Report: Circuit Theory Lab 5

Bilkent University Electrical and Electronics Department
EE202-03 Lab 5

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Purpose:

In this lab work, designing a band-pass filter with 50Ω load resistance is done.

Software Implementation:

Introduction:

The design specifications are given below for the required band-pass filter.

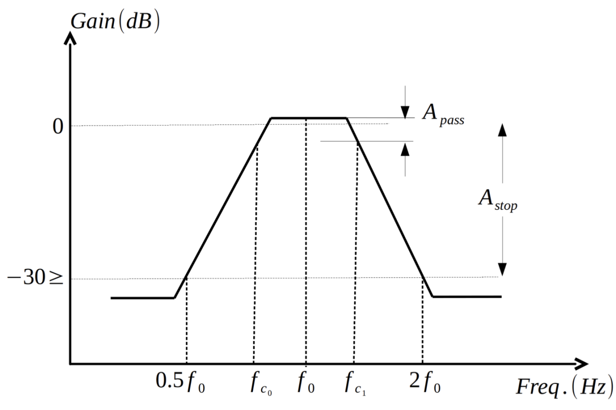


Figure 1: Design specifications.

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: $A_{stop} \geq 30dB$

Analysis:

For the analysis section, the calculations will be explained.

Type of The Filter

The choice of filter type for this design is the Butterworth filter. The selection of this type is not based on any specific reason but rather on the fact that it is the only type of filter studied thus far. As a result, other filter types have not been explored, and therefore the design is implemented using Butterworth filters.

Order of The Filter

This section of the report focuses on the design of the bandpass filter. The chosen approach involves utilizing a second-order filter to meet the specified requirements. The minimum degree is selected to ensure compliance with the given criteria. The relevant formulas and calculations for the design process are outlined below: where P_L = Load Power, P_A = Available Power, f_0 = Center Frequency.

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

The order of the filter is determined by the variable "n" in the formula. Additionally, the filter's order can be established based on the given requirements using the following criteria:

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

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

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

Since $\Delta f = f_{c1} - f_{c2} = 0.05 f_0$ and $f_0 = 5Mhz$ (this value is chosen). $\Delta f_1 = \frac{1}{20} 5 * 10^6 = 250kHz$, inserting to inequality that $f_0 = 5 * 10^6$, $f = 0.5 f_0$ it yields,

$$log_{10}(\frac{1}{1 + (\frac{5*10^6}{2.5*10^5})^{2n}(\frac{2.5*10^5}{5*10^6} - \frac{5*10^6}{2.5*10^5})^{2n}}) \leq -3dB$$

$$log_{10}(\frac{1}{1 + 1 + 20^{2n}(\frac{-3}{2})^{2n}}) = log_{10}(\frac{1}{1 + (-30)^{2n}}) \leq -3dB$$

$log_1 0(1 + 30^{2n}) \geq 3dB \Rightarrow 1 + 30^{2n} \geq 1000 \Rightarrow 30^{2n} \geq 999 \Rightarrow 2n \geq 2.0306$ $\Rightarrow n \geq 1.0153$ n need to be at least second-order.

Hence, it is necessary to select a minimum second-order filter for the desired application. In this laboratory experiment, a decision has been made to employ a second-order Butterworth filter. The next step involves determining the appropriate values for the capacitors and inductors in the filter circuit. To accomplish this, the following Butterworth filter formulas can be utilized. Inductor values can be determined by this formula,

$$L_i = \frac{b_i R}{2\pi f_c}$$

Capacitor values can be determined by using this formula,

$$C_i = \frac{b_i}{2\pi R f_c}$$

Series capacitor values by using resonance frequency,

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

Shunt parallel inductor values by using resonance frequency,

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

Initially, the design process involves creating a second-order low-pass filter utilizing the provided formulas and tables. The calculations can be performed as outlined below. Subsequently, by applying the resonance frequency formulas, it becomes possible to derive a band-pass filter that fulfills the specific requirements of this laboratory experiment.

$$L_1 = \frac{1.414 * 50}{(2 * 2\pi * 250^1 0^3} = 2.250 * 10^{-5}$$
$$C_1 = \frac{1 * 2}{2(2\pi * 5 * 10^6)^2 L_1} = 4.502 * 10^{-11}$$
$$L_1 = \frac{1.414}{2(2\pi * 250 * 50 * 10^3} = 9.00 * 10^{-9}$$
$$C_2 = \frac{1 * 2}{(2\pi * 5 * 10^6)^2 C_2} = 2.25 * 10^{-7}$$

Using the aforementioned calculations, one is now equipped to construct the filter. However, it is crucial to note that prior to designing the band-pass filter, it is necessary to create a low-pass filter employing the Butterworth coefficients and formulas discussed earlier. Subsequently, by applying the resonance frequency formulas, the values of the two remaining unknown capacitors and inductors can be determined.

The circuit can be found as following,

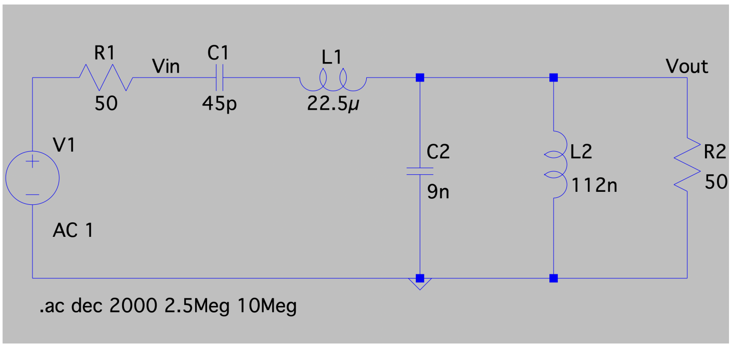


Figure 2: Designed circuit.

Simulation:

In the simulation part designed circuit and its simulation on LTSpice can be found.

Note that the figures below may seem little, but since they are high quality, the reader may zoom in as much as they wish. The size of the figures is as they are just because of aesthetic concerns. If plots are not as visible as required, please kindly zoom in.

Designed Circuit

The below figures include the simulations on the LTSpice,

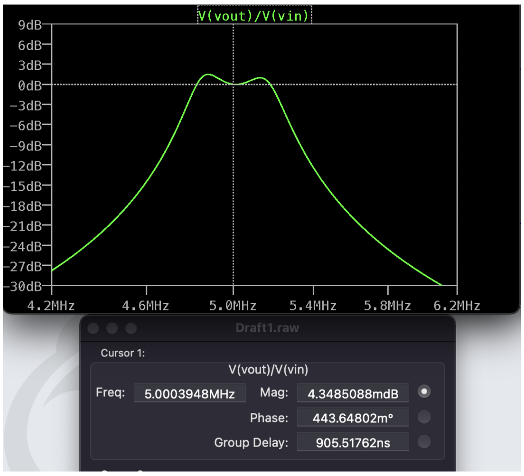


Figure 3: Center frequency $f_0 = 5MHz$.

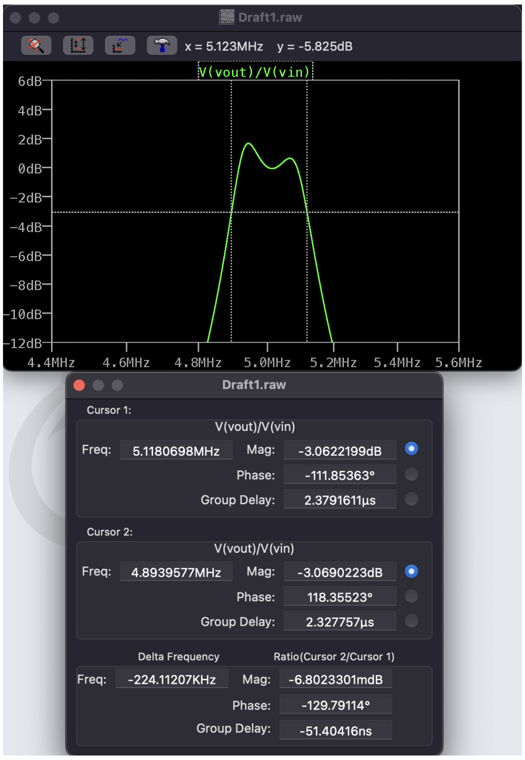


Figure 4: Bandpass $f_{c_1} - f_{c_0} \approx 250kHz$.

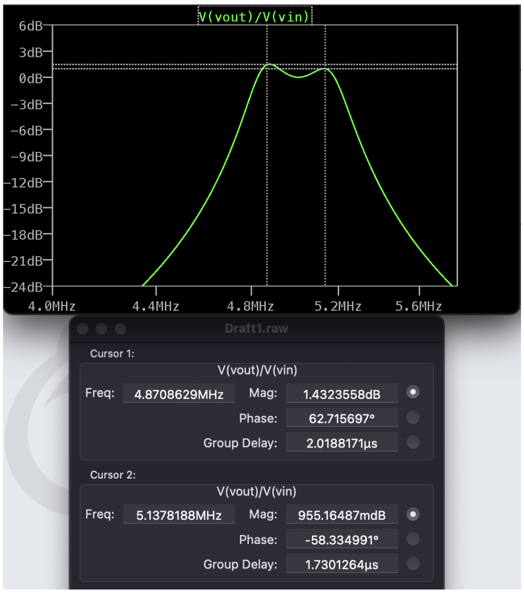


Figure 5: $A_{pass} \leq 3dB$.

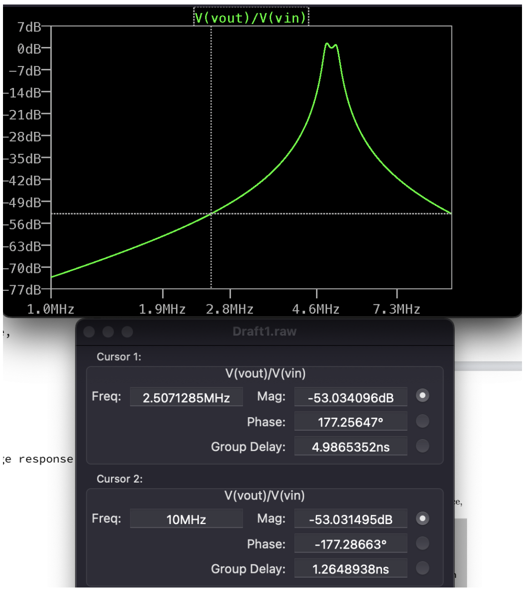


Figure 6: $A_{stop} \geq 30dB$.

Figure 7: Circuit satisfying requirements.

The figures confirm that, the required condition is satisfied for the proposed circuit.

Hardware Implementation:

The hardware implementation consists of the above-described software results' application.

Designed Circuit

This part is the implementation of the proposed circuit for the lab work. Hardware implementation of the circuit.

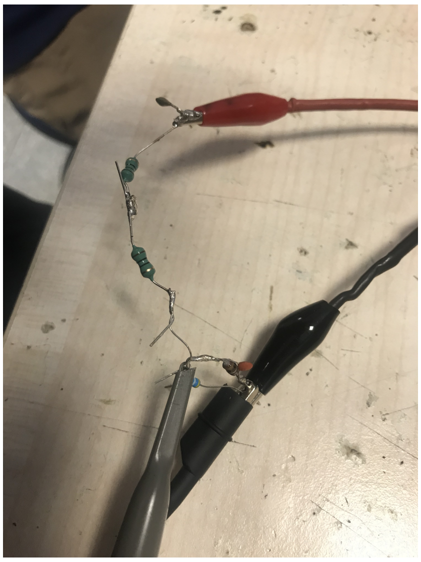
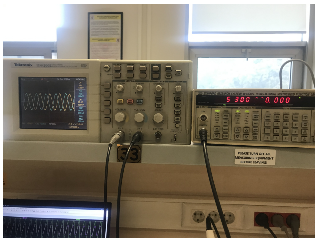
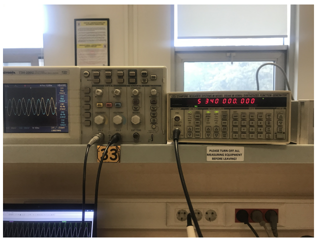


Figure 8: Designed circuit in hardware.

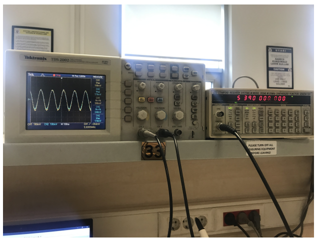
Since the lab-work requires 5 photos of center frequency and stop frequencies. The photos will be shown consequently and the results will be shared afterwards. After implementing the circuit its been noted that center frequency has been shifted to 5.39MHz this shift may have occured due to measurement errors and components errors.



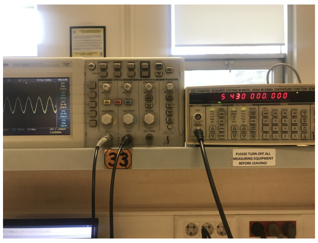
(a) Frequency is 5.3MHz



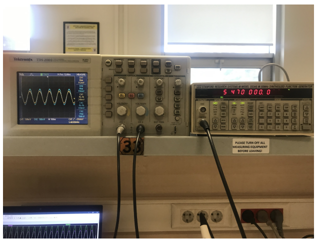
(b) Frequency is 5.34MHz



(c) Frequency is 5.39MHz



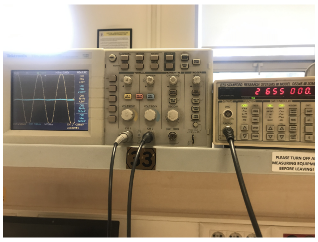
(d) Frequency is 5.43MHz



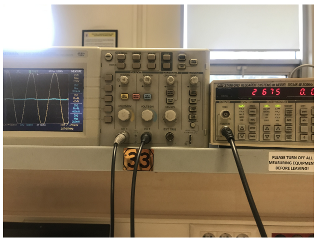
(e) Frequency is 5.47MHz

Figure 9: Around center frequency.

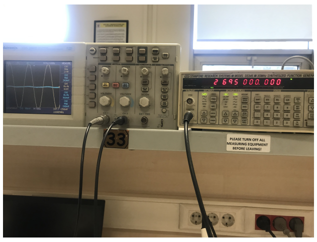
Now around stop frequencies will be given starting with lower stop frequency which is 2.65MHz.



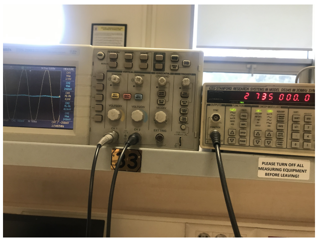
(a) Frequency is 2.65MHz



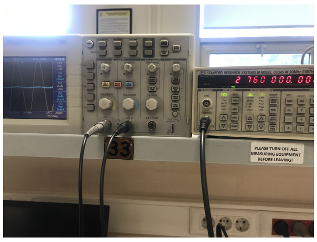
(b) Frequency is 2.67MHz



(c) Frequency is 2.69MHz



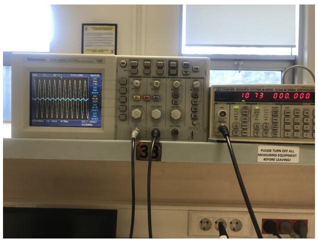
(d) Frequency is 2.73MHz



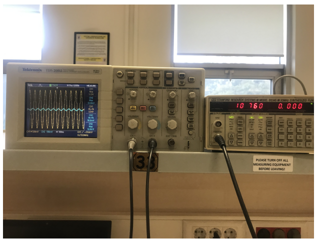
(e) Frequency is 2.76MHz

Figure 10: Around lower stop frequency.

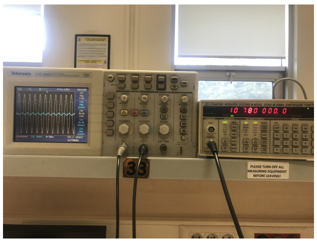
Finally around stop frequencies that is higher which is 10.78MHz.



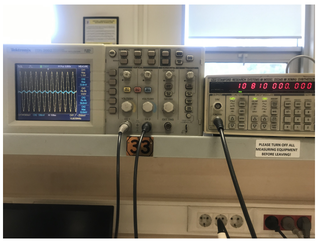
(a) Frequency is 10.73MHz



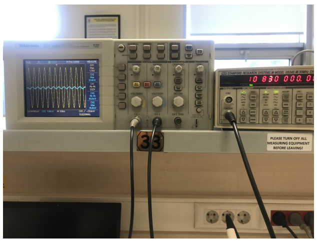
(b) Frequency is 10.76MHz



(c) Frequency is 10.78MHz



(d) Frequency is 10.81MHz



(e) Frequency is 10.83MHz

Figure 11: Around higher stop frequency.

The following table will include voltages and gains of each shown frequency.

Frequency	$V_{max_{Input}}$ (mV)	$V_{max_{Output}}$ (mV)	Gain
5.30MHz	168	164	-0.209
5.34MHz	192	164	-1.369
5.39MHz	188	176	-0.572
5.43MHz	156	132	-1.451
5.47MHz	156	112	-2.878

Table 1: Around center frequency.

As expected around the center frequency does not change more than 3dB.

Frequency	$V_{max_{Input}}$ (V)	$V_{max_{Output}}$ (mV)	Gain
2.655MHz	2.16	24	-39.1
2.675MHz	2.16	28	-37.7
2.695MHz	2.14	24	-39.0
2.735MHz	2.16	24	-39.1
2.76MHz	2.28	24	-39.5

Table 2: Around lower stop frequency.

As expected around lower stop frequency gain is lower than -30dB.

Frequency	$V_{max_{Input}}$ (V)	$V_{max_{Output}}$ (mV)	Gain
10.73MHz	1.76	40	-32.8
10.76MHz	1.78	32	-34.9
10.78MHz	1.78	32	-34.9
10.81MHz	1.76	32	-34.8
10.83MHz	1.76	32	-34.8

Table 3: Around higher stop frequency.

As expected around higher stop frequency gain is lower than -30dB.

Conclusion:

For this lab, the focus is on designing a band-pass filter that meets specific requirements. The filter's order, capacitance, and inductance values are determined using relevant formulas. The design utilizes a Butterworth type of filter. The process involves first designing a low pass filter and then incorporating additional components based on resonance frequency to create a complete band-pass filter circuit.

During the lab, various errors were encountered, primarily stemming from distressed lab elements. Additionally, the unavailability of capacitors and inductors with exact values required adjustments using the closest standard values, contributing to some errors. However, overall, the hardware implementation yielded expected results. While there was a slight shift in the center frequency of 250 KHz, the band-pass filter successfully met its requirements outlined in the Purpose section of the report.

References:

- Analog Electronics, A. Atalar, Accessed from Moodle.