EE 111L Lab Report 3

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1. 1. Objective

Build a band pass filter with series RLC circuit configuration.

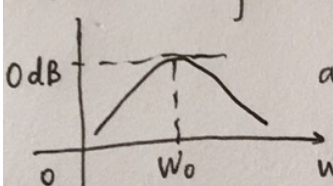
1.2. Theory

$$W_0 = 2\pi f = 2\pi \times 4.1\times 10^{3} = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{150\times 10^{-3}\times C}}$$

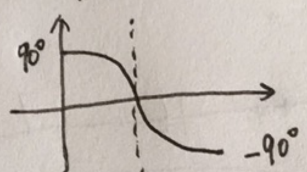
this gives $C = 10nF$. since 3dB bandwidth is 2.3 kHz. magnitude is $\frac{1}{\sqrt{2}}$ at 4.1 kHz − 1.15 kHz = 2.95 kHz. The response is $\frac{V_o}{V_i}$ =

$$\frac{R}{R+R_L+jLw+\frac{1}{jCw}} = \frac{1}{1+\frac{R_L}{R}+jQ\left(\frac{w}{w_0}-\frac{w_0}{w}\right)}$$

theoretically, the magnitude response is



and phase is

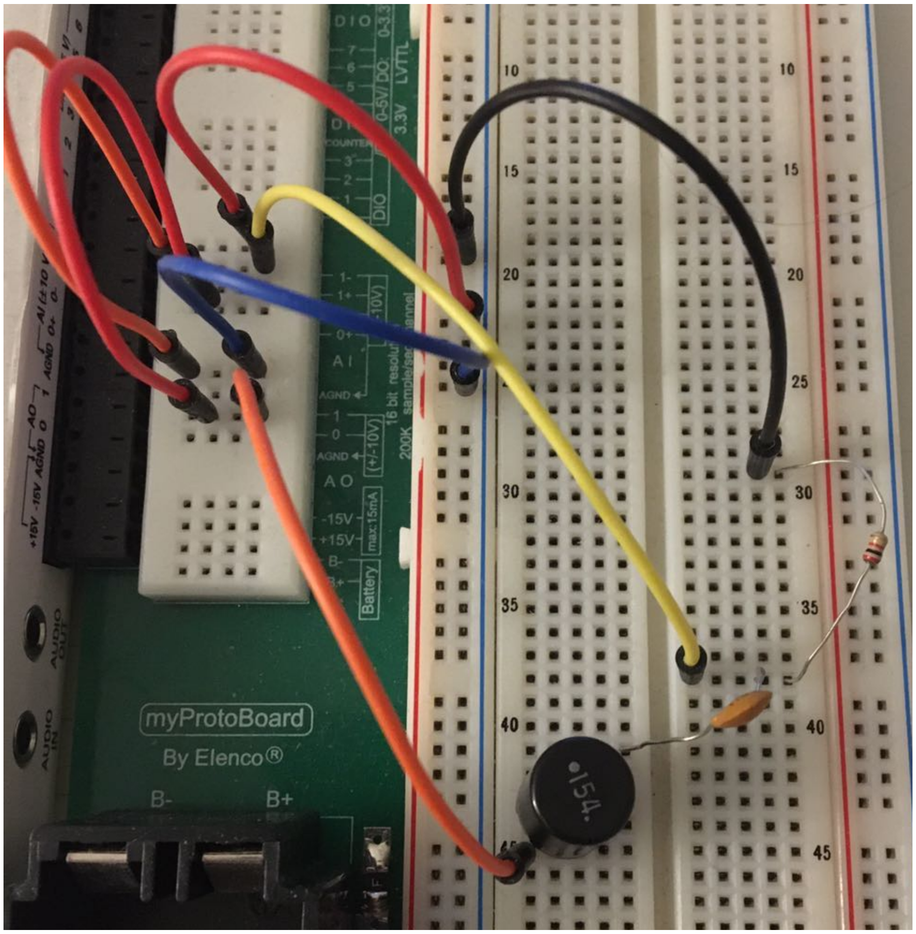


$$\text{at 3dB, } \left|\frac{1}{1+j\cdot\frac{150\times10^{-3}\times4.1\times10^{3}\times2\pi}{R}\left(\frac{2.95}{4.1}-\frac{4.1}{2.95}\right)}\right| = \frac{1}{\sqrt{2}}$$

solving this gives $R = 2590.22$, which is roughly $2.2k\Omega$.

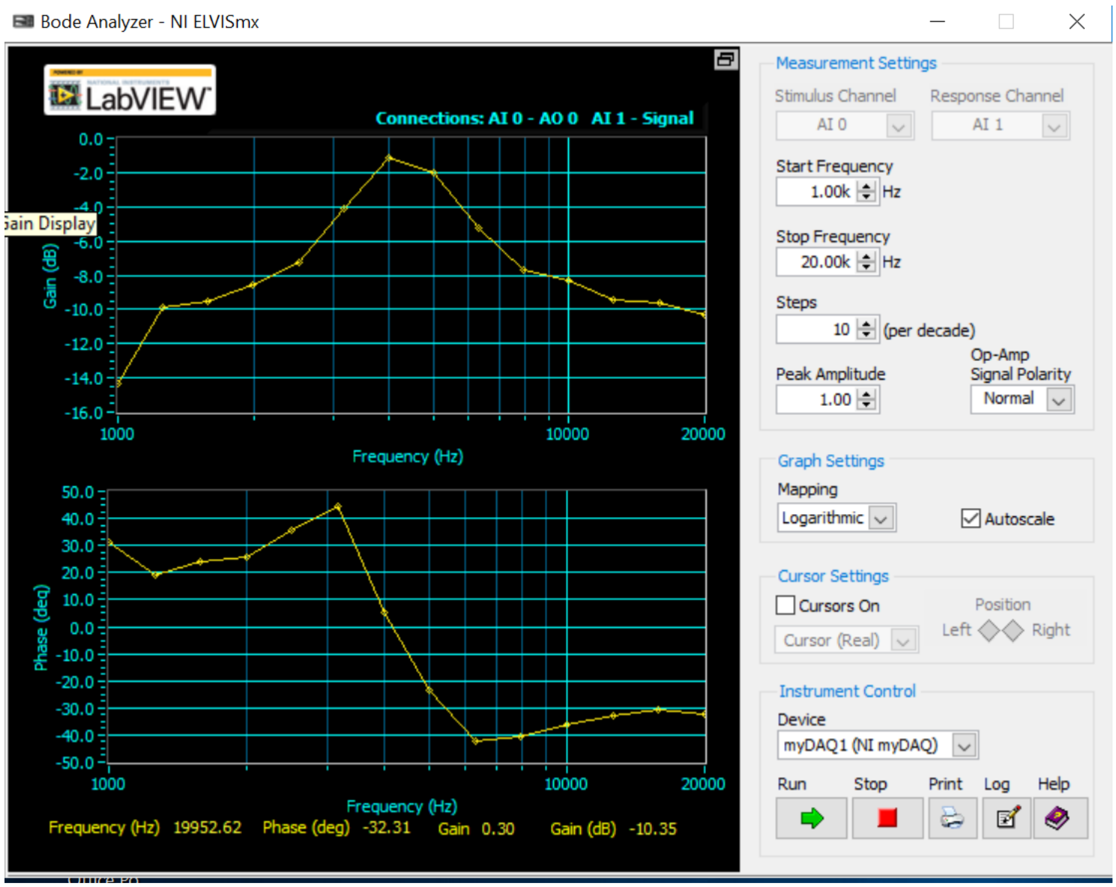
1.3 Procedure

We connect the circuit as shown below in the picture and measure the response of the voltage across the resistor at different frequencies, with the bode plot function of myDaq.



1.4 data and data analysis

The bode plot generated from myDaq is shown below. We can see a peak of magnitude around 4.1 Khz and the overall response is a band pass filter: the magnitude is highest at resonance frequency, and magnitude is small at both low and high frequencies.



1.5 error analysis

I have measured the resistance of the inductor to be 253 ohms. If we consider the effect of this resistance and plug the value into the formula we derived in theory section, we would expect the magnitude of response at resonance frequency to be 1/1+(253/2200), which is 0.89 instead of 1. And the magnitude in bode plot at resonance frequency will be 20log(0.89)=-1.0122 instead of 0. Indeed, we see the peak on bode plot to be around -1.0122 at resonance frequency.

1.6 Discussion

a. derivations are included in theory section.

b. Physically it is a band pass filter because at low frequency, the impedance of capacitor is very large so the current is low, and thus voltage across resistor is small. At high frequency, the impedance of inductor is very large so the current is low, and thus voltage across resistor is small. At resonance frequency, the impedance of inductor and capacitor cancels each other, and thus the current in the circuit is large, and the voltage across the resistor is thus large.

c. Q=2*π *(avg energy stored)/(avg energy dissipated). The energy stored in inductor is 0.25*L*| I |^2, and the energy stored in capacitor is 0.25*C*| Vc |^2= 0.25* (1/CW)^2*| I |^2, and the energy dissipated in resistor is 0.5*R*| I |^2. Plug these equations in to the equation of Q we would get Q=1/(RCW0).

d. The circuit resonance frequency is around 4.1 kHz as we would have expected. There might be small errors because we are using a step size of 1kHz.

e. The 3dB bandwidth is roughly 2.3kHz, there might be small errors because we are using the step size of 1kHz.

f. analysis is included in the error analysis section.

1.7 conclusion

We have verified our expectation of series RLC circuit acting as a bandpass filter.

2.1. objective

Build a low pass parallel RLC circuit and inspect the voltage across resistor.

2.2. Theory

$$W_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{150\times10^{-3}\times C}} = 2\pi\times5\times10^{3}. \quad C = 6.8nF.$$

$$\frac{V_o}{V_i}(jw) = \frac{\frac{R}{1+jRCw}}{\frac{R}{1+jRCw}+jLw} = \frac{1}{1-\left(\frac{w}{W_0}\right)^2 + j\frac{w}{QW_0}}$$

$Q = RCW_0 = 2.1352$. if R_L is included,

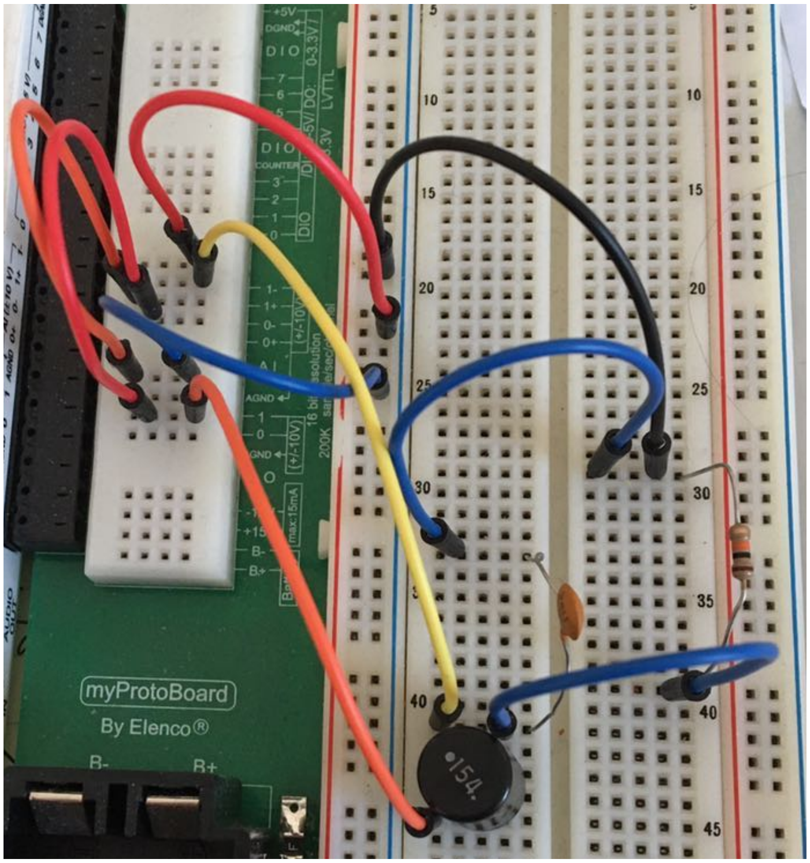
$$\frac{V_o}{V_i}(jw) = \frac{\frac{R}{1+jRCw}}{\frac{R}{1+jRCw}+jLw+R_L} = \frac{R}{R+R_L-LCRw^2+jw(L+RR_LC)}$$

$$= \frac{\frac{R}{R+R_L}}{1-\frac{LCR}{R+R_L}w^2 + jw\frac{L+RR_LC}{R+R_L}R} = \frac{k}{1-\left(\frac{w}{W_0}\right)^2 + j\frac{w}{QW_0}}$$

thus $k = \frac{R}{R+R_L}$, $W_0 = \sqrt{\frac{1}{LC}\left(1+\frac{R_L}{R}\right)}$ and $Q = R\sqrt{\frac{C}{L}} \cdot \frac{\sqrt{1+\frac{R_L}{R}}}{1+\frac{RR_LC}{L}}$. -3dB is achieved when $\left|\frac{1}{1-\left(\frac{w}{W_0}\right)^2 + j\frac{w}{QW_0}}\right| = \frac{1}{\sqrt{2}}$. I used a 10 nF capacitor instead of 6.8nF, and -3dB is at $W = 6214.97$ Hz.

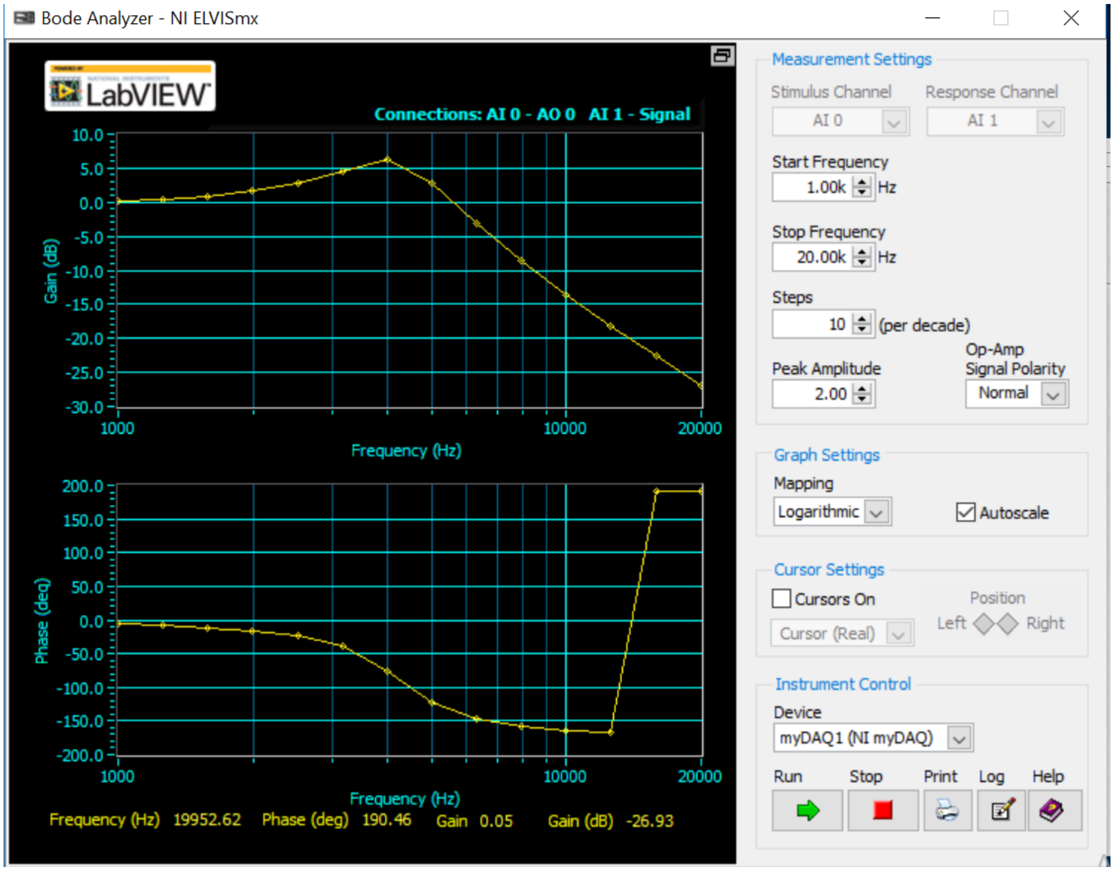
2.3 Procedure

We connect the components as shown in the below picture, and measure the voltage across the resistor.



2.4 data and data analysis

The bode plot is shown below. Here I used a 10nF capacitor because my 6.8 nF capacitor was bad (my 6.8nF capacitor did not work and produced a peak at 11kHz). We can see in the below bode plot that -3dB happens at 6214 Hz, which agrees with our theoretical value in the theory section.



2.5 error analysis

The resistance of inductor is about 253 Ohms, and is relatively small compared to the 10k Ohms resistor we are using. The resistance of inductor would make the resonance frequency to be 4163.13Hz instead of 4111.45 Hz. I am using a 10nF capacitor here because my 6.8 nF capacitor broke, and the theoretical resonance frequency is at 4111.45 Hz instead of 5kHz.

2.6 discussion

a. derivations are shown in the theory section.

b. The calculated transfer function suggested that -3dB happens at 6214 Hz, and this is roughly the same on the bode plot.

c. The circuit is a low pass filter because at low frequency, the impedance of inductor is small and impedance of capacitor is large, so all current flows through resistor, and thus the magnitude of response is big. At higher frequencies, the impedance of inductor becomes bigger and impedance of capacitor becomes smaller, and thus less current flows through the resistor, and the magnitude of response reduces.

d. they match each other.

e. The derivation is shown in the theory section. Here k=R/(R+R_L). Since R_L is roughly 253 Ohms, k is about 0.975.

f. The error caused by inductor resistance is relatively small. It could cause resonance frequency to be 4163 Hz instead of 4111Hz. I am using a 10 nF capacitor because my 6.8 nF capacitor broke down.

2.7 conclusion

Initially I got the wrong graph and during the lab session I got help from the TA s. I then figured out that my 6.8 nF capacitor was not working, so I replaced it with my 10 nF capacitor. From there I verified the low pass filter behavior of parallel RLC circuit.