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EC160: Experiment 8
RC Differentiator and Integrator

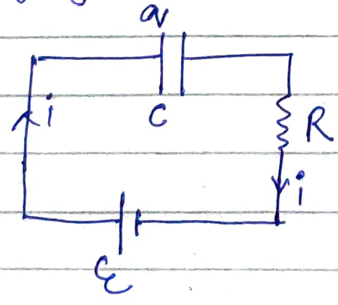
Objective:- i) to understand charging and discharging of RC circuit
(ii) to understand square wave response of RC circuit.
(iii) to understand RC circuit as integrator and differentiator.

Theory :-

Charging of a Capacitor

When a capacitor is connected to a battery, positive charge appears on one plate and negative charge on other. The potential difference between the plates ultimately becomes equal to emf of the battery. The whole process takes some time and during this time there is an electric current through the connecting wires and the battery.

A charging circuit of a capacitor is shown



Suppose a capacitor of capacitance C, a resistor R and a battery of emf $\mathcal{E}$ is connected as shown at $t=0$.

Name: Archit Agrawal
Student ID: 202052307

Suppose the charge on the capacitor and the current in the circuit are q and i respectively at time t.

$\therefore$ the potential drop across the capacitor is $\frac{q}{C}$

and across the resistor is iR.

also, charge deposited on capacitor plate in time dt is

$$dq = i\,dt$$

Using Kirchoff's Loop law,

$$\frac{q}{C} + Ri - \mathcal{E} = 0$$

$$R\frac{dq}{dt} = \varepsilon - \frac{q}{C}$$

$$\frac{dq}{\varepsilon C - q} = \frac{1}{RC}dt$$

Integrating using proper limits

$$\int_0^q \frac{dq}{\varepsilon C - q} = \int_0^t \frac{1\,dt}{CR}$$

After solving,

$$q = \varepsilon C\left(1 - e^{-t/RC}\right)$$

This gives charge on the capacitor at time t.

Also, the current i in the circuit at time t is,

$$i = \frac{dq}{dt} = \frac{\varepsilon}{R}e^{-t/RC}$$

Name: Archit Agrawal
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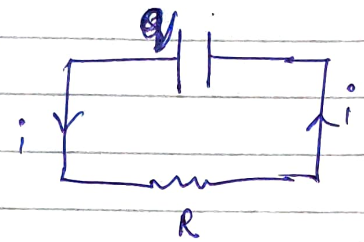
Discharging of Capacitor

If the plates of a charged capacitor are connected through a conducting wire, the capacitor gets discharged. Again there is a flow of charge through the wires and hence there is a current. Suppose a capacitor of capacitance C has a charge Q. At $t=0$, the plates are connected through a resistance R as shown



Let the charge on capacitor be q and current in the circuit be i at a time t.

Using Kirchoff's Loop law

$$\frac{q}{C} - Ri = 0$$

Here $i = -\frac{dq}{dt}$ because the charge q decreases as time passes,

Thus,

$$R\frac{dq}{dt} = -\frac{q}{C}$$

$$\frac{dq}{q} = -\frac{1}{CR}dt$$

$$\int_{Q}^{q}\frac{dq}{q} = \int_{0}^{t}\frac{-1}{CR}dt$$

Name: Archit Agrawal
Student ID: 202052307

$$\ln \frac{q}{Q} = \frac{-t}{CR}$$

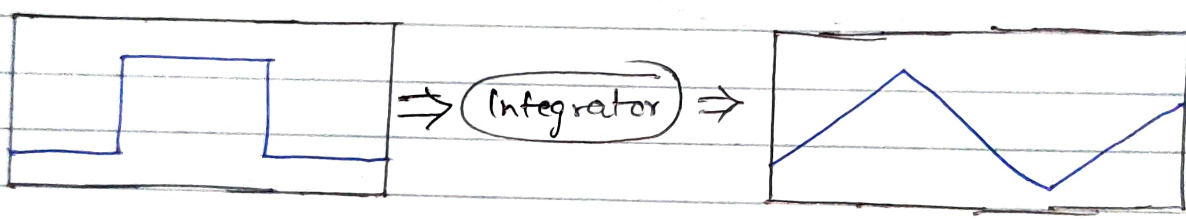
$$q = Q e^{-t/CR}$$

This gives the value of charge on capacitor at instant t.

$$i = -\frac{dq}{dt} = \frac{Q}{CR} e^{-t/CR}$$

This gives the value of current in the circuit at any instant t.

RC Integrator Circuit



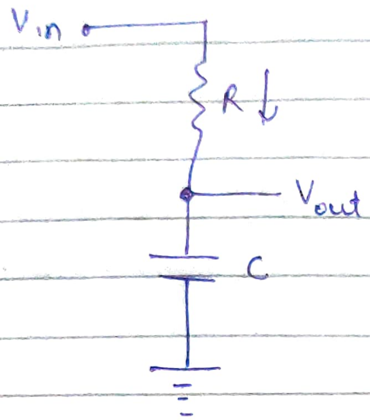
Integrator is a circuit that converts or 'integrates' a square wave input signal into triangular waveform output.

For a passive RC integrator circuit the input is connected to a resistance while the output voltage is taken from across a capacitor. The capacitor charges up when the input is high and discharges when the input is low.

If the signal is a sine wave, an RC integrator will simply acts as a simple low pass filter (LPF) above its cut-off point with the cut-off or corner frequency corresponding to the RC

Name: Archit Agrawal
Student ID: 202052307

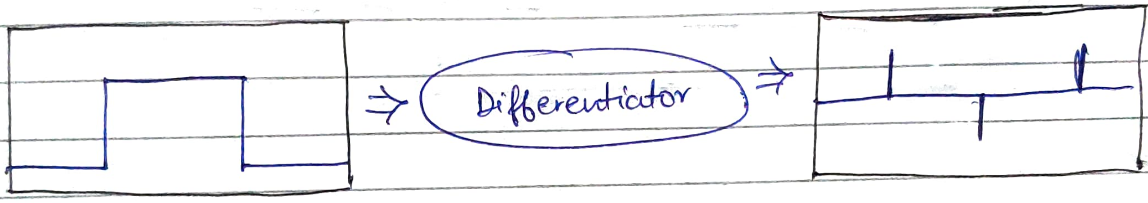
time constant (τ), thus reducing its output above the cut-off frequency point.



$$i_{c(t)} = C\frac{dv_{c(t)}}{dt}$$

$$V_{out} = V_c$$

RC Differentiator Circuit:-



The differentiator circuit convert a square wave input signal into high frequency spikes as its output.

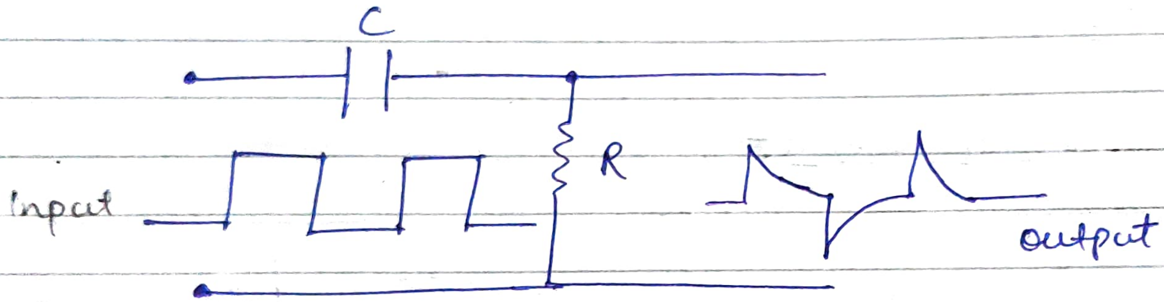
For a passive RC differentiator circuit, the input is connected to a capacitor while the output voltage is taken across a resistance being the exact opposite to RC integrator circuit.

A passive RC differentiator circuit is nothing more than a capacitance in series with a resistance, that is a frequency dependent device which has reactance in series with a fixed resistance.

Name: Archit Agrawal
Student ID: 202052307

At low input frequencies, the reactance X_c is high blocking any D.C voltage or slowly varying inputs. While at high frequencies, the capacitors reactance is low allowing rapidly varying pulses.

An RC differentiator will simply act as a simple High Pass Filter (HPF) with a cut-off or corner frequency corresponding to RC time constant (τ).



Procedure for the Experiment:-

For RC Integrator and Differentiator Circuit:-

Step 1: Set Resistance R = 10 kΩ and capacitance C = 0.1 uF.
Step 2: Click on 'ON' button to start the experiment.
Step 3: Click on 'square wave' button to generate the input waveform.
Step 4: Click on 'Oscilloscope' button to get the output waveform.
Step 5: Vary the amplitude, frequency and volt/div using controllers.

Name: Archit Agrawal
Student ID: 202052307

Step 6: Click on 'Dual' button to observe both the waveforms.
Channel 1 shows input waveform and Chanel 2 shows output waveform.

Step 7: Observe the waveforms for Integrator and Differentiator circuits.

Simulation Results

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RC Integrator

INSTRUCTION

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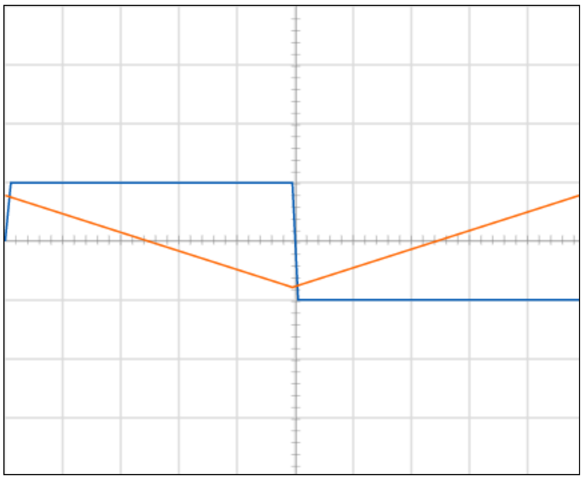


Channel 1 Channel 2 Ground Dual

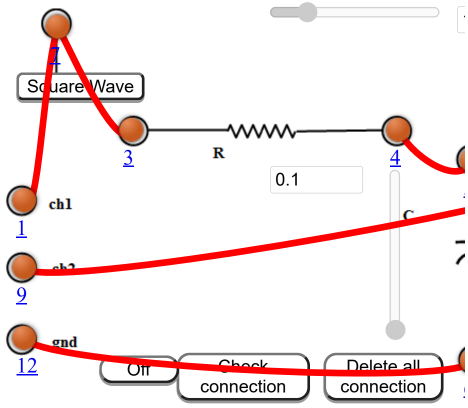
1000

Frequency(Hz)

1

Amplitude(Volt)

CIRCUIT



CONTROLS

μF

1

Volt(V)/div

Position-Y Channel 1 Position-Y

Position-X

0.1

Time(ms)/div

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RC Integrator

INSTRUCTION

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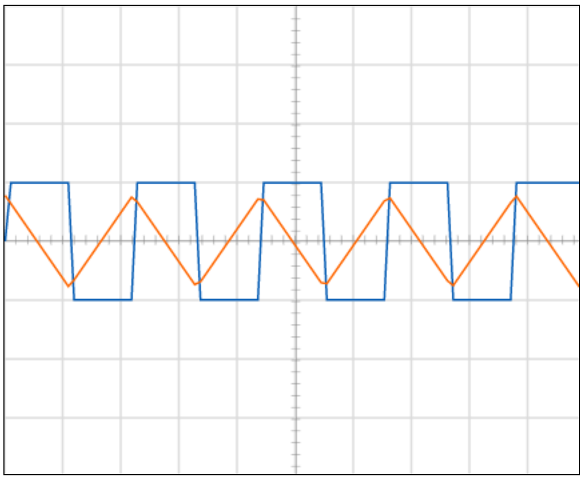
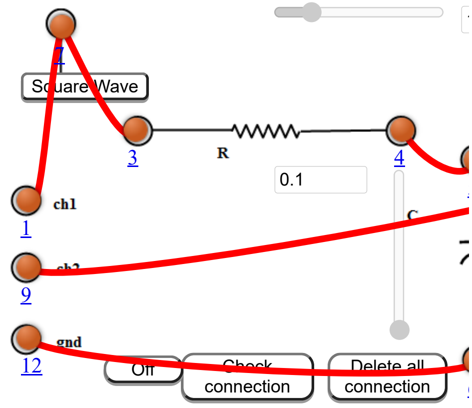


Channel 1 | Channel 2 | Ground | Dual

4500
Frequency(Hz)

1
Amplitude(Volt)

CIRCUIT



CONTROLS

μF

1
Volt(V)/div

Position-Y
Channel 1
Position-Y

Position-X

0.1
Time(ms)/div

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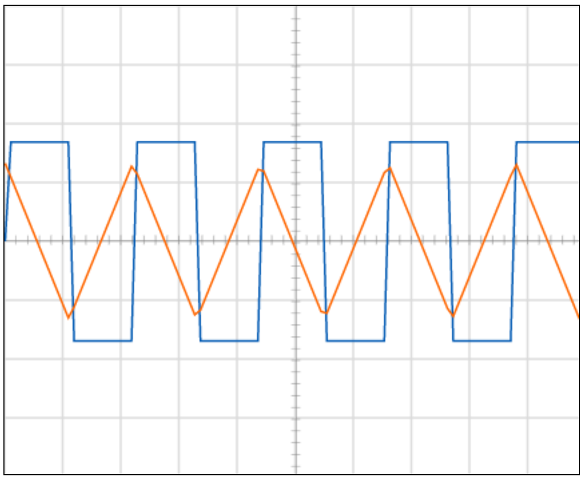
RC Integrator

INSTRUCTION

OSCILLOSCOPE

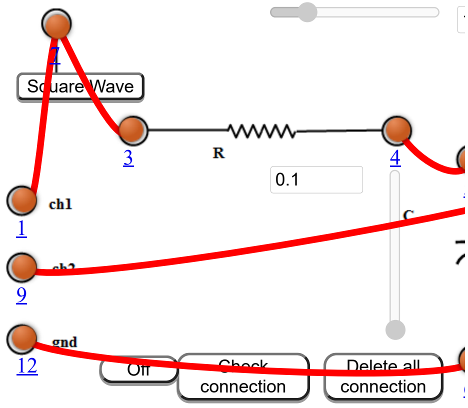


Channel 1 | Channel 2 | Ground | Dual

4500
Frequency(Hz)

2
Amplitude(Volt)

CIRCUIT



CONTROLS

μF

1
Volt(V)/div

Position-Y
Channel 1
Position-Y

Position-X
0.1
Time(ms)/div

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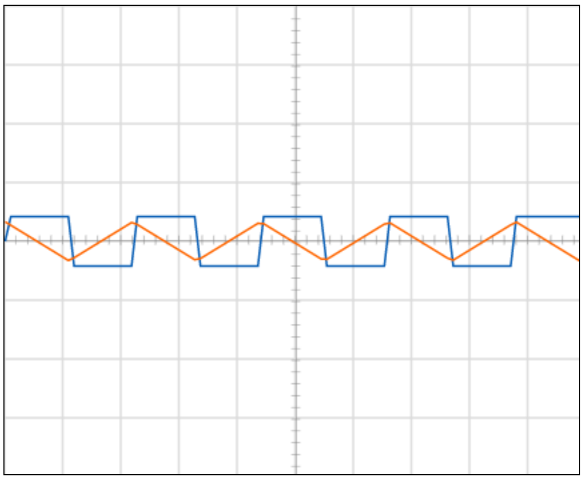
RC Integrator

INSTRUCTION

OSCILLOSCOPE

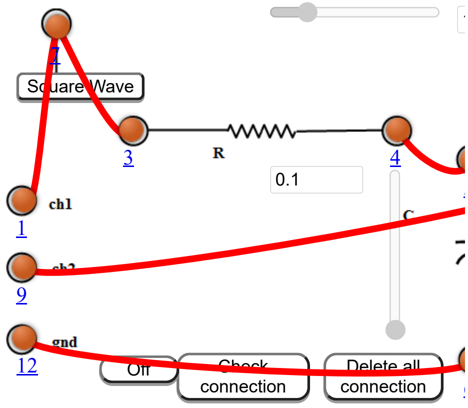


Channel 1 | Channel 2 | Ground | Dual

4500
Frequency(Hz)

2
Amplitude(Volt)

CIRCUIT



CONTROLS

μF

1.2
Volt(V)/div

Position-Y | Channel 1 | Position-Y

Position-X

0.1
Time(ms)/div

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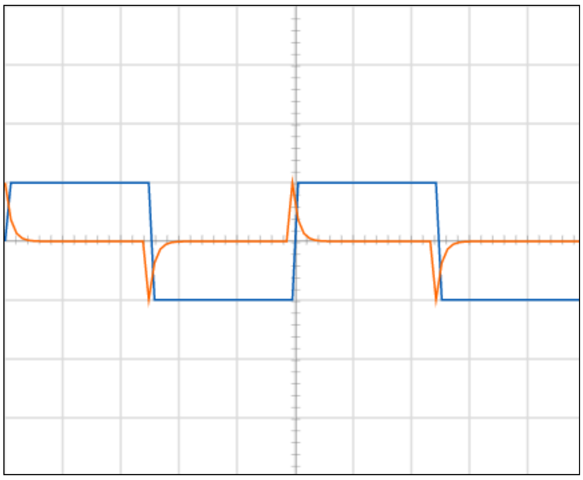
RC Differentiator

INSTRUCTION

OSCILLOSCOPE

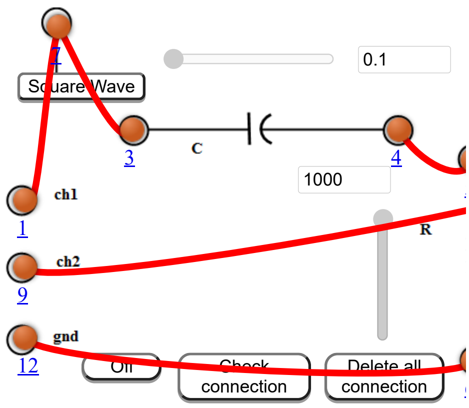


Channel 1 | Channel 2 | Ground | Dual

2000
Frequency(Hz)

1
Amplitude(Volt)

CIRCUIT



CONTROLS

ohn

1
Volt(V)/div

Position-Y Channel 1 Position-Y

Position-X

0.1
Time(ms)/div

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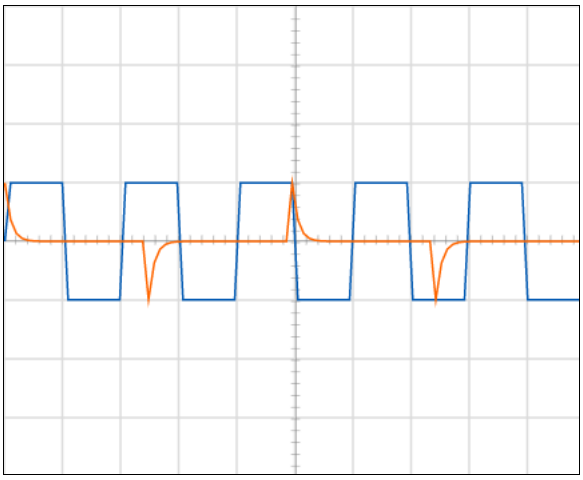
RC Differentiator

INSTRUCTION

OSCILLOSCOPE

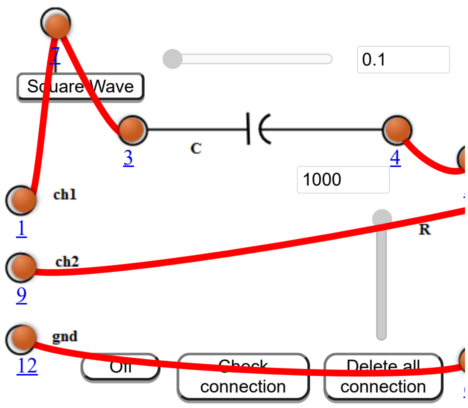


Channel 1 Channel 2 Ground Dual

5000
Frequency(Hz)

1
Amplitude(Volt)

CIRCUIT



CONTROLS

ohm

1
Volt(V)/div

Position-Y Channel 1 Position-Y

Position-X

0.1
Time(ms)/div

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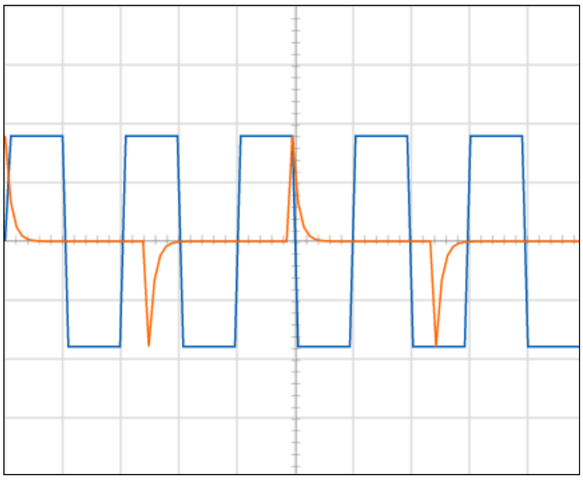
RC Differentiator

INSTRUCTION

OSCILLOSCOPE

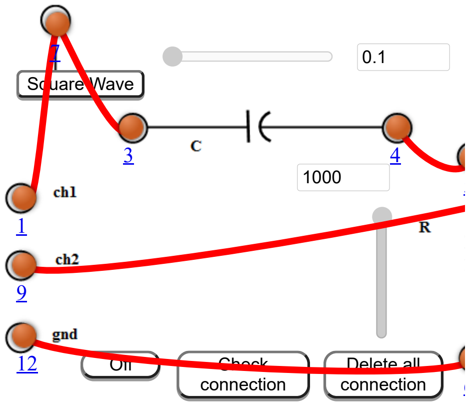


Channel 1 Channel 2 Ground Dual

5000
Frequency(Hz)

2
Amplitude(Volt)

CIRCUIT



CONTROLS

ohn

1
Volt(V)/div

Position-Y Channel 1 Position-Y

Position-X

0.1
Time(ms)/div

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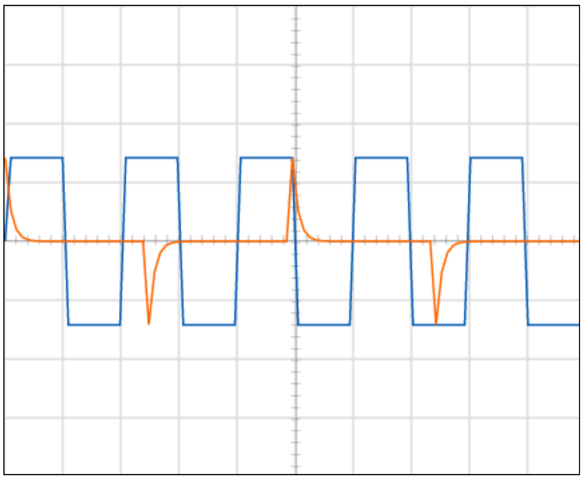
RC Differentiator

INSTRUCTION

OSCILLOSCOPE

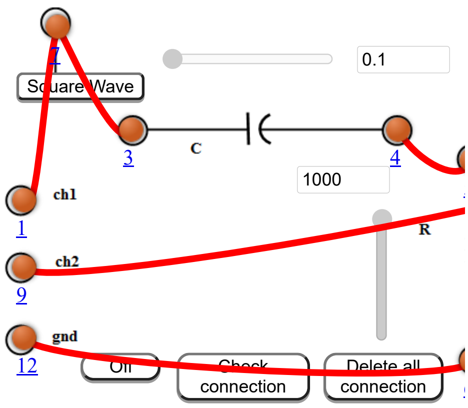


Channel 1 Channel 2 Ground Dual

5000
Frequency(Hz)

2
Amplitude(Volt)

CIRCUIT



CONTROLS

ohn

2.6
Volt(V)/div

Position-Y Channel 1 Position-Y

Position-X

0.1
Time(ms)/div

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Conclusion :- Performing the experiment, we can draw following conclusions -

(i) A RC integrator circuit converts a square wave into a triangular wave as output.
(ii) A RC differentiator circuit converts a square wave into high frequency spikes as output.
(iii) The procedure that how an RC integrator and RC differentiator circuit works.

Quiz Performance

RC Differentiator and Integrator

THEORY (#) PROCEDURE (#) OSCILLOSCOPE TUTORIAL (#) SIMULATION (#) QUIZ (#) REFERENCES (#)

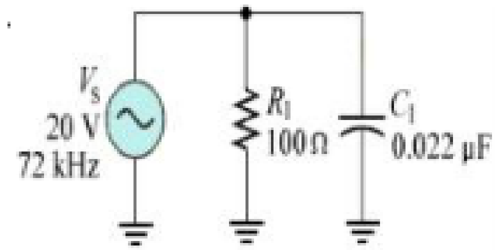
Quiz

Test Your Knowledge!!

✓ 1. Which statement about a series RC circuit is true?

- The capacitor's voltage drop is in phase with the resistor's voltage drop
- The current leads the source voltage
- The current lags the source voltage
- The resistor voltage lags the current

✓ 2. If the frequency increases in the given circuit, how would the total current change?



- The total current would increase
- The total current would decrease
- The total current would remain the same
- More information is needed in order to predict how the total current would change

✓ 3. What is the effect of increasing the resistance in a series RC circuit?

- There will be no effect at all
- The current will increase
- The input voltage will increase
- The phase shift will decrease

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