# Physics 219_2018 - Nick Pun/Exp. 4 (OpAmps)/Exp 4 Op-Amps

SIGNED by Nick Pun Nov 23, 2018 @02:22 PM PST

Nick Pun Nov 22, 2018 @12:46 PM PST

**Introduction**

In this lab we examine the properties of op-amps and how they work by comparing input signals with output through the op-amp. We will see that op-amps return an output signal that is similar to the input signal but with greater amplitude. The gain in the amplitude will be in part determined by the frequency of the input signal. We will see that op-amps at high frequencies do not produce as large of a relative gain as op-amps at low frequencies do. Furthermore, at certain offsets of V, we will see that the output signal can be distorted.

The important parameters we will be investigating are the inputs V+ and V- (which is the inverted input) and the output Vout.

In an ideal world, the open loop gain of an op-amp can be mathematically taken to be infinite and would not depend on frequency. However, from our experiments we will see that our op-amp is not mathematically ideal as the open loop gain will be observed to have a dependence on frequency, and will only have a maximum value bounded by the supply voltage.

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**4.1 Inverting Voltage Amplifier**

For a resistor setting of $R_g$ = 1 kOhm, $R_f$ = 100 kOhm, I expect a gain of 100. Attached in file 'lab4pt4_1.xlsx' are some data points that show that the gain is indeed about 100.

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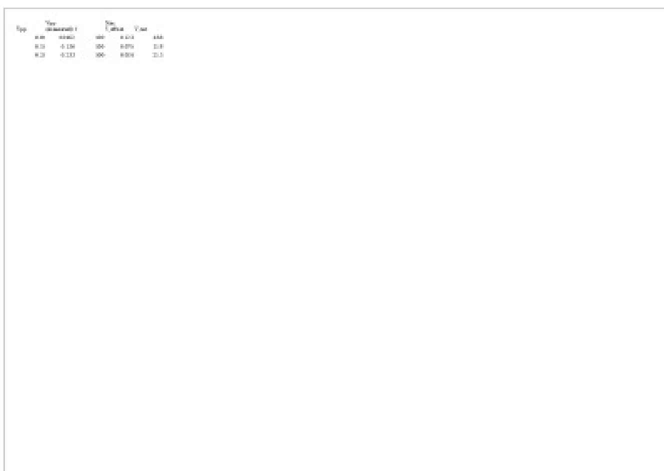

**lab4pt4_1.xlsx(8.5 KB)**

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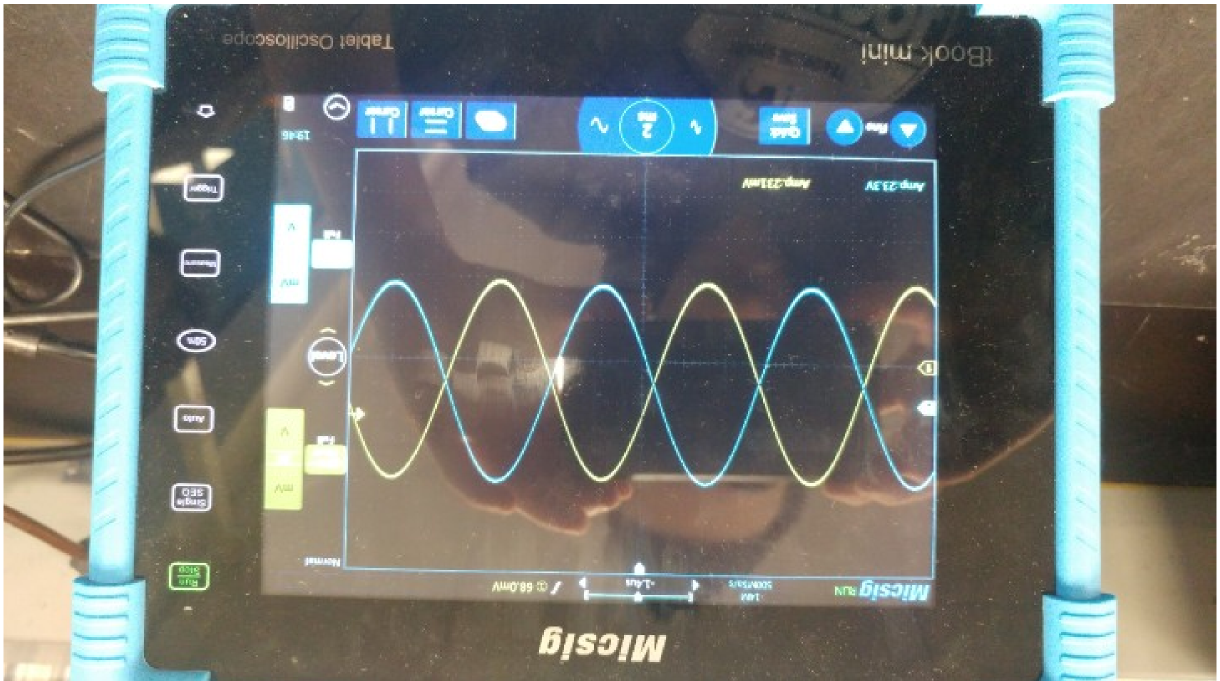
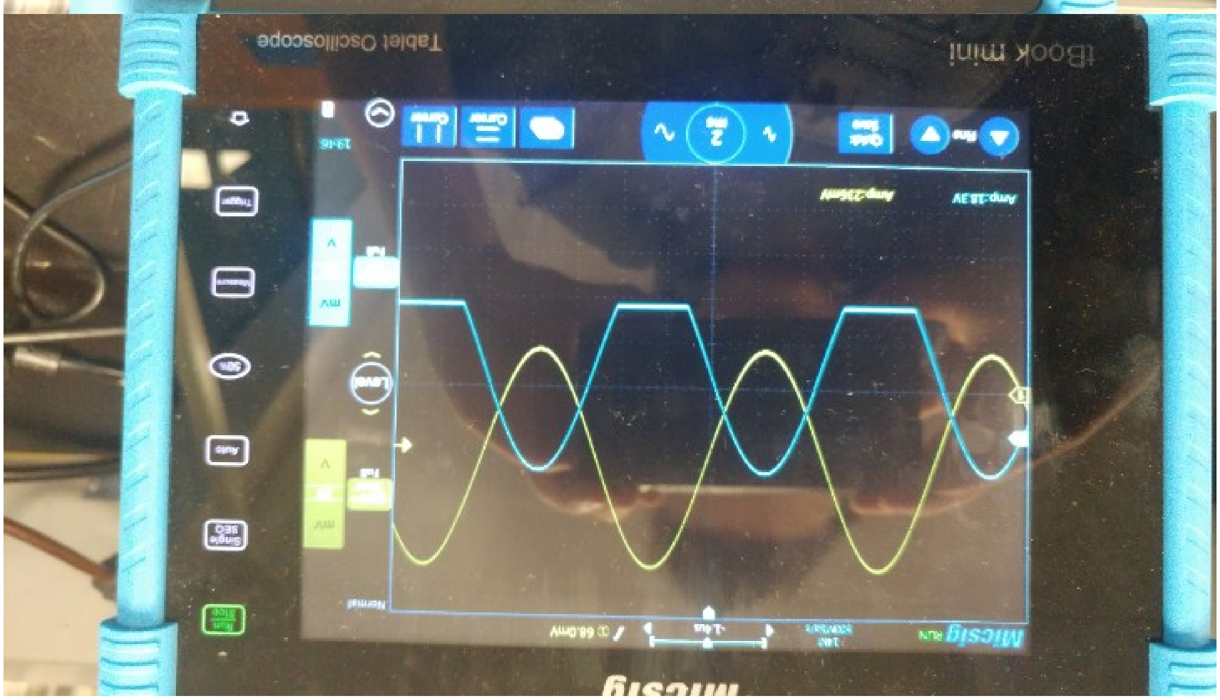
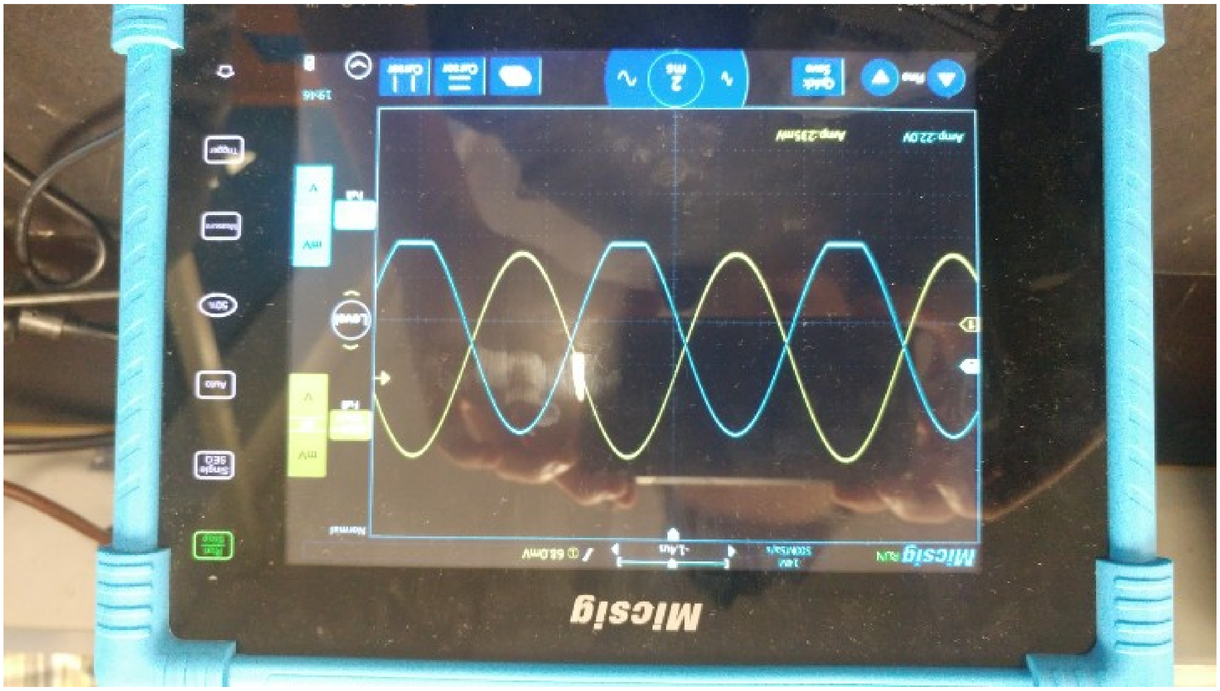
**4.2.1 Amplifier Measurements**

From varying both the Vpp and V_offset, we are able to see that the distortion in the signal cuts off the bottom of the wave. By increasing V_offset, the signal gets cut off by a larger amount. Furthermore, the larger we increase Vpp, the smaller V_offset can be in order to maintain an undistorted signal. We believe that the cause of the cut is because there is a limit on how much voltage we can apply in our experiment. If Vpp + V_offset exceeds this limit, then the bottom will be cut off. The images below show what the distortion looks like as we increase V_offset. Note: when uploading the images, labarchives keeps on rotating them upside down.





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**4.2.2 Amplifier Measurements**

Resistors used: $R_{100k}$ = 98.365 +/- 0.001 kOhm, $R_{1k}$ = 0.98455 +/- 0.00001 kOhm

It may be important to note that the value for which we are using for V_in is measured and determined by the oscilloscope, instead of the function generator. This is because we observed that what was measured by the oscilloscope was consistently smaller than what was given by the function generator. We assumed that there was some unaccounted for reason why the oscilloscope was measuring a smaller value, but didn't know what. Since the value given by the oscilloscope consistently resulted in a value for the gain that was more accurate with theoretical calculations, we used the oscilloscope's values, although we do also record the function generator's values. We assume that whatever is causing the drop, also causes the drop in V_out, and so in dividing V_out/V_in, the error will hopefully cancel out.

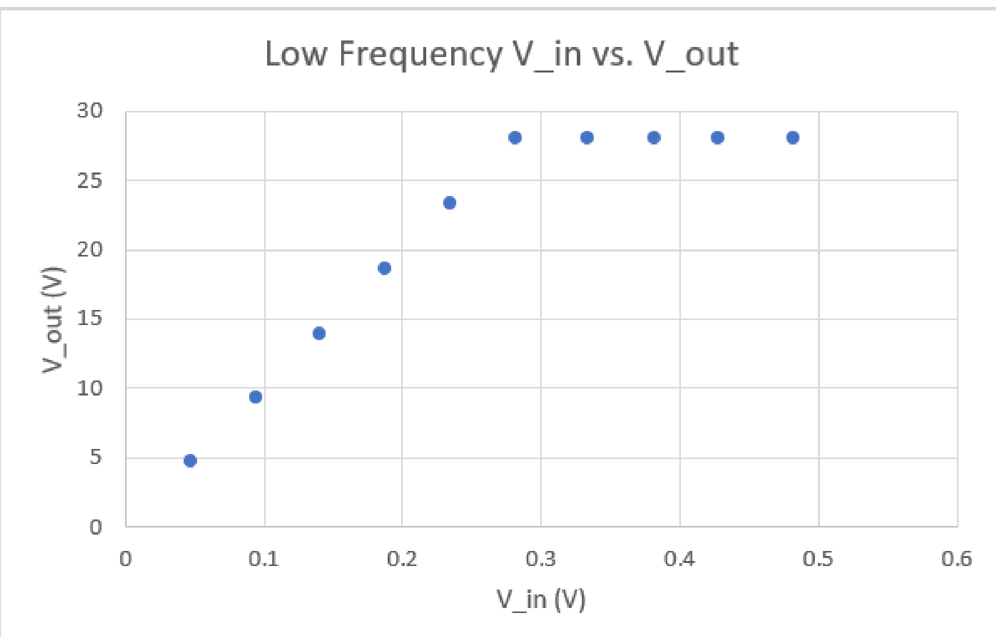
Both V_in and V_out were measured with the oscilloscope's auto measure amplitude tool. Their uncertainties are determined by the manufacturer to be 2%.

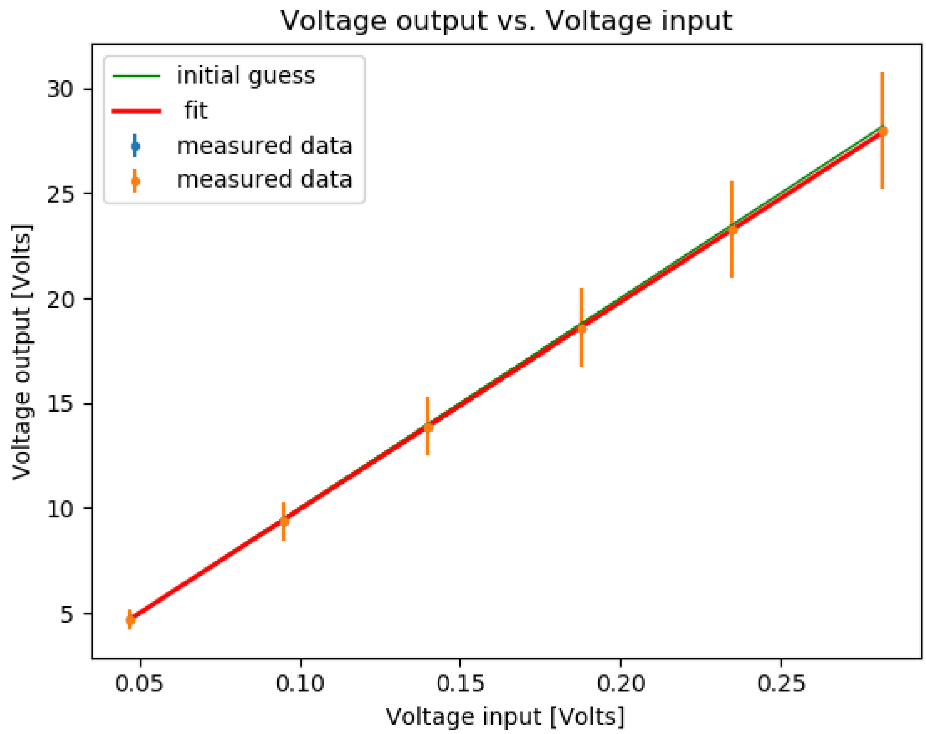
As we increase V_in, the output frequency also increases.

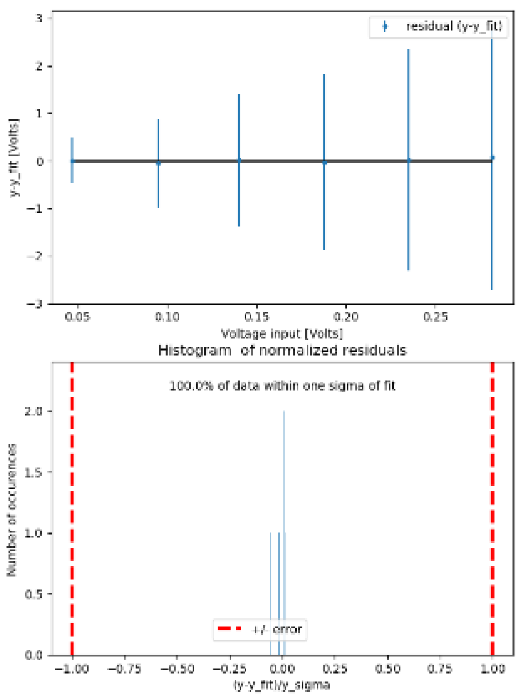
One of the main differences between high and low frequency is that the low frequency has a gain of 100 whereas the high frequency has a gain of less than 10. Another difference is that the high high frequency's gain is not linear, it decreases, whereas the low frequency's gain is consistently 100.

At a low frequency of 50 Hz with no offset, the data points form a linear graph, where the gain is approximately 100, which is consistent with the op-amp theory as low frequencies will not change the denominator in the formulas by much, and thus not affect the gain by much. Here, the ratio of V_out/V_in is approximately the same as the ratio of R_f/R_g. However, this graph only linearly increases until around V_in = 0.283 V, at which point it instantaneously stops increasing completely and becomes a plateau at V_out = 28.3 V.

guesses = (100, 0)






Goodness of fit - chi square measure:
Chi2 = 0.005212155286809062, Chi2/dof = 0.0013030388217022655

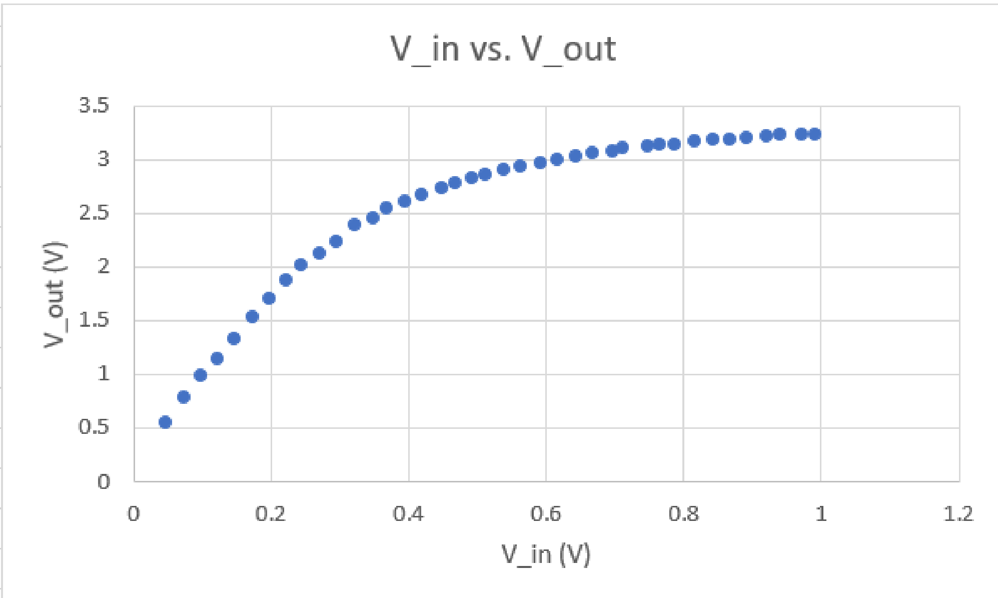
Fit parameters:
gain = 9.885e+01 +/- 7.054e+00
y intercept = 4.348e-02 +/- 6.665e-01

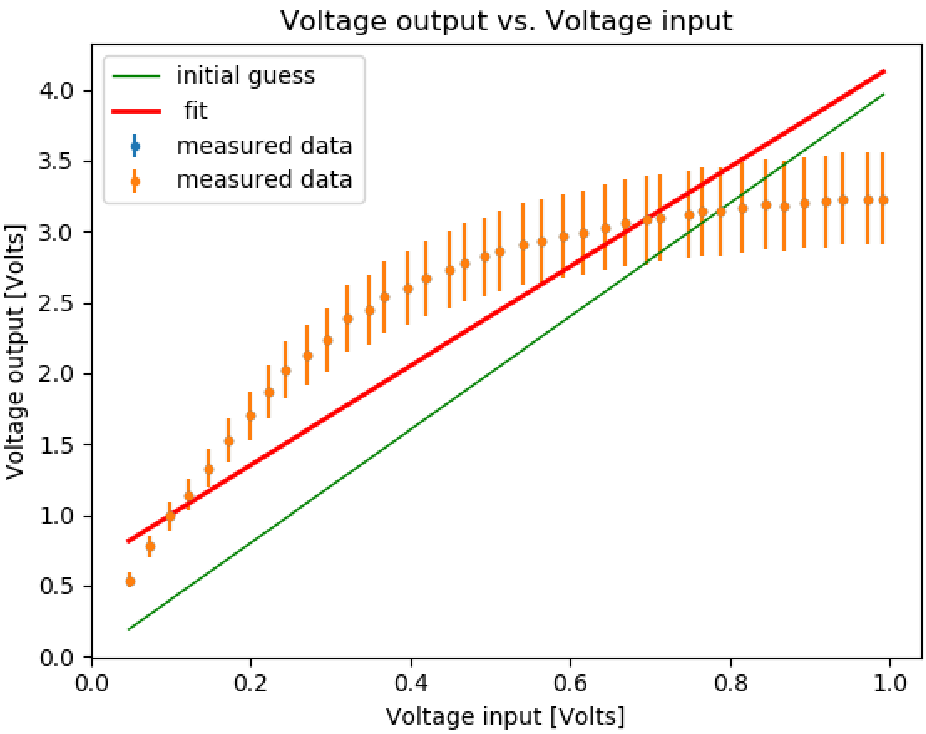
Residual information:
100.0% of data points agree with fit

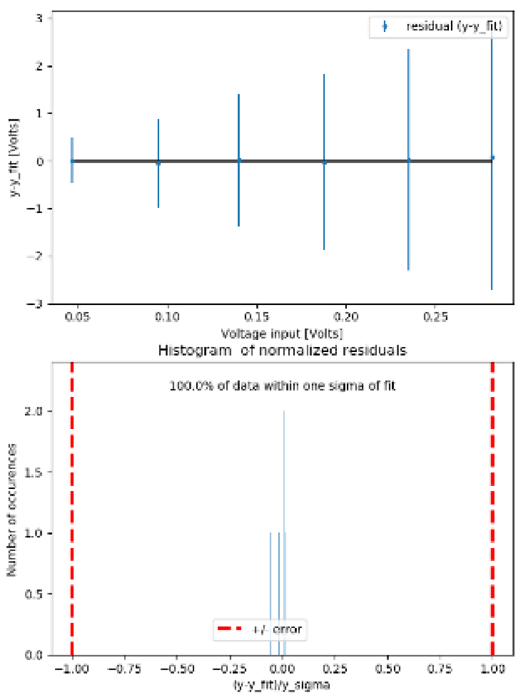
The $Chi^2$/dof is extremely close to 0 so this linear fit is very accurate.

At a high frequency of 100 kHz with no offset, the data points form a non-linear graph. Instead, they form a function with a positive slope and negative curvature resembling a square root function. For these data points, the gain actually starts much lower at around 10 and decreases as V_in becomes larger. Here, the ratio of V_out/V_in starts at approximately 10 times less and decreases to more than 30 times less than the ratio of R_f/R_g. This makes sense as according to the op-amp theoretical formulas, high frequencies will cause the denominator to be greater than 1, and thus affect the gain. The function begins to stop changing very much at around V_out = 3.3 V. On the oscilloscope, as V_in becomes larger, the function starts to become more linear between peaks and valleys as if to form a series of "V"s.

guesses = (4, 0)






Goodness of fit - chi square measure:
Chi2 = 138.10118120267853, Chi2/dof = 3.7324643568291496

Fit parameters:
gain = 3.508e+00 +/- 1.103e-01
y intercept = 6.478e-01 +/- 3.879e-02

Residual information:
28.2% of data points agree with fit

It is clear that a linear fit is poor as only 28.2% of data points agree with the linear fit. $Chi^2$/dof if low, but again, that is because only 28.2% of data points agree with the fit.

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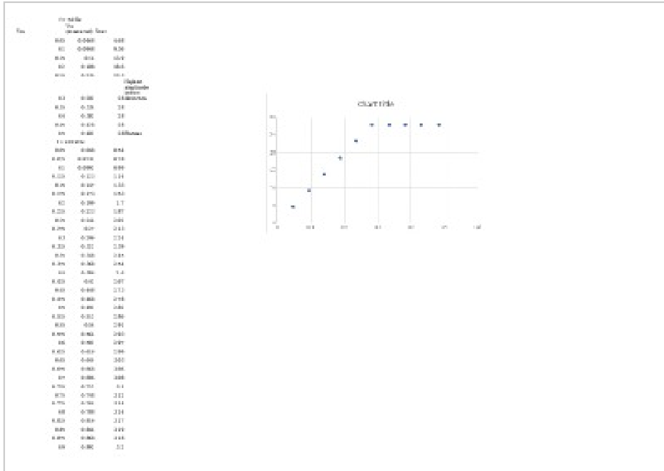

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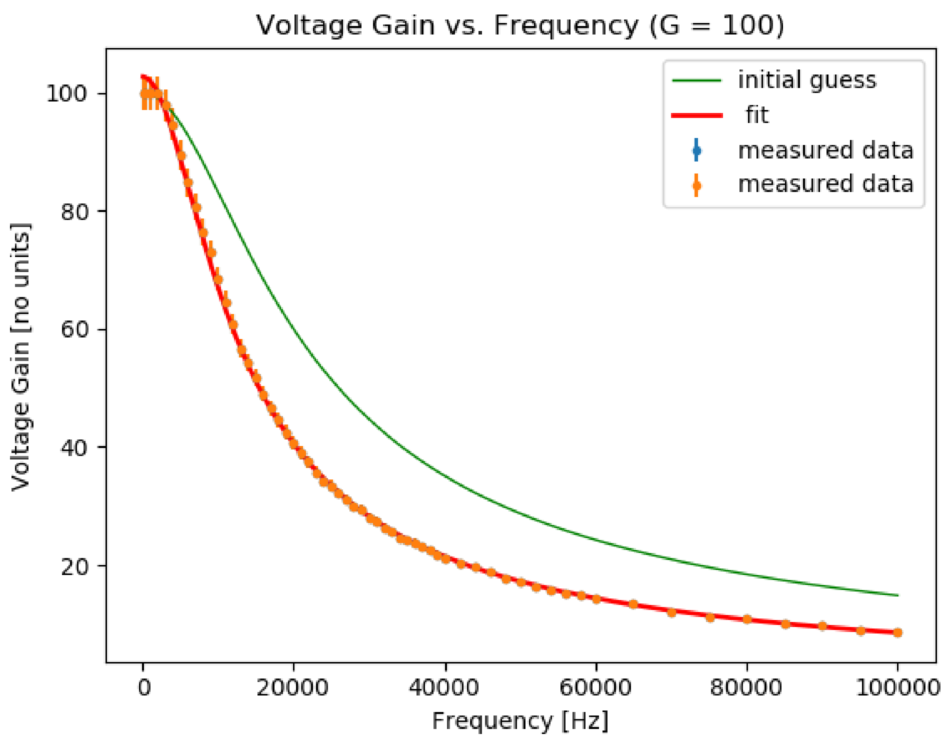
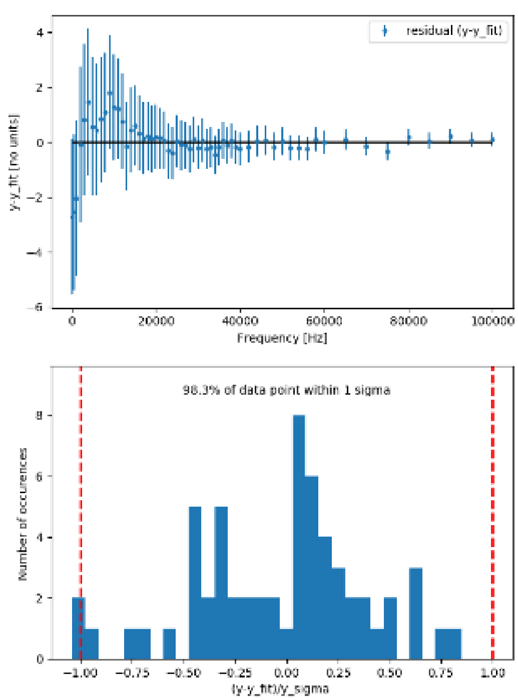
**4.2.3 Amplifier Measurements**

For the following three bandwidth experiments, the uncertainties used in the measurement of V_in and V_out was determined by the manufacturer to be 2%. Thus, when calculation V_out/V_in, I use the sum of the squares of their relative uncertainties to find the relative uncertainty in V_out/V_in, and thus find the absolute uncertainty in V_out/V_in.

Resistors used: $R_{100k1}$ = 98.365 +/- 0.001 kOhm, $R_{1k}$ = 0.98455 +/- 0.00001 kOhm; G: 99.91; Vpp: 200 mV

guesses = (100,1.5e6,0)




Goodness of fit - chi square measure:
Chi2 = 10.467043337385634, Chi2/dof = 0.18363233925237954

Fit parameters:
Gain = 1.031e+02 +/- 1.058e+00
FcA0 = 8.922e+05 +/- 9.530e+03
V_offset = -3.431e-01 +/- 1.804e-01

Covariance between fit parameters:
Gain and FcA0 : -2.333e+03

Gain and V_offset : 2.334e-02
FcA0 and V_offset : -1.557e+03

Correlation between fit parameters:
Gain and FcA0 : -2.314e-01
Gain and V_offset : 1.223e-01
FcA0 and V_offset : -9.055e-01

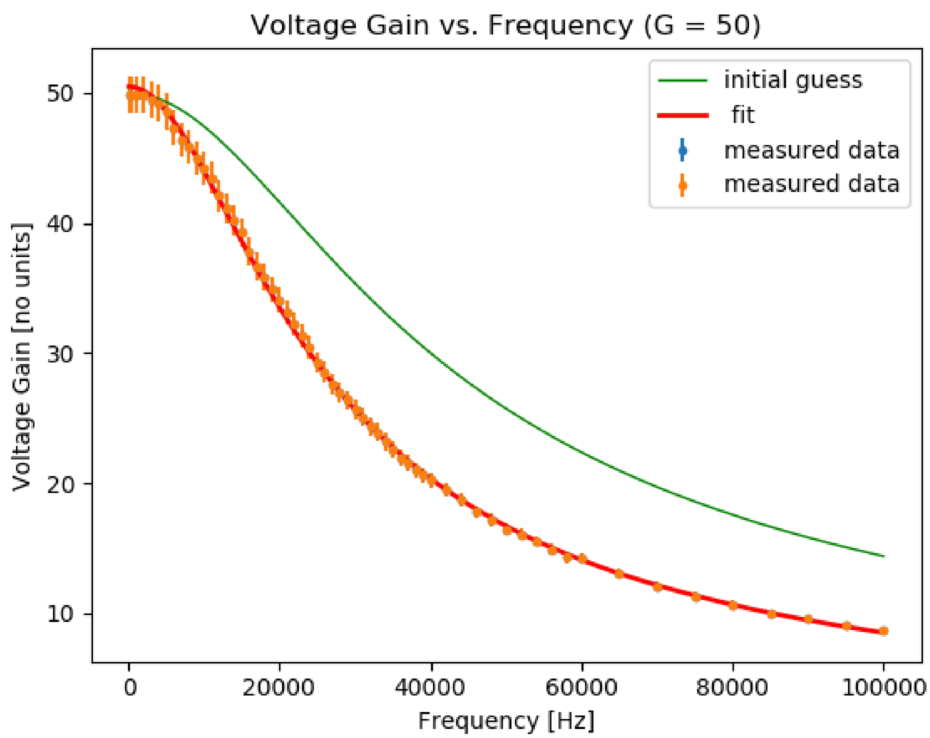
Residual information:
98.3% of data points agree within 1 sigma of fit

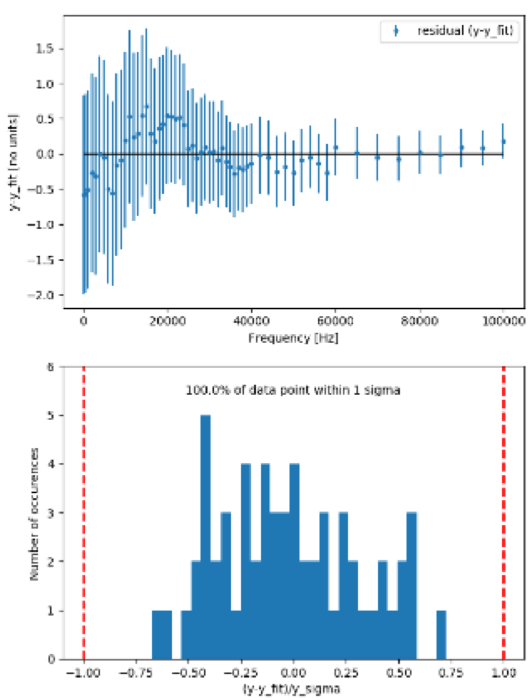
This is a very good fit as $Chi^2$/dof is extremely low.

To find the bandwidth here, we look at what frequency the graph drops to a gain of 29.289, which is the point at which the initial gain of 100 at a frequency of approximately 0 drops by a factor of 1/sqrt(2). The bandwidth is then approximately 29000 Hz.

Resistors used: $R_{100k1}$ = 98.365 +/- 0.001 kOhm, $R_{100k2}$ = 97.667 +/- 0.001 kOhm, $R_{1k}$ = 0.98455 +/- 0.00001 kOhm; G: 49.78; Vpp: 200 mV

guesses = (50,1.5e6,0)




Goodness of fit - chi square measure:
Chi2 = 6.727198767773948, Chi2/dof = 0.11802103101357804

Fit parameters:
Gain = 5.098e+01 +/- 4.070e-01
FcA0 = 9.140e+05 +/- 1.626e+04
V_offset = -5.073e-01 +/- 2.488e-01

Covariance between fit parameters:
Gain and FcA0 : 5.629e+02

Gain and V_offset : -2.241e-02
FcA0 and V_offset : -3.834e+03

Correlation between fit parameters:
Gain and FcA0 : 8.507e-02
Gain and V_offset : -2.213e-01
FcA0 and V_offset : -9.479e-01

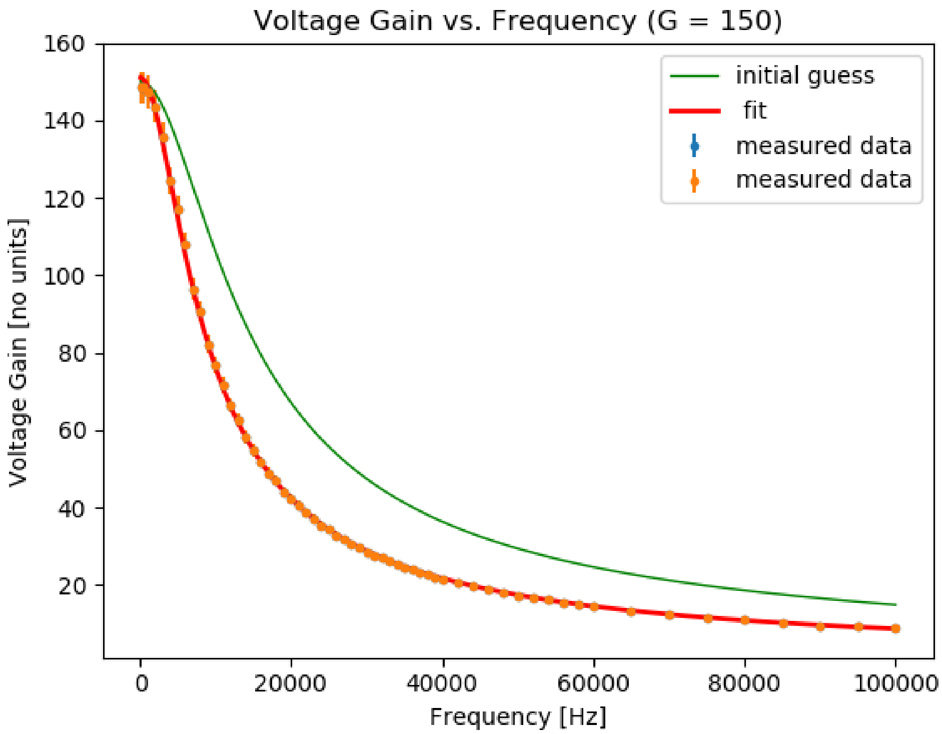
Residual information:
100.0% of data points agree within 1 sigma of fit

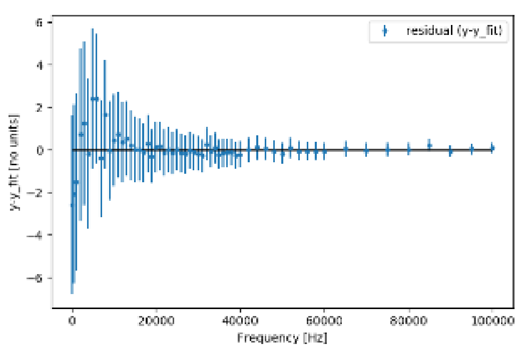
This is a very good fit as $Chi^2$/dof is extremely low.

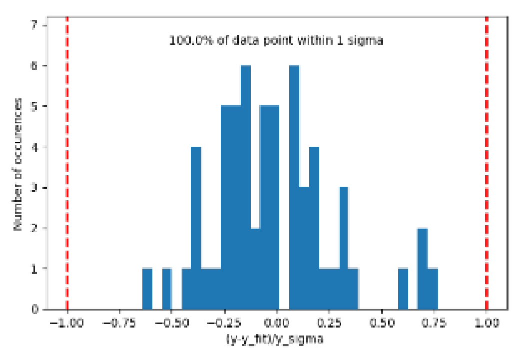
To find the bandwidth here, we look at what frequency the graph drops to a gain of 14.613, which is the point at which the initial gain of 49.8927 at a frequency of approximately 0 drops by a factor of 1/sqrt(2). The bandwidth is then approximately 56000 Hz.

Resistors used: $R_{100k1}$ = 98.365 +/- 0.001 kOhm, $R_{100k2}$ = 97.667 +/- 0.001 kOhm, $R_{100k3}$ = 97.956 +/- 0.001 kOhm, $R_{1k}$ = 0.98455 +/- 0.00001 kOhm; G: 152.31 ; Vpp: 200 mV

guesses = (150,1.5e6,0)




Goodness of fit - chi square measure:
Chi2 = 5.036855946274084, Chi2/dof = 0.08836589379428218

Fit parameters:
Gain = 1.512e+02 +/- 1.798e+00
FcA0 = 8.847e+05 +/- 8.036e+03
V_offset = -1.433e-01 +/- 1.639e-01

Covariance between fit parameters:
Gain and FcA0 : -3.522e+03

Gain and V_offset : 4.544e-02
FcA0 and V_offset : -1.164e+03

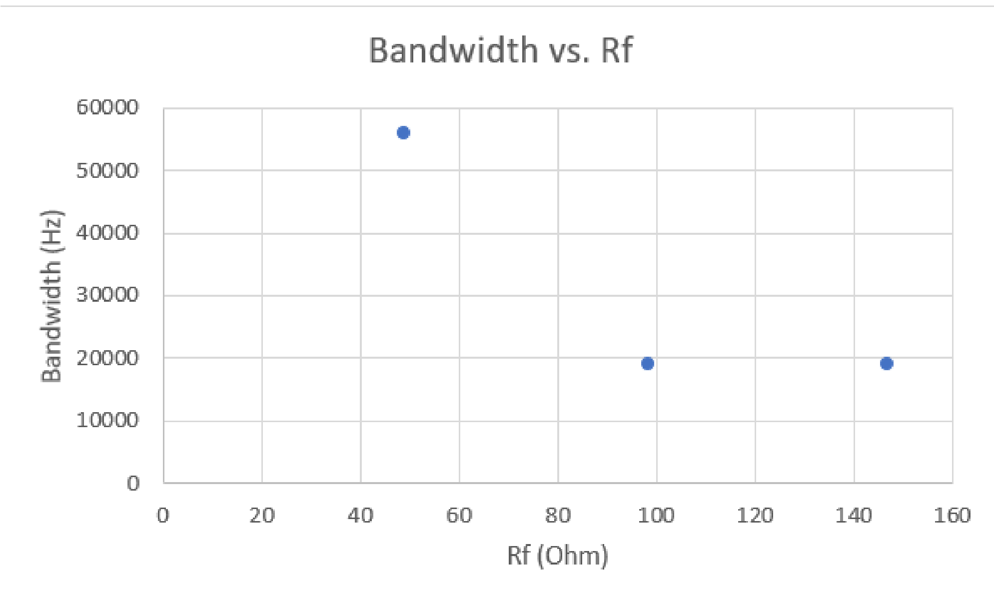
Correlation between fit parameters:
Gain and FcA0 : -2.438e-01
Gain and V_offset : 1.542e-01
FcA0 and V_offset : -8.834e-01

Residual information:
100.0% of data points agree within 1 sigma  of fit

This is a very good fit as Chi$^2$/dof is extremely low.

To find the bandwidth here, we look at what frequency the graph drops to a gain of 43.467, which is the point at which the initial gain of 148.4043 at a frequency of approximately 0 drops by a factor of 1/sqrt(2). The bandwidth is then approximately 19000 Hz.

Analyzing our values for bandwidth we can see that it seems to either linearly decrease and instantaneouslty flatten out at 19000 Hz, or exponentially decrease and gradually flatten out to a value around 19000 Hz. The latter would more accurately agree with EQN 4 as so that is what I believe is happening. It would agree because in EQN 4 we can see that the larger G is, the less the one in the square of the denominator has an effect on the equation, and thus G in the denominator can cancel out with G in the numerator. Hence, G has less of an effect on the equation at large G, and thus the larger Rf is (in ratio with Rg) the less of a change we will see in the bandwidth. Unfortunately, we did not have enough time to collect more than 3 values of Rf. The following is a graphical representation of the data:

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**lab4pt4_2a.xlsx(9.7 KB)**

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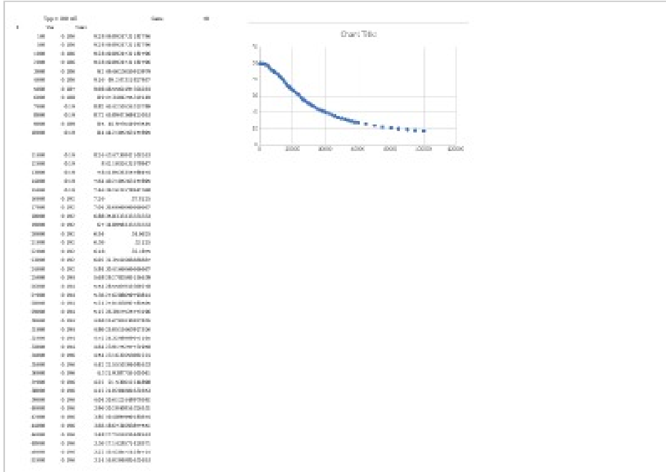


**lab4pt4_2b.xlsx(17.2 KB)**

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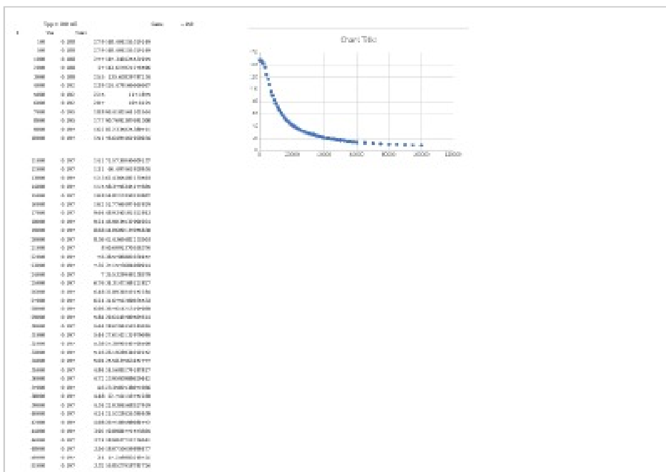


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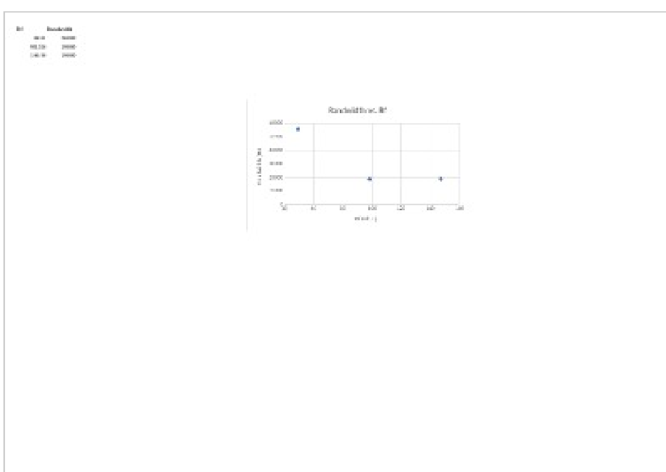

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**Conclusion**

In 4.1, we learned that the relationship of V_in to V_out is linear for low frequencies and not linear for high frequencies. We learned that frequency has an effect on the gain. In the linear one, our gain was 9.885e+01 +/- 7.054e+00.

In 4.2, we see that what we learned in 4.1 was true. We also learn that the bandwidth of the op-amp is affected by Rf, but is less affetected by Rf as Rf becomes larger. The three bandwidths measured were 56000 Hz, 19000 Hz, and 19000 Hz for gains of 5.098e+01 +/- 4.070e-01, 1.031e+02 +/- 1.058e+00, and Gain = 1.512e+02 +/- 1.798e+00 respectively.

In the future, I would improve my measurements by repeating the bandwidth measurement for more values of G in order to better understand how it is affected by Rf.

The following are pictures of the circuits we used and their diagrams: