91 out of 100

Operational Amplifier Circuits

Lab 1
ENSC 225

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Abstract

We did four experiments in this lab. In the first experiment we figured out the Offset Voltage, Bias Current, and Offset Current. Our experimental values did not go over the max values from the datasheet. However, they were not close to the typical values. On the second experiment we did a frequency sweep using the function generator and created two graphs from a non-inverting amplifier one with 10 gain and the other with 100 gain. Our unity gain fell into the range of the datasheet but it was below the typical value. For experiment three we measured the time period of a free running oscillator. Compared to the simulated data our experimental data for experiment three was a bit off, the cause must be faulty measuring. The last experiment was creating a triangular wave generator and was probably our most successful experiment. Our experimental values were always close to the simulated results.

Introduction

Operational amplifiers or as we call them in class "Opamps" are used to perform arithmetic operations with signals. They can even be used to integrate and differentiate signals. In this first lab for ENSC 225 we are using the op amp to do other special things. Firstly we will use it to figure out a circuits determination of input offset voltage, bias, and offset currents. Secondly we will use a technique called "sweeping the frequency" to figure out the Unity-Gain-Frequency. Thirdly, the op amp will be used calculate the time period and the peak to peak voltage of a free running oscillator. Finally, we will create a circuit that outputs a triangular wave onto the oscilloscope.

Experimental Procedure

The setup we used for the experiments were a breadboard, opamps, oscilloscope, function generator, dc power supply, digital multimeter, resistors, capacitor, wire cutter and stripper, and coloured wires. We set up a ±12 Volts supply and put the current limit to 80mA. We made sure to calibrate the oscilloscope and reset the function generator before we started our measurements.

Experiment-1: Determination of Input Offset Voltage, Bias, and Offset Currents

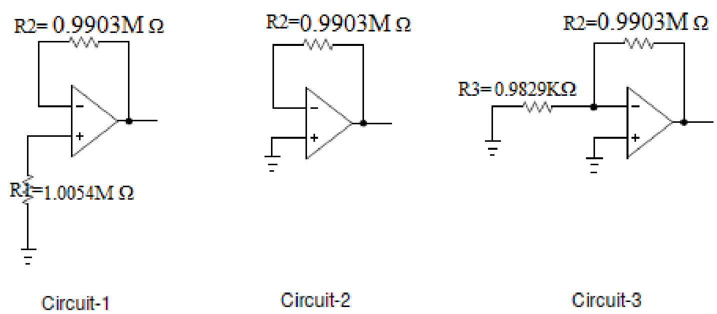

Figure 1: Three circuits to find the three DC imperfection parameters

We used three resistors (Figure 1) labeled and valued as *R1=1.0054M* Ω, *R2=0.9903M* Ω, and *R3=0.9829K*Ω and a TL074 chip to form three circuits. We measured the output voltages of circuit 1 and 2 normally. However, for circuit 3 we had to wait exactly between 6 and 15 seconds after we powered the opamp before we recorded the output voltage. If we failed to measure the voltage between the times provided, we had to turn the power off and wait for one minute to do it again. Using the three output voltages we found the Input Offset Voltage, Bias, and Offset Currents.

Experiment-2: Determination of Unity-Gain-Frequency

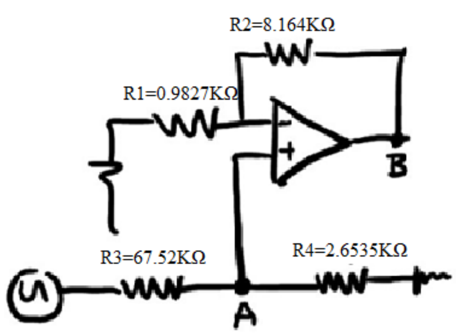

Figure 2: Non-inverting Amplifier with 10 Gain

We constructed a non-inverting amplifier with a gain of 10 using the same opamp we used in experiment 1 (Figure 2), making sure not to use any resistor less than 1K and more than 100K resistance. We then set up our function generator to display a clean sine wave of 100Hz and amplitude of 3V. We connected the function generator to a voltage divider so the output of the opamp will not go over 3V. We then recorded the input voltage and the output voltage from the oscilloscope, and the frequency from the function generator. After recording data for that particular frequency, we then incrementally increase the frequency until we reach 3MHz.

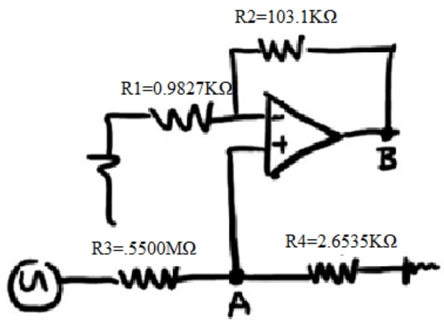

Figure 3: Non-inverting Amplifier with 100 Gain

After we reach 3MHz, we switched the resistors on the circuit to achieve an amplifier with a gain of 100 (Figure 3). Finally, we compare our experimental unity-gain-frequency with the data sheet provided.

Experiment-3: Free Running Oscillator

We constructed a free running oscillator based on the given circuit (Figure 4). R1 and R2 are values that can be anywhere in between 6K and 30K, but both should be close together so we chose the values *R1=11.917KΩ* and *R2=11.913KΩ*. R3 should be around 10K and our R3 was *9.763KΩ*. Lastly for the capacitor we used the 10nF from our parts kit and it measure exactly *C=10.56nF*.

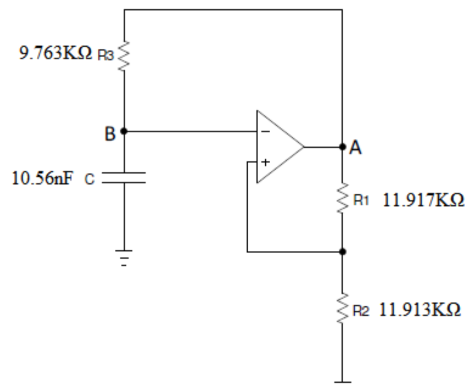

Figure 4: Free running oscillator circuit

We then calculated the expected values of the signals at nodes A and B. We found the voltage levels and period values. With our expected values, we then set up the circuit (Figure 4) again on LT-Spice. With our information we then compared the ideal values on LT-Spice with our expected values.

Experiment-4: Triangular Wave Generator

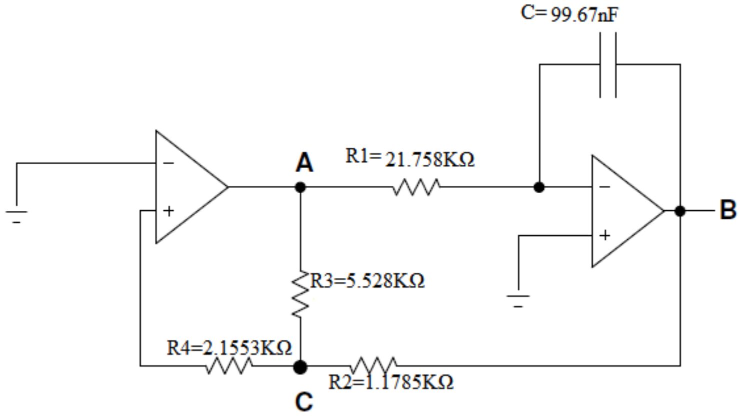

Figure 5: Circuit for triangular wave generator

We created a circuit following the schematic given (Figure 5). The values of the resistors and capacitor we used were *R1=21.758KΩ*, *R2=1.1785KΩ*, *R3=5.528KΩ*, *R4=2.1553KΩ*, and *C=99.67nF*. With our exact values we calculated the expected voltage levels and period signals at nodes A, B, and C. Then we simulated the circuit (Figure 5) on LT-Spice to get screen captures of the waveforms of A-B and B-C.

experiment data 7.5
answering point 7.5
presentation 8
total 25

Results

Experiment 1: Determination of Input Offset Voltage, Bias, and Offset Currents
The first circuit has a resistance of *1.0054MΩ* on the non-inverting input of the opamp, a resistance of *0.9903MΩ* on the inverting input, and the output to be *-1.08mV*. The second circuit has a resistance of *0.9903MΩ* on the inverting input, and the output to be *-1.04mV*. The third circuit has a resistance of *0.9903MΩ* and *0.9829KΩ* on the inverting input, and the output to be *-1.0628V*. We then are left with three equations and three unknowns. The equation we get from the first circuit is:

$$I_{B1}(0.9903x10^6) + V_{os} - I_{B2}(1.0054x10^6) = -1.08x10^{-3}$$

From the second circuit, we get:

$$V_{os} + I_{B1}(0.9903x10^6) = -1.04x10^{-3}$$

From the third circuit, we get:

$$\left(1 + \frac{0.9903x10^6}{982.9}\right)V_{os} + I_{B1}(0.9903x10^6) = -1.0628$$

Solving for these give us I_{B1} to be *1.396114*$x10^{-11}$ *amps*, I_{B2} to be *3.978516*$x10^{-11}$ *amps*, and offset voltage to be *1.0538mV*. To calculate the bias current we used the equation:

$$I_B = \frac{I_{B1} + I_{B2}}{2}$$

and get bias current to be *26.8733pA*. To calculate the offset current we used the equation:

$$I_{os} = |I_{B1} - I_{B2}|$$

and get the offset current to be *25.82372pA*. Comparing out calculated values to the data provided we get the following table:

	Experimental value	Max value from datasheet	Typical value from data sheet
Offset voltage	*1.0538mV*	*10mV*	*3mV*
Offset current	*25.82372pA*	*100pA*	*5pA*
Bias current	*26.8733pA*	*200pA*	*20pA*

Figure 6: Table for values of experiment 1

From Figure 6, we see that our experimental values are lower than the maximum value from the datasheet. This shows what the exact DC imperfection of our opamp is. There are multiple possible reasons why our values are over the typical value. It could be that the opamp we used has more imperfections compared to the average, or our equipment was faulty.

experimental data 5.5
answering point 3.5
presentation 7
total 16

Experiment 2: Determination of Unity-Gain-Frequency
To calculate the gain we used the formula:

$$Gain = (1 + \frac{R2}{R1})$$

The resistors we used for the circuit with a gain of 10 are: *R1=0.9827KΩ*, *R2=8.164KΩ*, *R3=67.52KΩ*, and *R4=2.6535KΩ*. We get the gain to be *9.30*. Sweeping the function generator give us the graph:

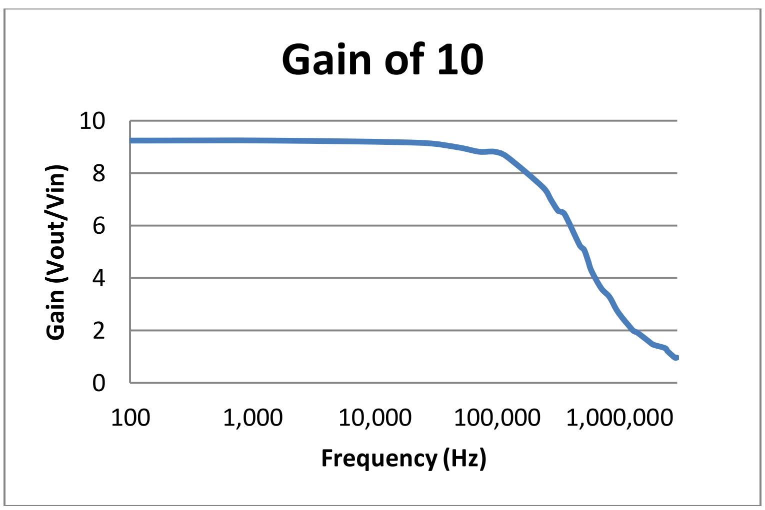

Figure 7: Gain vs. Frequency, non-inverting opamp with a gain of 10

We see in Figure 7 the f_{3dB} to be around *48KHz* and the f_T to be around *2.8MHz*.

The resistors we used for the circuit with a gain of 100 are: $R1=0.9827K\Omega$, $R2=103.1K\Omega$, $R3=.5500M\Omega$, and $R4=2.6535K\Omega$. We get the gain to be *104.9*. Sweeping the function generator give us the graph:

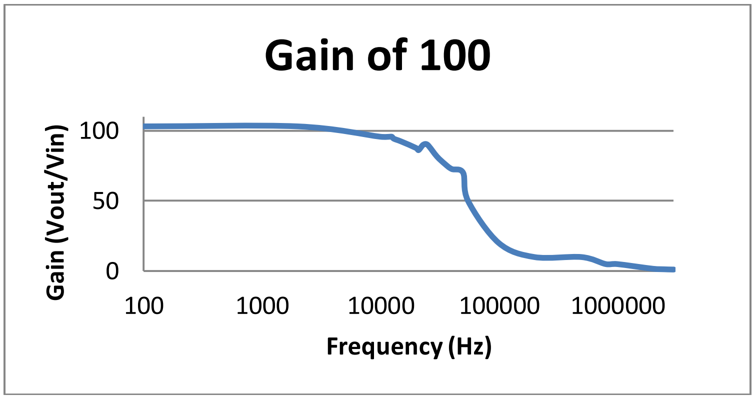

Figure 8: Gain vs. Frequency, non-inverting opamp with gain 100

Two F(t) should be significantly different.and should explain why.

We see in Figure 8 the f_{3dB} to be around 2KHz and the f_T to be past but close to 3MHz. According to the data sheet, the unity gain frequency has a minimum frequency of 2.5MHz and a typical frequency of 4MHz. We find f_T when the gain is 1 or when the peak to peak value of the input and the output is equal. This value should fall within the range of the datasheet, which our data did. Our f_T are over the minimum, but below the typical value. There are number of reasons why our experimental data is not perfect, but we suspect the voltage divider to be the main problem for this experiment.

total 25

Experiment 3: Free Running Oscillator

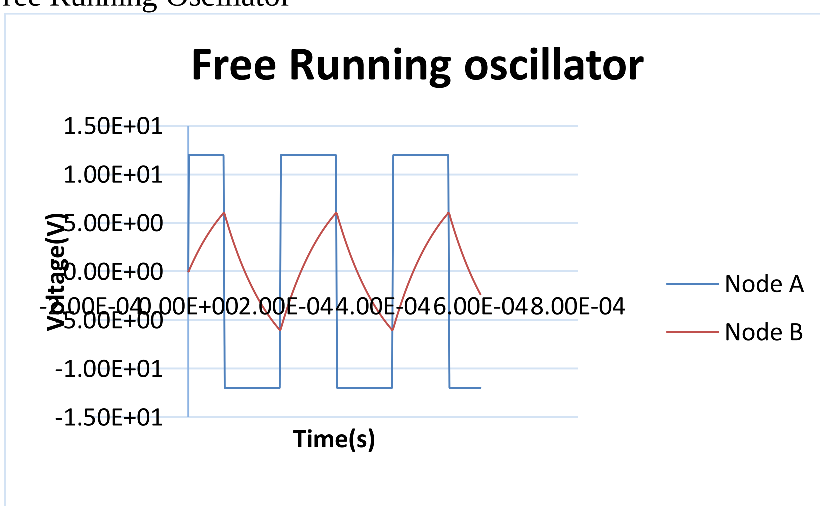

Figure 9: Voltage vs. Time of nodes A and B

The values used were $R1=11.917K\Omega$, $R2=11.913K\Omega$, $R3=9.763K\Omega$, and $C=10.56nF$. The image above (Figure 9) is the displayed image on the oscilloscope from LT-Spice. From the oscilloscope, we saw that at node A the measured peak to peak voltage value was $Va_{pk\text{-}pk}=21.6V$ and the period was $T=249.6\mu s$. While at node B the values were $Vb_{pk\text{-}pk}= 10.8V$ with a period of $T=249.8\mu s$. We then use the values given to find out our expected time period by using the formula:

$$T = 2RC(\ln\frac{(1+\lambda)}{(1-\lambda)})$$

To start finding the time period we first find the wavelength

$$\lambda = \frac{R2}{R2 + R1}$$

$$\lambda = \frac{11.913K\Omega}{11.913K\Omega + 11.917K\Omega}$$

$$\lambda = 0.499916$$

Now we plug in the wavelength to find the time period T

$$T = 2(9.763K\Omega)(10.56nF)(\ln\frac{(1+0.499916)}{(1-0.499916)}).$$

We then get our expected time period value which is

$$T = 226.48173x10^{-6}$$

$$T = 226.56\mu s$$

Comparing our experimented and simulated results, we were

$$off\ by = \left(1 - \frac{Texpected}{\text{Tsimulated}}\right) * 100$$

$$off\ by = \left(1 - \frac{226.56\mu s}{249.6\mu s}\right) * 100$$

$$off\ by = 9.2\%$$

Our calculated data was off compared to the experimental data because of the difference of the resistances R1 and R2 when theoretically they should be exactly even. Another reason could be the value of R3 being too far from being 10K and the capacitor not being exactly 10nF.

total 25

Experiment 4: Triangular Wave Generator

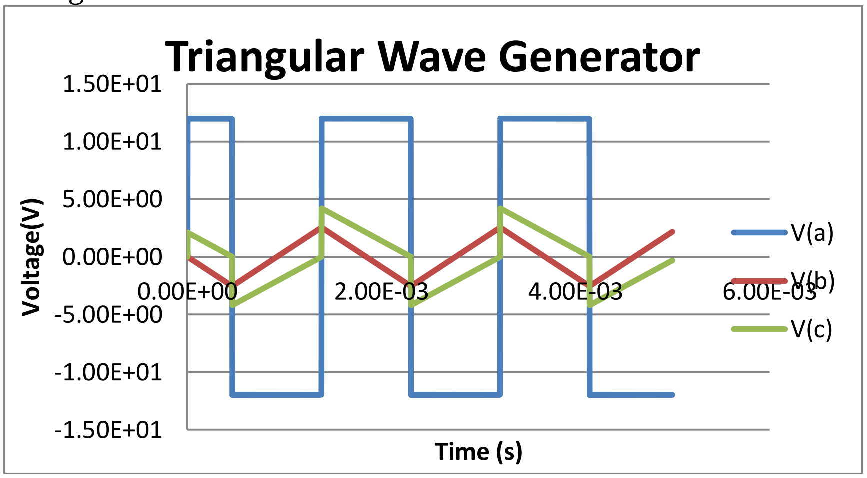

Figure 10: LT-Spice Voltage vs. Time graph of nodes A, B, and C

The values of the resistors and capacitor we used were $R1=21.758K\Omega$, $R2=1.1785K\Omega$, $R3=5.528K\Omega$, $R4=2.1553K\Omega$, and $C=99.67nF$.

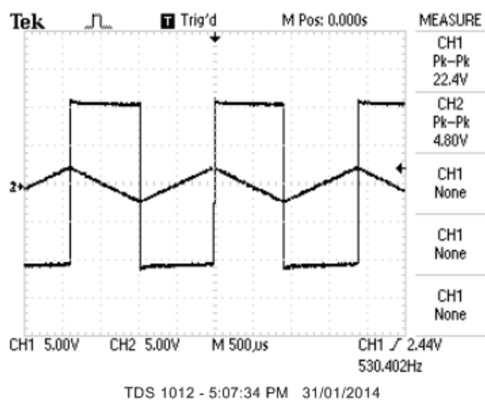

Figure 11: Nodes A-B

We can clearly see the Pk-Pk value of node B (CH2) which is $V_{CH2pk\text{-}pk} = 4.80V$ by looking at Figure 11. This is the simulated value. We will now calculate our experimental value. Using Figure 5 as a template, we assume that VCC=VEE and therefore at node A (Va) the voltage will be $+12V$ and the formula to find the voltage at node B (Vb) will be:

$$\frac{Va - 0}{R3} = \frac{0 - Vb}{R2}$$

We already have these values so

$$\frac{12V - 0}{5.528K\Omega} = \frac{0 - Vb}{1.1785K\Omega}$$

Solving for Vb

$$Vb = 2.55824V$$

We know that $Vbx2=Vb_{pk-pk}$, so we can then say that $Vb_{pk-pk}=5.11648V$ which is pretty close to the simulated value of 4.80V. Now that we have Vb, we can look for Vc.

$$\frac{Va - Vc}{R3} = \frac{Vc - Vb}{R2}$$

Plugging in our values

$$\frac{12V - 0}{5.528K\Omega} = \frac{0 - 2.55824V}{1.1785K\Omega}$$

Solving for Vc

$$Vc = 4.2174V$$

We know that $Vcx2=Vc_{pk-pk}$.We can see that our experimental value of $Vc_{pk-pk}=8.4348V$compared to the simulated value as seen from Figure 10 above and maybe from Figure 12 below is almost the same.

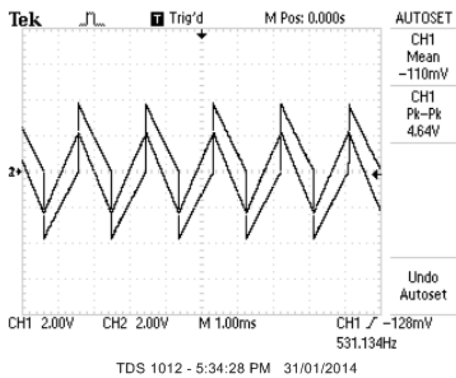

Figure 12: Nodes B-C

Lastly, we calculate the time period *t* from the formula:

$$\frac{1}{RC} * Vcc * t = 2Vb$$

Using the resistor R1 because it is in series with the capacitor and then finding for t

$$t = \frac{2 * 2.55824V * 21.758K\Omega * 99.67nF}{12V}$$

$$t = 0.000924s$$

$$t = 924\mu s$$

Comparing our $t=924\mu s$ with that of Figure 10 and Figure 11 we can see that our experimental t is pretty close the simulated t. There are errors and it must be from the experimental Vb. If not then the errors are from the measuring of R1 and the capacitor.

Conclusion

For experiment 1 we had acceptable values compared to the datasheet, but our experimental values were higher than their typical values. In experiment 2 we know our graphs for gain 10 and 100 are good because our unity gain is above the minimum. Our unity gain was below the typical frequency of 4MHz so we know our data is not perfect, however our graph looks perfect and so we are content. Experiment 3 had the most amount of errors. Our experimental data was off by a huge 9.2%. We did the experiment properly and as followed so the fault has to be with the machines recording the values. Lastly, for experiment 4 the voltages we found at node B and C and the time period t were really close to the actual simulated values. There were still some differences but they can be regarded as caused by small errors on measuring.

Reference

[1] Given pdf file that came with the lab file, Tl071.pdf