PHYS3150 Lab 1

Operational Amplifier Characteristics

By: Aysar Khalid (209728866)

Lab Partner: Hassan Chehaitli

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Background

The operational amplifier is a premier building block in electronic circuitry. It is a high-gain electronic voltage amplifier with a differential input. In a non-inverting amplifier, V_{out} changes in the same direction as V_{in}. In an inverting amplifier, V_{out} changes in the opposite direction of V_{in}. The input offset voltage is the differential voltage required between the input of the operational amplifier to make the output zero. The slew rate is when the output voltage reaches its maximum rate of change.

Objective

The purpose of this lab is to understand the characteristics of the operational amplifier through the building of the non-inverting and inverting configurations. And to observe the input offset voltage and current as well as the slew rate.

Apparatus

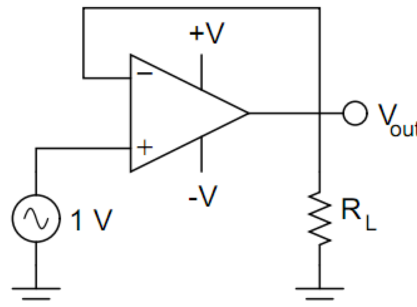
Item	Description
Tektronix TDS200 Digital Storage Oscilloscope (DSO)	A digital oscilloscope that channels voltage in real-time.
Agilent E3630A Triple Output DC Power Supply	Provides a direct current power supply.
Agilent 33120A Function/Arbitrary Waveform Generator	A waveform/function generator.
Breadboard, resistors, LM741-CN Operational Amplifier	

Procedure

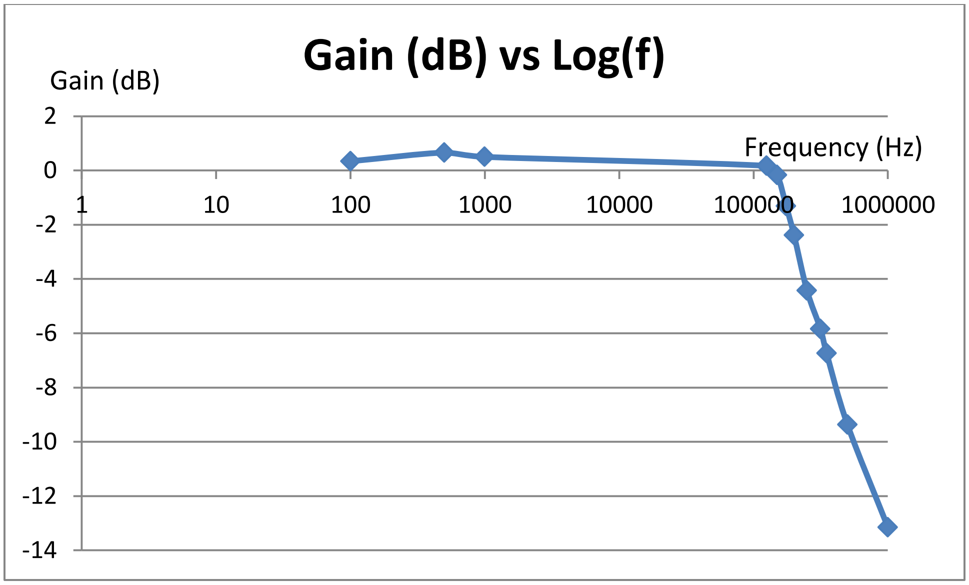
Please see the lab manual.

1.1 The Non-inverting Amplifier

The circuit to left was constructed (a voltage follower); which included R_L = 1 kOhm and V_{in} = 1V. The gain was measured as a function of frequency by varying the frequency from 100 Hz to 1 MHz.



Frequency (Hz)	V_{out} (V)	Gain ($20\log(V_{out}/V_{in})$) (dB)
100	**1.04**	**0.34**
500	**1.08**	**0.66**
1000	**1.06**	**0.50**
125 000	**1.02**	**0.17**
150 000	**0.98**	**-0.17**
175 000	**0.86**	**-1.31**
200 000	**0.76**	**-2.38**
250 000	**0.60**	**-4.43**
315 000	**0.51**	**-5.84**
350 000	**0.46**	**-6.74**
500 000	**0.34**	**-9.37**
1 000 000	**0.22**	**-13.15**



To determine the frequency at which the gain is -3 dB we calculated it using the following formula:

$$Gain = 20\log\left(\frac{Vout}{Vin}\right)$$

$$-3 = 20\log\left(\frac{Vout}{Vin}\right)$$

$$10^{-0.15} = \frac{Vout}{Vin} = 0.707$$

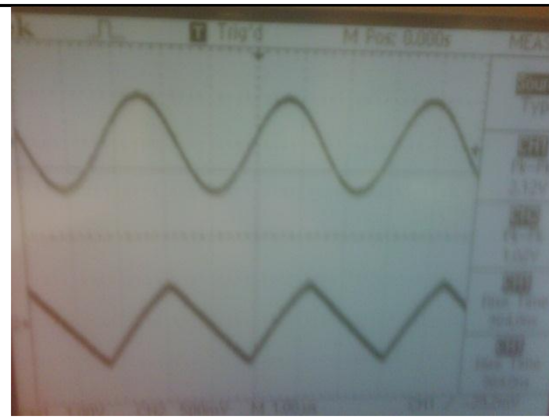
This comes out to be at around a frequency of 190 000 Hz.

The following are the observed graphs from the DSO for R_L = 1 kOhm, 500 Ohm, 100 Ohm, 50 Ohm, and 22 Ohm:

Note: x-axis depicts frequency in kHz and y-axis depicts power in dB

Output graph for R_L = 1 kOhm

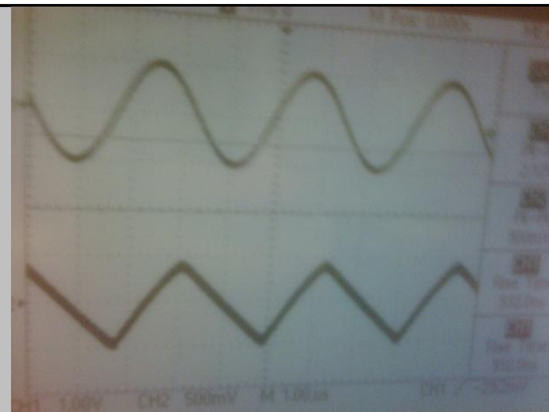
This graph showed the least amount of noise and distortion, it followed a relatively straight and jagged edge path. The path is uniform and periodic. The slew rate is clearly observed due to the sharp edges and clear rise/falls of the graph.



Output graph for R_L = 500 Ohm

This graph showed very little to no amount of noise and distortion; again it followed a relatively straight and jagged edge path. The path is uniform and periodic. The slew rate is clearly observed.

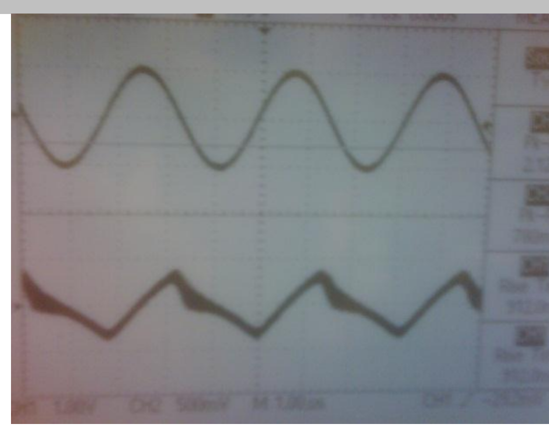
At frequency = 315 kHz, V_{out} = 0.46



Output graph for R_L = 100 Ohm

This graph showed a bit of noise and a starting pattern of distortion. The path is uniform and periodic. The slew rate can still be observed but is slowly becoming smaller.

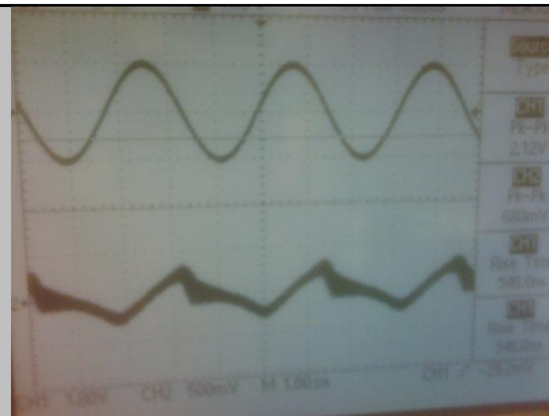
At frequency = 315 kHz, V_{out} = 0.38



Output graph for R_L = 50 Ohm

This graph showed more noise and distortion patterns. The path is uniform and periodic. The slew rate can still be observed but is becoming smaller and smaller which further causes distortion.

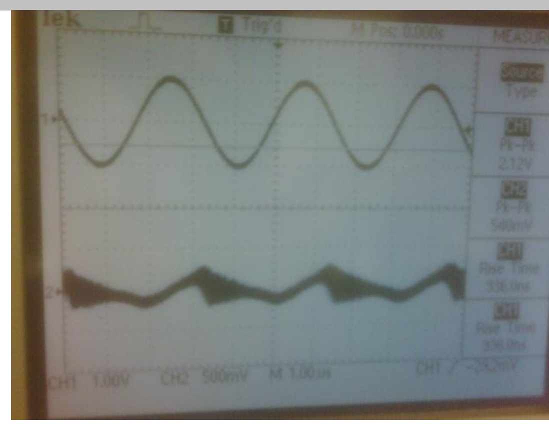
At frequency = 315 kHz, V_{out} = 0.32



Output graph for R_L = 22 Ohm

This graph showed the most noise and distortion patterns. The path is uniform and periodic. The slew rate is at its lowest here, and due to this limitation, the highest amount of distortion exists in this configuration.

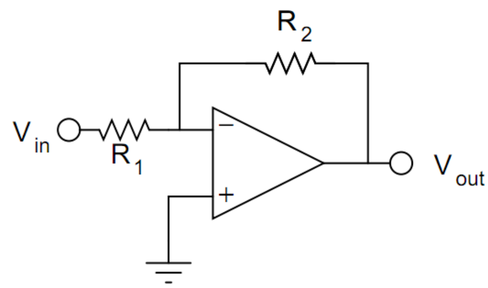
At frequency = 315 kHz, V_{out} = 0.29



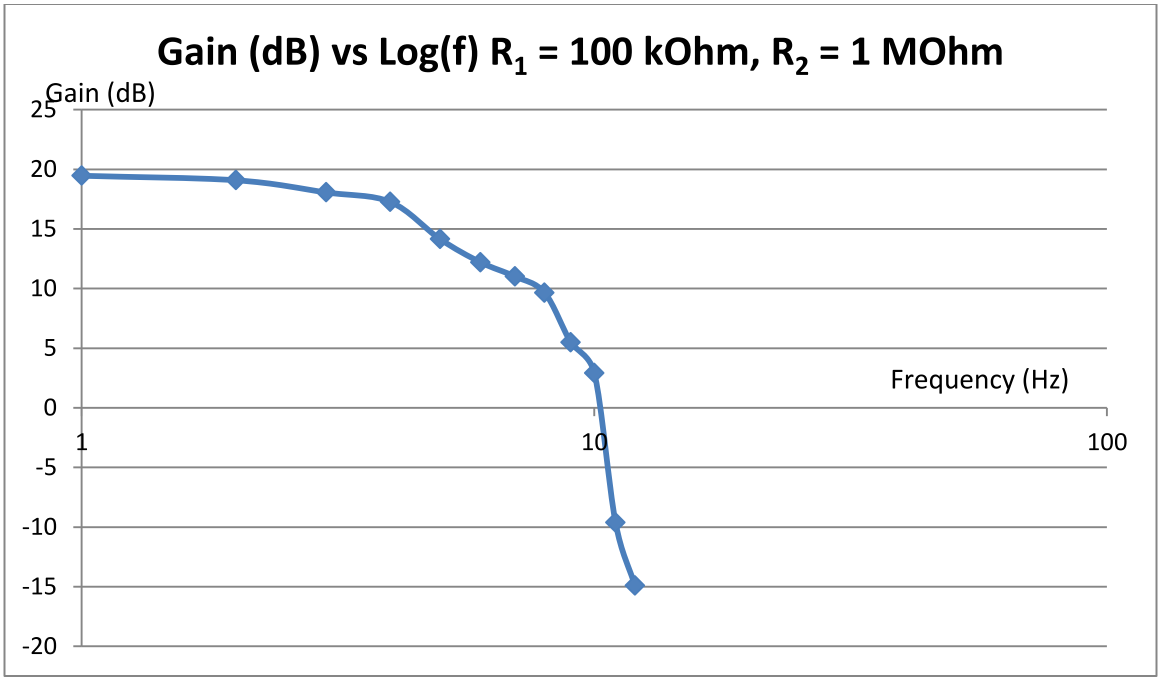
The output current limit of the LM-741 operational amplifier is 25 mA.

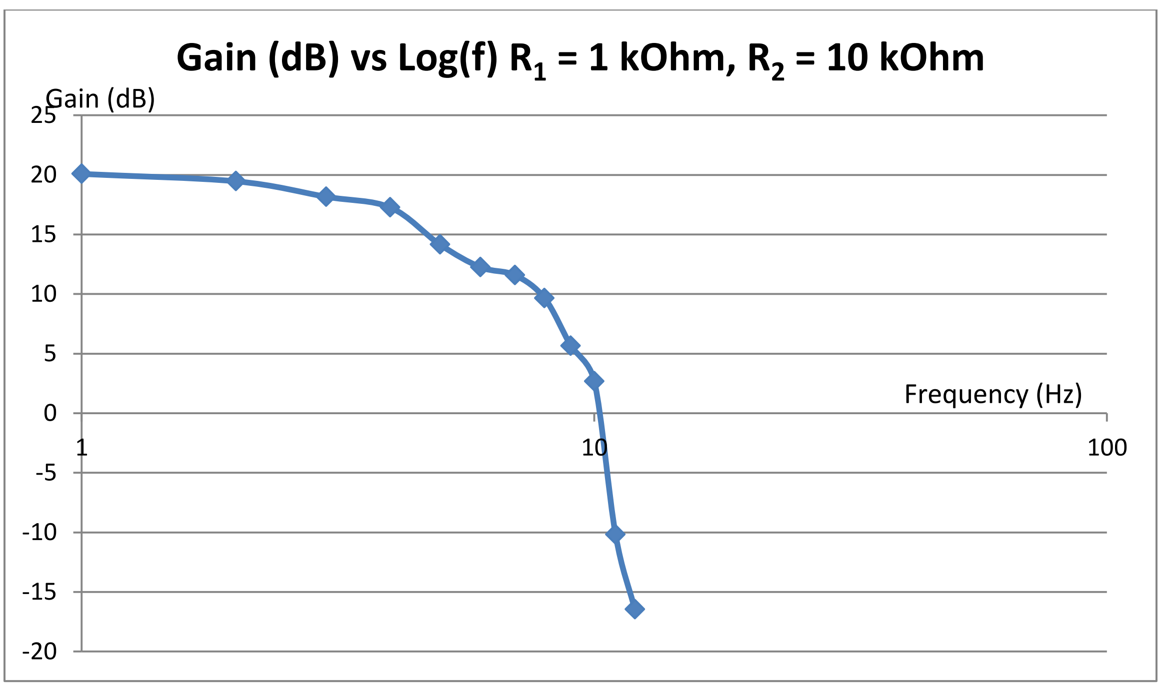
1.2 The Inverting Amplifier

The circuit to left was constructed; which included R_1 = 1 kOhm and R_2 = 10 kOhm. The voltage gain was measured as frequency was varied from 100 Hz to 1 MHz. With V_{in} = 1 V.



Frequency (Hz)	V_{out} (V) for R_1 = 1 kOhm, R_2 = 10 kOhm	Gain (20log(V_{out}/V_{in})) (dB)	V_{out} (V) for R_1 = 100 kOhm, R_2 = 1 MOhm	Gain (20log(V_{out}/V_{in})) (dB)
100	9.4	19.46	10.1	20.08
15 000	9	19.08	9.4	19.46
18 000	8	18.06	8.1	18.16
20 000	7.3	17.26	7.3	17.26
30 000	5.1	14.15	5.1	14.15
37 000	4.08	12.2	4.1	12.25
42 000	3.56	11.02	3.8	11.59
50 000	3.04	9.65	3.04	9.65
80 000	1.88	5.48	1.92	5.66
110 000	1.4	2.92	1.36	2.67
500 000	0.33	-9.62	0.31	-10.17
1 000 000	0.18	-14.89	0.15	-16.47





$$Gain\ Bandwidth\ Product\ (GBP) = Gain * Bandwidth$$

$$GBP = 19.46 * 100 = 1946\ Hz\ for\ 100\ Hz$$

$$GBP = 19.6 * 10\,000 = 196\,000\ Hz\ for\ 10\ KHz$$

No, our GBP is not within the specs- the specs say the GBP is 1 MHz.

For V_{in} (amplitude) = 1 V, Frequency = 100 Hz, A_V = 10, we measured V_{in} with respect to ground to be 0.708 V, V_{out} = 2.04 V.

For V_{in} (amplitude) = 1 V, Frequency = 10 KHz, A_V = 10, we measured V_{in} with respect to ground to be 0.708 V, V_{out} = 2.07 V.

For V_{in} (amplitude) = 0.1 V, Frequency = 100 Hz, A_V = 10, we measured V_{in} with respect to ground to be 70.53 mV, V_{out} = 7.12 V.

For V_{in} (amplitude) = 0.1 V, Frequency = 10 KHz, A_V = 100, we measured V_{in} with respect to ground to be 70.75 mV, V_{out} = 4.21 V.

R_1 (KOhm) [measured value]	**R_2 (KOhm) [measured value]**	**V_{out} (mV)**
1 [0.998]	100 [98.9]	2.43
10 [9.79]	1000 [988]	1.69

$$Vout = -Vin + \left(1 + \frac{R2}{R1}\right)Vio + Iio * R2$$

$$2430 = 0 + \left(1 + \frac{98900}{998}\right)Vio + 98900 * Iio$$

$$Iio = \frac{2430 - 100Vio}{98900}$$

$$1690 = 0 + \left(1 + \frac{988000}{9790}\right)Vio + 988000 * Iio$$

$$1690 = 101.9Vio + 988000 * \frac{2430 - 100Vio}{98900}$$

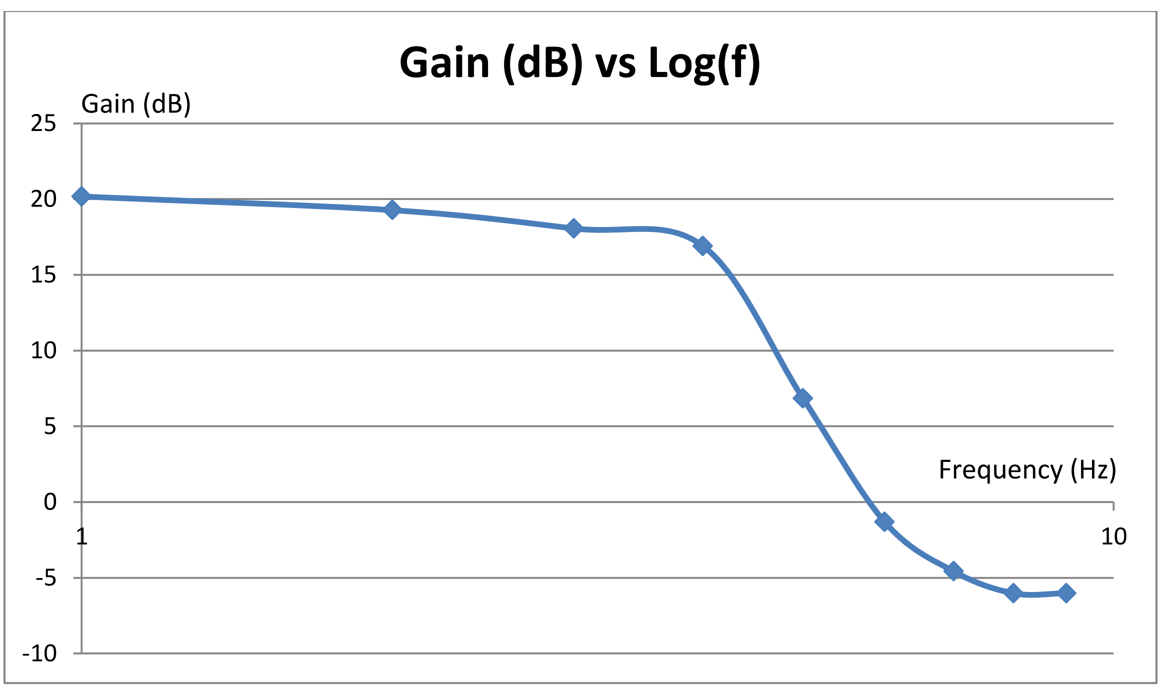
$$Vio = 25.176 \text{ V}$$

$$Iio = -8.857e - 4\ A$$

It seems like we are measuring the input bias current due to its small size.

Next we added a capacitor in parallel with R_2 and measured gain while varying frequency (V_{in} = 0.1 V).

Frequency (Hz)	**V_{out} (V)**	**Gain**
100	1.06	20.5
500	1.02	20.17
1000	0.92	19.27
1500	0.8	18.06
2000	0.7	16.90
10 000	0.22	6.84
50 000	0.086	-1.31
100 000	0.059	-4.58
500 000	0.05	-6.02
1 000 000	0.05	-6.02



As you can see the graph is much smoother than that of part 1.

Yes, after we measured the slew rate from the above DSO output, it was about 0.5 V/usec.

Sources of Error

- Human errors and limitations
- DSO and Function Generator built-in resistance
- Faulty wires/connections

Conclusion

To summarize, the objectives of this experiment, was to become familiar with the characteristics of the operational amplifier and build the inverting and non-inverting configurations. At first we built the non-inverting amplifier, and measured its gain as a function of frequency. We also concluded that the output current limit of the amplifier is 25 mA. Next we built the inverting amplifier and calculated its Gain Bandwidth Product which should have been 1 MHz but we did not get such a result. Next we calculated V_{io} and I_{io} after measuring R_1, R_2 and V_{out}. We discovered that the I_{io} value we calculated was likely to be the input bias current rather than the input offset current. Finally we measured the slew rate by feeding in a hih amplitude sine wave and confirmed that the measured slew rate was consistent with that of the amplifier's specifications.