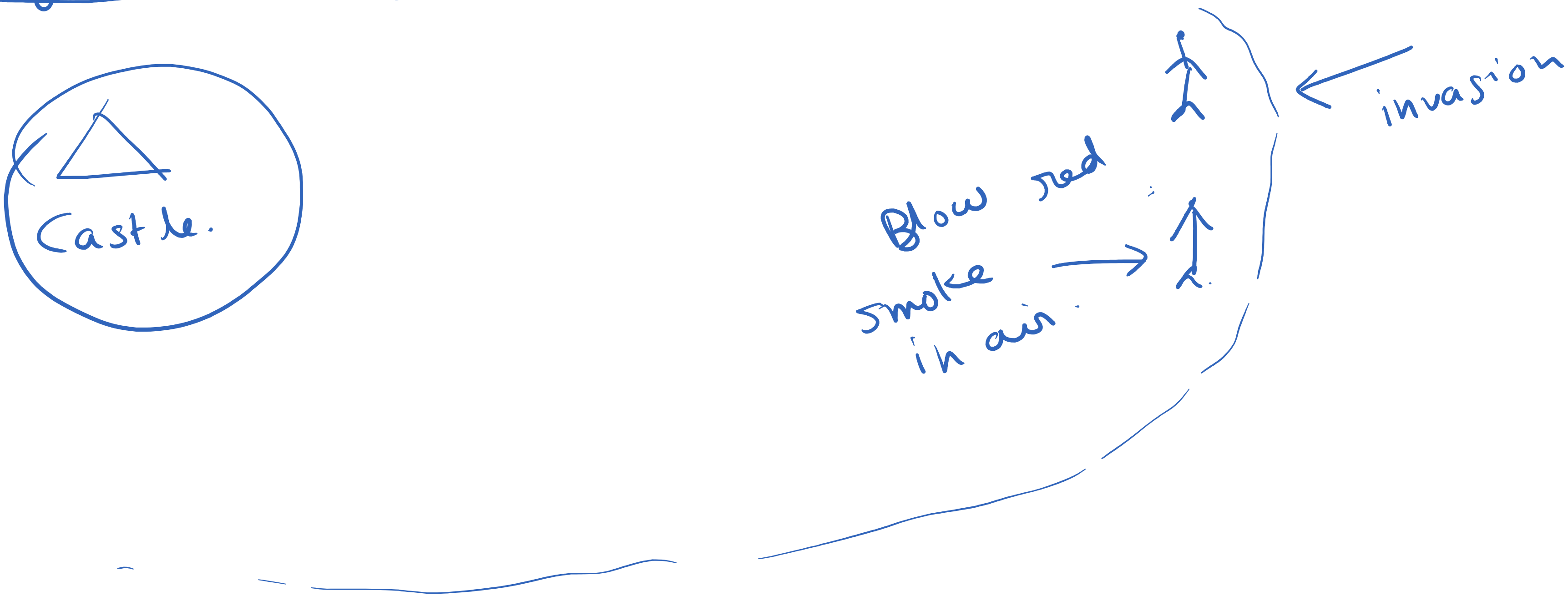
Basic Electronics.

High pass and low pass filters :-

Signal: An agent which contains information.



Mobile phones Internet connection. Etc.

Electromagnetic waves.

Extra EM waves

lightening

Air (Channel)

Sending end (signal is generated)

Noise :- Unwanted EM signal that gets attached to the clean signal.

Receiving end (receives the signal)

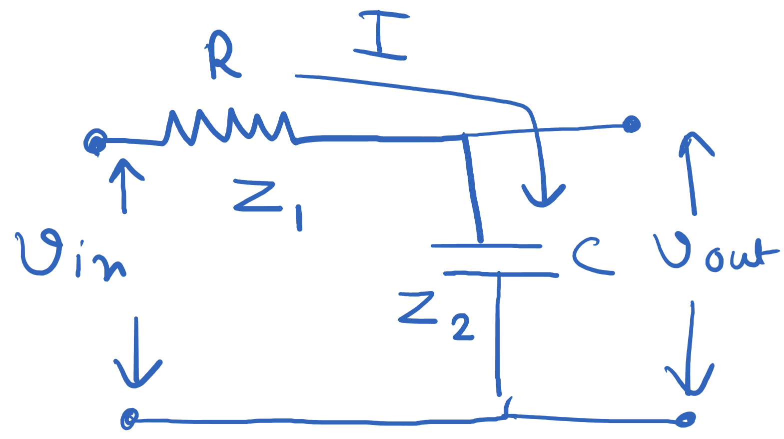
Human voice $\leq$ 20 KHz

Filter: Arrangements that remove unwanted frequencies from your signal. Also known frequency filters.

Low pass filter: Delivers the low frequency components to the output

$$v_{out} = \frac{v_{in}}{Z_1 + Z_2} \times Z_2$$

I



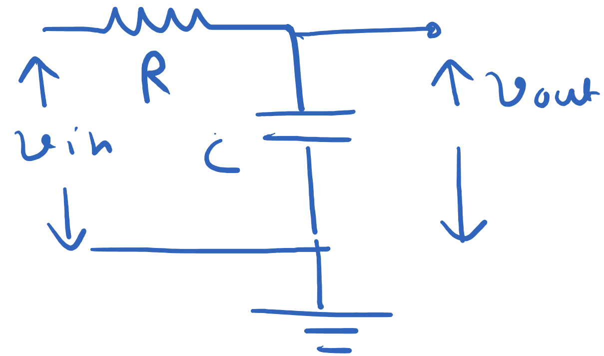
$$= \frac{v_{in} \times \frac{1}{j\omega C}}{R_1 + \frac{1}{j\omega C}}$$

$$Z_1 = R$$

$$Z_2 = \frac{1}{j\omega C}$$

$$= \frac{v_{in}}{Rj\omega C + 1}$$

$$\frac{v_{out}}{v_{in}} = \frac{1}{Rj\omega C + 1}$$



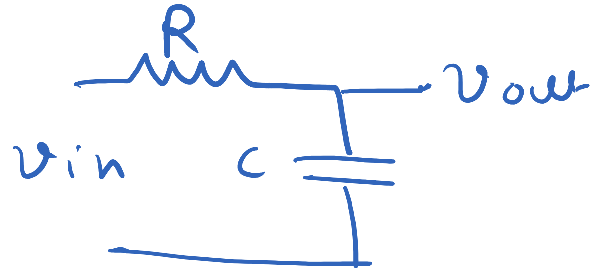
$$\left|\frac{v_{out}}{v_{in}}\right| = \frac{1}{\sqrt{(R\omega C)^2 + 1}}$$

At $\omega << \frac{1}{RC}$, $R\omega C << 1$

$$\left|\frac{v_{out}}{v_{in}}\right| \cong \frac{1}{\sqrt{0+1}} \cong 1$$

$$|v_{out}| \cong |v_{in}|$$

when $(R\omega C) >> 1$

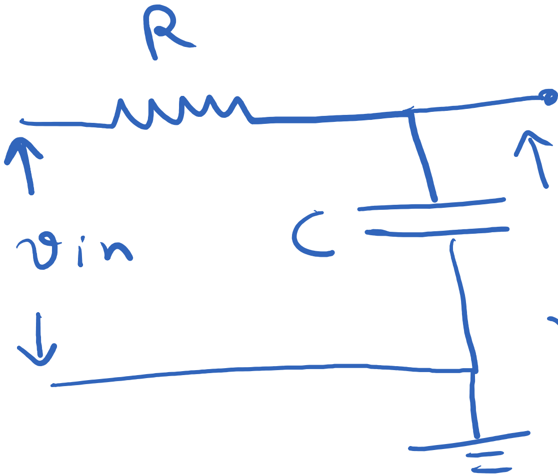


$$\left|\frac{v_{out}}{v_{in}}\right| \simeq \frac{1}{R\omega C} << 1 \simeq 0$$

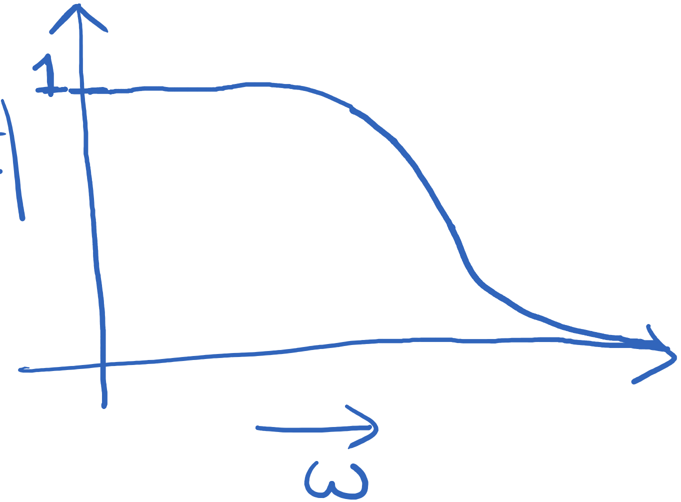
$$\left|\frac{v_{out}}{v_{in}}\right| \simeq 0$$

when ω is low, that is when $\omega << \frac{1}{RC}$, $\left|\frac{v_{out}}{v_{in}}\right| \simeq 1$

when ω is high, that is when $\omega >> \frac{1}{RC}$, $\left|\frac{v_{out}}{v_{in}}\right| \simeq 0$



$$A = \left|\frac{v_{out}}{v_{in}}\right|$$



$\omega = \text{low} \Rightarrow |v_{out}| \cong |v_{in}|$

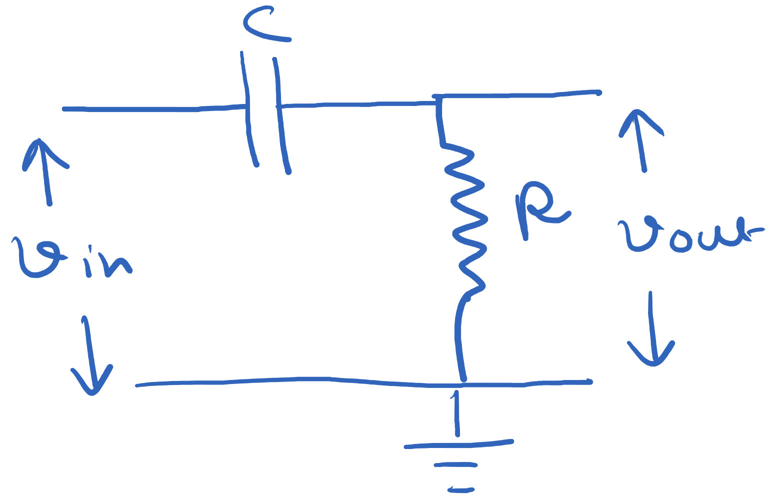
$\omega = \text{high} \Rightarrow |v_{out}| \cong 0$

This circuit acts as a low pass filter.

High-pass filters:- Delivers the high frequency components to the output

$$v_{out} = \frac{v_{in} \times R}{\frac{1}{j\omega C} + R} \, v_{in}$$

$$= \frac{jR\omega C}{jR\omega C + 1} \, v_{in}$$



$$\frac{v_{out}}{v_{in}} = \frac{jR\omega C}{jR\omega C + 1} \Rightarrow \left|\frac{v_{out}}{v_{in}}\right| = \frac{R\omega C}{\sqrt{(R\omega C)^2 + 1}}$$

When ω is low or $\omega << \frac{1}{RC} \Rightarrow R\omega C << 1$

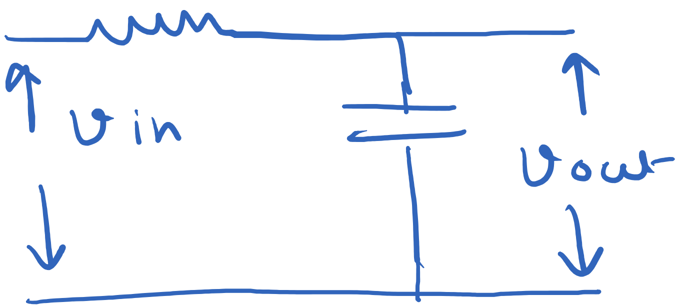
$$\left|\frac{v_{out}}{v_{in}}\right| \simeq R\omega C \simeq 0 \Rightarrow |v_{out}| \simeq 0$$

When ω is high, or $\omega >> \frac{1}{RC} \Rightarrow R\omega C >> 1$

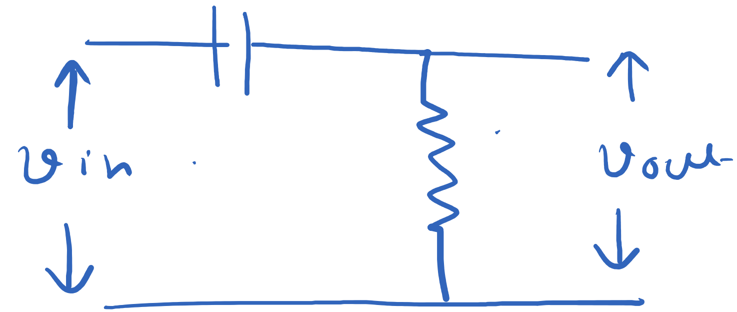
$$\left|\frac{v_{out}}{v_{in}}\right| \simeq \frac{R\omega C}{R\omega C} = 1 \Rightarrow |v_{out}| \simeq 1$$

This acts as a high pass filter

Low pass



High pass filter



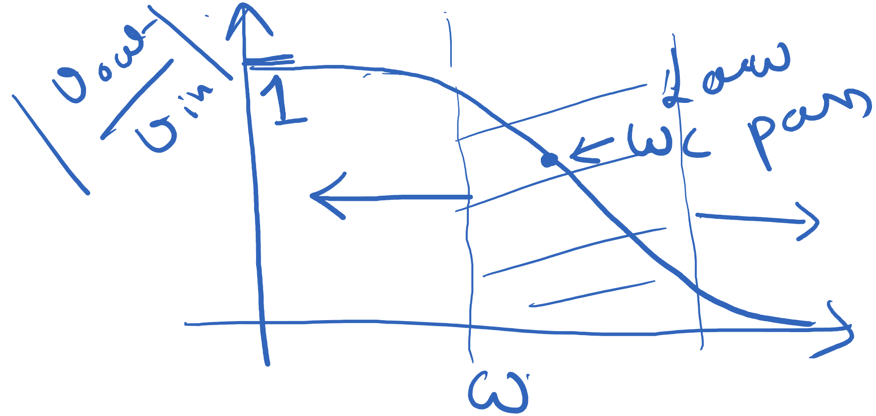
Capacitor:- 1) Acts as a open circuit at low frequency.

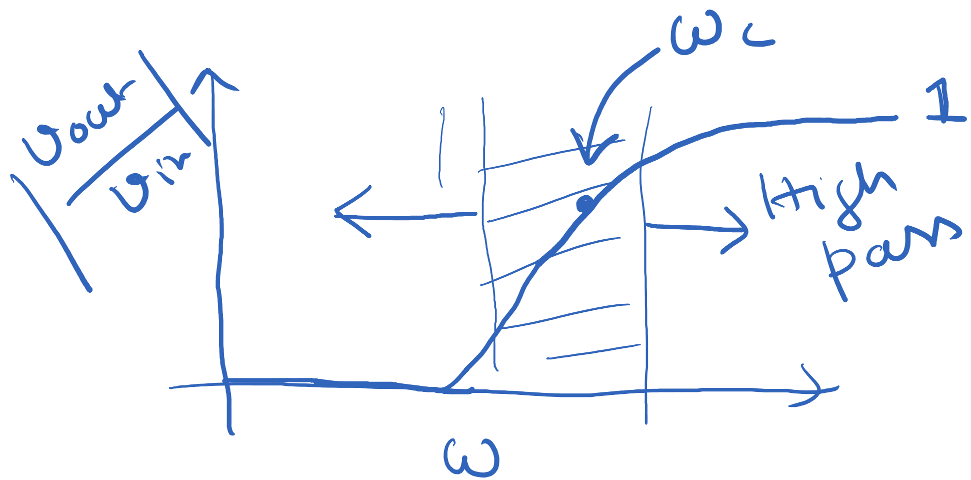
2) Acts as short circuit at high frequency.

Cut-off frequency:-

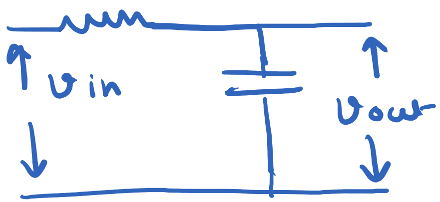
At $\omega = \omega_c$,

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





Low pass



$$\left|\frac{v_{out}}{v_{in}}\right| = \frac{1}{\sqrt{(R\omega_c C)^2 + 1}} = \frac{1}{\sqrt{2}}$$

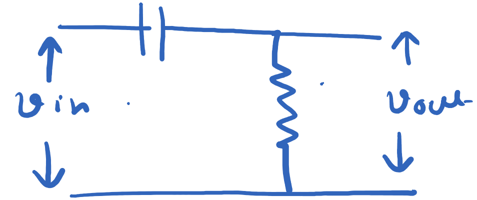
$$\Rightarrow (R\omega_c C)^2 + 1 = 2$$

$$\Rightarrow (R\omega_c C)^2 = 1$$

$$R\omega_c C = 1 \Rightarrow \omega_c = \frac{1}{RC}$$

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

High pass filter



$$\left|\frac{v_{out}}{v_{in}}\right| = \frac{R\omega_c C}{\sqrt{(R\omega_c C)^2 + 1}} = \frac{1}{\sqrt{2}}$$

$$\Rightarrow (R\omega_c C)^2 + 1 = 2\,(R\omega_c C)^2$$

$$\Rightarrow (R\omega_c C)^2 = 1$$

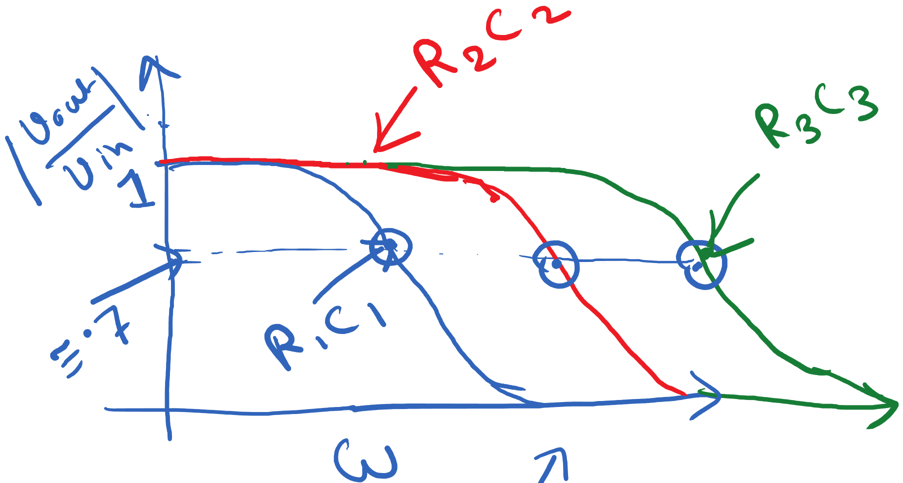
$$\Rightarrow \omega_c = \frac{1}{RC}$$

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

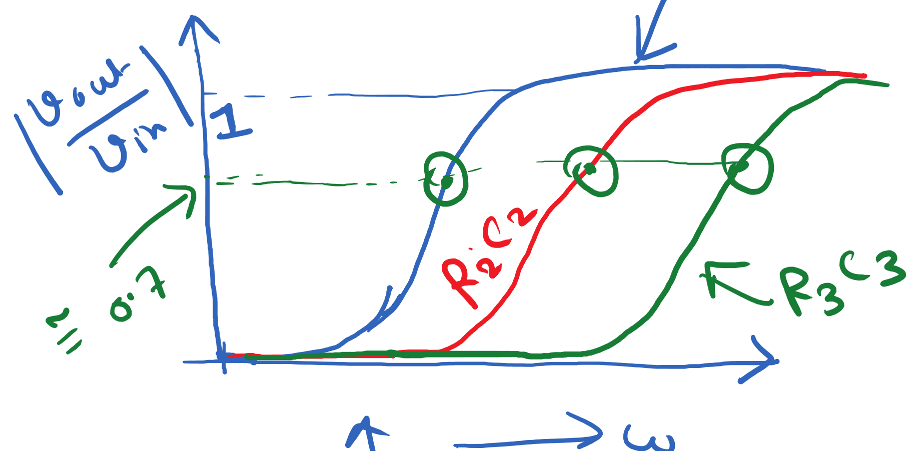
$$f_c = \frac{1}{2\pi RC}, \quad \omega_c = \frac{1}{RC}$$

Can we control the cut-off frequency?

R_1C_1



Low pass filter



High pass filter

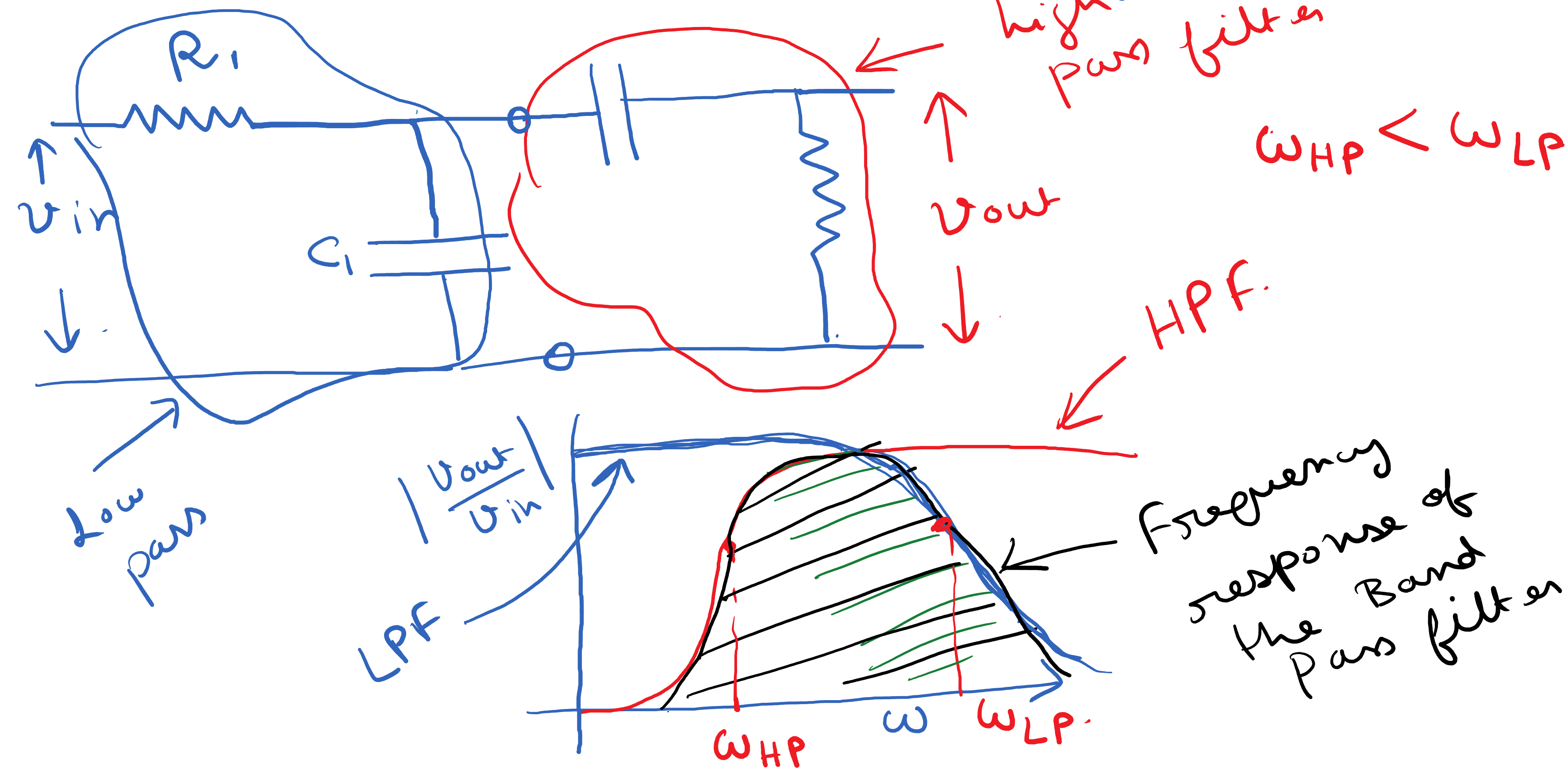
Transfer characteristics

$$R_1C_1 > R_2C_2 > R_3C_3$$

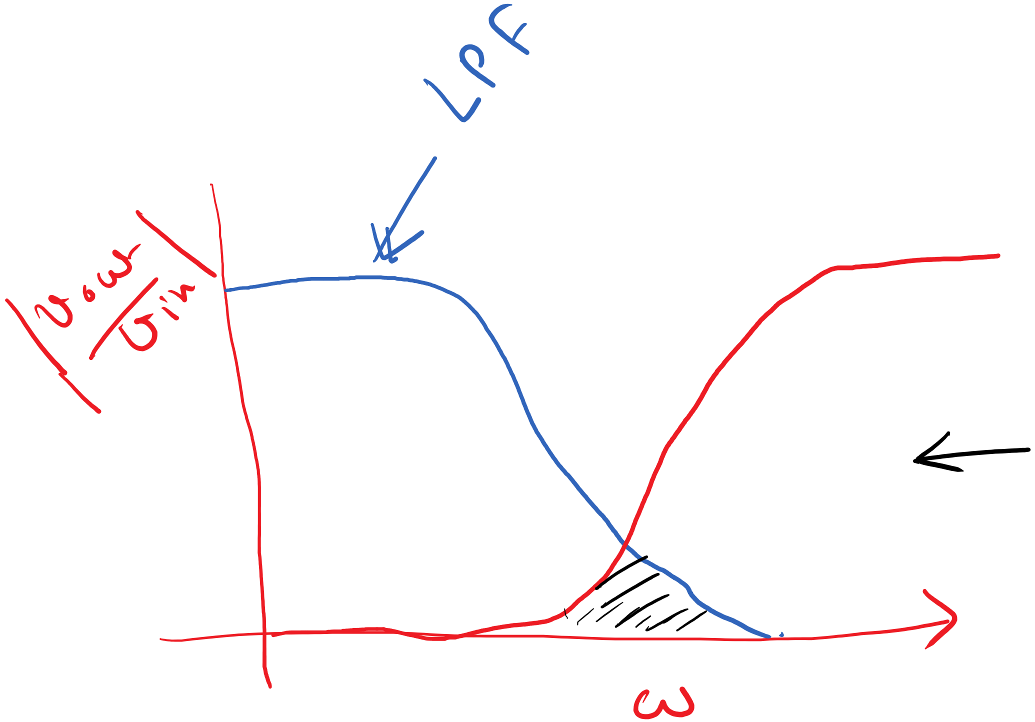
If we decrease the RC product, then the cut-off frequency for both low pass and high pass filter is going to increase.

Class-2

Band-pass Filter: Passes a Band of frequencies



$\omega_{HP} < \omega_{LP}$



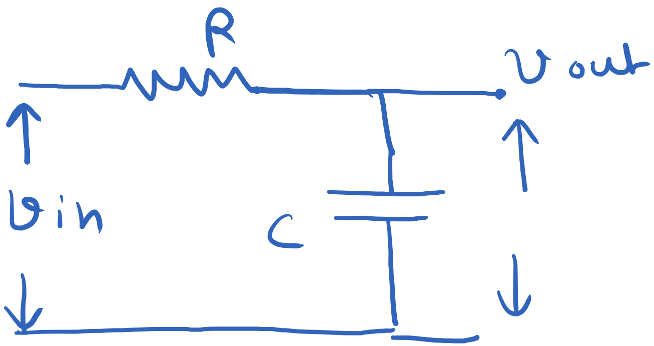
$\omega_{HP} > \omega_{LP}$

This doesn't act as a Band Pass filter

To get a Band pass filter, we must have $\omega_{HP} < \omega_{LP}$

Band pass filters: Filters out a band of frequencies from the input signal. Rejects the extreme high frequency and extreme low frequency components.

Low pass filter as an integrator:



$$v_{out} = \frac{1}{j\omega RC + 1} v_{in}$$

If $\omega RC \gg 1$,

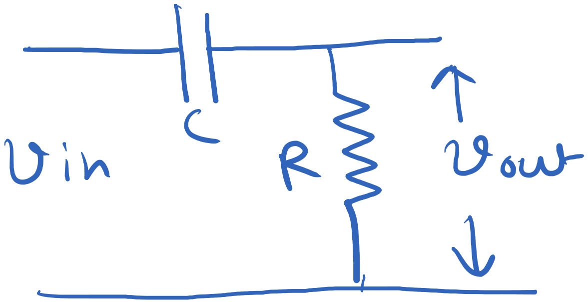
$$v_{out} \simeq \frac{1}{j\omega RC} v_{in}$$

Doing the inverse Fourier Transform,

$$v_{out}(t) \simeq \int \frac{1}{RC} v_{in}(t)\, dt$$

$$= \frac{1}{RC} \int v_{in}(t)\, dt.$$

High pass filter as a differentiator:-



$$v_{out} = \frac{j\omega RC}{j\omega RC + 1} v_{in}$$

If $\omega RC << 1$

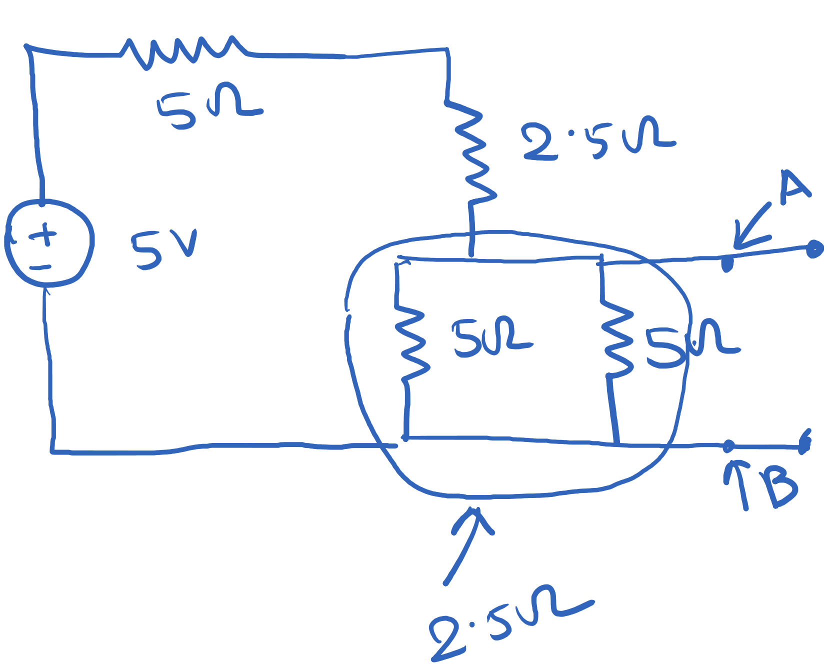
$$v_{out} \cong j\omega RC\, v_{in}$$

Doing the inverse Fourier Transform,

$$v_{out}(t) \cong RC \frac{d}{dt}\left[v_{in}(t)\right]$$

Thevenin's Theorem:

Any combination of independent voltage and current sources and resistors can be replaced by a single voltage source (V_{TH}) and a resistor (R_{TH}) in series with V_{TH}. The value of V_{TH} is equal to the open circuit voltage between the two terminals. V_{TH} is called the Thevenin's voltage

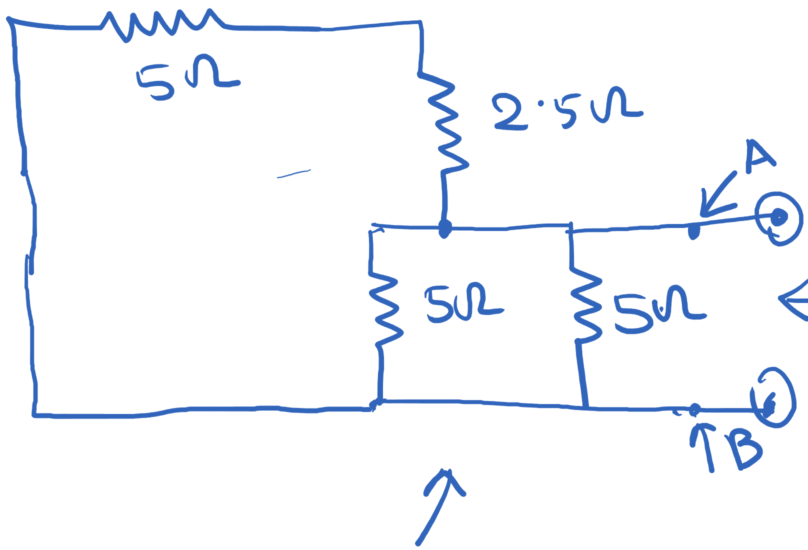


What is V_{TH} between the terminals A and B?

$$V_{TH} = 5V \times \frac{2.5\Omega}{10\Omega}$$

$$= 1.25V$$

R_{TH} is the resistance between the two terminals with all the voltage sources replaced by short circuit and all the current sources replaced by open circuit. R_{TH} is called Thevenin's resistance



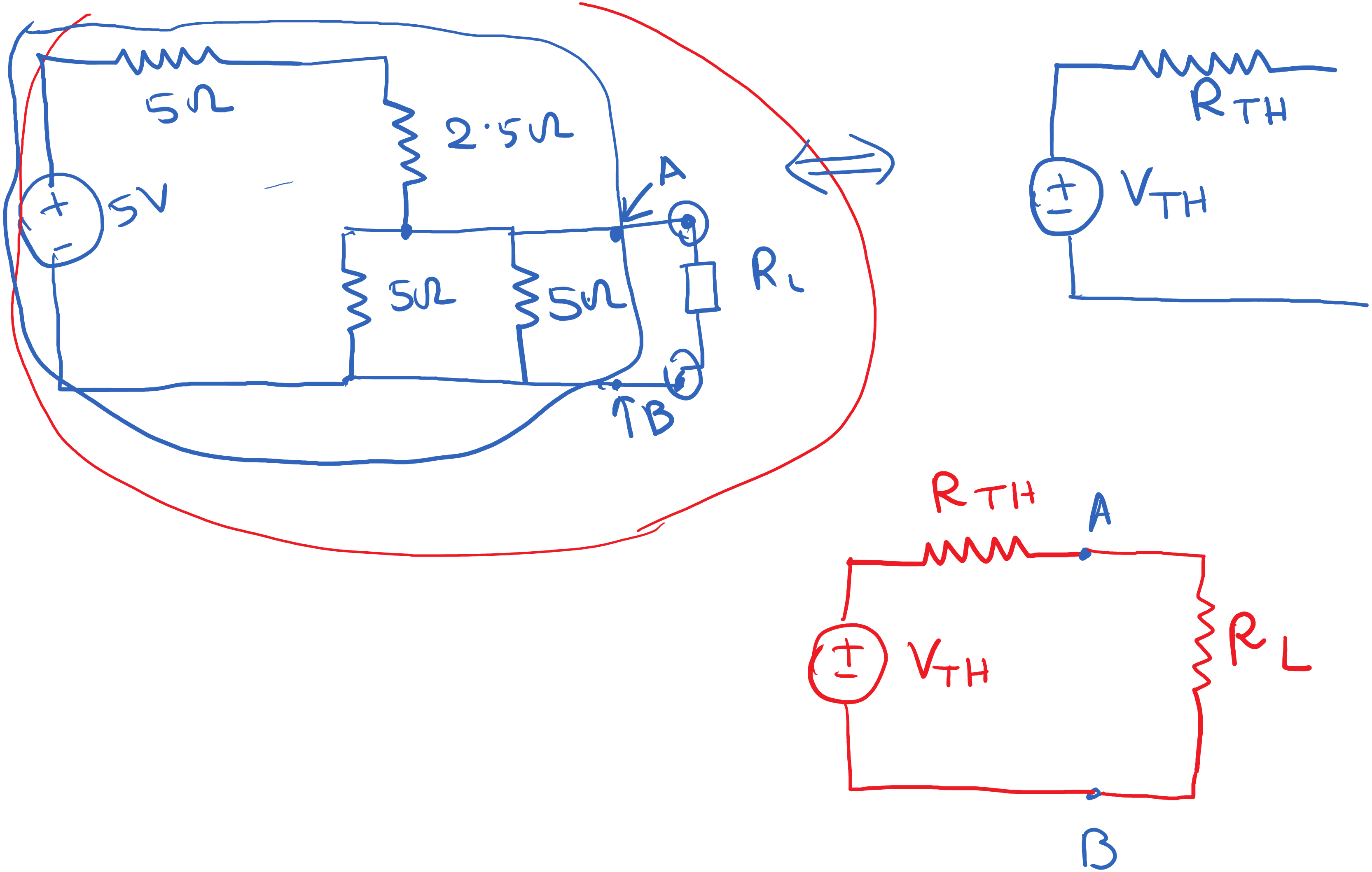
R_{TH} ?

$$R_{TH} = (5\Omega) \,||\, (5\Omega) \,||\, (2{\cdot}5+5)\Omega$$

$$= 5\Omega \,||\, 5\Omega \,||\, 7{\cdot}5\Omega$$

$$= \frac{1}{\frac{1}{5} + \frac{1}{5} + \frac{1}{7{\cdot}5}}\,\Omega$$

$$= \frac{15}{8}\,\Omega$$


5Ω
2·5Ω
5V
5Ω
5Ω
A
B
R_L
R_TH
V_TH
R_TH
A
V_TH
R_L
B

Class - 3

Classification of materials based on conductivity

- Metals (high conductivity)
- Semiconductors (moderate to low conductivity)
- Insulators (zero conductivity)

We can introduce impurities in semiconductors to manipulate or enhance their conductivity. This property makes semiconductors very attractive from the perspective of electronic device fabrication.

Elemental semiconductors: These are mainly semiconductors consisting of only one element. Generally these are Gr-IV elements in the periodic table. Eg: Si, Ge.

Compound semiconductors:- These semiconductors consist of more than one element.

Eg: Gr III - Gr V compounds → GaAs, GaN.

$\underbrace{\text{· Gr-II - Gr VI}}_{\text{not generally used.}}$

$$Si \rightarrow \underbrace{1s^2\, 2s^2\, 2p^6\, \boxed{3s^2\, 3p^2}}_{\text{Isolated atom of Si}}$$

Also known as Valence Electrons

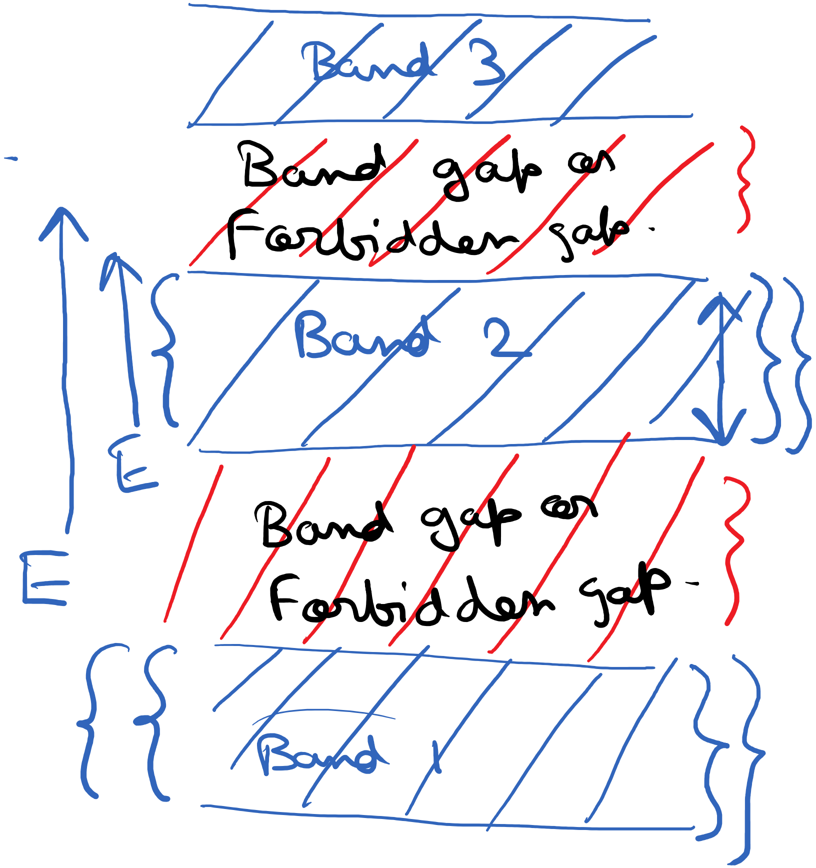
1 2 3

Outermost shell of Si.

These electrons Take part in bond formation

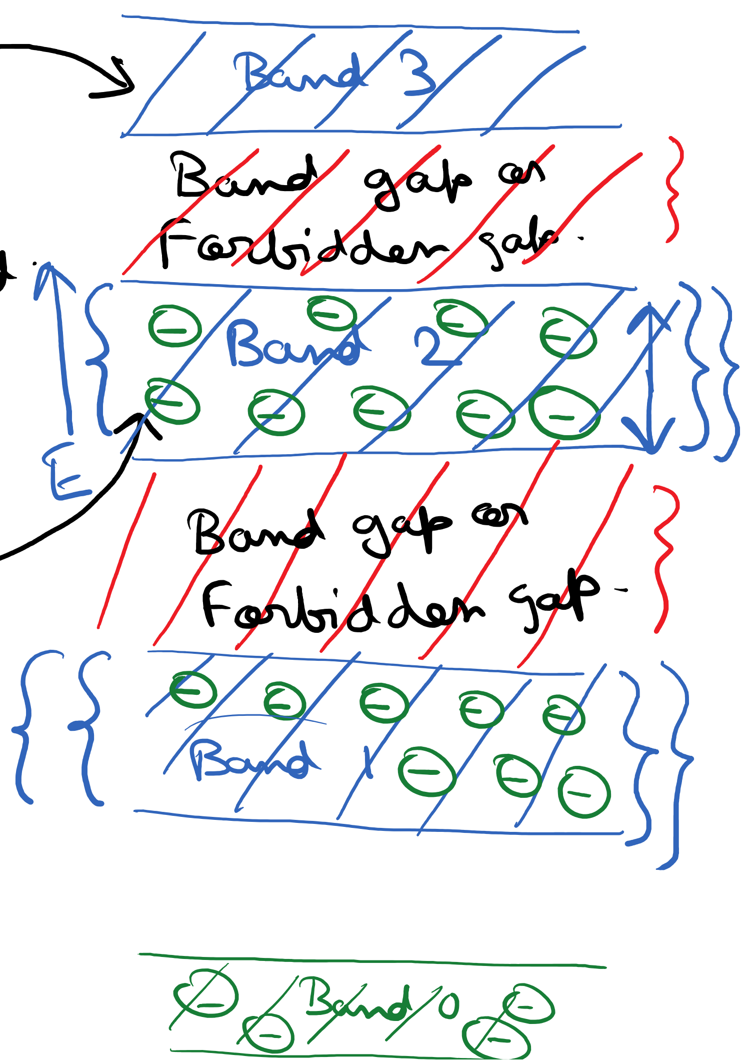
A single isolated Si atom has discrete energy states (orbitals). When these atoms are brought closer to each other, these orbitals must broaden out to form energy bands (because no two electrons can stay in the same state). Energy bands are basically a range of energy in which electrons can stay.

Two energy bands are separated by an energy gap. or Band gap. No electrons can stay in the band gap. Band gap is a range of energy in which electrons can't reside.



Lowest energy Band that is completely empty at 0K. This is known as the conduction Band.

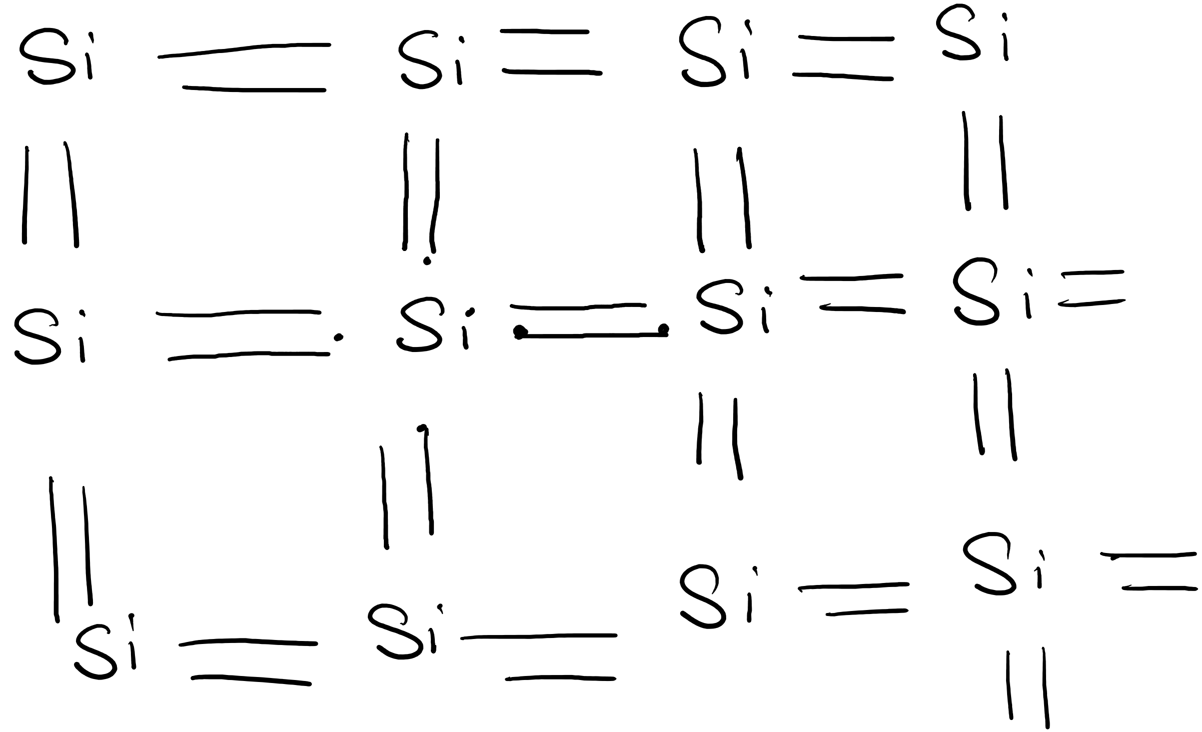
Highest Band that is completely filled at 0K. This is known as Valence Band.



~~Band~~ 0

$Si \rightarrow 1s^2\, 2s^2\, 2p^6\, \underbrace{3s^2\, 3p^2}_{\text{Valence electrons}}$

Valence electrons reside in the valence band at 0K. All the bands above the valence band are completely empty at 0K

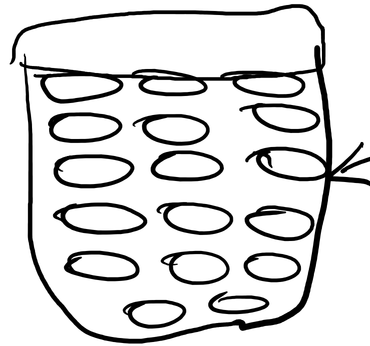


At 0K,

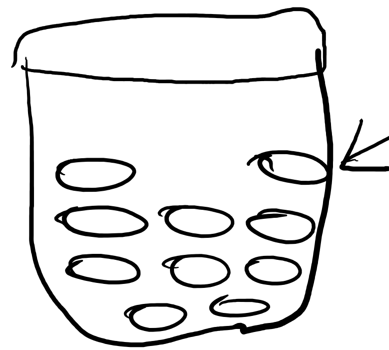
Valence band is completely filled $\rightarrow$ A completely filled band doesn't give rise to current. And so the VB doesn't conduct at 0K.

Conduction Band is completely empty. $\Rightarrow$ doesn't give rise to current flow.

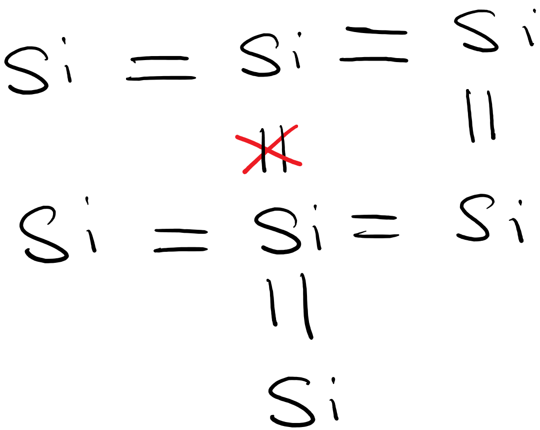
So, at 0K, a semiconductor behaves as an insulator.

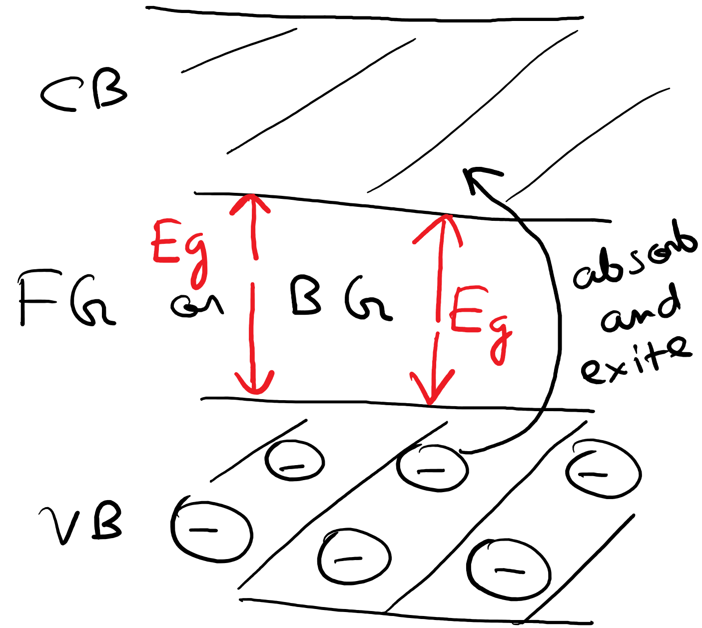


Capsules cant move around



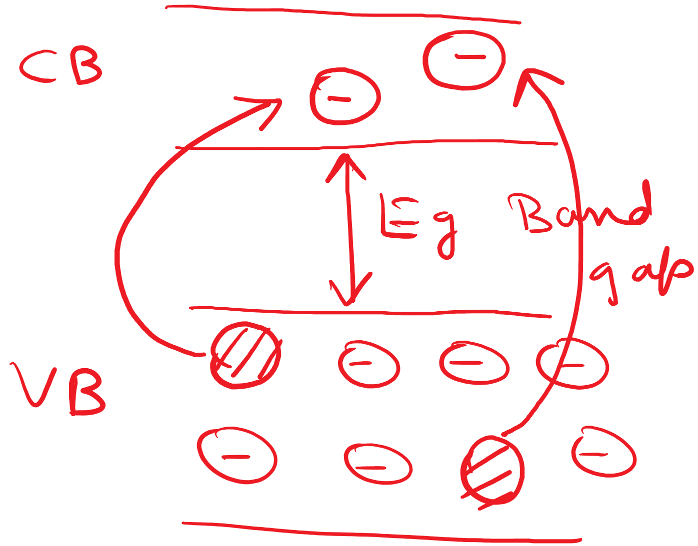
Now the capsules move around .



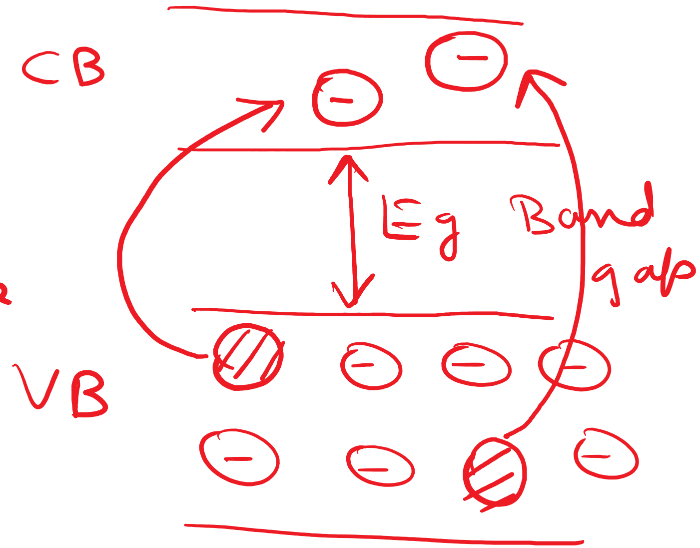


So, to go from the Valence to the conduction Band, the electrons must absorb a minimum energy E_g.

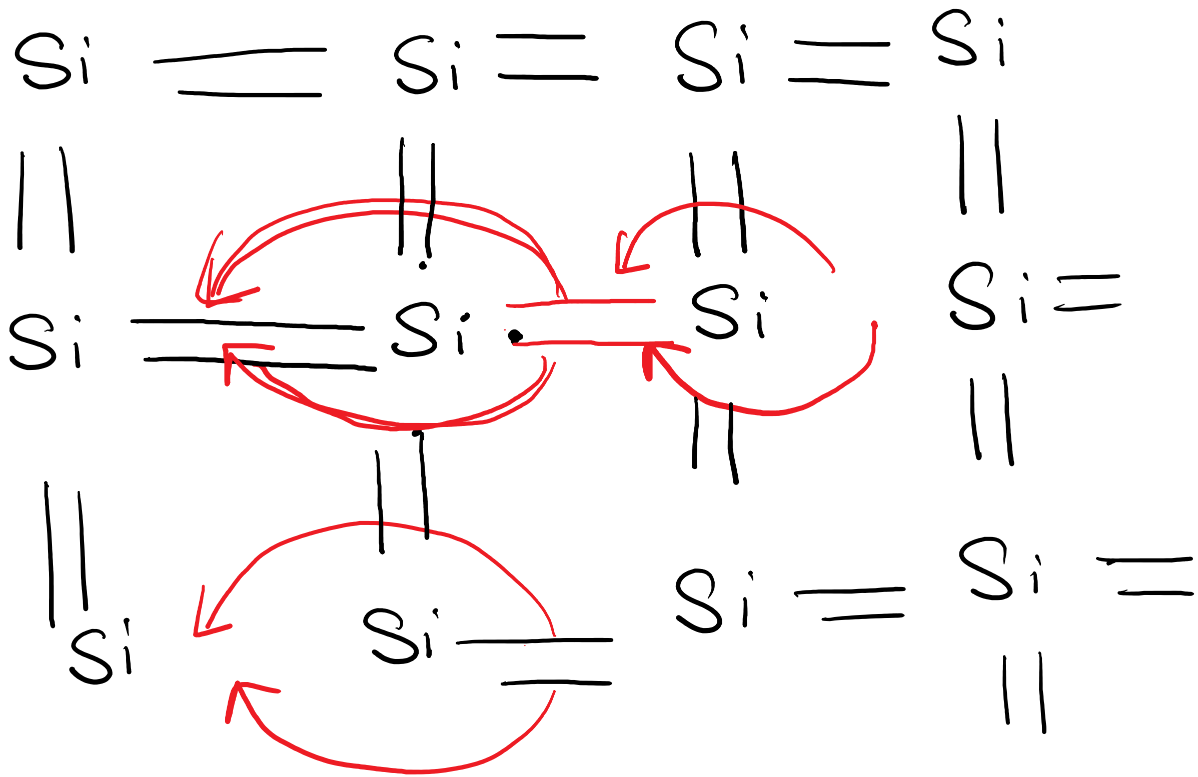
So, as the temperature increases, more electrons from the Valence Band gets excited to the conduction Band. This creates some electrons in the Conduction Band. and leaves behind some empty spaces in the Valence band. These empty spaces are known as holes.



Since, there are some electrons in the conduction Band, it can now contribute to current flow.



Now the valence Band has some empty spaces for movement of electrons. So, it also contributes to current flow.



At any given time the number of electrons that can simultaneously move in the valence band is equal to the number of holes in the valence Band.

Rate of movement of carriers in the CB is equal to the number ~~current~~ conducting particle of electrons in the CB.

Rate of movement of carriers in the VB is equal to the number of holes in the VB.

So, for a pure Semiconductor, the number of electrons in the CB is equal to the number of holes in the Valence Band.

i = intrinsic or pure

$n_i = p_i$ → no of holes in VB

→ no of electron in CB

i = intrinsic or pure

$n_i = p_i$ → no of holes in VB

n_i → no of electrons in CB

Class - 4

Class of materials based on conductivity

- At least one partially filled band at 0K.
  - ↓ Metals
- Only completely filled or completely empty bands at 0K. No partially filled bands at 0K.
  - Band gap comparable to 1eV ↓ At room temp these behave as Semiconductors
  - Higher Bandgap > 3 or 4eV ↓ At room temp they behave as insulators

behave as semiconductors behave as insulators

Semiconductors:- Conductivity can be enhanced by adding impurities.

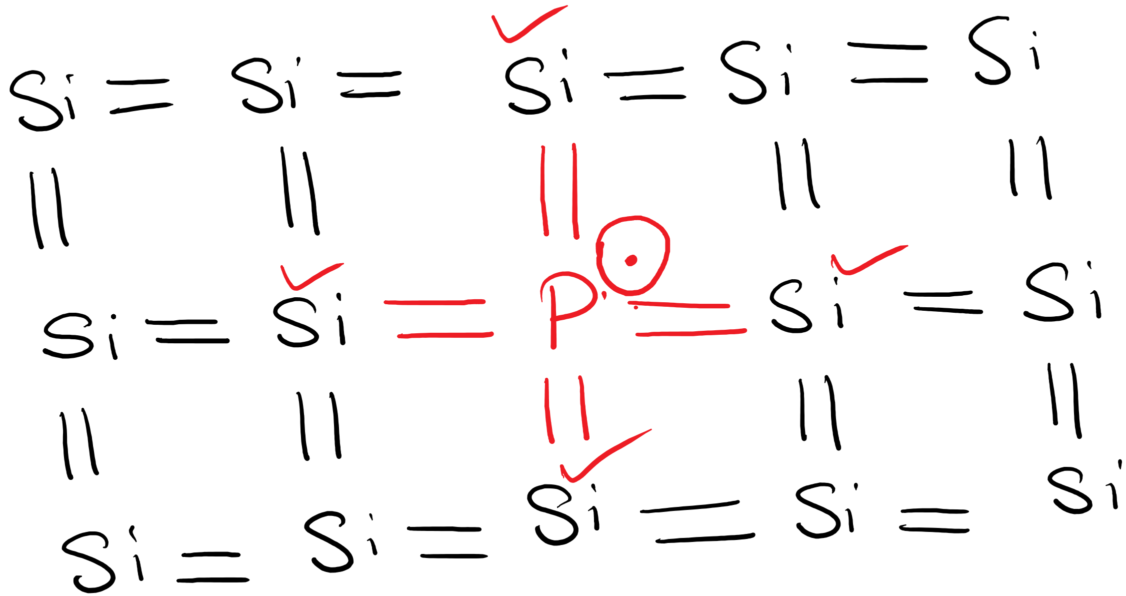
Doping: The phenomenon of enhancing the conductance or conductivity of semiconductors by introducing impurities is known as doping.

Intrinsic or pure semi-conductors:- Impurities are not added, that is, these are not doped semiconductors.

Extrinsic or impure semiconductors :- Impurities are added to enhance the conductivity of semiconductor.

These are doped semiconductors.

Eg: Introducing Phosphorous in Silicon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Si = Si = P = Si = Si
Si = Si = Si = Si = Si

N_D = concentration of phosphorous atoms.
n_i = intrinsic electron concentration in CB.

$$N_D \gg n_i$$

$$n \cong N_D$$

n = total electron concentration in the CB.

$n_i = 1.5 \times 10^{10} / cm^3$. (for Si at T = 300 K)

$N_D = 10^{16} / cm^3$ of P atoms.

Assuming $n \cong n_i + N_D$, $n \cong N_D$ ($\because n_i \ll N_D$)

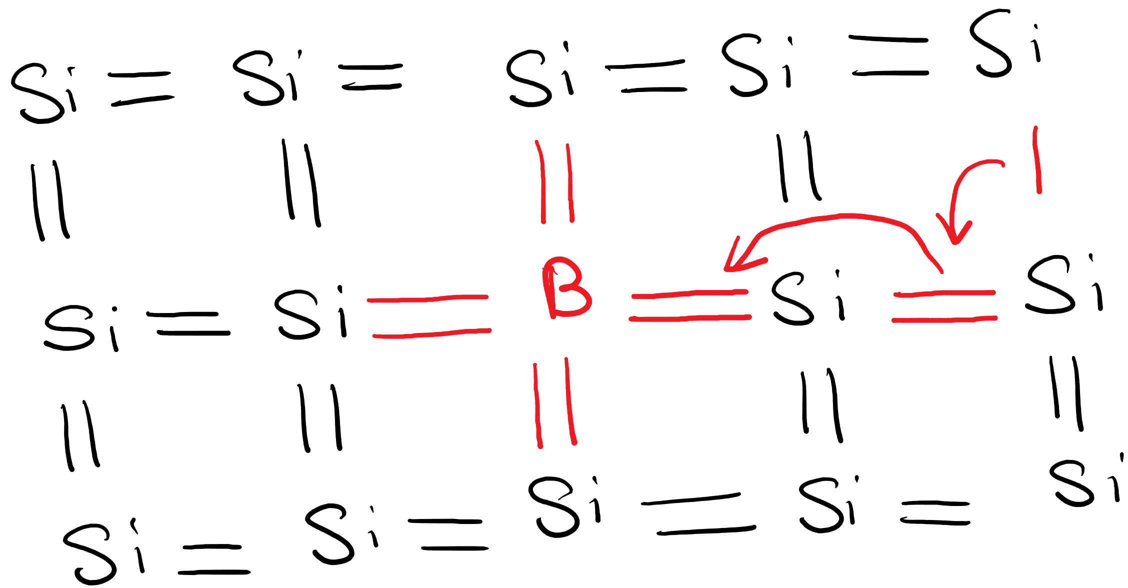
n-type dopants or donor dopants :- Impurities that donate electrons to the CB of semiconductors. Generally they are Gr V elements. Eg: P, As, N

P-type or Acceptor type dopants: Introduce holes in the Valence Band of Semiconductor.

These are generally Gr-III elements.

Eg: B, Al, In, Ga etc

Holes are assumed to have a positive charge. Since these impurities introduce holes in the Valence Band, they are known as p-type dopants.


Si = Si = Si = Si = Si
Si = Si = B = Si = Si
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$N_A \rightarrow$ conc. of acceptor type impurities.

$p_i \rightarrow$ intrinsic hole concentration

If, $N_A >> p_i$

we have $p \cong N_A$

total hole concentration in the valence Band.

Law of Mass Action :-

$$\underbrace{np = n_i p_i}_{} \simeq$$

Current flow in Semiconductor

Drift current.

* Driving agent is the electric field. Electrons and holes flow in the opposite and same direction as the electric field respectively.

Diffusion current.

Electrons or holes flow from the point of high concentration to the point of low concentration. This flow occurs due to a difference in carrier concentration or a gradient in carrier concentration

Drift current:-

v_d = average velocity with which the carriers are moving under the influence of the electric field.

mobility of electrons (holes) ← $\mu_n (\mu_p)$ = average drift velocity of the electrons (holes) per unit electric field.

$$v_d^n = -\mu_n \times E$$

$$v_d^p = \mu_p \times E$$

$$J_{drift} = \underbrace{(-q) n v_d^n}_{\text{drift current due to electrons in the CB}} + \underbrace{q p v_d^p}_{\text{drift current due to holes in the VB.}}$$

$$= -qn(-\mu_n E) + qp(\mu_p E)$$

$$= (\underbrace{qn\mu_n + qp\mu_p}_{\sigma})E$$

$$J_{drift} = \underbrace{(q n \mu_n + q p \mu_p)}_{\text{conductivity } (\sigma)} E$$

$$= \sigma E$$

$q \qquad \mathcal{E}$

$$F = q\mathcal{E}$$

$$\underbrace{a = \frac{q\mathcal{E}}{m}}$$