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EC160: Experiment 11

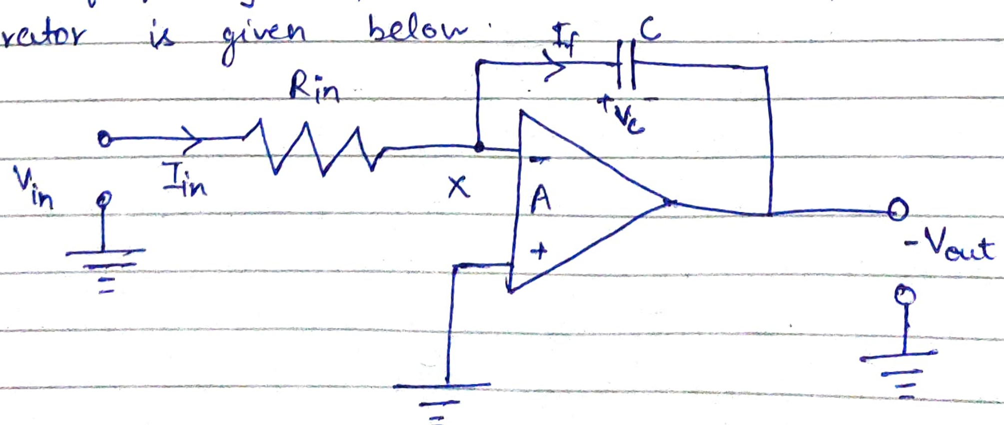
Differentiator and Integrator using Op-Amp

Objective :- (i) to study differentiator using Op-Amp.
(ii) to study integrator using Op-Amp.

Theory :- Operational Amplifier, commonly known as Op-Amp, is a linear electronic device having three terminals, two high impedance input and one output terminal. Op-Amp can perform multiple function when attached to different feedback combinations like resistive, capacitive or both. It is generally used as voltage amplifier and the output voltage of the Op-Amp is the difference between the voltages at its two input terminals.

Integrator Circuit Using Op-Amp :-

As its name implies, the Op-Amp Integrator is an operational amplifier circuit that performs the mathematical operation of Integration.
The integrator circuit layout is same as a inverting amplifier but the feedback resistor is replaced by a capacitor which makes the circuit frequency dependent. The circuit for Op-Amp Integrator is given below:



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In integrator circuit, the magnitude of output signal is determined by duration of time a voltage is present at its input as the current through the feedback loop charges or discharges the capacitor as the required negative feedback occurs through the capacitor.

Initially when the 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 its impedance start to increase with time and a potential difference develops across the capacitor resulting in charging current to decrease. This results in the ratio of capacitor's impedance and input resistance increasing causing a linearly increasing ramp output voltage that continues to increase until the capacitor becomes fully charged.

Since, the output voltage is the potential difference across capacitor

$$V_c = \frac{Q}{C}$$

or $$V_c = V_x - V_{OUT} = -V_{out}$$

therefore,

$$-V_{out} = \frac{Q}{C}$$

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

But $\frac{dQ}{dt}$ is electric current and since node voltage of integrating Op-Amp at its inverting input terminal is zero, the input current (I_{in}) flowing through the input resistor (R_{in}) is given as

$$I_{in} = \frac{V_{in} - 0}{R_{in}} = \frac{V_{in}}{R_{in}}$$

The current flowing through the feedback capacitor is

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

Assuming that input impedance of the Op-Amp is infinite, no current flows in the Op-Amp terminal. Therefore, nodal equation at inverting input terminal is,

$$I_n = I_f = \frac{V_{in}}{R_{in}} = \frac{dV_{out} \cdot C}{dt}$$

$$\therefore \quad \frac{V_{in}}{V_{out}} \times \frac{dt}{R_{in} C} = 1$$

$\therefore$ ideal voltage output for the Op-Amp Integrator,

$$V_{out} = -\frac{1}{R_{in} C} \int_0^t V_{in}\, dt = -\int_0^t V_{in} \frac{dt}{R_{in} \cdot C}$$

$$V_{out} = -\frac{V_{in}}{j\omega R_{in} \times C} \qquad (\omega = 2\pi f)$$

where $-ve$ sign indicates 180° phase shift.

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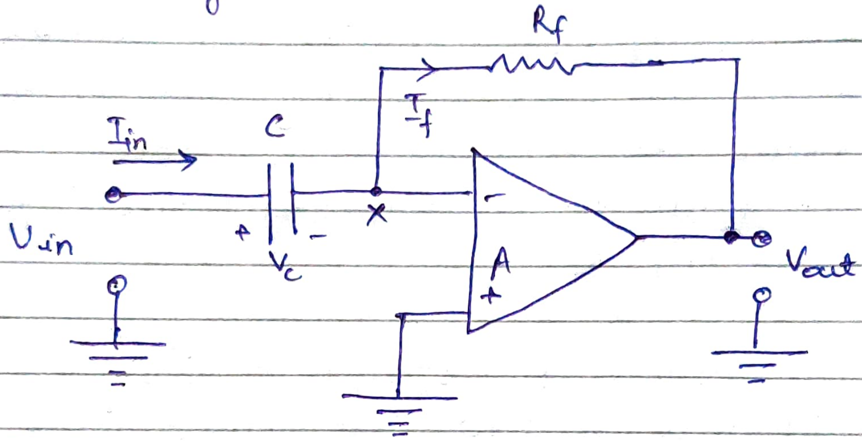
Differentiator circuit using Op-Amp

In the differentiator circuit, the input is connected to the inverting output of the Op-Amp through a capacitor (C) and a negative feedback is provided to the inverting input terminal thrugh a resistor (R_f). The differentiator Op-Amp circuit is given below,



The input signal to the differentiator is applied to the capacitor. The capacitor blocks any DC content so there is no current flow, to the amplifier summing point X, resulting in zero output voltage. The capacitor only allows AC type input voltage changes to pass through and whose frequency is dependent on rate of change of input signal.

At low frequencies, the reactance of capacitor is high resulting in a low gain (R_f/X_c) and low output voltage from the Op-Amp. At high frequencies, the reactance of capacitor is lower resulting in higher gain and

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higher output voltage from Op-Amp differentiator.

However, at high frequencies an Op-Amp differentiator circuit becomes unstable and oscillates. This is due to the first order effect mainly, which determines the frequency response of the op-amp circuit causing a second order response which, at high frequencies gives an output voltage far higher than expected. To avoid this, the high frequency gain of the circuit needs to be reduced by adding an additional small value capacitor across the feedback resistor R_f.

Since, node voltage of op-amp at its Inverting input terminal is zero, the current, i flowing through the capacitor,

$$I_{in} = I_f \text{ and } I_f = \frac{-V_{out}}{R_f}$$

The charge on capacitor equals capacitance time voltage across the capacitor

$$\therefore Q = C \times V_{in}$$

Thus the rate of change of charge,

$$\frac{dQ}{dt} = C \frac{dV_{in}}{dt}$$

but $\frac{dQ}{dt}$ is capacitor current, i

$$I_{in} = C\frac{dV_{in}}{dt} = I_f$$

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

from which, ideal voltage output for Op-Amp differentiator

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

Therefore, the output voltage V_{out} is $R_f C$ times the derivative of input voltage with respect to time. The minus sign indicates a 180° phase shift because the input signal is connected to inverting input terminal of the Op-Amp.

Procedure for the Experiment -:

1. Connect the circuit and check if it is a right connection.
2. Set the resistance 'R' and capacitance 'C'.
3. Click on 'ON' button to start the experiment.
4. Click on 'Square Wave' button to generate input waveform.
5. Click on 'Oscilloscope' button to get output waveform.
6. Vary the amplitude, frequency, volt/div using controllers.
7. Click on 'Dual' to observe both the waveforms.

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(Chanel 1 shows input waveform while chanel 2 shows output waveform)

8. Repeat the experiment by applying 'sine wave' as input in step 4.

Simulation Results

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Integrator using Opamp

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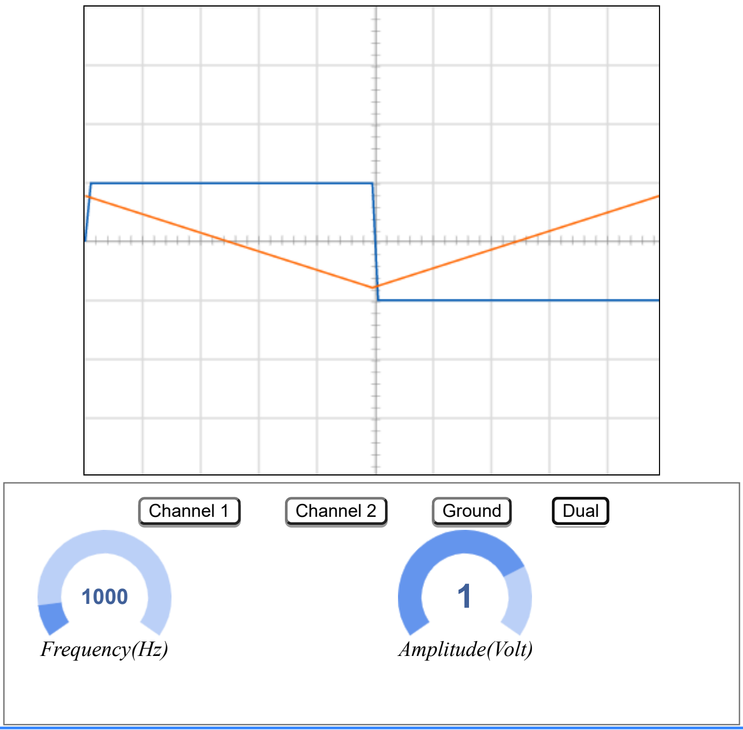
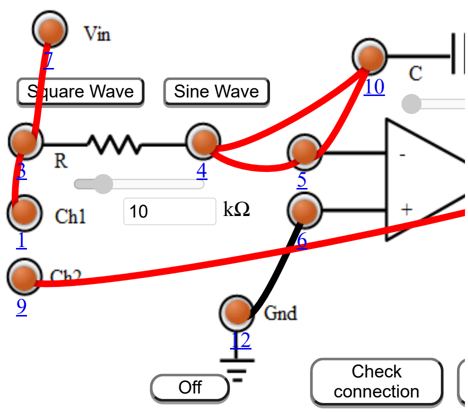
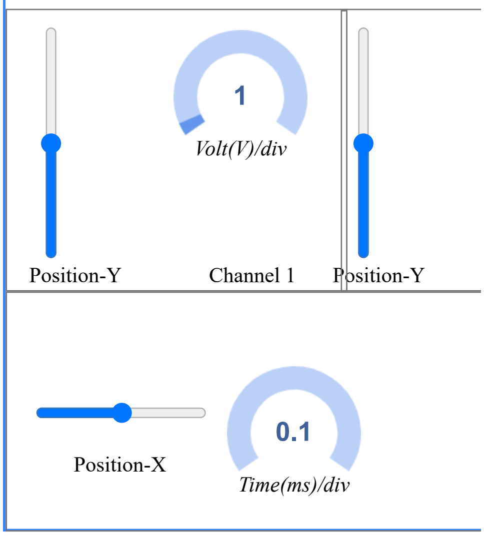


Virtual Oscilloscope Tutorial : Virtual Oscilloscope Tutorial

CIRCUIT



CONTROLS



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Integrator using Opamp

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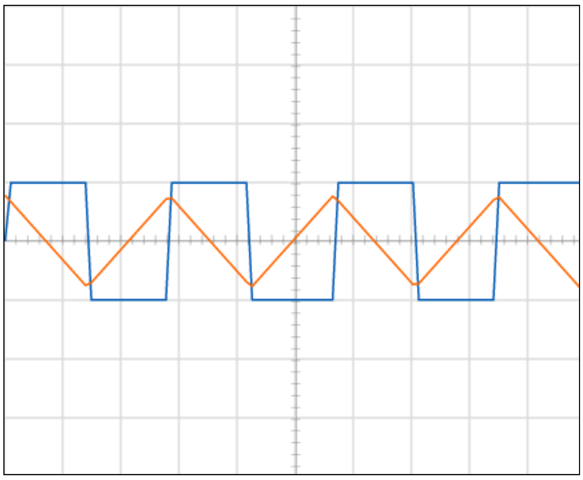
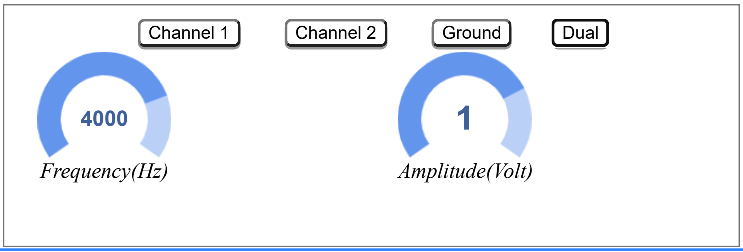
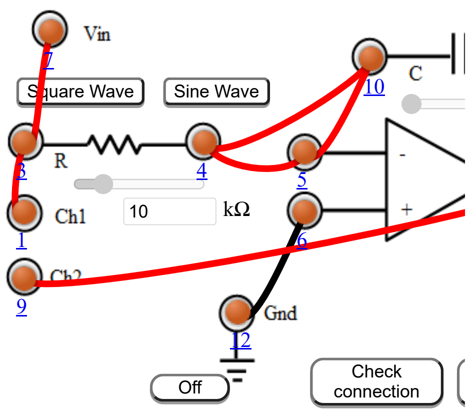




Virtual Oscilloscope Tutorial : [Virtual Oscilloscope Tutorial]

CIRCUIT



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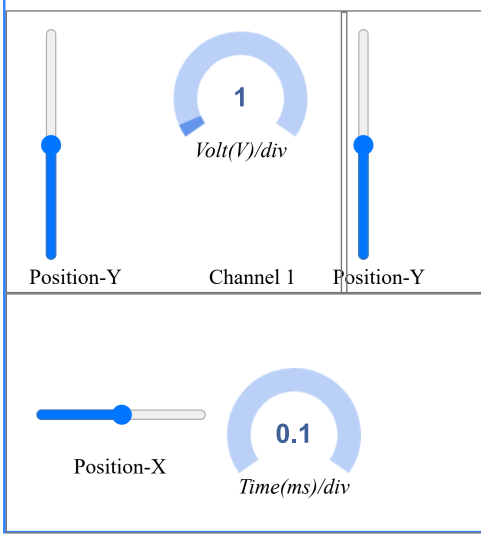

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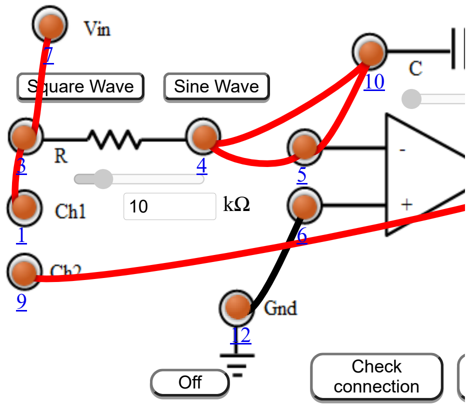
CIRCUIT



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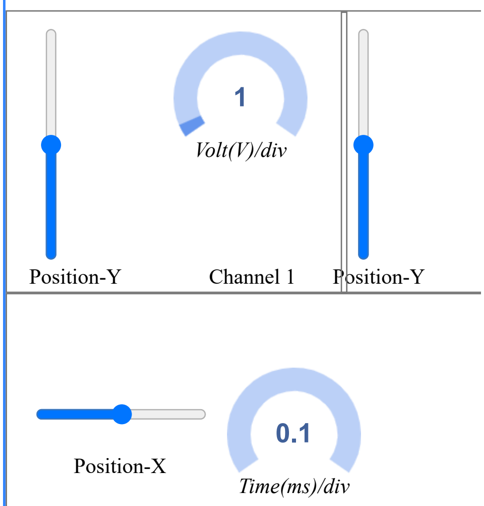

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Integrator using Opamp

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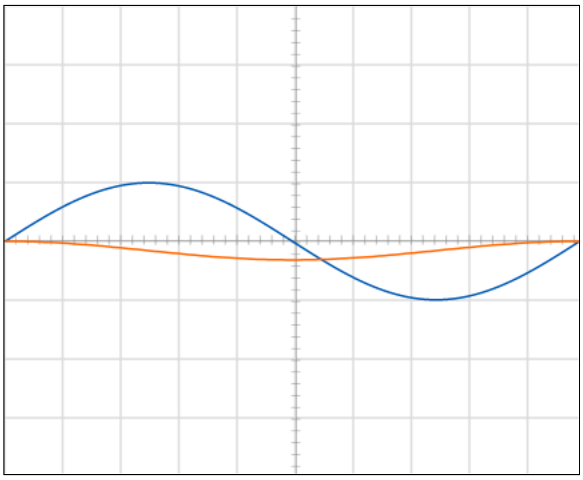

Channel 1 Channel 2 Ground Dual

1000
Frequency(Hz)

1
Amplitude(Volt)

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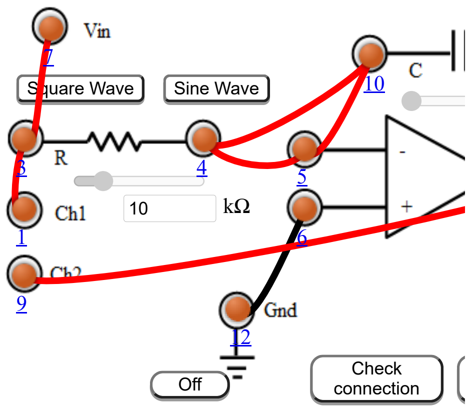
CIRCUIT



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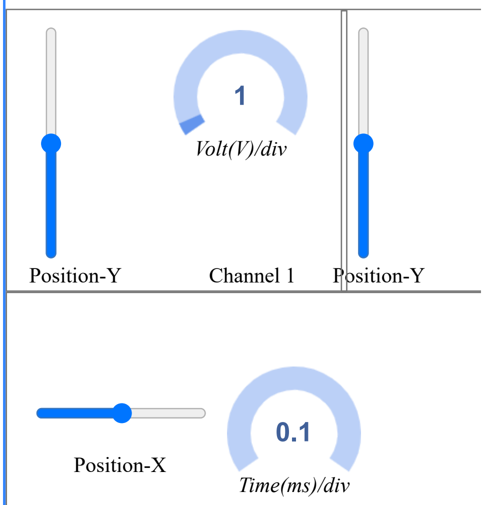

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Integrator using Opamp

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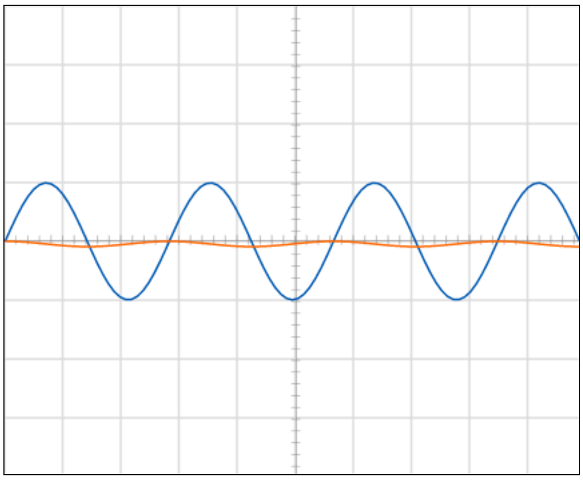

Channel 1 | Channel 2 | Ground | Dual

4000
Frequency(Hz)

1
Amplitude(Volt)

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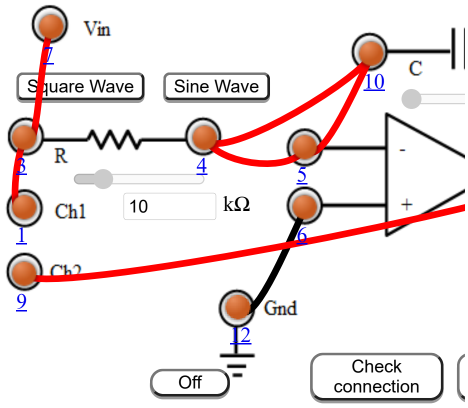
CIRCUIT



CONTROLS

Position-Y

1
Volt(V)/div

Channel 1

Position-Y

Position-X

0.1
Time(ms)/div

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Integrator using Opamp

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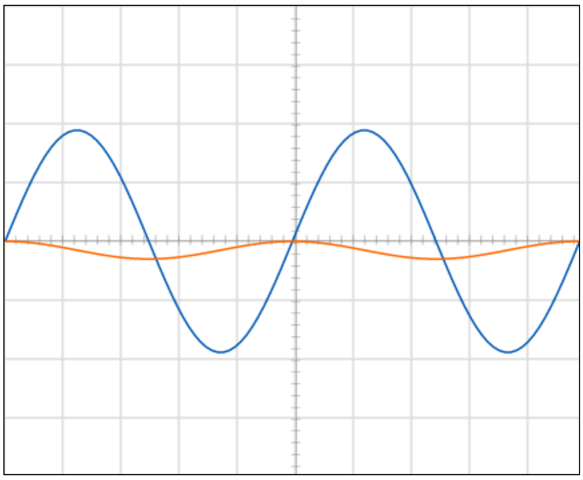

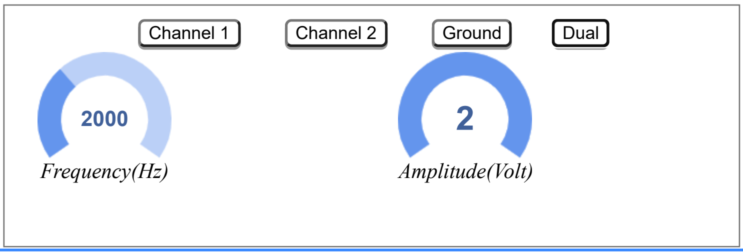

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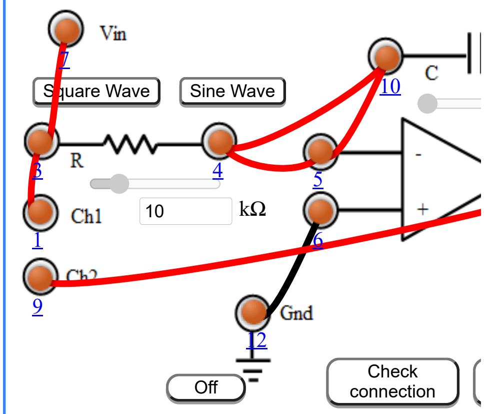
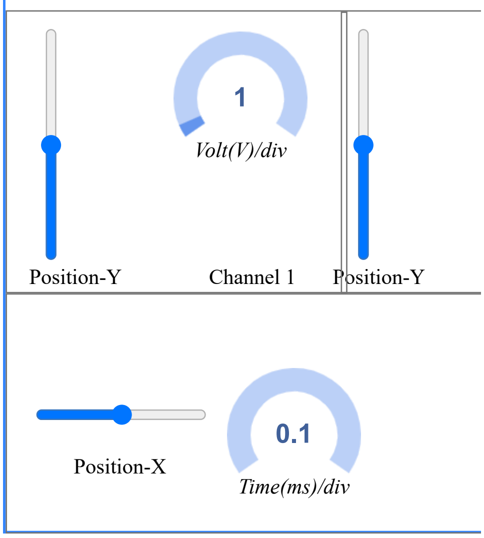
CIRCUIT



CONTROLS



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Differentiator using Opamp

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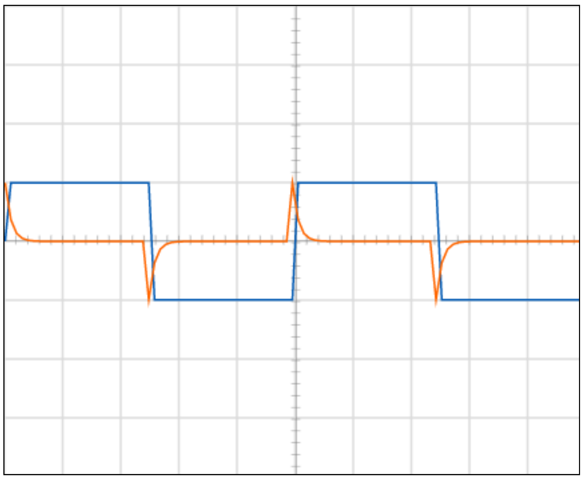


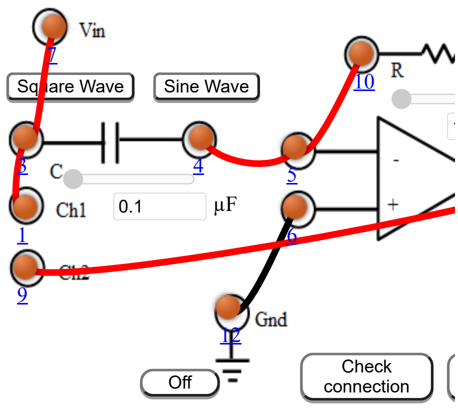
Channel 1 Channel 2 Ground Dual

2000
Frequency(Hz)

1
Amplitude(Volt)

Virtual Oscilloscope Tutorial : Virtual Oscilloscope Tutorial

CIRCUIT



CONTROLS

1
Volt(V)/div

Position-Y Channel 1 Position-Y

Position-X

0.1
Time(ms)/div

Differentiator using Opamp

INSTRUCTION

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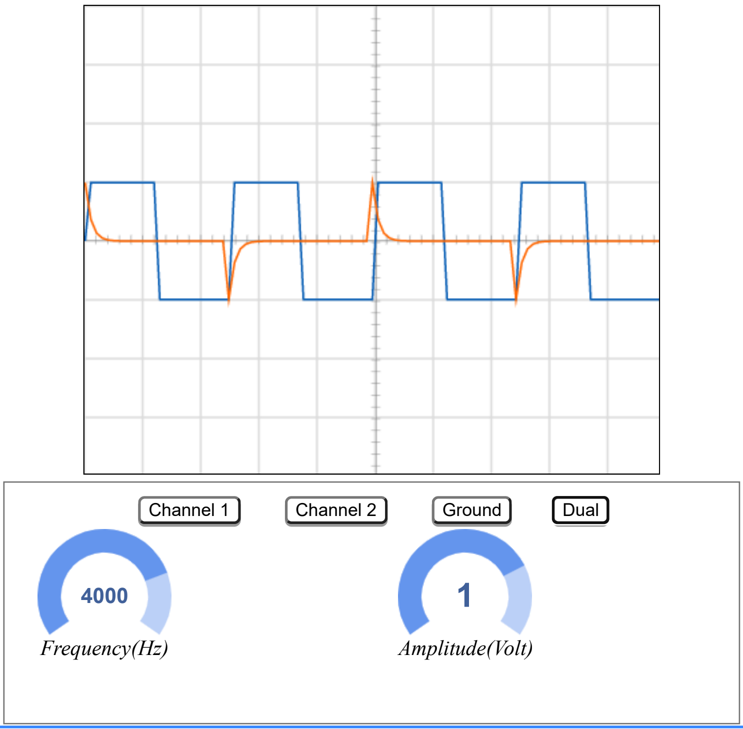
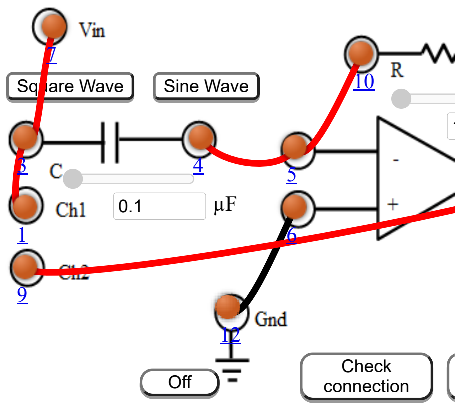
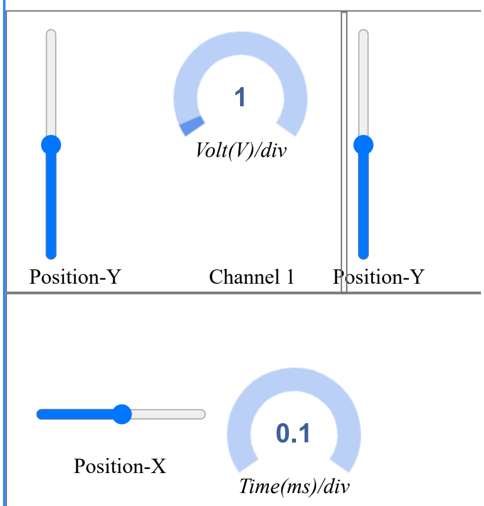


CIRCUIT



CONTROLS



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Differentiator using Opamp

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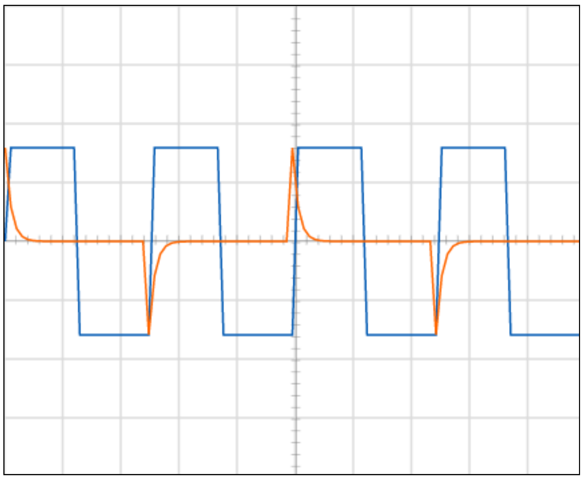


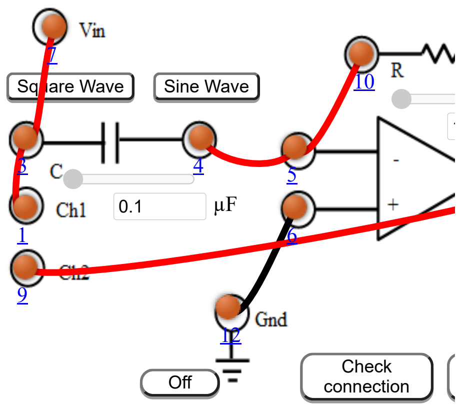
Channel 1 | Channel 2 | Ground | Dual

4000
Frequency(Hz)

1.9
Amplitude(Volt)

Virtual Oscilloscope Tutorial : Virtual Oscilloscope Tutorial

CIRCUIT



CONTROLS

1
Volt(V)/div

Position-Y
Channel 1
Position-Y

Position-X

0.1
Time(ms)/div

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Differentiator using Opamp

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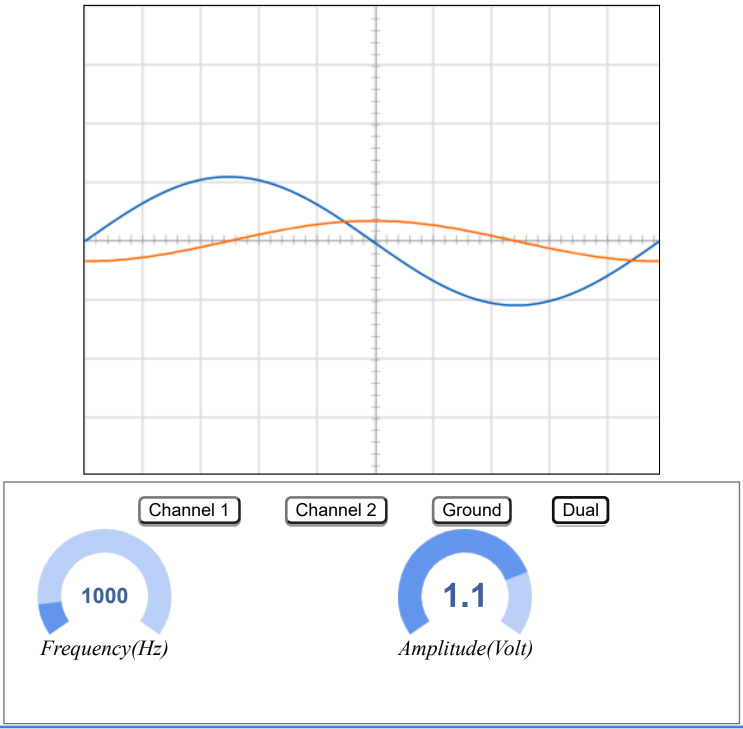

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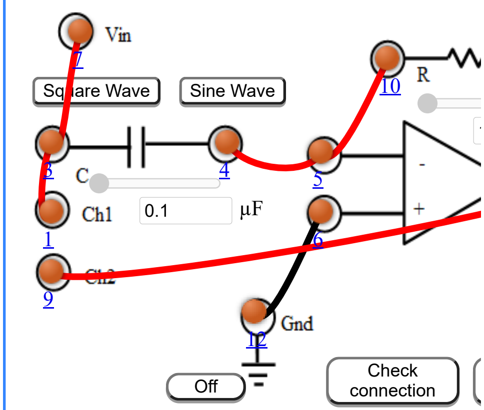
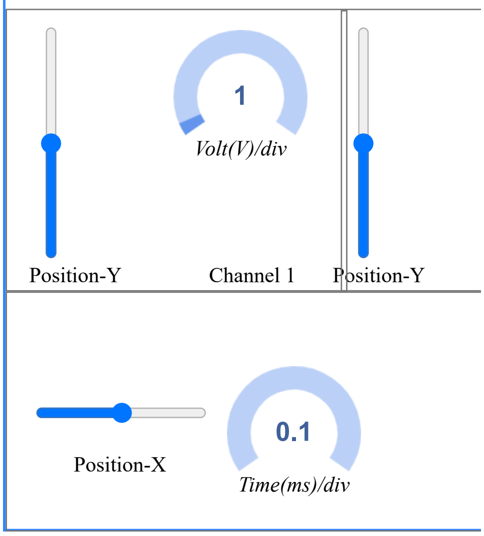
CIRCUIT



CONTROLS



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Differentiator using Opamp

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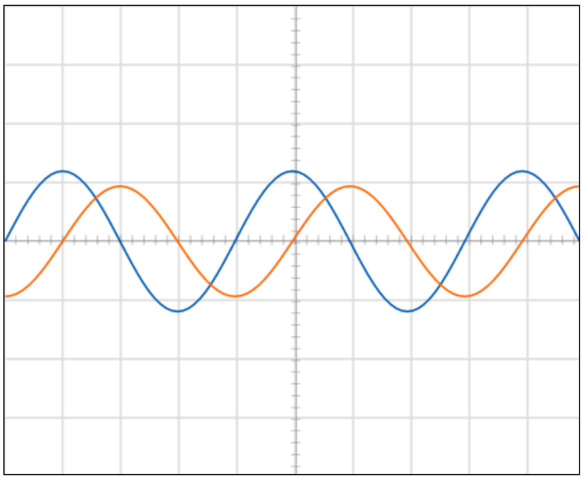


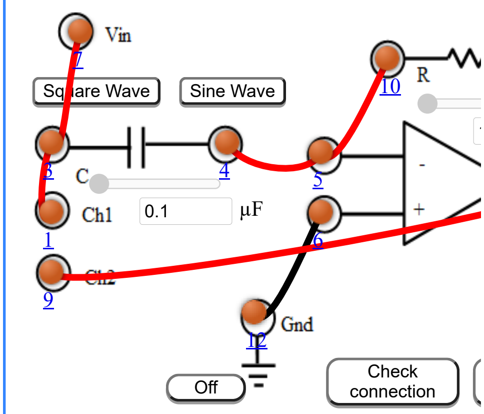
Channel 1 | Channel 2 | Ground | Dual

2500
Frequency(Hz)

1.1
Amplitude(Volt)

Virtual Oscilloscope Tutorial : [Virtual Oscilloscope Tutorial](#)

CIRCUIT



CONTROLS

Position-Y

1
Volt(V)/div

Channel 1

Position-Y

Position-X

0.1
Time(ms)/div

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Differentiator using Opamp

INSTRUCTION

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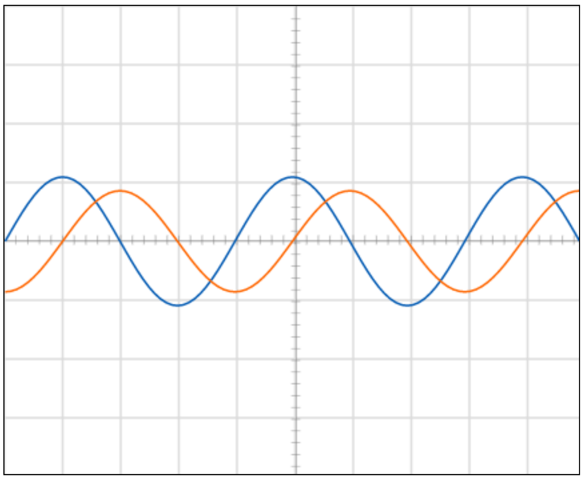

Channel 1 | Channel 2 | Ground | Dual

2500
Frequency(Hz)

2
Amplitude(Volt)

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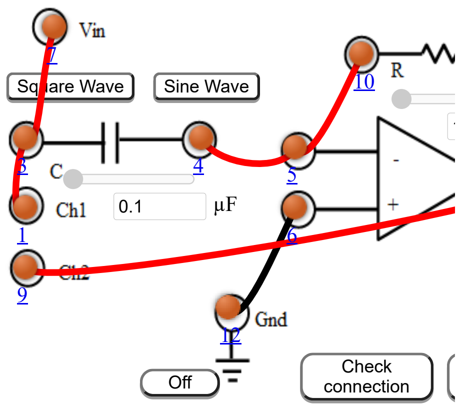
CIRCUIT



CONTROLS

1
Volt(V)/div

Position-Y
Channel 1
Position-Y

Position-X

0.1
Time(ms)/div

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Conclusion :- Performing the experiment, following conclusions can be drawn,

(i) An Op-Amp can be used to make an integrator or differentiator circuit.

(ii) The output waveform for Integrator Op-Amp circuit is

a) If input waveform is square wave; output is a triangular wave.

b) If input waveform is sine wave, output is a cosine wave.

(iii) The output waveform for Differentiator Op-Amp is

a) If input waveform is square wave, output is spikes.

b) If input waveform is sine wave, output is cosine wave.