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Lab 4: Filters and Resonance

Introduction

The purpose of this lab contains two sections. The first section is to become familiar with how to construct and interpret low pass filters. The second sections is to analyze resonance and bandwidths theoretically and through LabView results. The circuit constructed for analyzing resonance is shown in Figure 1.

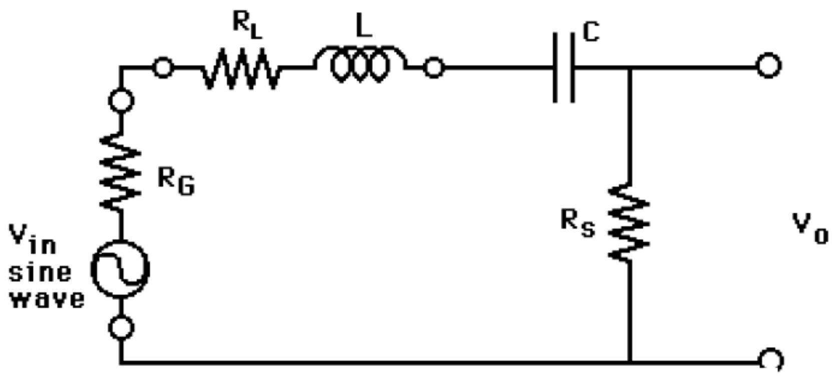

Figure 1. RLC circuit schematic for resonance section of the lab procedure (Gannett, lab handout, 2019).

Methodology

The circuit for a low pass filter is drawn in Appendix A section 1. In Lab 3, the high pass filter measurement was across the resistor. In this lab, since the measurement is across the capacitor, it is a low pass filter. To obtain gain plots, LabView was used by connecting the input and output voltages with channels. The gain equation for the 3dB point of a low pass filter is the same for that of a high pass filter (Gannett, lecture, 2019):

$$V_{out} = \frac{V_{in}}{\sqrt{2}}$$

The gain equation for the low pass filter is expressed as:

$$\frac{V_{out}}{V_{in}} = \frac{Z_c}{\sqrt{Z_R^2+Z_c^2}}$$

Where:

Zc	=	the impedance of the capacitor [[Ω]
ZR	=	the impedance of the resistor [[Ω]
Vout	=	the output voltage [V]
Vin	=	the input voltage [V]

Table 1 shows the given values of the capacitor and inductor used in the circuit followed by the measured internal resistance of the inductor in Figure 1. The resistance of the inductor was measured by using a multimeter. The point at which the resonant frequency occurs is where the impedance of the capacitor and inductor are equal and opposite, so the values cancel out and the only resistance is that of the resistor in this case (Gannett, lecture, 2019). Therefore, at resonant frequency the minimum impedance and maximum power transfer of the circuit occur (Boylestad and Nashelsky 2006). The bandwidth of the resonance curve is the outer bounds that contain the resonant frequency directly in the center.

Table 1. Circuit component values for the resonance procedure.

Decade Box Inductor [H]	Decade Capacitor [F]	Measured internal resistance of inductor [Ω]
1	1.0x10-6	40.5

The gain for a band-pass filter is given by the following equation:

$$Gain = \frac{V_{out}}{V_{in}} = \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}}$$

This equation results from applying the voltage-divider equation to an RLC circuit. In other words, the circuit's gain is the ratio of the resistance to the magnitude of the total impedance. When the input signal is near the resonant frequency, the impedances of the inductor and capacitor nearly cancel each other out, giving a gain value near 1. As the frequency moves further from the resonant frequency, the inductor and capacitor cause the total impedance to increase, bringing the gain down toward 0.

Results

The following table and plots present our experimental results alongside our theoretical predictions for the high-pass filter and bandpass filter circuits.

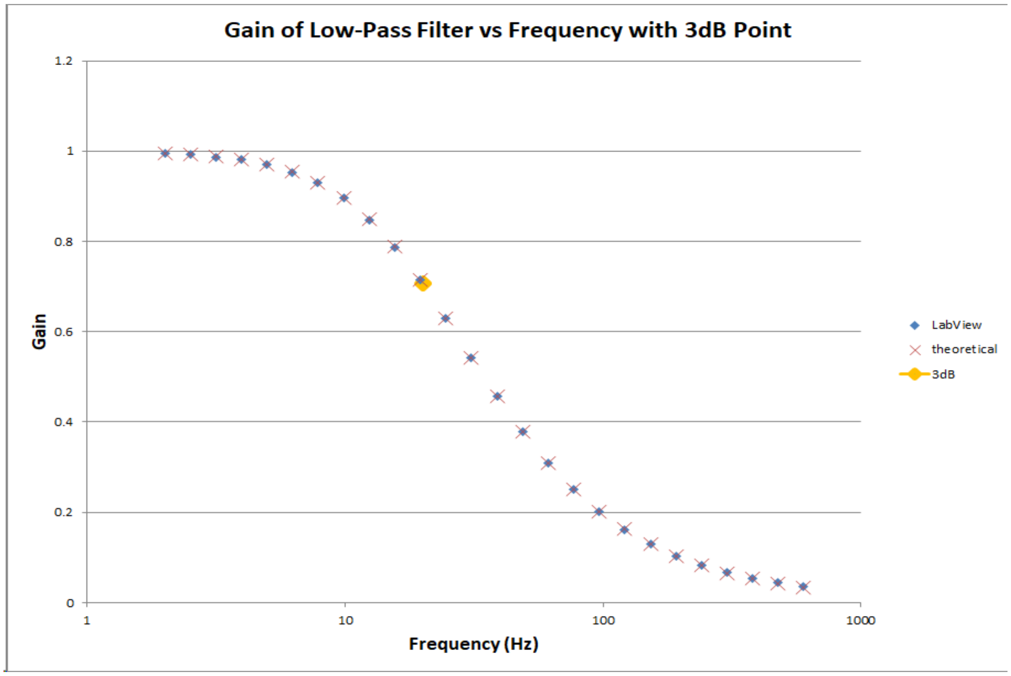

Figure 2. Gain of our low-pass filter circuit over a range of frequencies, with the 3 dB point emphasized.

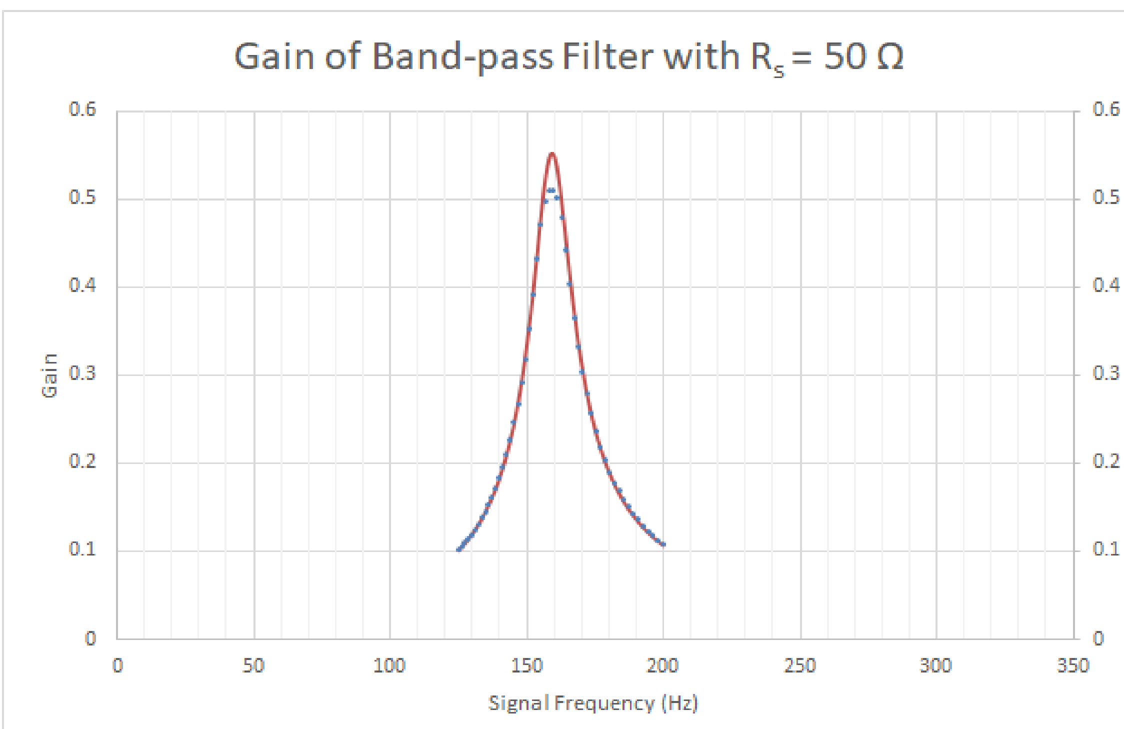

Figure 3. Gain of band-pass filter with R_s = 50 Ω. Blue points represent experimental data while the red curve represents the theoretical prediction.

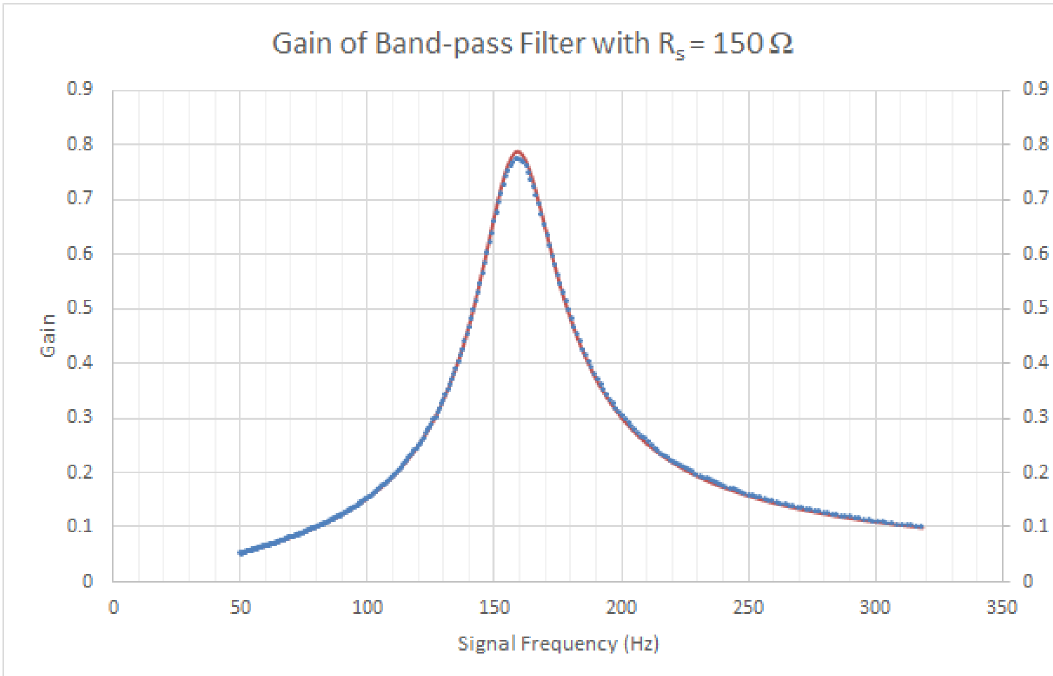

Figure 4. Gain of band-pass filter with R_s = 150 Ω. Blue points represent experimental data while the red curve represents the theoretical prediction.

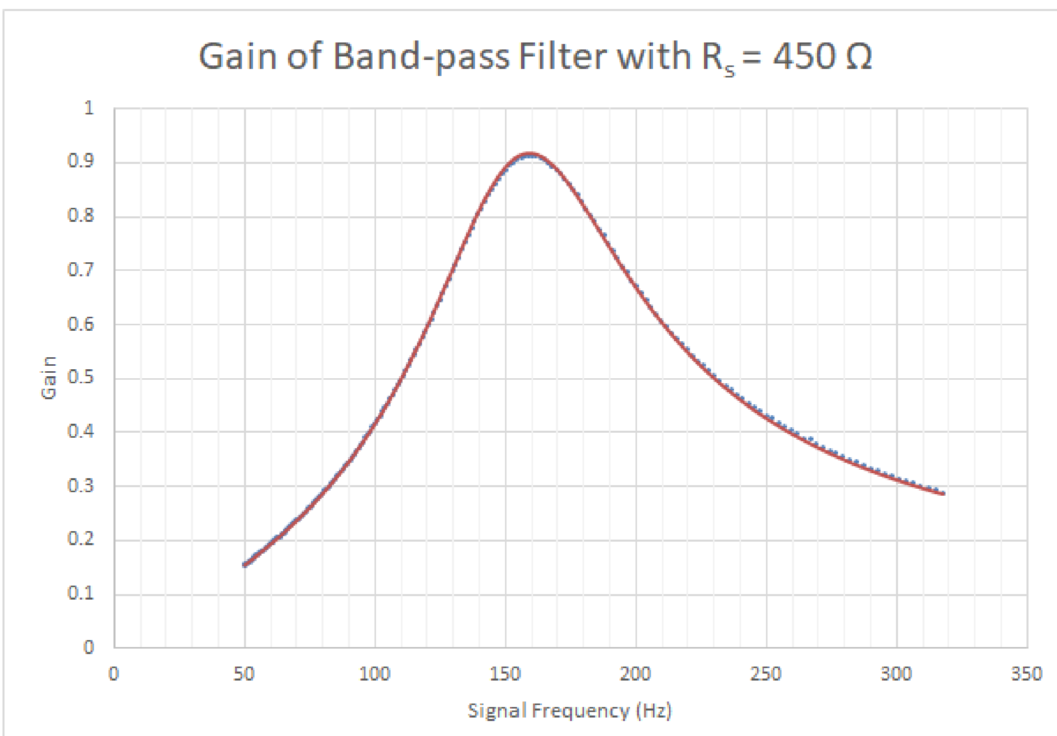

Figure 5. Gain of band-pass filter with R_s = 450 Ω. Blue points represent experimental data while the red curve represents the theoretical prediction.

Table 2. Comparison of experimental and theoretical values for the band-pass filter portion of the lab.

Output Resistance	3 dB Point	Estimated Bandwidth	Theoretical Bandwidth
50 Ω	0.391 V	15 Hz	14.4 Hz
150 Ω	0.557 V	30 Hz	30.3 Hz
450 Ω	0.649 V	75 Hz	78.1 Hz

Discussion

Our observations agreed very closely with the theoretical predictions for the low-pass filter and all three band-pass filters. In addition, our experimental and theoretical values for the bandwidths, shown in Table 2 above, were in close agreement. The largest discrepancy was in the graph of the 50 Ω band-pass filter, shown in Figure 3, where our measured voltage at resonance was about 20 mV below the predicted value. The 150 Ω filter, shown in Figure 4, also disagrees with the predicted voltage, but by a much smaller amount. The 450 Ω filter, shown in Figure 5, matched the predicted curve nearly perfectly.

This suggests that there may have been another source of impedance in the circuit that we did not take into account, such as internal impedance in the power supply or parasitic capacitance in the inductor. Our observations support this, because an additional impedance in the circuit would cause a smaller voltage drop at the output, and its effect would become less noticeable as the value of the output resistor increased.

With ideal components, the gain at resonant frequency would be 1, since the resistor at the output is effectively the only source of impedance. In reality, there are other sources of impedance in the circuit, most notably the inductor's internal resistance. Taking this into account, the maximum gain should be the ratio of the output resistor to the total resistance of the circuit. As the output resistance rises, it comprises a larger fraction of the total resistance, and the gain approaches the ideal value of 1.

Conclusion

Theoretical approaches for low pass and band pass filters are close approximations of actual measured values. The differences in the value could be due to impedances that are in the circuit that aren't taken into consideration in the theoretical calculations. Ideally, resonant frequency would be 1 since the impedance of the capacitor and inductor are equal and opposite.

References

Boylestad, R. L., and Nashelsky, L. (2006). *Introduction to electricity, electronics, and electromagnetics*. Pearson Education Taiwan, Taipei.