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Experiment 4: Operational Amplifiers

1. **The Inverting Amplifier**
   We set up the circuit as follows:

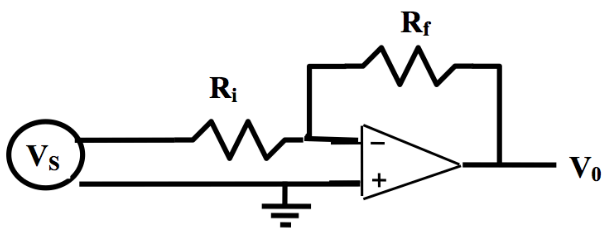


Fig. 4.2

First circuit we tested:
R_i = 1 kΩ ± 5%
R_f = 100 kΩ ±5%

We expect a gain of -100 since $A_v = V_0/V_s = -R_f/R_i$ = -100 kΩ / 1 kΩ = -100.

The 741 inverting OpAmp is inserted across the ravine in the breadboard. It is powered by the triple output power supply with V_{EE} = -15 V and V_{cc} = 15 V.

V_s is generated from the Waveform Generator:
- Sine wave
- Amplitude: 100.0 mVpp = 50.0mV
- Starting frequency: 100 Hz

Oscilloscope settings:
- Time divisions: 500.0us
- Channel 1 divisions: 2.00 V
  - Channel 1 measured Vo, t
- Channel 2 divisions: 20.0mV
- We set up the oscilloscope to display the Vpp for the two channels kayed at the bottom of the screen. These were the readings we used for our measurements.

Our circuits were set up with these conditions in mind:
1. Vs > 10mV, so that input noise, and the input offset current and voltage do not interfere with the measurements.
2. ABS(Av * Vs) < 15V, to keep within the amplifier's range
3. f * Av < 10^5, because I was told to in the lab instructions and the experiment won't work unless we do this.

We noticed that the splitter attached to the wave generator had some resistance and the Vs measured on the oscilloscope is lower than the voltage generated from the wave generator. We used the oscilloscope readings for all voltage measurements in this experiment.

Initial experimentation with the OpAmp showed that the waves become clipped when the DC offset is 100.0 mV DC. This makes sense because the amplitude plus the offset is 150.0mV, which is the limit of OpAmp. (150.0 mV * -100 = -15 V).

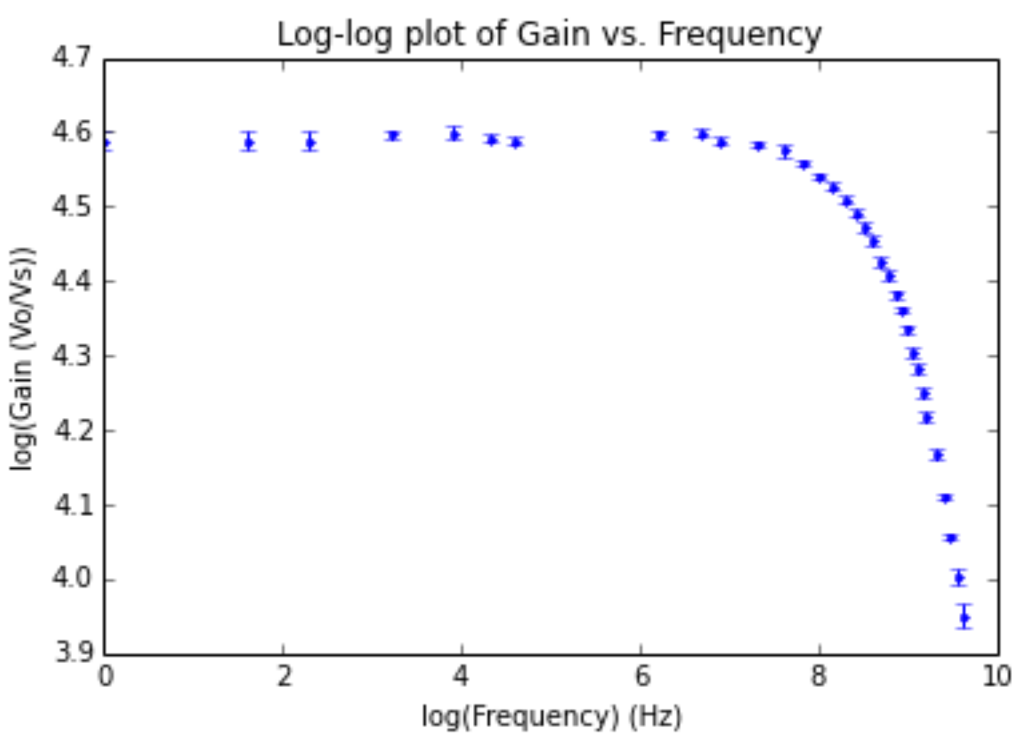
We also noticed that the gain decreases gradually when we increase the frequency. We expect the frequency at which the gain starts to decrease to depend on the resistors used in the circuit.

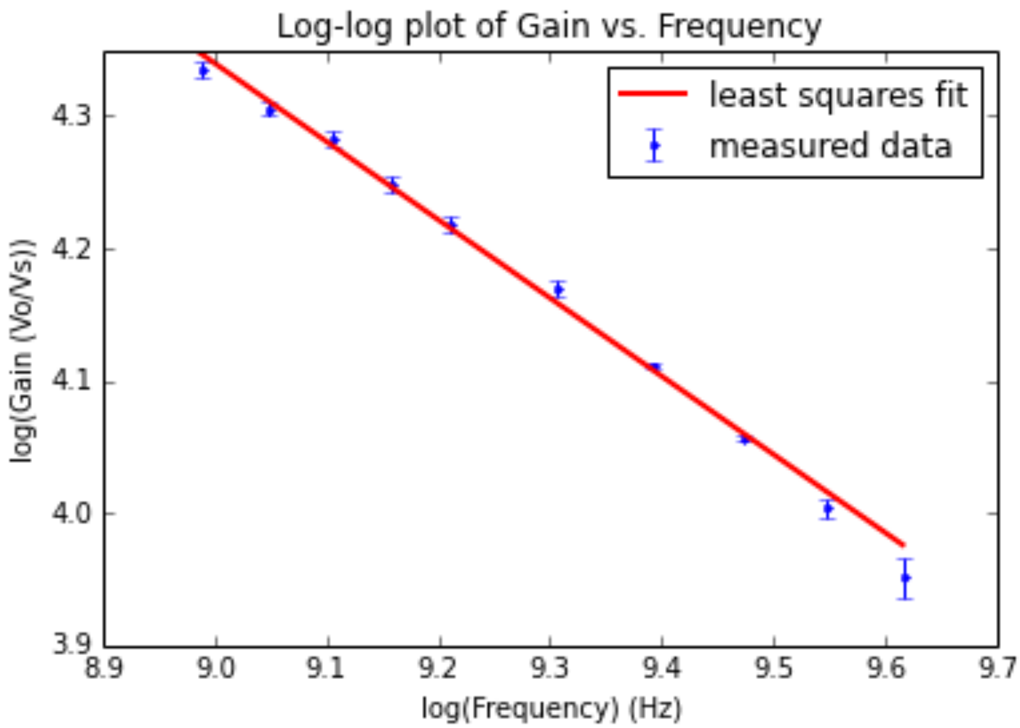
Uncertainties of our measurement for the voltages: We estimated all uncertainties in the experiment based on how much the Vpp readings displayed at the bottom of the screen vary. We noticed that the lines are a little fuzzy from the noise and the Vpp readings will flicker between several values. We took the most stable reading and estimated the uncertainty based on the range of the other numbers that showed up at the bottom.

This is the data plotted using the Python curve_fit script. The roll off power law is calculated by fitting the drop off part with a linear fit.

```
x = np.log(data[:,0])
y = np.log(data[:,3]/(data[:,1]*10**-3))
y_sigma = np.sqrt((data[:,2]/data[:,1])**2 +
(data[:,4]/data[:,3])**2)

#error is 1/y * dy since we are plotting log(y)
#dy is obtained by adding the relative dVo and dVs in quadrature
#(since # Gain = Vo/Vs) and then converting back to absolute
#uncertainty by multiplying by y.
```





Goodness of fit - chi square measure: Chi2 = 24.6, Chi2/dof = 3.076
Values of fit parameters: slope = -5.907e-01 +/- 7.549e-03 y_intercept = 9.656e+00 +/- 7.076e-02

Since this is a log log plot, the slope is the power of the power law.
Power law of the roll off is the slope = -5.907e-01 +/- 7.549e-03

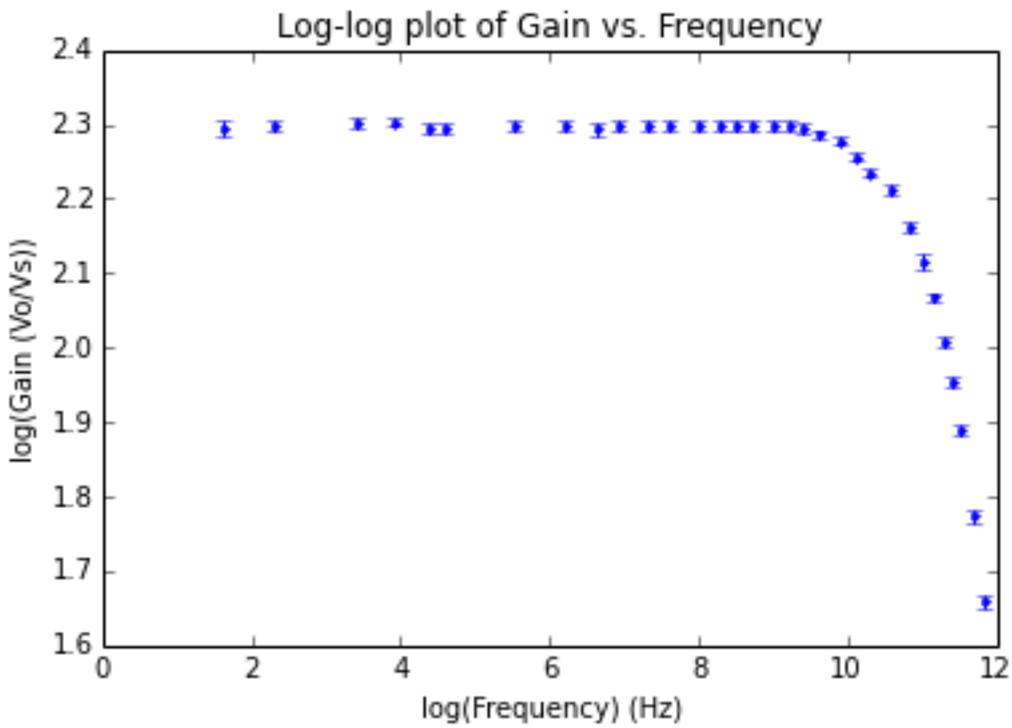
The bandwidth calculation is included in the last section.

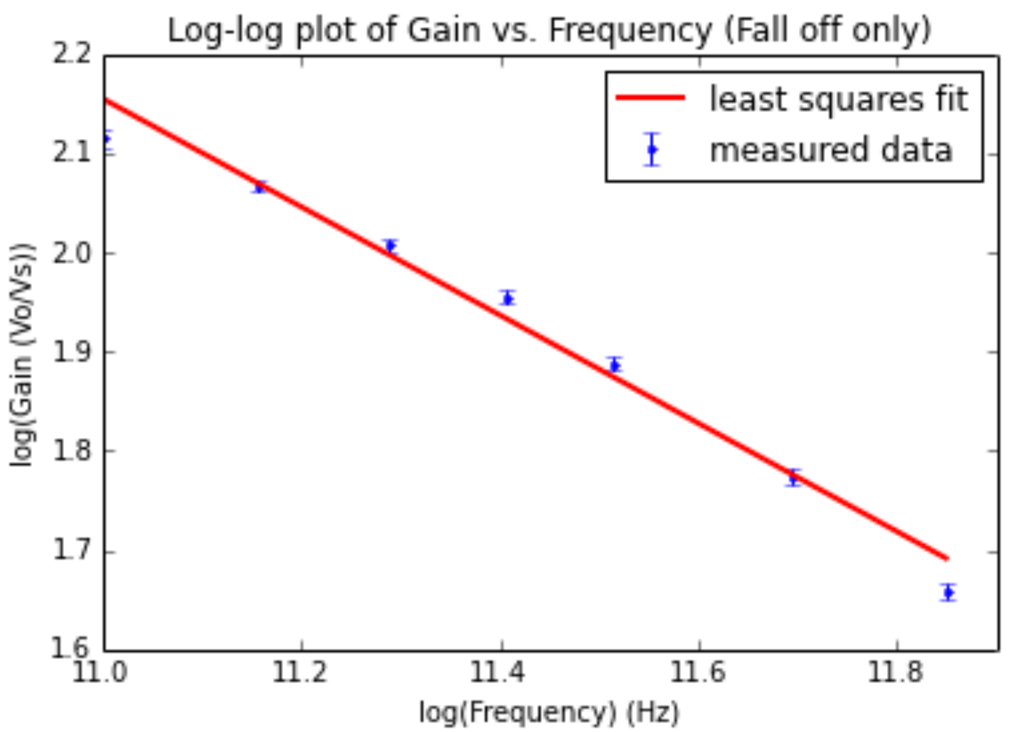
The second circuit we tested:
Everything was the same except, R_i = 1 kΩ ± 5% R_f = 10 kΩ ± 5%

We took points on a wide range of frequencies form 5Hz to 140 kHz, following the same procedures as above.

The same procedure as the first circuit was used to plot and fit the data:

Once again, the bandwidth calculation for this circuit is found in the last section.





Goodness of fit - chi square measure: Chi2 = 45.8, Chi2/dof = 9.161
Values of fit parameters: slope = -5.452e-01 +/- 1.165e-02 y_intercept = 8.152e+00 +/- 1.328e-01

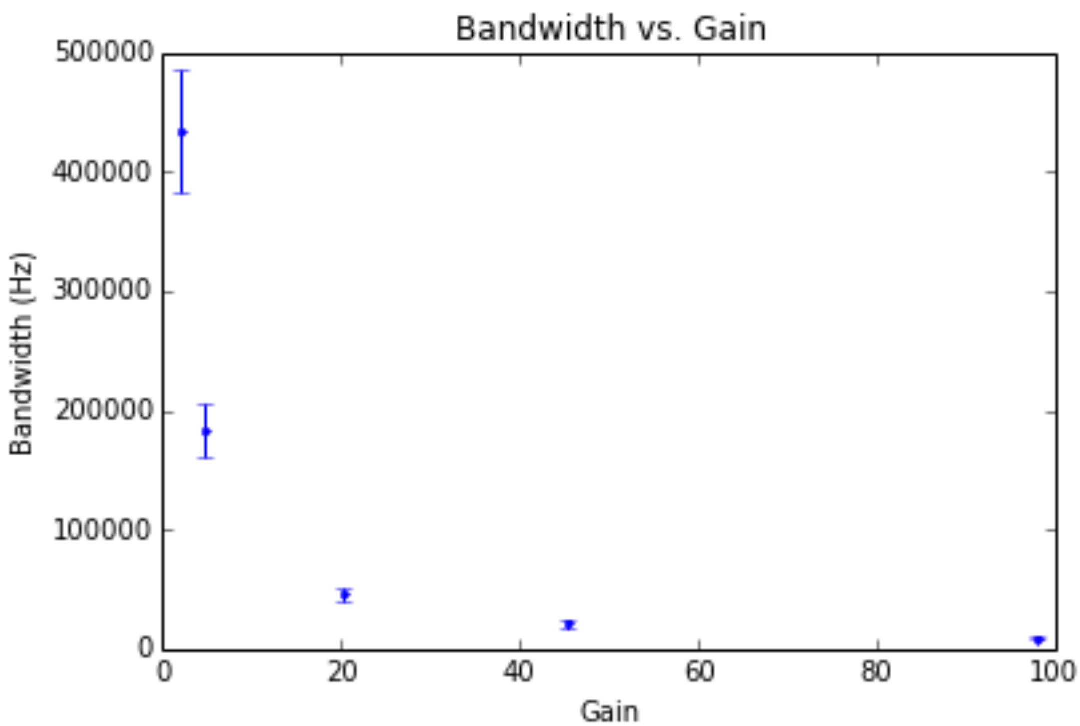
Power law = -5.452e-01 +/- 1.165e-02

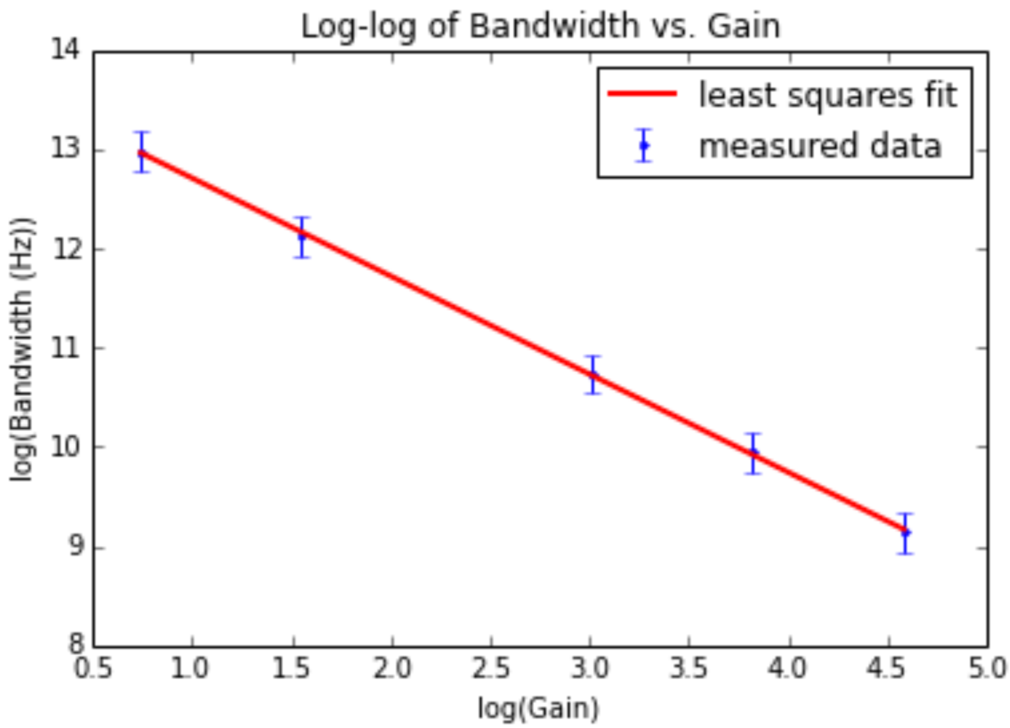
Testing the gain and bandwidth of other resistor pairs

This part was done in the second week. The Vpp produced from the generator was 20mV, which is significantly lower than last time. This resulted in slightly larger relative uncertainties, but we didn't notice this until we finished taking the data.

We tried 4 more different resistor pairs that gave different gains. For each resistor pair, we measure 3 points at low frequency (1kHz, 2kHz, and 3kHz). We then took the average of the gains (which were pretty much constant for each resistor pair at the low frequencies) and we divided that by sqrt(2). We adjusted the frequency until the gain was at approximately the low frequency gain divided by root 2. And we took another three measurements of gain around that frequency.

We constructed the following table by finding the gain and the bandwidth from each of our circuits. Uncertainties presented are calculated from the uncertainty in the Voltage readings using standard uncertainty propagation techniques.





Goodness of fit - chi square measure: Chi2 = 0.1, Chi2/dof = 0.028

Values of fit parameters: slope = -9.872e-01 +/- 6.313e-02 y_intercept = 1.369e+01 +/- 1.948e-01

Since the log-log plot of Bandwidth vs Gain is linear, we can conclude that the relationship follows a power law. This power law is approximately e^(1.369e+01)*Gain^(-0.9872).