EE203 - Electrical Circuits Laboratory

Experiment - 8 Simulation

Operational Amplifier Applications

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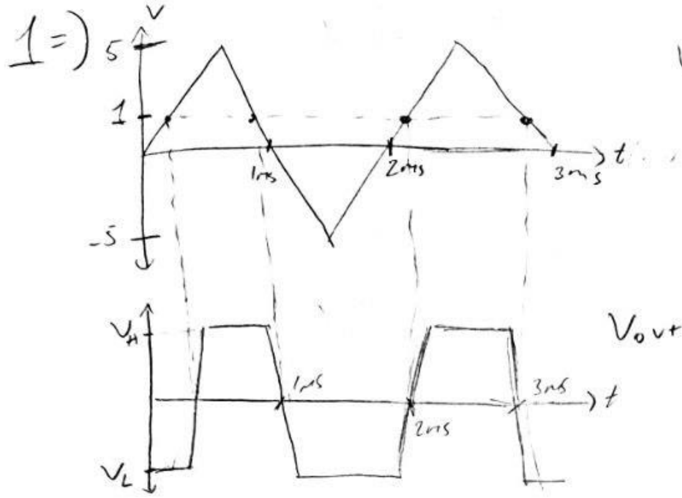
Preliminary Work

1=)

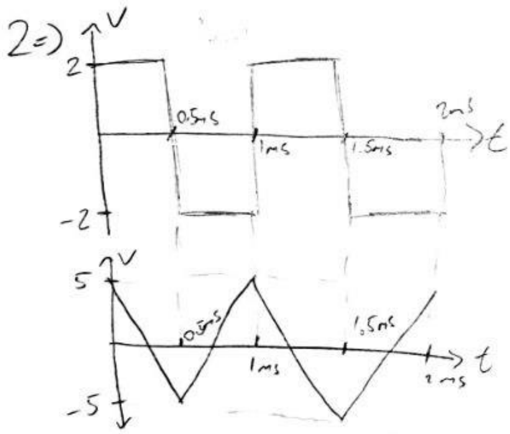


Vin Comparator

$$V_{out} = \begin{cases} V_H, & V_{in} \geq 1 \\ V_L, & V_{in} < 1 \end{cases}$$

Vout

2=)



Vin Integrator

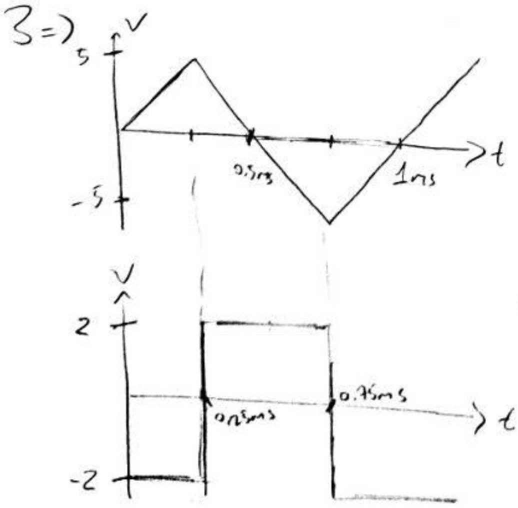
$$V_{out} = -\frac{1}{R_i C_f}\int_{t=0}^{t} V_{in}(t)\,dt$$

Vout

$$\Rightarrow -\frac{(2)(0.5\times10^{-3})}{(10^3)(100\times10^{-9})}$$

$$= 10\ V_{(peak\ to\ peak)}$$

3=)



Vin Differentiator

Vout

$$V_{out} = -R_f C_i \frac{dV_{in}}{dt}$$

$$\Rightarrow (10\times10^3)(10\times10^{-9}) \times \frac{5}{(0.25)\times10^{-3}}$$

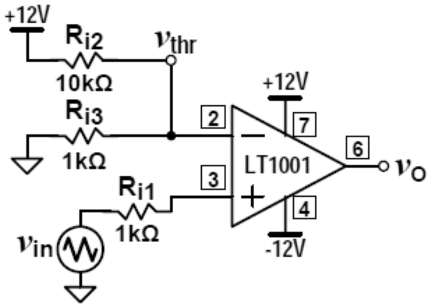
$$= 2$$

Results

LT1001 operational amplifier model will be used instead of **LM741** to obtain the simulation results on LTspice. Although **LT1001** has much better characteristics compared to **LM741**, both of the devices satisfy the basic requirements of an operational amplifier and the results obtained in the following steps will not be significantly different.

1. Build the circuit given on the right. Place separate DC voltage sources to obtain **+12 V** and −**12 V** supplies required for the opamp.

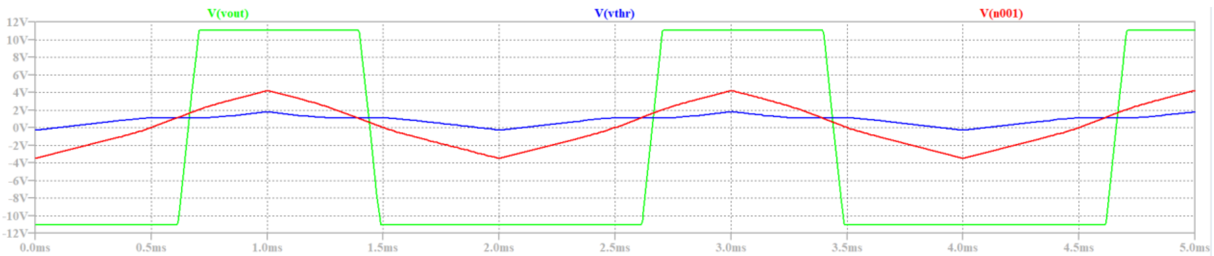
It is practical to connect these sources to net labels for each supply and use the same net labels for the opamp supply connections.



Set the v_{in} signal source to obtain **500 Hz triangular** wave with **10 Vp-p** amplitude. Use a pulse voltage source as v_{in} with the timing parameters, `Trise = 1m`, `Tfall = 1m`, `Ton = 0`, and `Tperiod = 2m` to obtain the triangular waveform.

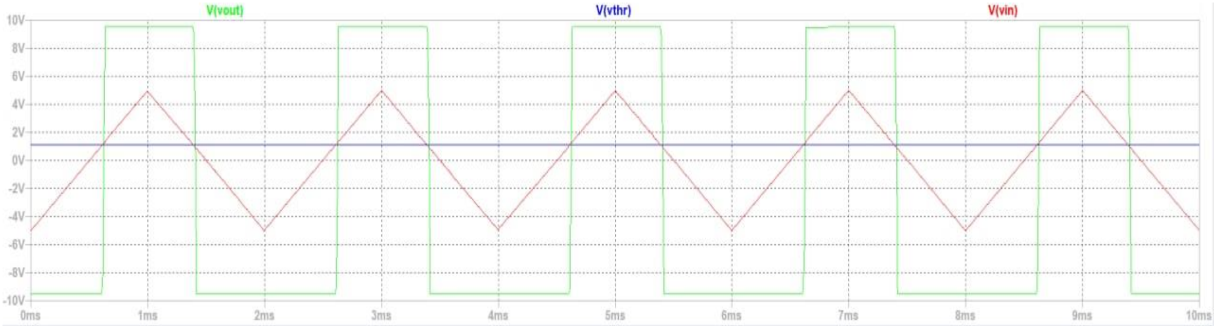
1.1 Display v_{in}, v_O and v_{thr} waveforms. Record the v_O voltage levels for every change at v_O and determine timing of v_O zero-cross points relative to the crossing points of v_{in} and v_{thr}. Calculate the slew rate of v_O according to the time difference corresponding to **+/-10 V** voltage change in the middle of v_O transitions.

Change in v_O (**V to V**)	relative time (**µs**) of v_O zero-cross	v_O slew rate (**V/µs**)
(rising) 10.932265V	48.052951µs	0.2275
(falling) 11.067385V	53.513514µs	0.2068



1.2 Replace **LT1001** with an **AD795 FET-input** opamp and repeat the measurements in the previous step.

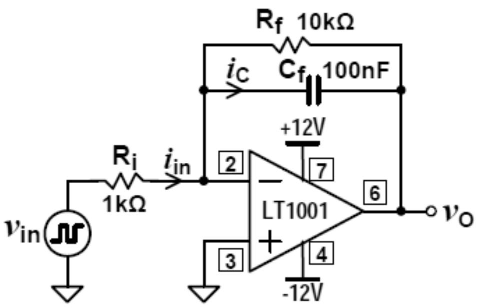
Change in v_O (**V to V**)	relative time (**µs**) of v_O zero-cross	v_O slew rate (**V/µs**)
(rising)9.5126592V	16.738621µs	0.5683
(falling)8.7556198V	12.871466µs	0.6802



1.3 Explain differences between the v_{thr}waveforms and the measurements obtained with **LT1001** and **AD795** opamps.

>>Slew rate of AD795 is greater than LT1001. It means that AD795 reacts faster that LT1001, this feature makes AD795 more quality than LT1001.

2. Build the integrator circuit given on the right, and set the v_{in} signal source to obtain **500 Hz square wave** with **2 Vp-p** amplitude. Use a pulse voltage source as v_{in} with the timing parameters, **`Trise = 1u`**, **`Tfall = 1u`**, **`Ton = 999u`**, and **`Tperiod = 2m`** to obtain the square waveform.



2.1 Display v_{in} and v_O waveforms. Measure the peak-to-peak output voltage for the following v_{in} frequency settings.

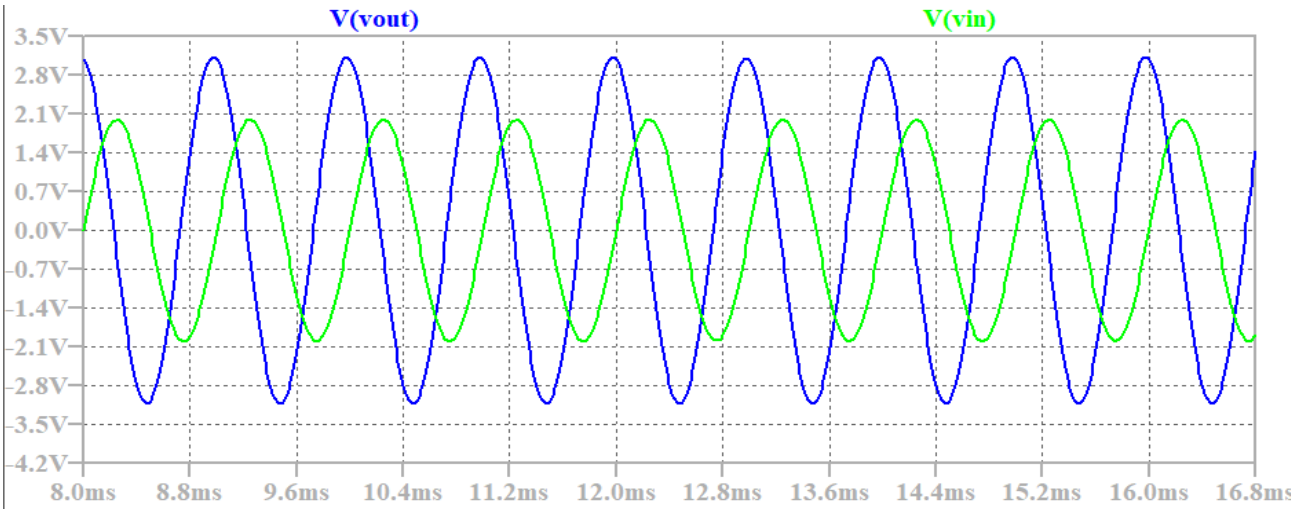
Note that you should increase the simulation time to see the output waveform with the final offset value, and zoom into the steady state response.

v_{in} square wave frequency	v_O amplitude (Vp-p)
500 Hz	9.2520967V
1 kHz	4.8045501V
2 kHz	2.4507162V

2.2 Set v_{in} frequency to **1 kHz**, and add another voltage source to obtain the following DC offset values at v_{in} by using the oscilloscope. Measure and record the corresponding DC offset values at v_O.

v_{in} offset (V)	v_O offset (V)
0.0	0,971595
-0.5	5,96941
+0.5	-4,029425

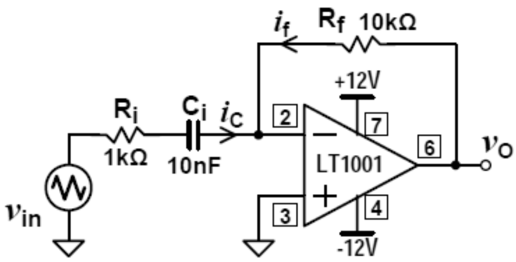
2.3 Set the v_{in} signal source to obtain **1 kHz sine wave** with **4 Vp-p** amplitude. Monitor v_{in} and v_o on the oscilloscope and plot the steady state waveforms.



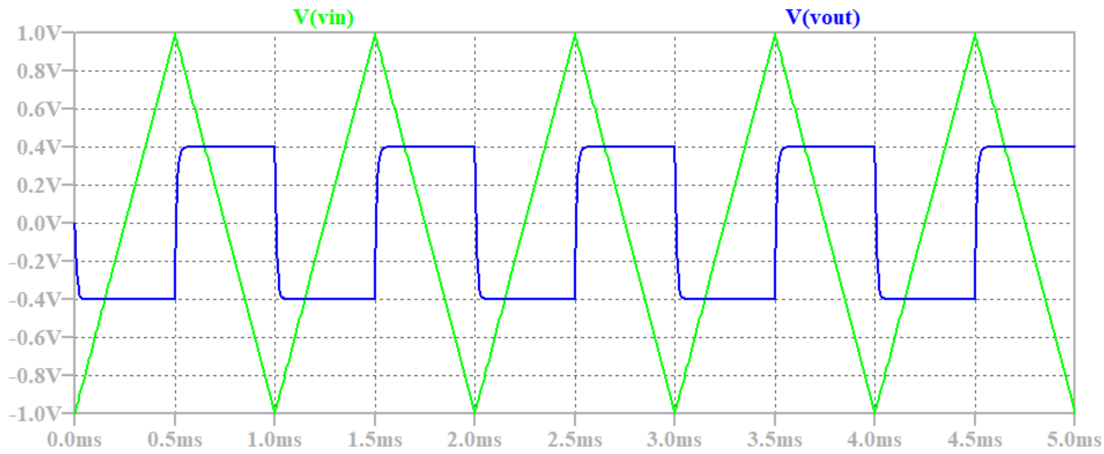
Measure the peak-to-peak output voltage for the following v_{in} frequency settings.

v_{in} sine wave frequency	v_o amplitude (**Vp-p**)
500 Hz	12.080456V
1 kHz	6.2350985V
2 kHz	3.0819406V

3. Build the differentiator circuit given on the right, and set the v_{in} signal source to obtain **500 Hz triangular** wave with **10 Vp-p** amplitude. Use a pulse voltage source as v_{in} with the timing parameters, `Trise = 1m`, `Tfall = 1m`, `Ton = 0`, and `Tperiod = 2m` to obtain the triangular waveform.



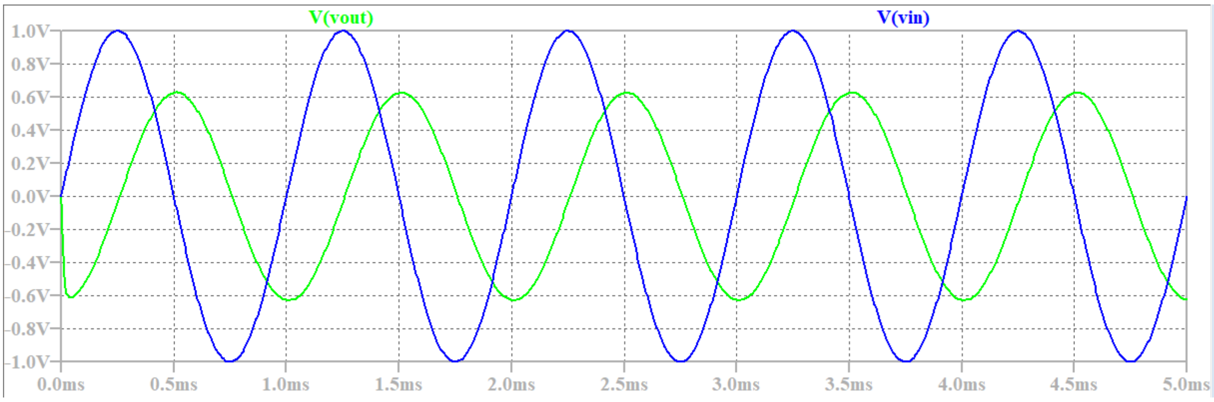
3.1 Display v_{in} and v_o waveforms. Measure the peak-to-peak voltage of the square wave output for the following v_{in} frequency settings.



Note: Ignore short overshoots and undershoots after the rising and falling edges when you measure peak-to-peak voltage of square wave output.

v_{in} triangular wave frequency	v_O amplitude (**Vp-p**)
500 Hz	1.9999943V
1 kHz	3.9999947V
2 kHz	8.0000009V

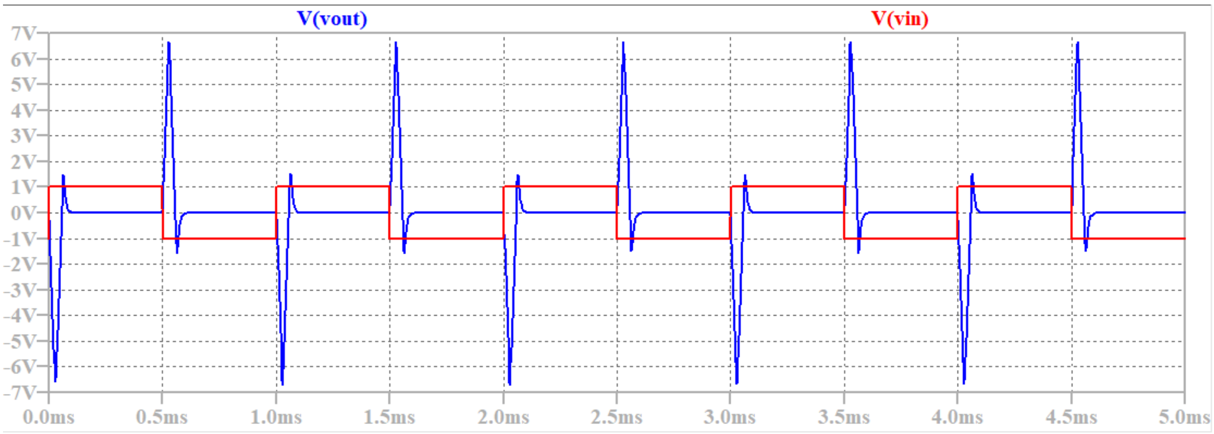
3.2 Set the v_{in} signal source to obtain **1 kHz sine wave** with **2 Vp-p** amplitude. Monitor v_{in} and v_O on the oscilloscope and plot the waveforms.



Measure the peak-to-peak output voltage for the following v_{in} frequency settings.

v_{in} sine wave frequency	v_O amplitude (**Vp-p**)
500 Hz	628.08987mV
1 kHz	1.2536448V
2 kHz	2.4975334V

3.3 Set the v_{in} signal source to obtain **1 kHz square** wave with **2 Vp-p** amplitude. Monitor v_{in} and v_O on the oscilloscope and plot the waveforms..



Questions

Q1.a) Explain the function of **R_f = 10 kΩ** resistor used in procedure step **2**.

>>Because of the resistor of **R_f**, Our opamp output dos not saturates any supply voltage due to any DC component at the input.

b) Explain the function of **R_i = 1 kΩ** resistor used in procedure step **3**.

>>To avoid instability which is very high closed loop gain at high frequency, **R_i** is added. Because **R_i** limits the AC closed loop gain.

Q2.a) Derive an expression that gives peak-to-peak output voltage of the integrator in step **2** as a function of square wave amplitude and frequency at the input.

>>

$$V((amp), f) = \frac{1}{(R_i C_f)} * \int_0^{1/2f} (amp) dt' = \frac{(amp)}{R_i C_f 2f}$$

(this amp represents peak amplitude)

>>If I integrate the signal to the half of the period, I would obtain the peak-to-peak output voltage. Because after the half of the period, our output starts to decrease and goes to the zero.

b) Derive an expression that gives DC output voltage of the integrator as a function of the input offset.

>>

$$V(offset) = \frac{-1}{(R_i C_f)} * \int_0^{1/f} (offset) dt' = \frac{-(offset)}{R_i C_f f}$$

>>If I take integral of whole period, I would obtain the output DC voltage.

c) Derive an expression that gives peak-to-peak output voltage of the integrator as a function of sine wave amplitude and frequency at the input.

>>

$$V((amp), f) = \frac{-1}{(R_i C_f)} * \left(\int_0^{1/4f} (amp) sin(wt) dt' \right) = \frac{2*(amp)*cos(0)}{R_i C_i * 2\pi f} = \frac{2*(amp)}{R_i C_i * 2\pi f}$$

>>Because at t = 1/(4f) this integral arrives its peak. If I multiply the result by two, I would obtain the peak-to-peak voltage.

d) Compare the results of your calculations in **(a)**, **(b)**, and **(c)** with the experimental results obtained in procedure steps **2.1**, **2.2**, and **2.3**.

>> All these 3 formulations are coming from $v_O(t) = -\frac{1}{R_i C_f}\int_{t'=0}^{t} v_{in}(t')\,dt'$ this formula. I just modified for different situation.

v_{in} square wave frequency	v_O amplitude (**Vp-p**)	*Calculated*	*Error%*
500 Hz	9.2520967V	10V	7.48
1 kHz	4.8045501V	5V	3.91
2 kHz	2.4507162V	2.5V	2

v_{in} offset (**V**)	v_O offset (**V**)	*Calculated*	*Error%*
0.0	0,971595	0V	-
-0.5	5,96941	5V	19.38
+0.5	-4,029425	-5V	19.41

v_{in} sine wave frequency	v_O amplitude (**Vp-p**)	*Calculated*	*Error%*
500 Hz	12.080456V	12.732V	5.12
1 kHz	6.2350985V	6.366V	2.05
2 kHz	3.0819406V	3.183V	3.20

>>We have pretty close result that proves that our expressions are right.

Q3.a) Derive an expression that gives peak-to-peak output voltage of the differentiator in step **3** as a function of triangular wave amplitude and frequency at the input.

>>

$$V((amp), f) = R_f C_i\left(\frac{(amp)}{1/2f} - \frac{(-amp)}{1/2f}\right) = 4R_f C_i (amp) f$$

>> The derivative of the signal gives us the slope of it. Thus, I calculated the slopes of triangular waves and subtracted to obtain peak to peak output voltage.

b) Derive an expression that gives peak-to-peak output voltage of the differentiator as a function of triangular wave amplitude and frequency at the input.

>>

$$V((amp), f) = 2{*}R_f C_i \underbrace{\left(\frac{d((amp)\sin(wt))}{dt}\right)}_{\text{at } t=0} = 2{*}R_f C_i (amp)\underbrace{\cos(wt)}_{=1}{*}w = 4{*}R_f C_i (amp)\pi f$$

>>The same logic is also valid here. When t is equal to zero, we have the highest amplitude. Thus, I multiplied that result by two to obtain peak to peak output voltage.

c) Compare the results of your calculations in **(a)** and **(b)** with the experimental results obtained in procedure steps **3.1** and **3.2**.

>>All these 2 formulations are coming from $v_O(t) = -R_f C_i \frac{dv_C}{dt} = -R_f C_i \frac{dv_{in}}{dt}$ this formula.

I just modified for different situation.

v_{in} triangular wave frequency	v_O amplitude (Vp-p)	*Calculated*	*Error%*
500 Hz	1.9999943V	2V	~0
1 kHz	3.9999947V	4V	~0
2 kHz	8.0000009V	8V	~0

v_{in} sine wave frequency	v_O amplitude (Vp-p)	*Calculated*	*Error%*
500 Hz	628.08987mV	628.318mV	0.037
1 kHz	1.2536448V	1.256V	0.238
2 kHz	2.4975334V	2.513V	0.636

>>We have pretty close result that proves that our expressions are right.

Q4. List all factors that can affect the peak output voltage in procedure step **3.3** (differentiator with square wave input). Describe the effect of each factor that can be one of the input waveform parameters, circuit components, or opamp supply voltages.

>>Because of high slew rate, we observe greater spikes which results in greater output voltage. Thus, if we have more ideal square wave input signal which has infinity slew rate, we would observe the output voltage at power supply. To increase that power supply we are supposed to increase the supplier voltages. Also, according to formula, R_f and C_i affects the output voltage. If we have greater resistance and/or capacitance values, again we would observe greater output voltage. To sum up, if we want to observe greater peak output voltage, we are supposed to increase;

*R_f and/or C_i

*slew rate of square wave which can be done by increasing the amplitude or decreasing the rise/fall time of the wave.

*supply voltages

Conclusion

>>In this laboratory session, we acknowledged most popular operational amplifier amplifiers which are comparator, integrator and differentiator. We observed their responses on different signals with different frequencies to be familiar with them and to learn their behavior for common circumstances.

In the first part of this experiment, we were dealing with comparator circuits. We observed the slew rate of different kind of opamp component and we learned how to calculate it.

In the second part, our circuit was integrator circuit. We find out how circuit react the square wave at different frequencies and different offsets. Then, we observed the behavior, when we have sine wave as an input with various frequencies.

In the last part of the experiment, we used differentiator circuit. Similar to the second part, we observed the behavior of the circuit when we have triangular wave input signal with different frequencies. Then, we did the same thing with the sinus wave.

In questions, we were having to express all the results that we observed from the experiment in mathematical way. That’s why, questions forced us to find out how to calculate the output voltage behaviors without simulating the circuits. Also, we find out the function of the resistors on the integrator and differentiator. Lastly, we learned the factors that affects the peak output voltages of the differentiator amplifier with the square wave signal.

In conclusion, we obtained loads of information about operational amplifier applications in detail theoretically and practically.