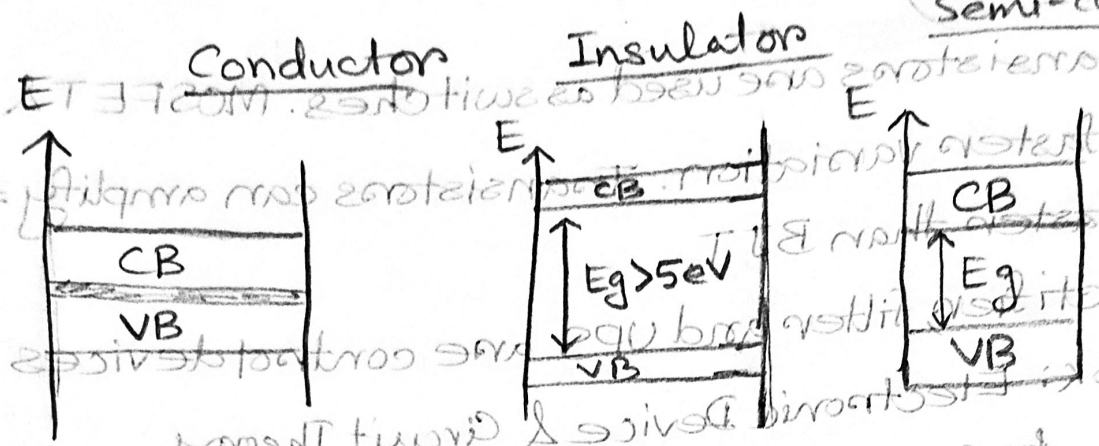
2-9-2024
MONDAY

EEE 4383
Md. Sayed Hasan Rifat sir

* Diodes make electricity unidirectional as a rectifier (AC → DC)
* Transistors are used as switches. MOSFET & JFET are its faster variation. Transistors can amplify too. MOSFET is faster than BJT.
* Rectifier, filter and UPS are control devices.
* Book: Electronic Device & Circuit Theory
  by Robert L. Boylestad
  Microelectronic circuit
  by Sedra Smith
* Solid state devices require semi-conductor material of the highest purity.
* GaAs, GaN, CdS etc. are semi-conductors w/ compound structures. Si, Ge are single crystal SC.
* Ge has less temperature stability.
* GaAs can speed up a device 5x than Si can. It's, however, more expensive.
* CB = Conduction Band
  VB = Valence Band
  E = Energy

* Energy band for different types of materials:



* Eg (Energy gap)

Si → 1.1eV

Ge → 0.67eV

GaAs → 1.4eV

* SCs are doped w/ impurities to change its characteristics. SCs can be doped w/ n- or p-type materials. Pure SCs are Intrinsic Materials; after fabrication, they become Extrinsic Materials.

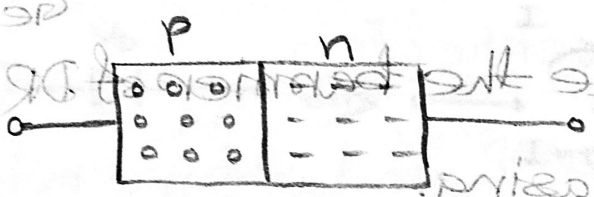
* Si connect w/ each other by means of covalent bonds.

* n-type materials → P, Sb etc.

Here's electrons are the majority carrier and holes function as the minority carrier. The

opposite is true for p-type materials.

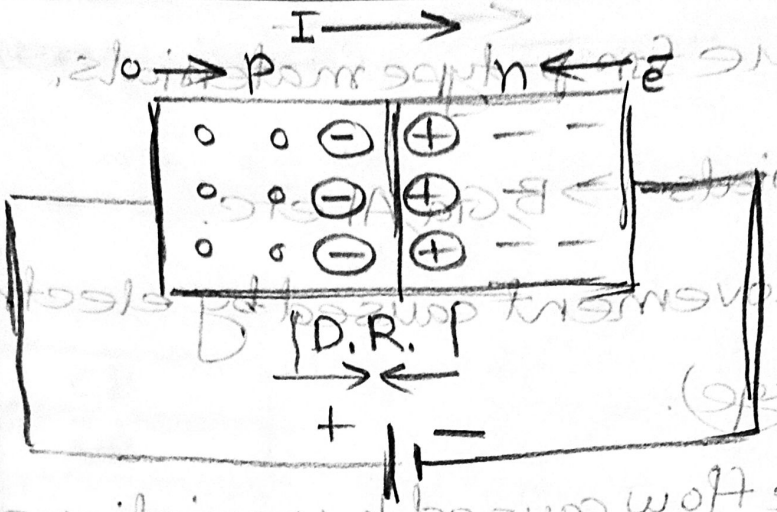
* p-type materials → B, Ga, Al etc.
* Drift is the movement caused by electric fields (example: voltage).
* Diffusion is the flow caused by variations in the concentration of charge carriers.
*



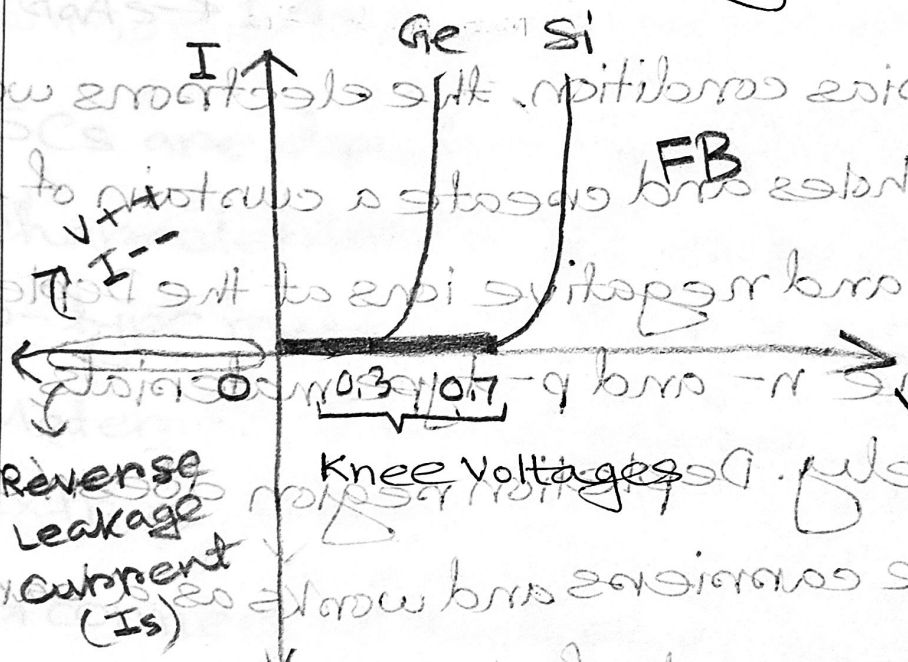
⇒ semi-conductor diode

Under no bias condition, the electrons would occupy the holes and create a curtain of layer of positive and negative ions at the Depletion Region in the n- and p-type materials, respectively. Depletion region doesn't host any charge carriers and works as a barrier for the movement of charges.

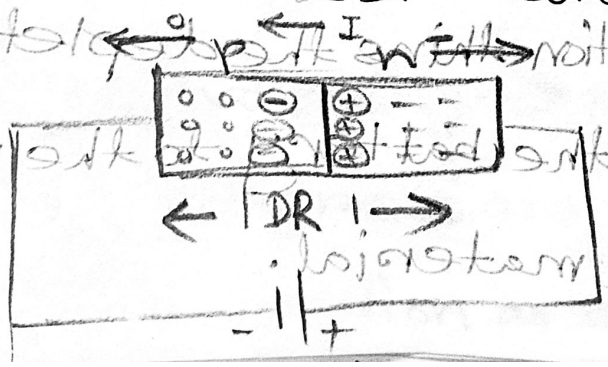
Forward bias condition thins the depletion region by connecting + of the battery to the p- and − to the n-type material.



* At least, $\underset{0.3}{\overset{0.7}{\sim}}$ V needs to applied for $\underset{Ge}{\overset{Si}{\sim}}$ diodes to overcome the barrier of DR by using forward biasing.



* In Reverse Bias condition, $V_D < 0$.



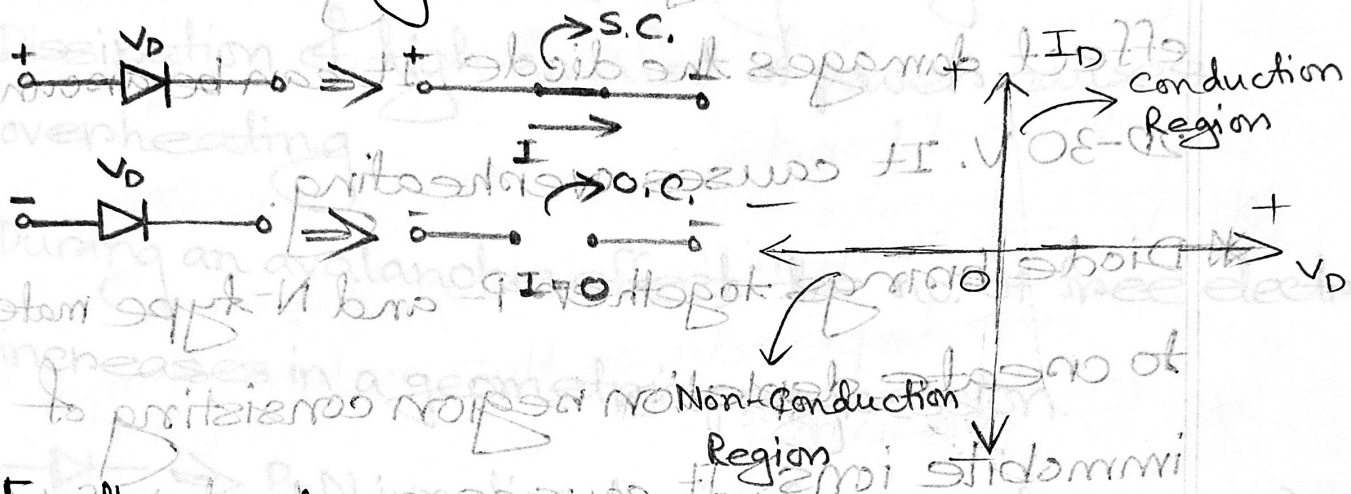
⑥ The minority carriers cause current leakage in RB.

EEE 4383

7-9-2024
SATURDAY

Rabiul Al Mahmud sir

* The diode is a 2-terminal device and it ideally conducts in only one direction.



For the conduction region, the voltage across the diode is 0V and the current can be infinite (limited by the circuit). The diode acts like short and the forward resistance is defined as $R_F = \frac{V_F}{I_F}$.

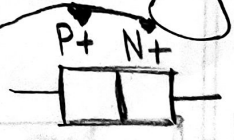
9-9-2024
MONDAY

EEE4383
Md. Sayed Hasan Rifat sir

* Knee or cut-in voltage is material-dependent
* RB turns the diode off, only leakage current is seen.
* For Si / Ge, reverse saturation current is less than 20 ~ 50 μA.
* Breakdown voltage, caused by the avalanche effect, damages the diode. It can be around 20-30 V. It causes overheating.
* Diode brings together P- and N-type materials to create depletion region consisting of immobile ions. It causes an electric field.
* Increase in the RB voltage intensifies the electric field of the depletion region and speeds up the transfer of minority charge carriers. This results in collisions among the moving charges and the immobile ions. Thus, freeing new electrons in a chain reaction and producing much heat. Once the heat surpasses a certain limit, the avalanche

effect damages the diode. In turn, reverse current increases.

* PIV ⇒ Peak Inverse Voltage
  ⇒ Max. amount of (RB) voltage a diode can withstand w/o getting damaged.
* Dissipation of high amount of power causes overheating.
* During an avalanche effect, the no. of free electrons increases in a geometric progression.
* ⇒ P-N junction diode (general purpose)
  ⇒ Zener diode
  ⇒ Eliminates avalanche effect, but shows zener breakdown effect.
* Zener diodes are doped highly, causing the depletion region to be very thin.



It decreases the distances between the holes and the electrons, allowing them to combine near the junction.

* Zener diodes have higher amount of holes, electrons and immobile ions, leading to a stronger electric field (upto 500kV/m). It's known as Built-in Electric Field. Adding external EF will free electrons from Si's valence shells by breaking the covalent bonds.

* V_Z → Zener Breakdown Voltage
  - → depends on the material and the doping
  - → the diode won't be damaged
  - → reverse current flows via Quantum Tunnelling
  - → used as voltage regulator (maintains a constant voltage output)

* $$\boxed{I_D = I_S\left(e^{V_D/nV_T} - 1\right)}$$ Shockley eqn.

I_S → reverse saturation current

V_D → diode voltage

$n \rightarrow$ ideality factor (generally 1) $\Rightarrow 1 \leq n \leq 2$

$V_T \rightarrow$ thermal voltage

$\Rightarrow \frac{KT}{q}$

$I_D \rightarrow$ diode current

Shockley's eqn. explains the V-I curve of Zener diodes.

* ~~Diode t~~ Voltage drop for a diode equals to its knee voltage.

* Ideal diode doesn't have a knee voltage.

* The rise in the I-v/s-V graph for a diode in FB is caused by its resistance for piecewise-linear equivalence. Simplified equivalence removes the resistance. The ideal equivalence also removes the voltage source and keeps just the ideal diode.

* Ideal equivalence for a diode will only be expressed ~~as~~ by a SC (for FB) or an OC (for RB).

* The point where the load line intersects with

the V-I characteristic curve is called the Q/Operating Point.

* $R\uparrow \Rightarrow Q\downarrow$

* The load line analysis shows us the range of values for which the diode will function. It shows the point at which the diode is operating at based on the circuit's structure.

* Diodes can work as half wave rectifiers to convert AC signals to DC ones.

*

$V_A > V_C \Rightarrow$ current will flow $A \rightarrow C$

* $V_m \Rightarrow$ Peak Voltage Value

* $V_{dc} = 0.318\, V_m = V_m/\pi$

DC voltage is the average voltage for the DC circuit.

* $V_o = V_m \sin \omega t$

$$V_{dc} = \frac{1}{2\pi}\int_0^{2\pi} V_m \sin \underbrace{\omega t}_{\omega t \approx t}\, dt \rightarrow dt \approx d(\omega t)$$

$$= \frac{1}{2\pi} \cdot V_m \left[\int_0^{\pi} \sin \omega t \, dt + \int_{\pi}^{2\pi} 0 \, dt \right]$$

$$= \frac{V_m}{2\pi} \left[-\cos \omega t \right]_0^{\pi}$$

$$= \frac{V_m}{2\pi} \left(-\cos \pi + \cos 0 \right)$$

$$= \frac{V_m}{2\pi} (1+1) = \frac{V_m}{\pi} = 0.318 \, V_m$$

For a full wave rectifier, $V_{dc} = \frac{2V_m}{\pi} = 0.636 V_m$

* For an AC source, the polarity constantly switches back and forth.
* When diode is used as a rectifier, it turns the current unidirectional.
* Center-tapped transformer can create a rectifier.
* Polarity of the source decides the direction of the flow.
* Rectifiers' conversion involves ripples which differentiates it from DC signals. Adding a

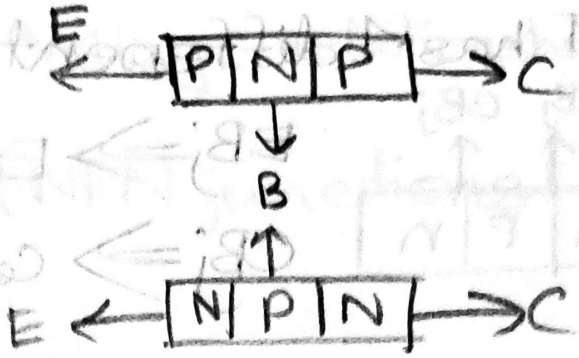
capacitor parallel to the resistance removes this discrepancy.

* In a Clipper Circuit, we clip either the positive or the negative part of the sinosoidal wave.
* Diode is in FB if $V_{anode} > V_{cathode}$.
* Biased ⇒ adding a traditional DC voltage source to the circuit
* Clamper Circuit shifts the voltage output to a different DC level. The signal isn't changed or disrupted. It's made up of resistance, diode & capacitor. Capacitor does the shifting.
* τ = Time Constant
  $= RC$

A capacitor needs τ time to charge or discharge. Better to measure it as 5τ for its full capacity.

* Both electron & hole are available as

carriers for a BJT.



E ⇒ Emitter

⇒ emits the carriers

B ⇒ Base

⇒ controls the emission

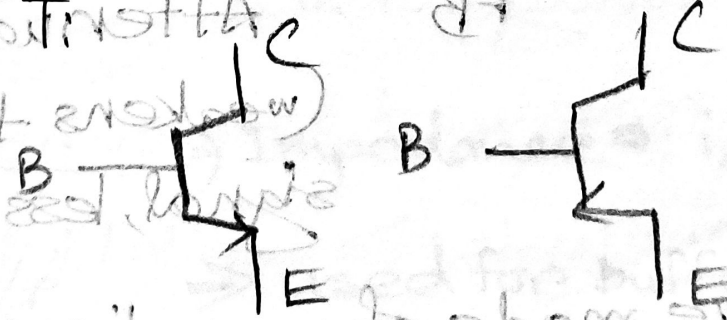
C ⇒ Collector

⇒ collects the carriers

* Doping: E > C > B

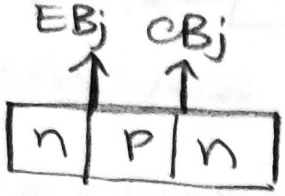
Thickness: C > E > B

* Symbol of BJT:



npn pnp

* BJT has 4 different modes of operations.



EBj ⟹ Emitter-Base junction

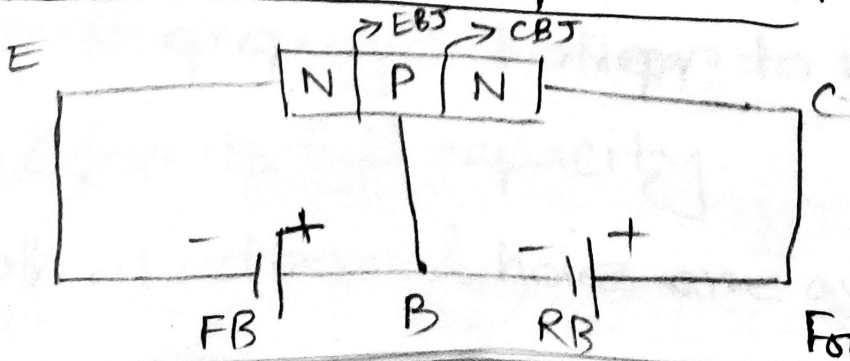
CBj ⟹ Collector-Base junction

These junctions ~~will always~~ can be in opposite biases.

~~1) Active Mode: used as an amplifier~~

EBj	CBj	Application	Mode
FB	RB	Amplifier	Active
FB	FB	ON switch	Saturation
RB	RB	OFF switch	Cut off
RB	FB	Attenuator (weakens the signal, less used)	Reverse Active

* Active mode of operation:



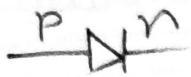
$V_B > V_E$

$V_C > V_E$

$V_C > V_B > V_E$

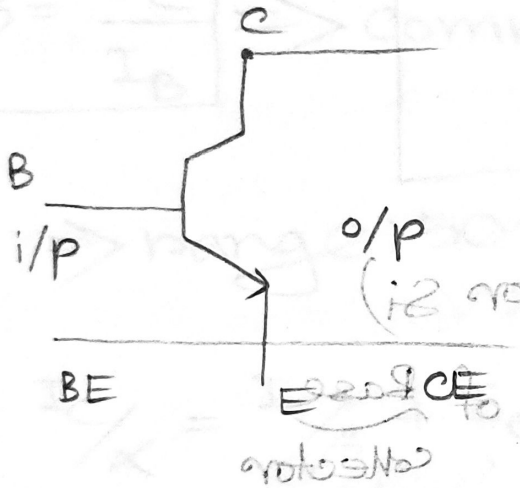
For PNP, $V_E > V_B > V_C$

* ~~Saturation m. of op.~~ Voltage relationships are reversed for PNP & NPN junctions.

* 

* Saturation m. of op. : $V_B > V_C$
  $V_B > V_E$

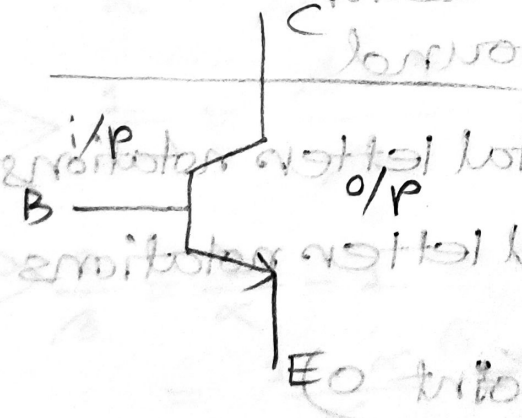
* Common Emitter Configuration:



⇒ moderate impedance (on both sides) & gains.

⇒ much used for switching or amplifying

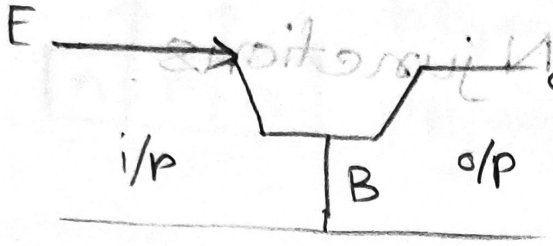
* C. Collector C:



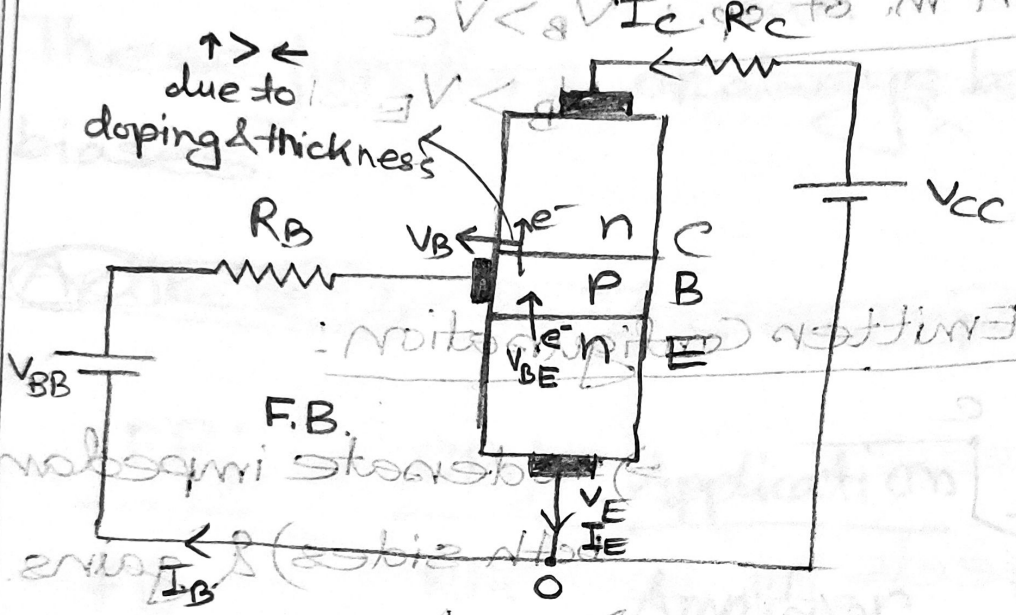
⇒ Impedance: i/p > o/p

⇒ used for buffer circuits & ~~voltage~~ signal isolation & low voltage gain

C. Base C.



⇒ used as amplifiers



$V_{BE} = V_B - V_E = 0.7V$ (for Si)

V_{BB} = Source voltage of Base
CC

V_B = Voltage of the Base terminal
C
Collector
compared to ground

DC analysis ⇒ capital letter notations
AC analysis ⇒ small letter notations

$I_E = I_B + I_C$ (KCL at point O)

For NPN transistors, currents flow from C to E (opposite for e^-'s flow &

the PNP transistor's direction).

Generally, $R_C < R_B$.

Equations for BJT:

$$\boxed{I_E = I_B + I_C}$$

$$\boxed{\alpha = \frac{I_C}{I_E}} \Rightarrow \text{Common Base Current Gain}$$

$\Rightarrow$ range: 0.9 ~ 0.998

$$\boxed{\beta = \frac{I_C}{I_B}} \Rightarrow \text{Common Emitter Current Gain}$$

$\Rightarrow$ range: 50 ~ 400

$$\therefore \frac{I_C}{\alpha} = \frac{I_C}{\beta} + I_C$$

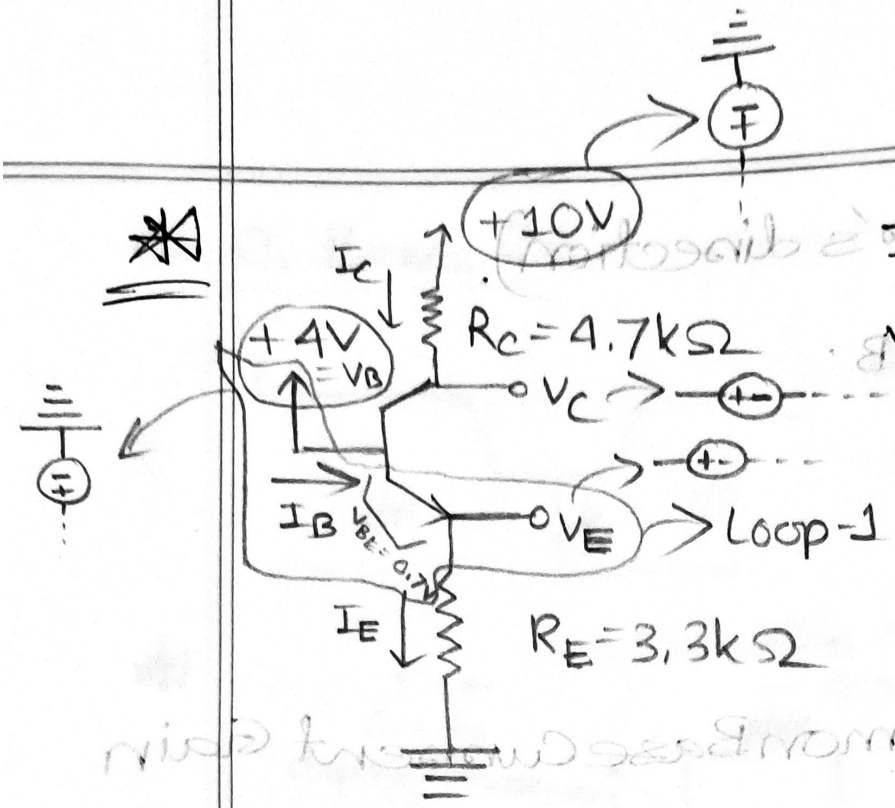
$$\Rightarrow \frac{1}{\alpha} = \frac{1}{\beta} + 1$$

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

$$\Rightarrow \frac{1}{\beta} = \frac{1}{\alpha} - 1$$

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

$$\boxed{I_E = I_B (1 + \beta)}$$



$I_B = ?$ $I_C = ?$ $I_E = ?$

$V_C = ?$ $V_E = ?$

if $\beta = 100$

$V_B = 4V$

KVL at loop-1:

$-4V + V_{BE} + V_E = 0$

$\Rightarrow V_E = 4 - 0.7 = 3.3V$

$$I_E = \frac{V_E}{R_E} = \frac{3.3}{3.3k} = 1mA$$

$$I_C = \alpha I_E$$

$$= \frac{\beta}{\beta+1} \times \frac{1}{1000}$$

$$= \frac{1}{1010} = 0.99mA$$

$\therefore I_B = I_E - I_C = 0.01mA$

~~$V_C = I_C \times R_C = 4.7k \times 0.01m$~~

Applying KVL at the Collector region:

$$-10 + I_C R_C + V_C = 0$$

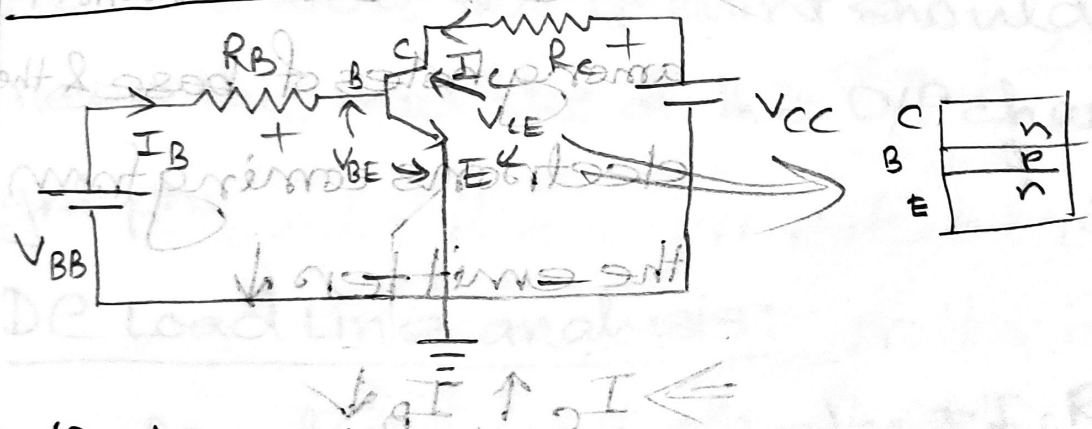
$$\Rightarrow V_C = 10 - I_C R_C$$

$$= 10 - (0.99 \times 4.7)$$

$$= 5.3\,V$$

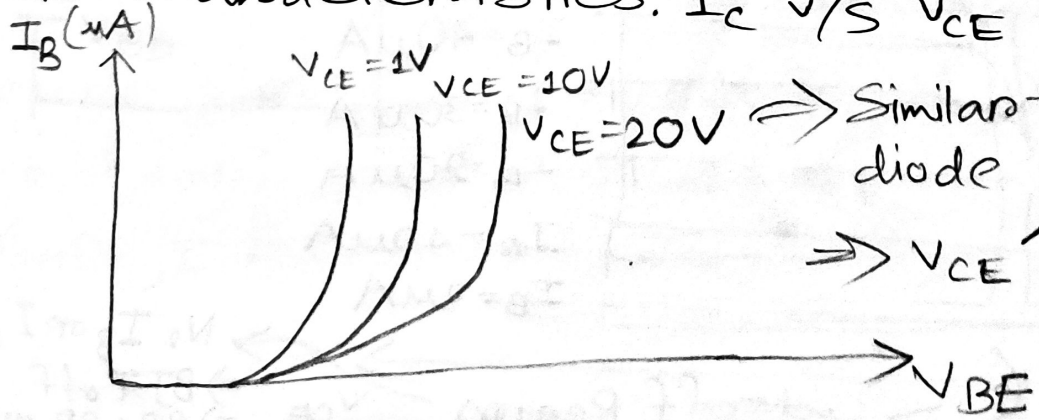
Similarly, $V_E = 1mA$

* BJT characteristics curve:



I/P characteristics: I_B v/s V_{BE}

O/P characteristics: I_C v/s V_{CE}



$\Rightarrow$ Similar to FB applied to a diode

$\Rightarrow V_{CE} \uparrow I_B \downarrow$

$V_{CE} = V_{CB} + V_{BE}$ → fixed

$= V_{CB} + 0.7 \Rightarrow V_{CE}\uparrow \; V_{CB}\uparrow \; (V_{CE} \propto V_{CB})$

(increasing the RB of the CB portion for the ACTIVE moo)

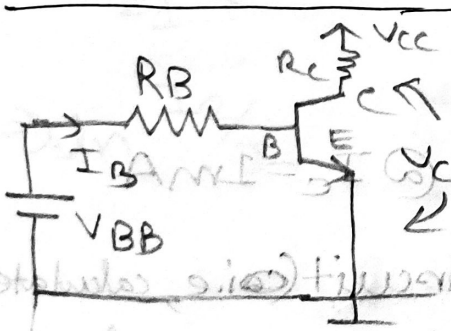
⇒ width of the depletion region ↑, effective area of the base region ↓

⇒ rate of recombination among holes of base & the electrons coming from the emitter ↓

⇒ $I_C\uparrow, I_B\downarrow$

$I_C \uparrow I_B \uparrow \quad [\because I_C = \beta I_B]$

* BJT can go through both AC and DC analysis
* To work as an amplifier, a BJT is powered by a DC power supply. The DC elements will determine the Q-point of the BJT. This operating point, in return, determines the gain for the amplifier.
* Saturation region distorts amplification. Same case for the cutoff region. Therefore, to ensure ACTIVE MOD, the Q-point should be stationed near the middle of the O/P characteristic graph.
* <u>DC Load Line analysis:</u>

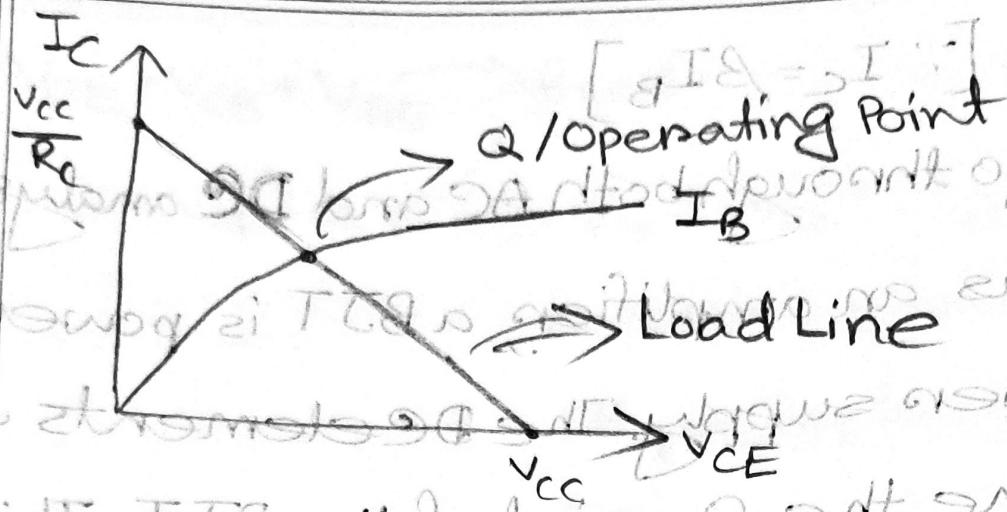


KVL $\Rightarrow -V_{CC} + I_C R_C + V_{CE} = 0$

$\Rightarrow V_{CE} = V_{CC} - I_C R_C$

If $I_C = 0$, $V_{CE} = V_{CC}$

If $V_{CE} = 0$, $I_C = \dfrac{V_{CC}}{R_C}$



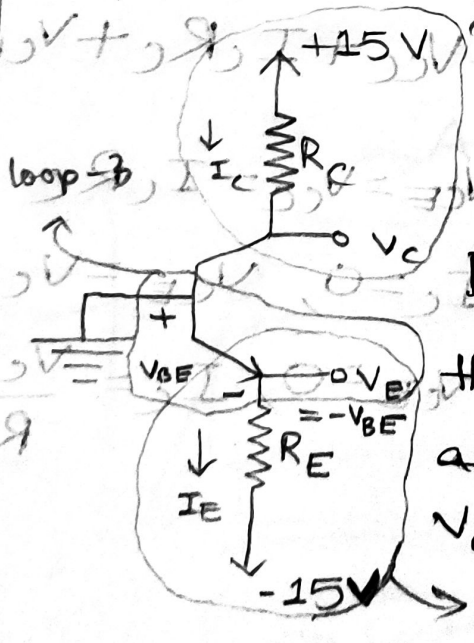
For different values of I_B, the Q-point can move.

$R_C \uparrow \quad \frac{V_{CC}}{R_C} \downarrow \Rightarrow$ Q-point shifts towards the Saturation Region (for a fixed I_B)

$V_{CC} \downarrow \quad \frac{V_{CC}}{R_C} \downarrow \Rightarrow$

* Q-point determines the level of amplification.

*



$\beta = 100$

$V_{BE} = 0.7\,V$ @ $I_C = 1mA$

Design the circuit (i.e., calculate the values of the resistors) so that ~~a circuit current of~~ $I_C = 2mA$ & $V_C = 5\,V$.

- KVL @ loop-1 $\Rightarrow -15 + I_c R_c + \underbrace{5}_{V_c} = 0$

$$\Rightarrow R_c = \frac{15-5}{2m} = 5k\Omega$$

Given that, $V_{BE} = 0.7V$ for $I_c = 1mA$

For $I_c = 2mA$, we get $\boxed{I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right)}$ Shockley's eqn for diodes

applicable for BJTs because their input signals adhere by diode's characteristics

$\Rightarrow I_D = I_S e^{V_D/nV_T}$ [$\because I_S$ is negligible] → Saturation Current

$\therefore I_1 = I_S e^{V_1/nV_T}$ and $I_2 = I_S e^{V_2/nV_T}$

$\therefore I_2/I_1 = e^{V_2/nV_T} - e^{V_1/nV_T}$

$$\Rightarrow \ln I_2/I_1 = \frac{V_2 - V_1}{nV_T}$$

→ identity factor (can be assumed to be 1)

$\Rightarrow V_2 - V_1 = V_T \ln I_2/I_1$

$\Rightarrow \boxed{V_2 = V_1 + V_T \ln I_2/I_1}$

V_T is fixed at 25mV at 25°C $\left[V_T = \frac{kT}{q}\right]$

$$\therefore V_{BE2} = V_{BE1} + V_T \ln \frac{I_{C2}}{I_{C1}}$$

$$= 0.7 + 25\,mV\left(\ln 2/1\right)$$

$$= 0.717\,V$$

KVL @ loop-3 $\Rightarrow V_{BE} + V_E = 0$

$$\Rightarrow V_E = -V_{BE} = -0.717\,V$$

Now, $\alpha = \frac{I_C}{I_E}$

$$\Rightarrow I_E = I_C/\alpha = \frac{I_C(1+\beta)}{\beta}$$

$$= \frac{I_C \times 101}{100} = \frac{I_C}{0.99}$$

$$= \frac{2mA}{0.99}$$

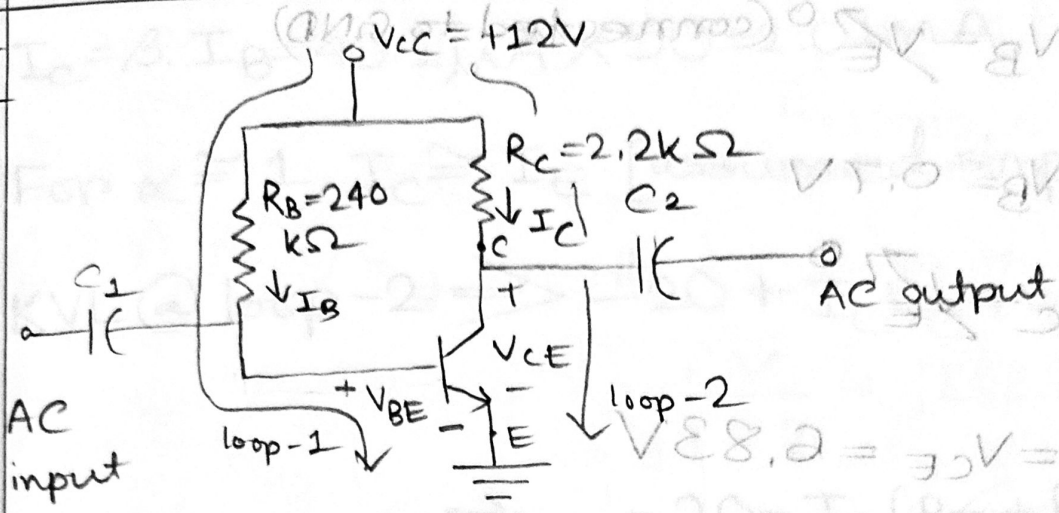
$$= 2.02\,mA$$

KVL @ loop-2 $\Rightarrow -V_E + I_E R_E - 15 = 0$

$$\Rightarrow R_E = (15 + V_E)/I_E$$

$$= \frac{15 - 0.717}{2.02m} = 7.07\,k\Omega$$

$\beta = 50$



$X_C \Rightarrow$ Capacitive Reactance

$$X_C = \frac{1}{2\pi f C}\ \Omega$$

$C \Rightarrow$ capacitance

$f \Rightarrow$ frequency

$= 0$ for DC signals

$$V_C = I_C \times X_C = \frac{I_C}{2\pi f C}$$

$\therefore$ for DC, $X_C = 1/0 = \infty \Rightarrow$ Open Circuit

For DC analysis, applying KVL @ loop-1 $\Rightarrow$

$$-12 + I_B R_B + V_{BE} = 0$$

$$\Rightarrow I_B = \frac{12 - V_{BE}}{240k\Omega} = 47.08\mu A$$

$$\therefore I_C = \beta . I_B = 50 \times 47.08\mu A = 2.3mA$$

KVL @ loop-2 $\Rightarrow -12 + I_C R_C + V_{CE} = 0$

$$\therefore V_{CE} = 6.83V$$

$V_{BE} = V_B - \cancel{V_E}^{\,0}$ (connected to GND)

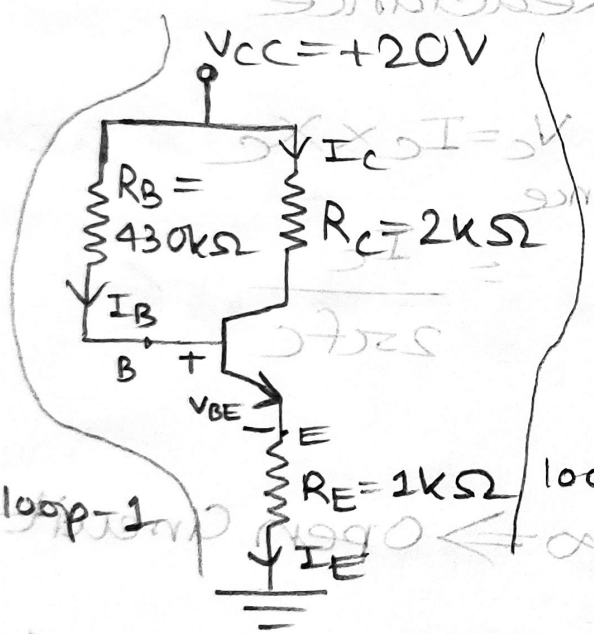
$= V_B = 0.7V$

$V_{CE} = V_C - \cancel{V_E}^{\,0}$

$\Rightarrow V_C = V_{CE} = 6.83V$

$V_{BC} = V_B - V_C = 0.7 - 6.83 = -6.13V$

*



$\beta = 50$

- For DC analysis, the capacitors can be replaced with OCs.

KVL @ loop-1 $\Rightarrow -20 + I_B R_B + V_{BE} + I_E R_E = 0$

$$\Rightarrow I_B = \frac{20 - V_{BE} - R_E I_B (1+\beta)}{R_B}$$

$$\Rightarrow I_B = \frac{20 - 0.7}{R_B + (\beta+1) R_E} = 40.1\mu A$$

$I_C = \beta . I_B = 40.1\mu A \times 50 = 2.01 mA$

For $\alpha \cong 1$, $I_C \cong I_E$ [assumed simplification]

KVL @ loop-2 $\Rightarrow -20 + I_C R_C + V_{CE} + I_E R_E = 0$

I_C

$\Rightarrow V_{CE} = 20 - I_C (R_E + R_C)$

$= 13.97V$

* Fixed-Bias configuration $\Rightarrow$ no R_E

$\Rightarrow V_{BE}$ constant

Emitter-Bias configuration $\Rightarrow$ R_E present

$\Rightarrow V_{BE}$ not constant

* $V_{CE} \rightarrow 0 \Rightarrow$ Saturation Region

≈ 0

* $\boxed{I_{C_{sat.}} = \frac{V_{CC}}{R_C + R_E}}$

* Loadline curve = Output characteristic curve

* $V_{CE} = V_{CC} - I_C R_C$

(1) $V_{CE} = 0 \Rightarrow I_C = \frac{V_{CC}}{R_C}$

(2) $I_C = 0 \Rightarrow V_{CE} = V_{CC}$

* Output characteristic graph can alone solve a circuit

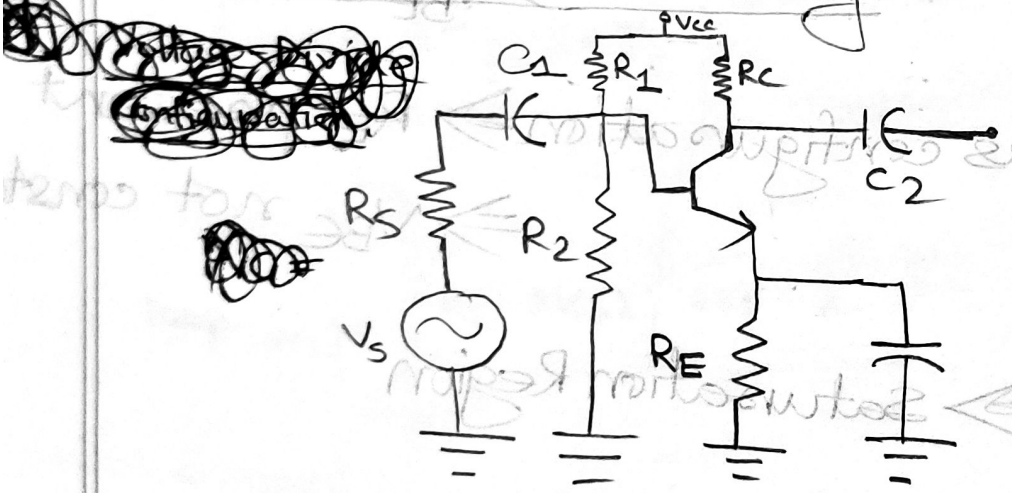
* If R_E is present, then $V_{CE} = V_{CC} - I_C(R_C + R_E)$

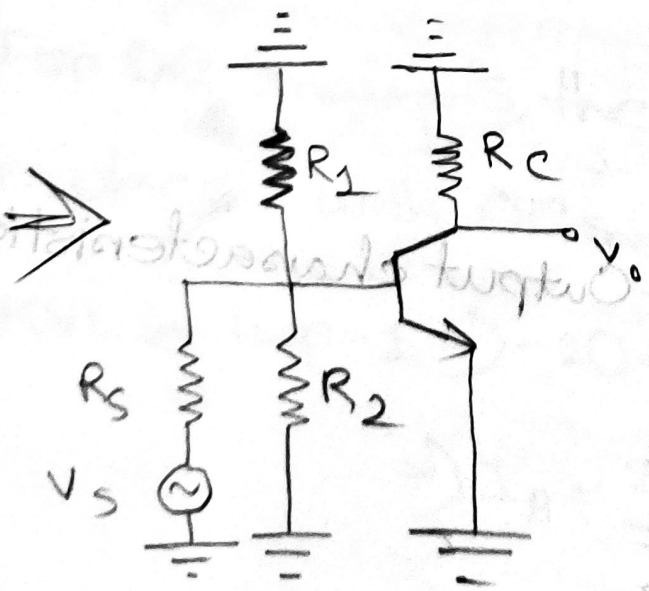
$$V_{CE} = 0 \Rightarrow I_C = \frac{V_{CC}}{R_C + R_E}$$

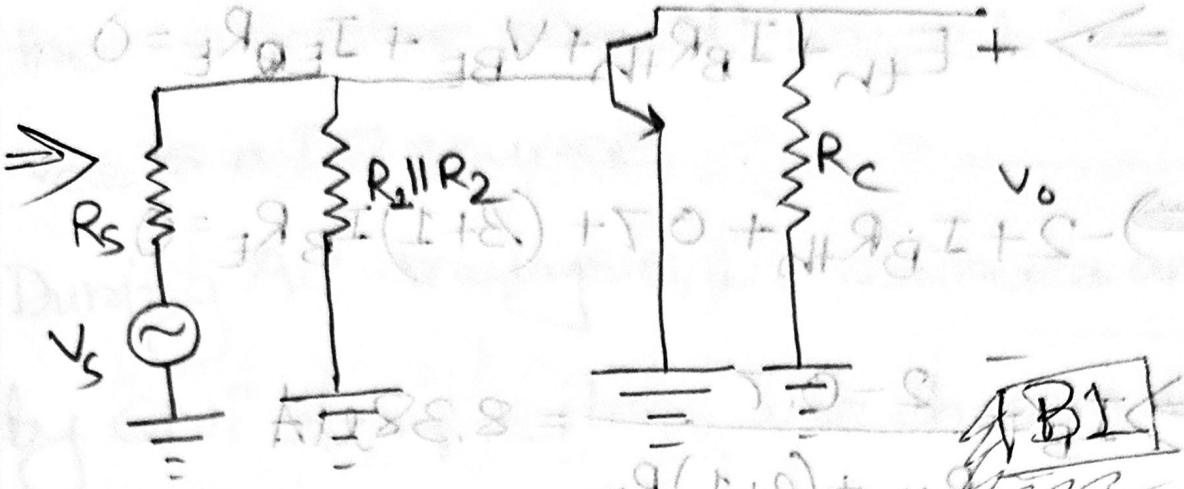
$$I_C = 0 \Rightarrow V_{CE} = V_{CC}$$

* We get I_{C_Q} & V_{CC_Q} values from the load-line graph.

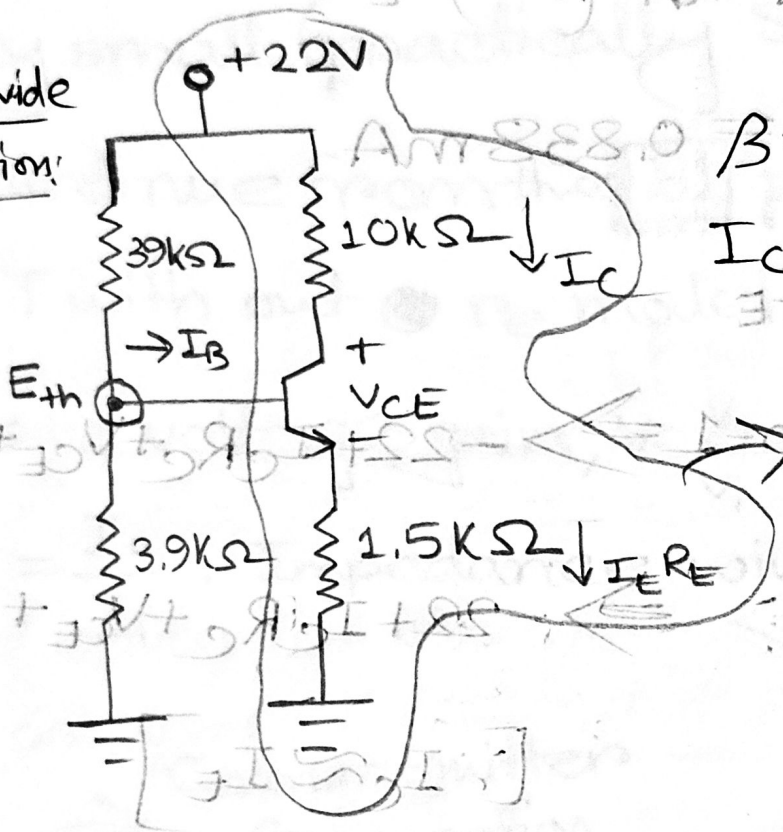
* BJT Transistor Modeling:







Voltage-Divide Configuration:

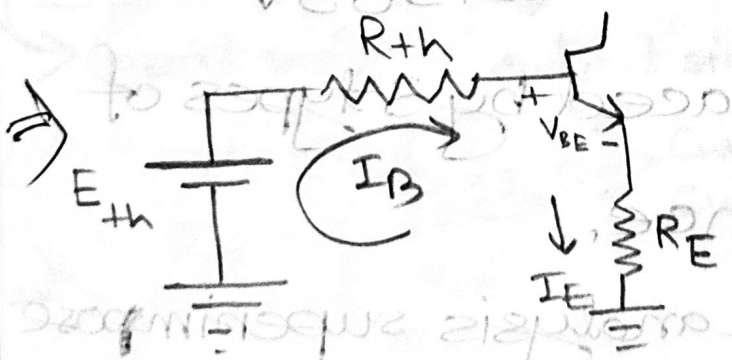


$\beta = 100$

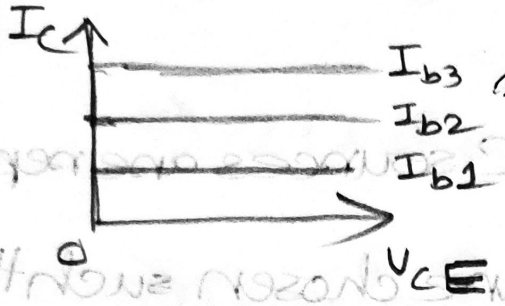
$I_C = ?$ $V_{CE} = ?$

$$E_{th} = \frac{3.9k}{3.9k + 39k} * 22 = 2V$$

$$R_{th} = 3.9K \| 39K = \frac{3.9 * 39}{3.9 + 39} = 3.5K\Omega$$

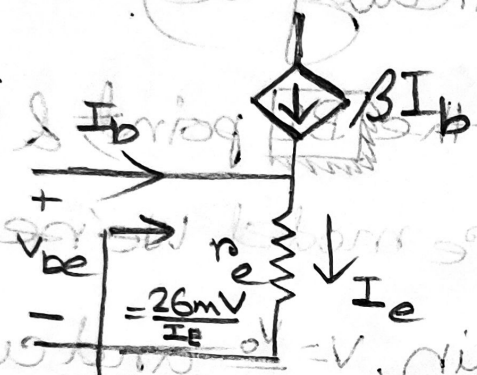


Constant β characteristic (for r_e models):



⇒ adding a resistance parallel to collector current (output) will introduce slope

⇒



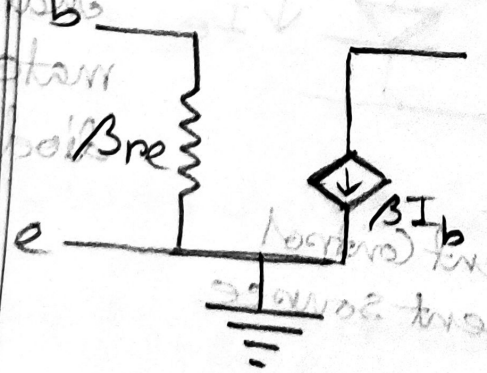
$$Z_i = \frac{V_{be}}{I_b} = \frac{I_e r_e}{I_b} = \frac{(I_c + I_b) r_e}{I_b} = \frac{I_b(1+\beta) r_e}{I_b} = r_e(1+$$

$$r_D = \frac{26mV}{I_D}$$

[proved @ book's page no. 279]

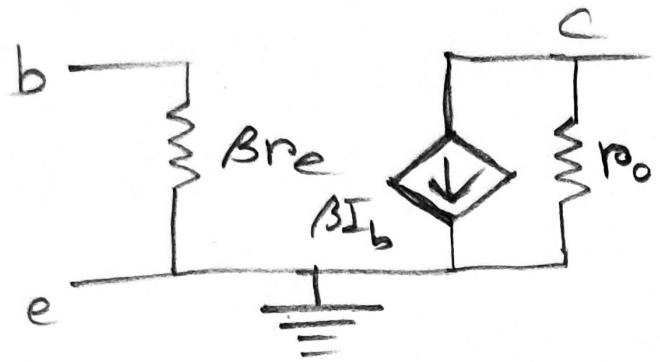
If $r_e \ll \beta r_e$, then $Z_i = \beta r_e$

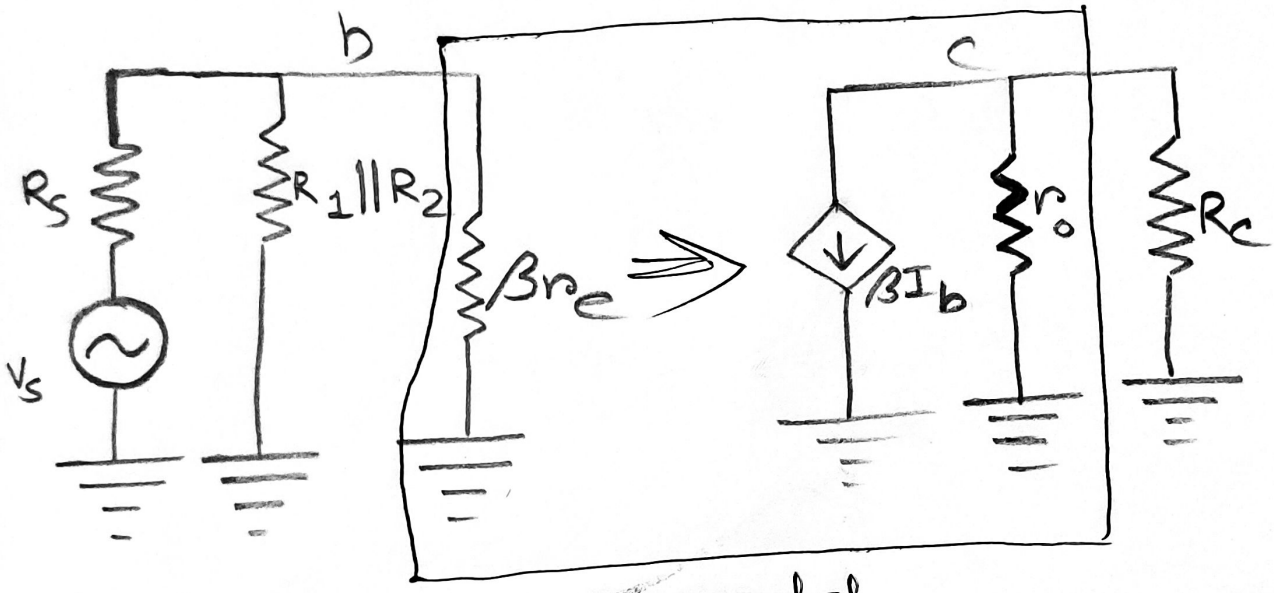
⇒ Improved equivalent circuit:



[assumption: $I_c = I_e$ & r_e is negligibly small]

After ~~indro~~ introducing slopes in the output signal:





r_e model