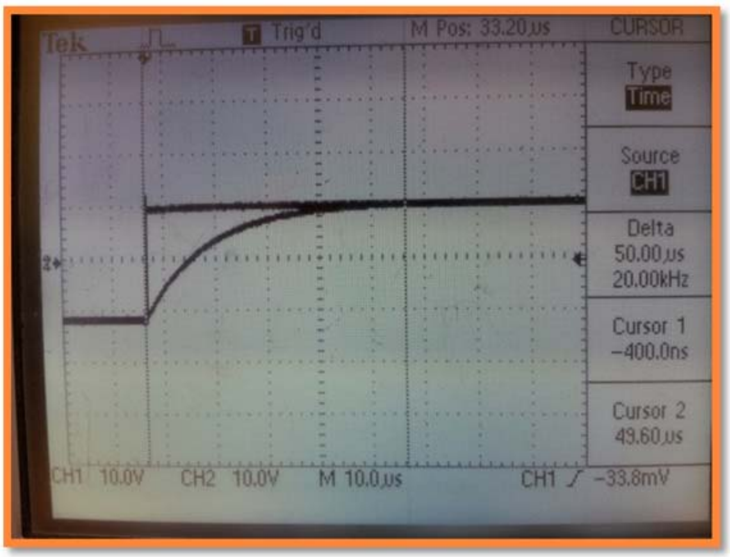
Electrical Engineering 110L
Circuits Measurements Lab

LAB 6: Step Response & Advanced Filter Topics



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OBJECTIVE

In this lab we studied simple step response and first-order filters and twin-T notch filter. To do this we will investigate the step response of capacitive and inductive circuits. We will be designing our circuit with resistors, capacitors, and inductors similar to a design provided in the lab manual. We will design and measure an advanced RC filter during this lab as well.

When we are building the notch filter we will focus on a provided design. We will test the notch filter and find out the rejected frequency. We will create a gain vs. frequency plot for the notch filter as well. By the time we finished we should have basic understanding of notch filters and how to build simple first-order filters and analyze their step response.

THEORY

In this lab we were using the following governing equations to conduct experiments, collect data, and verify principles:

Governing Equations	Equations Information
[1] $X_L = j\omega L$	Inductor's Impedance X = Impedance (Ω), ω = (rad/s), L = Inductance (H)
[2] $X_C = 1/(j\omega C)$	Capacitor's Impedance C = Capacitance (F)
[3] $\omega_R = \frac{1}{\sqrt{LC}}$ or $f_R = \frac{1}{2\pi\sqrt{LC}}$	ω_R= (rad/s) and f_R= resonant frequency (Hz) Resonant frequency occur when: - The impedance goes to zero OR - The gain is maximum
[4] $Z = [R^2+(\omega L-(\frac{1}{\omega C}))^2]^{1/2}$	Series RLC's Impedance (derive from [1] and [2] with KCL) (note: one possible form)
[5] $Q = X_{at\ resonance}/R$	Q = quality factor (unitless) X = Impedance of inductor or capacitor at resonance
[6] BW = $\omega_{Hi} - \omega_{Lo}$	BW = Bandwidth
[7] $\angle Z = tan^{-1}(\frac{\omega L-\frac{1}{\omega C}}{R}))$	Phase angle for Z (RLC circuit in series)
[8] f=1/T	f = frequency (Hz) and T = period (s)
[9] dB = 20*log(V_{in}/V_{out})	Voltage ratio to dB conversion
[10] Gain = V_{out}/V_{in}	Gain of the circuit
[11] BW = $\omega_{HI}-\omega_{LO}$	Bandwidth (ω are usually obtain from 3dB drop from maximum)
[12] Q = ω_R/(BW) = $\|\|Z_c\|\|/R = \|\|Z_L\|\|/R$	Quality factor of the circuit
[13] v(t) = v(0)+[v(∞)-v(0)](1-$e^{-t/\tau}$)	Voltage across an element, t = time, τ = time constant

[14] b = k / (k+1)	Gain of Notch filter (equation variables based on lab manual figure 2)
[15] τ = RC = L/R	τ = time constant for RC and LC circuits

Table 1: Governing Equations for the experiments that follow.

Kirchhoff's Current Law (KCL) –

Sum of all the current coming in equals the current going out. This law is useful when trying to setup a general equation for the circuit. This law may help with finding the impedance.

Kirchhoff's Voltage Law (KVL) –

Voltage in an enclosed loop adds up to zero. This law is useful when trying to setup a general equation for the circuit. This law may help with finding the impedance as well.

Step Response –

A step input to a resistive divider will output a step voltage. This is because of the linearity between resistor and current.

PROCEDURE

Experiment 1: Measure the function generator internal resistance

First we set the square wave to the function generator. We also have to adjust for voltage output to be 10V peak to peak. Then we measure the output voltage and use the voltage divider equation to solve for the internal resistance R_s. When measuring the voltage we prefer having the measured output voltage half of the input voltage.

Experiment 2:

In this part of the experiment we are supposed to create circuit 4 to 7 in our lab manual. After we create each circuit we would measure the Vin and the Vout on two different channel using the, oscilloscope. With the oscilloscope we will be looking for the shape of the graph in which $5\tau < T/2$, $5\tau < 1/(2f)$, or $f < 1/(10\tau)$ are satisfied.

Experiment 3:

In this third experiment we are going to build a notch filter like that shown in the figure below. It should be noted that the resistor R/2 and 2C has two resistors and capacitors in parallel respectively. We were supposed to find values such that the resistance is half and the capacitor is twice.

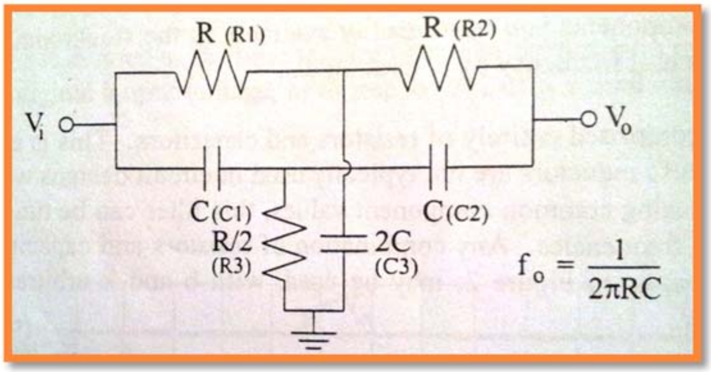

Figure 1: Notch Filter circuit design.

Note that the channel 1 will be connected to the V_i location and channel 2 will be connected to the V_o location.

DATA, DATA ANALYSIS, ERROR ANALYSIS, AND DISCUSSION

Error Analysis Equation

If the general equation is $F(x_1, x_2, \ldots, x_n)$ then the error for F (identified as σ_F) would be given by the following error propagation equation:

$$\sigma_F = \sqrt{(\frac{dF}{dx_1}\sigma_{x_1})^2 + (\frac{dF}{dx_2}\sigma_{x_2})^2 + \cdots + (\frac{dF}{dx_n}\sigma_{x_n})^2}$$

Experiment 1:

Data

	Exp 1	uncertainty	Exp 2	uncertainty
f (Hz)	1kHz	±.05	1kHz	0.46
V_O (V)	1	±.05	10	8.46
V_i (V)	2	±.05	20	9.80
R_L (Ω)	47.0		41.0	
R_S (Ω)	47.0		41.0	

Table 2: Data collected for the function generator resistance calculation

$$R_S = \frac{R_L V_i}{V_o} - R_L$$

Data Analysis & Error Analysis

The above equation can be used to determine the internal resistance of the function generator. Since we measured both voltages on the input and output as well as the resistance we can now look for the R_S. this part of the experiment we notice that there is a slight resistance change when we perform the calculation and find the resistance of the function generator. It seems that at the higher voltage the function generator's resistance decreased.

Discussion

During this part of the experiment we notice that there is a slight resistance change when we perform the calculation and find the resistance of the function generator. It seems that at the higher voltage the function generator's resistance decreased. The change is pretty small when comparing it to the change in voltage. From the table's resistance and voltage relationship for the oscilloscope it seems their relationship is inversely proportional. We choose to take the average of the resistance for R_s so R_s = 44 Ω.

Experiment 2:

Data

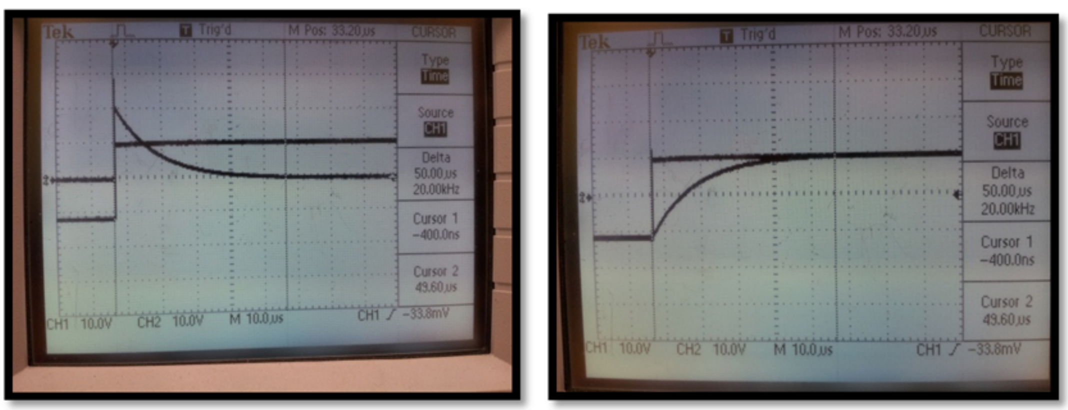

Figure 2: Oscilloscope graph for both RC circuit A (left) and B (right)

R_s = 44 Ω ±.5

RC-Circuit (Circuits A and B)

	Circuit A	uncertainty	Circuit B	uncertainty
R_1	1.093 kΩ	±.0005	1.093 kΩ	+/-.0005
C	10.40 nF	±.005	10.40 nF	+/-.005
τ(theoretical)	11.36 µs	±.008	11.36 µs	+/-.008
τ(theoretical w/ R_{int})	11.82 µs	±.009	11.82 µs	±.009
τ (experimental)	10.00 µs	±.05	10.00 µs	±.05
Percent Error	12.0%		12.0%	
Percent Error (w/R_{int})	15.4%		15.4%	

Table 3: RC – circuit recorded data.

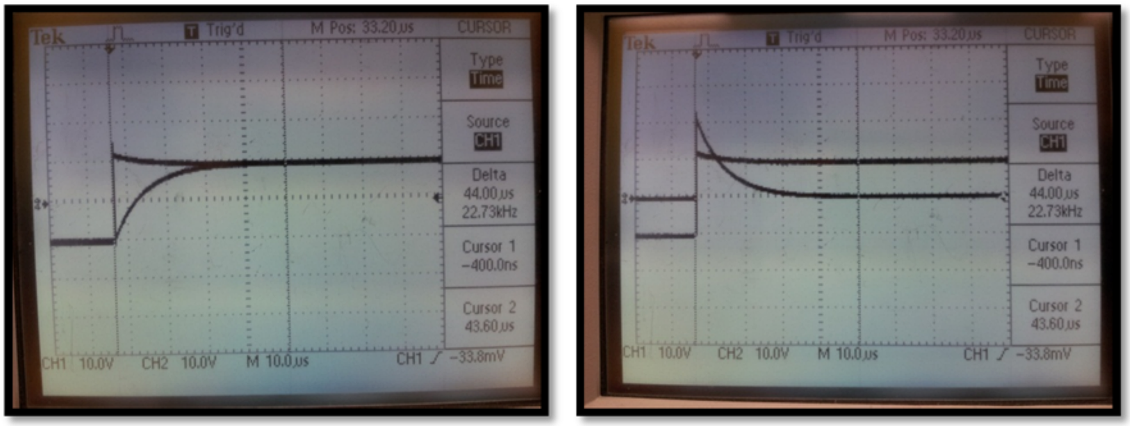

Figure 3: Oscilloscope graph for both LR circuit C (left) and D (right)

RC-Circuit (Circuits A and B)

	Circuit A	uncertainty	Circuit B	uncertainty
R_2	387.9 Ω	±.05	387.9 Ω	±.05
L	3.41 mH	±.005	3.41 mH	±.005
τ(theoretical)	8.8 µs	±.02	8.8 µs	±.02
τ(theoretical w/ R_{int})	7.9 µs	±.02	7.9 µs	±.02
τ (experimental)	8.8 µs	±.05	8.8 µs	±.05
Percent Error	0.0%		0.0%	
Percent Error (w/R_{int})	11.4%		11.4%	

Table 4: RC – circuit recorded data

Data Analysis & Error Analysis

In this part of the experiment we find both time constant with the R load only and a combination of resistor's load and R_s. To find the time constant for an RC circuit all we have to do was use the simple equation [15] for RC. When calculating for the theoretical with R_s all we have to do is add the R_s (or R_{int}) to the original $R_{load\ (1\ or\ 2)}$. That new value will just go in the location of R for example $\tau = (R+R_s)*C$ and $L/(R+R_s)$ is the theoretical equation with R_s.

The two circuits A and B are actually quite different. A is called a high pass filter and B is called a low pass filter. High pass filter only let high frequency pass and low pass only lets low frequency pass. We calculated the same time constants for each case.

To find the time constant for an LR circuit all we have to do was use the simple equation [15] for L/R. When calculating for the theoretical with R_s all we have to do is add the R_s (or R_{int}) to the original $R_{load\ (1\ or\ 2)}$. That new value will just go in the location of R for example $\tau = (R+R_s)*C$ and $L/(R+R_s)$ is the theoretical equation with R_s.

The two circuits C and D are actually quite different. D is called a high pass filter and C is called a low pass filter. We calculated the same time constants for each case and not surprisingly they are the same time constant.

When performing the error analysis we always obtain a higher percent error for the w/ R_s value. It should be noted that all the value do now fall within the others range. This also makes it difficult to verify any theories. The error for this lab was slightly greater than most other lab we had before. This could be due to the poor measurement we were taking when estimating the time constant with the cursor function.

Discussion

In this part of the experiment we were quite surprised by the value we got for our percent error. They were almost never that high in our previous experiment. Their values were all quite close in the range when we look at the values only. The problem is that the uncertainty does not account for the error in the discrepancy. The other problem is that calculating for the error when using the cursor function cannot easily be quantified so this will be adding further uncertainty that is currently not accounted for. Even if we ignore this all of the value are all in the microseconds range with a +/– 2 from its theoretical value.

Experiment 3:

Data

	Value	uncertainty
f_n (theoretical)	56.8 Hz	+/- 2.9
f_n (experimental)	56.0 Hz	+/-2.0
Percent Error	1.55%	
$V_o/V_i\|_{f=fn}$	0.013	+/-.00023
Rejection Ratio	0.013	+/-.00023

Table 5: Table for the notch frequency

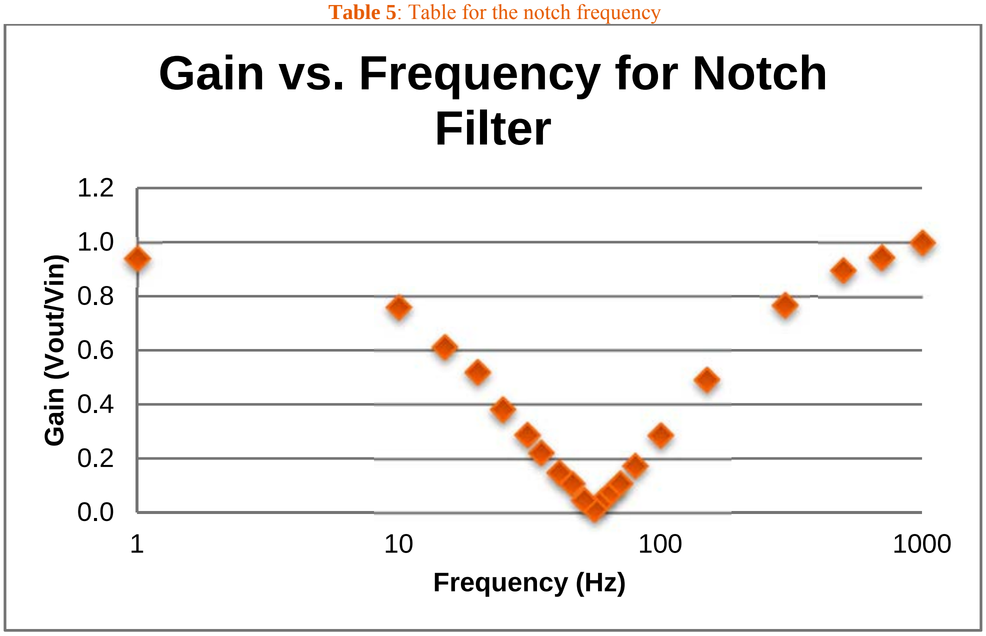

Figure 4: Gain vs. Frequency for Notch Filter Graph. (Note the close to zero gain represent the notch frequency.)

Data Analysis & Error Analysis

R = 280 +/- 3 kΩ

C = 10 +/- .5 nF

In this experiment all of our resistors fall within the range of 277 to 283. So we can assume that the range of the overall resistor is 280+/-3 kΩ. The same goes for the capacitors. We can say that they all fall within the range of 10 +/- .5 nF. In doing so we can now use the following formula in the lab manual to calculate for the f_n and its possible uncertainty using the error propagation formula.

$$f_n = \frac{1}{2\pi RC} = 56.8 +/- 2.9\ Hz$$

$$Rejection\ Ratio = \frac{V_{o,min}}{V_{o,max}} = 1.30E\text{-}02$$

From the calculation it seems like our calculation fair well and they both falls within the range of uncertainty and the percent error is extremely small.

Discussion

This experiment provides a really nice graph that easily tells us the results of how the gain varies with frequency. We can clearly see the huge dip in the around the 56 Hz like we expected from our theoretical calculation. It is said that a notch filter reject basically one specific frequency strongly more than the rest and this would be the 56 Hz or so frequency.

We can say that the experiment for this section was a huge success as we were able to verify the notch frequency.

CONCLUSION

In conclusion this experiment was a great success we were able to get extremely small percent error for the experiment 3. The second experiment we didn't run into problems at all when we were experimenting. But for some reason the percent error were around 10% which is quite high. Though it is true that equipment and our ability to use the cursor function does affect our measurement.

Even with this problem we were able to still complete the RC and LR circuit and understand their step response. Our notch filter was a great success. We were able to obtain an extremely small % error and they both fall within each other range of uncertainty.

To improve in our future experiment we need a better method of measuring the time using the cursor function. Beside that the overall experiment was a great success.