ECT202
ANALOG CIRCUITS

PREREQUISITE:

EST130 BASICS OF ELECTRICAL AND ELECTRONICS ENGINEERING

TEXT BOOKS

I. Robert Boylestad and L Nashelsky, "Electronic Devices and Circuit Theory", 11/e Pearson, 2015.

2. Sedra A. S. and K. C. Smith, "Microelectronic Circuits", 6/e, Oxford University Press, 2013.

REFERENCE BOOKS

1. Razavi B., "Fundamentals of Microelectronics", Wiley, 2015

2. Neamen D., "Electronic Circuits, Analysis and Design", 3/e, TMH, 2007.

3. David A Bell, "Electronic Devices and Circuits", Oxford University Press, 2008.

4. Rashid M. H., "Microelectronic Circuits - Analysis and Design", Cengage Learning, 2/e,2011

5. Millman J. and C. Halkias, "Integrated Electronics", 2/e, McGraw-Hill, 2010.

MODULE 1

- WAVE SHAPING CIRCUITS
  - Analysis and design of RC differentiating and integrating circuits.
  - Analysis and design of First order RC low pass and high pass filters.
  - Clipping circuits - Positive, negative and biased clipper.
  - Clamping circuits - Positive, negative and biased clamper.
- TRANSISTOR BIASING
  - Need of biasing, operating point, bias stabilization, concept of loadline
  - Design of fixed bias, self bias, voltage divider bias.

WAVE SHAPING CIRCUITS

6 Different Wave shaping circuits

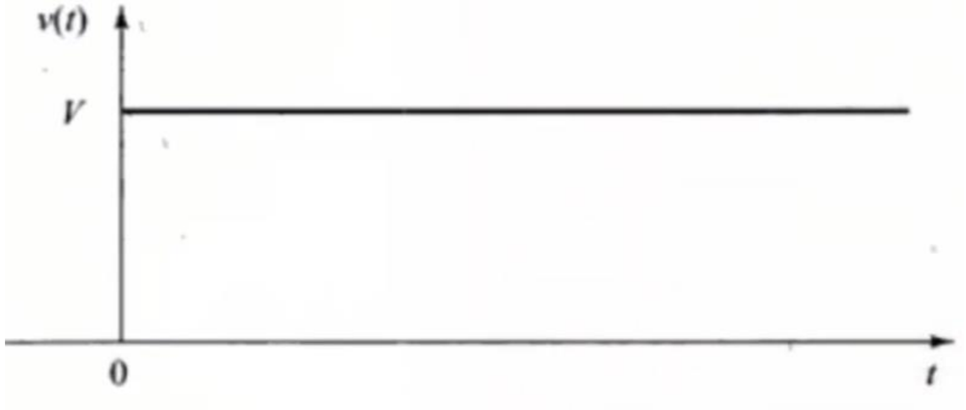
- RC DIFFERENTIATING CIRCUIT
- RC INTEGRATING CIRCUIT
- 1ST ORDER LOW PASS FILTER
- 1ST ORDER HIGH PASS FILTER
- CLIPPER CIRCUITS
- CLAMPER CIRCUITS

WAVE SHAPING CIRCUITS

- The process of changing shape of any given waveform is called **Wave Shaping.**
- The basic function of these wave shaping circuits are to change the shape of any input signal according to the time period at output.
- Most wave-shaping circuits are used to generate periodic waveforms.
- The common periodic waveforms include the Square, Sine, Rectified Sine, Sawtooth, Triangular, Periodic Arbitrary wave etc.
- The Arbitrary wave can be made to conform to any shape during the duration of one period. This shape then is followed for each successive cycle.

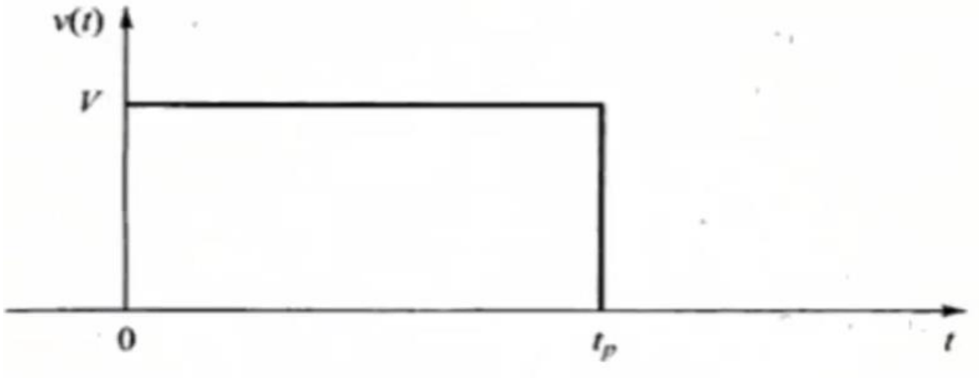
COMMON WAVEFORMS

STEP WAVEFORM



$$v(t) = \begin{cases} 0 & \text{for } t < 0 \\ V & \text{for } t \geq 0 \end{cases}$$

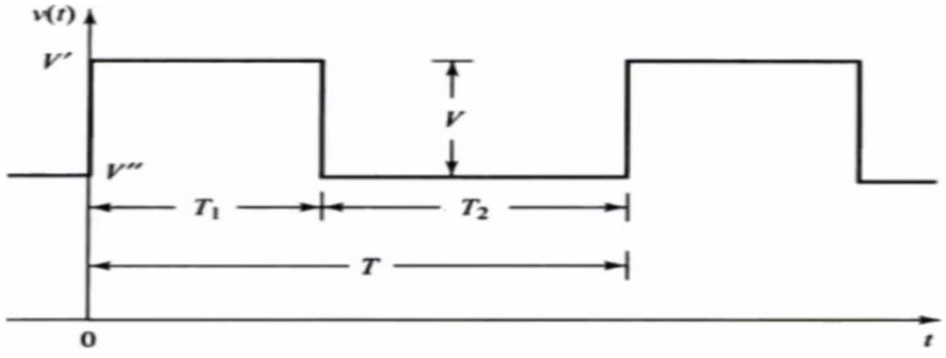
PULSE WAVEFORM



$$v(t) = \begin{cases} V & \text{for } 0 \leq t \leq t_p \\ 0 & \text{elsewhere} \end{cases}$$

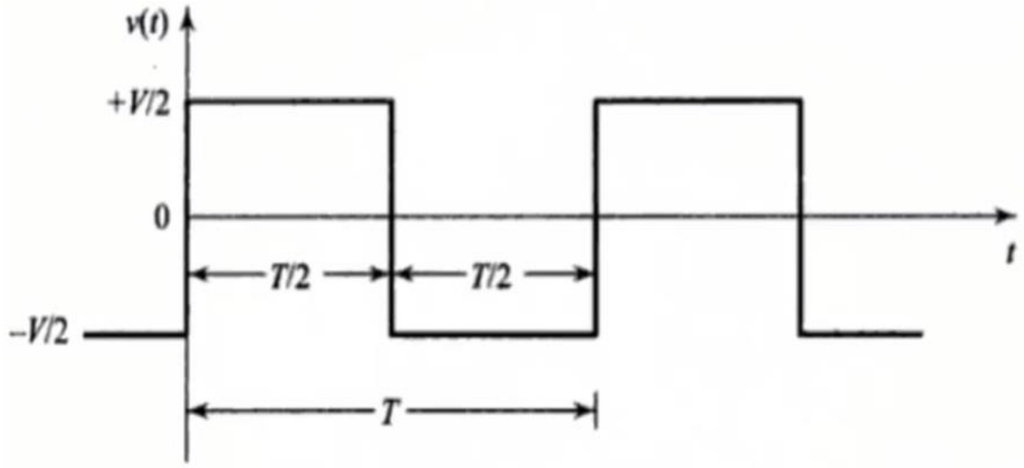
COMMON WAVEFORMS

SQUARE WAVEFORM



$$\text{Duty Cycle, D} = \frac{\mathbf{T1}}{\mathbf{T1+T2}} = \frac{\mathbf{T1}}{\mathbf{T}}$$

SYMMETRIC SQUARE WAVEFORM

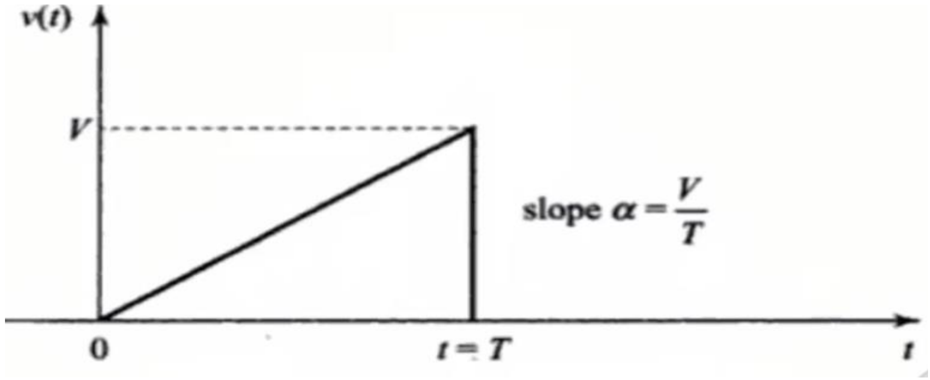


$$\text{T1} = \text{T2} = \frac{\mathbf{T}}{\mathbf{2}}$$

$$\text{Duty Cycle, D} = \frac{\mathbf{T1}}{\mathbf{T1+T2}} = \frac{\mathbf{1}}{\mathbf{2}}$$

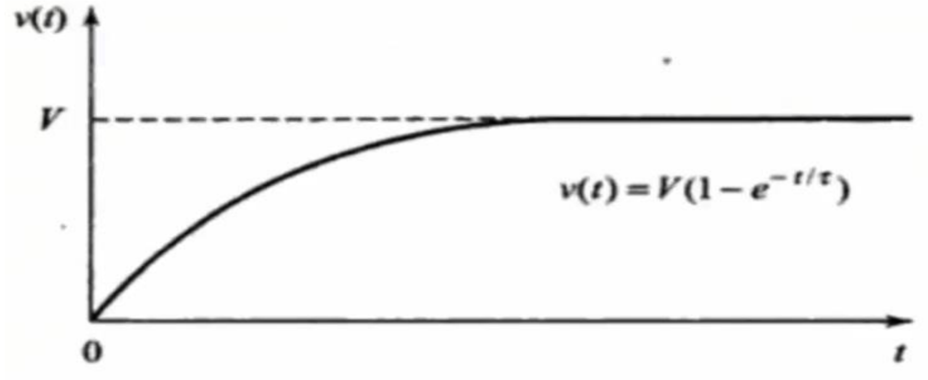
COMMON WAVEFORMS

RAMP WAVEFORM



$$v(t) = \begin{cases} 0 & \text{for } t < 0 \\ \alpha t & \text{for } t \geq 0 \end{cases}$$

EXPONENTIAL WAVEFORM



τ

is the Time Constant

$$v(t) = V(1 - e^{-t/\tau})$$

LINEAR WAVE SHAPING CIRCUITS

- Linear elements such as resistors, capacitors and inductors are employed to shape a signal in this linear wave shaping.
- Linear wave shaping circuits mostly rely upon Differentiation and Integration.
- The linear wave shaping circuits alter the shape of a waveform by passing them through a process of **Differentiation** and **Integration**.
- For Eg:
  - A Step waveform can be converted into decaying exponential waveform by transmitting it through a differentiator.
  - A Step waveform can be converted into rising exponential waveform by transmitting it through a Integrator.

NON LINEAR WAVE SHAPING CIRCUITS

- The process of producing non-sinusoidal output wave forms from sinusoidal input, using non-linear elements is called as Nonlinear wave Shaping.
- Along with resistors, the non-linear elements like diodes are used in nonlinear wave shaping circuits to get required altered outputs.
- Either the shape of the wave is attenuated or the dc level of the wave is altered in the Non-linear wave shaping.
- The two important classes of circuits known as Non Linear wave shaping circuits are Clipping and Clamping circuits.

NON LINEAR WAVE SHAPING CIRCUITS

- Clamping operation involves storage of energy in the circuit, which uses 2 components Capacitors and Inductors.
- Clipping circuit is generally designed with diodes and resistors and they do not contain any energy storing components.
- The function performed by clipping circuits is essentially either limiting or slicing.

WAVE SHAPING CIRCUITS

LINEAR WAVE SHAPING CIRCUITS

- RC DIFFERENTIATOR
- RC INTEGRATOR
- 1ST ORDER LOW PASS FILTER
- 1ST ORDER HIGH PASS FILTER

NON LINEAR WAVE SHAPING CIRCUITS

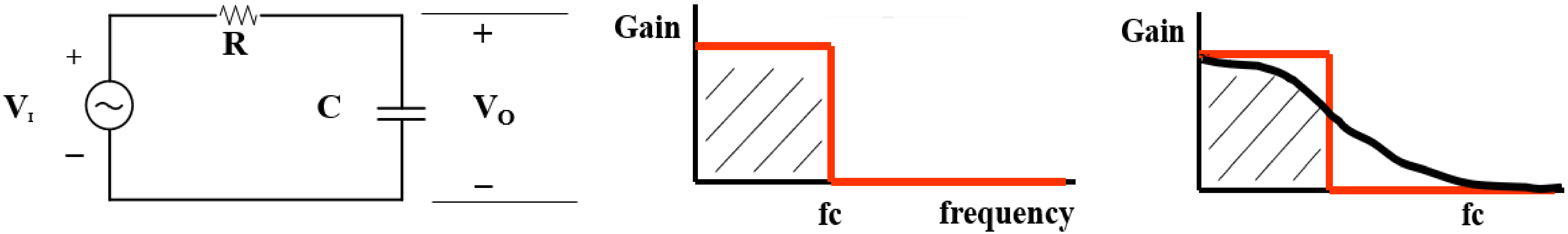
- CLIPPER CIRCUIT
- CLAMPER CIRCUIT

What Is A Filter And Classification Of Filters

- An electric filter is a circuit, which can be designed to **modify, reshape** or **reject** all the **undesired frequencies** of an electrical signal and **pass** only the **desired signal**.
- Frequency selective network that passes a specified band of frequencies and block signals of frequencies outside the band.
- 4 main types of filters
  - **LOW PASS FILTER (LPF)**
  - **HIGH PASS FILTER (HPF)**
  - **BAND PASS FILTER (BPF)**
  - **BAND REJECT FILTER (BRF)**

LOW PASS FILTER

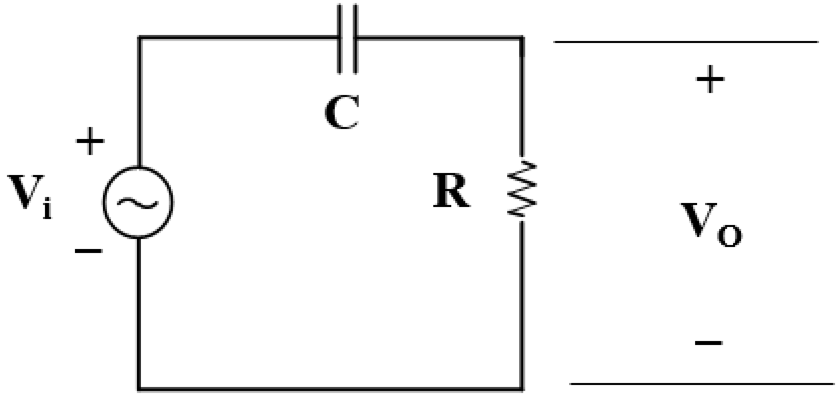
- A filter that provides a constant output from DC up to a cutoff frequency **fc,** and then passes no signal above that frequency is called a **Low Pass Filter.**

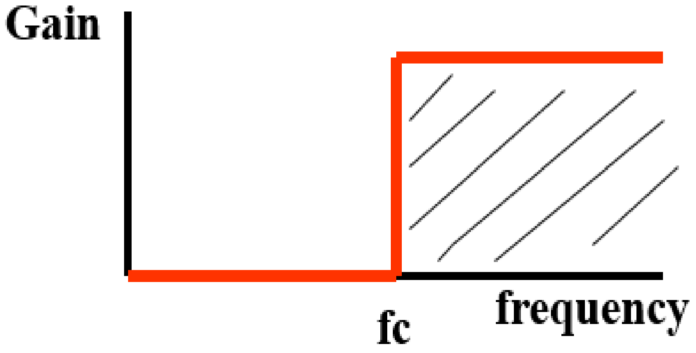


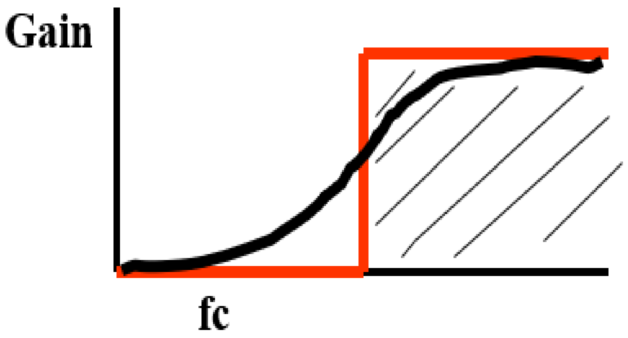
- Filter circuit which allows a set of frequencies that are below a specified value. The filter passes the lower frequencies.

HIGH PASS FILTER

- A filter that passes signals above a cut off frequency **fc,** is called a **High Pass Filter.**
- Filter circuit that allows a set of frequencies that are above a specified value. This filter passes higher frequencies

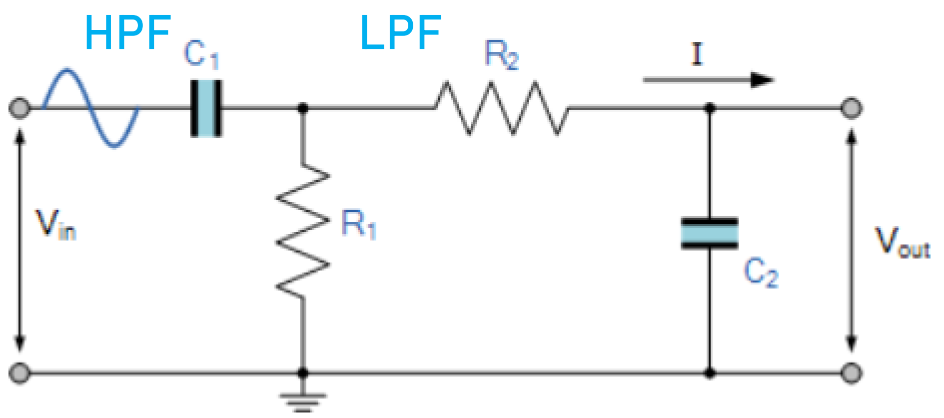


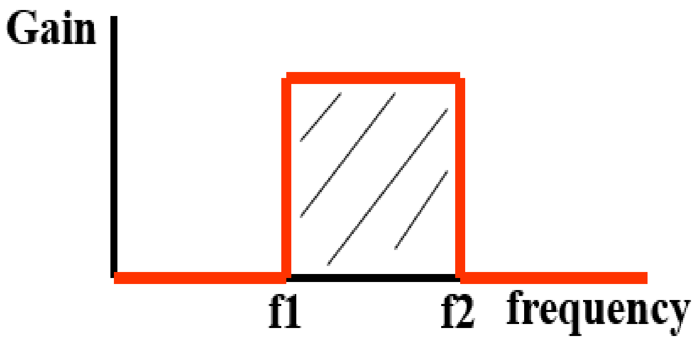


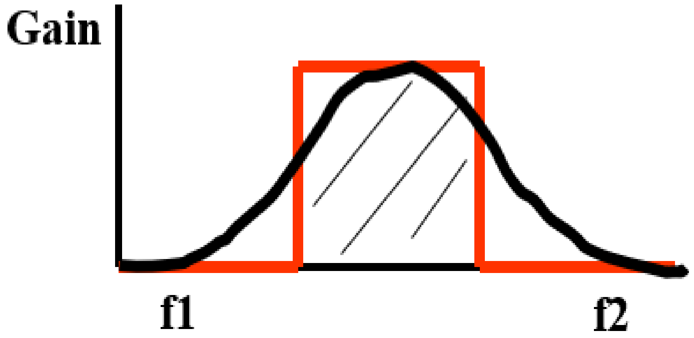


BAND PASS FILTER

- When the Filter circuit passes signals that are above one cut off frequency and below a second cut off frequency, it is called a **Band Pass Filter.**
- A filter that allows a set of frequencies that are between two specified values. This filter passes a band of frequencies.

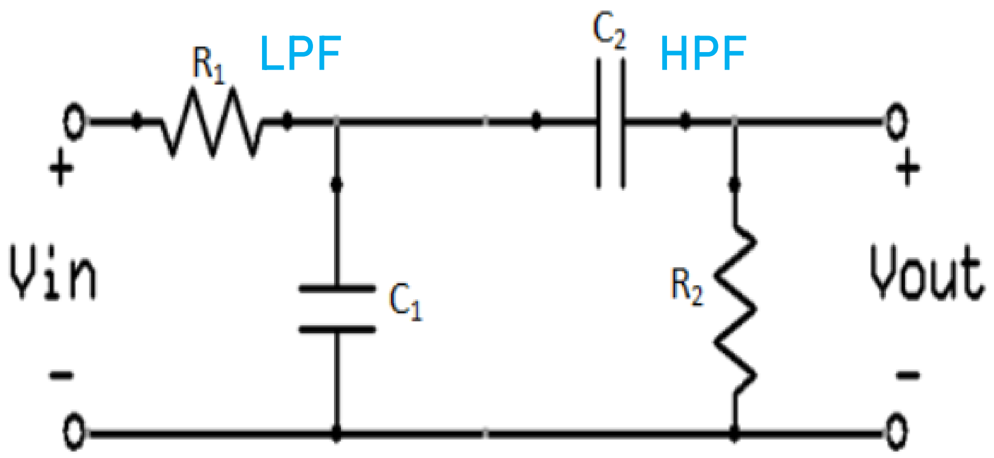


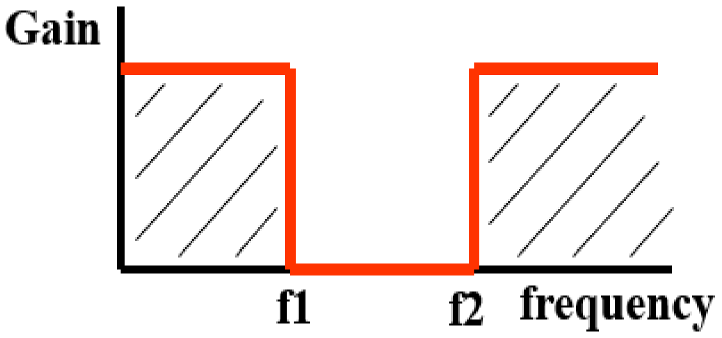


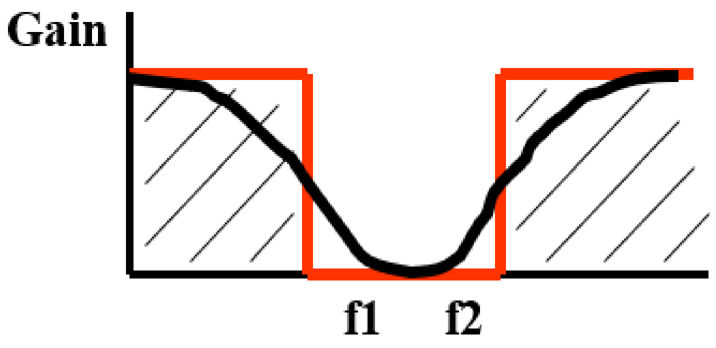


BAND STOP FILTER

- When the Filter circuit rejects signals that are above one cut off frequency and below a second cut off frequency, it is called a **Band Pass Filter.**
- A filter that blocks a set of frequencies that are between two specified values. This filter rejects a band of frequencies.

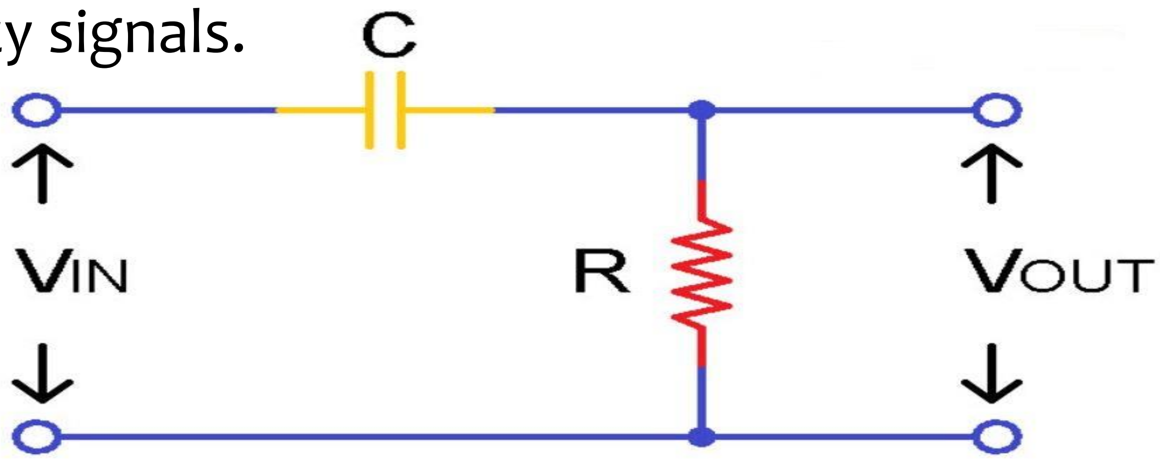






1ST ORDER RC HIGH PASS FILTER

- Filter circuit that allows a set of frequencies that are above a specified value. This filter passes higher frequencies.
- The capacitor is connected in series with the resistor.
- The input voltage is applied in series to the capacitor but the output is drawn only across the resistor.
- High Pass filter allows the frequencies which are higher than the cut off frequency ‘fc’ and blocks the lower frequency signals.
- The value of the cut off frequency depends on the component values chosen for the circuit design.



CAPACITIVE REACTANCE OF HPF

Capacitive Reactance of a HPF

$$X_C = \frac{1}{j\omega C}$$

$$X_C = \frac{1}{j2\pi f C}$$

ω - Angular Frequency

f – Frequency

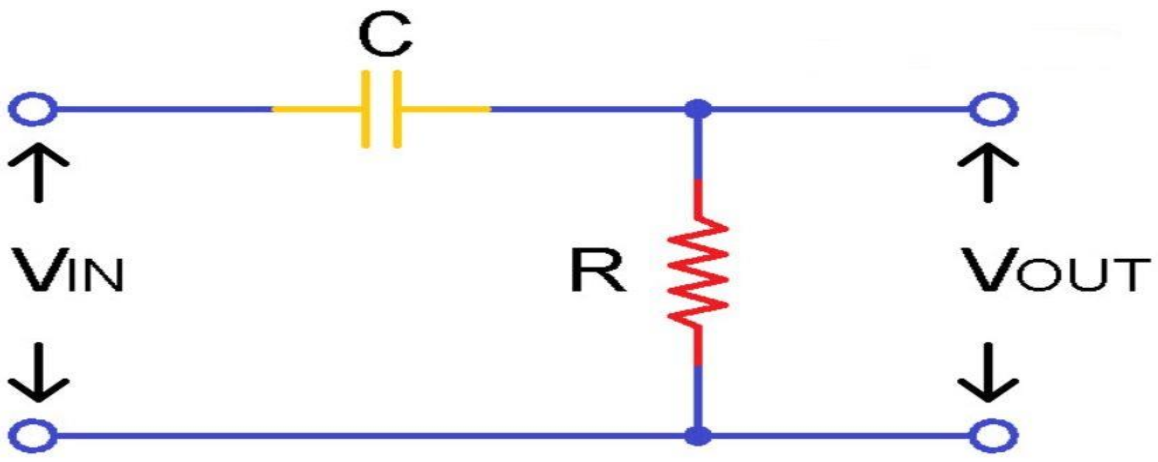
X_C – Capacitive Reactance

C – Capacitance

Reactance of capacitor is **inversely proportional** to **frequency** of the signal through it

CAPACITIVE REACTANCE OF HPF

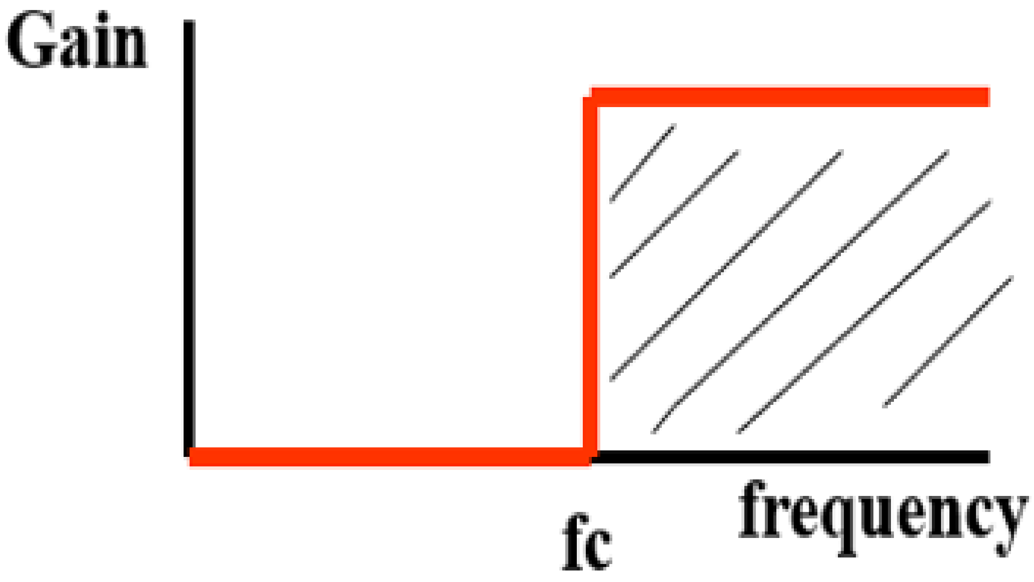
$$X_C = \frac{1}{j2\pi f C}$$

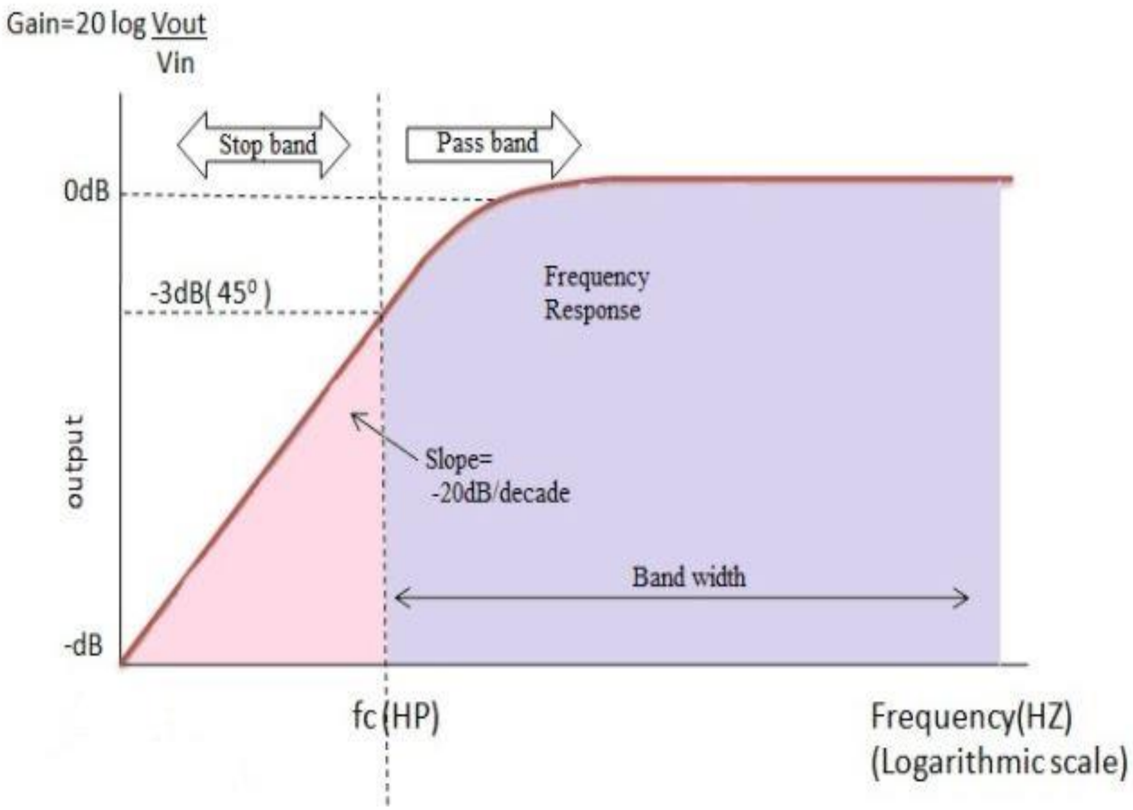


At **Higher frequencies, Reactance** of Capacitor is **low**, so the capacitor act as **Short circuit** and virtually input appears at the output.

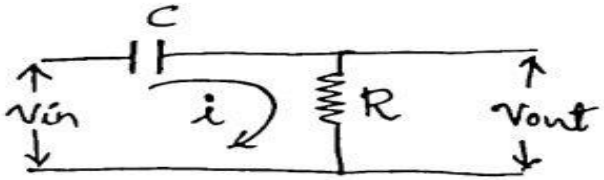
At **Low frequencies, Reactance** of Capacitor is **Very High**, so the capacitor act as **Open circuit** and virtually no input appears at the output.

FREQUENCY RESPONSE OF HPF





ANALYSIS OF 1ST ORDER HPF



$$V_o = iR \longrightarrow (1)$$

$$V_o = i(R + X_c)$$

$$V_o = i\left(R + \frac{1}{j\omega C}\right) \longrightarrow (2)$$

TRANSFER FUNCTION,

$$\frac{V_o}{V_i} = \frac{\cancel{i}(R)}{\cancel{i}\left(R + \frac{1}{j\omega C}\right)}$$

$$\frac{V_o}{V_i} = \frac{\cancel{R}}{\cancel{R}\left(1 + \frac{1}{j\omega RC}\right)}$$

$$\frac{V_o}{V_i} = \frac{1}{\left(1 + \frac{1}{j\omega RC}\right)} \longrightarrow (3)$$

$$\frac{V_o}{V_i} = \frac{1}{\left(1 + \frac{1}{j2\pi f RC}\right)} \longrightarrow (4)$$

$j^2 = -1$

$$\frac{V_o}{V_i} = \frac{1}{\left(1 - \frac{j}{2\pi f RC}\right)} \longrightarrow (5)$$

Assume $f_1 = \frac{1}{2\pi RC}$ (lower Cut off frequency)

$$\boxed{\frac{V_o}{V_i} = \frac{1}{\left(1 - j\frac{f_1}{f}\right)}} \longrightarrow (6)$$

magnitude of $|a+jb| = \sqrt{a^2+b^2}$

$$\left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{(1)^2 + \left(\frac{f_1}{f}\right)^2}}$$

$$\boxed{\left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{1 + (f_1/f)^2}}} \longrightarrow (7)$$

ANALYSIS OF 1ST ORDER HPF

$$\boxed{\left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{1+(f_1/f)^2}}}$$

Substituting values for f,

$f=0$, $\left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{1+(f_1/0)^2}}$

$$\frac{V_o}{V_i} = \frac{1}{\sqrt{1+\infty}} = \frac{1}{\infty} = 0$$

$f=f_1$, $\left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{1+(f_1/f_1)^2}}$

$$\left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{1+1}} = \frac{1}{\sqrt{2}}$$

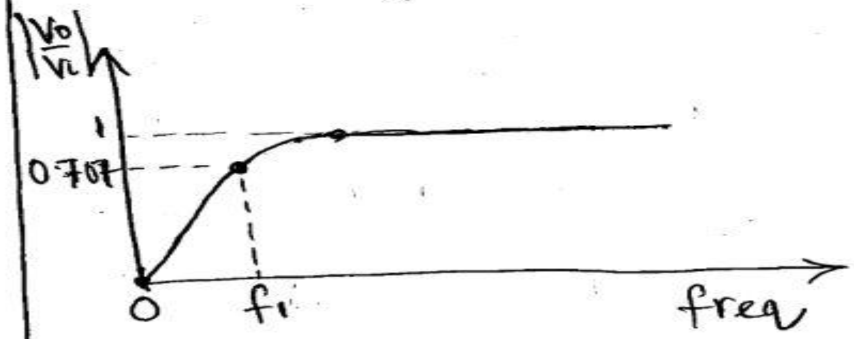
$f=\infty$, $\left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{1+(f_1/\infty)^2}}$

$$\left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{1+0}} = 1$$

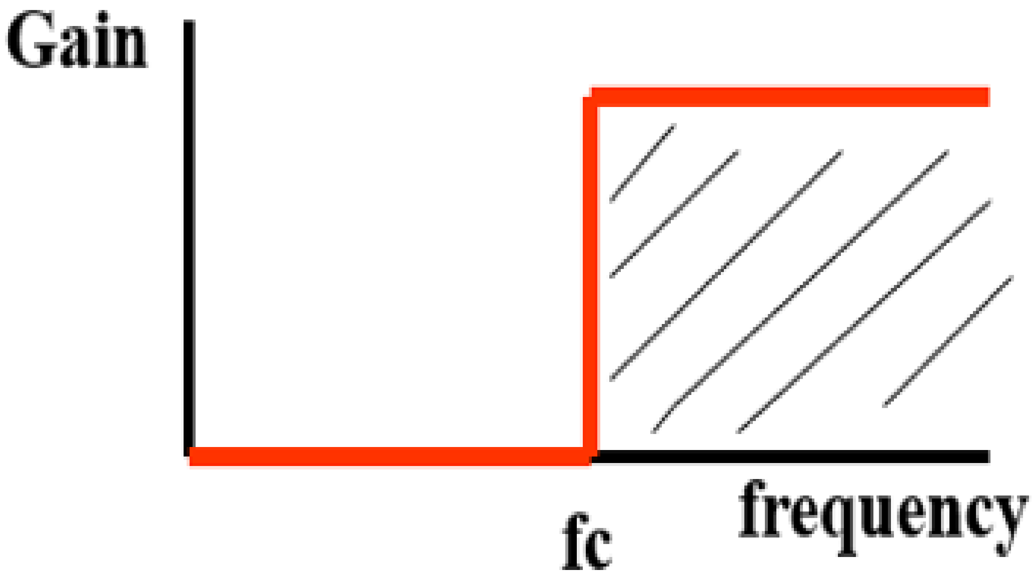
$f=0$, $\left|\frac{V_o}{V_i}\right| = 0$

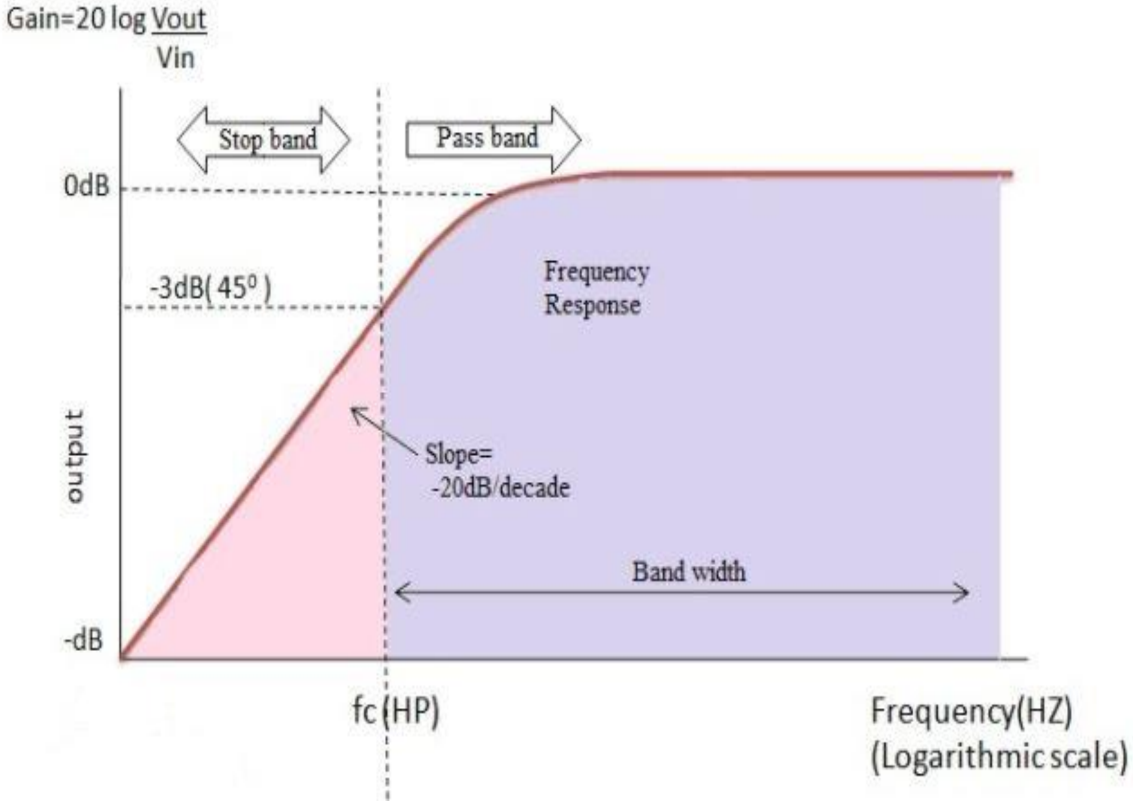
$f=f_1$, $\left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{2}} = 0.7071$

$f=\infty$, $\left|\frac{V_o}{V_i}\right| = 1$



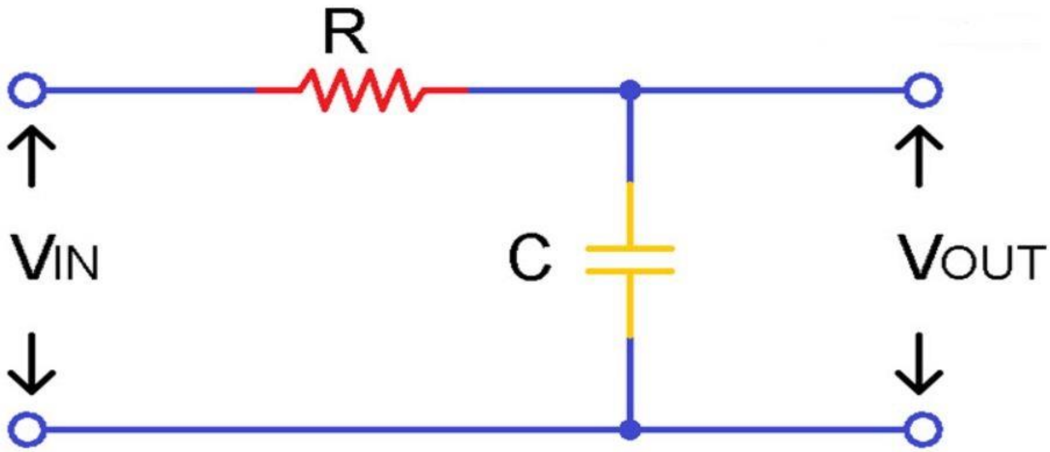
FREQUENCY RESPONSE OF HPF





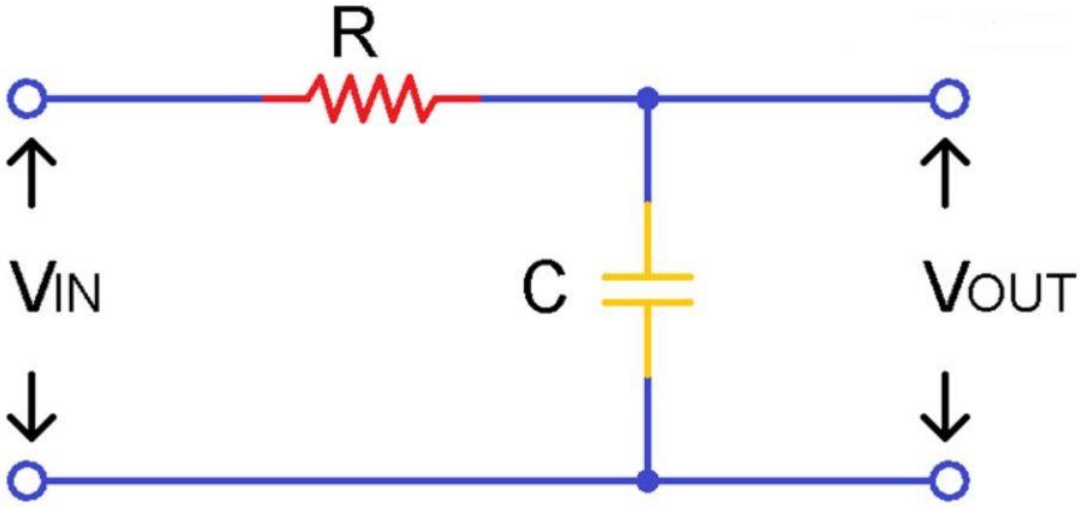
1ST ORDER RC LOW PASS FILTER

- Filter circuit which allows a set of frequencies that are below a specified value. The filter passes the lower frequencies
- The Resistor is connected in series with the Capacitor.
- The input voltage is applied in series to the Resistor but the output is drawn only across the Capacitor.
- Low Pass filter allows the frequencies which are lower than the cut off frequency 'fc' and blocks the higher frequency signals.
- The value of the cut off frequency depends on the component values chosen for the circuit design.



CAPACITIVE REACTANCE OF LPF

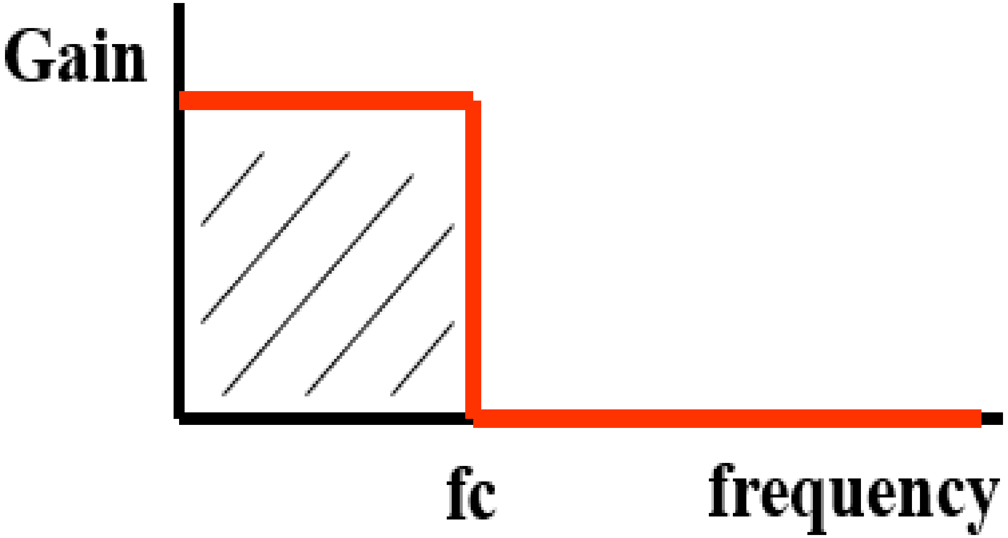
$$X_C = \frac{1}{j2\pi f C}$$

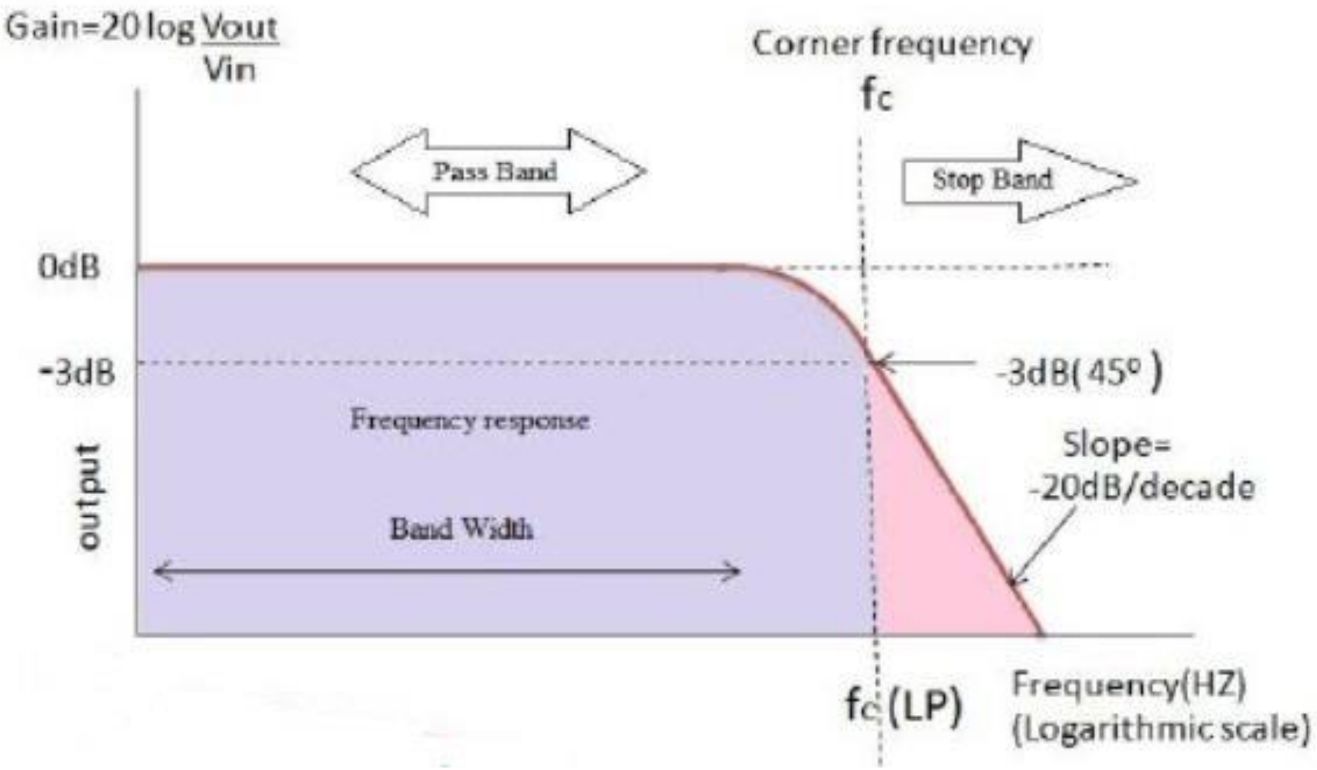


At **lower frequencies, Reactance** of Capacitor is **very high**, so the capacitor act as **Open circuit** and virtually input appears at the output.

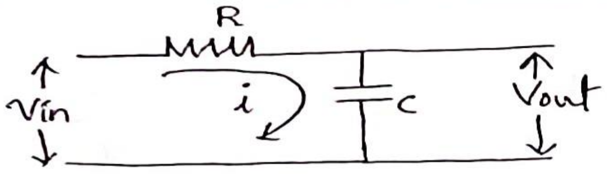
At **High frequencies, Reactance** of Capacitor is **very low**, so the capacitor act as **Short circuit** and virtually no input appears at the output.

FREQUENCY RESPONSE OF LPF





ANALYSIS OF 1ST ORDER LPF



$$V_{out} = i X_c = i \cdot \frac{1}{j\omega C} \longrightarrow (1)$$

$$V_{in} = i\left(R + \frac{1}{j\omega C}\right) \longrightarrow (2)$$

Transfer function,

$$\frac{V_{out}}{V_{in}} = \frac{i/j\omega C}{i\left(R + 1/j\omega C\right)}$$

$$\frac{V_{out}}{V_{in}} = \frac{1/j\omega C}{\frac{(Rj\omega C + 1)}{j\omega C}}$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{1 + j\omega RC} \longrightarrow (3)$$

$$\omega = 2\pi f$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{1 + j2\pi f RC} \longrightarrow (4)$$

Assume $f_2 = \frac{1}{2\pi RC}$, upper cutoff frequency

$$\boxed{\frac{V_{out}}{V_{in}} = \frac{1}{1 + j(f/f_2)}} \longrightarrow (5)$$

To find magnitude

$$\boxed{a+ib \Rightarrow |a+ib| = \sqrt{a^2+b^2}}$$

So, $$\left|\frac{V_{out}}{V_{in}}\right| = \frac{1}{\sqrt{(1)^2 + (f/f_2)^2}}$$

$$\boxed{\left|\frac{V_{out}}{V_{in}}\right| = \frac{1}{\sqrt{1 + (f/f_2)^2}}}$$

ANALYSIS OF 1ST ORDER LPF

Substituting values for f

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{1}{\sqrt{1+(f/f_2)^2}}$$

$f = 0$, $\left|\frac{V_{out}}{V_{in}}\right| = \frac{1}{\sqrt{1+0}}$

$$\left|\frac{V_{out}}{V_{in}}\right| = 1$$

$f = f_2$, $\left|\frac{V_{out}}{V_{in}}\right| = \frac{1}{\sqrt{1+1}}$

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{1}{\sqrt{2}}$$

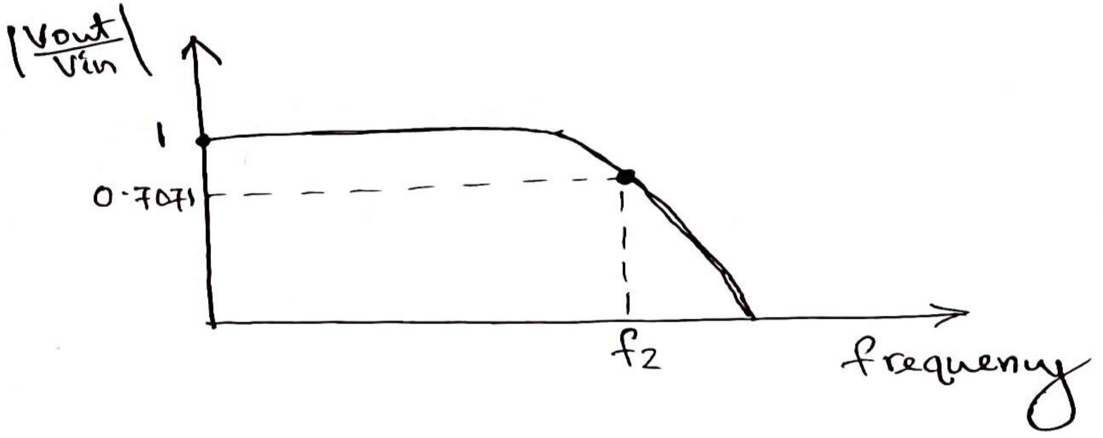
$f = \infty$, $\left|\frac{V_{out}}{V_{in}}\right| = \frac{1}{\sqrt{1+\infty}} = \frac{1}{\infty}$

$$\left|\frac{V_{out}}{V_{in}}\right| = 0$$

$f = 0$, $\left|\frac{V_{out}}{V_{in}}\right| = 1$

$f = f_2$, $\left|\frac{V_{out}}{V_{in}}\right| = \frac{1}{\sqrt{2}} = 0.7071$

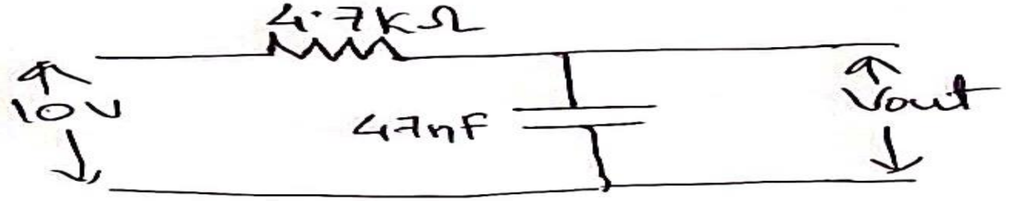
$f = \infty$, $\left|\frac{V_{out}}{V_{in}}\right| = 0$



Example: A low pass filter consisting of a resistor of 4.7Kohm in series with a capacitor of 47nF is connected across a 10V sinusoidal supply. Calculate the output voltage Vout at a frequency of 100KHz?.

Given, $C = 47nF$, $R = 4.7K\Omega$

$V_{in} = 10V$, $f = 100HZ$, $V_{out} = ?$



$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 100 \times 47 \times 10^{-9}}$$

$$X_C = 33{,}863\Omega$$

$$V_{out} = V_{in} \cdot \frac{X_C}{\sqrt{R^2 + X_C^2}}$$

$$V_{out} = 10 \times \frac{33863}{\sqrt{(4700)^2 + (33863)^2}}$$

$$V_{out} = 9.9V$$

Example: Calculate the cut-off or breakpoint frequency (fc) for a simple passive High Pass filter consisting of an 82pF capacitor connected in series with a 240Kohm resistor?.

Given, $C = 82pF$, $R = 240\,k\Omega$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 240 \times 10^{3} \times 82 \times 10^{-9}}$$

$$f_c = 8087\,Hz \quad \text{or} \quad 8.087\,kHz$$

RC HIGH PASS FILTER AS DIFFERENTIATOR

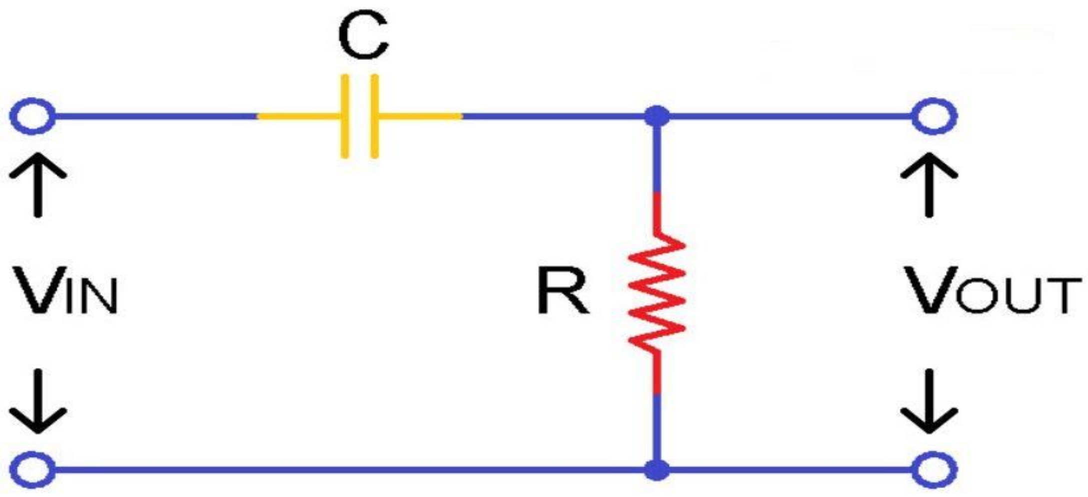
- Filter circuit which allows a set of frequencies that are above a specified value. The filter passes the Higher frequencies

- A HPF can be considered as differentiator if it satisfies certain conditions.
  - Output voltage is directly proportional to differentiation of input voltage.

$$\mathrm{V_o} \propto \frac{d}{dt}(\mathrm{V_{in}})$$

  - The value of R is 10 or more times smaller than Xc

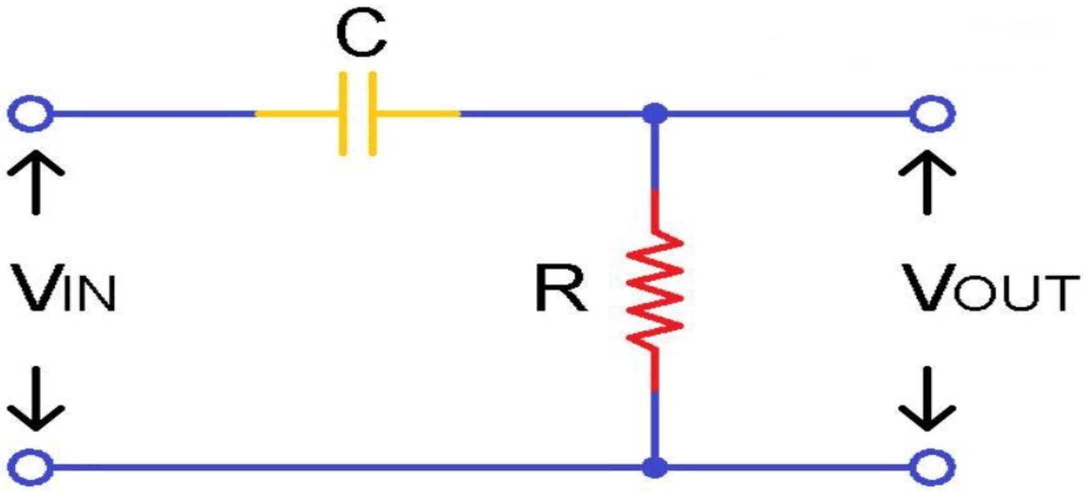
$$\mathrm{X_C} \gg 10\,R$$



RC HIGH PASS FILTER AS DIFFERENTIATOR

- The time constant $\boldsymbol{\tau}$ (RC) of the circuit should be very small as compared to the time period of input wave.

$$\mathrm{RC} \ll 0.0016T$$



$$\frac{V_o}{V_i} = \frac{1}{1 - j/2\pi fRC}$$

V_0/V_i is a complex quantity, with magnitude and phase. The phase angle between input and output is

$$\angle\frac{V_o}{V_i} = -\tan^{-1}\left(\frac{-1}{2\pi fRC}\right)$$

$$= \tan^{-1}\left(\frac{1}{\omega RC}\right)$$

The phase angle required for the differentiator is 90^0

$$\therefore \quad 90 = \tan^{-1}\left(\frac{1}{\omega RC}\right)$$

which makes $1/\omega RC = \tan 90 = \infty$ which is not a practically realizable condition. Hence we choose a higher value for $1/\omega RC$

Let: $\quad \dfrac{1}{\omega RC} \geq 100$

which gives a phase angle of $\tan^{-1}100 = 89.42^0$, a practically acceptable condition.

$$\frac{1}{\omega RC} \geq 100; \quad \frac{1}{2\pi fRC} \geq 100$$

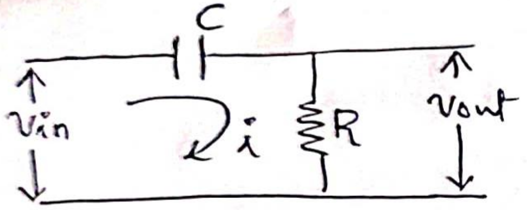
$$\therefore \quad RC \leq \frac{1}{100\ 2\pi f}$$

$$\text{or} \quad RC \leq \frac{T}{2\pi \times 100}$$

$$\text{i.e.} \quad \boxed{RC \leq 0.0016T}$$

where T is the period of input signal and RC is the time constant of the circuit.

Input And Output Relationship



From the circuit,

$V_{out} = iR \longrightarrow (1)$

For differentiator, $X_C >> R$

so assume Capacitor reactance, X_C much higher than resistance, R.

so most of the i/p voltage will available across the capacitor

so for capacitor,

$i = C\frac{dV_{in}}{dt} \longrightarrow (2)$

$i = C\frac{dv}{dt}$

$v = \frac{1}{C}\int i\,dt$

substituting (2) in (1)

$V_{out} = C\frac{dV_{in}}{dt} \cdot R$

$$\boxed{V_{out} = RC\frac{dV_{in}}{dt}}$$

$RC = \tau$ - Time Constant

$$\boxed{V_o \propto \frac{d}{dt}(V_{in})}$$

- So, output voltage is proportional to derivative of input voltage
- So circuit work as a DIFFERENTIATOR

Response to Square Input

The response of a differentiator to a square input is shown in Fig.5.5. At t = 0, input rises to a large positive value. Since the capacitor cannot respond to sudden change, this is reflected at the output. The charging and discharging action of capacitor makes the output wave to appear as shown. The low time constant of the circuit converts a square wave into a trigger pulse or a spike which is used to trigger multivibrators.

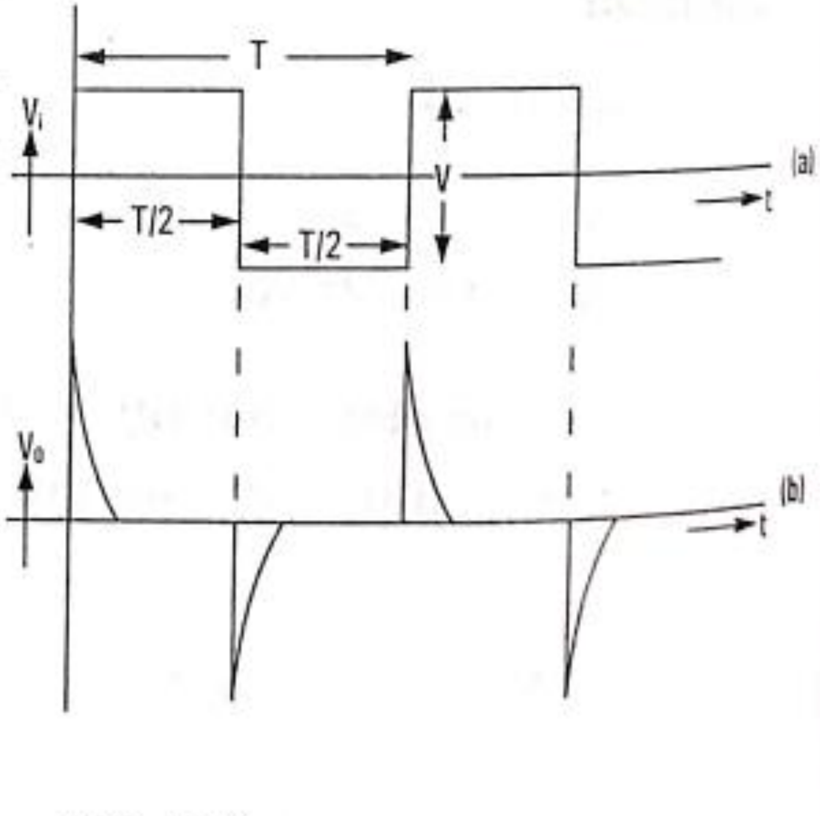
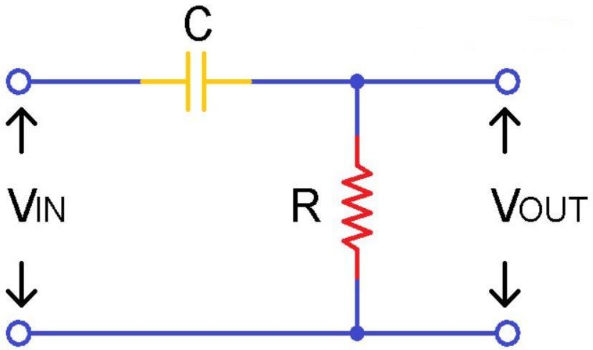
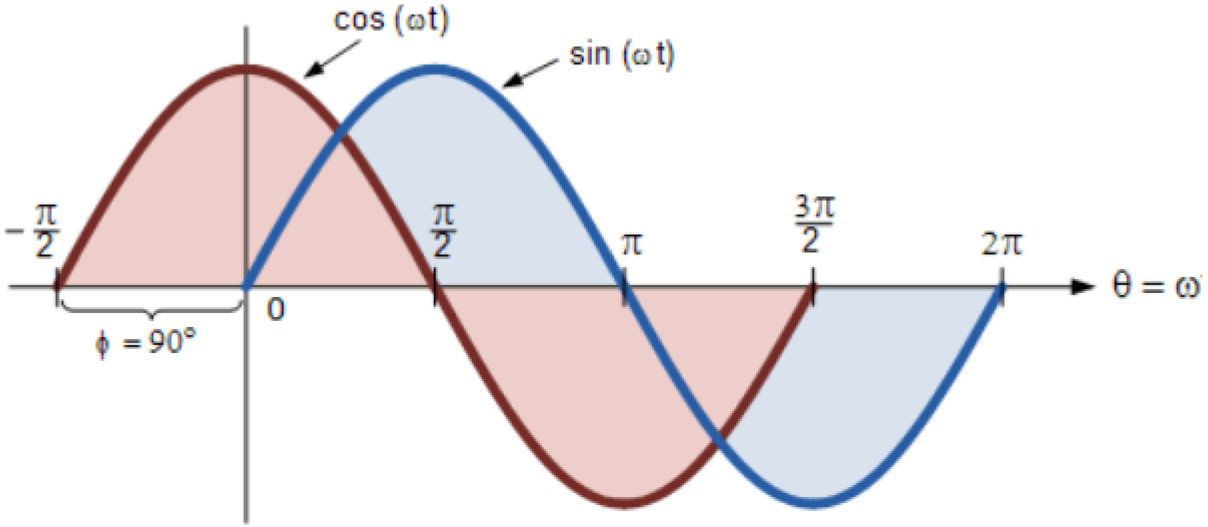


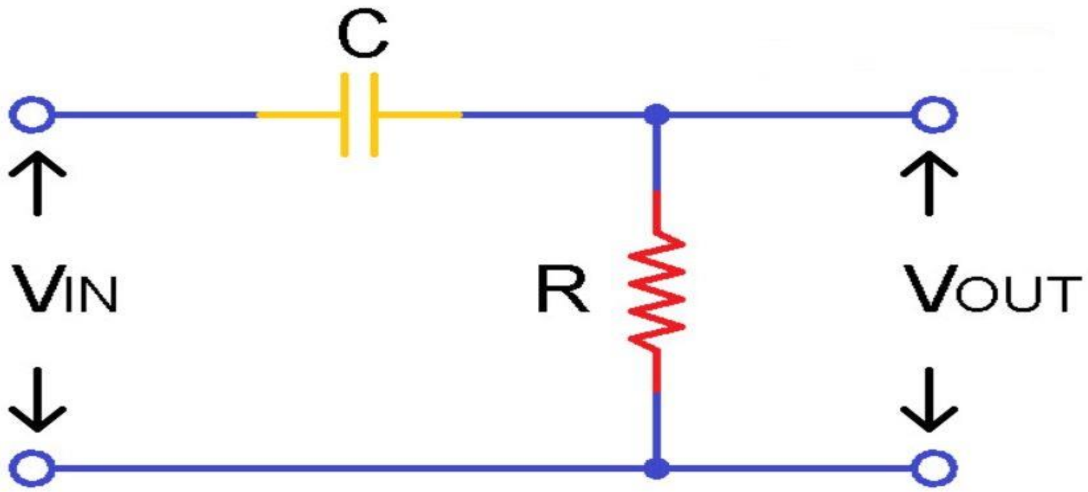
FIG.5.5
Respose of a differentiator to a square wave
(a) Input (b) Output



1. Response of RC HPF to Sine Wave

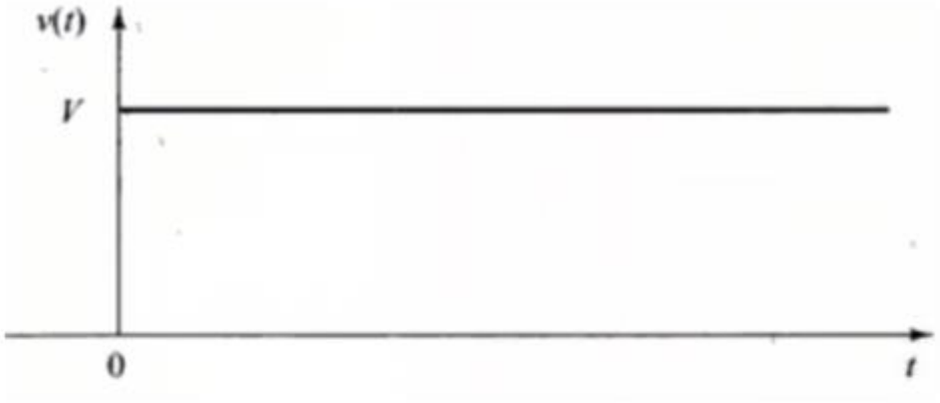
- Output proportional to derivative of input.
- Differentiated version of Sine is Cosine.
- There will be a Phase difference of 90 degrees between input and output.





2. Response of RC HPF to Step Input

- When *Vin* is applied at the input, the capacitor begins to charge and output voltage decays exponentially.

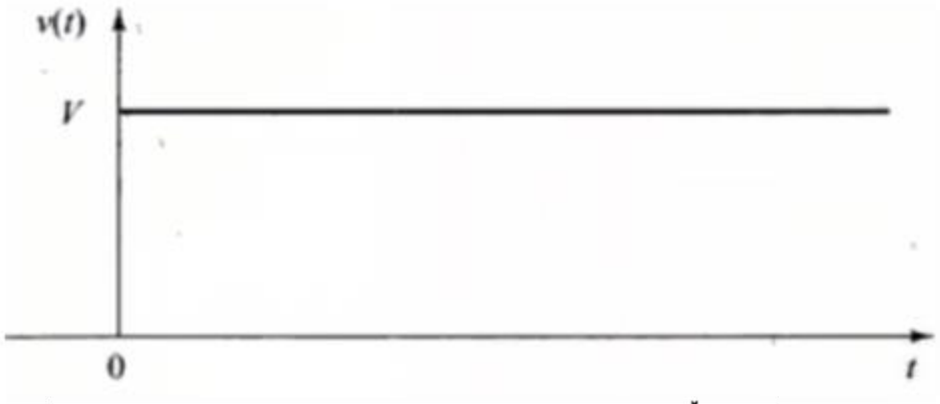


$$v(t) = \begin{cases} 0 & \text{for } t < 0 \\ V & \text{for } t \geq 0 \end{cases}$$

For a step input RC High Pass Filter response is

$$V_0 = V\, e^{-\frac{t}{RC}}$$

2. Response of RC HPF to Step Input



$$v(t) = \begin{cases} 0 & \text{for } t < 0 \\ V & \text{for } t \geq 0 \end{cases}$$

$$V_0 = V\, e^{-\frac{t}{RC}}$$

$t = 0, \quad v_0 = v$

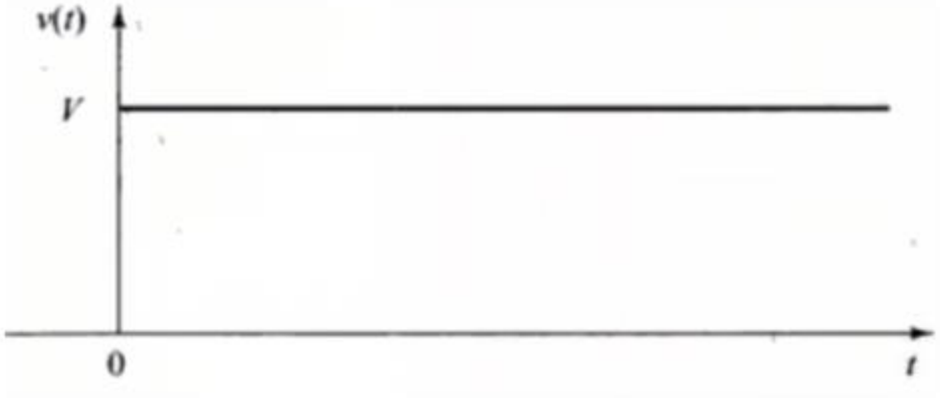
$t = 0 \cdot 5RC, \quad v_0 = v \cdot \mathrm{e}^{-.5} = 0 \cdot 606v$

$t = RC, \quad v_0 = v \cdot \mathrm{e}^{-1} = 0 \cdot 367v$

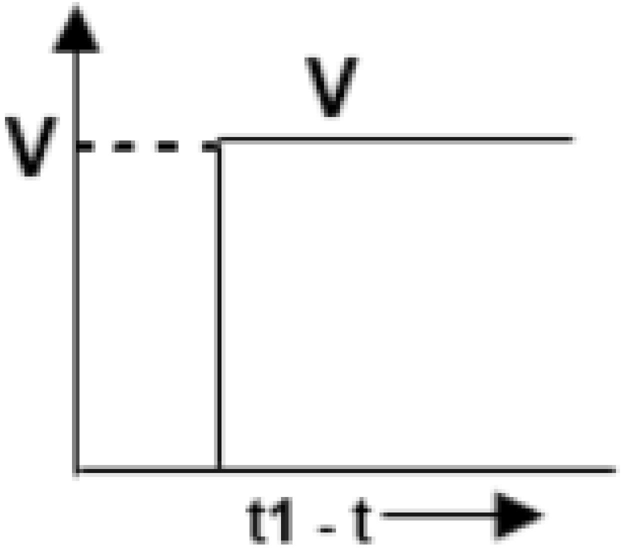
$t = 2RC, \quad v_0 = v \cdot \mathrm{e}^{-2} = 0.135v$

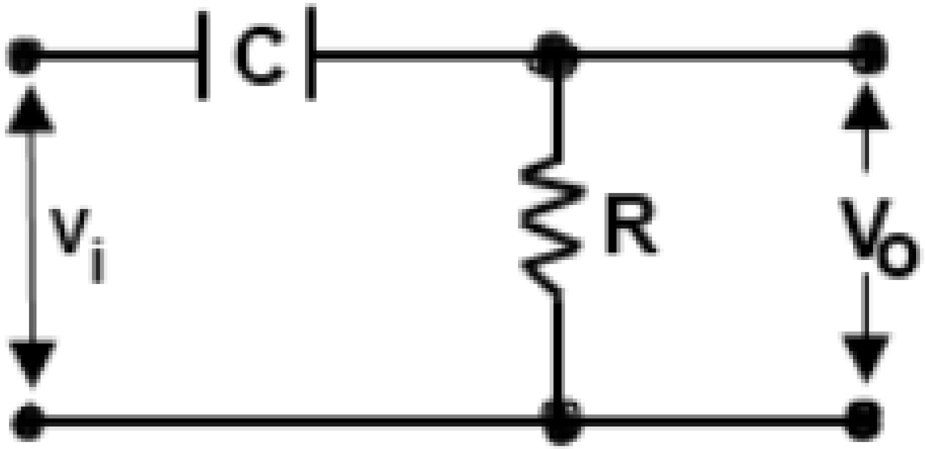
$t = 5RC, \quad v_0 = v \cdot \mathrm{e}^{-5} = 0 \cdot 007v$

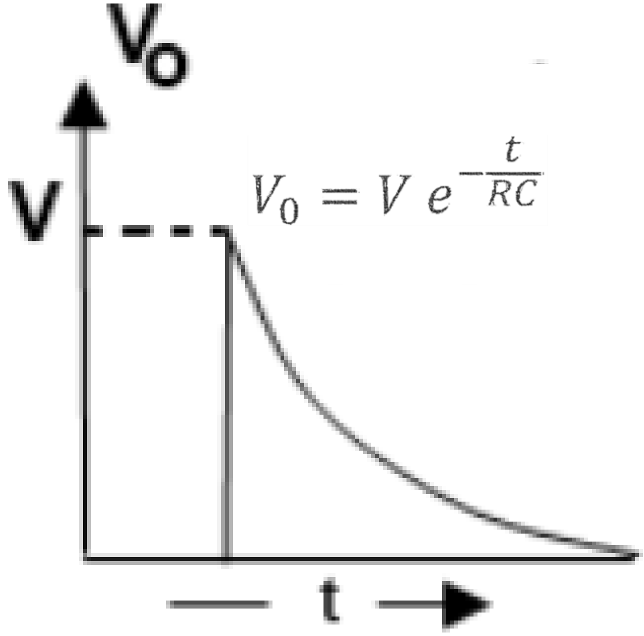
2. Response of RC HPF to Step Input



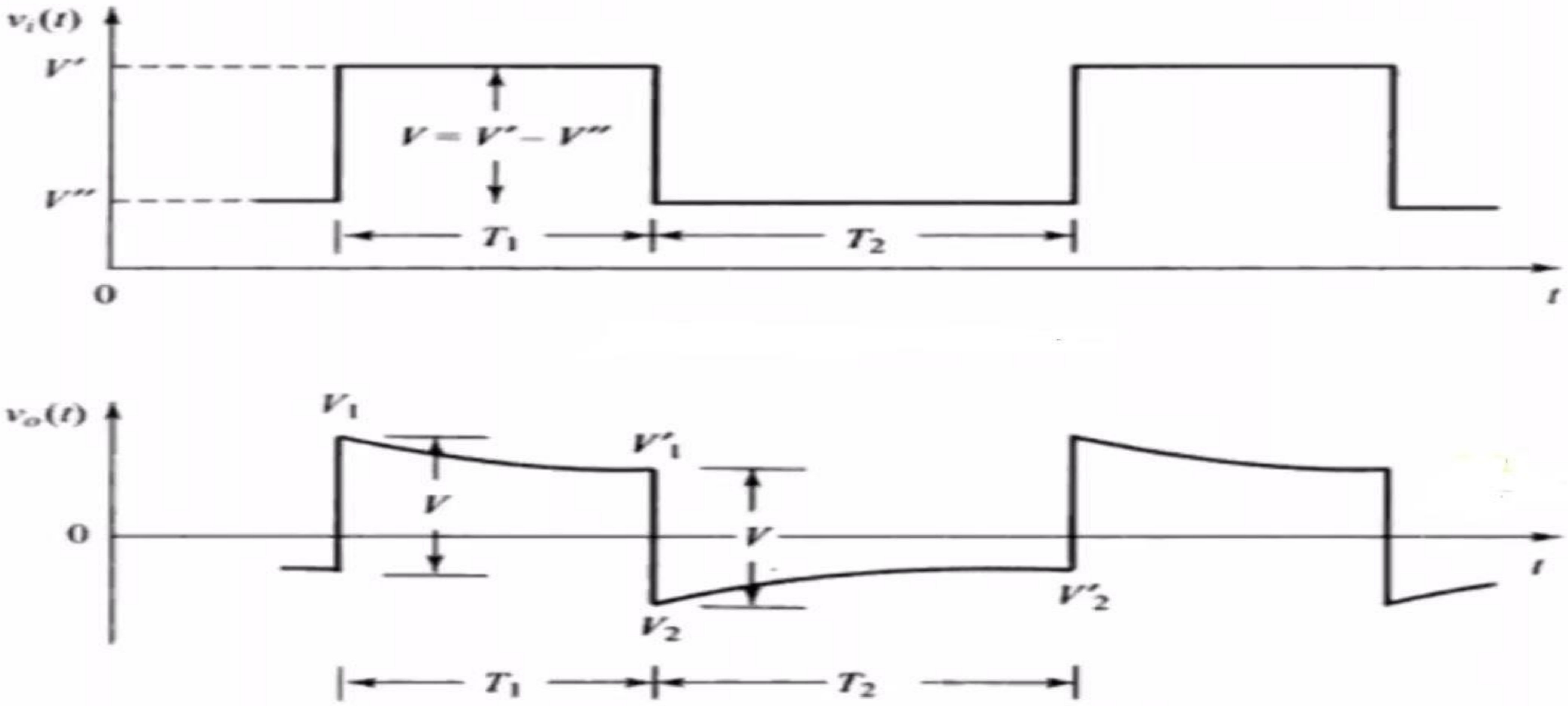
$$v(t) = \begin{cases} 0 & \text{for } t < 0 \\ V & \text{for } t \geq 0 \end{cases}$$





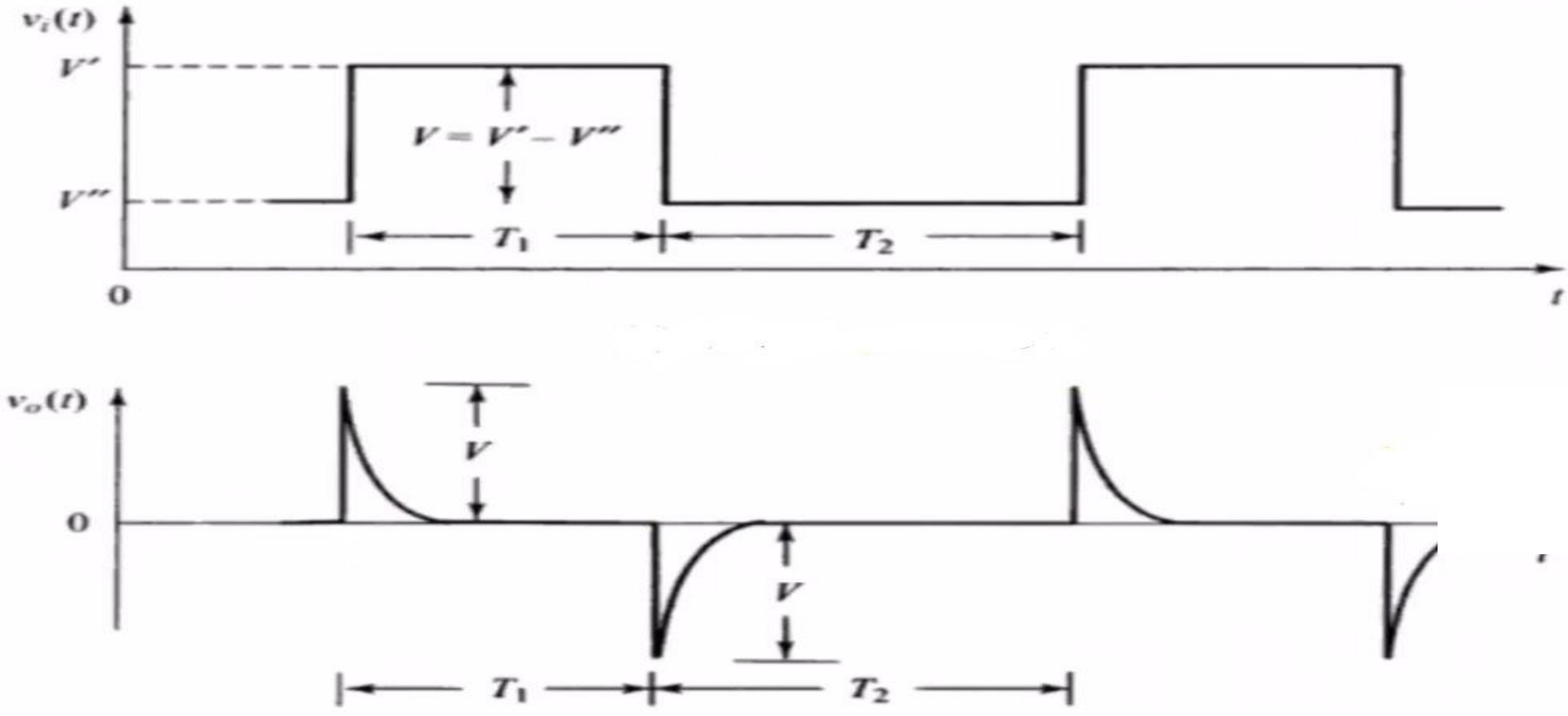


3. Response of RC HPF to Square Input



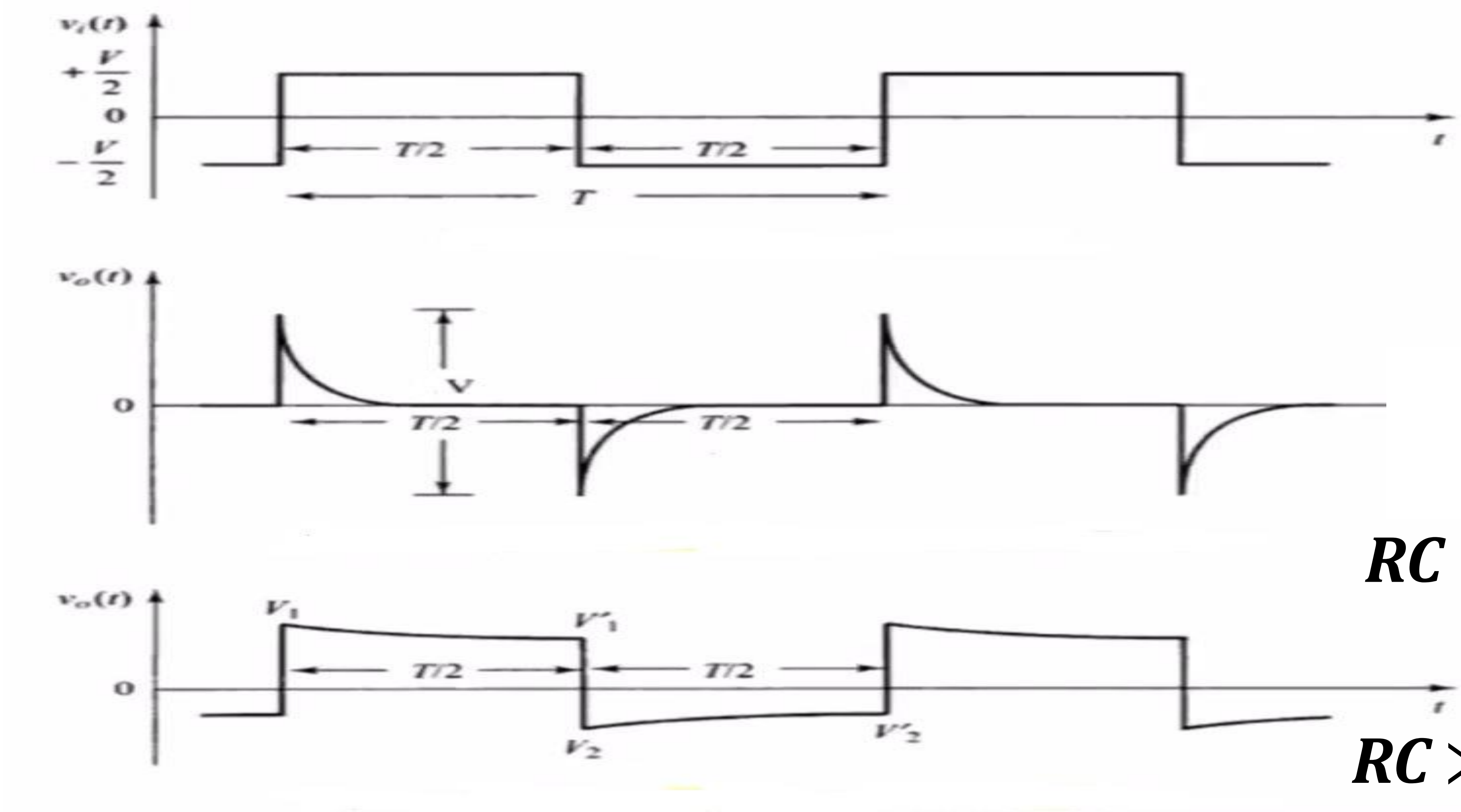
$RC \gg T$

3. Response of RC HPF to Square Input



$RC \ll T$

4. Response of RC HPF to Symmetrical Square Input



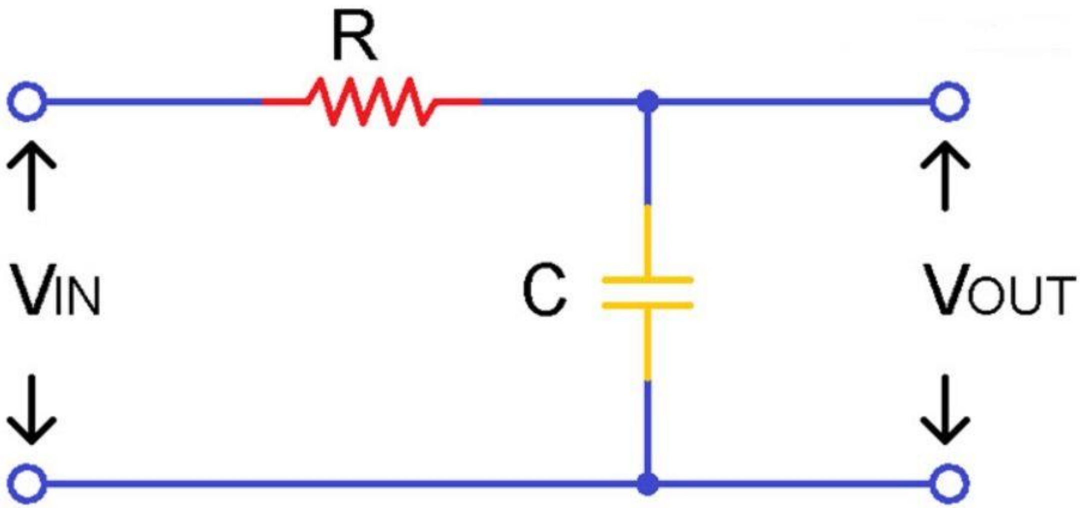
$RC \ll T$

$RC \gg T$

RC LOW PASS FILTER AS INTEGRATOR

- Filter circuit which allows a set of frequencies that are below a specified value. The filter passes the lower frequencies
- The Resistor is connected in series with the Capacitor.
- A LPF can be considered as Integrator if it satisfies certain conditions.
  - Output voltage is directly proportional to Integration of input voltage.

$$\mathbf{V_o \propto \int Vin}$$



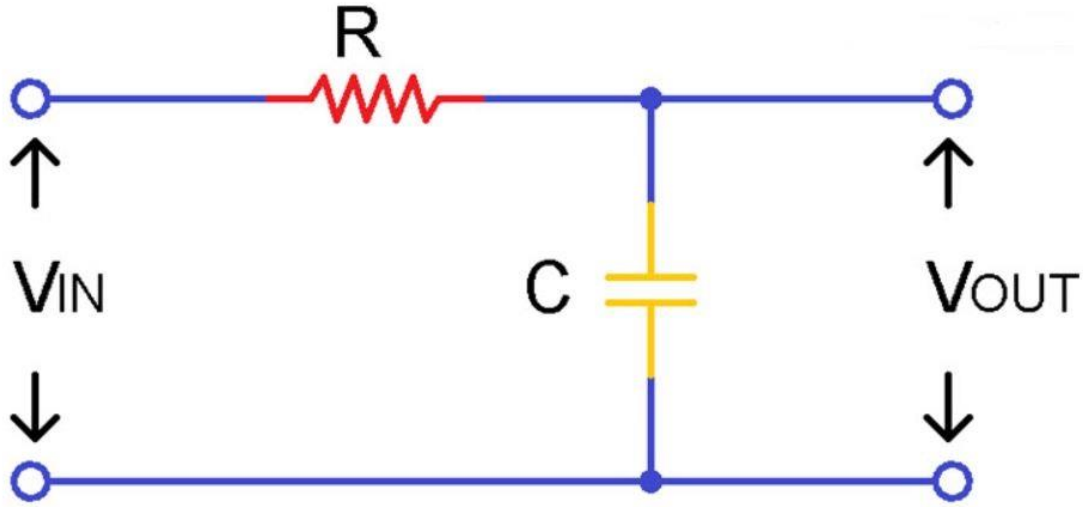
  - The value of R is 10 or more times greater than Xc

$$\mathbf{R \gg 10\, X_C}$$

RC LOW PASS FILTER AS INTEGRATOR

- The time constant τ (RC) of the circuit should be very large as compared to the time period of input wave.

$$\mathbf{RC \gg 16T}$$



$$\frac{V_o}{V_i} = \frac{1}{1 + j2\pi fRC}$$

The phase angle between input and output is

$$\angle\frac{V_o}{V_i} = -\tan^{-1}(2\pi fRC) = -\tan^{-1}(\omega RC)$$

As in a differentiator, the phase angle required is 90^0, which makes $\omega RC = \infty$ which is not a practically realizable situation. So we choose a higher value for ωRC

If $\omega RC \geq 100$ then, phase angle is 89.42^0.

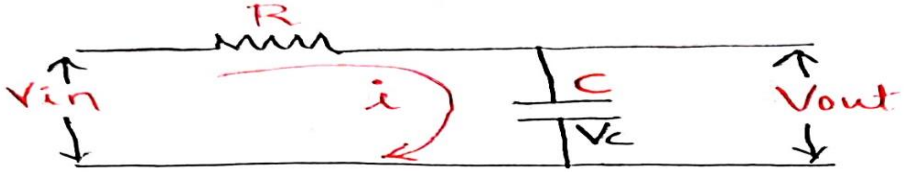
i.e., $$2\pi fRC \geq 100$$

or $$RC \geq \frac{100}{2\pi f}$$

$$RC \geq \frac{100 \times T}{2\pi}$$

i.e. $$\boxed{RC \geq 16T}$$

Input And Output Relationship



$R >> X_C$, $X_C = \frac{1}{2\pi f C}$

$V = \frac{Q}{C} = \frac{\int i\,dt}{C}$; $i = \frac{dQ}{dt}$

$V_{out} = \frac{1}{C}\int i\,dt \longrightarrow (1)$

$V_{in} = iR \longrightarrow (2)$

Sub (2) in (1)

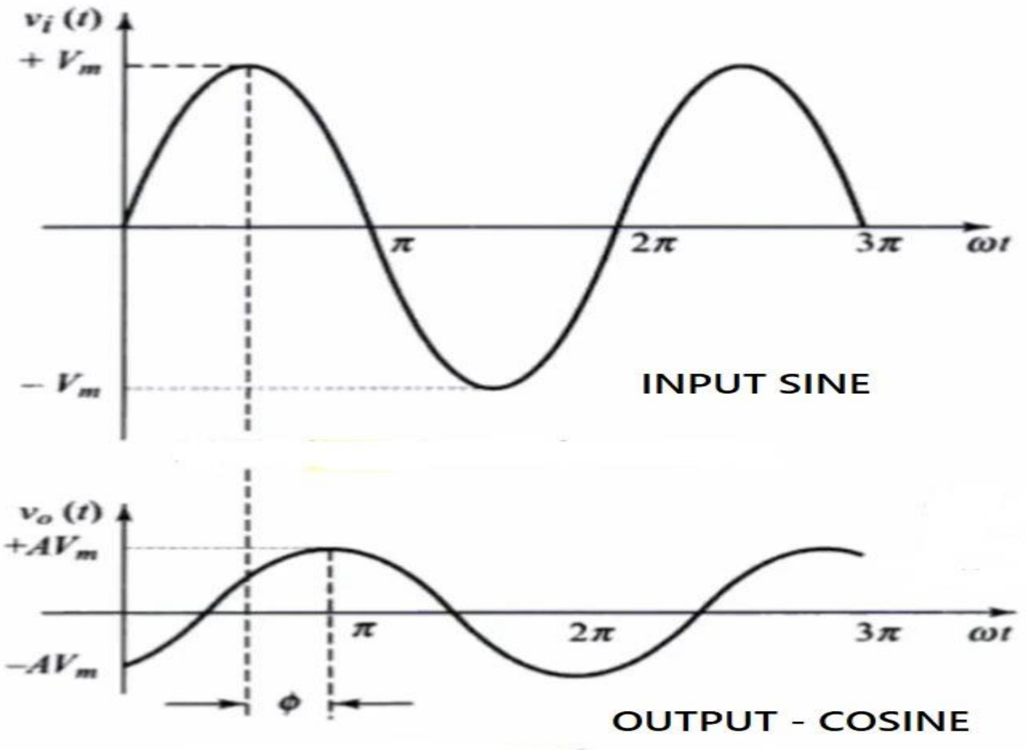
$V_{out} = \frac{1}{C}\int \frac{V_{in}}{R}\,dt$

$$\boxed{V_{out} = \frac{1}{RC}\int V_{in}\,dt}$$

output is proportional to Integral of Input voltage.

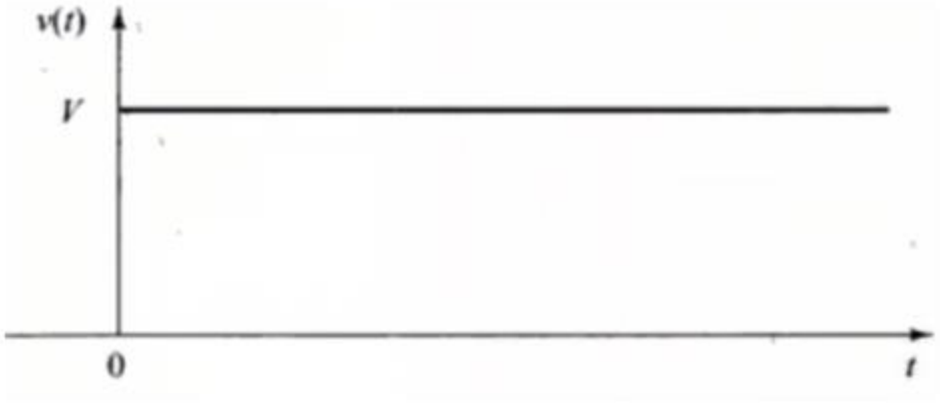
1. Response of RC LPF to Sine Wave

- Output proportional to integration of input.
- Differentiated version of Sine is - Cosine.
- There will be a Phase difference of - 90 degrees between input and output.



2. Response of RC LPF to Step Input

- When *Vin* is applied at the input, output voltage Rises exponentially.

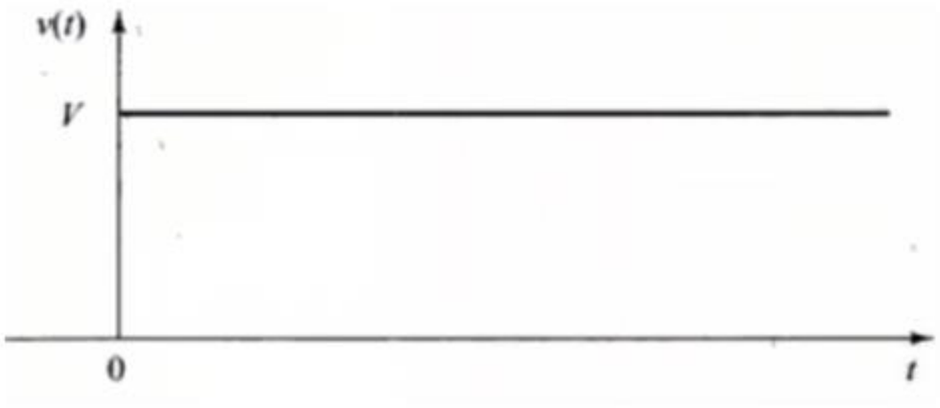


$$v(t) = \begin{cases} 0 & \text{for } t < 0 \\ V & \text{for } t \geq 0 \end{cases}$$

For a step input RC Low Pass Filter response is

$$V_0 = V\,(1 - \; e^{-\frac{t}{RC}})$$

2. Response of RC LPF to Step Input

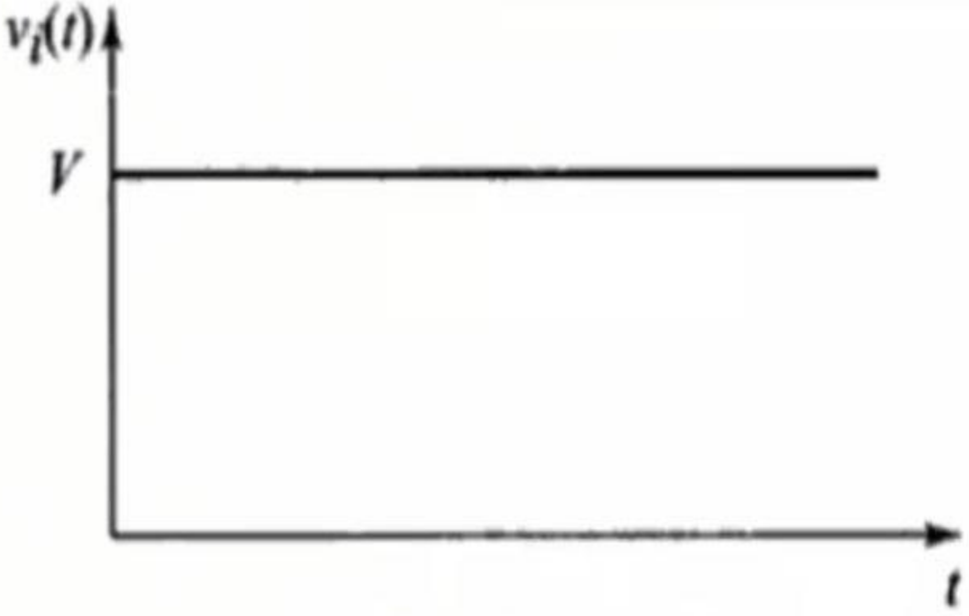


$t = 0, \qquad v_0 = v\,(1 - 1) = 0$
$t = RC, \qquad v_0 = v(1 - e^{-1}) = \quad 0 \cdot 394v$
$t = 2RC, \qquad v_0 = v(1 - e^{-2}) = \quad 0.865v$

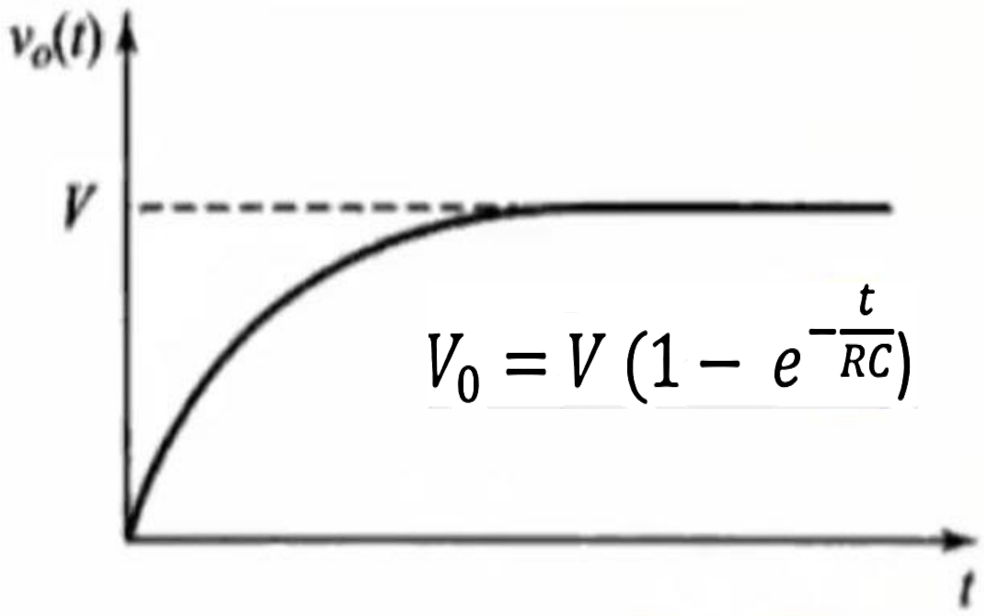
$$v(t) = \begin{cases} 0 & \text{for } t < 0 \\ V & \text{for } t \geq 0 \end{cases}$$

$t = 0, \qquad v_0 = v\,(1 - 1) = 0$
$t = RC, \qquad v_0 = v(1 - e^{-1}) = \quad 0 \cdot 394v$
$t = 2RC, \qquad v_0 = v(1 - e^{-2}) = \quad 0.865v$

2. Response of RC LPF to Step Input



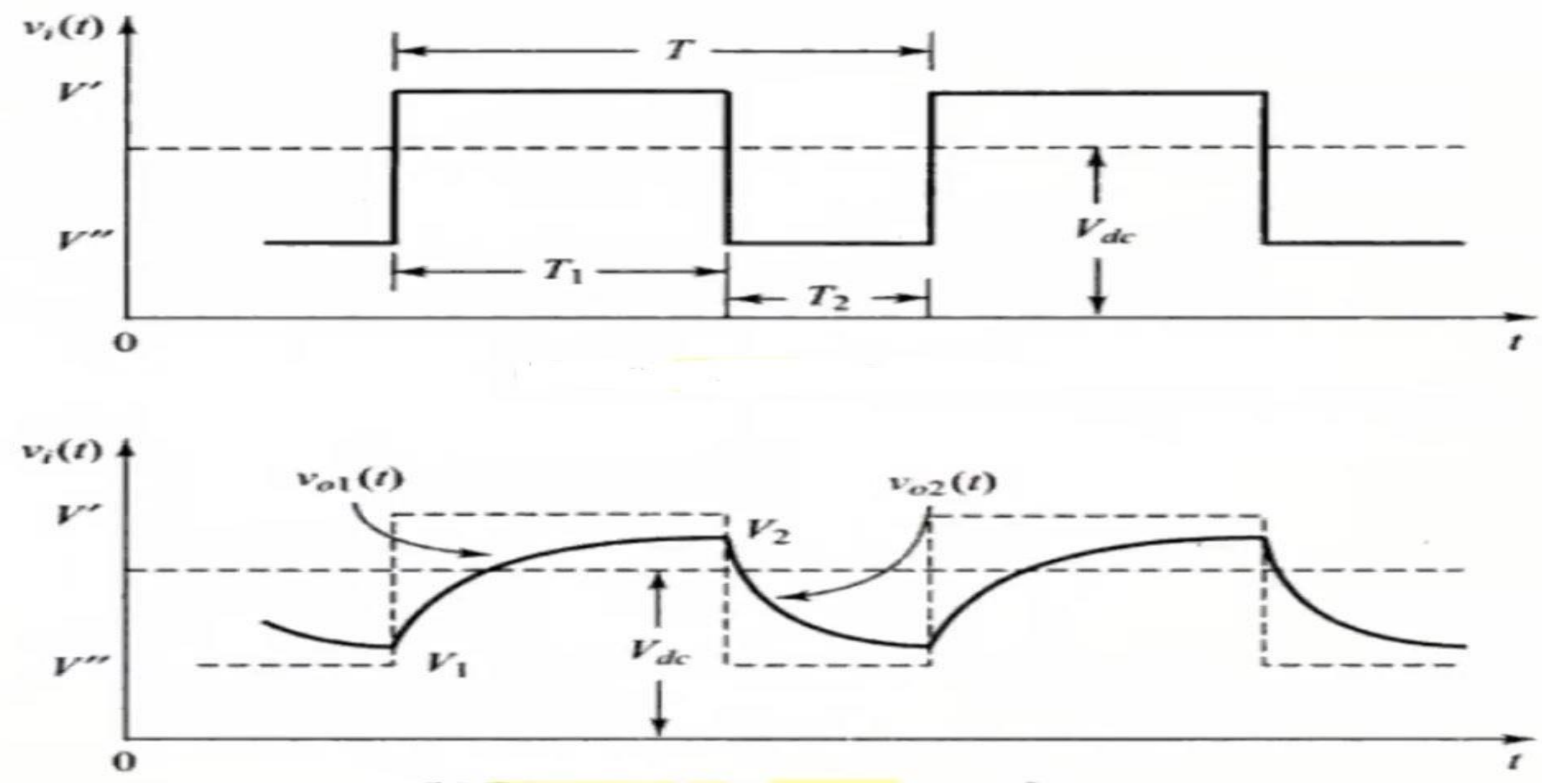
Step Input Waveform



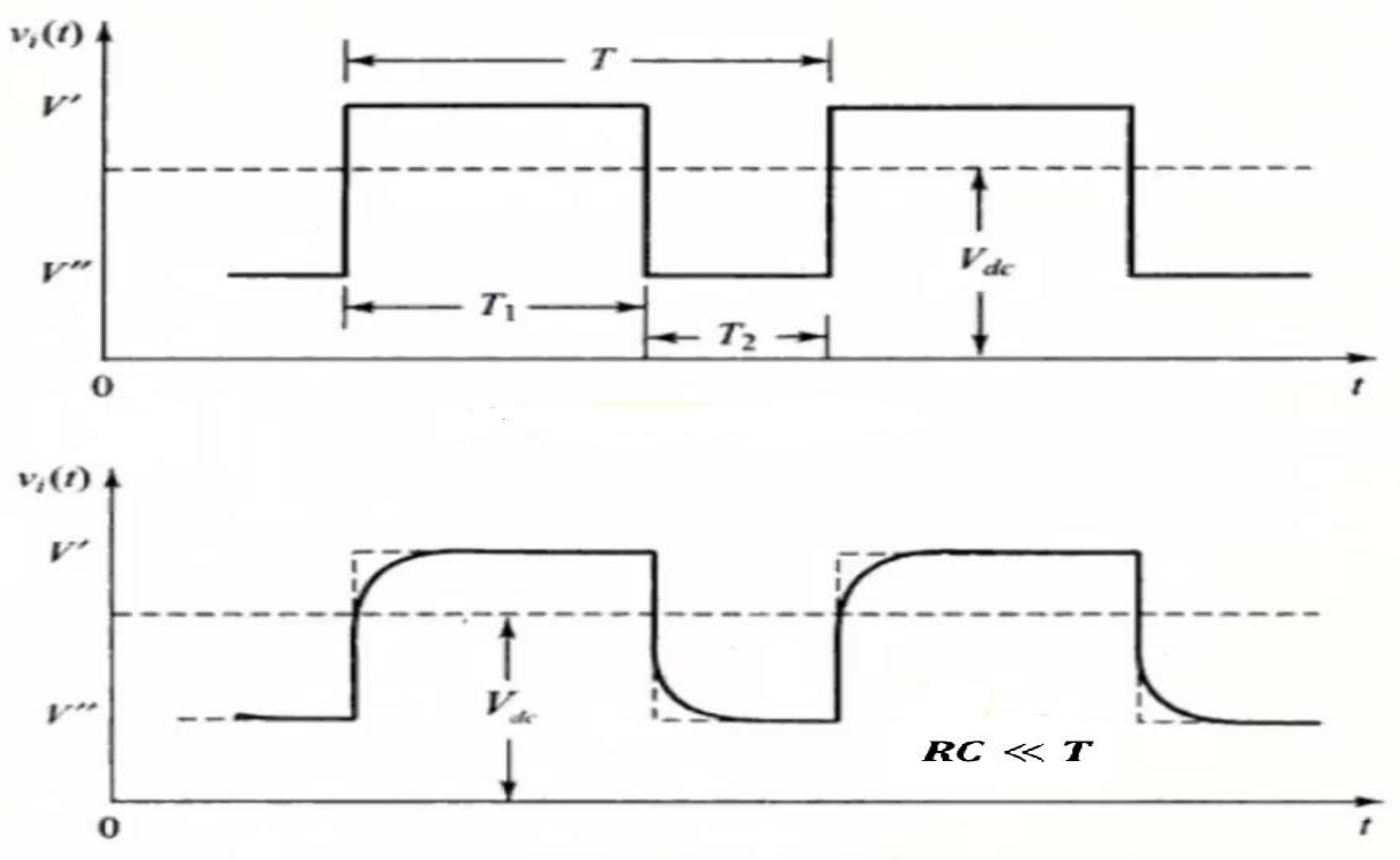
Output Waveform

3. Response of RC LPF to Square Input

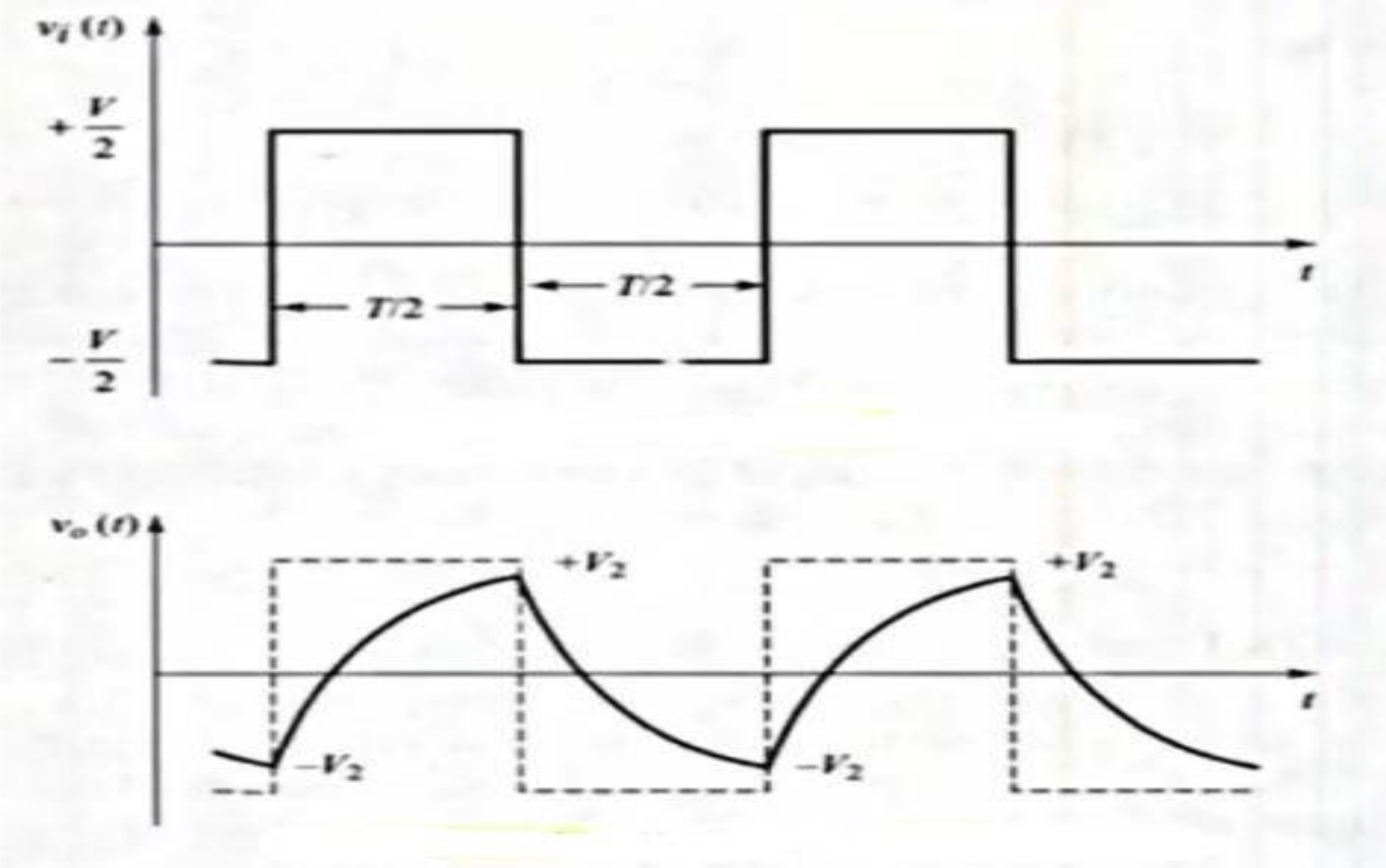
- If input is a Square Wave, output will be Triangular.
- Integration means summation so output will be sum of all input waves at any instant.



3. Response of RC LPF to Square Input



4. Response of RC LPF to Symmetrical Square Input



4. Response of RC LPF to Symmetrical Square Input