Electronic Devices & Circuits II - EE 3EJ4
Lab #4

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Questions for Part 1

Question 1

(1) At $f\ =\ 100Hz$ the following were obtained for the voltage gain of each stage…

$$Ad_1\ =\ 7.38dB$$

$$Ad_2\ =\ 70.05dB$$

$$Ad_3\ =\ 0.00dB$$

(2) The overall differential-mode voltage gain for the circuit was found as…

$$Ad\ =\ 77.43dB\ =\ 7434.5\frac{V}{V}$$

(3) The non-inverting input of the operational amplifier is V_2, since it is in-phase with the output voltage

(4) The upper-3dB frequency of this amplifier is 6338 Hz. This was obtained by determining the frequency at which the initial phase ($\approx\ 180\ deg$) dropped by about 45 deg ($\approx\ 134\ deg$)

Frequency	M(I(Q1:B))	P(I(Q1:B))	M(V(Vo1))	P(V(Vo1))	M(V(Vo2))	P(V(Vo2))	M(V(Vo))	P(V(Vo))	Ad1	Ad2	Ad3	Ad	Ad	Rin = R11
Hz	Amps	Degrees	Volts	Degrees	Volts	Degrees	Volts	Degrees	dB	dB	dB	dB	V/V	Ohm
100	2.45E-08	-179.9809954	0.004677083	-0.489609801	14.86961187	179.0738614	14.86895629	179.0737912	7.38	70.05	0.00	77.43	7434.5	81757.3

Frequency	M(I(Q1:B))	P(I(Q1:B))	M(V(Vo1))	P(V(Vo1))	M(V(Vo2))	P(V(Vo2))	M(V(Vo))	P(V(Vo))
Hz	Amps	Degrees	Volts	Degrees	Volts	Degrees	Volts	Degrees
100	2.45E-08	-179.9809954	0.004677083	-0.489609801	14.86961187	179.0738614	14.86895629	179.0737912

Frequency	M(I(Q1:B))	P(I(Q1:B))	M(V(Vo1))	P(V(Vo1))	M(V(Vo2))	P(V(Vo2))	M(V(Vo))	P(V(Vo))
6338.408102	2.45E-08	-178.7972833	0.003631441	-19.96197874	10.39231079	134.2730085	10.39185035	134.2685606

Question 2

The gain found in question 5 of lab 3 was $70.07dB$. The gain for stage 1, as found above, is $7.38dB$. The large difference in gain here can be explained by the use of feedback. In our circuit, stage 1 (I.e. relating to Ad_1) is a feedback stage, containing a pnp BJT. We know that feedback circuits in general have a substantially lower gain in priority of much greater stabilization, which can be explained by the feedback-gain formula, $A_f\ =\frac{A}{1+A\beta}$, which shows us that feedback gain decreases by a factor of $(1\ +\ A\beta)$.

Question 3

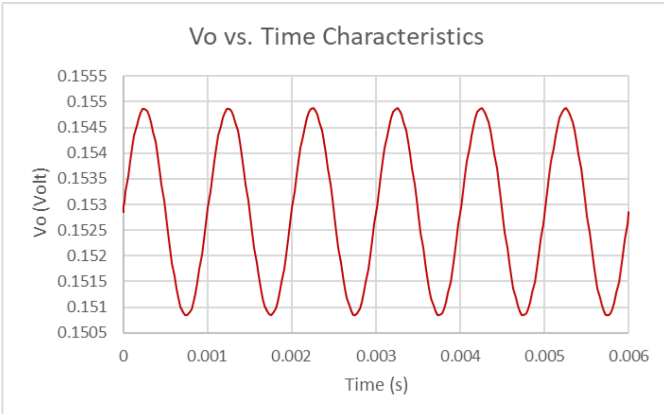
Based on step 1.2 and 1.3… $R_{in}\ =\ 81757.3\Omega$ and $R_{out}\ =\ 460.9\Omega$

Rin = R11
Ohm
81757.3

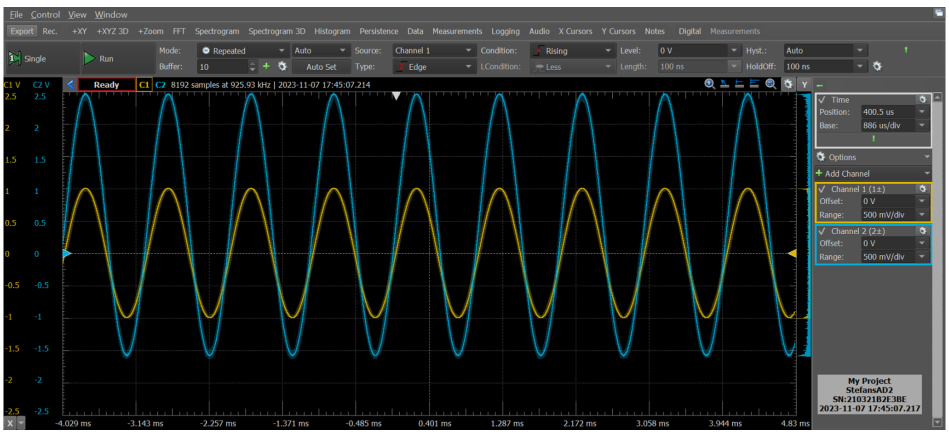
Rout
Ohm
460.9

Question 4

(1) Based on step 1.6, the following graph can be obtained…



Based on step 1.13 the following graph can be obtained…



(2)For step 1.6…

$$V_{pp} = 0.155 - 0.151 = 0.004V$$

$$V_p = \frac{0.004}{2} = 0.002V$$

$$V_{dc} = 0.155 - 0.002 = 0.153V$$

For step 1.13…

$$V_{pp} = 2.5 - (-1.5) = 4V$$

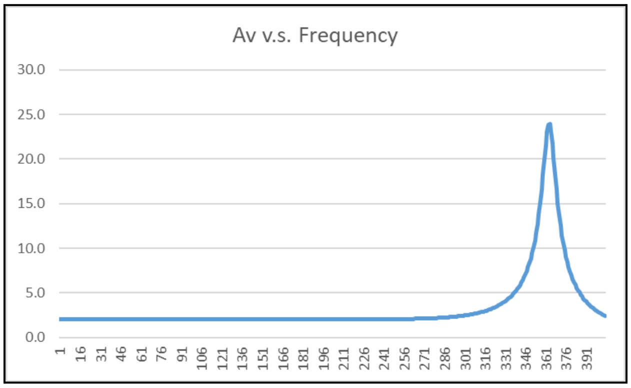
$$V_p = \frac{4}{2} = 2V$$

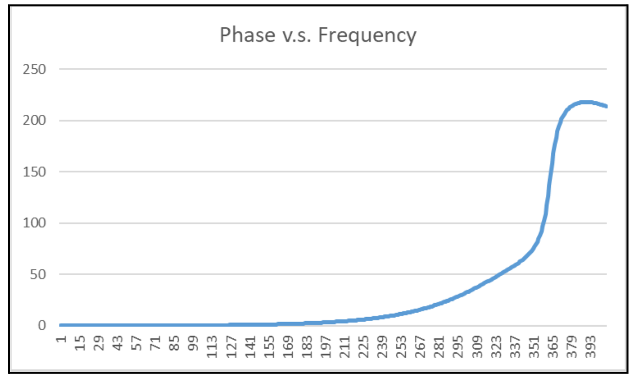
$$V_{dc} = 2.5 - 2 = -0.5V$$

These differences can be explained by the differences in AC input voltages. In step 1.6, we used an AC input of amplitude $1mV$, but in step 1.13 we used an AC input of amplitude $1V$

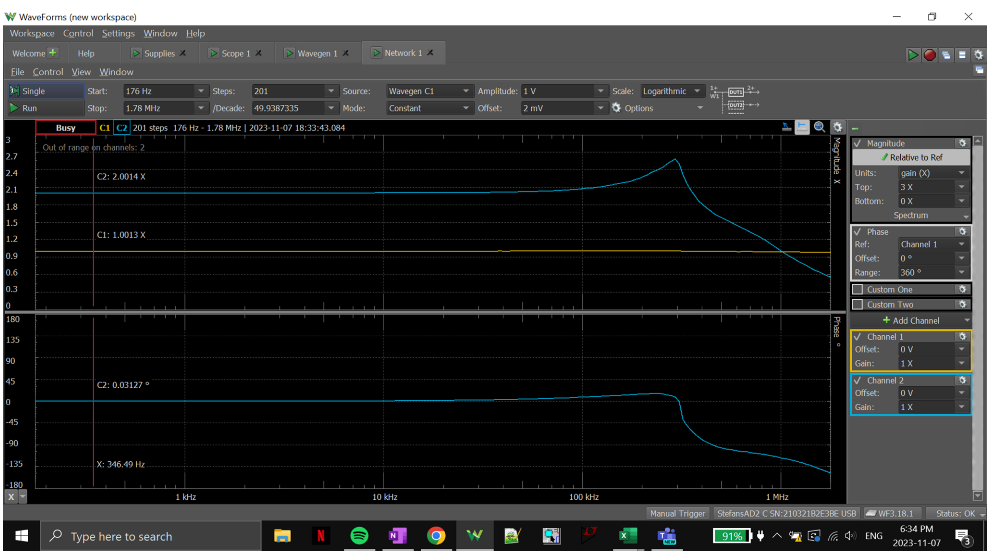
Question 5

(1) Based on step 1.7 the following graphs can be obtained…





Based on step 1.14 the following graphs can be obtained…



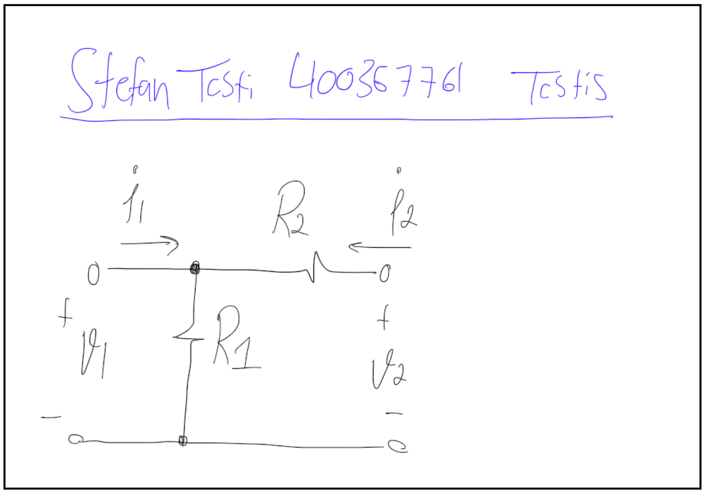
(2) Based on the above, we can see that we should keep the frequency within 100KHz to maintain a constant gain

Question 6

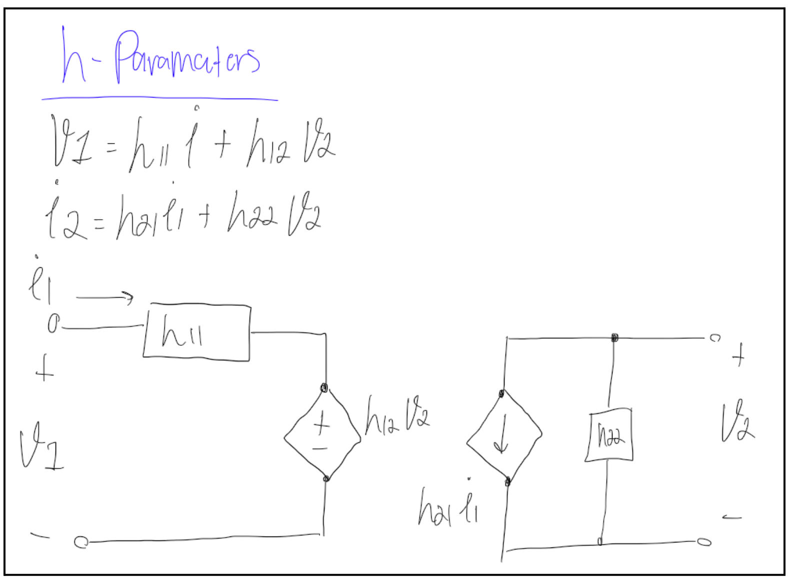
The amplifier is a series-shunt configuration. The input is connected in series with the respective differential amplifier, and the output is connected to one of the amplifiers, thus providing feedback in a shunt connection.

Question 7

By removing the input and output terminals, we can find the Beta network of the circuit as follows…



Since we determined that we have a series-shunt connection in question 6, we know that we have current excitation at port 1, and voltage excitation at port 2. This tells us that we should be using the h-parameters to find the related parameters…



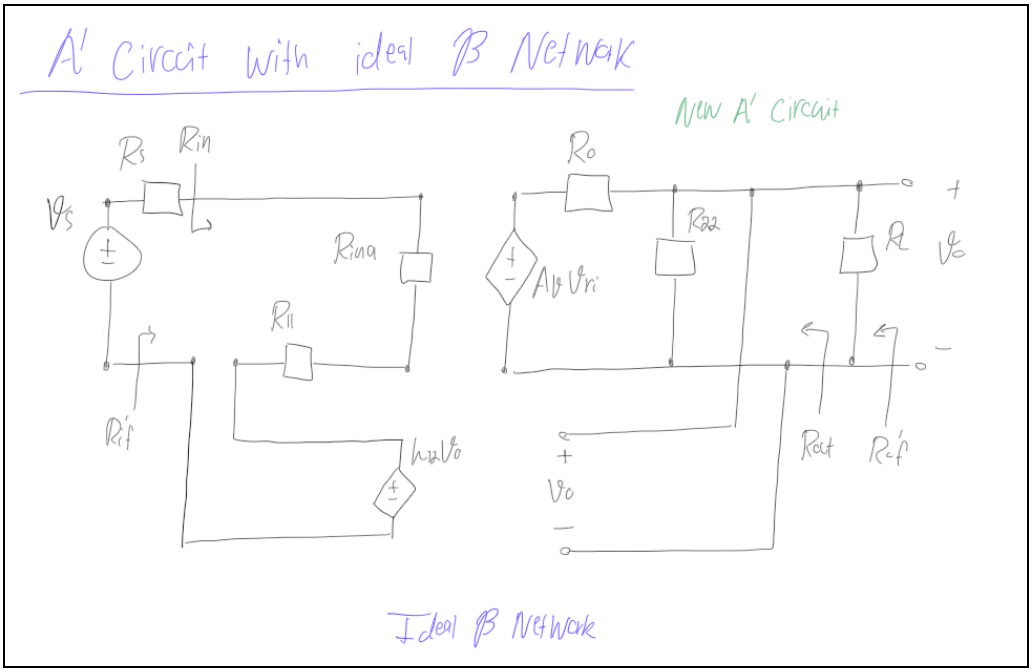
$\beta = \frac{R_1}{R_1+R_2} = \frac{100k}{100k+100k} = 0.5$

$R_{11} = R_1 || R_2 = 100k || 100k = 50k\Omega$

$R_{22} = R_1 + R_2 = 100k + 100k = 200k\Omega$

Question 8

We can determine the following by disconnecting R_{11} & R_{22} from the beta network, and forming the related A' network of the circuit…



We can then use the above to obtain the following…

$$A_{vf}' = \frac{A_v'}{1+A_v'\beta} \approx \frac{1}{\beta} = \frac{1}{0.5} = 2\frac{V}{V}$$

$$R_{if}' = (R_i')(1 + A_{vf}'\beta) = (R_{ina} + R_{11} + R_s)(1 + 0.5\beta) = 303\ M\Omega$$

$$R_{of}' = \frac{R_{22} \,||\, R_L \,||\, R_o}{1+A_{vf}'\beta} = \frac{(200k) \,||\, (240k) \,||\, (460.9)}{1+0.5\beta} = 0.2\Omega$$

$$R_{in} = R_{if}' - R_s = 303\ M\Omega$$

$$\frac{1}{R_{out}} = \frac{1}{R_{of}'} - \frac{1}{R_L} \Rightarrow R_{out} = \frac{1}{\frac{1}{R_{of}'} - \frac{1}{R_L}} = 0.2\Omega$$

Questions for Part 2

Question 9

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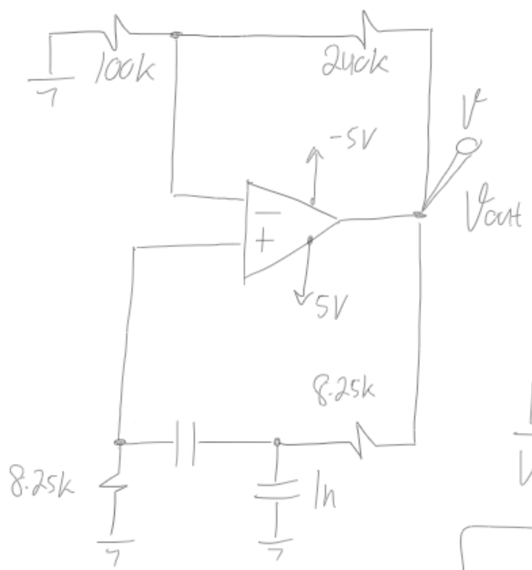


$R_3 = R_4 = R = 8.25k\Omega$

$C_1 = C_2 = C = 1nF$

$$V_0 = V_+\left(1+\frac{1}{SCR}\right) + RV_+\left(\frac{1}{R} + SC\left(1+\frac{1}{SCR}\right)\right)$$

$$V_0 = V_+\left(1+\frac{1}{SCR}\right) + V_+(2+SCR)$$

$$\frac{V_+}{V_0} = \frac{S/CR}{S^2 + S\left(\frac{3}{CR}\right) + \left(\frac{1}{CR}\right)^2}$$

$$\boxed{L(S) = \left(1+\frac{R_2}{R_1}\right)\frac{S/CR}{S^2 + S\frac{3}{CR} + \left(\frac{1}{CR}\right)^2}}$$

Zero loop phase: $\boxed{\omega_0 = \frac{1}{CR}}$

At zero loop phase frequency $|L(j\omega)| = \frac{1}{3}\left(1+\frac{R_2}{R_1}\right)$, thus for oscillation we require $\frac{1}{3}\left(1+\frac{R_2}{R_1}\right) \geq 1$

$$\Rightarrow \boxed{\frac{R_2}{R_1} \geq 2}$$

Question 10

The settling times observed in step 2.4 are as follows…

$$R_2 = 220k\Omega \Rightarrow 1.765ms$$

$$R_2 = 240k\Omega \Rightarrow 0.925ms$$

$$R_2 = 280k\Omega \Rightarrow 0.486ms$$

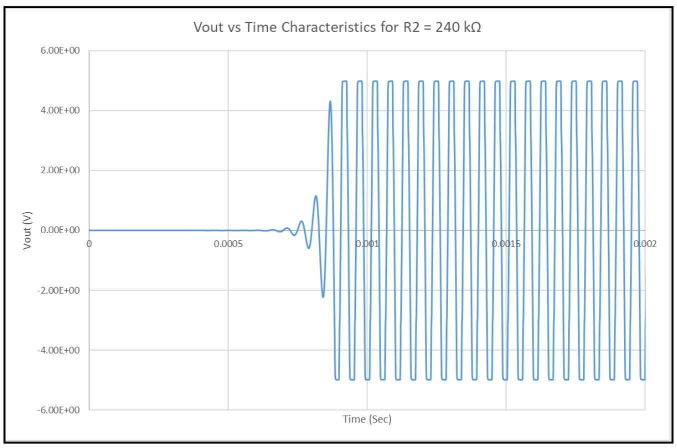
R2 = 220 kΩ	R2 = 240 kΩ	R2 = 280 kΩ
Settling Time (ms)	Settling Time (ms)	Settling Time (ms)
1.765	0.925	0.486

The trend in the above data is that resistance and settling time are inversely proportional. As resistance increases, the settling time of the circuit decreases.

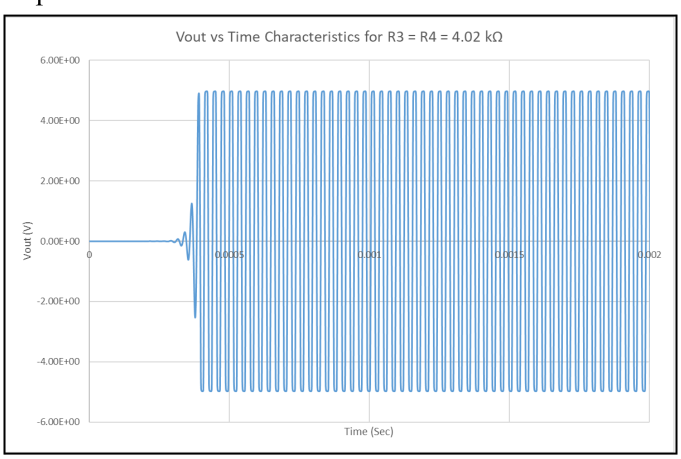
This can be explained by examining the equation derived in Question 9. Increasing R_2 subsequently increases $L(s)$, which reduces settling time of the circuit. A higher loop-gain shifts the dominant pole of the circuit to a higher frequency, thus leading to a faster settling time.

Question 11

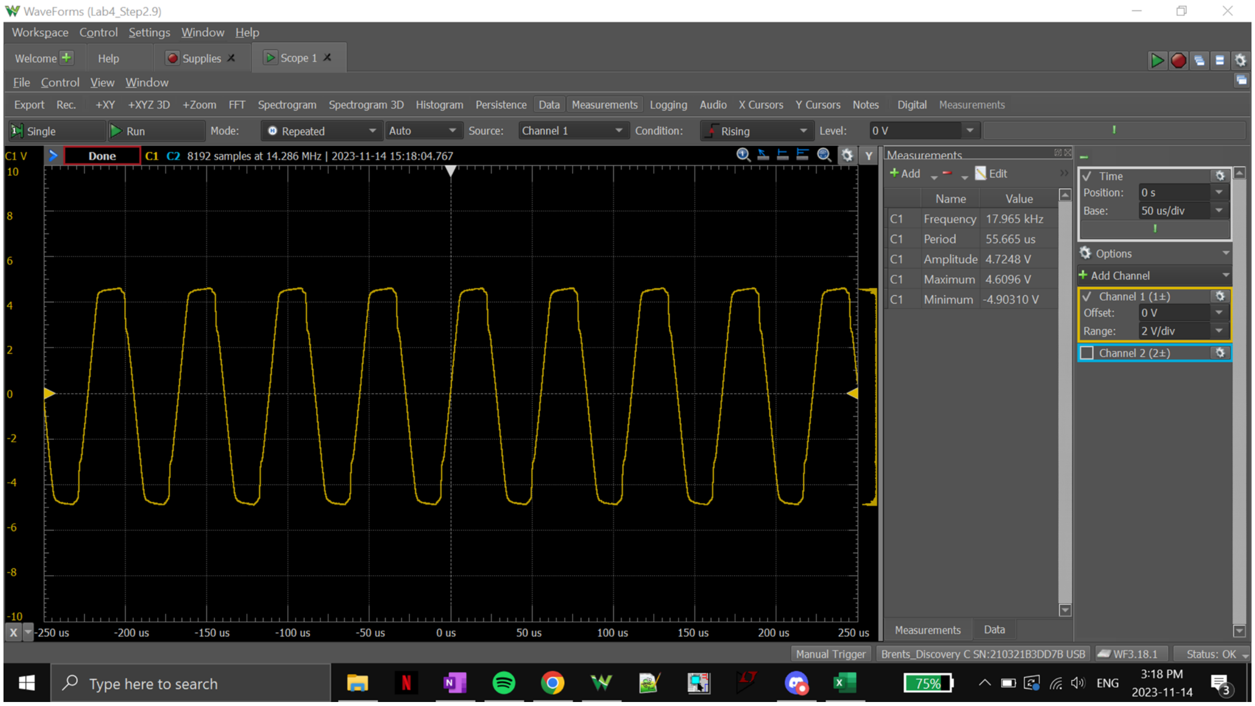
Step 2.3…



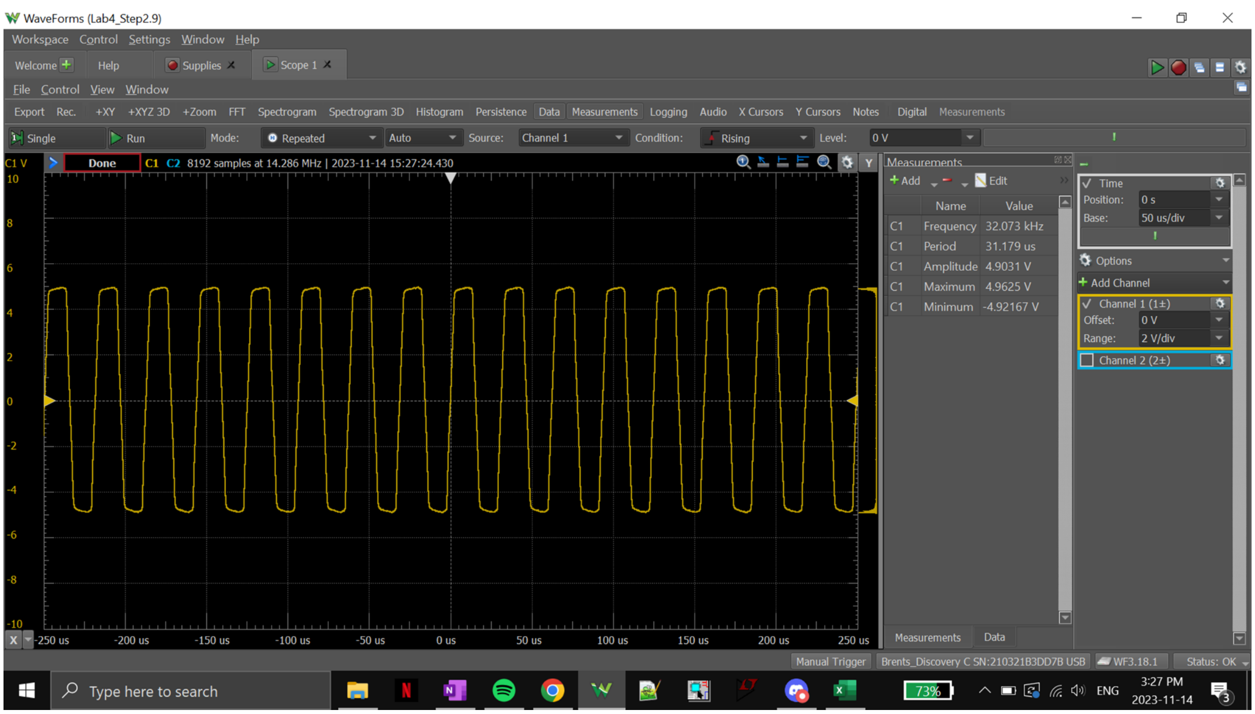
Step 2.5…



Step 2.8…



Step 2.9…



Step 2.3… 18 KHz

Step 2.5… 34 KHz

Step 2.8… $17.965\ KHz$

Step 2.9… $32.073\ KHz$

The data above matches our theoretical calculations. As we saw in question 9, $\omega = \frac{1}{CR}$, which tells us that frequency and resistance are inversely proportional. When we change $R_3 = R_4 = 8.25k\Omega$ to $R_3 = R_4 = 4.02k\Omega$, we double the resistance, and as we can see above, we nearly half the frequency. The simulated data follows this trend exactly, and the measured frequencies match the theoretical frequencies very closely.