LAB REPORT 6

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BATCH-5

EXPERIMENT 1

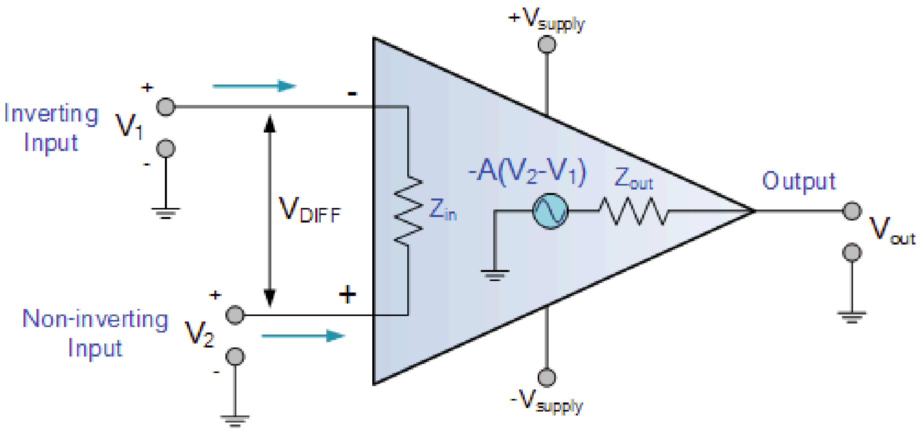
Study of basic properties of operational amplifier: inverting and non-inverting amplifiers

AIM:

At the end of the experiment, the student would be able to

- Explain Inverting Opamp
- Explain Non- Inverting Opamp
- Explain Gain

Equivalent circuit of ideal op-amp

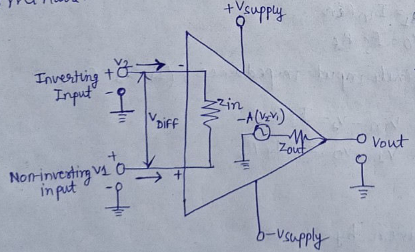


Theory with equations(inverting op-amp)

Operational Amplifier

Operational Amplifiers are linear devices that have all properties required for nearly ideal DC amplification and used extensively in signal conditioning, filtering, or to perform mathematical operations such as add, subtract, integration and diffrentiation.

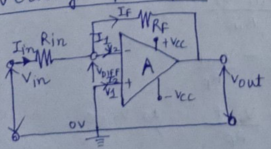
It has two high impedance input and output terminal. Op-Amp can perform different function when attached to different feedback combinations like resistive, capacitive or both. Generally it is used as a voltage amplifier and output voltage is difference between voltage at its two input terminals.



Properties of Ideal Op-Amp

- Zin ⟼ ∞
- Zout ⟼ 0
- Bandwidth ⟼ ∞
- (open loop) Gain → ∞
- Voffset → 0
- Common gain → 0

Inverting op-Amp



An inverting op-amp is a type of op-amp circuit which produces an output which is out of phase with respect to its input by 180°. The open loop gain (A_o) of op-amp is very high which makes it very unstable, so to make it stable with a controllable gain a feedback is applied through some external resistor (R_f) from its output to inverting input terminal (i.e, also known as negative feedback) resulting in reduced gain. (A_{cl}). Non-inverting terminal is grounded, and the inverting terminal behaves like a virtual ground as the junction of the input and feedback signal are at the same potential.

Mathematically the voltage gain offered by the circuit is given as; $A_v = \frac{V_o}{V_{in}}$

Where, $V_{in} - V_1 = I_{in} R_{in}$

$V_2 - V_o = I_f R_f$

ideal op-amp has infinite input impedance, ($I_1 = I_2 = 0$)

($I_{in} = I_f$) $V_{in} - V_2 = I_f R_{in}$

$V_1 - V_o = I_f R_f$

$V_2 = 0$

current can be given by

$$I = \frac{V_{in} - V_{out}}{R_{in} + R_f}$$

or,

$$I = \frac{V_{in} - V_2}{R_{in}}$$

or,

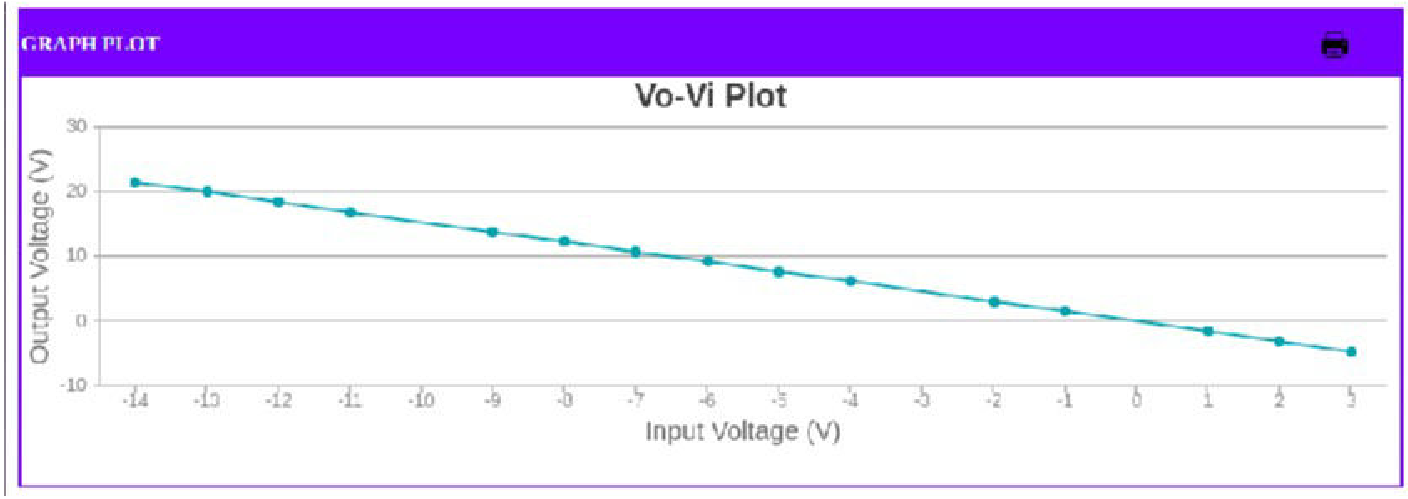
$$I = \frac{V_{in}}{R_{in}} - \frac{V_2}{R_{in}} = \frac{V_2}{R_f} - \frac{V_{out}}{R_f}$$

so, $$\frac{V_{in}}{R_{in}} = V_2\left(\frac{1}{R_{in}} + \frac{1}{R_f}\right) - \frac{V_{out}}{R_f}$$ as $V_2 = 0$

$$\boxed{\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}}$$

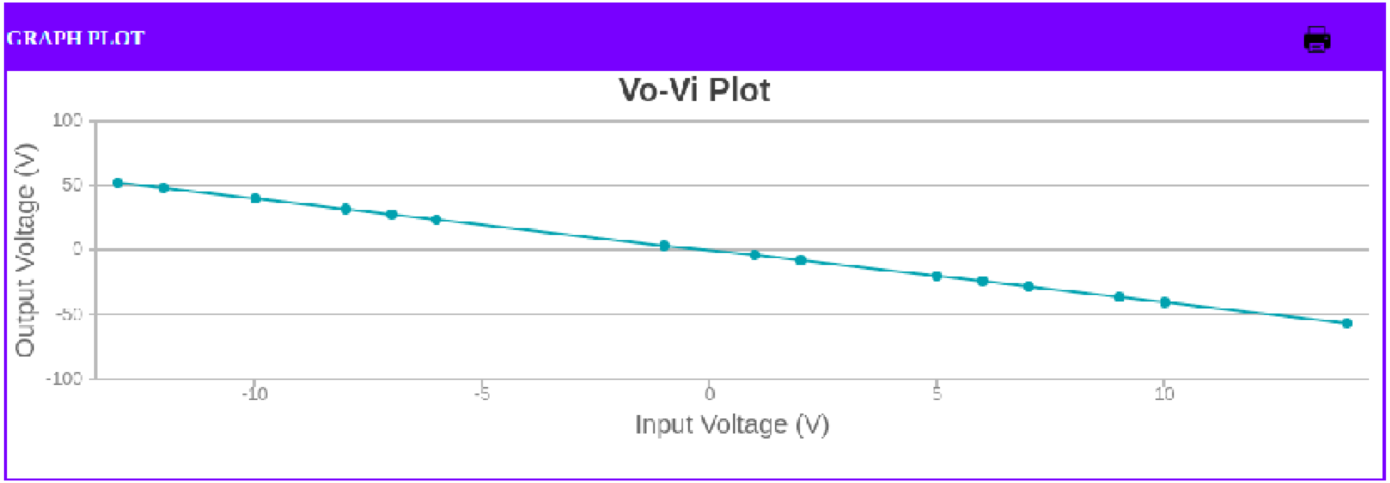
Simulated data-1

Resistance: 13 KΩ	Rf=20 Kohm		
Serial No.	**Input Voltage V**	**Output Voltage V**	**Current mA**
1	-14	21.5	-0.0269
2	-13	20	-0.025
3	-12	18.5	-0.0231
4	-11	16.9	-0.0212
5	-9	13.8	-0.0173
6	-8	12.3	-0.0154
7	-7	10.8	-0.0135
8	-6	9.23	-0.0115
9	-5	7.69	-0.00962
10	-4	6.15	-0.00769
11	-2	3.08	-0.00385
12	-1	1.54	-0.00192
13	1	-1.54	0.00192
14	2	-3.08	0.00385
15	3	-4.62	0.00577



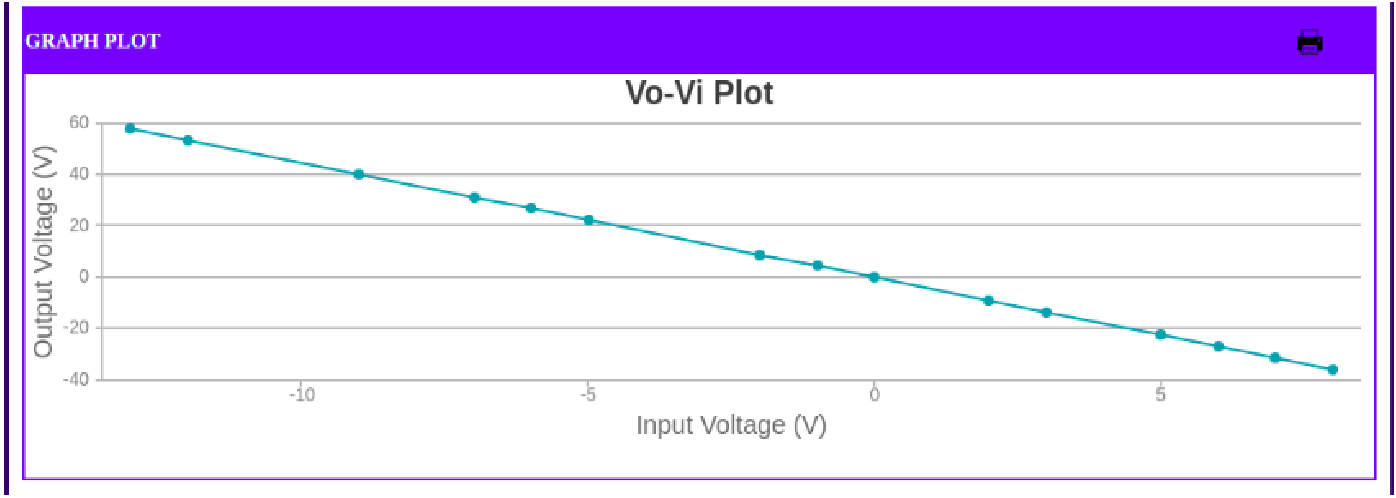
Simulated data-2

Resistance: 12 KΩ	Rf:48 KΩ		
Serial No.	Input Voltage V	Output Voltage V	Current mA
1	-13	52	-0.0521
2	-12	48	-0.0481
3	-10	40	-0.0401
4	-8	32	-0.0321
5	-7	28	-0.028
6	-6	24	-0.024
7	-1	4	-0.00401
8	1	-4	0.00401
9	2	-8	0.00801
10	5	-20	0.02
11	6	-24	0.024
12	7	-28	0.028
13	9	-36	0.0361
14	10	-40	0.0401
15	14	-56	0.0561



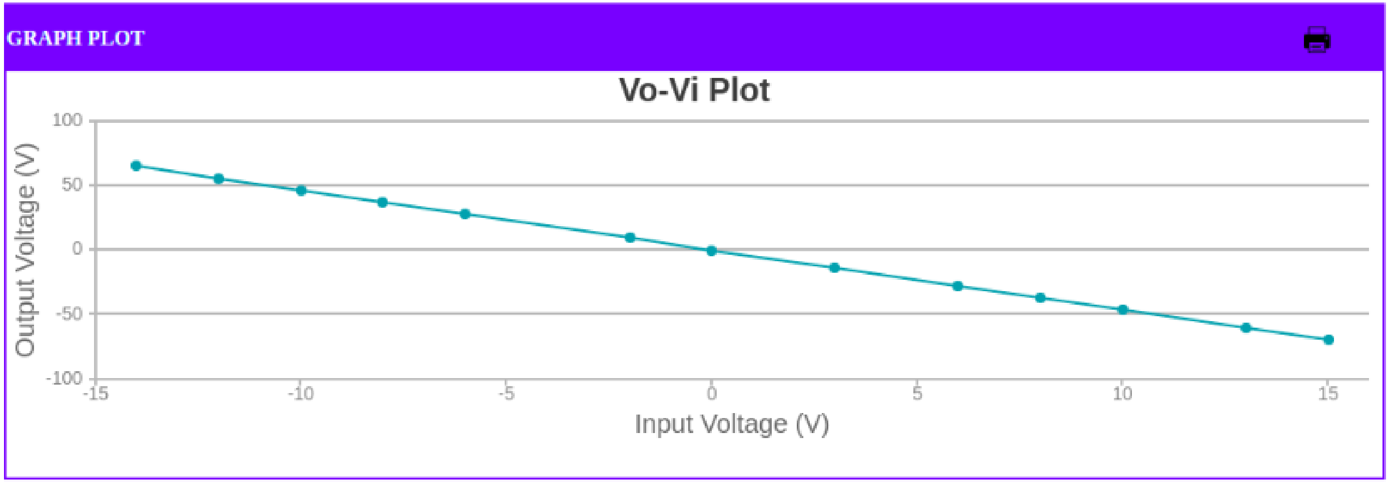
Simulated data-3

Resistance: 15 KΩ	Rf:67 KΩ		
Serial No.	**Input Voltage V**	**Output Voltage V**	**Current mA**
1	-13	58.1	-0.0454
2	-12	53.6	-0.0419
3	-9	40.2	-0.0314
4	-7	31.3	-0.0244
5	-6	26.8	-0.0209
6	-5	22.3	-0.0174
7	-2	8.93	-0.00698
8	-1	4.47	-0.00349
9	0	0	0
10	2	-8.93	0.00698
11	3	-13.4	0.0105
12	5	-22.3	0.0174
13	6	-26.8	0.0209
14	7	-31.3	0.0244
15	8	-35.7	0.0279



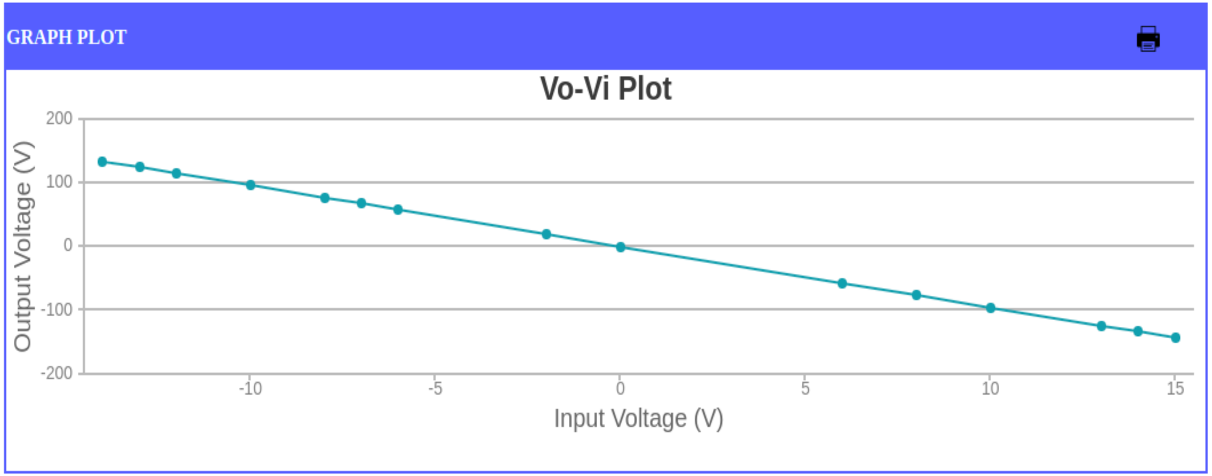
Simulated data-4

Resistance: 17 KΩ	Rf: 79 KΩ		
Serial No.	**Input Voltage V**	**Output Voltage V**	**Current mA**
1	-14	65.1	-0.0444
2	-12	55.8	-0.0381
3	-10	46.5	-0.0317
4	-8	37.2	-0.0254
5	-6	27.9	-0.019
6	-2	9.29	-0.00635
7	0	0	0
8	3	-13.9	0.00952
9	6	-27.9	0.019
10	8	-37.2	0.0254
11	10	-46.5	0.0317
12	13	-60.4	0.0413
13	15	-69.7	0.0476



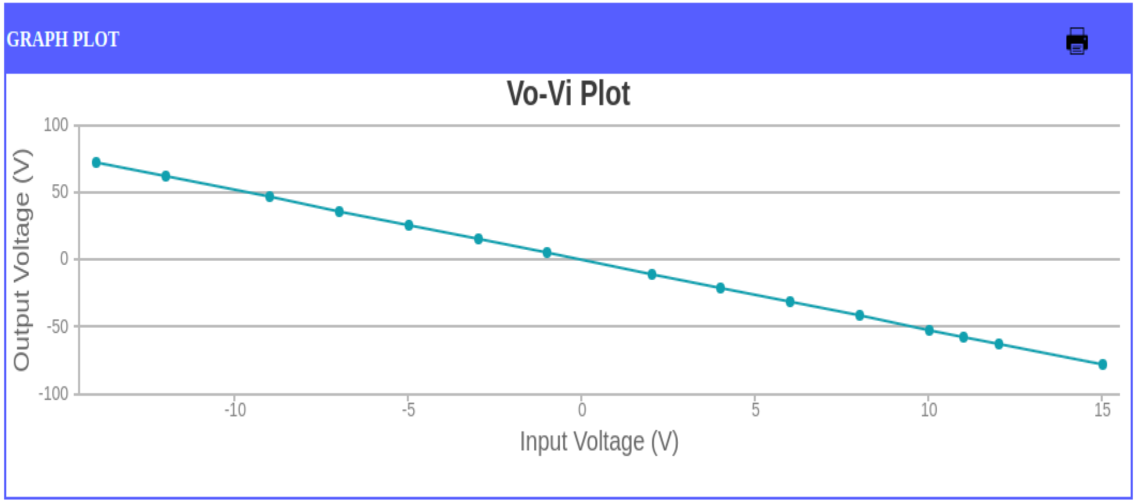
Simulated data-5

Resistance: 5 KΩ	Rf: 48 KΩ		
Serial No.	**Input Voltage V**	**Output Voltage V**	**Current mA**
1	-14	134	-0.271
2	-13	125	-0.251
3	-12	115	-0.232
4	-10	96	-0.193
5	-8	76.8	-0.155
6	-7	67.2	-0.135
7	-6	57.6	-0.116
8	-2	19.2	-0.0387
9	0	0	0
10	6	-57.6	0.116
11	8	-76.8	0.155
12	10	-96	0.193
13	13	-125	0.251
14	14	-134	0.271
15	15	-144	0.29



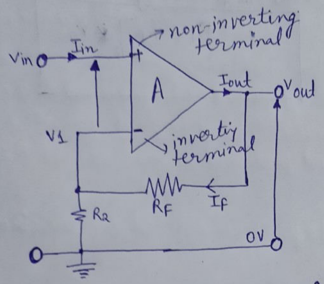
Simulated data-6

Resistance:5 KΩ	Rf: 26 KΩ		
Serial No.	Input Voltage V	Output Voltage V	Current mA
1	-14	72.8	-0.165
2	-12	62.4	-0.141
3	-9	46.8	-0.106
4	-7	36.4	-0.0825
5	-5	26	-0.0589
6	-3	15.6	-0.0354
7	-1	5.2	-0.0118
8	2	-10.4	0.0236
9	4	-20.8	0.0471
10	6	-31.2	0.0707
11	8	-41.6	0.0943
12	10	-52	0.118
13	11	-57.2	0.13
14	12	-62.4	0.141
15	15	-78	0.177



Theory with equations(non inverting op-amp)

Non-Inverting Op-Amp



In this configuration, input signal fed directly to non inverting terminal resulting in a positive gain and output voltage in phase with ~~output~~ input as compared to inverting op-amp where gain is negative, and to provide stability a negative feedback is applied through a resistor(R_f) and inverting terminal is grounded with a input resistor (R_2). This inverting op-amp like layout at inverting terminal creates a virtual ground at the summing point make the R_f and R_2 a potential divider across inverting terminal. Hence determine the gain of the circuit.

Equations

$$V_1 = \left(\frac{R_2}{R_2+R_F}\right) \times V_{out}$$

in ideal condition $V_1 = V_{in}$

so, $$V_{in} = \left(\frac{R_2}{R_2+R_F}\right) \times V_{out}$$

Now $A_{CL} = \frac{V_{out}}{V_{in}}$

so, closed loop gain is

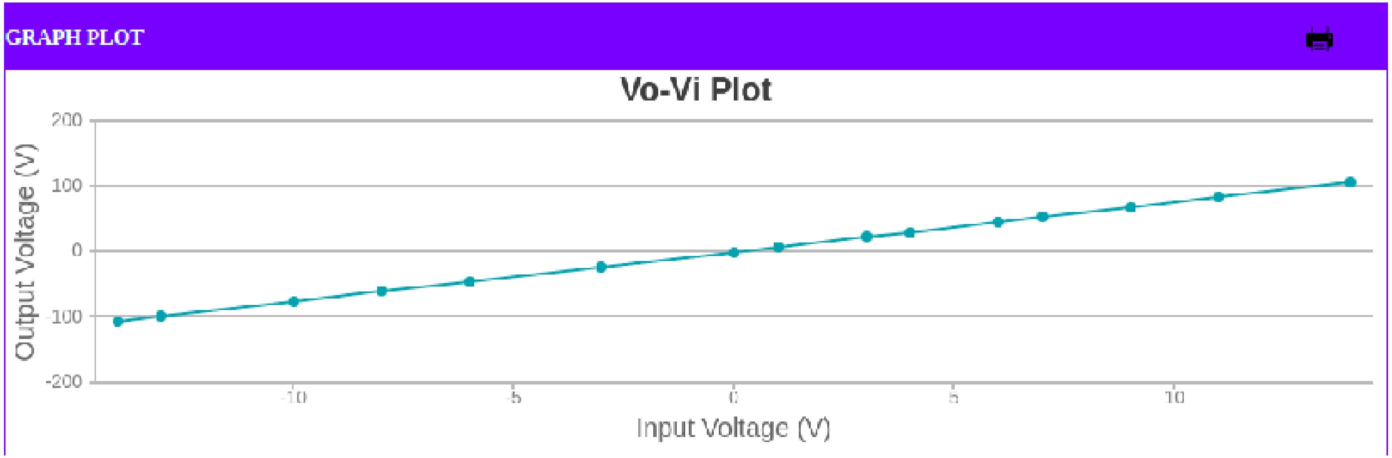
$$\boxed{A_{Cl} = \frac{R_2+R_F}{R_2} = 1+\frac{R_F}{R_2}}$$

and output voltage (V_{out}) is given by

$$\boxed{V_{out} = \left[1+\frac{R_F}{R_2}\right] * V_{in}}$$

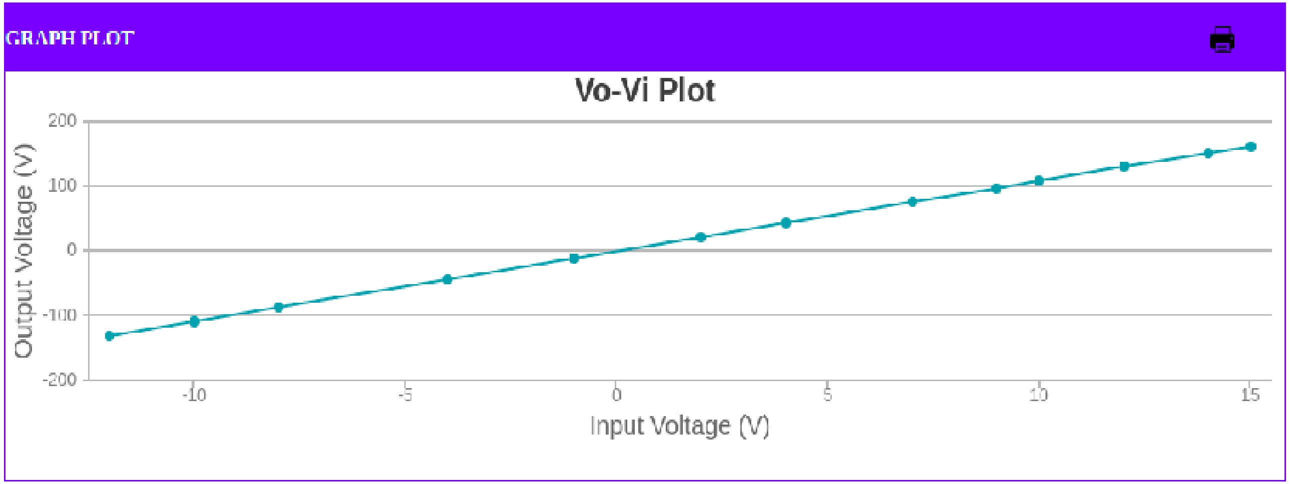
Simulated data-1

Resistance: 5 KΩ	Rf:33 KΩ		
Serial No.	**Input Voltage V**	**Output Voltage V**	**Current mA**
1	-14	-106	-0.225
2	-13	-98.8	-0.208
3	-10	-76	-0.161
4	-8	-60.8	-0.128
5	-6	-45.6	-0.0957
6	-3	-22.8	-0.0469
7	0	0	0
8	1	7.6	0.015
9	3	22.8	0.0469
10	4	30.4	0.0638
11	6	45.6	0.0957
12	7	53.2	0.113
13	9	68.4	0.144
14	11	83.6	0.176
15	14	106	0.225



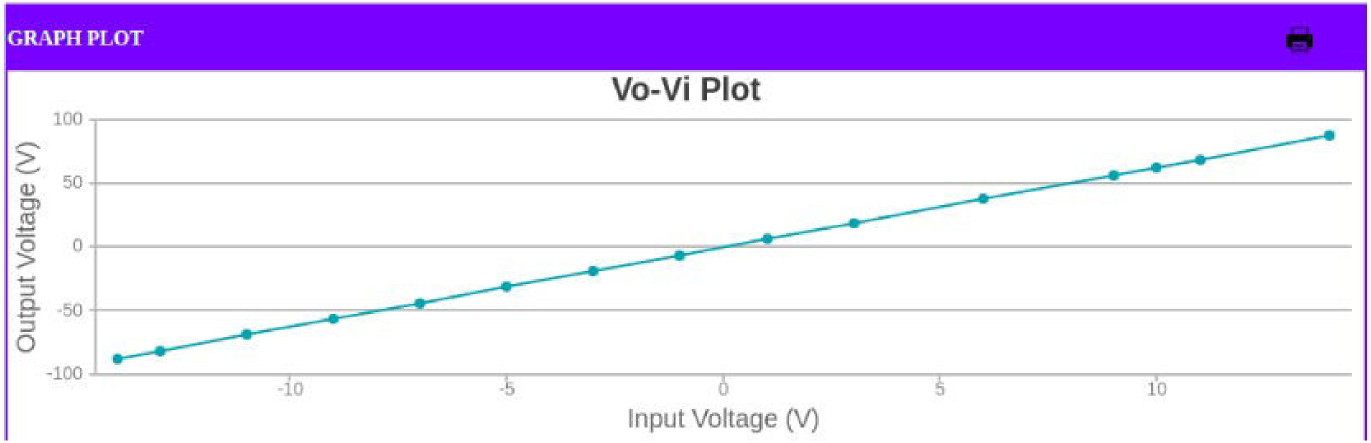
Simulated data-2

Resistance: 5 KΩ	Rf:49 KΩ		
Serial No.	**Input Voltage V**	**Output Voltage V**	**Current mA**
1	-12	-130	-0.257
2	-10	-108	-0.215
3	-8	-86.4	-0.171
4	-4	-43.2	-0.0856
5	-1	-10.8	-0.02
6	2	21.6	0.0419
7	4	43.2	0.0856
8	7	75.6	0.149
9	9	97.2	0.193
10	10	108	0.215
11	12	130	0.257
12	14	151	0.301
13	15	162	0.322



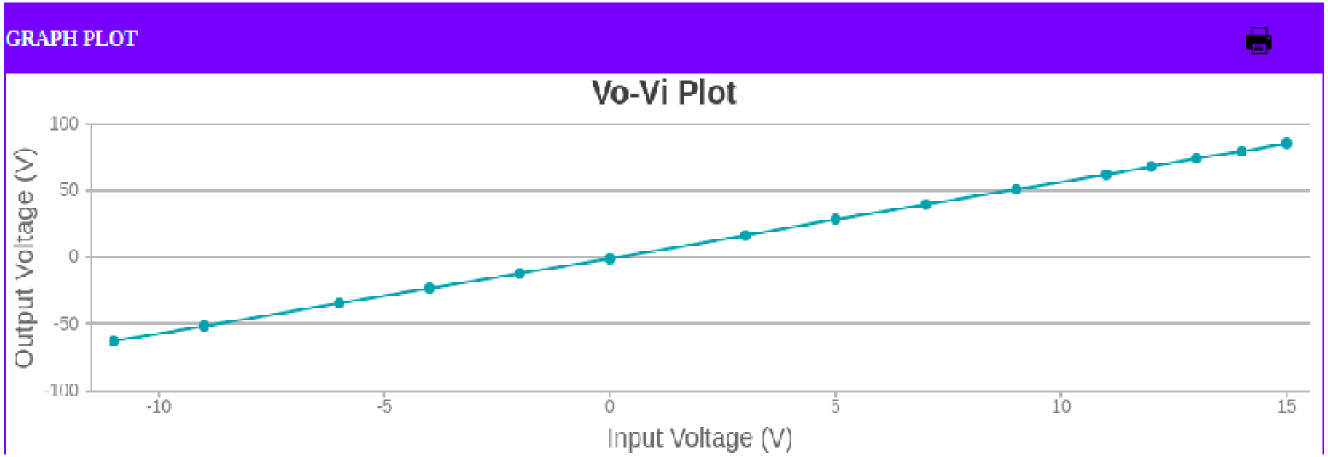
Simulated date-3

Resistance: 11 KΩ	Rf:59 KΩ		
Serial No.	**Input Voltage V**	**Output Voltage V**	**Current mA**
1	-14	-87.8	-0.0872
2	-13	-81.5	-0.0812
3	-11	-69	-0.0691
4	-9	-56.5	-0.0561
5	-7	-43.9	-0.0432
6	-5	-31.4	-0.0311
7	-3	-18.8	-0.0181
8	-1	-6.27	-0.00604
9	1	6.27	0.00604
10	3	18.8	0.0181
11	6	37.6	0.0371
12	9	56.5	0.0561
13	10	62.7	0.0622
14	11	69	0.0691
15	14	87.8	0.0872



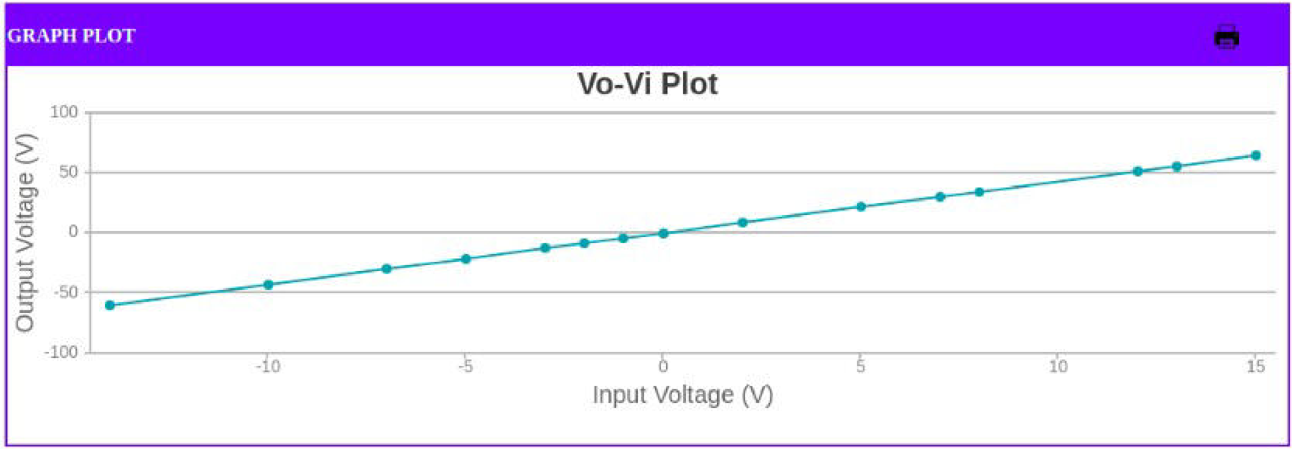
Simulated data-4

Resistance: 14 KΩ	Rf:66 KΩ		
Serial No.	**Input Voltage V**	**Output Voltage V**	**Current mA**
1	-11	-62.9	-0.0498
2	-9	-51.4	-0.0409
3	-6	-34.3	-0.0273
4	-4	-22.9	-0.0177
5	-2	-11.4	-0.00887
6	0	0	0
7	3	17.1	0.0136
8	5	28.6	0.0225
9	7	40	0.0321
10	9	51.4	0.0409
11	11	62.9	0.0498
12	12	68.6	0.0546
13	13	74.3	0.0593
14	14	80	0.0641
15	15	85.7	0.0682



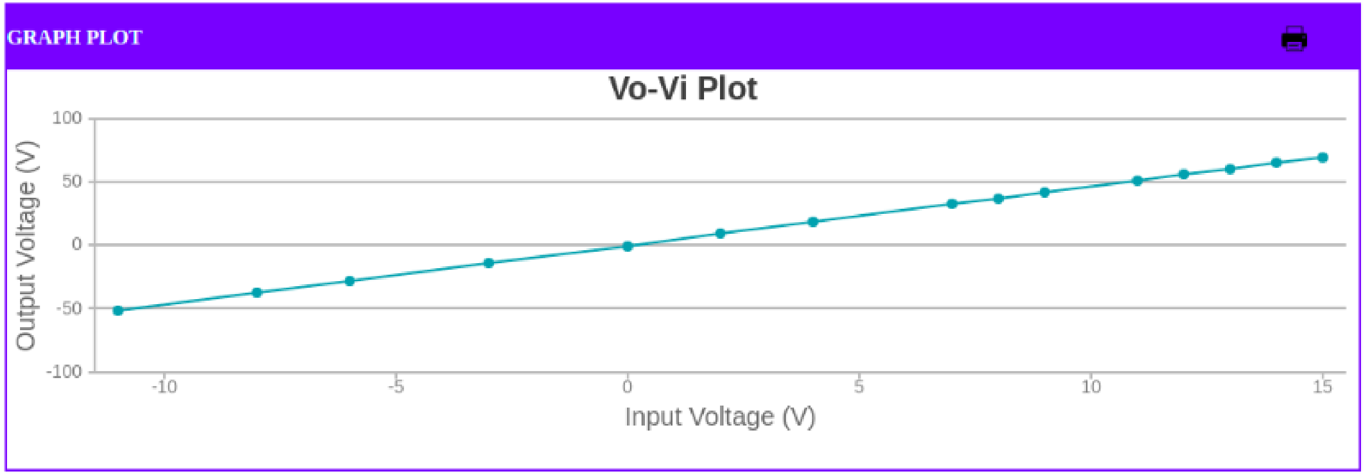
Simulated data-5

Resistance: 21 KΩ	Rf:69 KΩ		
Serial No.	**Input Voltage V**	**Output Voltage V**	**Current mA**
1	-14	-60	-0.0341
2	-10	-42.9	-0.024
3	-7	-30	-0.0171
4	-5	-21.4	-0.012
5	-3	-12.9	-0.00692
6	-2	-8.57	-0.00461
7	-1	-4.29	-0.00231
8	0	0	0
9	2	8.57	0.00461
10	5	21.4	0.012
11	7	30	0.0171
12	8	34.3	0.0194
13	12	51.4	0.029
14	13	55.7	0.0314
15	15	64.3	0.0364



Simulated data-6

Resistance: 18 KΩ	Rf:66 KΩ		
Serial No.	**Input Voltage V**	**Output Voltage V**	**Current mA**
1	-11	-51.3	-0.0332
2	-8	-37.3	-0.0241
3	-6	-28	-0.0177
4	-3	-14	-0.00857
5	0	0	0
6	2	9.33	0.00589
7	4	18.7	0.0118
8	7	32.7	0.0209
9	8	37.3	0.0241
10	9	42	0.0268
11	11	51.3	0.0332
12	12	56	0.0359
13	13	60.7	0.0391
14	14	65.3	0.0423
15	15	70	0.045



Observations

- The inverting op-amp provides output 180 degree out of phase with the input waveform.
- The non inverting op-amp produces an output waveform in the same phase as the input waveform.
- To stabilize gain a feedback resistor is added,in case of non-inverting op-amp,closed loop voltage gain>=1 always irrespective of value of R1,Rf
- The potential difference between the inverting and non-inverting terminal is zero for ideal op-amp as gain is infinite and output has to be finite voltage.
- The graph of Vo vs Vi is a straight line with +ve slope for a non-inverting op-amp and with -ve slope for an inverting op-amp.
- If the ratio Rf/R1 increased,gain increases in both cases.

Conclusion

- The non-inverting op-amp with feedback control is used as a voltage follower circuit by shorting the feedback resistor
- The gain is larger in case of non inverting op-amp for same values of R1 and Rf.
- The output impedance for an ideal op-amp is zero whereas input impedance is infinite so it can act as a current sink as well a cuurent source
- The maximum and minimum output voltage is limited by the supply voltages and hence output voltage cannot be infinite.
- In case of a practical op-amp gain is finite and voltage difference between inverting and non-inverting terminal is no longer zero.

EXPERIMENT 2

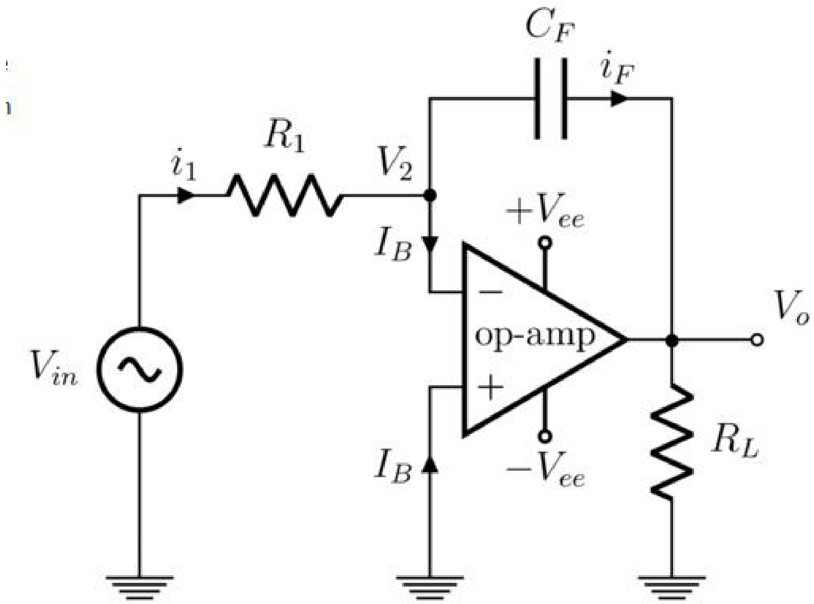
Study of Differentiator and Integrator using Operational Amplifier

AIM:

At the end of the experiment, the student would be able to

- Explain Differentiator using Opamp
- Explain Integrator using Opamp

Circuit for integrator op-amp



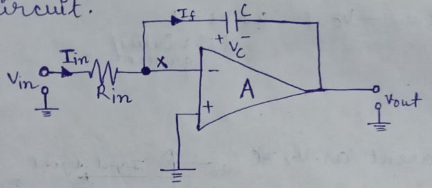
Source:Wikipedia

Theory with equations(integrator op-amp)

Op-Amp-Integrator circuit

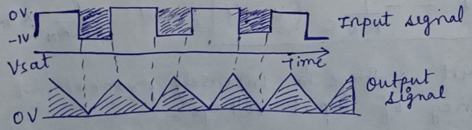
Operational amplifiers can be used as part of a positive or negative feedback amplifier or as an adder or subtractor type circuit using just pure resistances in both input and feedback loop.

But if we replace the resistive element with a frequency dependent complex element that has reactance such as Capacitor. We can obtain the Integrator and Differentiator circuit.



Through this circuit, we can cause output to respond to changes in the input voltage over time as the op-amp generator/integrator produces output proportional to integral of input voltage.

When we provide a square wave as input, a ramp generator output is obtained which is why it is also referred to as ramp generator.



This circuit is frequency dependent. Initially when voltage is applied to integrator the uncharged capacitor allows maximum current to pass through it and no current flows through the op-amp due to presence of virtual ground, the capacitor starts to charge at the rate of RC time constant and impedance starts to increase with time and therefore charging current decreases. This results in the ratio of capacitor's impedance and input resistance causing a linearly increasing ramp output voltage that continues to increase until capacitor becomes fully charged.

Equations

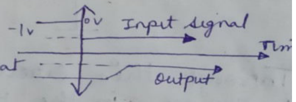
$$V_C = Q/C$$

$$V_C = V_X - V_{out} = -V_{out} \quad \text{as } V_X = 0$$

X is virtual ground

$$-\frac{dV_{out}}{dt} = \frac{1}{C}\times\frac{dQ}{dt}$$

$\frac{dQ}{dt}$ is current as $V_X = 0$



$$I_{IN} = \left(\frac{V_{IN}-0}{R_{IN}}\right)$$

$$I_f = -C\times\frac{dV_{out}}{dt} = C\times\frac{1}{C}\times\frac{dQ}{dt}$$

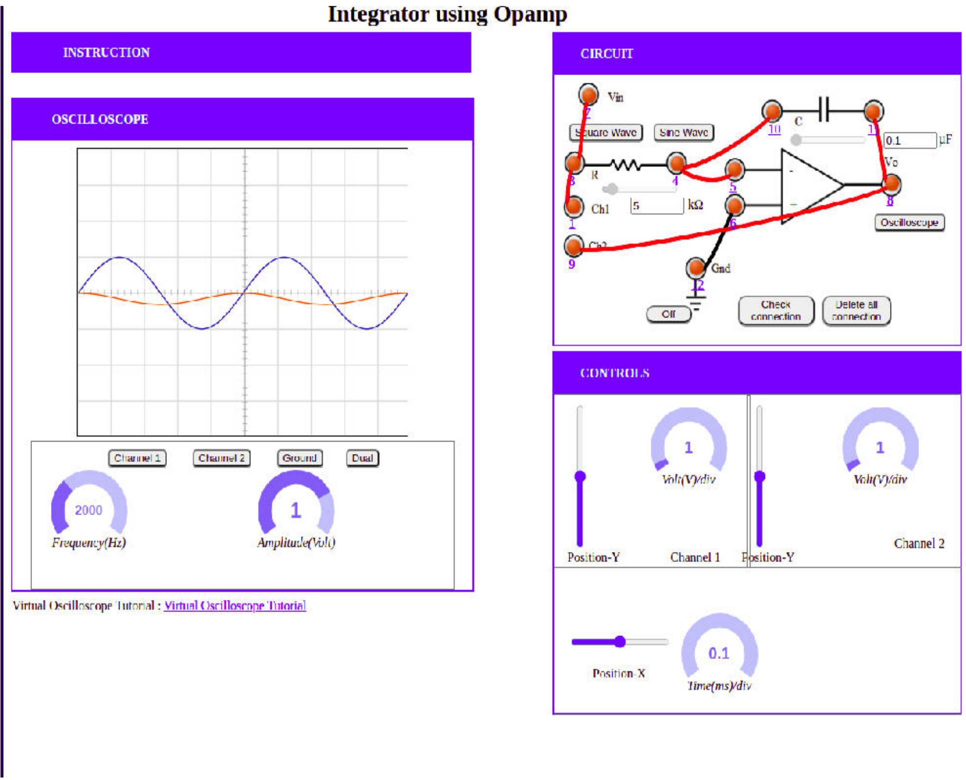
$$I_f = \frac{dQ}{dt}$$

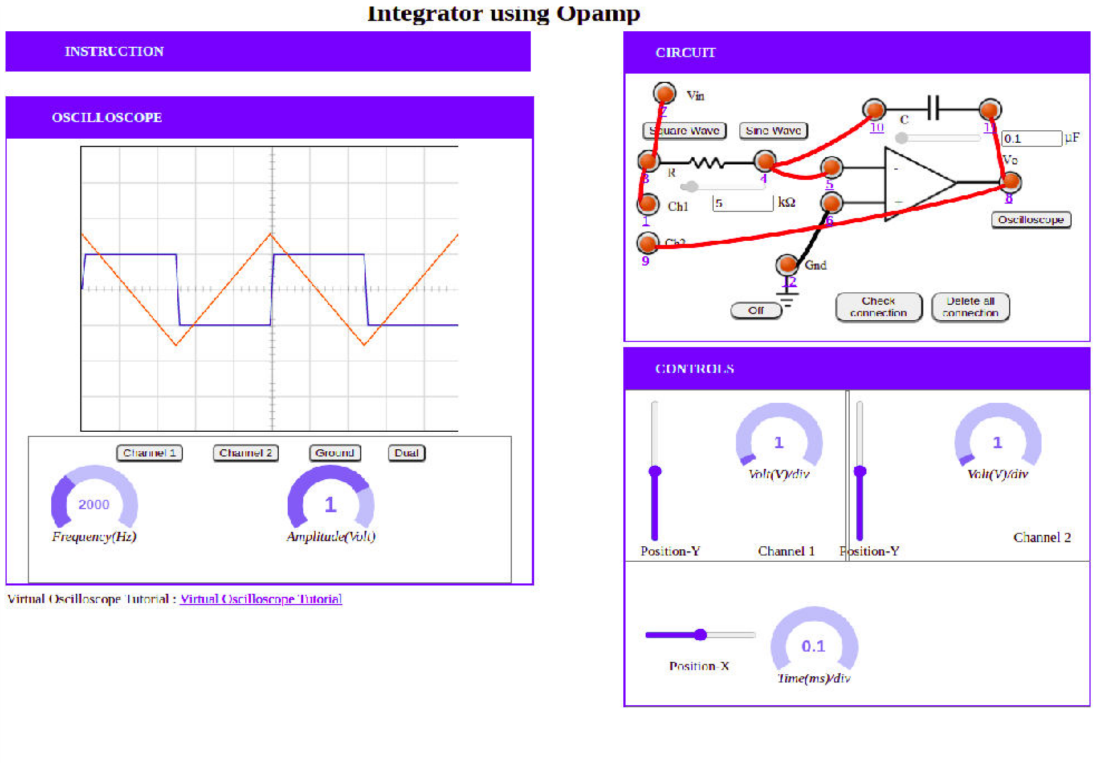
$$I_{IN} = \frac{V_{IN}}{R_{IN}} = I_f = \frac{dQ}{dt} = -C\times\frac{dV_{out}}{dt}$$

$$\boxed{V_{out} = -\frac{1}{R_{IN}\cdot C}\int V_{in}\cdot dt} \; ; \; V_{out} = -\frac{1}{j\times\omega R_{IN}\cdot C}\times V_{IN}$$

The output voltage is inversely proportional to frequency of input voltage.

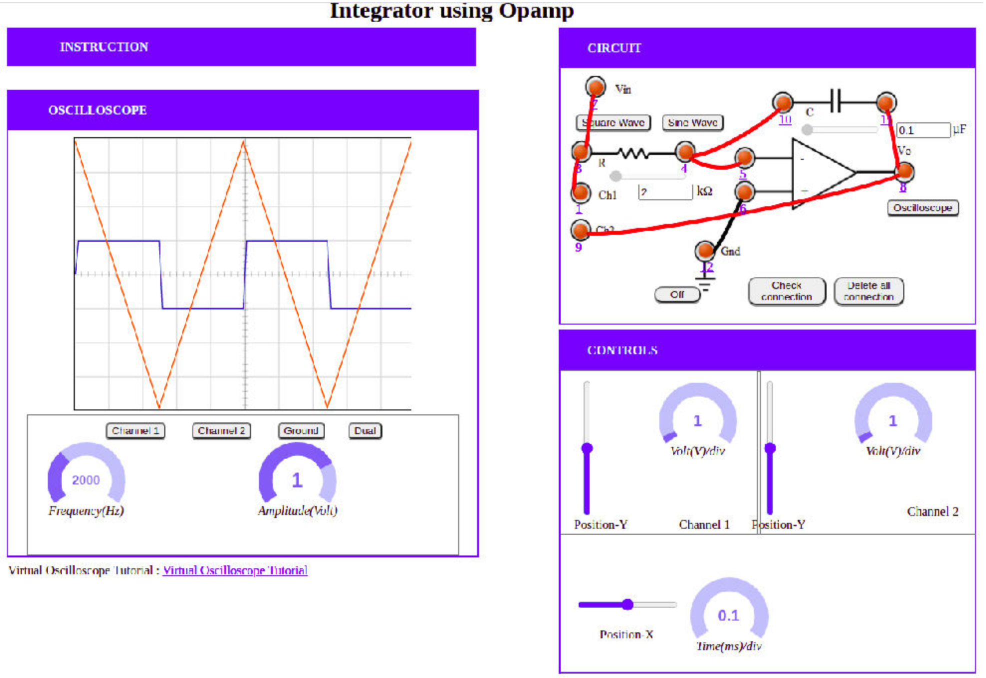
Simulated date-1(integrator)

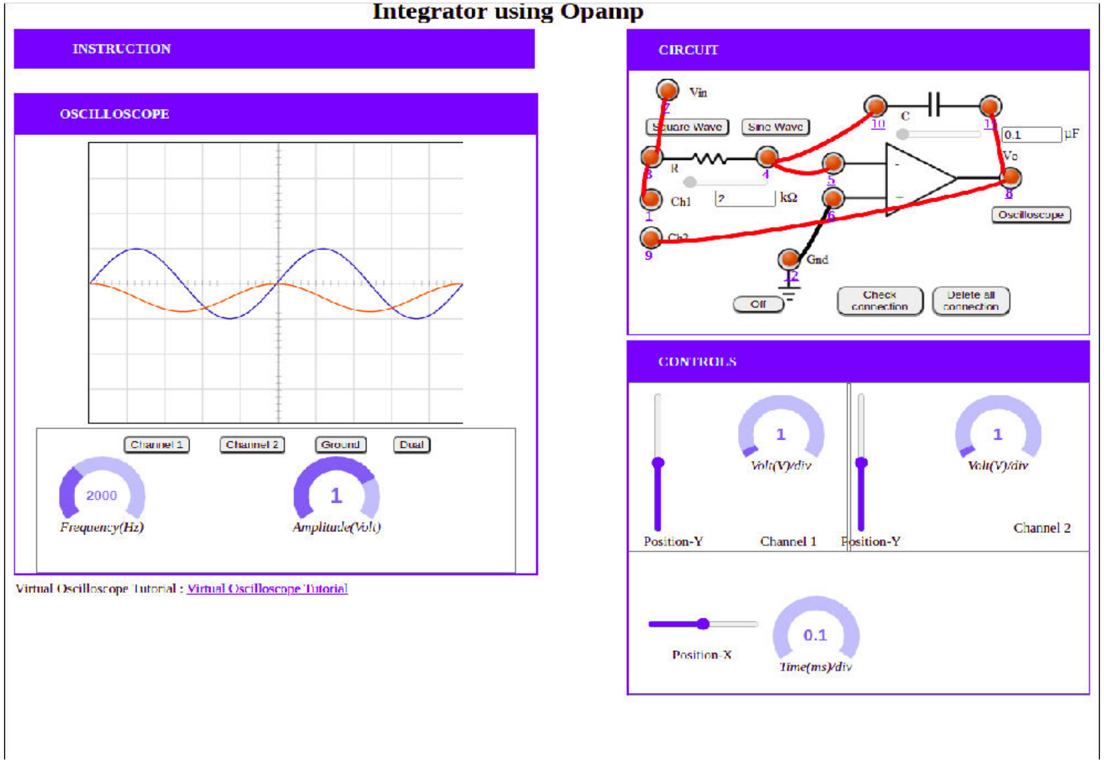




R=5 Kohm and C=0.1 microfarad

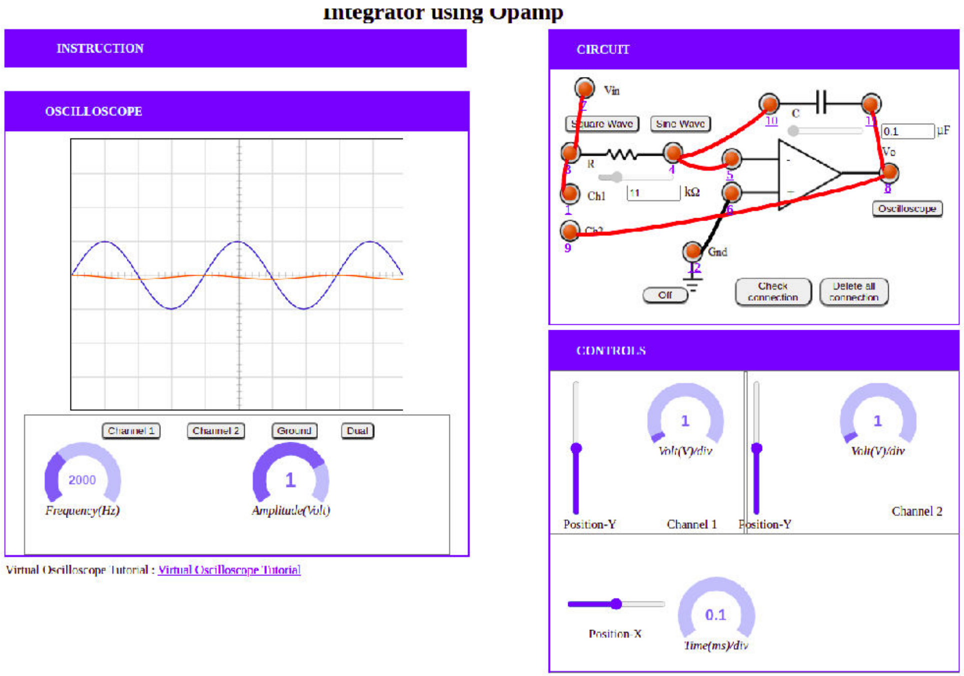
Simulated date-2(integrator)

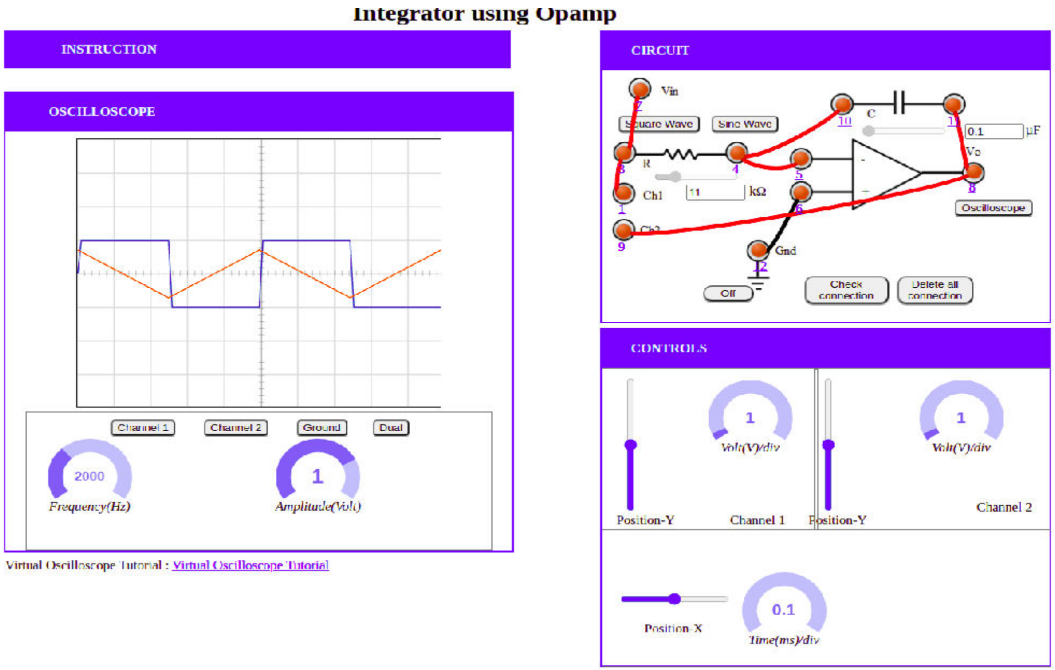




R=7 Kohm and C=0.1 microfarad

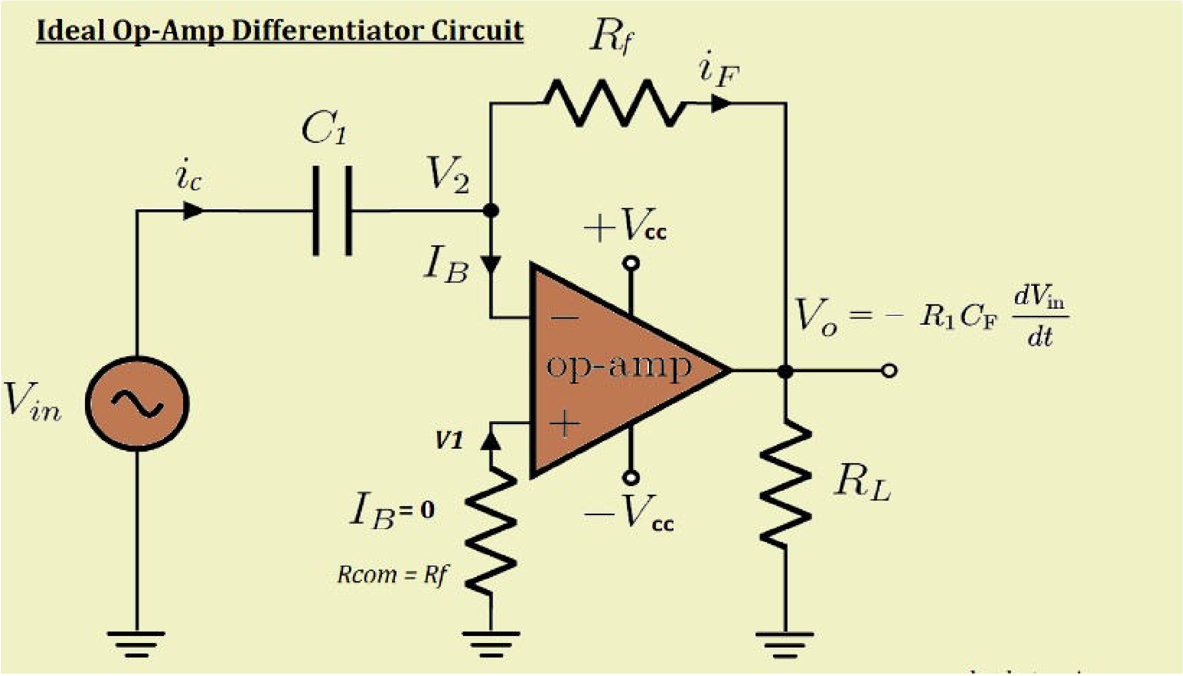
Simulated date-3(integrator)





R=11 Kohm and C=0.1 microfarad

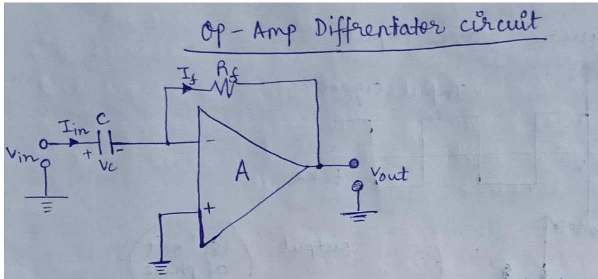
Circuit for diffrentiator op-amp



Source: Hackatronic.com

Theory with equations(diffrentiator op-amp)

Op-Amp Diffrentiator circuit



Here position of the capacitor and resistor have been reversed and now the reactance, X_C is connected to the input terminal of the inverting amplifier while the resistor, R_f forms the negative feedback element across the operational amplifier as normal.

It produces a output voltage which is directly proportional to the input voltage's rate of change with respect to time. The output is kind of spikes for a square wave input. The output is 180° out of phase and amplified with a factor $R_f * C$. The capacitor allows only AC component and restrict DC, at low frequency causing a low gain and high frequency vice versa but the circuit becomes unstable then.

Equations

since $V_x = 0$

$$I_{IN} = I_f = -V_{out}/R_f$$

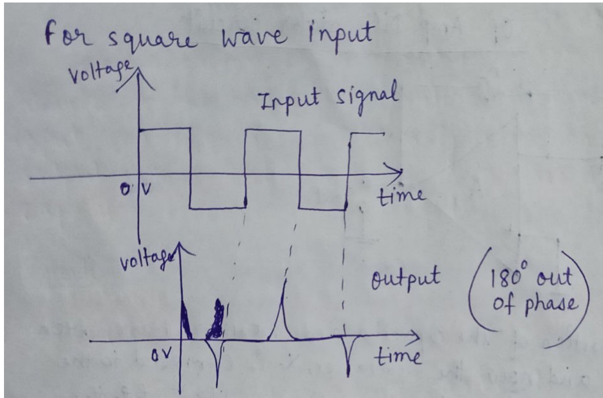
$$Q \text{ (charge across capacitor)} = C \times V_{IN}$$

$$\frac{dQ}{dt} = C \times \frac{dV_{IN}}{dt}$$

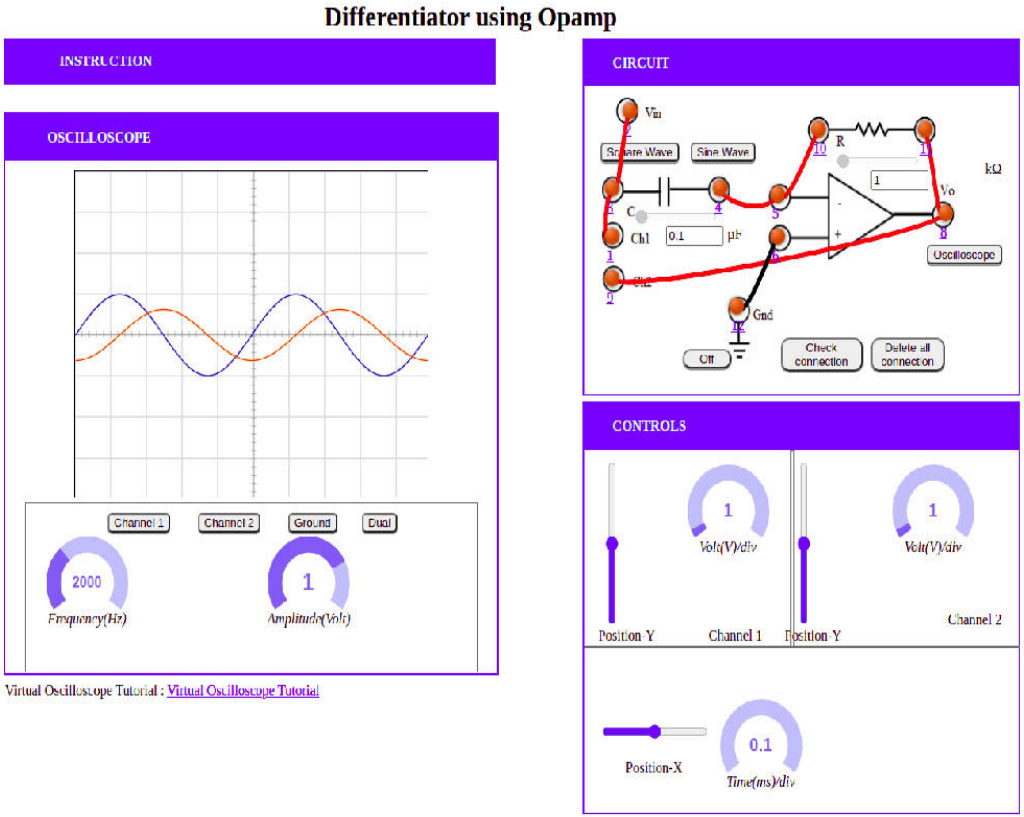
$$I_f = C \times \frac{dV_{IN}}{dt} = I_{IN}$$

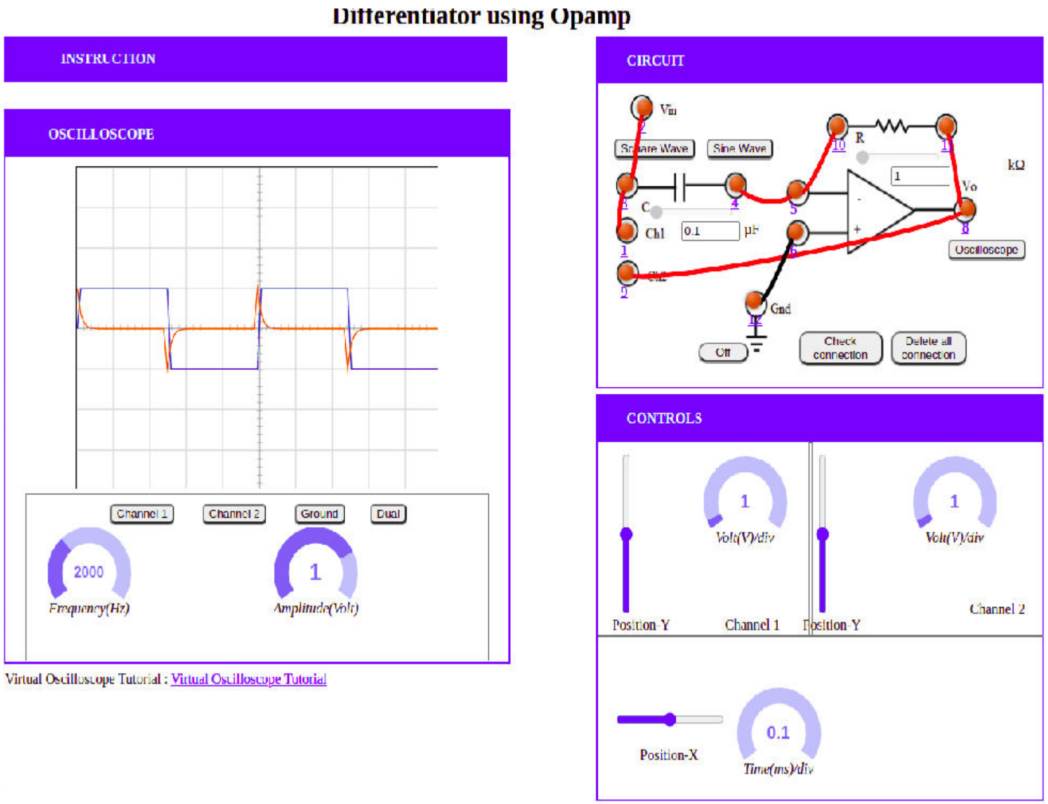
$$\boxed{-\frac{V_{out}}{R_f} = C \times \frac{dV_{IN}}{dt}} \quad \boxed{V_{out} = -R_f \times C \times \frac{dV_{IN}}{dt}}$$

For square wave input



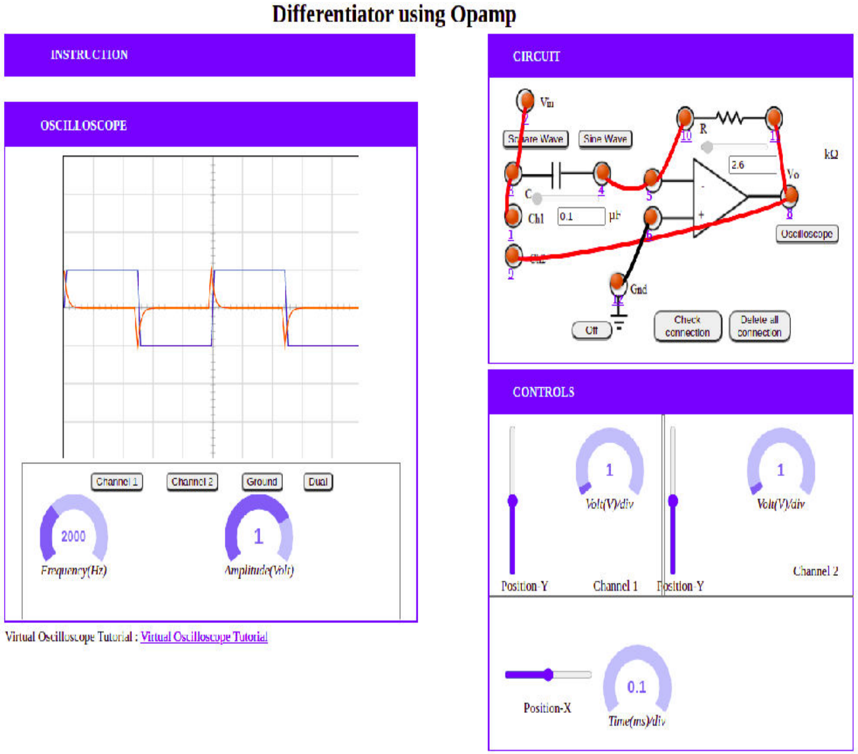
Simulated data-1(diffrentiator)

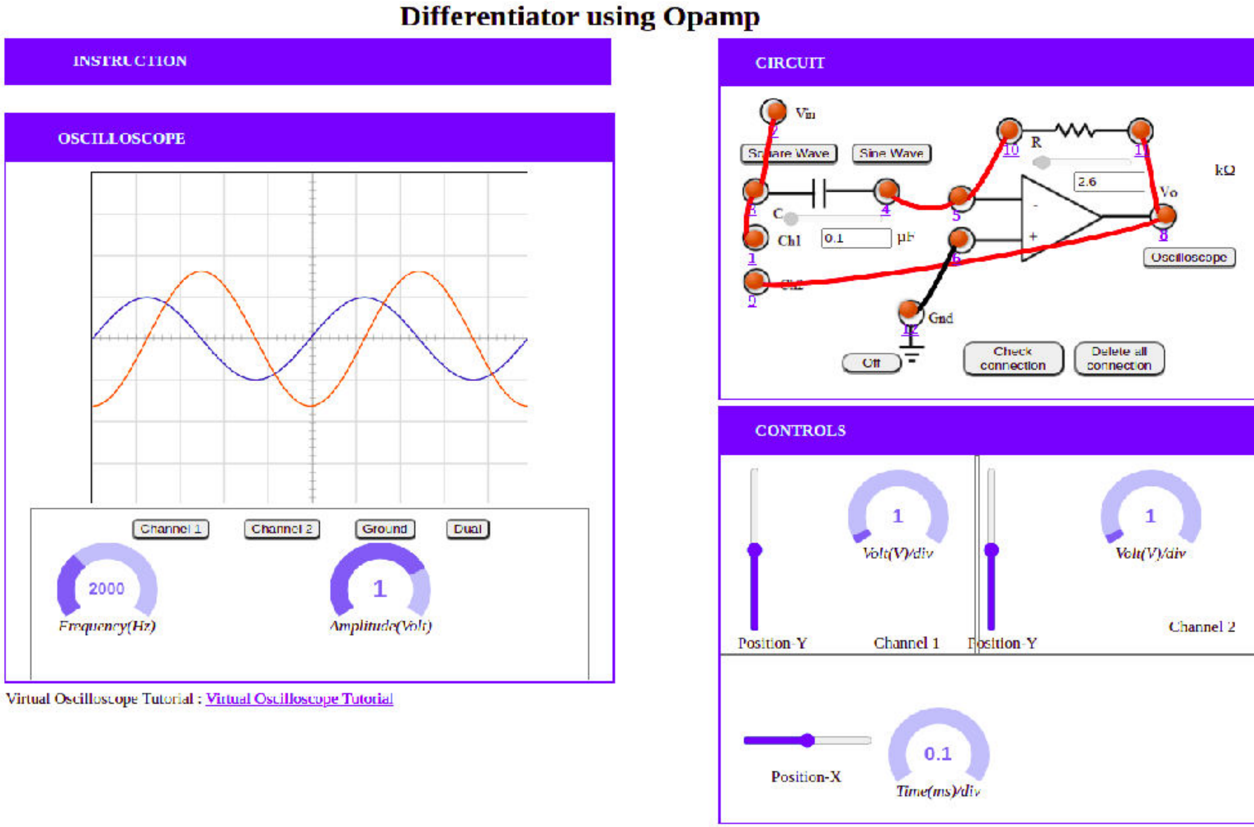




R=1 Kohm and C=0.1 microfarad

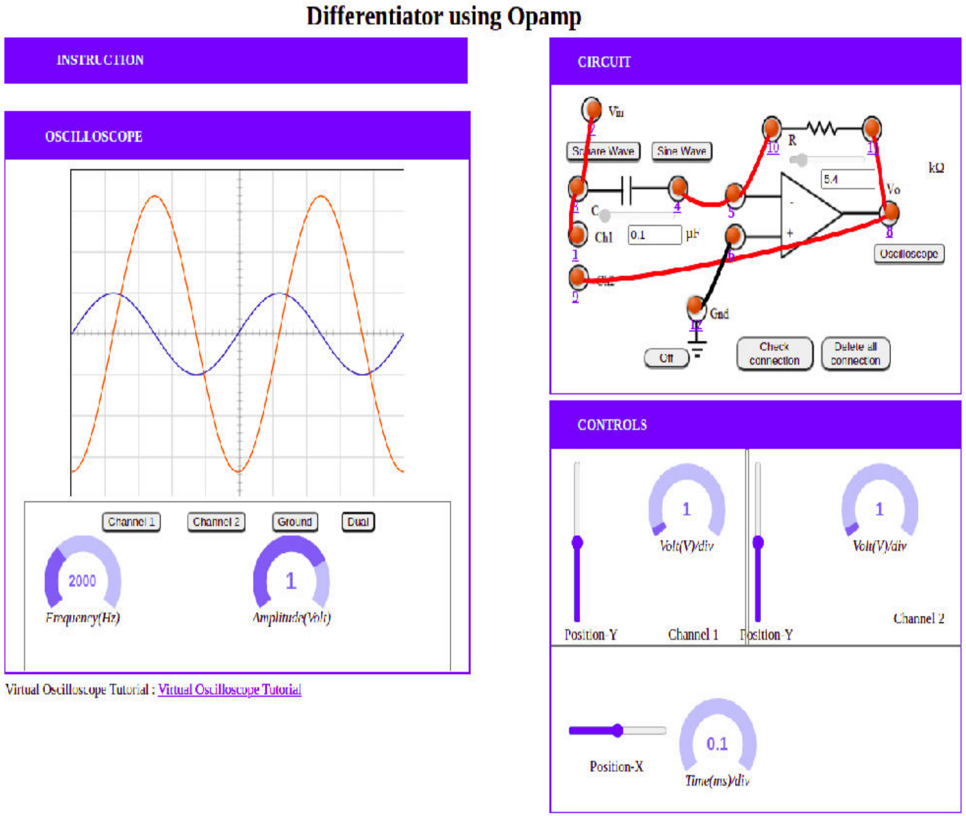
Simulated data-2(diffrentiator)

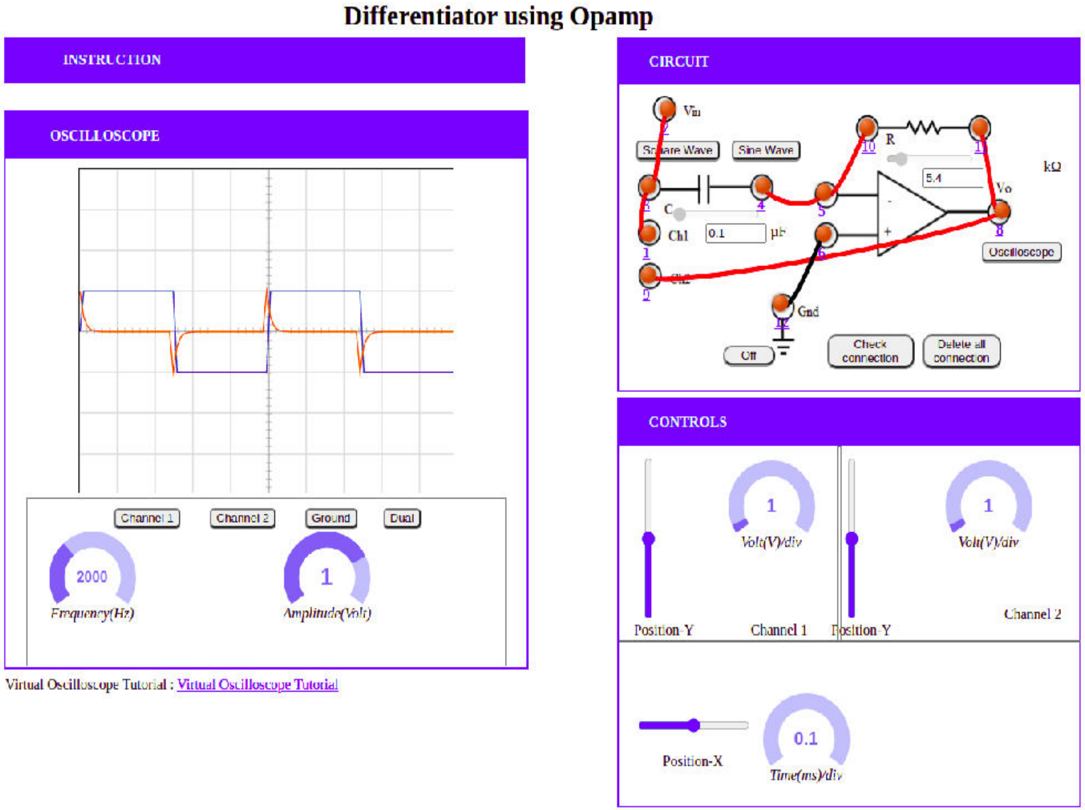




R=2.6 Kohm and C=0.1 microfarad

Simulated data-3(diffrentiator)





R=5.4 Kohm and C=0.1 microfarad

Observations

- The vlabs page had a glitch,the output waveform in diffrentiator circuit for square wave input was same for all values of R ,C and frequencies
- For a diffrentiator circuit and sine wave input,output is amplified by a factor of R*C.
- For an integrator circuit and sine wave input,output is amplified by a factor of 1/(R*C).
- For an diffrentiator circuit and square wave input,output is amplified by a factor of R*C
- For an integrator circuit and sine wave input,output is amplified by a factor of 1/(R*C)
- Smaller value of R*C means amplification factor is larger for an integrator circuit while it is vice versa for a diffrentiator circuit.
- Higher frequencies increase gain of diffrentiator circuit making it unstable while lower frequencies decrease its gain.
- Higher frequences decrease gain of integrator circuit making it stable while lower frequencies increase it gain making it unstable.

Conclusion

- The replacement of feedback resistor by a capacitor makes the circuit frequency dependent.
- The gain cannot be very high else circuit becomes unstable.
- The integrator circuit is also known as a ramp generator which is produced on providing a square wave as an input.
- In a practical op-amp gain is not infinite so the voltage will not be equal at the inverting and non inverting terminal.
- Time constant of circuit is inversely proportional to gain in integrator circuit whereas it is directly proportional to gain in diffrentiator circuit.
- In both integrator and diffrentiator circuits,the output waveform is out of phase with respect to the input waveform.