Name	S.S.S.Vardhan
Roll Number	19CH30018

Experiment - 2

RC Frequency Response

Objectives

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

- Explain RC Voltage Dividers
- Explain RC Circuit as a Low Pass Filter
- Explain RC Circuit as a High Pass Filter

Apparatus

S.No.	Apparatus	Range	Type	Quantity
1	Resistor	0.1kΩ - 10kΩ		1
2	Capacitor	0.01nF - 50nF		1
3	Voltage Source	2 - 10V	AC	1
4	Voltmeter	2 - 10V	Moving Coil	1

Theory

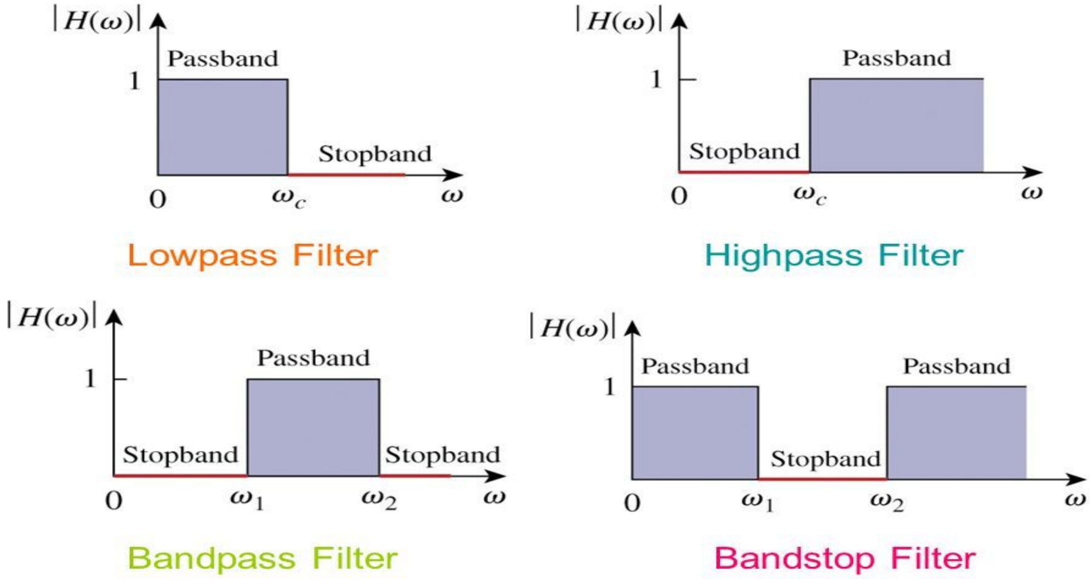
In electronic circuits systems it is often helpful to separate a specific range of frequencies from the total spectrum. A filter is a type of circuit that passes a specific range of frequencies while rejecting other frequencies. A passive filter consists of passive circuit elements, such as capacitors, inductors and resistors.There are four basic types of filters :

1. Low-pass filter : It is designed so as to pass all frequencies below the cut-off frequency and reject all other frequencies above the cut-off frequency(fc)

2. High-pass filter : It is designed so as to pass all frequencies above the cut-off frequency and reject all other frequencies above the cut-off frequency(fc)

3. Band-pass filter: It passes all the frequencies within a band of frequencies and rejects all other frequencies outside the band.

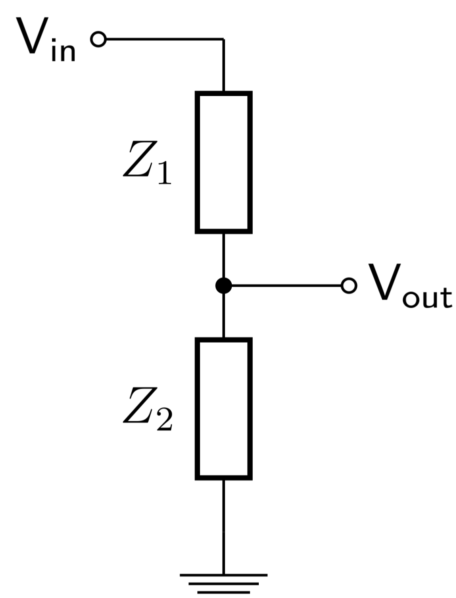
4. Band-stop filter: It ranges all the frequencies within a band of frequencies and rejects all other frequencies outside the band.



In this lab we will explore the low and high-pass filter

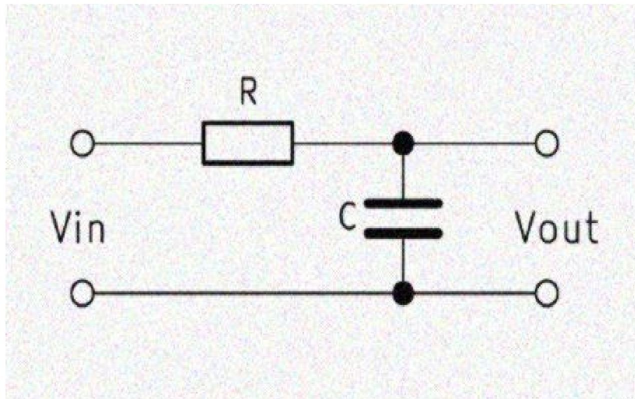
RC as Voltage Dividers

A voltage divider (also known as a potential divider) is a passive linear circuit that produces an output voltage (Vout) that is a fraction of its input voltage (Vin). Voltage division is the result of distributing the input voltage among the components of the divider.
Resistor voltage dividers are commonly used to create reference voltages, or to reduce the magnitude of a voltage so it can be measured, and may also be used as signal attenuators at low frequencies. For direct current and relatively low frequencies, a voltage divider may be sufficiently accurate if made only of resistors



RC as Low Pass filter

A low-pass filter (LPF) is a filter that passes signals with a frequency lower than a selected cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency. The exact frequency response of the filter depends on the filter design. A low-pass filter is the complement of a high-pass filter.

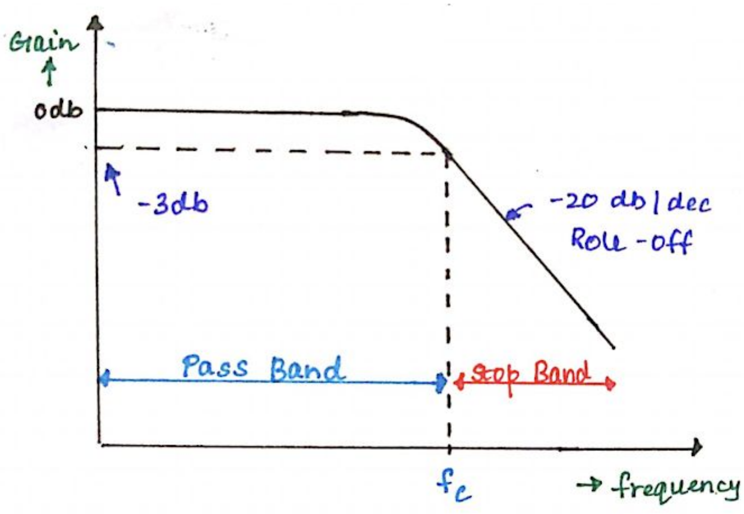


Low Pass Filter

The capacitor exhibits reactance, and blocks low-frequency signals, forcing them through the load instead. At higher frequencies the reactance drops, and the capacitor effectively functions as a short circuit.

This circuit may be understood by considering the time the capacitor needs to charge or discharge through the resistor:

- At low frequencies, there is plenty of time for the capacitor to charge up to practically the same voltage as the input voltage.
- At high frequencies, the capacitor only has time to charge up a small amount before the input switches direction. The output goes up and down only a small fraction of the amount the input goes up and down.



Frequency Response of a LPF

Cutoff frequency

A cutoff frequency, corner frequency, or break frequency is a boundary in a system's frequency response at which energy flowing through the system begins to be reduced (attenuated or reflected) rather than passing through. Typically in electronic systems such as filters and communication channels, cutoff frequency applies to an edge in a lowpass, highpass, bandpass, or band-stop characteristic - a frequency characterizing a boundary between a passband and a stopband. From a graph we can find the cutoff frequency by finding the frequency where the magnitude of the output voltage is 70.7% off from the maximum value. In another way, the frequency when the signal magnitude is Vpp/sqrt(2). It can also be calculated from the R and C values as-

$$f_c = \frac{1}{2\pi R C}$$

fc - Cut-off Frequency (in Hz)
R - Resistance of the circuit (in Ω)
C - Capacitance (in F)

Low-Pass Filter Phase Shift

Each reactive element in a circuit introduces 90° of phase shift, but this phase shift does not happen all at once. The phase of the output signal, just like the magnitude of the output signal, changes gradually as the input frequency increases. In an RC low-pass filter, we have one reactive element i.e. the capacitor, and consequently the circuit will eventually introduce 90° of. phase shift

$$X_c = \frac{1}{2\pi f C}$$

$$Z = \sqrt{R^2 + X_c^2}$$

$$\text{Magnitude} = 20 \log \frac{X_c}{Z}$$

$$V_{out} = V_{in} \left(\frac{X_c}{Z} \right)$$

$$\phi = \tan^{-1} \left(\frac{1}{2\pi f RC} \right)$$

$f_c \rightarrow$ Cut - off frequency (in Hz)

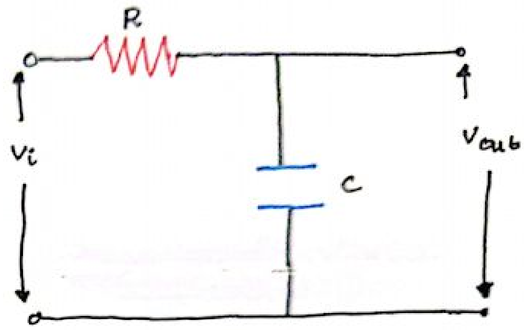
$X_c \rightarrow$ Capactive Reactance (in Ω)

$V_{in} \rightarrow$ Input Voltage (in V)

$V_{out} \rightarrow$ Output Voltage (in V)

$f \rightarrow$ frequency of circuit (in Hz)

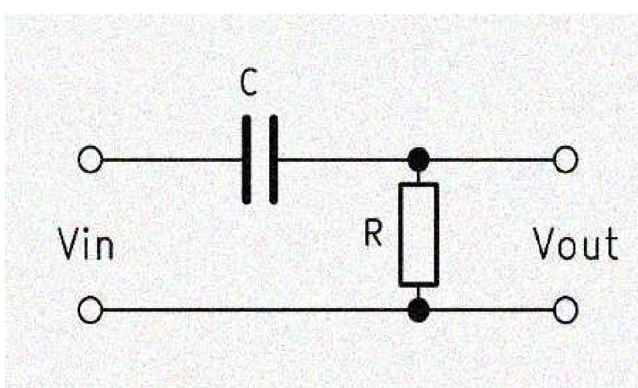
Low - Pass Filter



$$f_c = \frac{1}{2\pi RC}$$

High pass filter

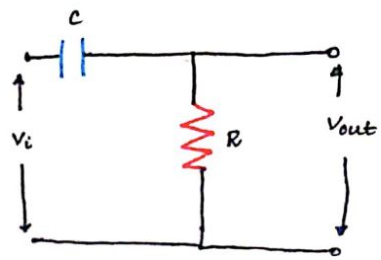
A high-pass filter (HPF) is an electronic filter that passes signals with a frequency higher than a certain cutoff frequency and attenuates signals with frequencies lower than the cutoff frequency. The amount of attenuation for each frequency depends on the filter design. A high-pass filter is usually modeled as a linear time-invariant system.



High Pass Filter

In this circuit, the reactance of the capacitor is very high at low frequencies so the capacitor acts like an open circuit and blocks any input signals at (Vin) until the cut-off frequency point (fC) is reached. Above this cut-off frequency point the reactance of the capacitor has reduced sufficiently as to now act more like a short circuit allowing all of the input signal to pass directly to the output

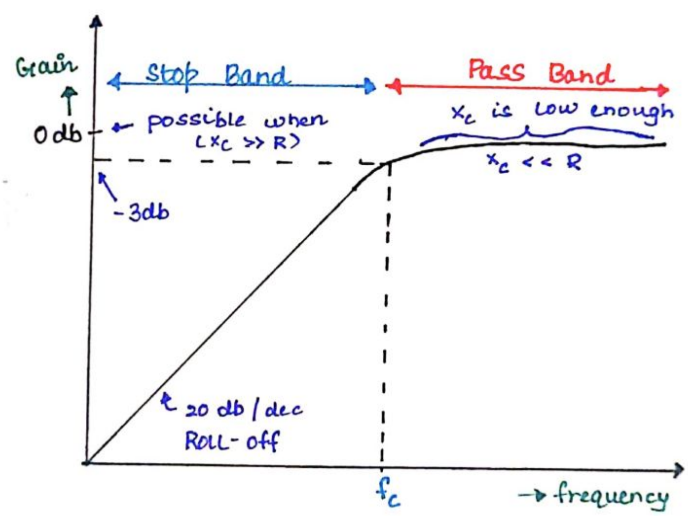
$$|H| = \left| \frac{R}{R + jX_c} \right| = \left| \frac{R}{R + \frac{j}{\omega C}} \right|$$



$$\boxed{|H| = \frac{R\omega C}{\sqrt{1 + \omega^2 C^2 R^2}}} \quad ---- \; (1)$$

where $H = \frac{V_{out}}{V_{in}}$

Thus, it is clear from equation (1) that with increase in frequency Vout also increases.

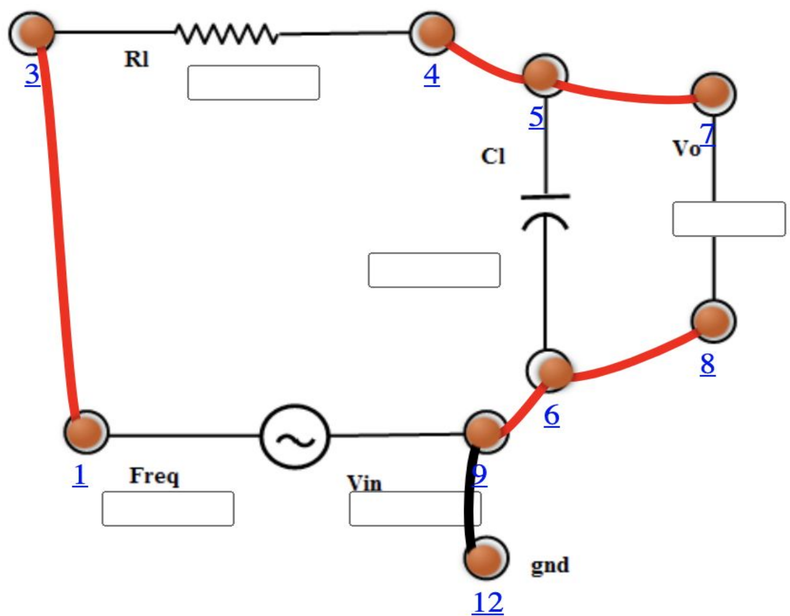


$$\boxed{Gain = 20 \log_{10} \left(\frac{V_o}{V_i} \right)}$$

Thus from this equation we can conclude, gain will be zero only when $X_c >> R$

Circuit Diagrams:

Low Pass Filter



High Pass Filter

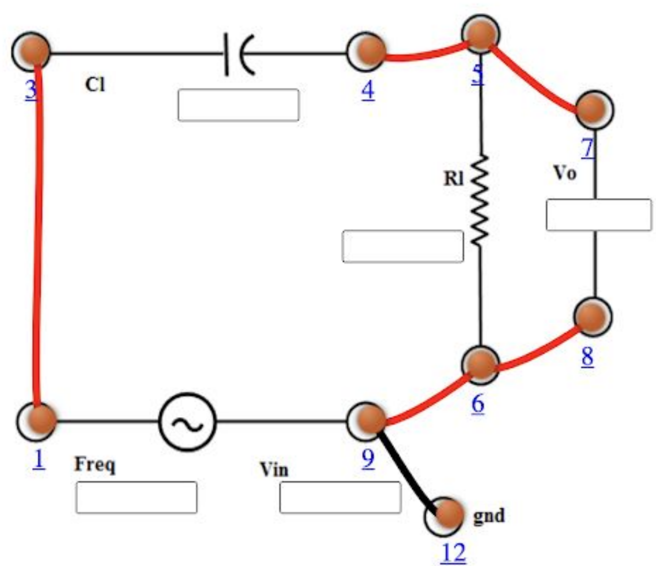
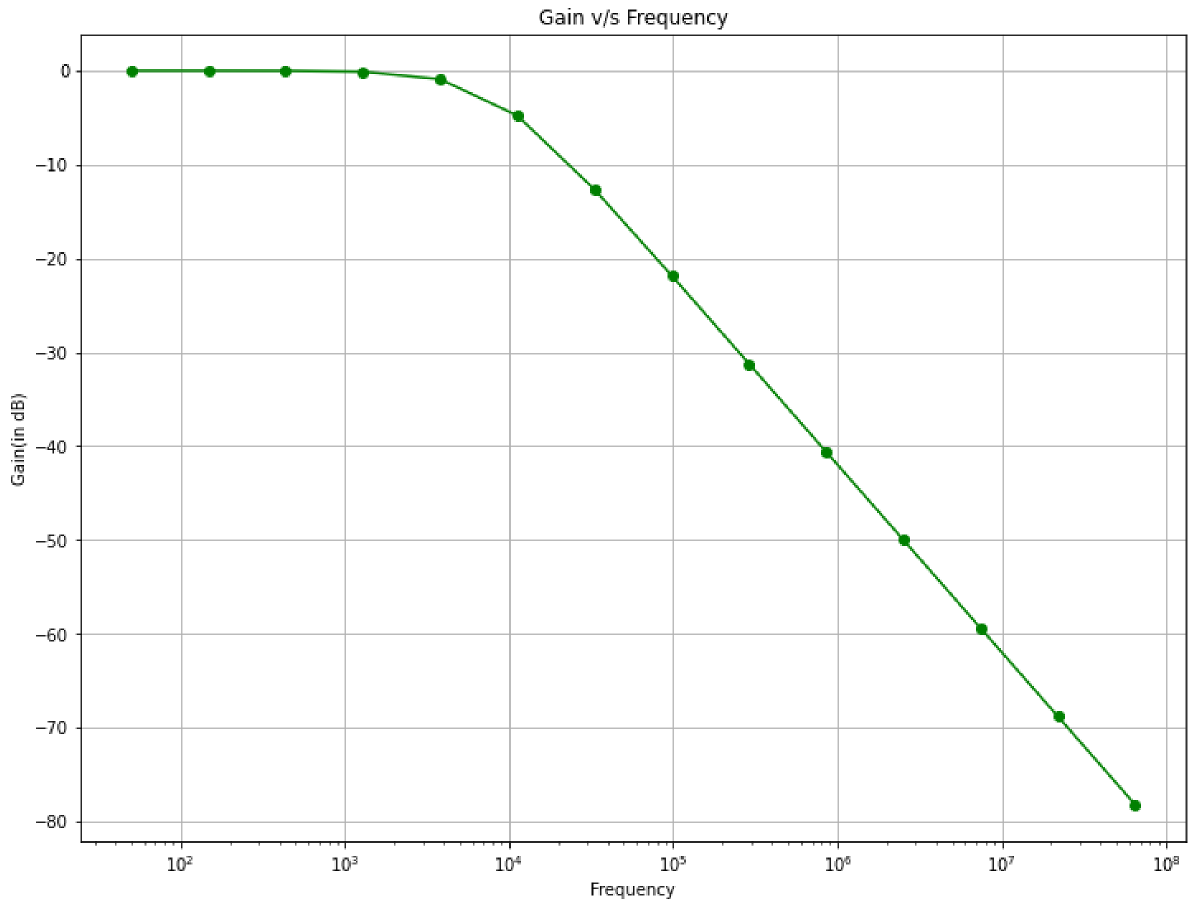


Table:
Low Pass Filter

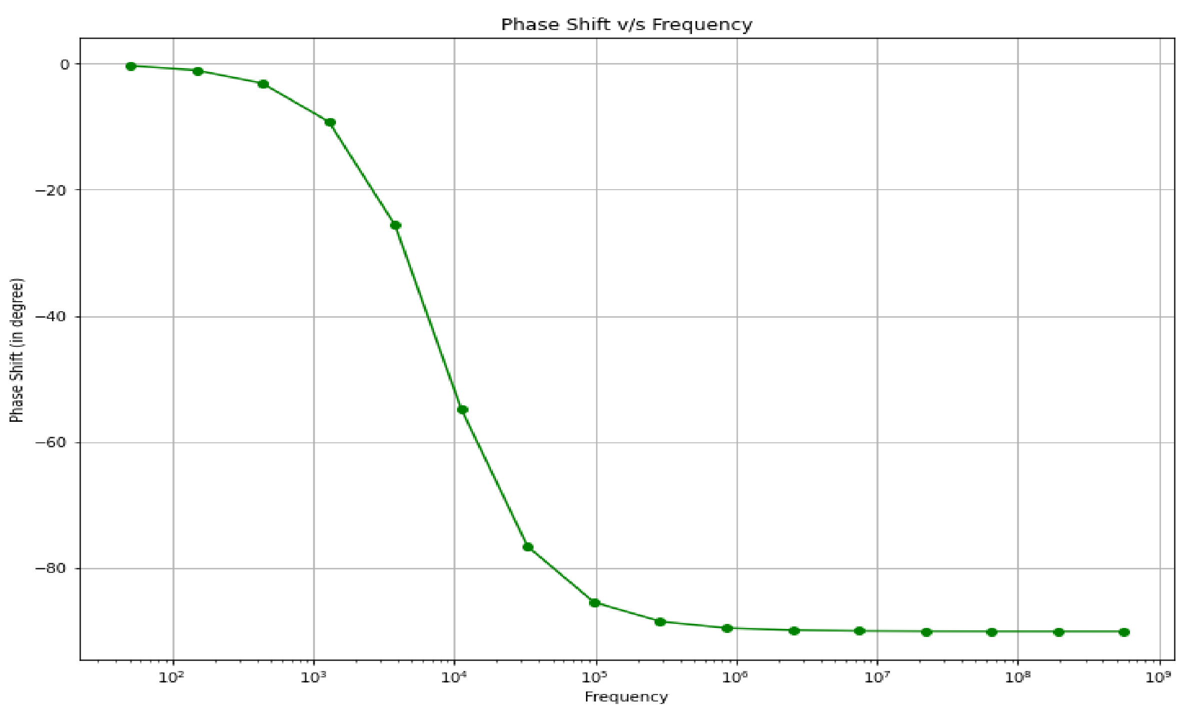
Serial No.	Frequency(Hz)	Magnitude(dB)	Phase(theta)	Output Voltage(V)
1	50	-0.00017	-0.362728	9.9998
2	149	-0.00151	-1.07038	9.9983
3	438	-0.01317	-3.15608	9.9848
4	1294	-0.11339	-9.24273	9.8703
5	3818	-0.90047	-25.6541	9.0152
6	11267	-4.78094	-54.8087	5.7670
7	33252	-12.6665	-76.5866	2.3263
8	98134	-21.8534	-85.4096	0.80786
9	289614	-31.2282	-88.4717	0.27453
10	854713	-40.6252	-89.5122	0.093054
11	2522440	-50.0250	-89.8649	0.031532
12	7444240	-59.4248	-89.9844	0.010685
13	21969500	-68.8248	-90.0249	0.0036204
14	64836600	-78.2248	-90.0386	0.0012267
15	191346000	-87.6248	-90.0433	0.00041568
16	564703000	-97.0248	-90.0448	0.00014085

Resistance = 2000 Ω
Capacitance = 10.01 nF
Vin = 10 V

Graph :



Gain v/s Frequency
Gain(in dB)
Frequency
0
−10
−20
−30
−40
−50
−60
−70
−80
10^2
10^3
10^4
10^5
10^6
10^7
10^8



Phase Shift v/s Frequency
Phase Shift (in degree)
Frequency
0
−20
−40
−60
−80
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9

Discussion

$R = 2000\,\Omega$

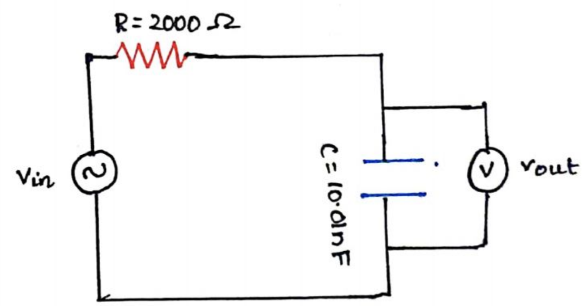
$C = 10.01\,nF$

WKT, $f_c = \dfrac{1}{2\pi R C}$

$\Rightarrow f_c = \dfrac{10^9}{2\pi \times 2 \times 10^3 \times 10.01}$

$\therefore f_c = 7949.797\ Hz$

$\therefore f_c = 7.9498kHz$



The capacitor exhibits reactance, and blocks low-frequency signals, forcing them through the load instead. At higher frequencies the reactance drops, and the capacitor effectively functions as a short circuit.
This circuit may be understood by considering the time the capacitor needs to charge or discharge through the resistor:

- At low frequencies, there is plenty of time for the capacitor to charge up to practically the same voltage as the input voltage.
- At high frequencies, the capacitor only has time to charge up a small amount before the input switches direction. The output goes up and down only a small fraction of the amount the input goes up and down.

Conclusion :

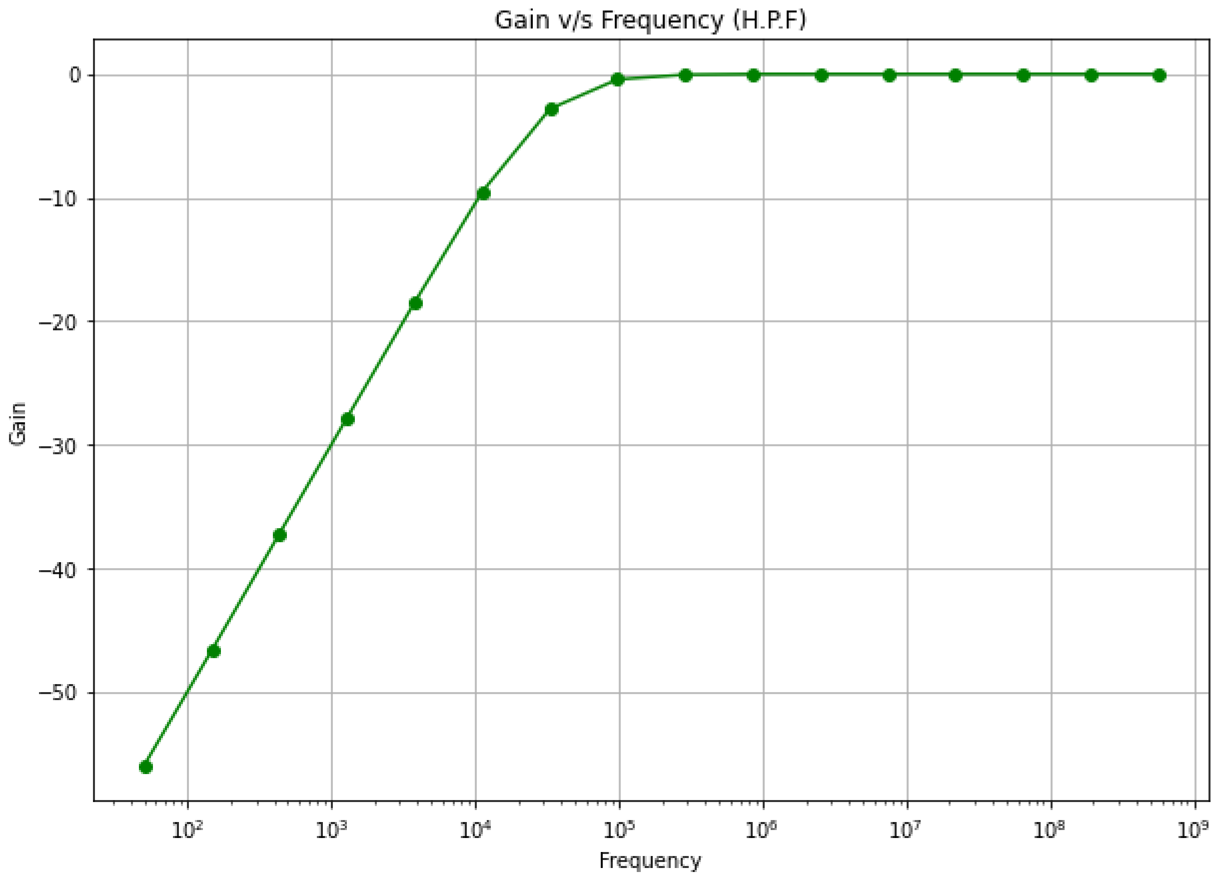
- Low pass filter pass the signals with low frequency and attenuate the signals with high frequency the voltage gain
- The voltage gain at well below the cutoff frequency is approximately equal to 1
- Frequencies at well about the cutoff the dB per decade rolling decreases by 20 dB per decade per increase in frequency
- The phase of low pass between the input and output change is 90 degrees over the frequency range and 45 degrees at the cut-off frequency
- If their assistance of capacitance changes the cutoff frequency also changes. Cutoff frequency is inversely proportional to resistance and capacitance.
- Role off remains constant even though there is change in capacitance or resistance.

Table
High Pass Filter

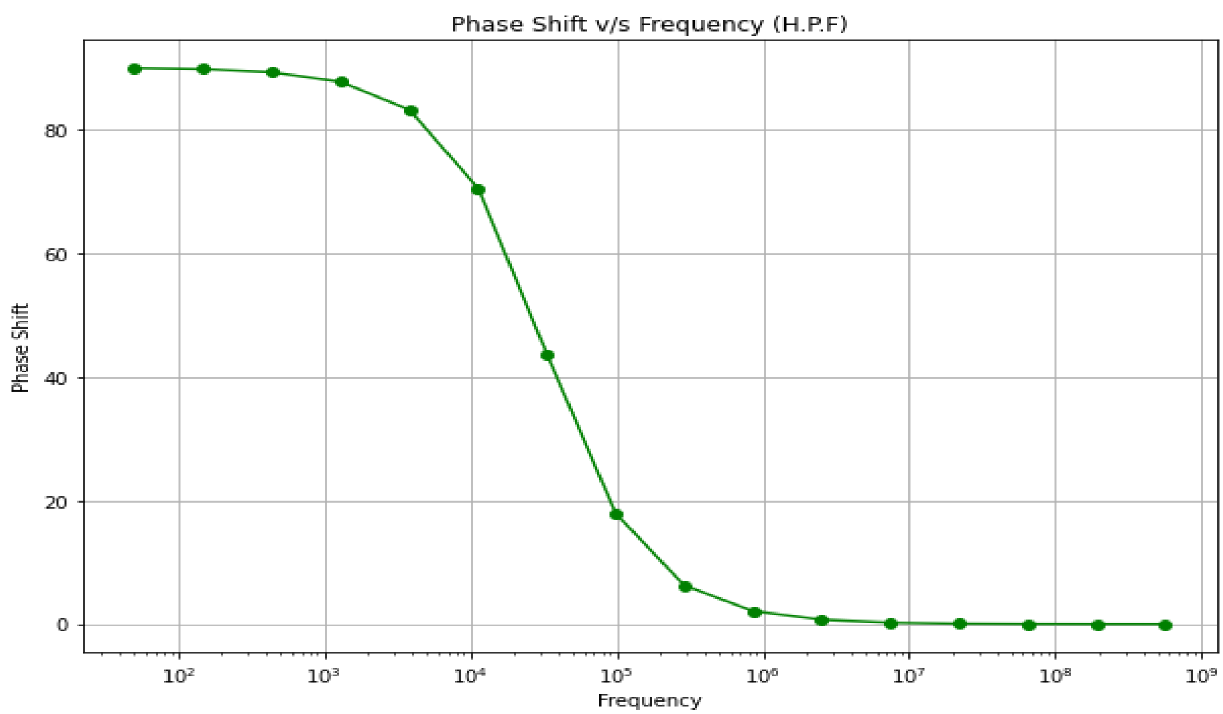
Serial No.	Frequency(Hz)	Magnitude(dB)	Phase(theta)	Output Voltage(V)
1	50	-56.0076	89.9549	0.0079175
2	149	-46.6078	89.7778	0.023366
3	438	-37.2084	89.2551	0.068952
4	1294	-27.8148	87.7137	0.20334
5	3818	-18.46986	83.1926	0.59632
6	11267	-9.52176	70.5163	1.6706
7	33252	-2.81856	43.7285	3.6145
8	98134	-0.43322	17.9551	4.7567
9	289614	-0.05199	6.26602	4.9702
10	854713	-0.00600	2.13071	4.9965
11	2522440	-0.000698	0.722273	4.9996
12	7444240	-0.000079	0.244750	5.0000
13	21969500	-0.0000091	0.0829325	5.0000
14	64836600	-0.0000011	0.0281012	5.0000
15	191346000	-1.19826e-7	0.00952195	5.0000
16	564703000	-1.375782e-8	0.00322645	5.0000

Resistance: 1000 Ω
Capacitance: 5.01nF
Voltage: 5V

Graph



Gain v/s Frequency (H.P.F)
0
−10
−20
−30
−40
−50
Gain
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
Frequency



Phase Shift v/s Frequency (H.P.F)
80
60
40
20
0
Phase Shift
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
Frequency

Discussion

$R = 1000\,\Omega$

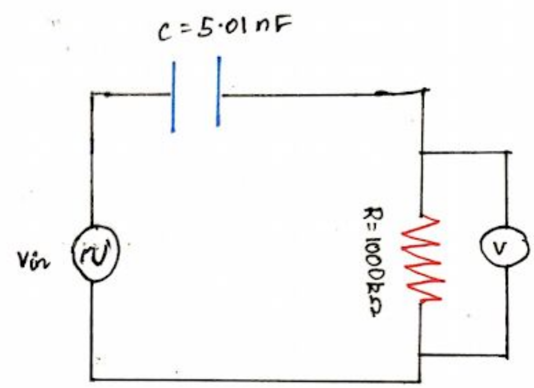
$C = 5{\cdot}01\,nF$

WKT, $f_c = \dfrac{1}{2\pi RC}$

$$\Rightarrow f_c = \frac{10^9}{2\pi \times 10^3 \times 5{\cdot}01}$$

$$= 31767.44\ Hz$$

$$\therefore f_c = 31{\cdot}767\ kHz$$



In this circuit, the reactance of the capacitor is very high at low frequencies so the capacitor acts like an open circuit and blocks any input signals at (Vin) until the cut-off frequency point (fC) is reached. Above this cut-off frequency point the reactance of the capacitor has reduced sufficiently as to now act more like a short circuit allowing all of the input signal to pass directly to the output

Conclusion

- A high pass filter passes high frequency signals and attenuates low frequency signals.
- Voltage gain at well above the cutoff frequency is 1
- High Pass Filter frequencies below fc the dB per decade role of decreases by 20 DB per decade decreasing frequency
- In addition the phase of high-pass between the input and output changes 90 degrees over the frequency range and 45 degrees over at the cut-off frequency
- If the resistance or capacitance changes, the cutoff frequency also changes .Cut-off frequency is inversely to the resistance and capacitance
- Role off remains constant even though there is change in capacitance or resistance.

RC Differentiator and Integrator

Objectives

At the end of this experiment one would be able to

- Explain charging of RC circuit with DC source
- Explain discharging of RC circuit with DC source
- Explain Square wave response of RC circuit
- Explain RC circuit as Integrator
- Explain RC circuit as Differentiator

Apparatus

S.No.	Apparatus	Range	Type	Quantity
1	Resistor	0.1kΩ - 10kΩ		1
2	Capacitor	0.01nF - 50nF		1
3	Voltage Source	2 - 10V	AC	1
4	Voltmeter	2 - 10V	Moving Coil	1
5	Inductor	50mH - 1H		1

Theory

RC Integrator

A circuit in which the output voltage is proportional to the integral of the input voltage is known as an integrating circuit. Resistors and capacitors constitute two of the most ubiquitous circuit elements used in electronics. A capacitor is a circuit element whose function is to store charge between two conductors, hence storing electrical energy in the form of a field E(R, t). This is in contrast to an inductor, which stores energy in the form of a magnetic field B(R, t). The process of storing energy in the capacitor is known as "charging", as an equal amount of charges of opposite sign build on each conductor. A capacitor is defined by its ability to hold charge, which is proportional to the applied voltage,

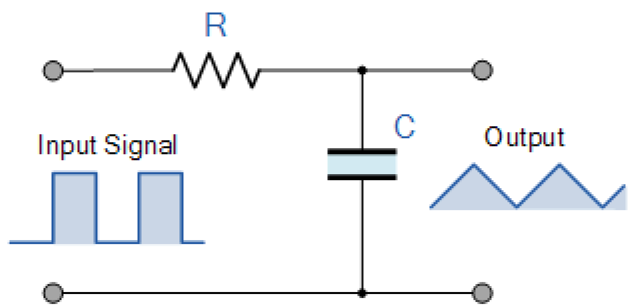
$$Q = C V$$

With the proportionality constant C called the capacitance. A simple model for a capacitor consists of two parallel conducting plates of cross-sectional area A separated by air or a dielectric. The presence of the dielectric does not allow for the flow of DC current; therefore a capacitor acts as an open circuit in the presence of a DC current. However, if the voltage across the capacitor terminals changes as a function of time, the charge accumulated on the capacitor plates is given by:

q (t) = C V (t)

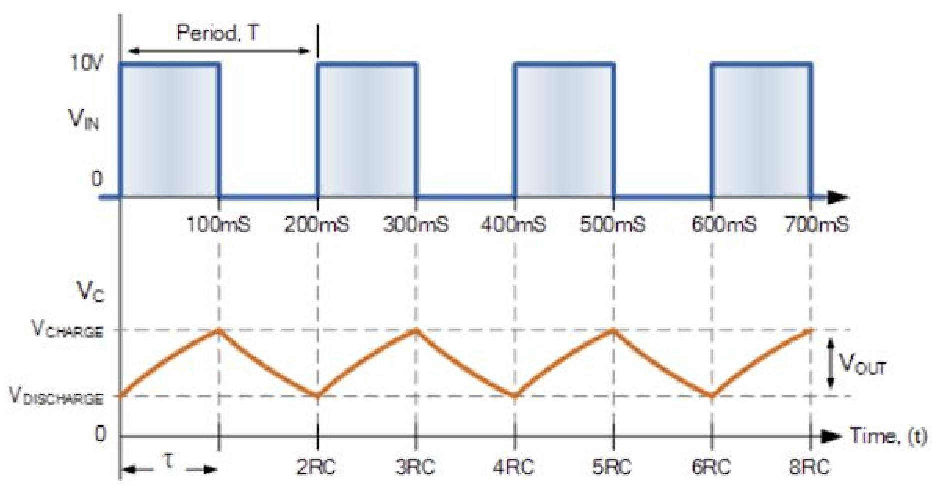
Although no current can flow through the capacitor if the voltage across it is constant, a time-varying voltage will cause charge to vary in time. Thus if the charge is changing in time, the current in the circuit is given by:

The shapes of electrical signals must often be modified to be in a suitable form for operation of circuits. The simple RC circuit often plays a part in the formation of suitable waveforms.



RC Integrator circuit

The circuit passes low frequencies readily but attenuates high frequencies because the reactance of the capacitor decreases with increasing frequency. At very high frequencies the capacitor acts as a virtual short circuit and the output falls to zero. This circuit also works as an integrating circuit. The condition for integrating circuits is RC value must be much greater than the time period of the input wave (RC >> T).



Vin and Vout Graph for RC Integrator

Let V_i be the alternating input voltage and i is the resulting current. Applying Kirchoff's voltage law to RC low pass circuit,

$$V_i = iR + \frac{1}{C}\int_0^t i \cdot dt$$

Multiplying throughout by C, we get

$$CV_i = iRC + \int_0^t i \cdot dt$$

Since $RC >> T$, the term $\int_0^t i\,dt$ may be neglected

$$CV_i = iRC$$

Integrating w.r.t T on both sides,

$$\int_0^t CV_i\,dt = RC\int_0^t i\,dt$$

$$\Rightarrow V_o = \frac{1}{C}\int_0^t i\,dt$$

$$\therefore V_o = \frac{1}{RC}\int_0^t V_i\,dt$$

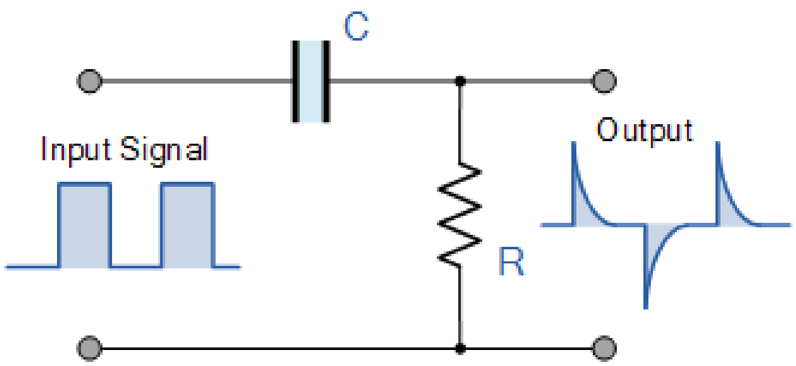
Capacitor charging $V_{c(t)} = V\left[1 - e^{-(t/RC)}\right]$

Capacitor Discharging $V_{c(t)} = V\left[e^{-(t/RC)}\right]$

RC Differentiator

RC differentiator, the output is equal to the voltage across the resistor, that is: VOUT equals VR and being a resistance, the output voltage can change instantaneously.

However, the voltage across the capacitor can not change instantly but depends on the value of the capacitance, C as it tries to store an electrical charge, Q across its plates. Then the current flowing into the capacitor, that is it depends on the rate of change of the charge across its plates. Thus the capacitor current is not proportional to the voltage but to its time variation giving: i = dQ/dt.



RC Differentiator Circuit

As the amount of charge across the capacitors plates is equal to Q = C x Vc, that is capacitance times voltage, we can derive the equation for the capacitors current as:

Thus, the capacitor current can be written as:

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

As Vout equals V_R and V_R according to Ohm's law is $i_R \times R$. The current that flow through the capacitor must also flow through the resistance as they are both connected together in series.

$$V_{out} = V_R = R \times i_R$$

$$i_c = C \frac{dV_i}{dt}$$

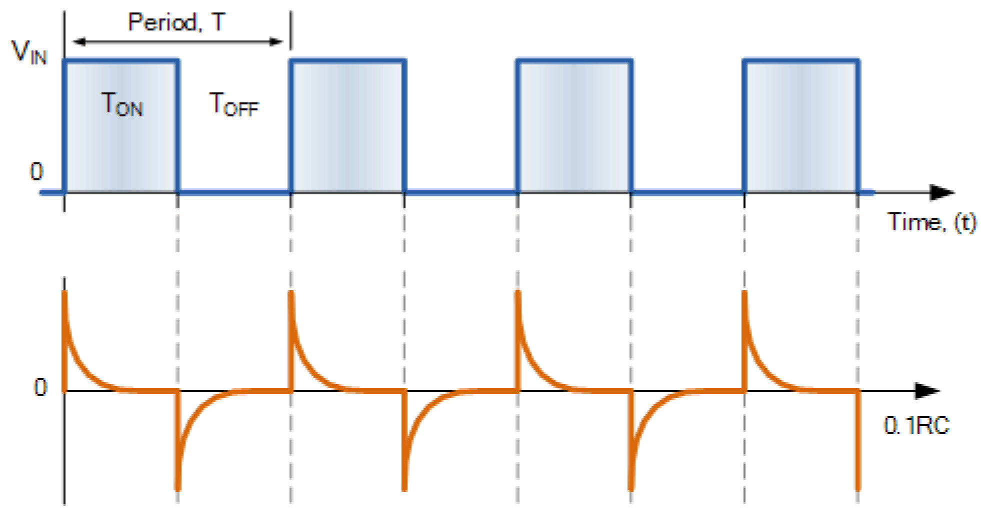
Since $i_R = i_c$,

$$V_{out} = RC \frac{dV_i}{dt}$$

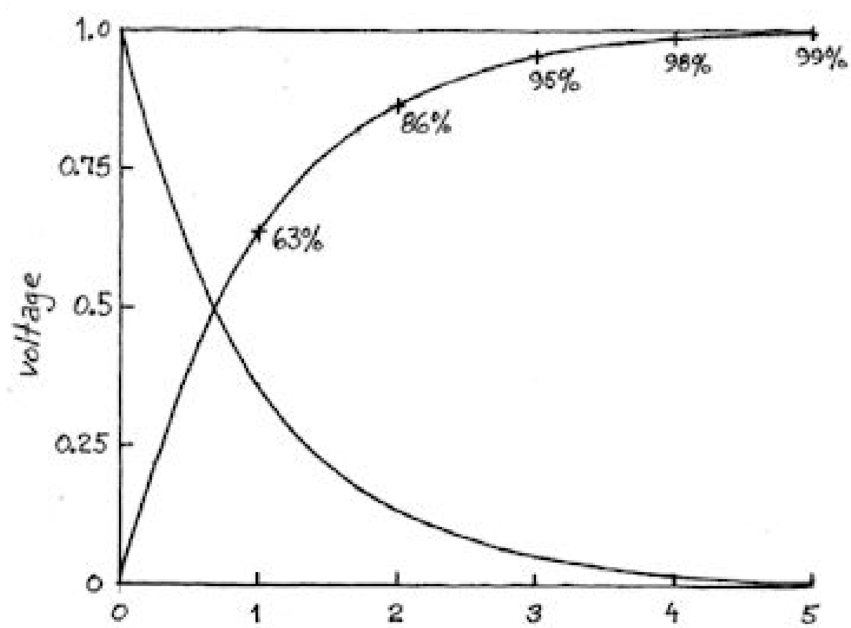
Thus, we can see that the output voltage, Vout is derivative of input voltage, V_{in} which is weighted by the constant of RC.

RC differentiator output is effectively a graph of the rate of change of the input signal which has no resemblance to the square wave input wave, but consists of narrow positive and negative spikes as the input pulse changes value.

By varying the time period, T of the square wave input pulses with respect to the fixed RC time constant of the series combination, the shape of the output pulses will change as shown.



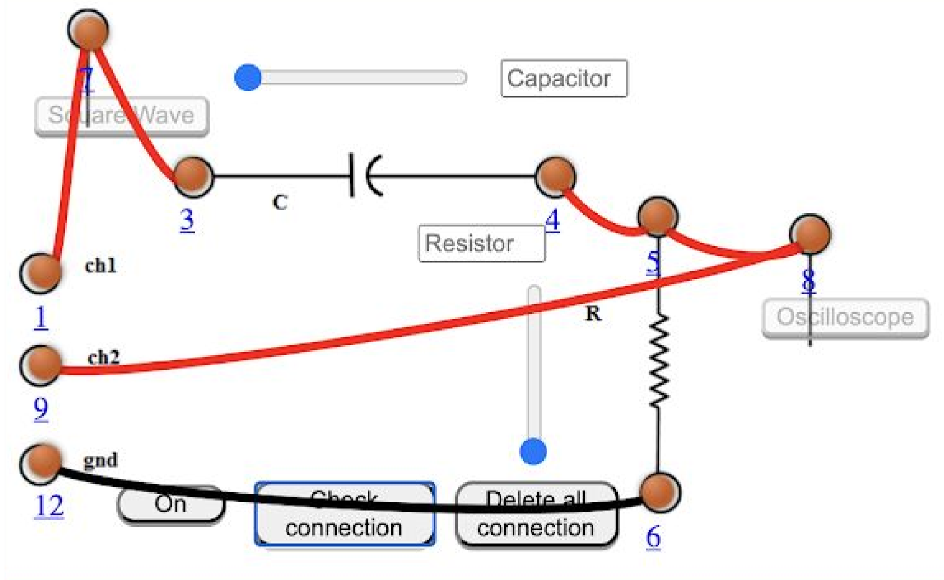
Vin and Vout Graph for RC Differentiator



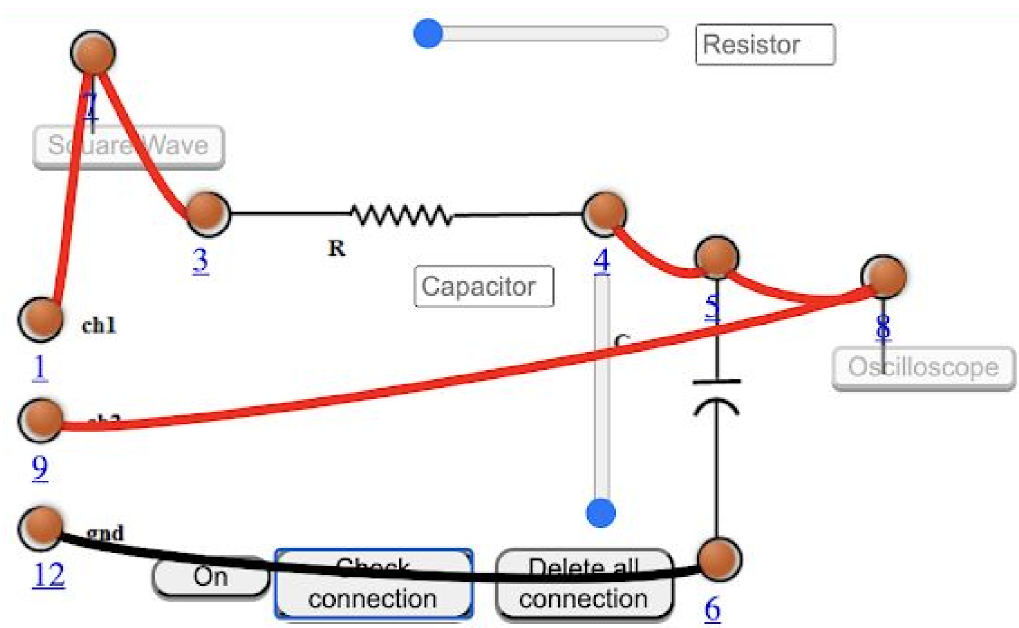
RC Charging and Discharging Curves

Circuit Diagrams

RC Differentiator

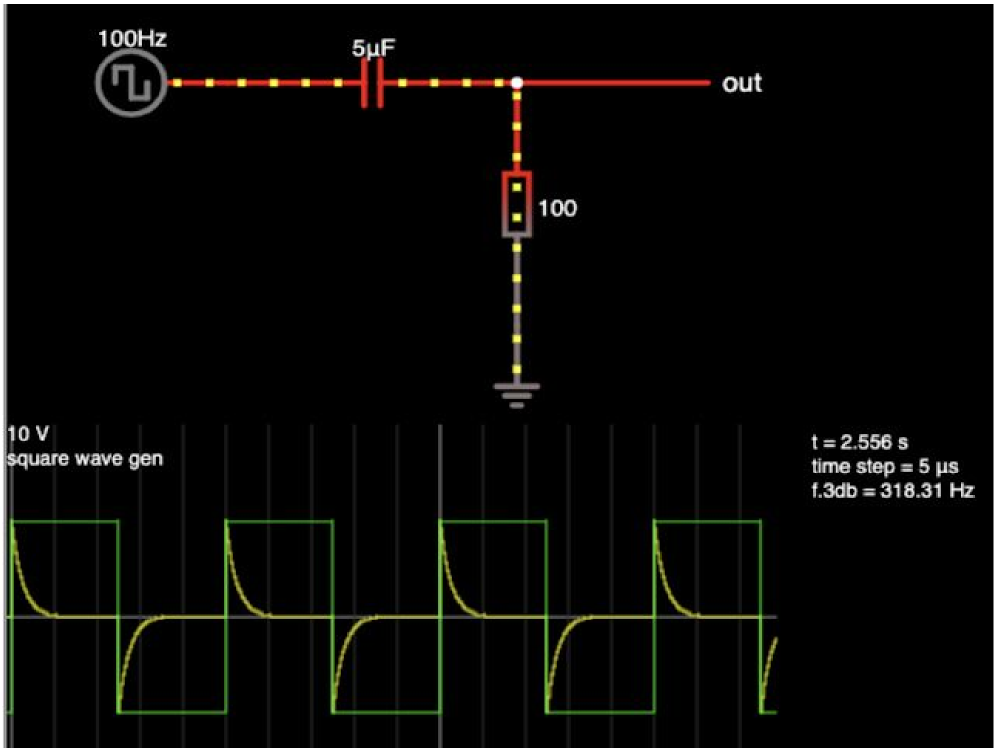


RC Integrator

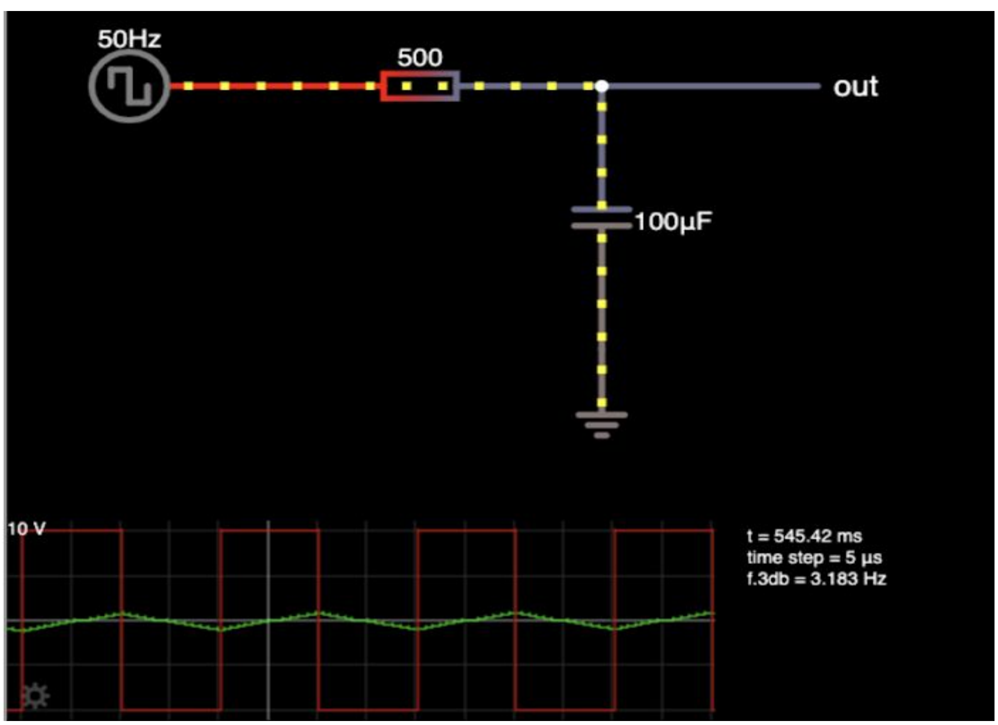


Graph :

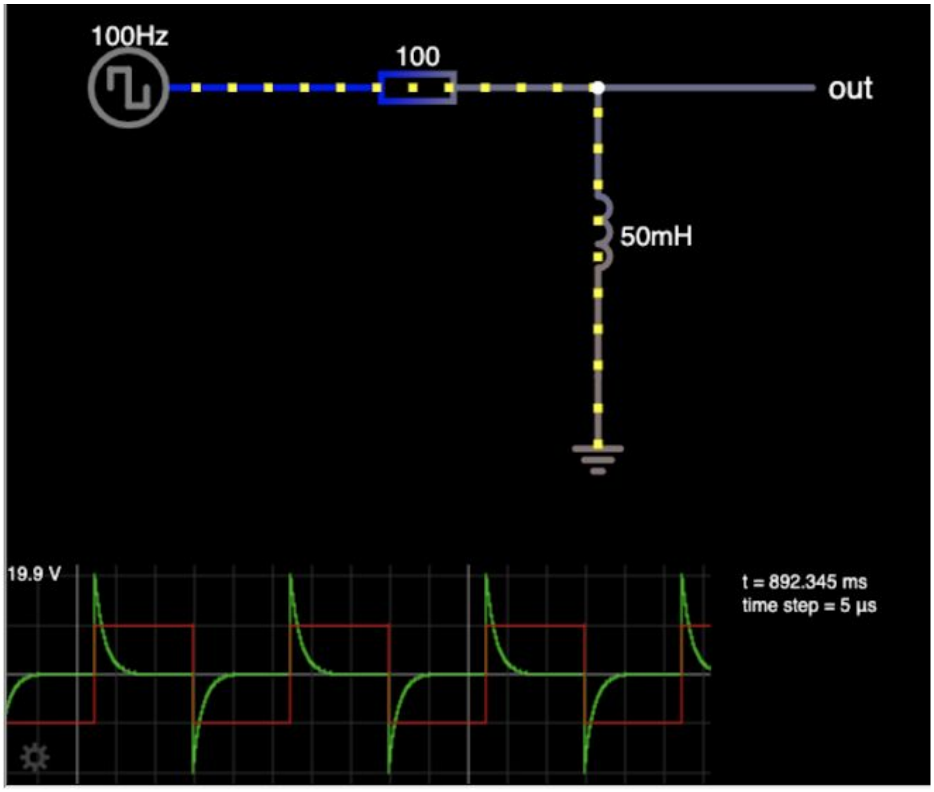
1) RC Differentiator



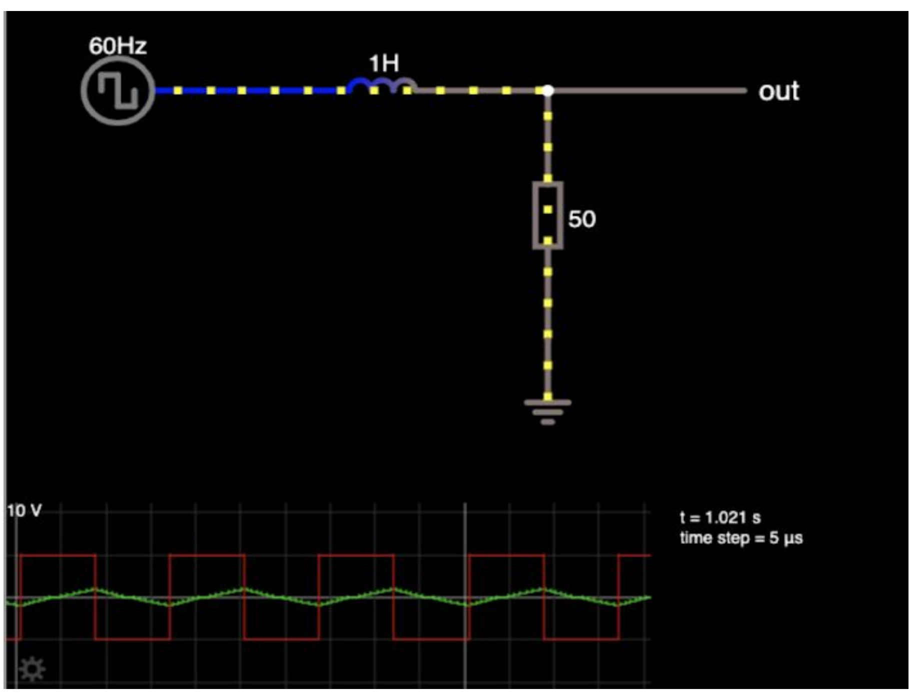
2) RC Integrator



3) RL Differentiator



4) RL Integrator



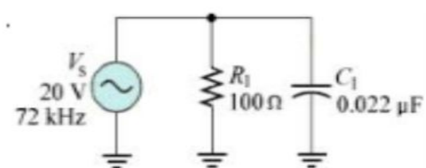
Discussion:

These experiments were done in the time domain. However in this frequency domain a signal which changes fast would mean it’s high frequency signal (or it has frequency components), a signal which changes slowly would mean it has low frequency components and a signal which does not change very fast has medium frequency components.
The Differentiator circuit converts or 'differentiates' a square wave input signal into high frequency spikes at its output.In an RC circuit if we take the voltage drop across R, and if we keep RC time constant is very short compared to the time period of the input waveform we will be differentiating the square wave.
The Integrator is a circuit that converts or ‘integrates a square wave input signal into triangular waveform output.So, we put a resistor such that we can control the current and ideally try to have dVout/dt to be a constant. Since the current does not change much during the initial part of the charging and discharging of the capacitor , the value of RC must be chosen such that it is large compared to the time period of the square wave.

✓ 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

Quiz as in Vlabs

Conclusion :

In a RC Integrator,

At very high frequencies the capacitor acts as a virtual short circuit and the output falls to zero. This circuit also works as an integrating circuit. The condition for integrating circuits is RC value must be much greater than the time period of the input wave (RC >> T).

In a RC differentiator,

The output is effectively a graph of the rate of change of the input signal which has no resemblance to the square wave input wave, but consists of narrow positive and negative spikes as the input pulse changes value.