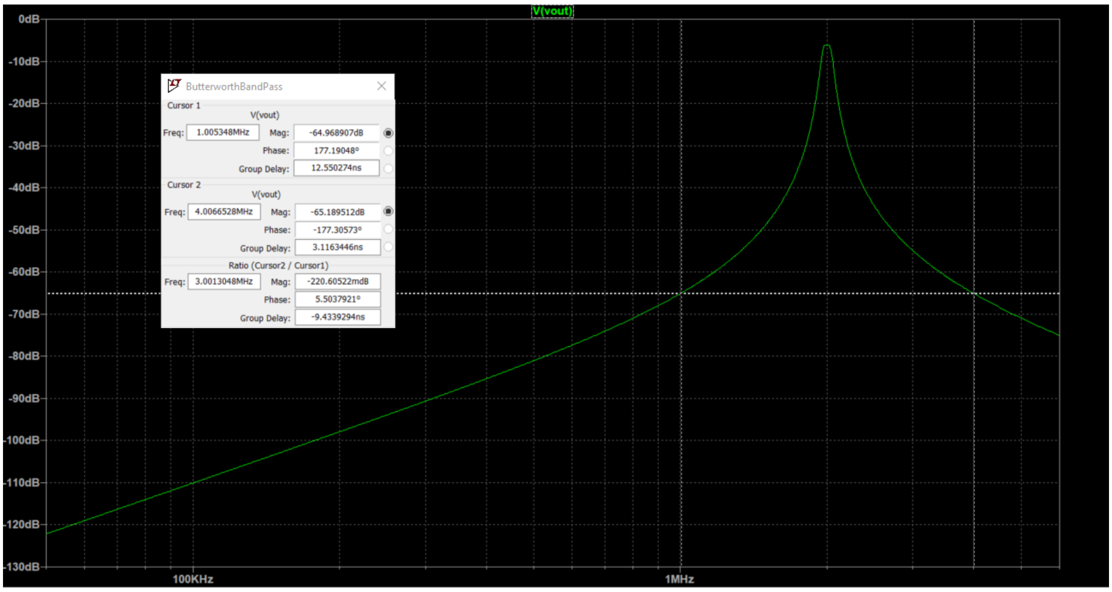

Figure 9 – Rejection of the BPF

It was stated that the rejections should be bigger in dB than 30dB. As we see in the graph, rejections of the points are -64.969dB and -65.190dB respectively. Which means their absolute values are nearly equal to the double of what is required, which is a nice accomplishment. Therefore, we can conclude that we have successfully designed a Butterworth Band-Pass Filter that fits the criteria given.

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Conclusion

This software lab demanded us to design a band pass filter with center frequency in the range 1MHz and 6Mhz and 3dB cutoff frequency equal to $0.05f_0$. We have chosen the frequency to be 2MHz and hence the 3dB bandwidth has become 100kHz. Then using what we have learned in EEE-211 Analog Electronics, we have designed a Butterworth band-pass filter that fit the criteria. As the steps of designing Butterworth included two steps, we designed those steps and finally simulated each on LTSpice. We see that the circuit worked nearly perfect with some minor and unimportant errors.

Finally, we can say that this software lab was very useful for our knowledge on band-pass filters and Butterworth filters. Furthermore, we have increased our knowledge on using LTSpice and resonating circuits.