Lab 2 Report

R-1: Internal Resistance of a DC Power Supply

To determine the internal resistance of the E36311A DC power supply, we measured the voltage drop across a 1.200 ± 0.001 kΩ external resistor connected to the -25V output port. We set the input voltage to $V_{in} = -15.000 \pm 0.005$ V and recorded a voltage across the external resistor of $V_{out} = -14.962 \pm 0.005$ V.

Figure 1: Verifying the resistance of the selected "1.2kΩ" resistor using the multimeter

The current was determined using Ohm's Law:

$$I = \frac{V_{out}}{R} = \frac{14.962V}{1.2k\Omega} = 0.0125A$$

Next, the internal resistance r was derived as follows:

$$V_{in} = I(R + r) = IR + ir = V_{out} + Ir \tag{1}$$

Solving for r:

$$r = \frac{V_{in} - V_{out}}{I} = R\left(\frac{V_{in} - V_{out}}{V_{out}}\right) \tag{2}$$

Using our measured values:

$$r = 1.18 \times 10^3 \left(\frac{15.000 - 14.962}{14.962}\right) = 2.997 \pm 0.5\Omega \tag{3}$$

The small internal resistance confirms that the power supply is well-regulated, with minimal voltage drop due to its internal impedance.

R-2: Measuring the Resistance and Capacitance of the Components

Before constructing the RC divider, we used a digital multimeter to precisely measure the resistance and capacitance of the components. The nominal 10 kΩ resistor was measured as $R = 10.011 \pm 0.001$ kΩ, and the nominal 22 nF capacitor was initially recorded as an anomalously high $C \approx 0.05\mu$F due to the inherent capacitance of the breadboard. In particular, the breadboard has metal clips that hold the wires in place, which have capacitances that effectively add in parallel to the capacitance of the 22nF capacitor. This measurement was corrected by removing the capacitor from the breadboard and using alligator clips. The final measured value was $C = 23.5 \pm 0.05$ nF.

Figure 2: Measured voltage drop across the external resistor for determining internal resistance.

R-3: Frequency Response of the RC Divider

The RC circuit was connected to a function generator producing a 2V peak-to-peak sine wave. We applied a logarithmic frequency sweep from 0.1 Hz to 20 MHz, measuring the input voltage (V_{Ch1}), the output voltage across the resistor (V_{Ch2}), and the phase difference between the two signals.

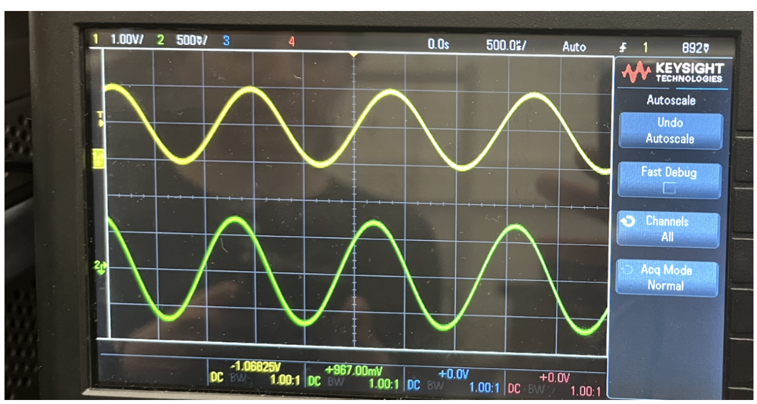


Figure 3: Oscilloscope trace of the input (yellow) and output (green) voltages at a selected frequency.

We plotted the logarithm of the attenuation $A(f) = \frac{|V_{output}(f)|}{|V_{input}(f)|}$ and phase shift against the logarithm of the frequency.

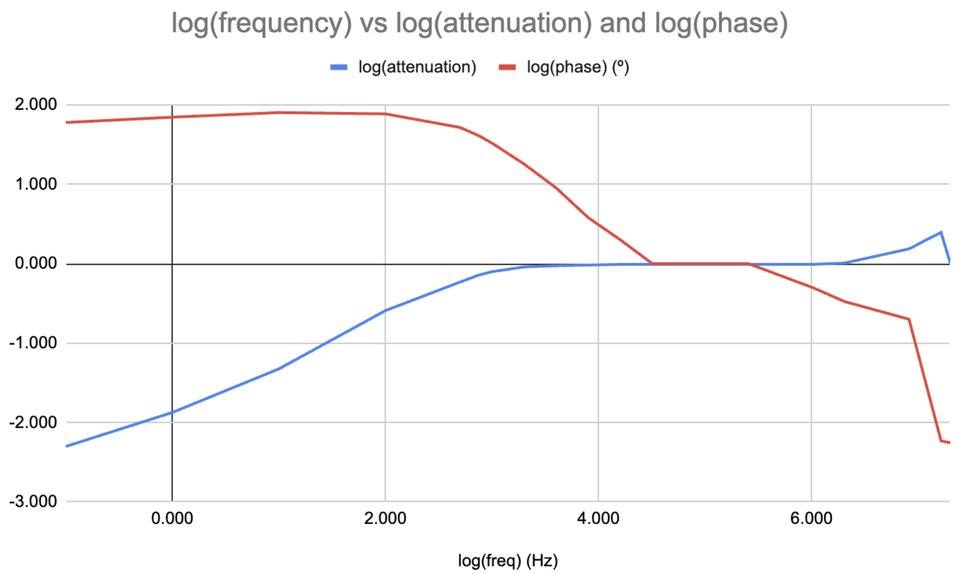


Figure 4: loglog plots of attenuation vs frequency and phase vs frequency using manually-recorded measurements

R-4: Observed vs Expected Frequency Response

As expected, the circuit behaved as a high-pass filter when measuring across the resistor, with attenuation having lower values at lower frequencies. The theoretical 3 dB frequency for an RC high-pass filter is given by:

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(10.0 \times 10^3 \Omega)(23.5 \times 10^{-9} F)} \approx 677\,\mathrm{Hz}$$

Our experimentally determined cutoff frequency, where the output voltage dropped to approximately 70% of the input voltage, was recorded at 700 ± 10 Hz, with an attenuation value of 0.690 ± 0.005.

R-5: Bode Plot Analysis

To further analyze the frequency response of the RC circuit, we used the oscilloscope's Frequency Response Analysis (FRA) function to generate a Bode plot. We set a start frequency of 10 Hz and a stop frequency of 20 MHz, using an output amplitude of 1.00 Vpp and a high-Z load. Comparing the automated Bode plot with our previous hand-measured frequency response data, the shape of the two plots was very similar, although quantitatively we did not obtain the same values reflected in the oscilloscope in our "hand-drawn" plot.

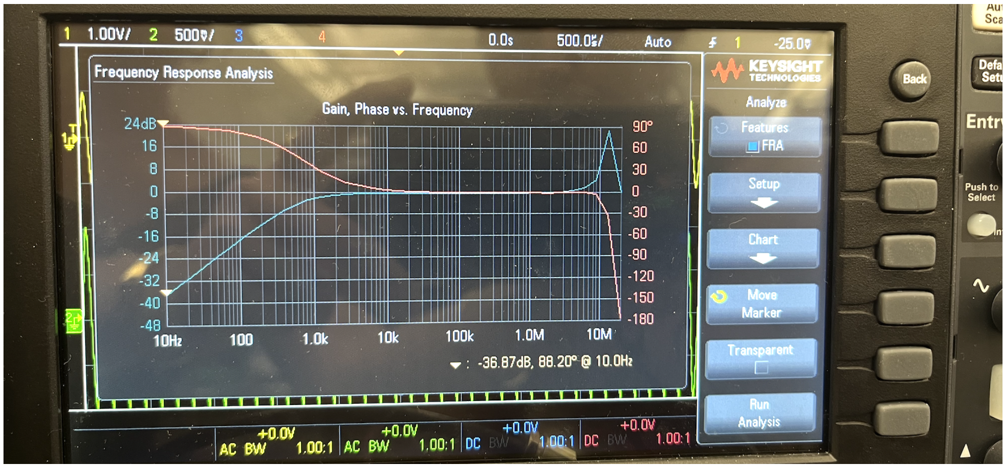


Figure 5: Bode plot of the RC circuit generated using the oscilloscope's Frequency Response Analysis function.

R-6: Computer-Generated Bode Plot

To further analyze the frequency response of the RC circuit, we generated a Bode plot using Pyvisa and the oscilloscope:

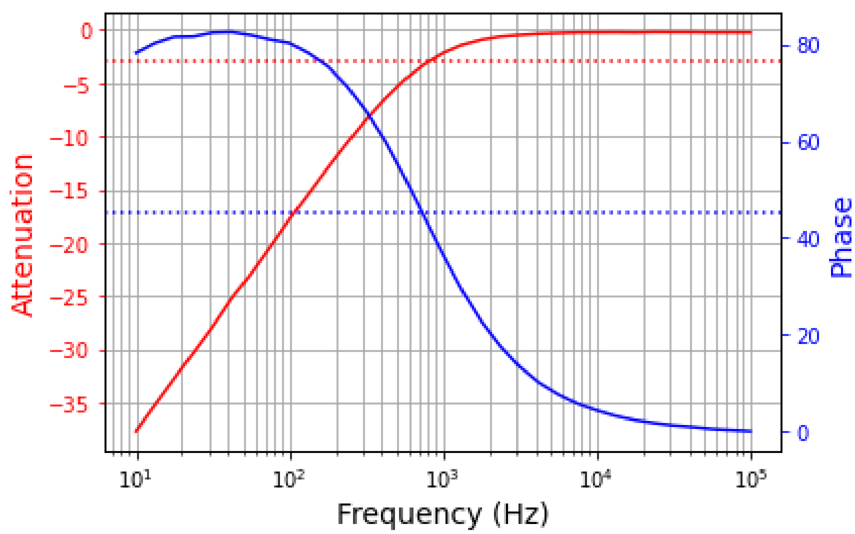
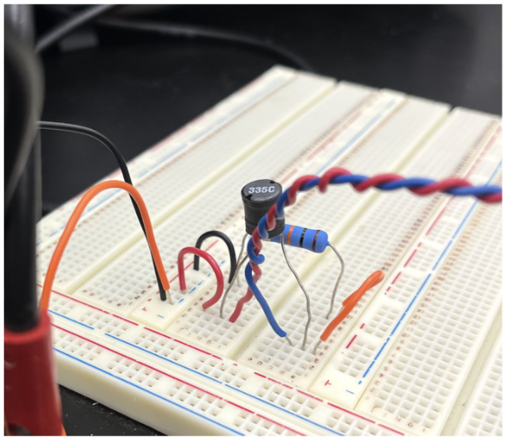


Figure 6: Bode plot generated using Python to control the oscilloscope.

The plot we obtained for R6 seems different since the code originally set the stopping frequency to about 100kHz, however, the high-pass behaviour remains. We were able to fix the bug later on in the lab (eg in R7), but had no time to go back and fix this plot.

R-7: RL Circuit Frequency Response

We measured the output voltage across a 3.3 mH inductor in a series RL circuit, expecting a high-pass response. However, the measured Bode plot exhibited low-pass behavior, likely due to parasitic capacitance from the breadboard or imperfections in the inductors such as internal resistance or self-resonance, making it non-ideal.



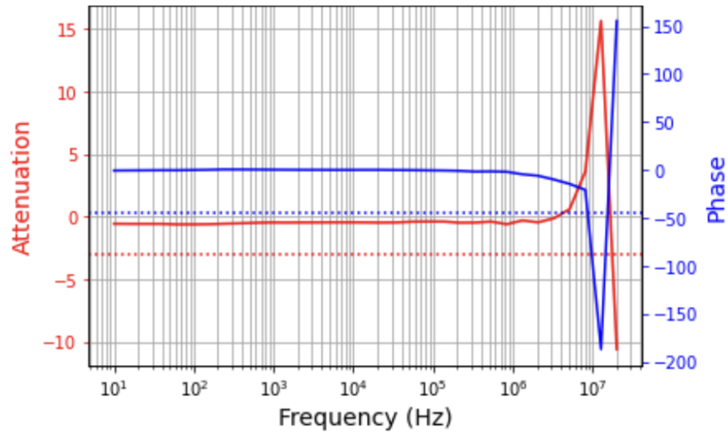


Figure 7: Left: Breadboard implementation of the RL circuit with a 3.3 mH inductor and 10 kΩ resistor. Right: Bode plot for the RL circuit, showing attenuation and phase response.

Moreover, results show some discrepancies at very high frequencies, particularly near the 10 MHz range, where unexpected fluctuations appear. These deviations could be due to parasitic effects from the breadboard, wire inductance, and high-frequency noise.

R-8: Band-Pass Filter Design and Implementation

We constructed a band-pass filter by cascading a high-pass and a low-pass RC filter. The high-pass section consisted of a $46.53 \pm 0.05\,\Omega$ resistor and a $7.10 \pm 0.05\,\mu F$ capacitor, while the low-pass section consisted of a $99.59 \pm 0.05\,\Omega$ resistor and a $3.25 \pm 0.05\,\mu F$ capacitor. The LED was reluctant to light up at lower voltages, but it lit up very slightly approaching 8V. We decided not to increase the voltage further in order not to damage the component.

The theoretical cut-off frequencies for each section were calculated as follows:

- **High-Pass Filter (HPF)**:

$$f_c^{\text{HPF}} = \frac{1}{2\pi RC} = \frac{1}{2\pi(46.53)(7.10 \times 10^{-6})} \approx 449.2 \text{ Hz}$$

- **Low-Pass Filter (LPF)**:

$$f_c^{\text{LPF}} = \frac{1}{2\pi RC} = \frac{1}{2\pi(99.59)(3.25 \times 10^{-6})} \approx 491.7 \text{ Hz}$$

Figure 8: Verifying the values of the resistors and inductors used in the RL circuit

Thus, the expected band-pass range is approximately 449 Hz to 490 Hz.

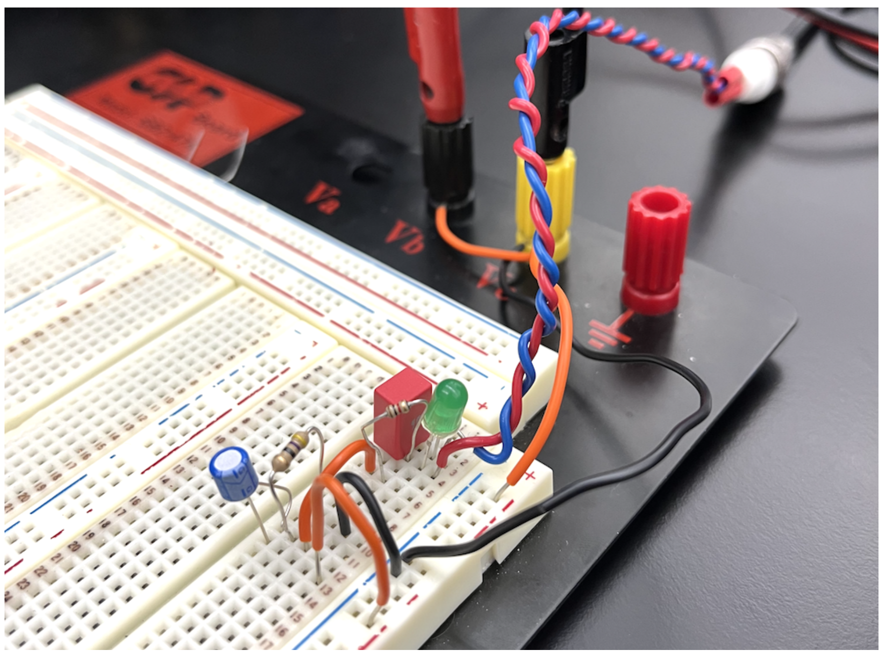


Figure 9: Bandpass circuit on breadboard with green LED.