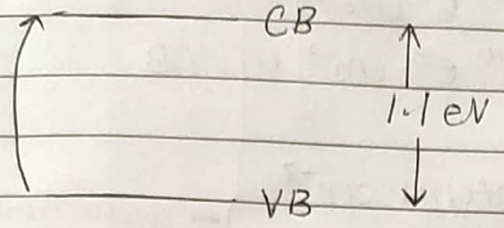
01/07/2020

Silicon

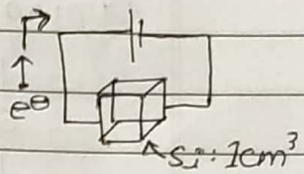


$e^{\ominus}$ jumps from VB to CB at room T by acquiring reqd. energy, creating holes in VB

In conduction band @ room T, there are $\sim 1.5\times10^{10}\,cm^{-3}$ $e^{\ominus}$ in silicon

$\boxed{\#\, e^{\ominus} = \#\text{ holes}}$

in CB — in VB



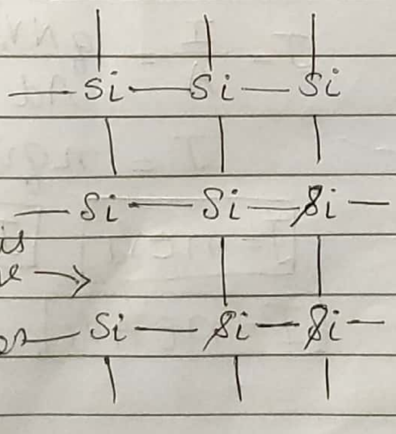
- $e^{\ominus}$ immobile in VB (attached to atom)
- $e^{\ominus}$ mobile in CB, and conducts electricity.

Si (semiconductor)		Al (conductor)
5×10^{22} atoms/cm^3		5×10^{22} atoms/cm^3
CB $e^{\ominus}$: $1.5\times10^{10}\,cm^{-3}$ ⟹ current very low (compared to conductor)	<<<<	CB $e^{\ominus}$: $5\times10^{22}\,cm^{-3}$

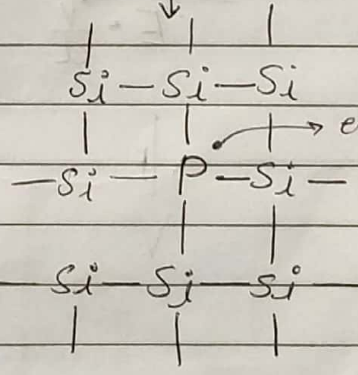
Doping using P

Intrinsic silicon → introduce P atom

P → 15
Si → 14



Suppose this $e^{\ominus}$ has gone into the conduction band



extra $e^{\ominus}$, which goes into the conduction band with only a little bit of energy.

Holes are faster bound than electrons

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Without P: 5×10^{22} Si atoms cm^{-3}

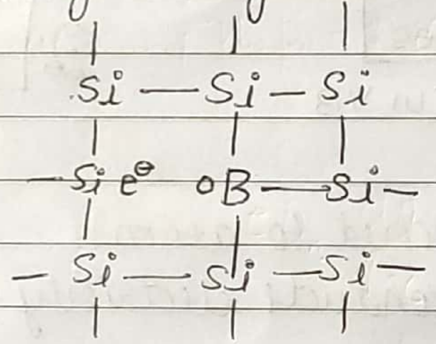
$\hookrightarrow 2\times10^{23}\ e^{\ominus}\ cm^{-3}$

$\hookrightarrow 1\times10^{10}\ e^{\ominus}\ cm^{-3}$ in CB

w/ P: 10^{16} P atoms cm^{-3}

$\boxed{\hookrightarrow 10^{16}\ e^{\ominus}\ cm^{-3} \text{ in CB}}$ ⇒ conductivity ↑

Doping using B



Hole is created due to lack of $e^{\ominus}$
number of holes are same as above.

$$E = \frac{V}{d}$$

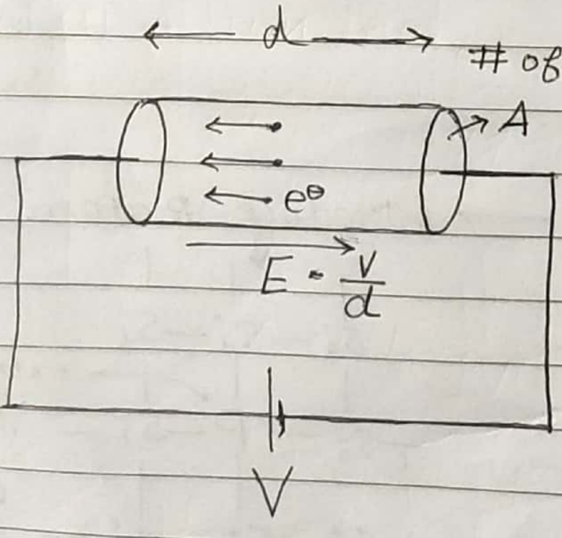
$$V_d = \mu E$$

mobility

drift velocity

n = doping conc^n, or, # of $e^{\ominus}$/vol^m in device.

of $e^{\ominus}$ = N



$$I = \frac{Q}{t} = \frac{qNV_d}{d}$$

$$J = \frac{I}{A} = \frac{qNV_d}{Ad}$$

$$J = nqv_d$$

$$\boxed{J = nev_d} \quad \boxed{J = ne\mu E}$$

$$\boxed{I = neAV_d}$$

Holes are slower than free e^-s

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$$J = neV_d \qquad V_d = \mu E$$
$$J = ne\mu E$$
$$J = \sigma E \Rightarrow \sigma = ne\mu$$

$$\sigma_{total} = ne\mu_n + pe\mu_p \qquad (e \text{ is charge of } e^{\ominus})$$

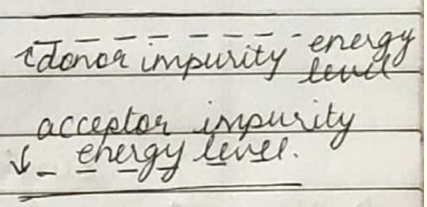
$$\boxed{10^{15} \leq n \leq 10^{17} \text{ (generally)}} \qquad J_{drift} = (ne\mu_n + pe\mu_p)E = \sigma E$$

conc^n of holes and electrons

** All electrons donated by phosphorus in silicon will have a same and unique energy level known as donor energy level.

$$P: 1s^2 2s^2 2p^6 3s^2 (3p^2 + 3p^1)$$

extra $e^{\ominus}$



Fermi Level

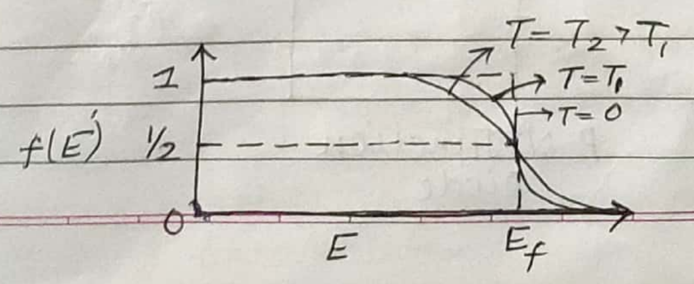
- ↳ Energy level below which all bands are filled and above which all bands are empty at 0K.
- ↳ Probability of finding an $e^{\ominus}$ is 1/2 at fermi level

$$f(E) = \frac{1}{1 + e^{\frac{E - E_f}{kT}}}$$

} Probability of finding electron at energy level E and temperature T

E_f = Fermi Level.

@ $E = E_f$, T = anything: $f(E) = 1/2$



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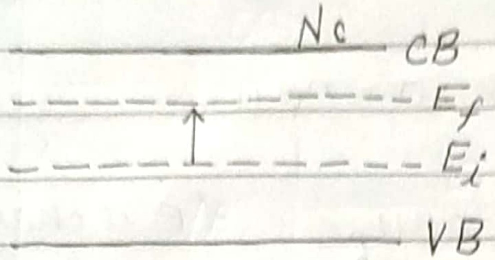
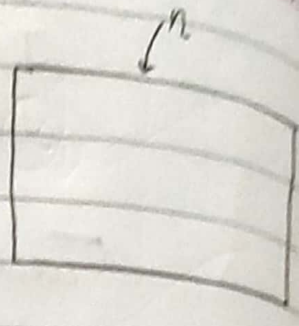




$$n_0 = n_i e^{\left(\frac{E_F - E_i}{kT}\right)}$$

$$p_0 = n_i e^{\left(-\frac{(E_F - E_i)}{kT}\right)}$$

$$\Downarrow$$

Mass-action Law $\rightarrow$ $\boxed{n_0 p_0 = n_i^2}$

$$n_0 = N_c e^{-\left(\frac{E_c - E_F}{kT}\right)}$$

$$p_0 = N_v e^{-\left(\frac{E_F - E_v}{kT}\right)}$$

$$n_0 p_0 = N_c N_v e^{\left(\frac{E_v - E_c}{kT}\right)}$$

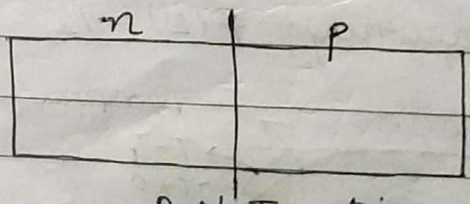
$$J_{diff} = eD_n \frac{dn}{dx}$$

Einstein Relationship

Diffusivity $\rightarrow \frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T = 25.8 \text{ meV at } 300K / \text{room T.}$

→ Mass Action Law
→ Einstein Relationship
→ Drift current, diffusion current

$$n + N_A^- = p + N_D^+$$

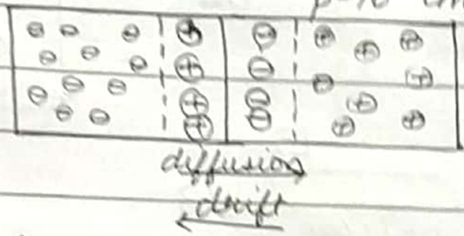


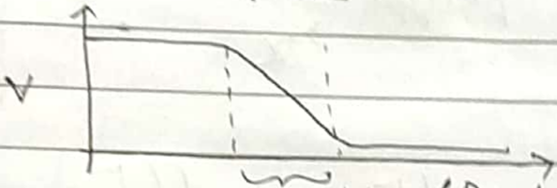
P-N Junction Diode

01/11/2020

Junction Diode $\longrightarrow \vec{E}$

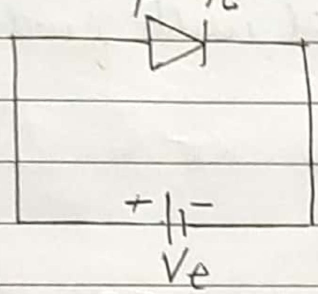
$n = 10^{15}\,cm^{-3}$ $p = 10^{15}\,cm^{-3}$



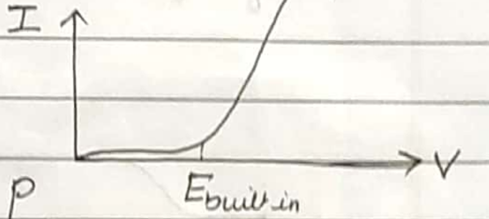


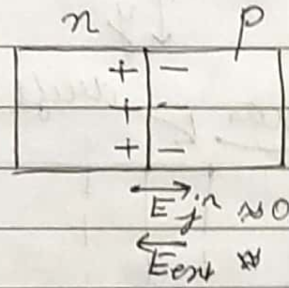
Junction (Depletion region)

Voltage drop @ junction = Junction Potential / Built-in potential $\approx 0.6-0.7V$ for Si

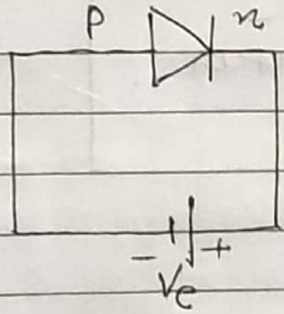
- 

Forward Bias $p \to +$, $n \to -$

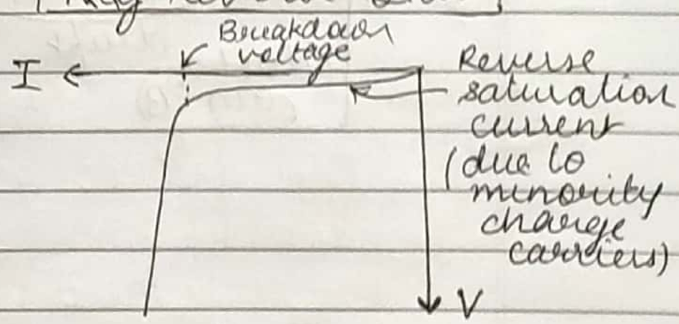


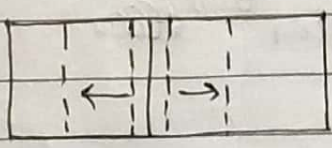


when $E_{ext} = E_{j^n}$, Large current is allowed to flow.

- 

~~Neg~~ Reverse Bias





At first, as we increase V, size of depletion region increases ~~such that~~ $\frac{V_1}{d_1} = \frac{V_2}{d_2}$ such ~~that E remains constant.~~

when d reaches its maximum limit, E increases, causing breakdown.

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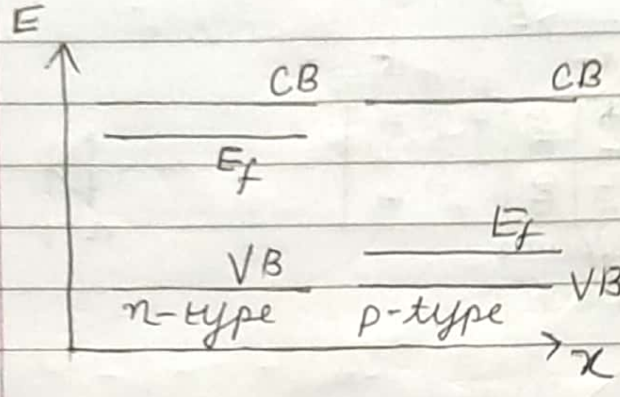
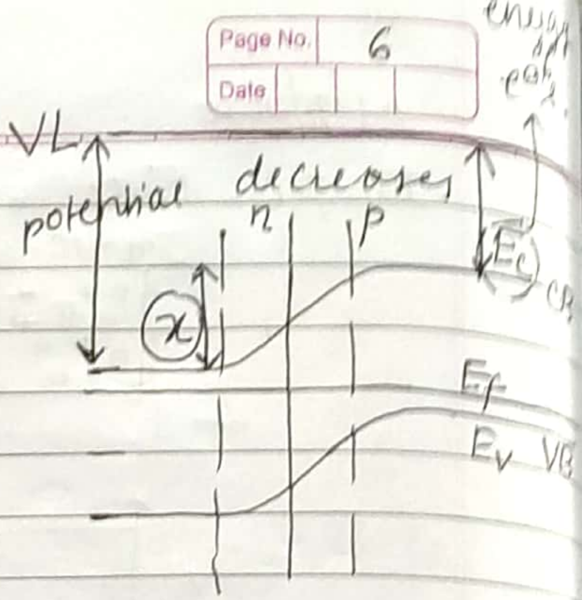
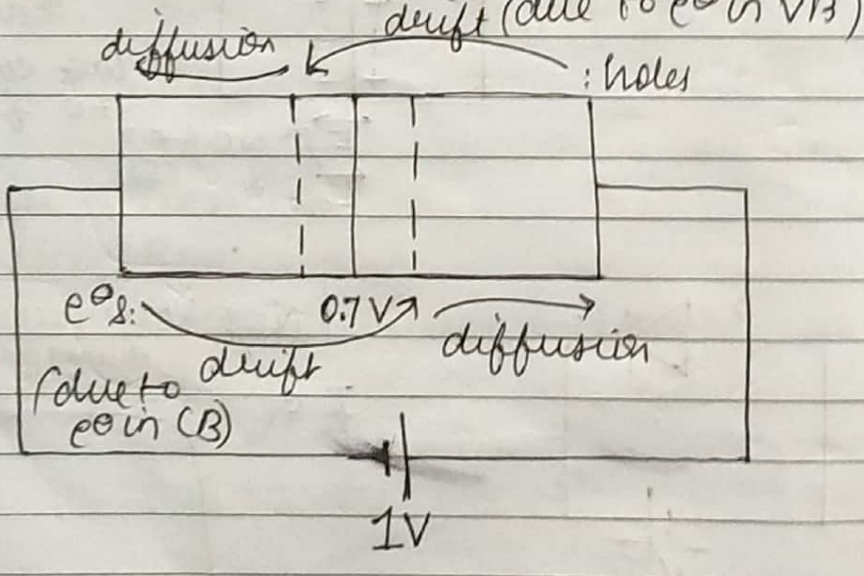




$$\mathcal{E} = \frac{-d(E_c)}{dx} = \frac{-d(E_v)}{dx}$$

x: junction potential without bias
y: junction potential with fwd bias

$$y <<< x$$



$$J = J_{e^\ominus/drift} + J_{e^\ominus/diffusion}$$

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Let I_0 = reverse saturation current

$$\boxed{I = I_0\left(e^{\frac{V}{\eta V_T}} - 1\right)}$$ Shockley's Equation

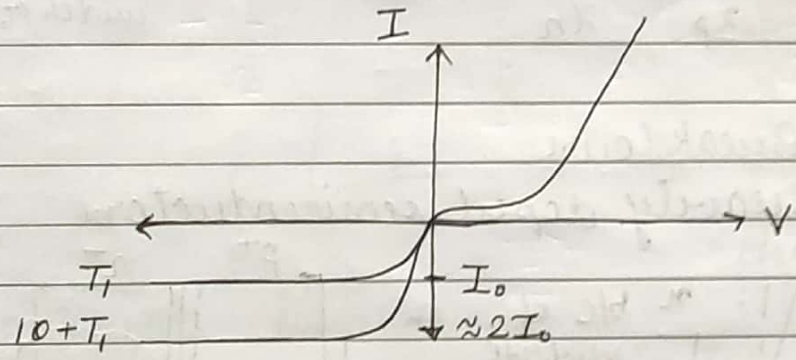
V_T = thermal voltage $\simeq 25.8\,mV = KT/q = \frac{T}{11600}$

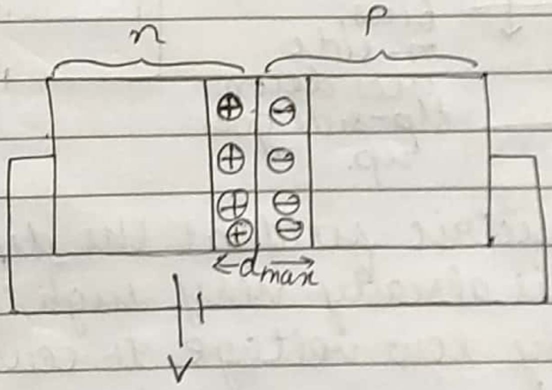
η = ideality factor = 1 for Ge, 2 for Si
"best value"

$I_0 \simeq 10^{-10} A$ (generally)

Temperature Dependence of V/I characteristics
The reverse saturation current approximately doubles every time we increase the current by 10°C.

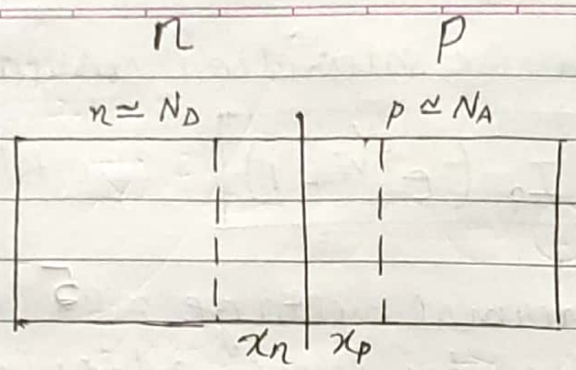
$$I_S(T) = I_{S1}\left(2^{\frac{T-T_1}{10}}\right)$$





"Avalanche Breakdown" when V passes dmax.

01/13/2020

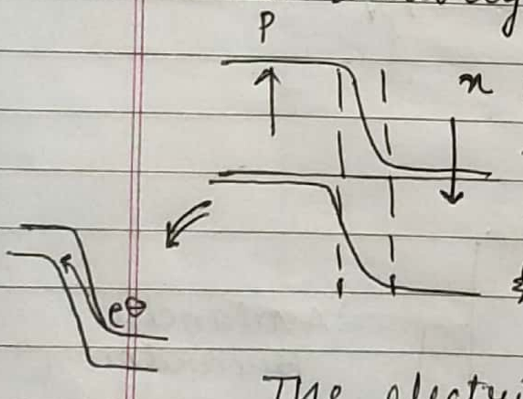


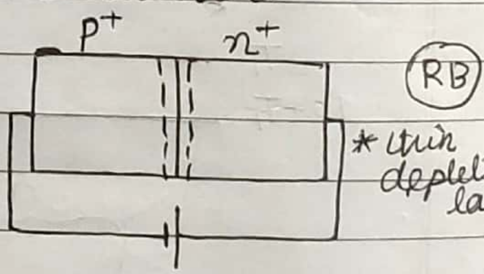
If $N_D > N_A \Rightarrow x_p > x_n$ and vice versa
↳ because, if doping concentration is less, the same number of majority charge carriers will take more space than the side with higher doping concentration

$$\Rightarrow \frac{N_D}{x_p} = \frac{N_A}{x_n} \quad \text{and} \quad x_p + x_n = \underbrace{d}_{\text{width of depletion layer.}}$$

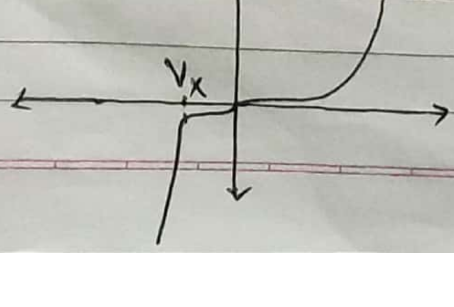
Zener Breakdown

For heavily doped semiconductors





The electric field at the depletion layer is already very high, so it takes a very low voltage to cause a breakdown.



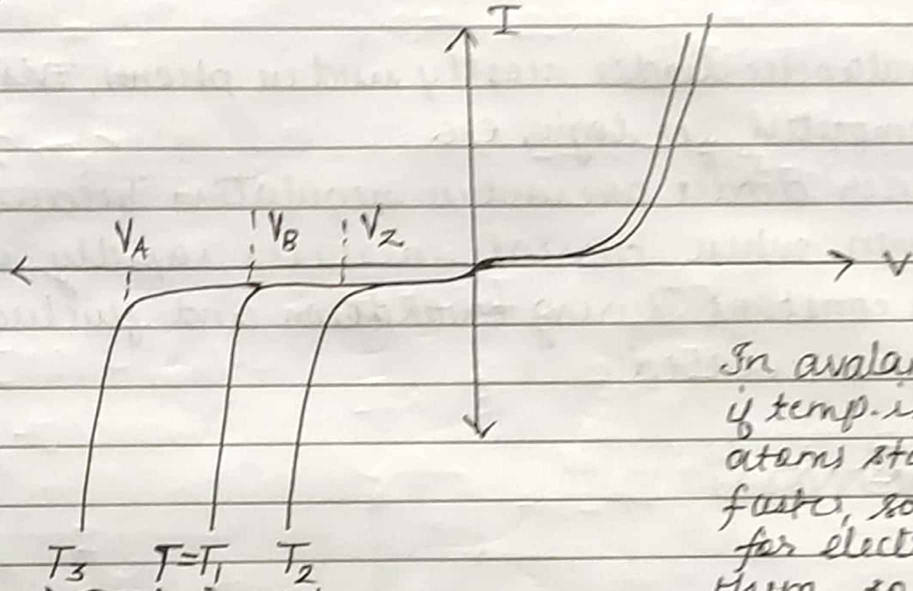
Forward bias has normal characteristics

01/13/2019 (the "19" is overwritten with "20")

* Avalanche breakdown is harmful because you are forcing the electrons to be pulled out of the valence band ⇒ CAUSE PERMANENT DAMAGE TO ATOMS *

* Zener breakdown is safe because the diode is heavily doped

Effects of Temperature on Zener Breakdown



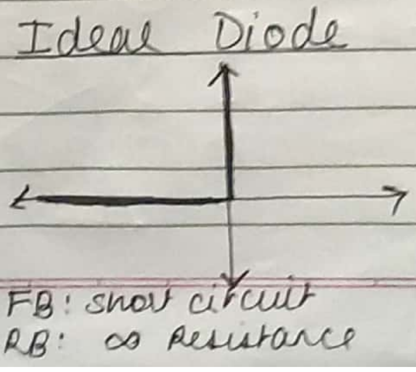
Normal (Avalanche) Breakdown $T_3 > T_1$

Zener Breakdown $T_2 > T_1$

In avalanche b/d, if temp. is increased, atoms start to oscillate faster, so it is harder for electrons to hit them, so, B/D voltage increases.

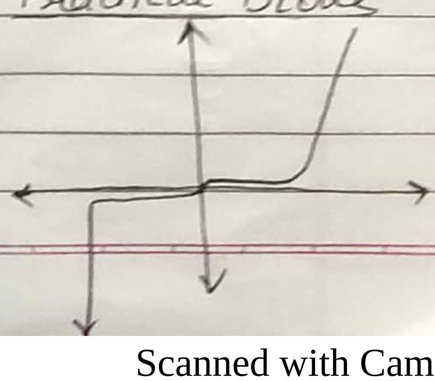
In Zener b/d, if temp. is ↑, electrons are not concerned with hitting atoms, so it helps e^-s cross the barrier, decreasing the voltage.

Ideal Diode



FB: short circuit
RB: ∞ Resistance

Practical Diode



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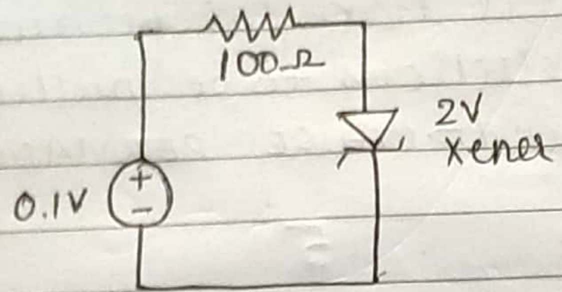
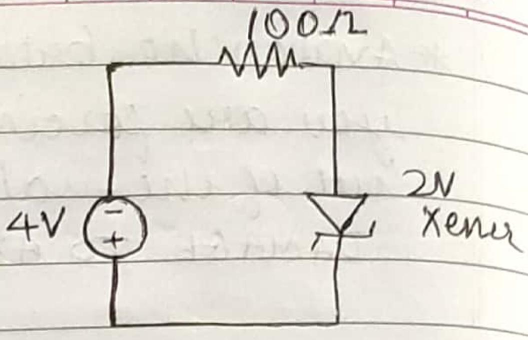


Zener diode behaves like an ideal diode in FWD Bias



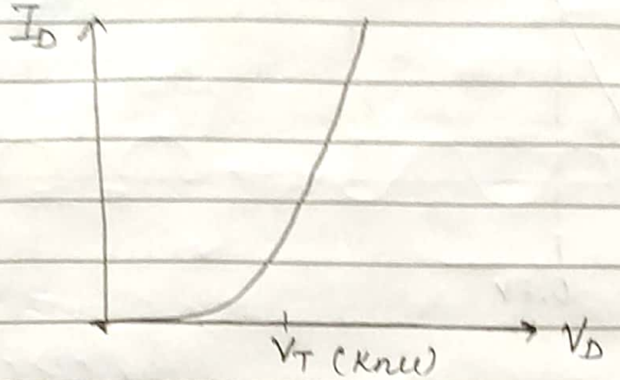
⇒ 2V drop accross Xener, b/c 4V > 2V in REVERSE BIAS ⇒ 2V drop accross resistance ⇒ $i = 20mA$.

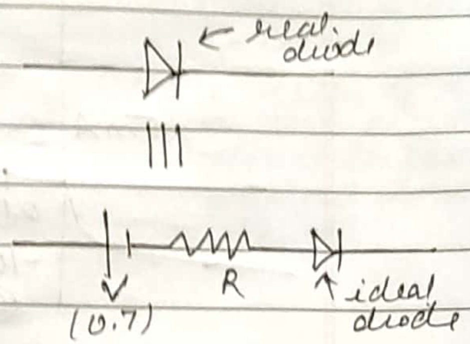
→ Avalanche diodes mostly used in phones, TVs, computers, for logic, etc.

→ Zener diodes are used in regulators because even when current increases rapidly, voltage is constant during breakdown and fluctuation is prevented.

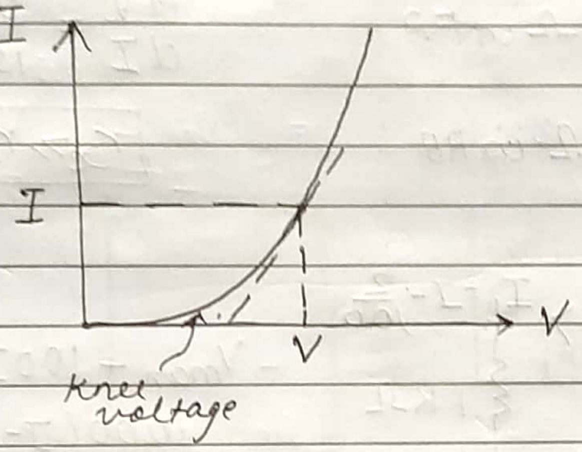
~~01/22/2020~~

01/14/2020





Diode Resistance: Static and Dynamic



$R_{static} = V/I$

$\frac{dV}{dI} = R_{dynamic}$

$I = I_0 \left(e^{\frac{V}{nV_T}} - 1\right)$

$\frac{dI}{dV} = \frac{I_0}{nV_T} e^{\frac{V}{nV_T}}$

$\Rightarrow \frac{dV}{dI} = \frac{nV_T}{I_0} e^{-\frac{V}{nV_T}}$

$$\Rightarrow \boxed{\frac{dV}{dI} = \frac{nV_T}{I + I_0}}$$

I ↑ order of 10^{-3} ; I_0 ↖ order of 10^{-10} A

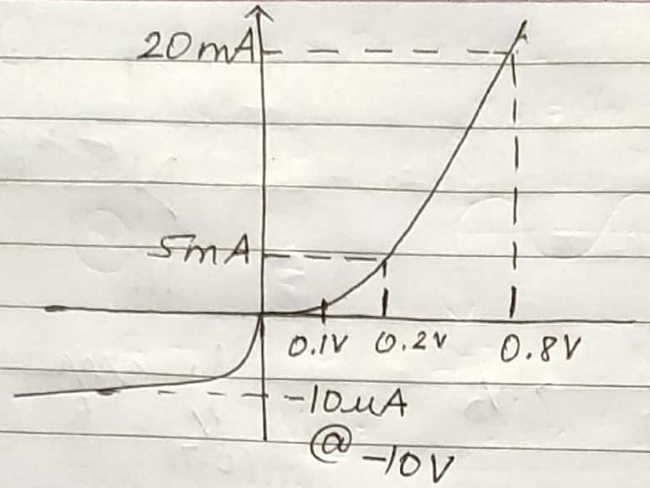
$$\frac{dV}{dI} = R_d \approx \frac{nV_T}{I} \rightarrow \text{(AC resistance)}$$

* capacitor blocks DC voltage *

For Ge: $n = 1 \Rightarrow R_d \approx \frac{V_T}{I} = \frac{26}{I}$ mΩ

01/14/2020

Q)



DC Resistance

(i) $R_S = \frac{0.2}{5\times10^{-3}} = 40\Omega$ in FB

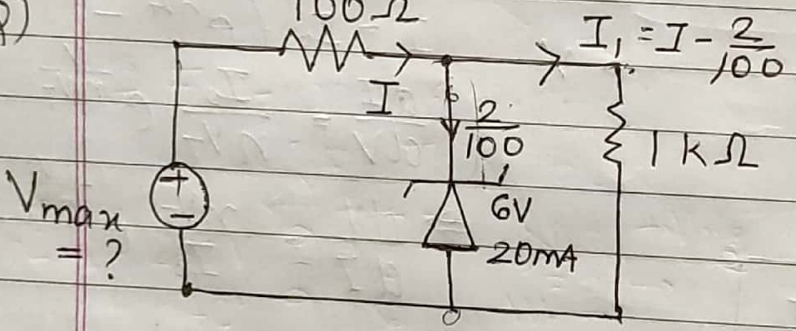
(ii) $\frac{-10V}{10^{-5}} = -10^{6}\Omega$ in RB

AC Resistance

$\frac{dV}{dI} = \frac{0.6V}{15mA} = 40\Omega$

$\boxed{r_{DC} \gg r_{AC}}$

Q)



V_{max}

$-V_{max} + 100I = 6$

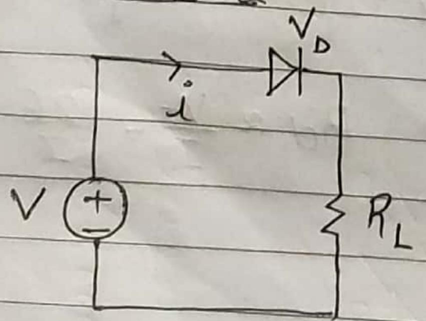
$1000\left(I - \frac{20}{1000}\right) = 6$

$I = \frac{26}{1000}$

$V_{max} = ...$

$V_{max} = 8.6$??

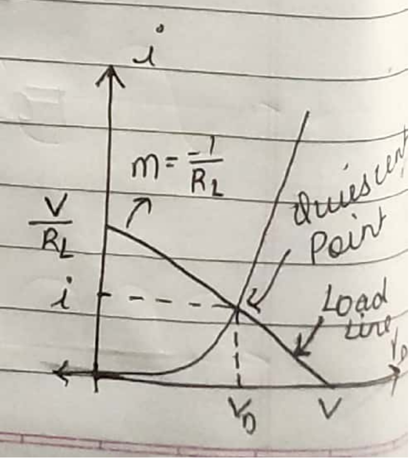
Load line



$V = V_D + iR_L$

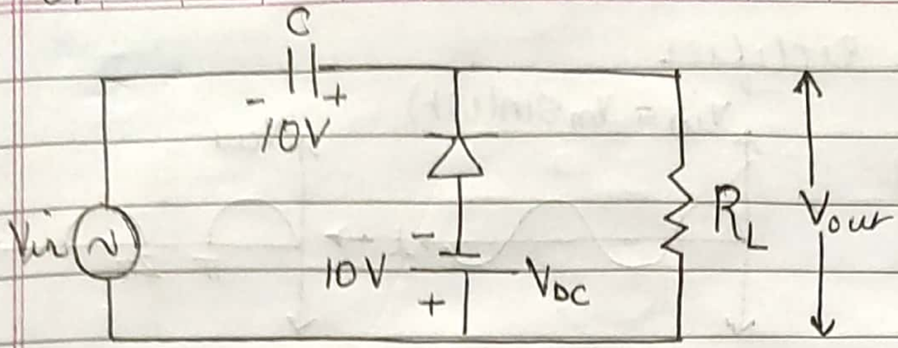
If $i = 0 \Rightarrow V_D = V$

If $V_D = 0 \Rightarrow i = \frac{V}{R_L}$



Clamper circuits from Boylestead

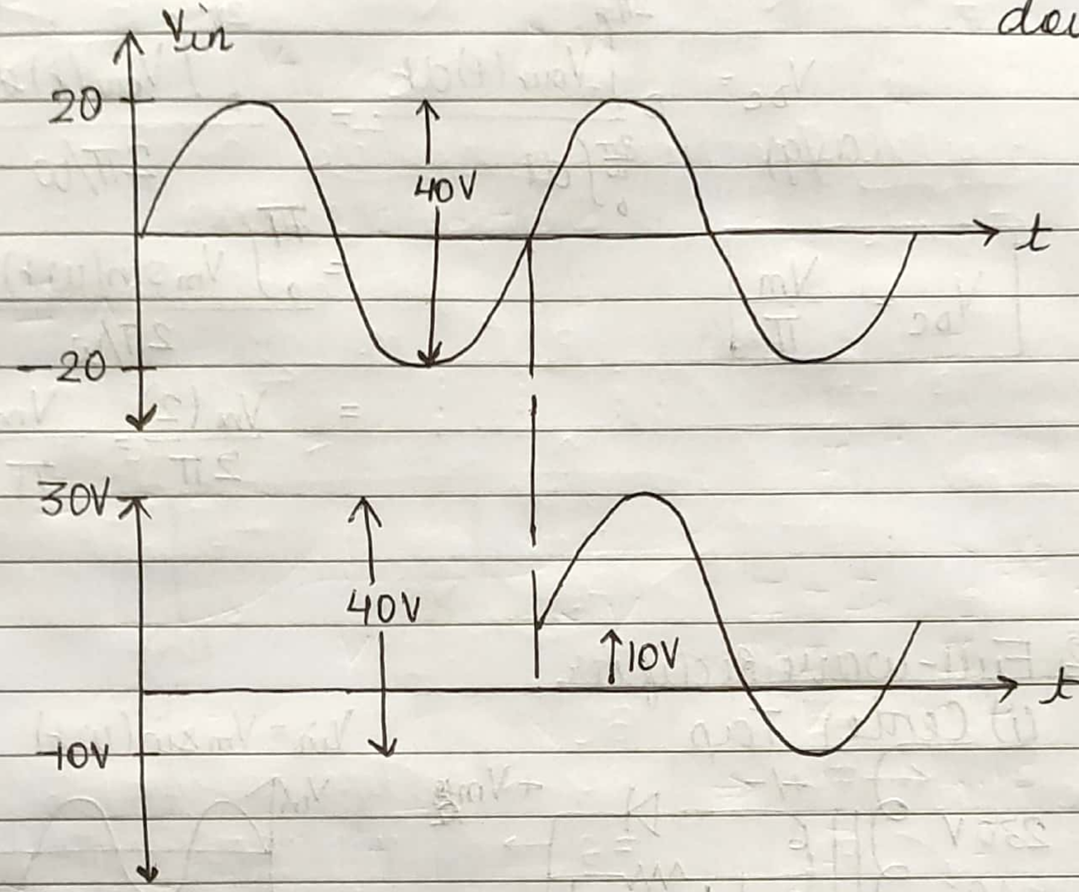
01/23/2020



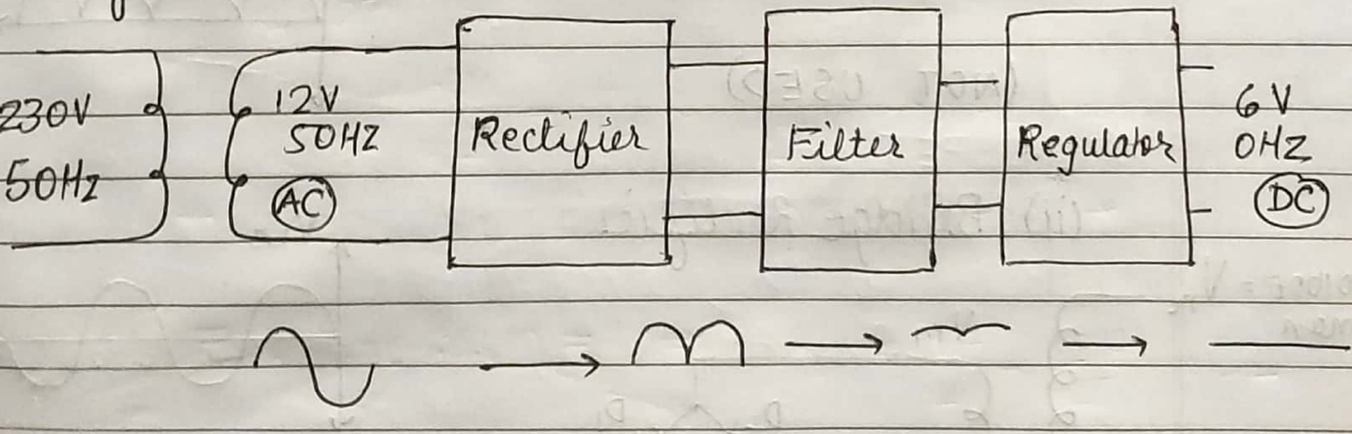
① Direction of diode to decide whether pushed up or down.

② Direction of battery to decide whether further pushed up or down.

*UNITS



Rectifier (AC → DC)

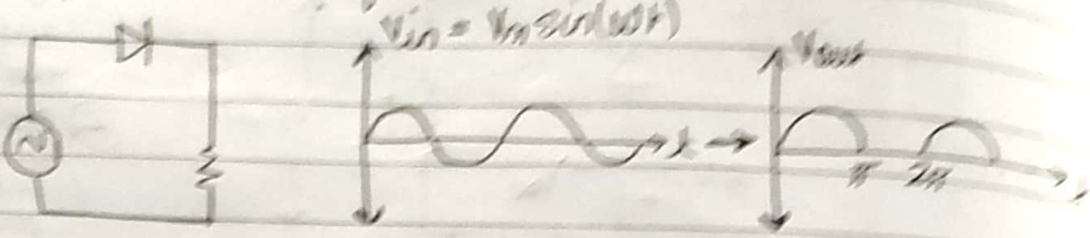


PIV = Peak Inverse Voltage

01/23/2020

① Half Wave Rectifier

$V_{DIODE_{max}} = V_m$



$$V_{DC\,(avg)} = \frac{\int_0^{2\pi} V_{out}(t)\,dt}{\int_0^{2\pi} dt} = \frac{\int_0^{2\pi} V_{out}(t)\,dt}{2\pi/\omega}$$

$$= \frac{\int_0^{\pi} V_m \sin(\omega t)\,dt}{2\pi/\omega}$$

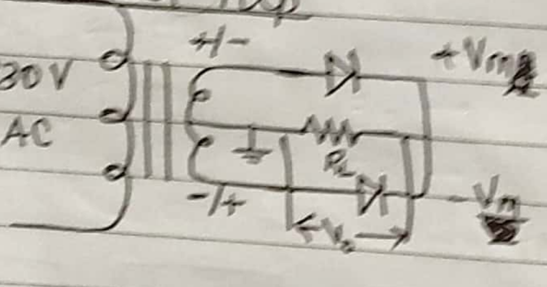
$$= \frac{V_m(2)}{2\pi} = \frac{V_m}{\pi}$$

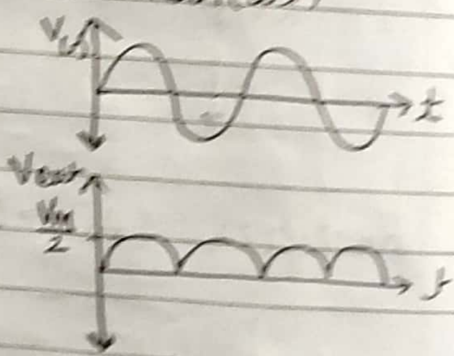
$$\boxed{V_{DC} = \frac{V_m}{\pi}}$$

② Full-wave Rectifier

(i) Center Tap

$V_{DIODE_{max}} = 2V_m$

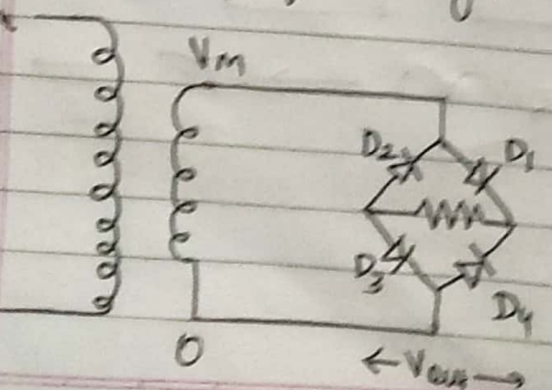


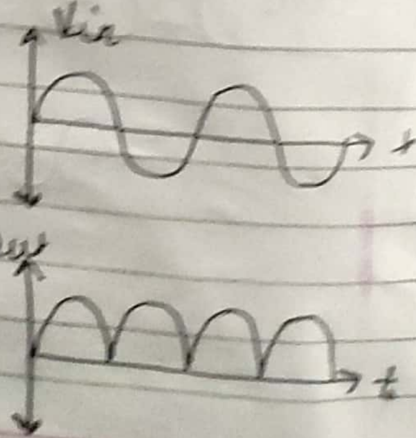


(NOT USED)

(ii) Bridge Rectifier

$V_{DIODE_{max}} = V_m$



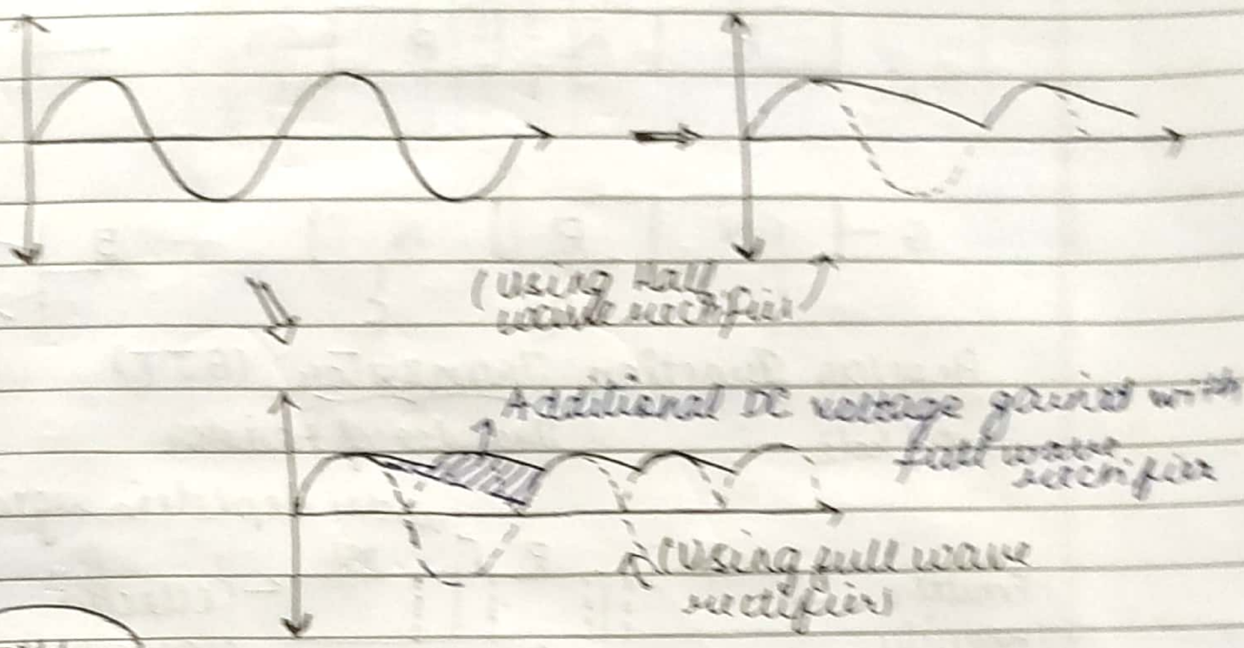


* NO VOLTAGE LOSS IN BRIDGE RECTIFIER

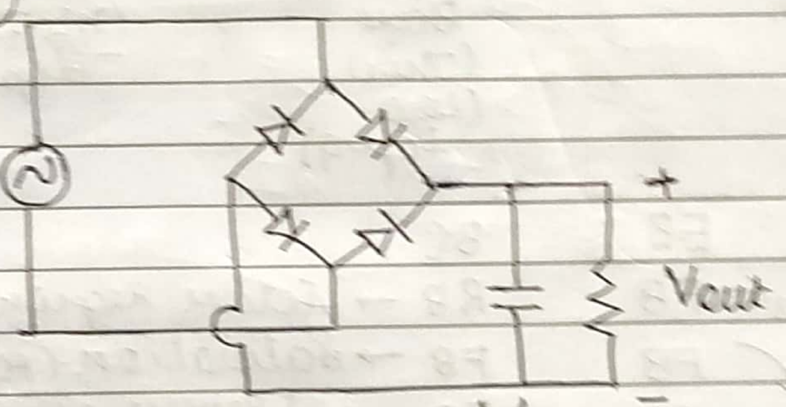
Read terminologies from Books

01/27/2020

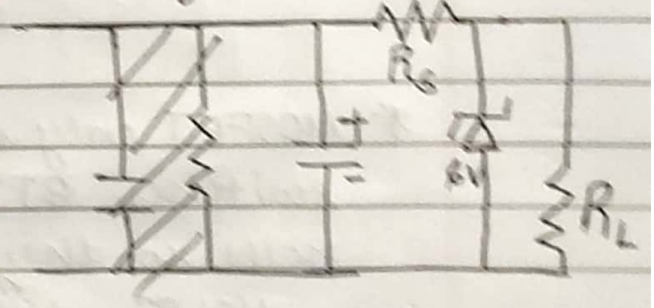
Converting AC to DC



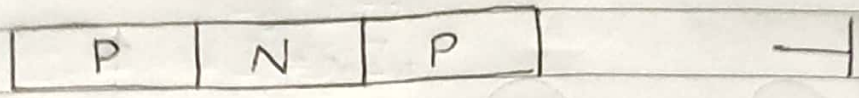
→ Filter

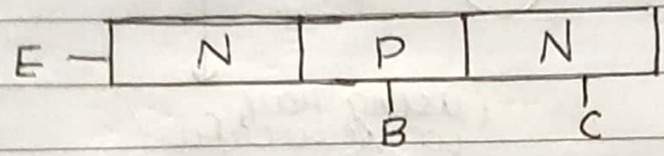


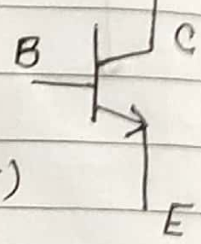
Further towards a regulator



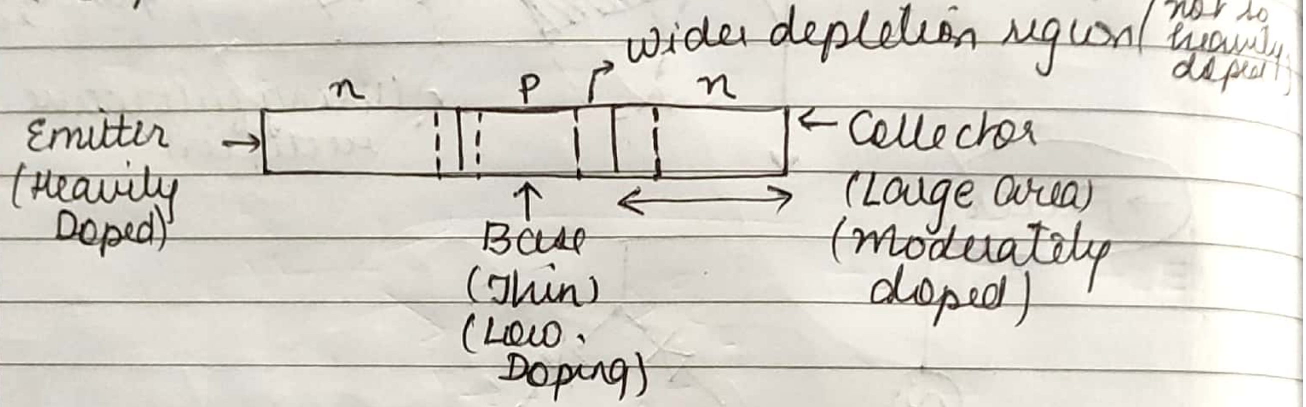
01/27/2020 Transistor





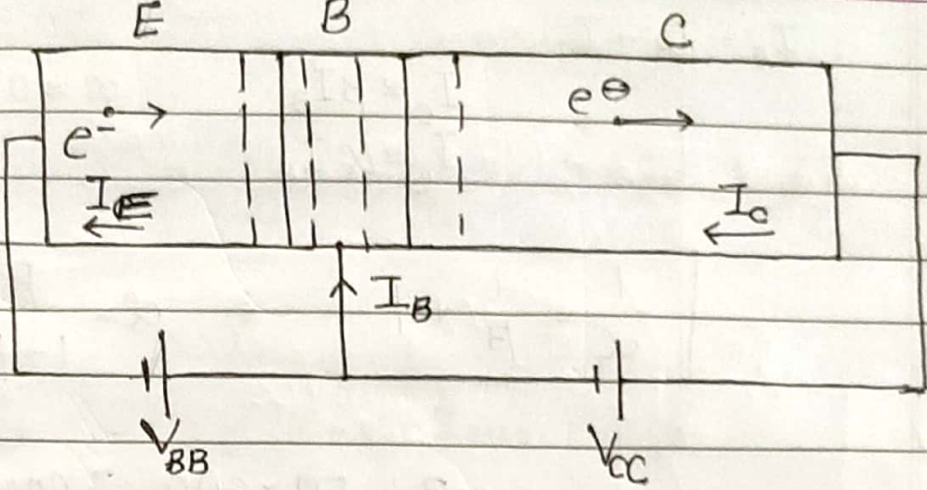


Bipolar Junction Transistor (BJT)
e^+ & hole
Transfer of resistor



	E-B	B-C	
Used for amplification ←	FB	RB	→ Active Region (used for amplification)
Used as a binary switch	FB	FB	→ Saturation (High current flow)
	RB	FB	→ X {Reverse-active, never used}
Used as a binary switch	RB	RB	→ cut-off region (no current flowing)

* MOSFET only uses electrons, so, are used as switches. BJT uses both electrons and holes, so, they aren't used as switches.
HOLES ARE very slow *



$I_E = I_B + I_C$ $\qquad \frac{I_C}{I_B} = \beta \qquad \frac{I_C}{I_E} = \alpha$

$$\Rightarrow \frac{I_E}{I_C} = \frac{I_B}{I_C} + 1$$

$$\frac{1}{\alpha} = \frac{1}{\beta} + 1$$

01/30/2020

$I_E = I_B + I_C$

$I_C \simeq \beta I_B \qquad \alpha \approx 0.9$

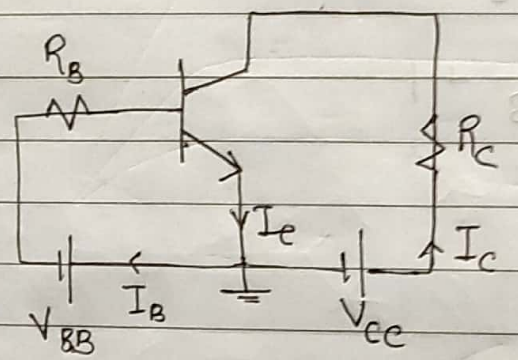
$I_C \simeq \alpha I_E$

$$\boxed{\frac{1}{\alpha} = \frac{1}{\beta} + 1} \Rightarrow \alpha = \frac{\beta}{1+\beta}$$

β : 50 - 600 } normally, this is
α : almost 1 } the range.

Common Emitter

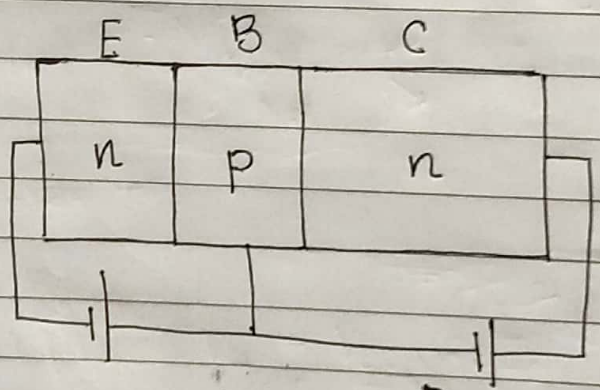
*180° phase change (shift)



$I_C = \beta I_B + \underbrace{I_{CEO}}$

reverse sat. current

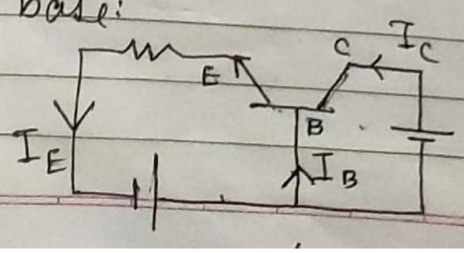
$I_C \simeq \beta I_B$ } I_C is actually Larger.



Reverse Bias

must have saturation current (negligible)

in common base:



$I_C = \alpha I_E + I_{CBO}$

* GO THROUGH ~~REV~~ HANDBOOK *

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$$I_C = \beta I_B + I_{CEO} = \alpha I_E + I_{CBO}$$

$$\cancel{1 = \beta\left(\frac{I_B}{I_C}\right) + \frac{I_{CEO}}{I_C} = \alpha\left(\frac{I_E}{I_C}\right) + \frac{I_{CBO}}{I_C}}$$

$$\beta I_B + I_{CEO} = \alpha I_E + I_{CBO}$$

$$I_C = \alpha(I_C + I_B) + I_{CBO}$$

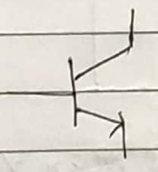
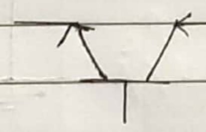
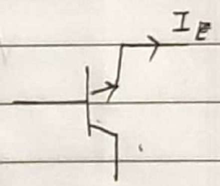
$$I_C(1-\alpha) = \alpha I_B + I_{CBO}$$

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}$$

$$I_C = \beta I_B + \frac{I_{CBO}}{1-\alpha}$$

$$I_C = \beta I_B + I_{CEO}$$

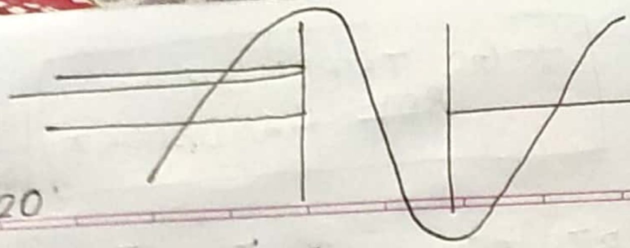
$$\Rightarrow I_{CEO} = \frac{I_{CBO}}{1-\alpha}$$

	(Input from Base) CE	(Input from collector) CB	CC
			
A_I:	Medium	Low	High
Av:	Medium	~~Low~~ High	Low
Impedance: Zin:	Low	Low	Medium
Impedance: Zout:	High	Medium	$\boxed{\text{LOW}}$ Why?

Both current gain and voltage gain → commonly used.

POWER GAIN

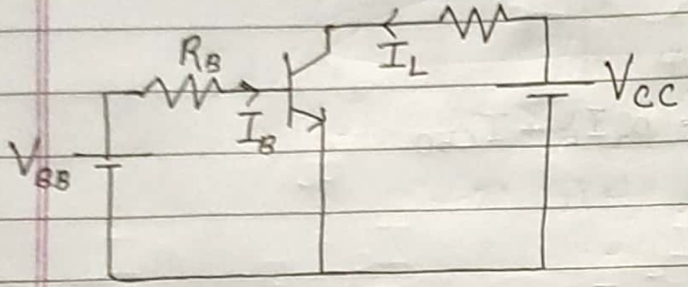
CAPACITOR
DC

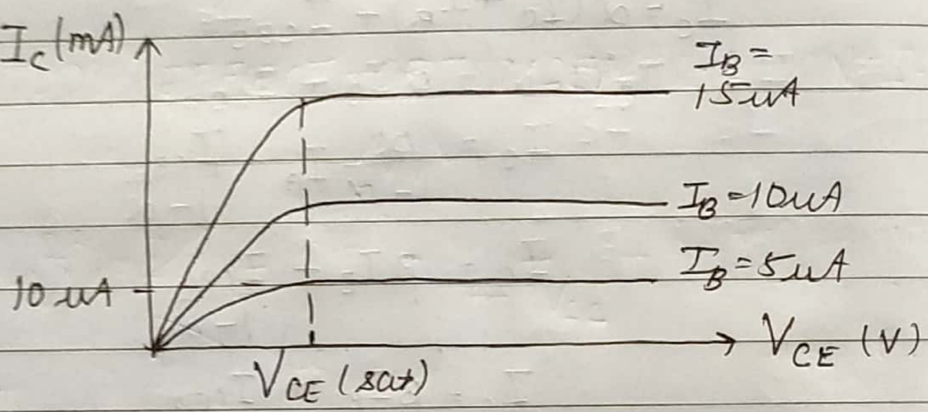


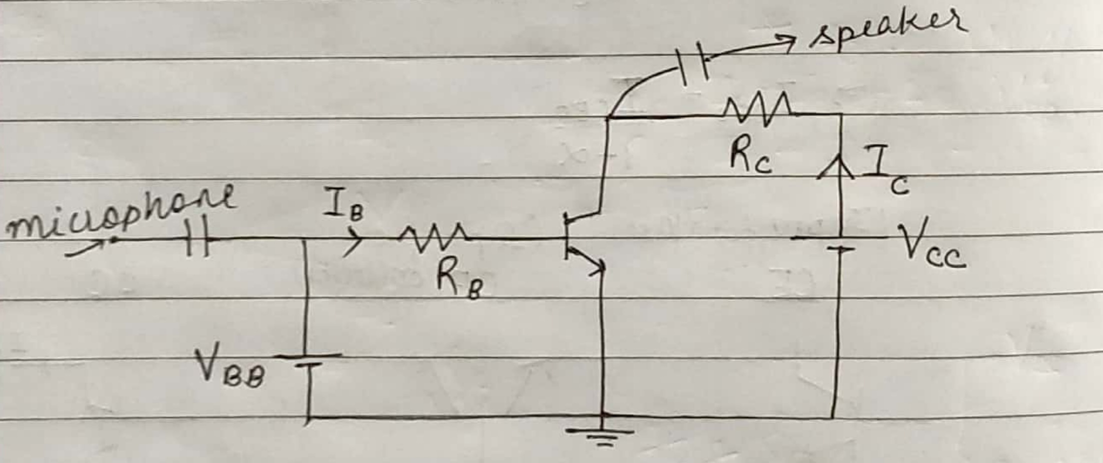
02/09/2020

BJT as an Amplifier

$I_E = \beta I_B + (1+\beta) I_{CBO}$ } where did this come from?





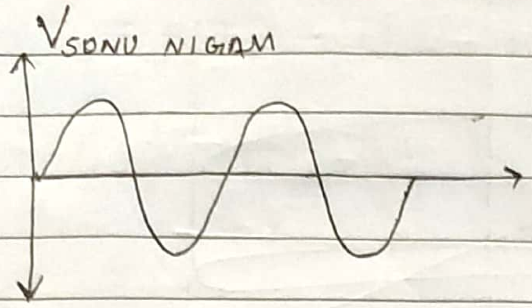


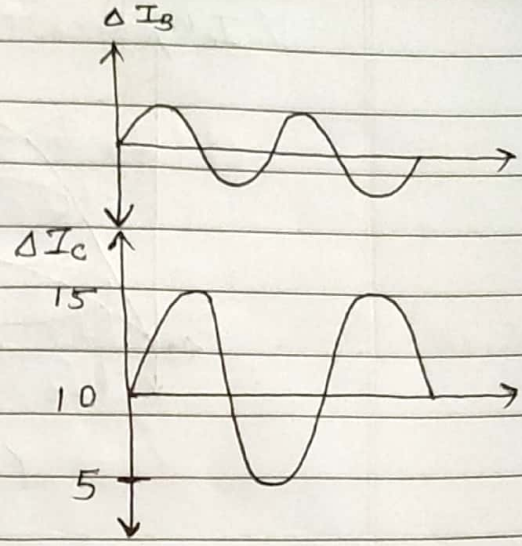
$V_L = V_{CC} - R_C I_C$ } Max value of $V_L = V_{CC}$ when $R_C = 0$ / $I_C = 0$.

due to input AC signal

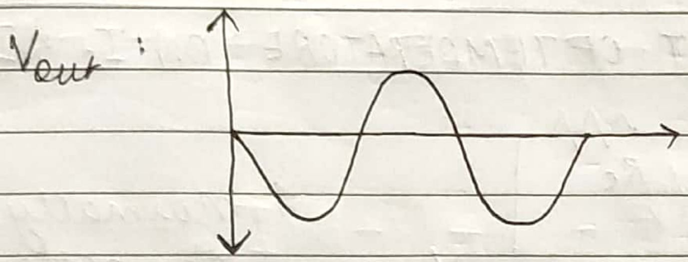
$$\left\{\begin{aligned} I_B' &= \overset{5uA}{I_B} + \Delta I_B \\ I_C' &= \underset{10uA}{I_C} + \Delta I_C \end{aligned}\right\} \Delta I_C = \beta \Delta I_B$$

02/02/2020





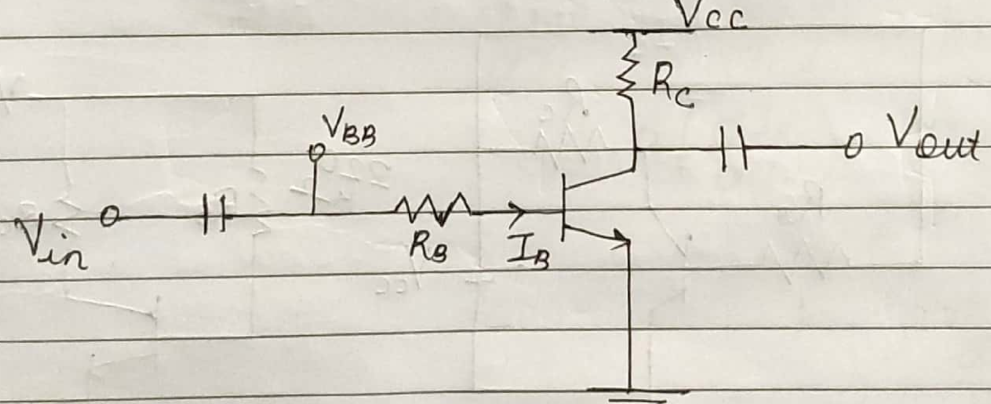
* Adding capacitor b/w V_L and speaker only lets AC signal pass through.



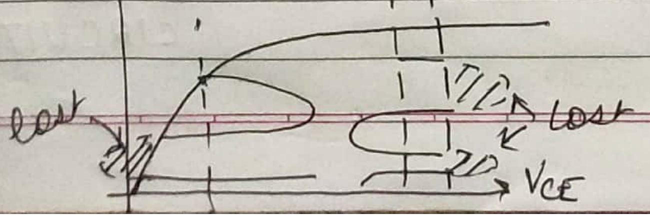
* Input/Output have a phase difference of π in common emitter configuration.

$$V_L = -I_C R_C \quad (\text{say } V_C = 0)$$
$$\Delta V_L = -\Delta I_C \cdot R_C$$
$$V_L \ max = 12V$$
$$V_L \ min = 4V$$

Final circuit :

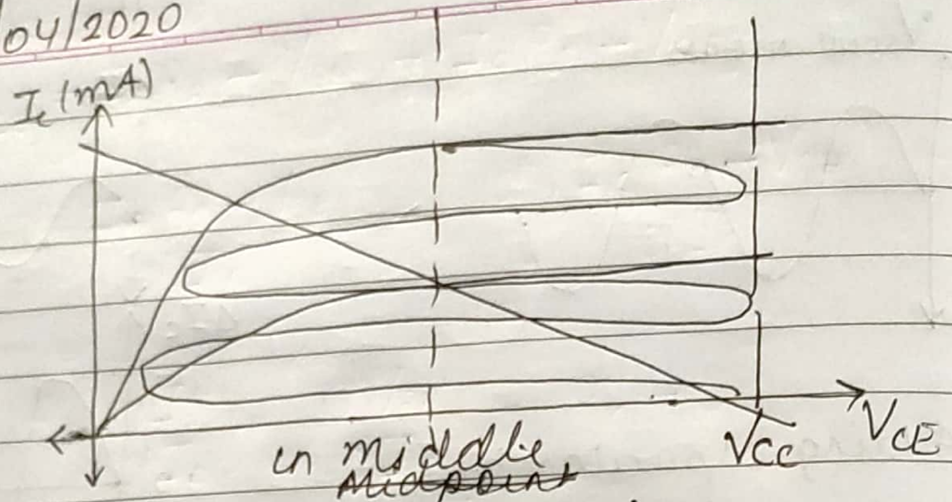


Choose values so V_{CE} is somewhere in the middle.



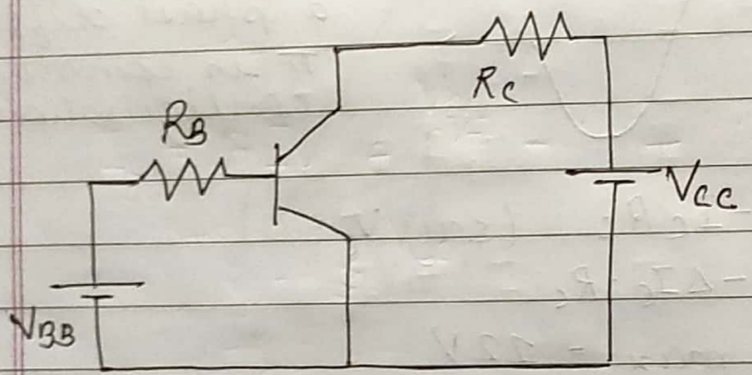
If I_C changes by the slightest amount, Q point changes ~~significantly~~

02/04/2020



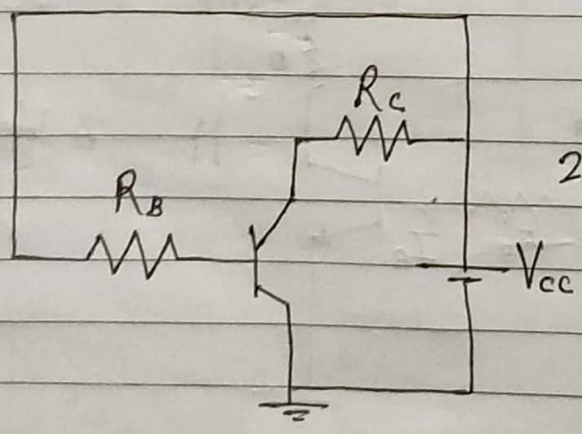
in middle
Midpoint
(for max swing)

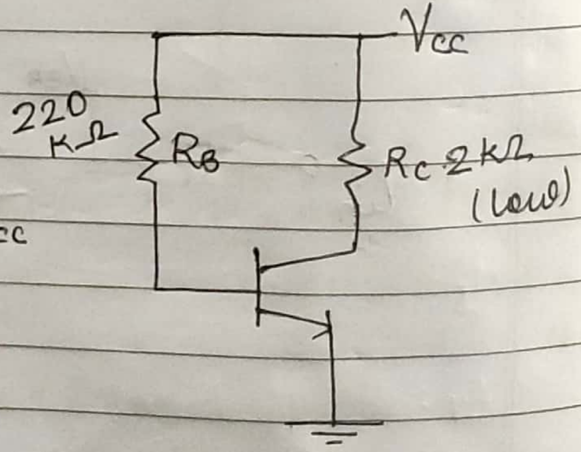
STUDY EFFECT OF TEMPERATURE ON I_C & I_B



* normally, only one battery is used, so here we will remove V_{BB}
* i_B is very low, so is V_{BB}.

⇓





"FIXED BIAS CIRCUIT"

02/04/2020

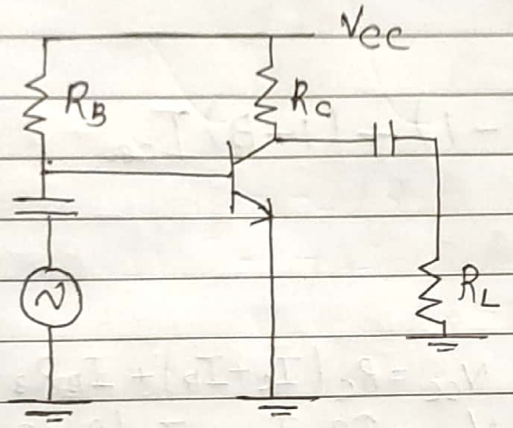
$$I_c = \beta I_B + (1+\beta) I_{CBO} \quad ???$$

Stability Factors

$$S = \left.\frac{dI_c}{dI_{CBO}}\right|_{\beta, V_{BE}} \qquad S' = \left.\frac{dI_c}{dV_{BE}}\right|_{\beta, I_{CBO}} \qquad S'' = \left.\frac{dI_c}{d\beta}\right|_{V_{BE}, I_{CBO}}$$

⇑ most important.

Fixed Bias Circuit For Amplification



$$S = \frac{dI_c}{dI_{CBO}}$$

$$I_c = \beta I_B + (1+\beta) I_{CBO}$$

$$\frac{dI_c}{dI_c} = \beta\left(\frac{dI_B}{dI_c}\right) + (1+\beta)\left(\frac{dI_{CBO}}{dI_c}\right)$$

$$1 = \beta\left(\frac{dI_B}{dI_c}\right) + \frac{(1+\beta)}{S}$$

$$S = \frac{1+\beta}{1 - \beta \underbrace{\frac{dI_B}{dI_c}}_{\text{very small}}}$$

⇓

$$S \approx 1 + \beta$$

02/04/2020

$$V_{cc} = I_B R_B + V_{BE} = I_C R_C + V_{CE}$$

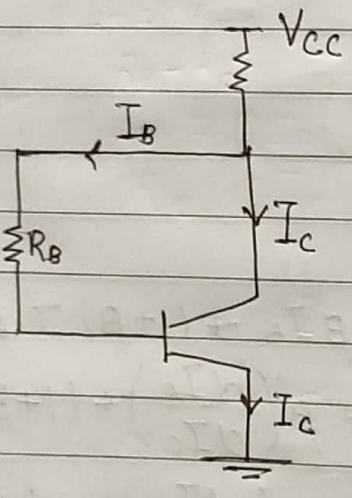
$$\frac{d(I_B R_B + V_{BE})}{dI_c} = \frac{d(I_C R_C + V_{CE})}{dI_c}$$

$$R_B \frac{dI_B}{dI_c} + \frac{dV_{BE}}{dI_c} = R_c + 0$$

$$\frac{dI_B}{dI_c} = \frac{R_c}{R_B}$$

$$\left. S \approx 1+\beta \right\} \text{LARGE} \rightarrow \text{not stable}$$

$$I_c = \beta I_o \left(e^{\frac{V_{BE}}{\eta V_T}} - 1\right) + (1+\beta) I_{CBO}$$



Collector Feedback Bias

$$V_{CC} = R_c(I_c + I_B) + I_B R_B + V_{BE}$$

$$\underbrace{V_{CC}}_{\text{constant}} = \uparrow \underbrace{R_c I_c}_{\text{If increased}} + I_B \underbrace{(R_C + R_B)}_{\text{fixed}} + V_{BE}$$

↓ must go down

⇓

I_B must go down

⇓

I_C comes back down

→ That is why this configuration is very stable (considering $\beta \rightarrow$ constant)

02/04/2020

$$S = \frac{1+\beta}{1-\beta \frac{dI_B}{dI_C}}$$

$$V_{CC} = I_C R_C + I_B R_B + I_B R_C + V_{BE}$$

$$\frac{d(V_{CC})^{0}}{dI_C} = R_C + \frac{dI_B}{dI_C}(R_B + R_C) + \frac{dV_{BE}^{\,0}}{dI_C}$$

$$0 = R_C + \frac{dI_B}{dI_C}(R_B + R_C)$$

$$\frac{dI_B}{dI_C} = \frac{-R_C}{R_B + R_C}$$

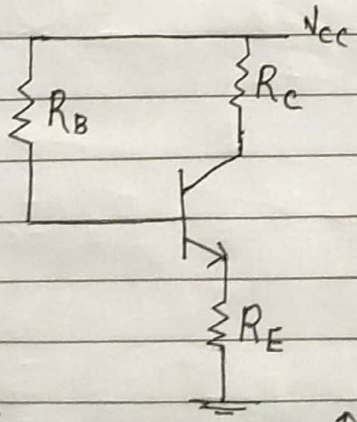
$$\Rightarrow S = \frac{1+\beta}{1 + \frac{\beta R_C}{R_B + R_C}}$$

} $S < 1+\beta$
Denominator High
→ more stable than previous circuit.

$$S'' = \frac{dI_C}{d\beta}\Big|_{I_B, V_{BE} \to \text{fixed}}$$

} only occurs when transistor dies ⇒ β changes.

Emitter Feedback



$$V_{CC} = I_B R_B + V_{BE} + I_E R_E$$

$$V_{CC} = I_C R_C^{\uparrow} + I_B (R_B + R_C) + V_{BE}^{\downarrow}$$

$$I_C^{\uparrow} \rightarrow V_{BE}^{\downarrow} \rightarrow I_B^{\downarrow} \rightarrow I_C^{\downarrow}$$

$$I_C^{\uparrow} = \beta I_B + (1+\beta) I_{CBO}^{\uparrow}$$

* R_B is very large, theoretically *

02/04/2020

$$\frac{d}{dI_c}(V_{cc}) = \frac{d}{dI_c}\left(I_B R_B + V_{BE} + I_E R_E\right)$$

$$0 = (R_B + R_E)\left(\frac{dI_B}{dI_c}\right) + R_E$$

$$\frac{dI_B}{dI_c} = \frac{-R_E}{R_B + R_E}$$

$$\Rightarrow S = \frac{1+\beta}{1 + \frac{\beta R_E}{R_B + R_E}}$$

C	E
$S_c = \dfrac{1+\beta}{1 + \frac{\beta R_c}{R_B + R_c}}$	$S_E = \dfrac{1+\beta}{1 + \frac{\beta R_E}{R_B + R_E}}$
R_c	R_E

$$\left.\begin{array}{l} R_c > R_E \Rightarrow S_c < S_E \\ R_c < R_E \Rightarrow S_c > S_E \end{array}\right\} \text{which case is practical here?}$$

$$S'' = \left.\frac{dI_c}{d\beta}\right|_{V_{BE},\, I_B \to \text{const.}}$$

* Resistance have tolerances of 10%, which means ΔI_B ~~is~~ is large if Resistance is large.
So, high R_B

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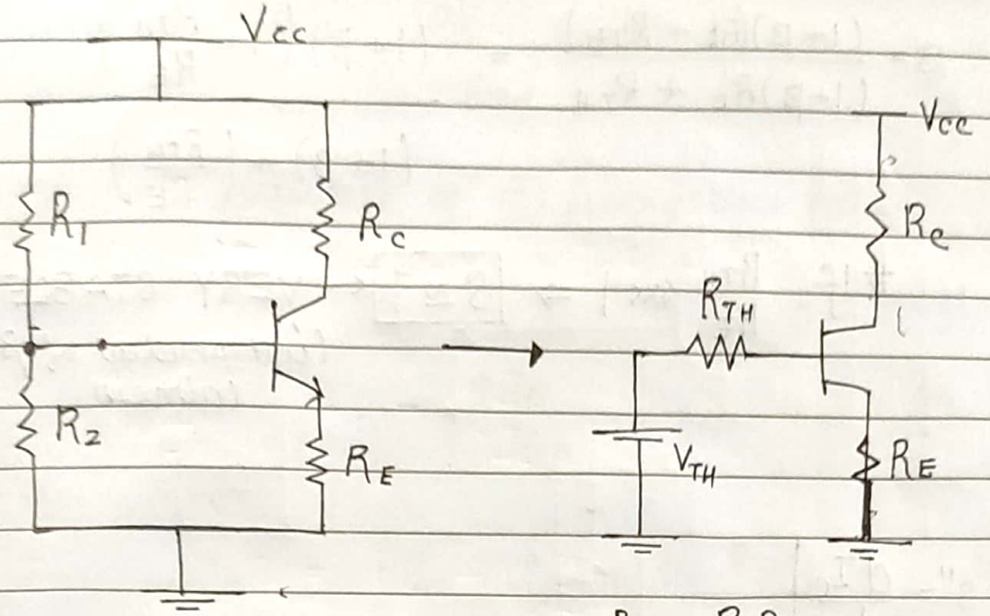
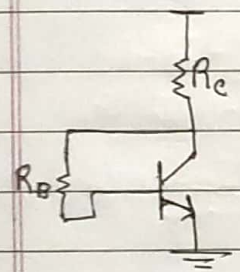


$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2} \qquad V_{TH} = \frac{V_{CC} R_2}{R_1 + R_2}$$

$$V_{TH} = I_B R_{TH} + V_{BE} + I_E R_E$$

$$V_{TH} = I_B (R_{TH} + R_E) + V_{BE} + I_C R_E \qquad \because I_E = I_B + I_C$$



$$V_{CC} = (I_C + I_B) R_C + I_B R_B + V_{BE}$$

$$\frac{d(I_C)}{dI_C} = \frac{d}{dI_C}\left(\beta I_B + (1+\beta) I_{CBO}\right)$$

$$1 = \beta \left(\frac{dI_B}{dI_C}\right) + \frac{(1+\beta)}{S}$$

generally $R_B >> R_C$ so V. unstable.

$$\frac{(1+\beta)\left(1+\frac{R_B}{R_C}\right)}{\left(1+\beta+R_B/R_C\right)} = S \Leftarrow S = \frac{1+\beta}{1-\beta\frac{dI_B}{dI_C}}$$ } in original circuit

$$\frac{d(V_{TH})}{dI_C} = \frac{d}{dI_C}\left(I_B R_{TH} + V_{BE} + I_E R_E\right)$$

$$0 = R_{TH}\frac{dI_B}{dI_C} + 0 + R_E \frac{dI_B}{dI_C} + R_E \Rightarrow S = \frac{1+\beta}{1+\frac{\beta R_E}{R_E + R_{TH}}}$$

02/10/2020

$$S = \frac{(1+\beta)(R_E + R_{TH})}{(1+\beta)R_E + R_{TH}} = \frac{(1+\beta)\left(1+\frac{R_{TH}}{R_E}\right)}{(1+\beta)+\left(\frac{R_{TH}}{R_E}\right)}$$

If $\frac{R_{TH}}{R_E} \lll 1 \Rightarrow \boxed{S \simeq 1}$ ← VERY STABLE (independent of β) (almost)

$$S'' = \left.\frac{dI_C}{d\beta}\right|_{I_{B}, V_{BE} \rightarrow \text{const.}}$$

$$\frac{d(I_C)}{dI_C} = \frac{d}{dI_C}\left(\beta I_B + (1+\beta)I_{CBO}\right)$$

$$1 = \beta\frac{dI_B}{dI_C} + I_B\frac{d\beta}{dI_C} + I_{CBO}\frac{d\beta}{dI_C}$$

$$1 - \beta\frac{dI_B}{dI_C} = (I_B + I_{CBO})\frac{d\beta}{dI_C}$$

$$S'' = \frac{I_B + I_{CBO}}{1-\beta\frac{dI_B}{dI_C}} \quad \text{— (1)}$$

$$\frac{d(V_{TH})}{dI_C} = \frac{d}{dI_C}\left(R_{TH}I_B + V_{BE} + R_E(I_C + I_B)\right)$$

$$0 = R_{TH}\frac{dI_B}{dI_C} + R_E + R_E\frac{dI_B}{dI_C}$$

02/10/2020

$$\Rightarrow \frac{dI_B}{dI_C} = \frac{-R_E}{R_E + R_{TH}} \quad \text{—}(2)$$

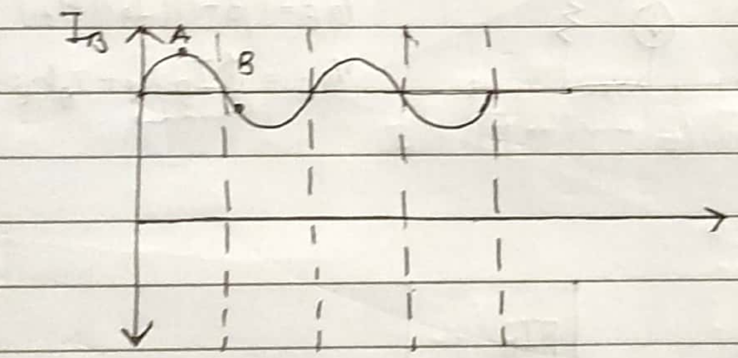
↳ evaluate eqⁿ (1) using this value

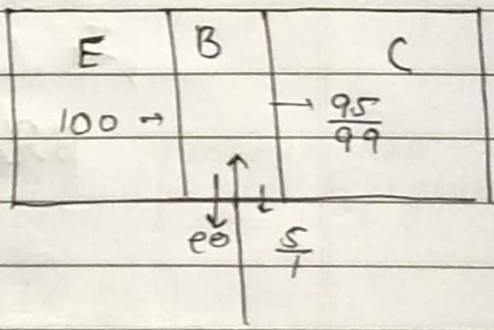
$$\Rightarrow S'' = \frac{I_B + I_{CBO}}{1 + \frac{\beta R_E}{R_E + R_{TH}}}$$

$$\Rightarrow S'' = \frac{(I_B + I_{CBO})(1 + R_{TH}/R_E)}{\left(1 + \beta + \frac{R_{TH}}{R_E}\right)}$$

If $\frac{R_{TH}}{R_E} \lll 1 \Rightarrow \boxed{S'' = \frac{(I_B + I_{CBO})}{(1+\beta)}}$ ← VERY STABLE ⇒ ~~β is in the~~ denominator

BJT AC ANALYSIS



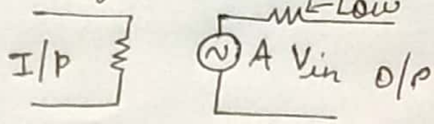


At point A: I_B is high, say 5 e⁰s come out

At point B: I_B is low, say 1 e⁰ comes out

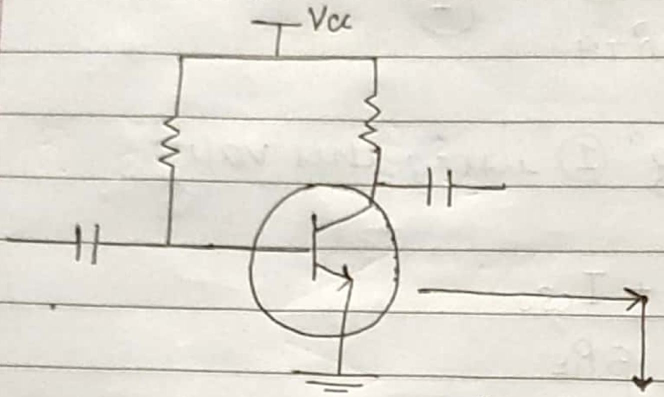
⇒ If frequency of I_B is very high, speed of e⁰s is being varied very quickly, they may not be able to physically cope up with it. Hence, I_C of transistor may not correctly represent the input signal.

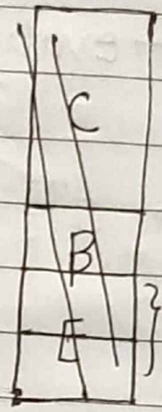
Buffer Circuit

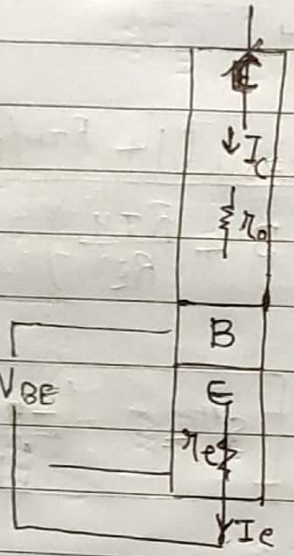


02/11/2020

Fixed Bias :

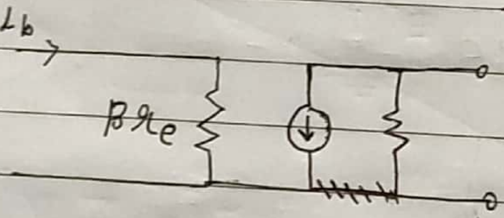






$$r_e = \frac{\eta V_T}{I_e}$$

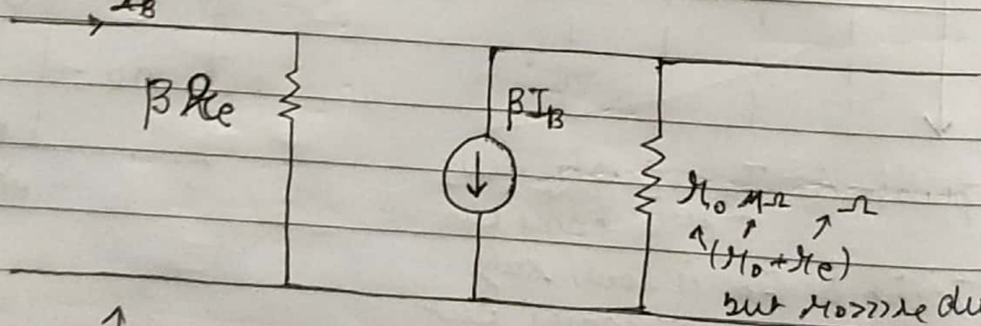
$$V_{BE} = I_e r_e$$



$$V_{BE} = (I_C + I_B)\, r_e$$

$$V_{BE} = (\beta+1)(I_B)(r_e)$$

$$V_{BE} = \underbrace{\beta I_B r_e} + I_B r_e$$

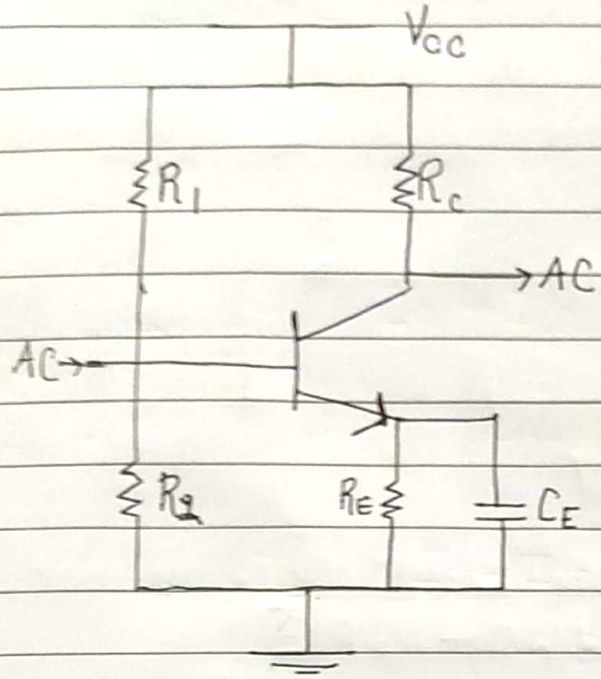


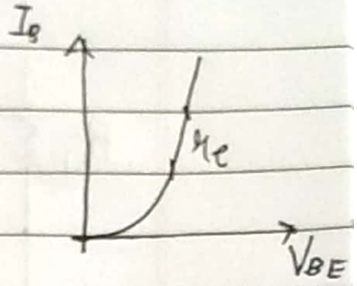
but ro >> re due to rev. bias in C–B

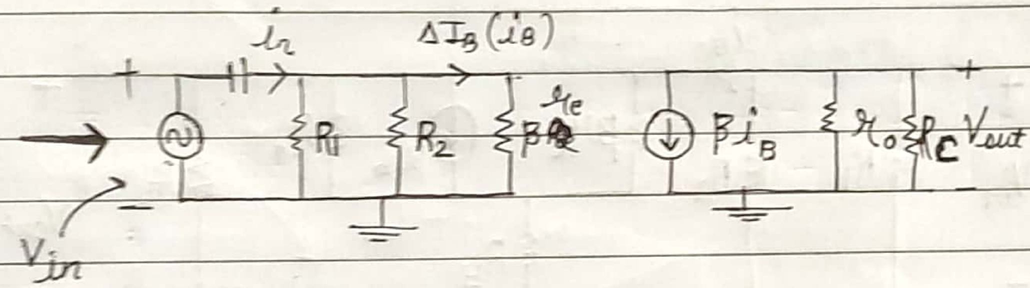
Representation of Transistor

|| Actual transistor also
|| has some capacitance ???

02/13/2020







$Z_{in} = R_1 || R_2 || \beta r_e$

$A_V = \dfrac{V_{out}}{V_{in}}$ } since we ~~have ass-~~ -umed both as the same polarity

$Z_{out} = R_c || R_o$

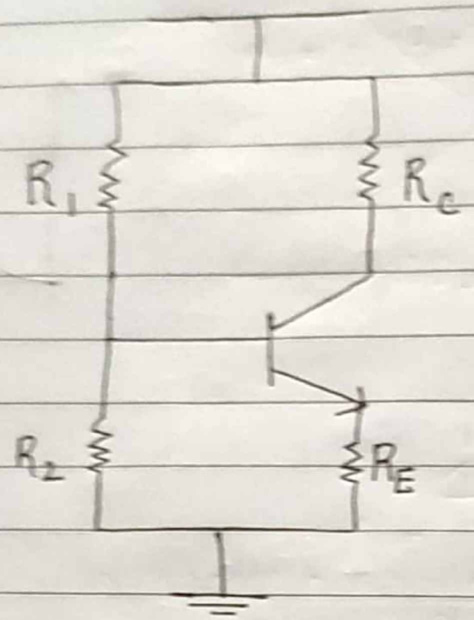
$V_{out} = -\beta i_b (R_c || r_o)$
or $-\beta i_b (R_c || r_o || R_L)$ } only in case when R_L is given

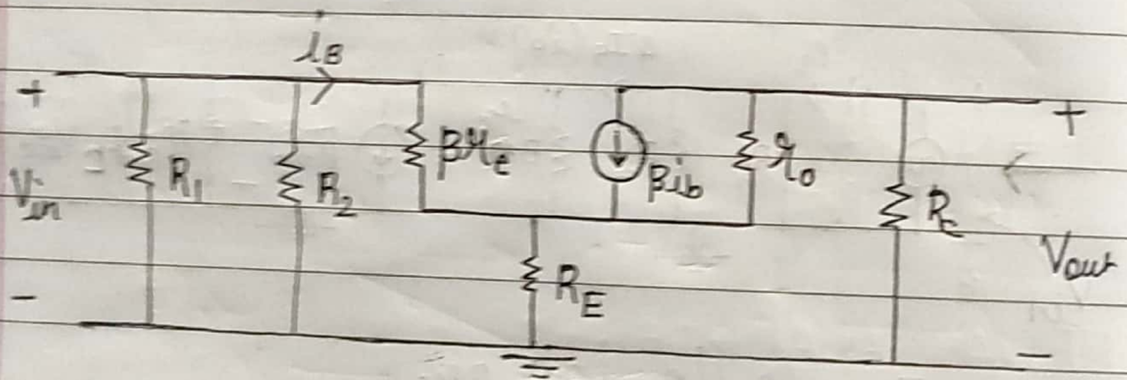
However, take $V_{out} = -\beta i_b (R_c || r_o)$

$$A_V = \frac{-\beta i_B (r_o || R_c)}{i_B \beta r_e}$$

$$= \frac{-r_o || R_c}{r_e} \sim \frac{-R_c}{r_e}$$

02/13/2020





$Z_{in} = \beta r_e + (1+\beta) R_E$

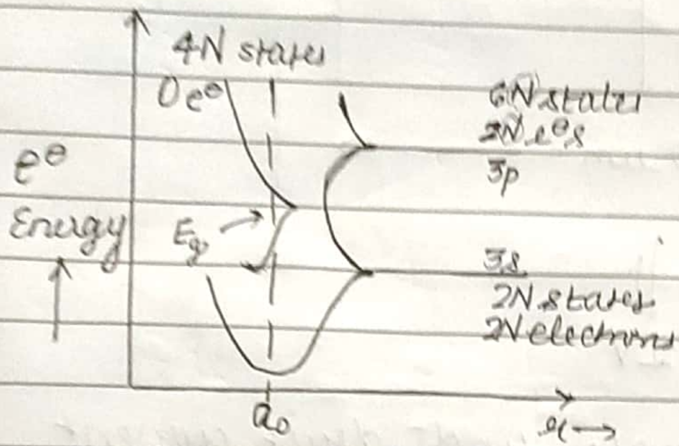
$Z_{out} = ?$

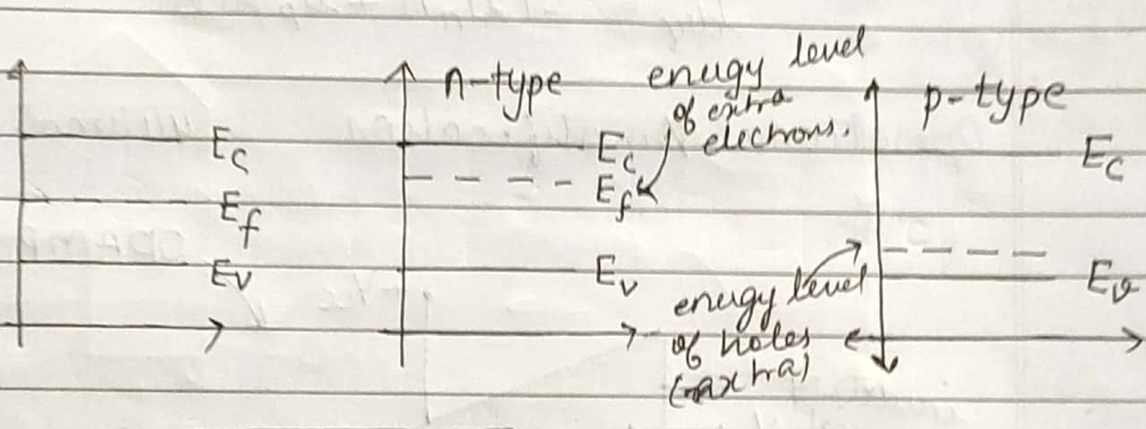
$V_{out} = ?$

$V_{in} = ?$

02/18/2020

REVISION





$$\boxed{n_0 p_0 = n_i^2}$$

$$n_0 = n_i \exp\left[\frac{E_F - E_{Fi}}{kT}\right]$$

$$p_0 = n_i \exp\left[\frac{-(E_F - E_{Fi})}{kT}\right]$$

$E_F \rightarrow$ Doped E_F

$E_{Fi} \rightarrow$ Intrinsic E_F

- $J_{drf} = e(n\mu_n + p\mu_p)E = \sigma E$

$$\rho = \frac{1}{\sigma}$$

$$J_{nx|dif} = eD_n \frac{dn}{dx}$$

$$J_{px|dif} = -eD_p \frac{dp}{dx}$$