EEE 108L MICRO-ELECTRONICS 1
LAB 3

Lab Session: Tuesday 3PM - 5:40PM

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PRE-LAB CALCULATIONS

STEP 1.

$$Av1 = \frac{Rb}{Ra} + 1$$

Ra has been selected as 10kΩ, leaving Rb to be 20kΩ to meet spec.

This selection allows Av1 to be exactly 3V/V

(Please see figure 1 in appendix A for complete calculations)

STEP 2.

$$VN1 = Vout\left(\frac{Ra}{Ra + Rb}\right)$$

Rin is infinite.

(Please see figure 1 in appendix A for complete calculations)

STEP 3.

$$Av2 = -\frac{Rb}{Ra}$$

Using the resistance values from before, Av2 is exactly -2V/V

(Please see figure 2 in appendix A for complete calculations)

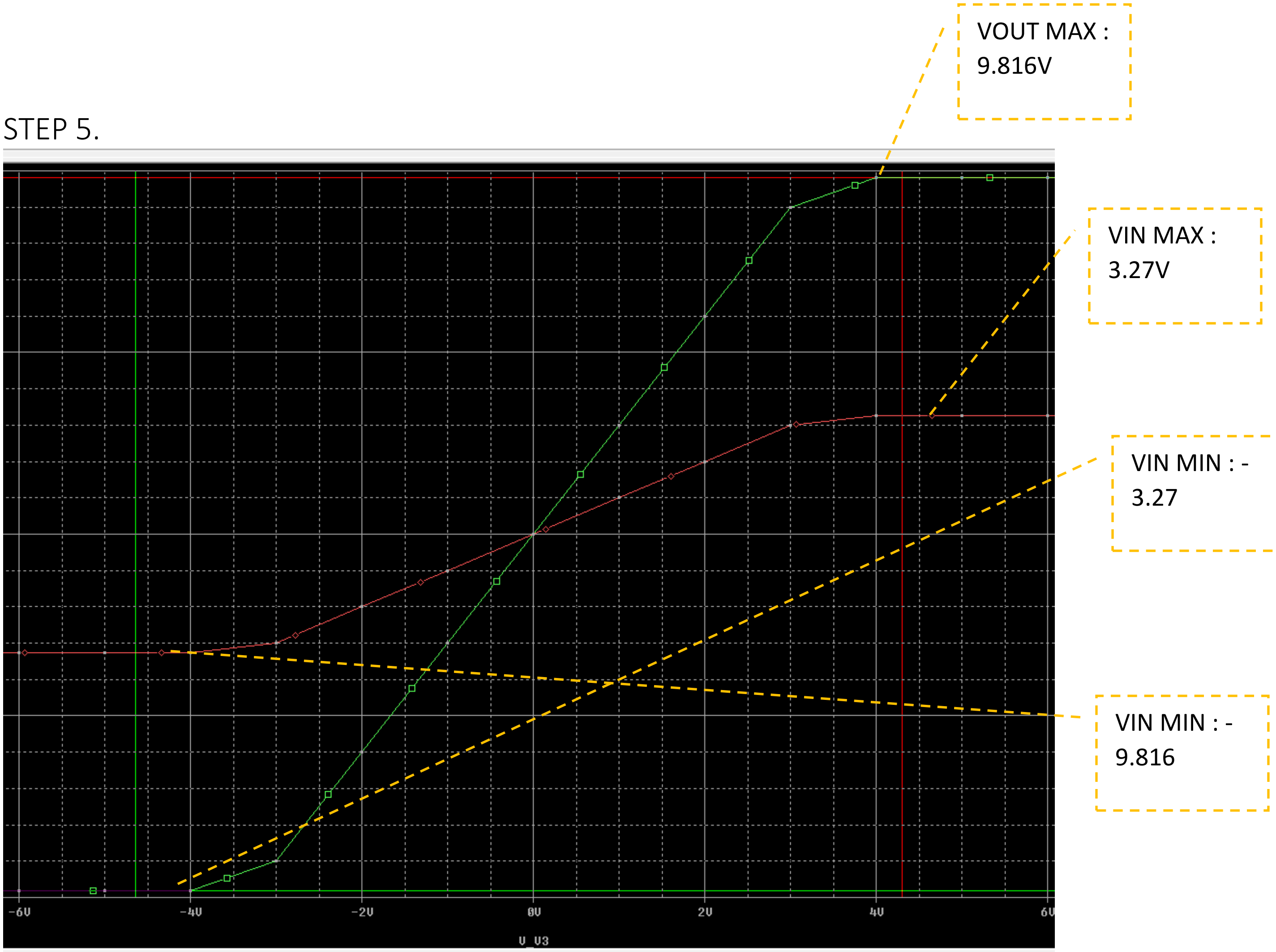
STEP 4.

$$Rin = \frac{Rb}{2} = Ra$$

(Please see figure 2 in appendix A for complete calculations)

SPICE SIMULATION

STEP 5.



The green curve represents Vout, and the red curve is Vin. There is response from about -4V to +4V but only a stable linear response from -3V to +3V.

Placing cursors far left and right yield Vout MAX = 9.816V and Vout MIN = -9.816V

Slope during linear response

$$\frac{\Delta Vout1}{\Delta Vin1} = \frac{6.0014 + 5.9981}{1.9999 + 1.9999} = \frac{12.000}{3.9998} \cong 3V/V$$

This agrees with my prior calculations.

STEP 6.

The green curve represents Vout, and the red curve is Vin. There is stable linear response from -5V to +5V.

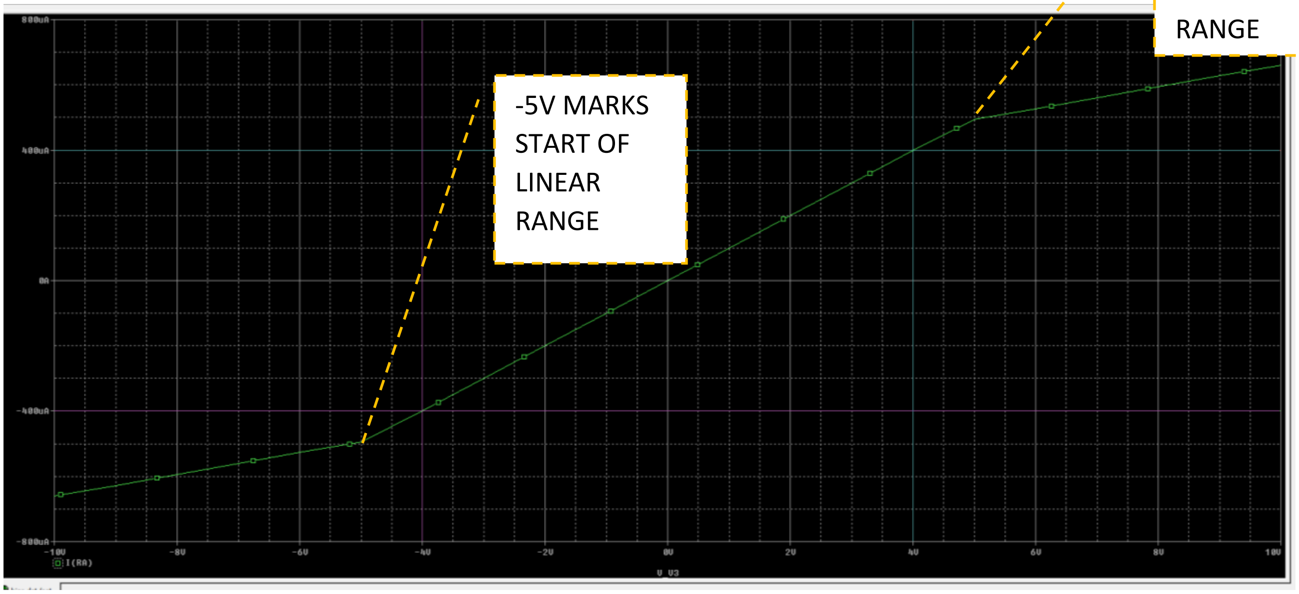
Placing cursors far left and right yield Vout MAX = 9.816V and Vout MIN = -9.816V

Slope during linear response

$$\frac{\Delta Vout2}{\Delta Vin2} = \frac{4.9903 - 8.0015}{-2.4944 + 4.0000} = \frac{-3.0112}{1.5056} \cong -2V/V$$

This agrees with my prior calculations.

STEP 7.



This is the current is2 as a function of the Vs2 DC sweep

$$\frac{\Delta Vs2}{\Delta is2} = \frac{4V + 4V}{399.994u\ + 399.998u} \cong 10k\Omega$$

This also agrees with my prior calculations.

STEP 8.

The values of Vout MAX and Vin MAX regarding steps 5 and 6 are indeed the same.

We also noted Vn does not always equal Vp, this can occur when the output becomes saturated.

EXPERIMENT – NON-INVERTING OPAMP

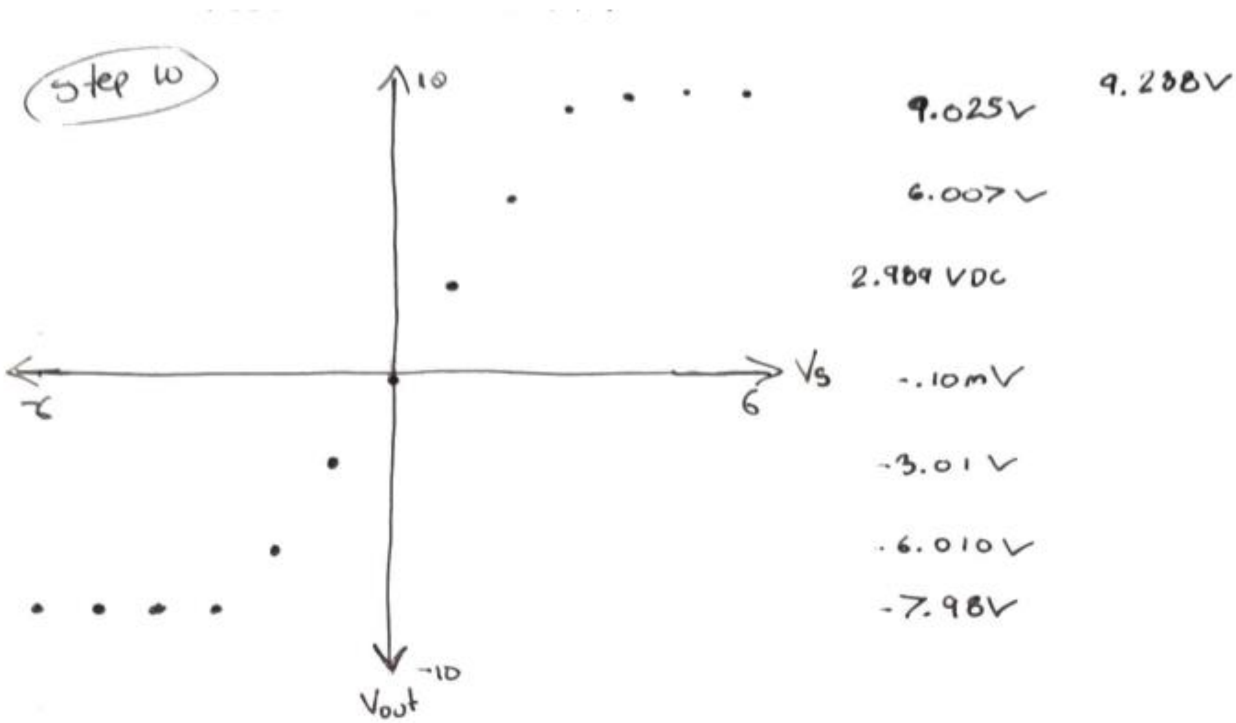
STEP 9.

(No image to be shown here)

After grounding Vs1, our Vout measured 3.45 mV. The non-inverting Op-amp configuration yields a gain as follows: $Av = 1 + \frac{R2}{R1}$. Given $R2 = 20.02\ kohms$ and $R1 = 9.91\ kohms$, our gain is approximately 3.02 volts per volt. This means Vos is roughly 1.142 mV.

STEP 10.

As can be seen in figure 3 of Appendix A.



Data points were taken at 1V increments starting at -6V and ending at +6V. Using data from -2V to +2V:

$$\frac{\Delta Vout}{\Delta Vs1} = \frac{6.007V + 6.010V}{2V + 2V} = \frac{12.017}{4} = 3.00425\frac{V}{V}$$

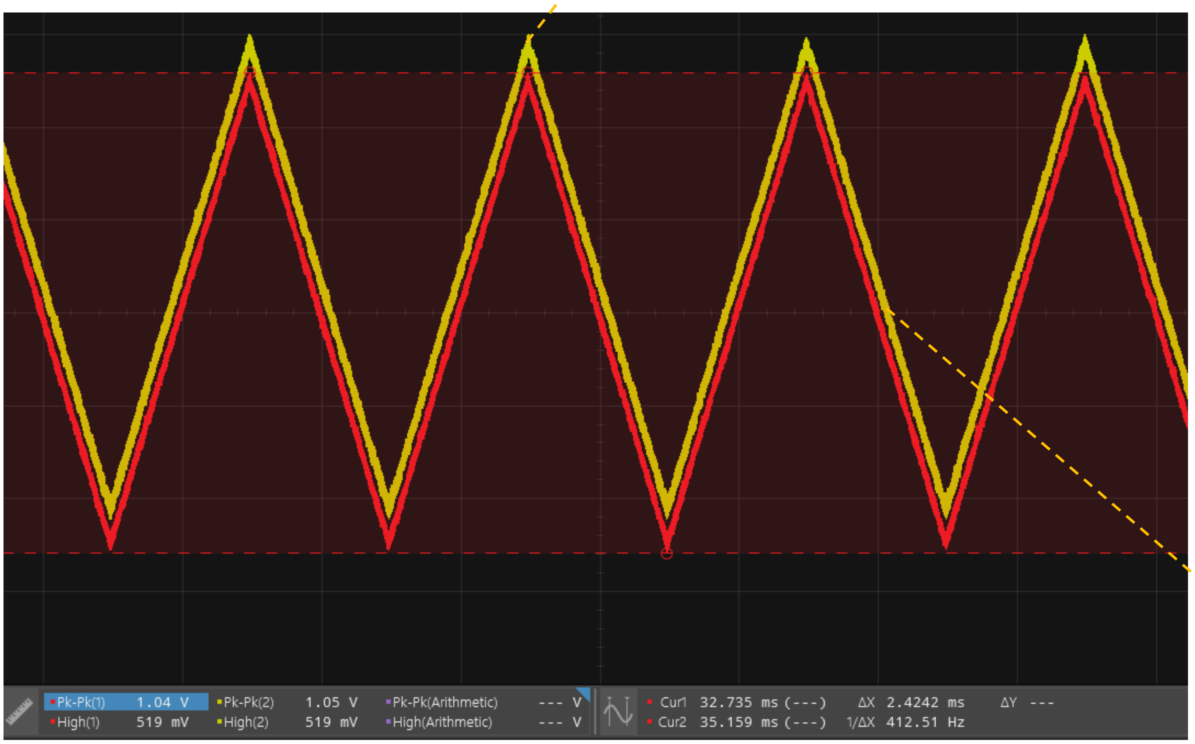
This figure is extremely close to the calculated values of step 1, and the observed values of step 5 (both 3V/V)

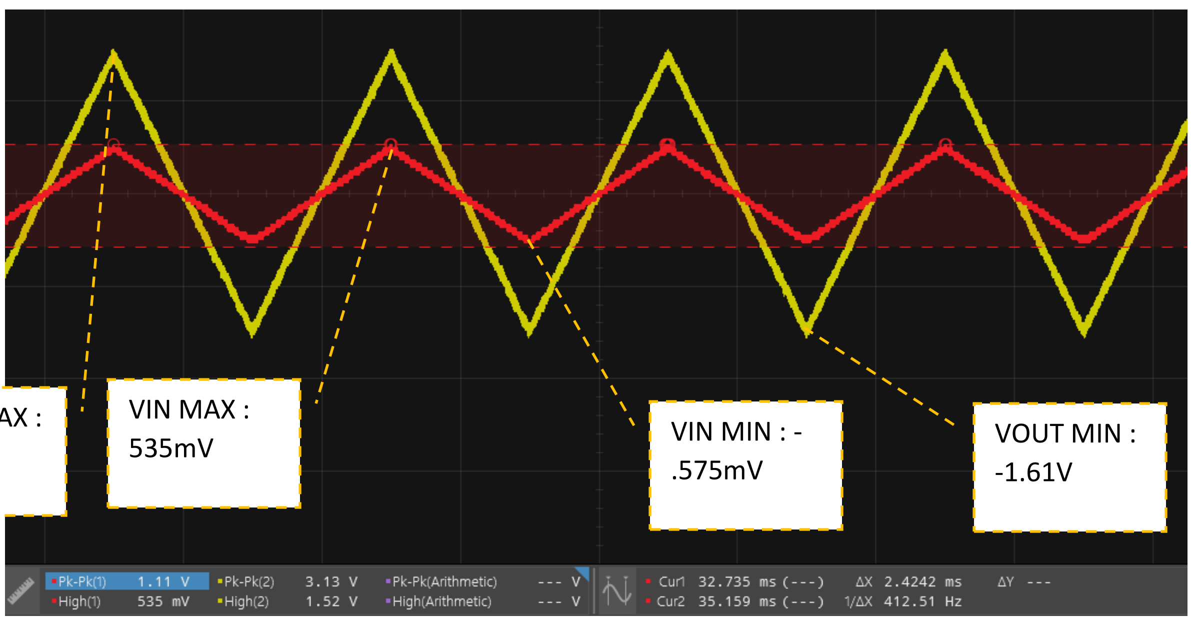
Vout MAX : 9.288V

Vout MIN : -7.98V

STEP 11.

The first image is Vn1 to Vout, and the second image is Vin to Vout





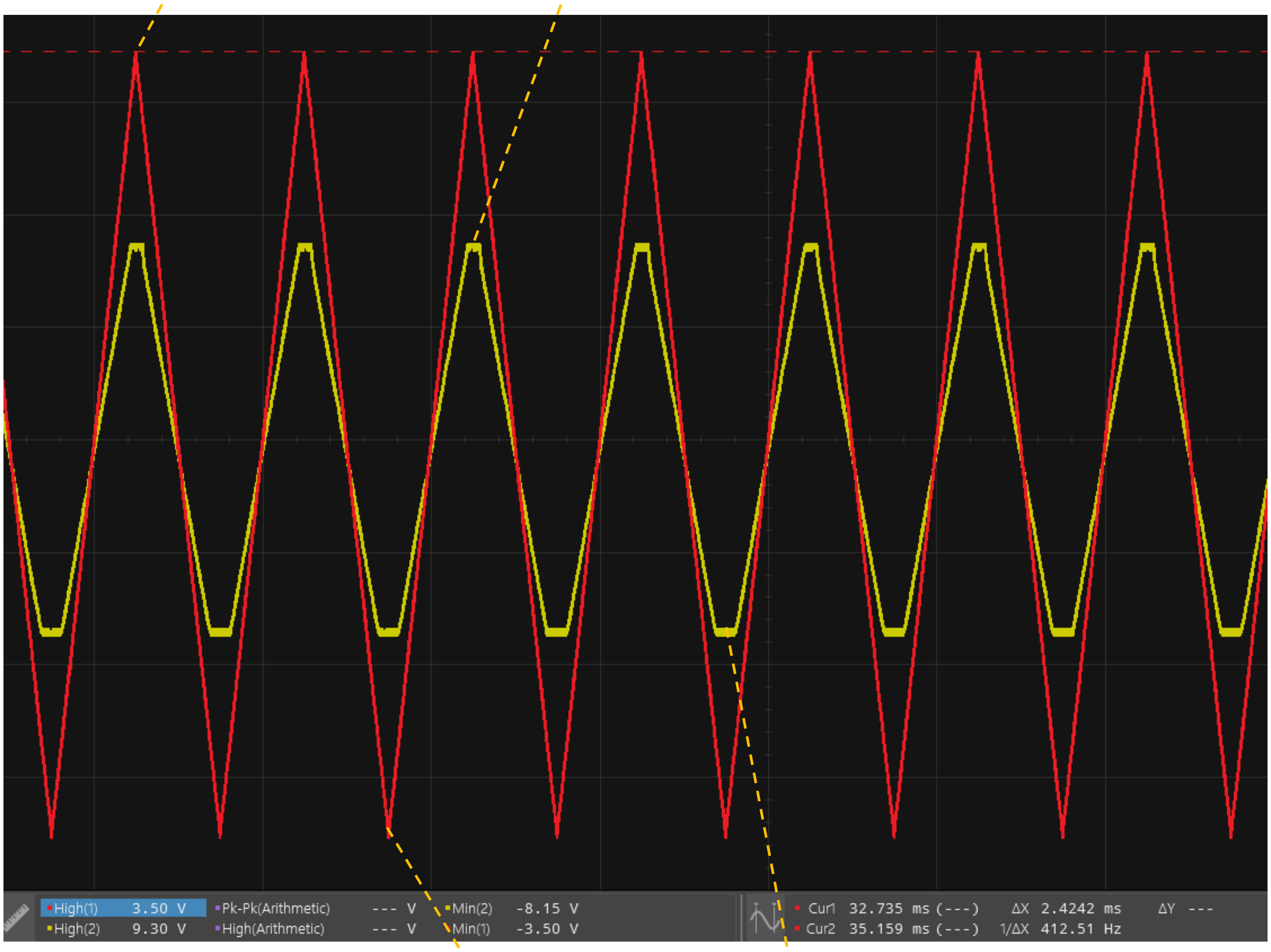
Using a positive peak:

$$\frac{\Delta Vout}{\Delta Vs1} = \frac{1.52V}{535mV} = \frac{1520mV}{535mV} = 2.84112\frac{V}{V}$$

STEP 12.

VIN MAX :
3.5V

VOUT MAX :
9.3V



Pos clipping level: 9.3V

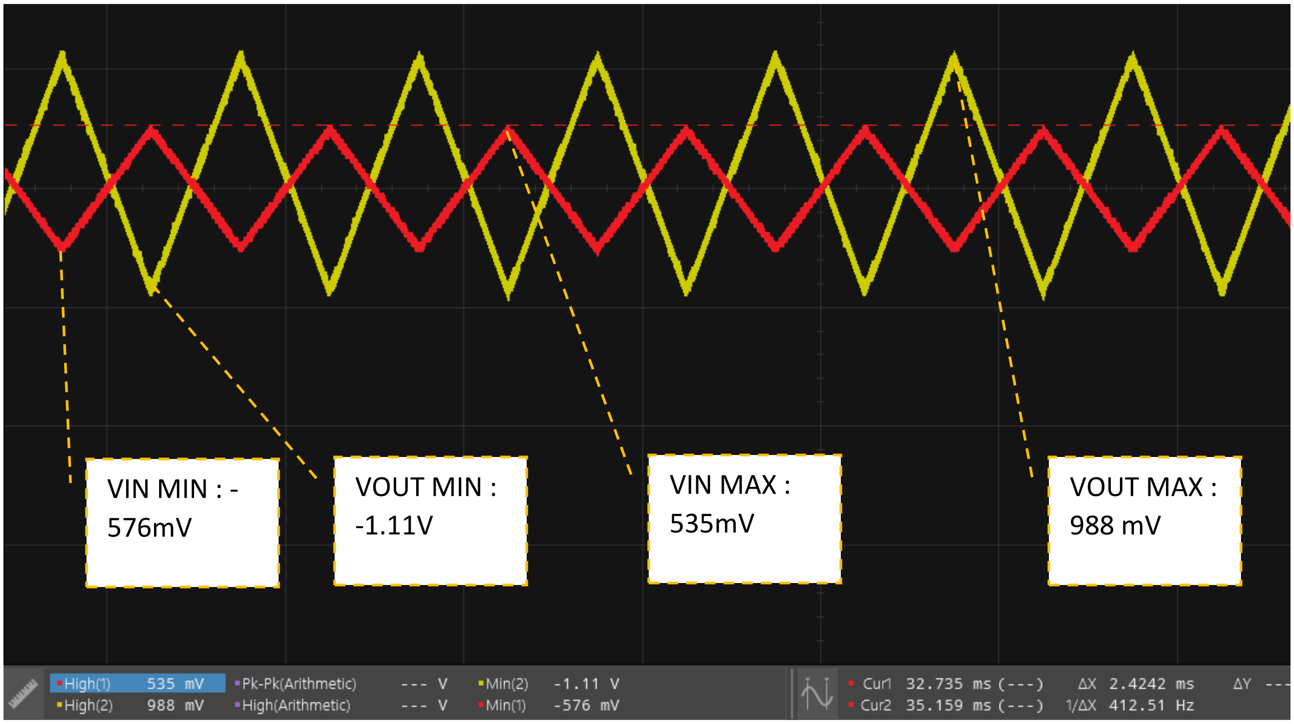
Neg clipping level: -8.15V

VIN MIN : -
3.5V

VOUT MIN :
-8.15V

EXPERIMENT – INVERTING OPAMP

STEP 13.



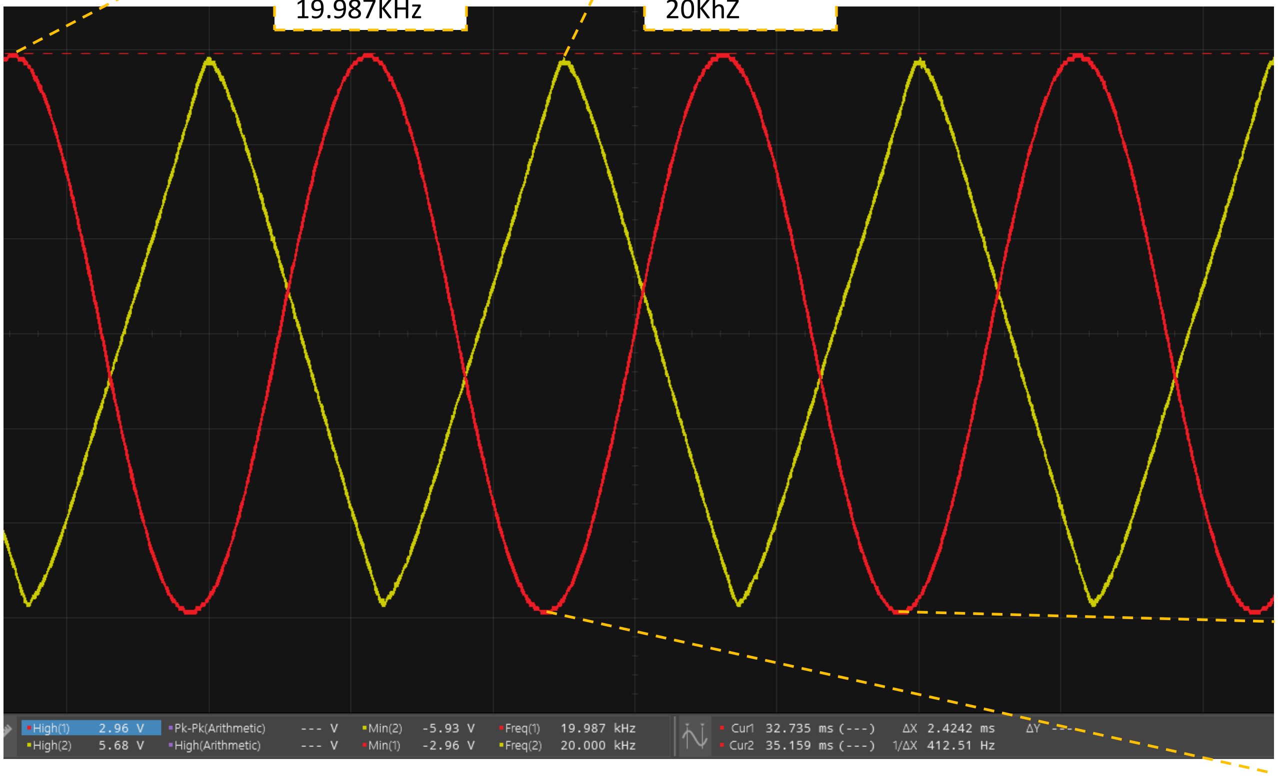
As there is no clipping here, I will use corresponding peaks for the small signal gain

$$\frac{\Delta Vout2}{\Delta Vs2} = \frac{988mV}{-535mV} = -1.8467\frac{V}{V}$$

STEP 14.

To measure the small signal input resistance Rin2 we first disconnected all outside sources of energy besides our reference of ground. We then used our DMM and measured from ground to the input terminal of the integrated op amp to get a value of 9.9kohms. This value is nearly the 10kohms calculated in step 4.

STEP 15.



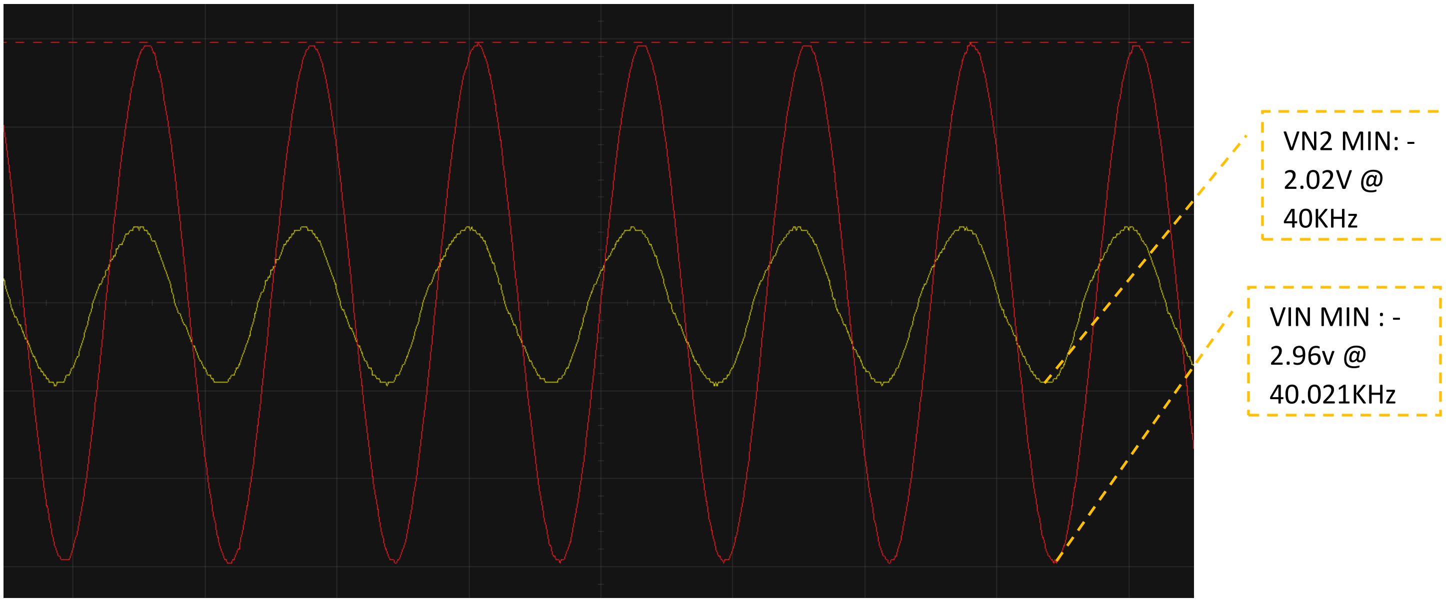
Slew rate is defined as the rise in voltage per time.

Our graph gave frequency, max voltage , and min voltage for the output, this will work for the slew rate.

F = 1/period => period = 1/F = 1/20kHz = 50microseconds. Half of this is a single rise. One rise takes place from -5.93V to 5.68V. Total rise of 11.61V.

$$slew\ rate = \frac{V}{t} = \frac{11.61V}{25us} = .4644\frac{V}{us}$$

STEP 16.



As the frequency increased, VN2 became less of a virtual ground and more of a non-negating sine wave.

STEP 17.

(Instructed that we could not perform this part without differential mode probes)

Although As I read it again now, it seems it would have been simple to complete and the statement must have been about performing a differential measurement directly without the approach of grounding one input.

CONCLUSIONS

Item 1.

Compare the SPICE simulation results to the laboratory measurements with regard to gain and output clipping levels. Suggest reasons for any differences.

The SPICE simulations appear to use models much closer to ideal representations. The gain found by hand and in SPICE for the non-inverting model both came out at 3V/V exactly, yet the real-world op amp was slightly under this value, at 2.84V/V. I suspect this is because we cannot achieve ideal models in the real world, there is some sort of loss somewhere, always. The clipping levels are very near each other for the top end but off by a good amount for the bottom end. I think the bottom end issue is due to the reliance of the negative feedback for accurate results. If an output is more negative than the input, then the feedback loop doesn't really feedback.

Item 2.

Summarize the data and calculations you did to determine the input offset voltage (VOS) of your operational amplifier. Suppose that the amplifier circuit of Figure 1 is constructed with your operational amplifier with RA = 100 Ω and RB = 100 kΩ. Assuming that VOS has not changed, what is the DC output voltage of the operational amplifier when the input is zero?

After grounding Vs1, our Vout measured 3.45 mV. The non-inverting Op-amp configuration yields a gain as follows: $Av = 1 + \frac{R2}{R1}$. Given $R2 = 20.02\ kohms$ and $R1 = 9.91\ kohms$, our gain is approximately 3.02 volts per volt. This means Vos is roughly 1.142 mV.

If Ra = Rb we would have a gain of 2V/V instead, given our Vos was calculated to be 1.142mV, the output should be 2.284mV when the input is zero.

Item 3.

Review your data of Steps 11 and 12 and make a general statement relating the output voltage swing of an operational amplifier to its power supply voltages.

An op-amp's output cannot exceed the value of its corresponding maximum or minimum power supply voltages. The power supply voltages serve as the ceiling and floor of the outputs range.

Item 4.

Summarize the measurements of Step 16. Multiply each measured open-loop gain by the frequency at which it was measured. The result is called the gain-bandwidth product (GBP) of the operational amplifier. Does the GBP appear to be constant for the two cases?

(We didn't complete the last part of step 16, it seems we missed reading this part)

Item 5.

Compare the voltage gain Adm found in Step 17 with theory. Does the voltage gain Acm found in Step 17 seem reasonable?

(My misinterpretation has now cost me twice)

APPENDIX A

Figure 1.

Lab 3 Pre Lab

– Step 1. $V_{P1} = V_{N1}$ $\quad i_b = \frac{V_{N1} - V_{out}}{R_b}$

$$i_a = \frac{-V_{N1}}{R_A}$$

@ Node V_{N1} : $i_a = i_b$

$$\frac{-V_{N1}}{R_A} = \frac{V_{N1} - V_{out}}{R_b} = \frac{V_{N1}}{R_b} - \frac{V_{out}}{R_b}$$

$$\frac{(R_b)(-V_{N1})}{R_A} = V_{N1} - V_{out} \qquad V_{N1} = V_{S1}$$

$$\frac{(R_b)(-V_{N1})}{R_A} - V_{N1} = -V_{out}$$

$$\boxed{\frac{R_b}{R_A} + 1 = \frac{V_{out}}{V_{N1}} = A_{V_1}}$$

if we want A_{V_1} to $= 3\frac{V}{V}$ and use $10K\Omega$ for R_A then

$$\frac{R_b}{10K\Omega} + 1 = 3 \Rightarrow \frac{R_b}{10K} = 2$$

$$R_b = 20K$$

– Step 2. infinite input impedance (or zero input current)

$$R_{in} = \frac{V_{S1}}{R_{S1}}, \quad \infty = \frac{V_{S1}}{R_{S1} \to 0}$$

$V_{out} > V_{N1}$ so current flows left. Drop across R_A is V_{N1}

$$\boxed{V_{N1} = V_{out}\left(\frac{R_A}{R_A + R_B}\right)}$$

Figure 2.

- Part 3

$$i_a = i_b = i_{s2} \qquad i_a = \frac{V_{s2} - V_{N2}}{R_A}$$

$$V_{N2} = V_{p2} \qquad i_b = \frac{V_{N2} - V_{out2}}{R_B}$$

$$\frac{V_{s2}}{R_A} - \frac{V_{N2}}{R_A} = \frac{V_{s2} - V_{N2}}{R_A} = \frac{V_{N2} - V_{out2}}{R_B} = \frac{V_{N2}}{R_B} - \frac{V_{out2}}{R_B}$$

$$\frac{V_{s2}}{R_A} - \frac{V_{N2}}{R_A} - \frac{V_{N2}}{R_B} = -\frac{V_{out2}}{R_B}$$

note: $\left(V_{p2} = 0 \text{ so } V_{N2} = 0 \right)$

$$\frac{V_{s2}}{R_A} = -\frac{V_{out2}}{R_B} \Rightarrow \boxed{\frac{-R_B}{R_A} = \frac{V_{out2}}{V_{s2}} = A_{v2}}$$

using previous values of R_A & R_B we set:

$$\frac{-20k\Omega}{10k\Omega} = A_{v2} = -2 \ \tfrac{V}{V}$$

- Part 4

using the gain calculated $\frac{V_{out2}}{V_{s2}} = -2 \ \tfrac{V}{V}$, $-\frac{V_{out2}}{2} = V_{s2}$

$$\boxed{R_{in2} = \frac{V_{s2}}{i_{s2}} = \frac{-V_{out2}}{2\, i_{s2}} = \frac{-V_{out2}}{2\left(\frac{-V_{out2}}{R_B}\right)} = \frac{R_B}{2}}$$

Figure 3.

Lab 3

(Step 9 R_A 9.91 kΩ R_B 20.02 kΩ

Vout : 3.45 mV

(step 10)

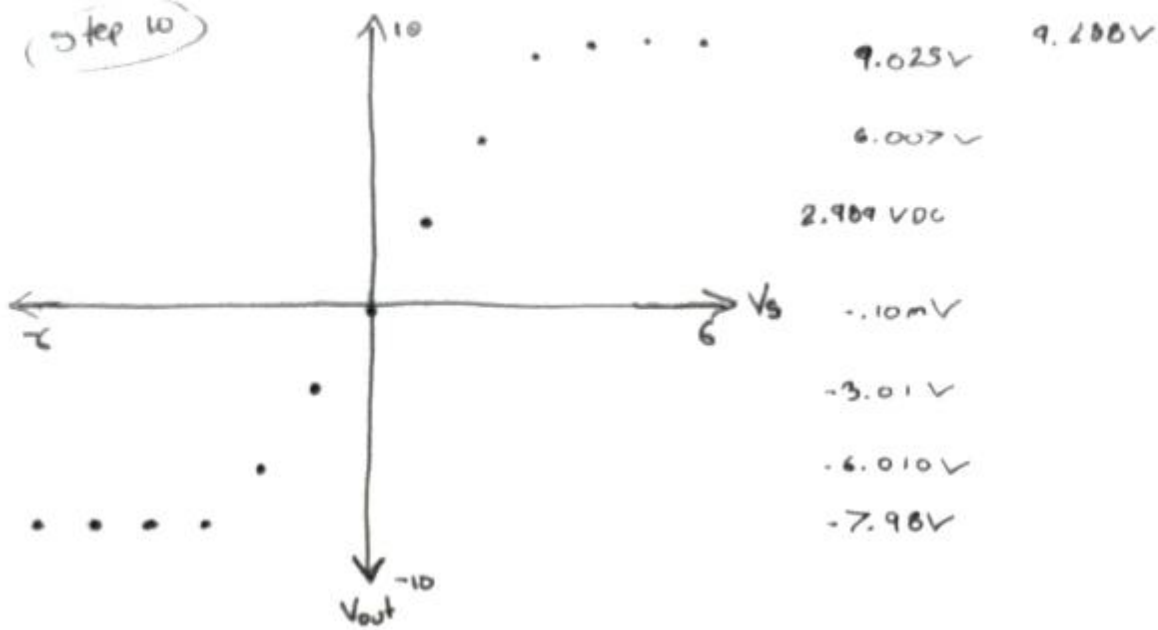


Figure 4.

Step 14 9.9 kΩ Rin 2 using
~~Pen~~ DMM (virtual bench)

step 16. As frequency increased VN2 was less of a virtual ground and turned into a wave thats not negative

step 17

R3 - 4.62 k
R4 - 4.63 k
R5 - 4.63 k
R6 - 4.63 k

Step 18a
cannot do,
no differential probe

Vout
Vin