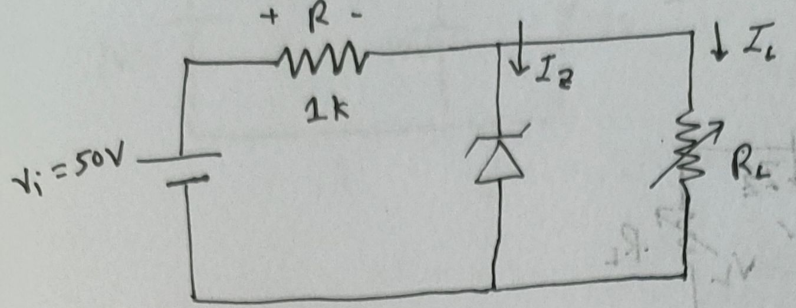
L-12/ 02.09.2023/



R_L	min	max
I_L	max	min

$$V_Z = V_L = \frac{V_i \times R_{L\,min}}{R + R_{L\,min}}$$

$$\Rightarrow 10 = \frac{50 \times R_{L\,min}}{R + R_{L\,min}}$$

$$\Rightarrow 50 R_{L\,min} = 10R + 10R_{L\,min}$$

$$\Rightarrow 40 R_{L\,min} = 10R$$

$$\therefore R_{L\,min} = \frac{10R}{40} = \frac{10k\Omega}{40} = 0.25\,k\Omega$$

$$I_{L\,max} = \frac{V_L}{R_{L\,min}} = \frac{10}{0.25} = 40\,mA$$

$$I_R = \frac{V_R}{R} = \frac{50-10}{1k\Omega} = 40\,mA$$

$$I_R = I_Z + I_L$$

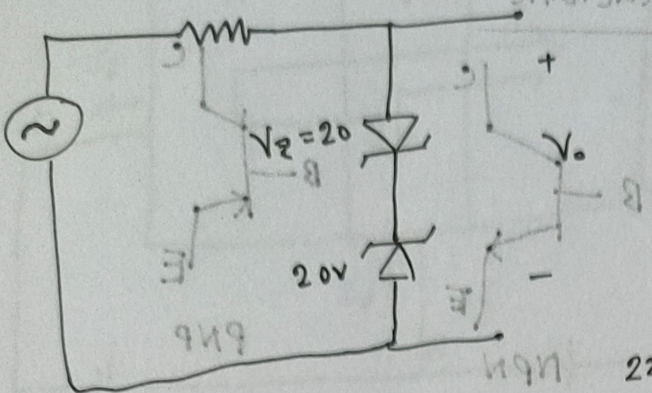
$$I_{L\,min} = I_R - I_Z$$

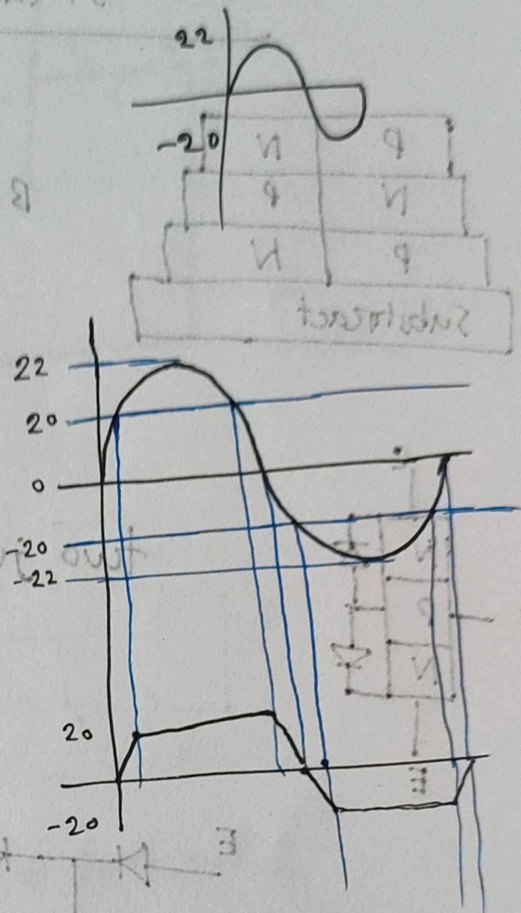
$$= I_R - I_{ZM}$$

$$= 40 - 32 = 8\,mA$$

$$R_{L\,max} = \frac{V_L}{I_{L\,min}} = \frac{10}{8mA} = 1.25\,k\Omega$$

AC Regulator

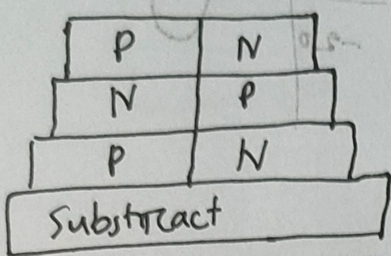


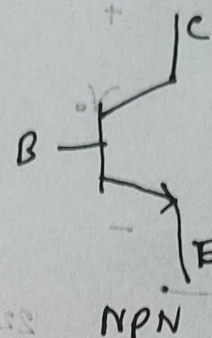


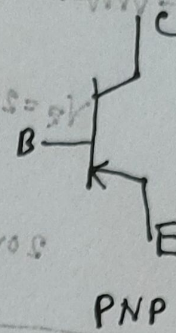
⊛ Transistor : Transfer energy from low to high resistance.

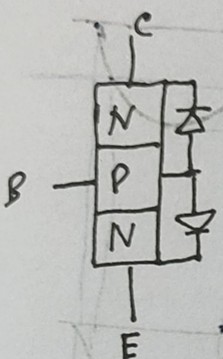
L-13/07.09.2023/

BJT Structure



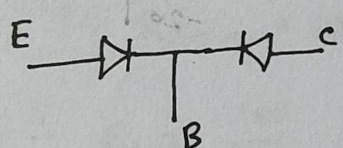


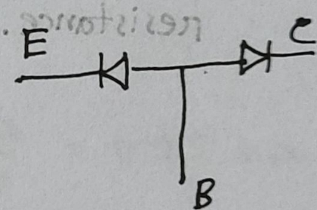




two juction NP , PN

CB , BE



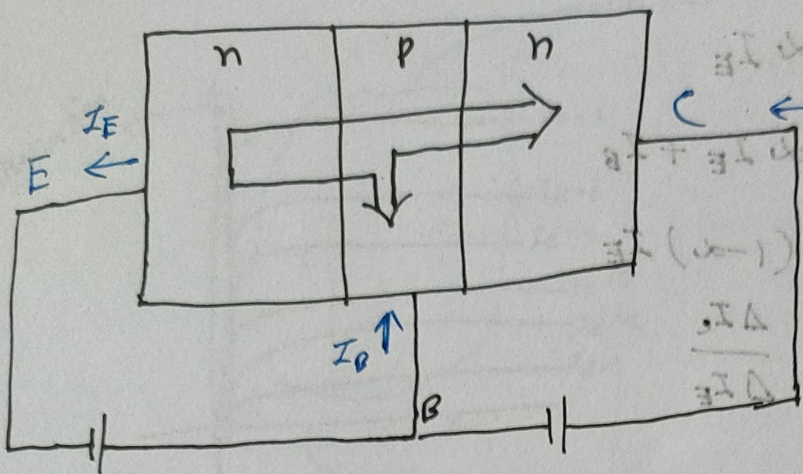


(*) Mode of Operation (from Slide)

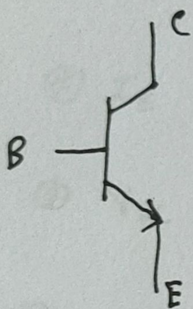
(*) Amplification = Active

Switch = cut off & Saturation

(*)



$$I_E = I_c + I_B$$



$$I_c = I_{c\,maj} + I_{c\,min}$$

cut off mode ⇒ Both off

Saturation Mode ⇒ Both on

(*) PNP ⇒ Active Mode ⇒ Here holes are inject in place of electron.

(*) Common emitter used for amplification.

(*) if 100 electron injected and 98 electrons passed then,

$$\alpha = \frac{98 \rightarrow I_c}{100 \rightarrow I_E}$$

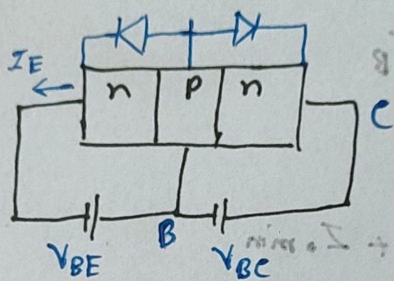
(*) From previous circuit,

$$I_C = \alpha I_E$$

$$I_E = \alpha I_E + I_B$$

$$I_B = (1-\alpha) I_E$$

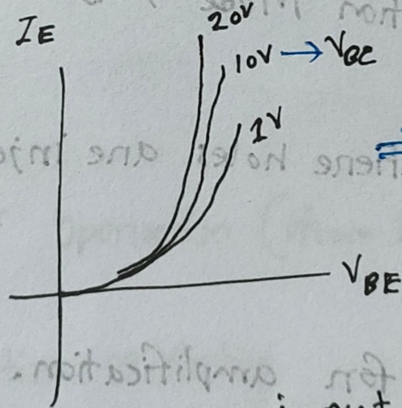
$$\alpha_{AC} = \frac{\Delta I_C}{\Delta I_E}$$



O/P

I/P

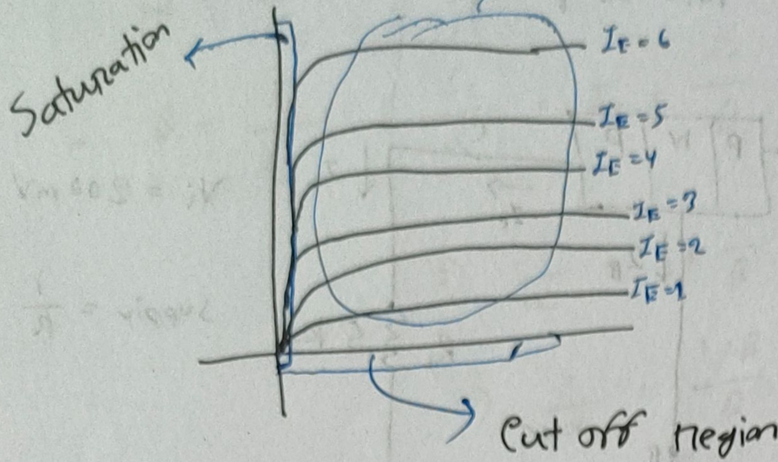
I_E vs V_{BE} $\qquad$ I_C vs V_{BC}



⇒ Like a forward Bias of a Diode

input characteristic

Output Charecteristic



$\alpha = 0.9 - 0.998$

$\cong 1$

$I_C = \alpha I_E$

$I_C = I_E$

$I_B \cong 0$

- ⊛ I_C dependent on I_E
- ⊛ I_E dependent on V_{BE}
- ⊛ V_{DC} is negligible
- ⊛ When, $I = 0$, But voltage present (cut off)
- ⊛ Voltage 0 But current present (saturation)

Quiz-2 END

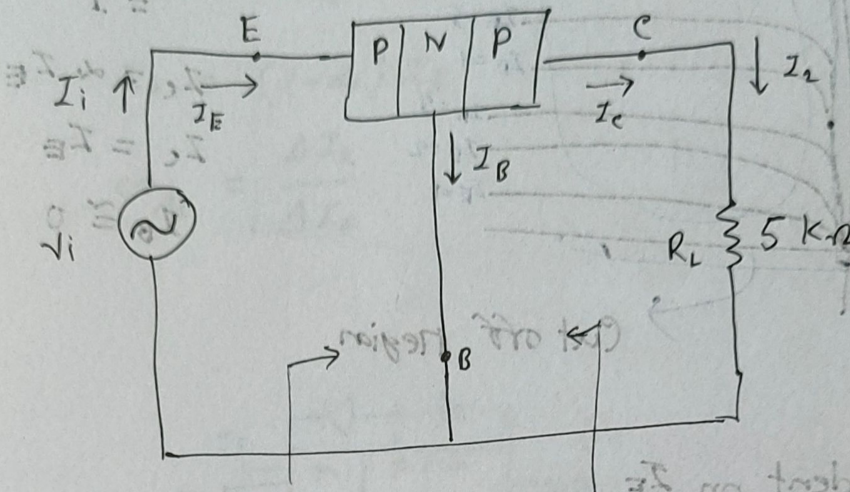
Quiz-2 ⇒ 16.09.2023

Midterm ⇒ 21.09.2023

L-14 / 14.09.2023 /

(*) Active region used for amplification.

⇒



$V_i = 200\,mV$

$\text{Supply} = \frac{i}{R}$

$R_i = 20\,\Omega$

$R_o = ?$

$$I_i = \frac{V_i}{R_i} = \frac{200\,mV}{20\,\Omega} = 10\,mA$$

$I_E = I_i$

$I_C = I_E$

$$V_L = (5\,k\Omega \times 10\,mA) = 50\,V$$

$$\therefore \text{voltage gain, } A_v = \frac{V_L}{V_i} = \frac{50\,V}{200\,mV} = 250$$

(*) Common Emitter Configuration:

$$\text{Amplification factor, } \beta = \frac{I_C}{I_B}$$

Relation between α & β

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

$$\beta = \frac{I_C}{I_B}$$

$$I_E = I_C + I_B$$

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

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

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

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

Common Emitere Charaeteristic

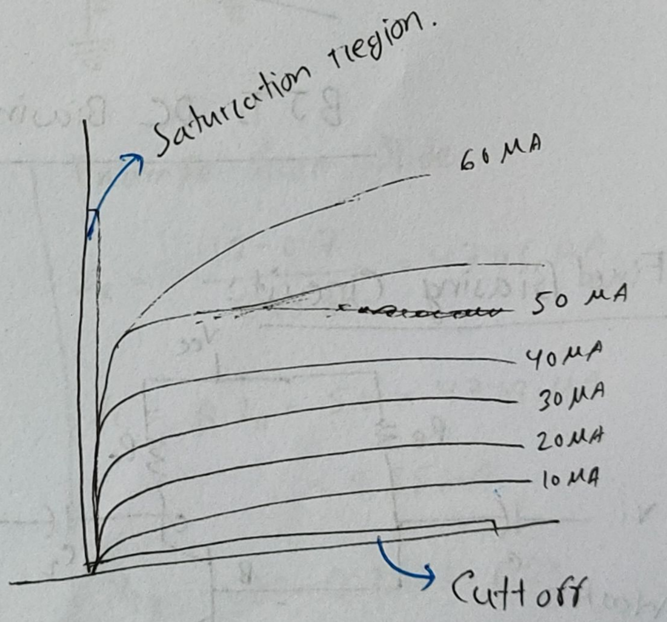
<u>Input</u>

I_B vs V_{BE}

<u>Output</u>

I_C vs V_{CE}

$I_C = \beta I_B$ → 50, 100, etc



$$\boxed{\begin{array}{c}\text{Next Class - Quiz-2} \\ \text{Only Lecture-5}\end{array}}$$

L-15 / 16.09.2023 /

Quiz-02

No Class

Next Class Midterm

L1-6

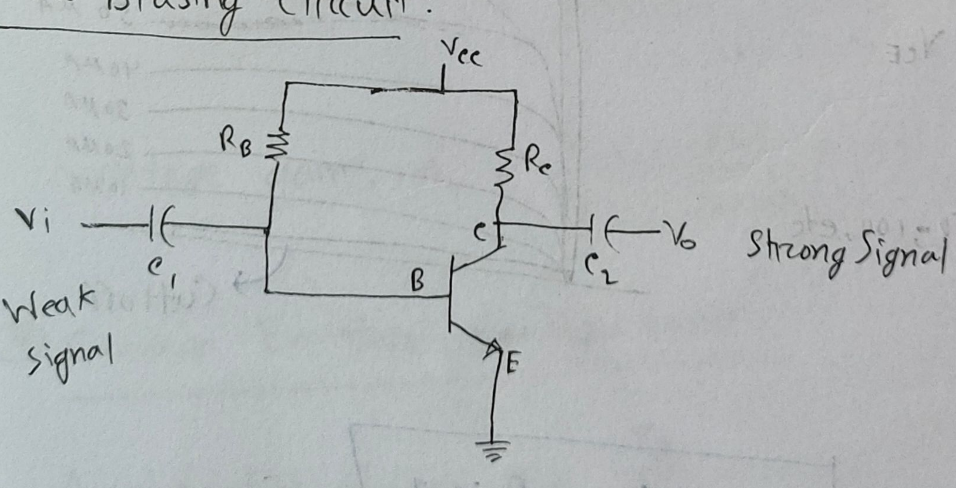
L-16 / 21.09.2023 /

Midterm Exam

L-17 / 23.09.2023 /

BJTs DC Biasing

Fixed Biasing Circuit:



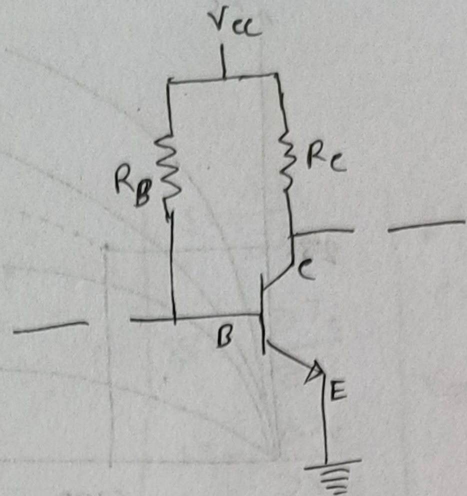
Step-1: DC Analysis

Step-2: AC Apply

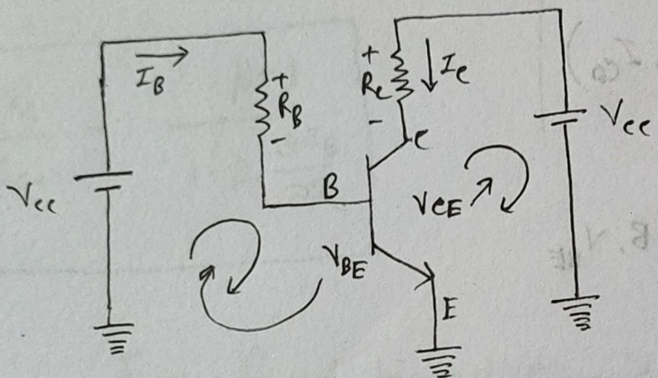
⊛ DC Analysis

$f = 0$

$X_c = \dfrac{1}{2\pi f c} = \infty$



⊛ Simplify:



$V_{cc} - I_B R_B - V_{BE} = 0$

$I_B = \dfrac{V_{cc} - V_{BE}}{R_B}$ --- (i)

$V_{CE} + I_c R_c - V_{cc} = 0$

$V_{CE} = V_{cc} - I_c R_c$

$I_c = \beta I_B$

Example from Slide

$I_B = \dfrac{12 - 0.7}{240\ k\Omega} = 47.08\ \mu A$

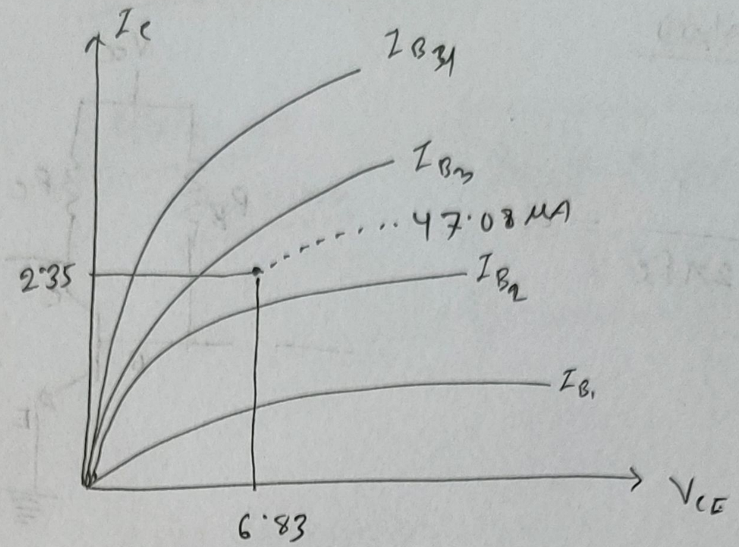
$I_c = \beta \cdot I_B = 50 \times 47.08\ \mu A$

$= 2.35 mA$

$V_{CE} = 12 - 2.35 mA \cdot 2.2k$

$= \cdots$

$V_{BC} =$



$$I_c = f\left(\beta, I_B, I_{CO}\right)$$

$$S = \left.\frac{\partial I_c}{\partial I_{CO}}\right|_{\beta,\, V_{BE}}$$

L-18/30.09.2023

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

$$1 = \beta \frac{\partial I_B}{\partial I_c} + (\beta+1)\frac{\partial I_{co}}{\partial I_c}$$

$$\frac{\partial I_{co}}{\partial I_c} = \frac{1-\beta \frac{\partial I_B}{\partial I_c}}{(\beta+1)}$$

$$\boxed{S = \frac{\partial I_c}{\partial I_{co}} = \frac{\beta+1}{1-\beta \frac{\partial I_B}{\partial I_c}}}$$

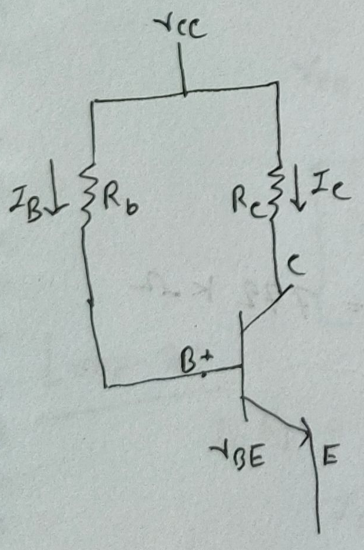
$S = \frac{\partial I_c}{\partial I_{co}}$ | β & V_{BE} constant

$S' = \frac{\partial I_c}{\partial \beta}$ | V_{BE} and I_{co}

$S'' = \frac{\partial I_c}{\partial V_{BE}}$

For fixed biased circuit

$$I_B = \frac{V_{cc} - V_{BE}}{R_B}$$



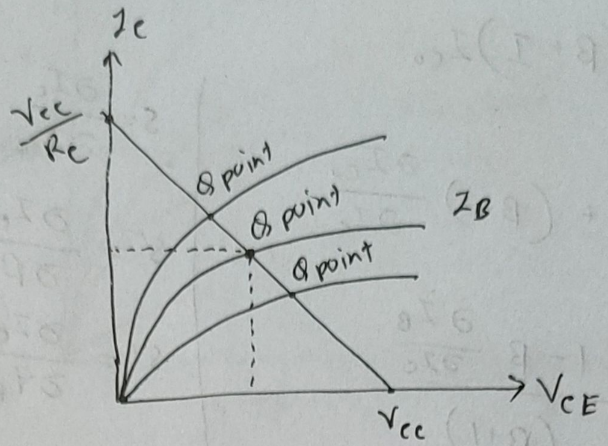
$$\frac{\partial I_B}{\partial I_c} = 0$$

$$\boxed{S = \frac{\beta+1}{1-\beta\cdot 0} = \beta+1}$$

$$I_c = \frac{V_{cc} - V_{CE}}{R_c}$$

$$= I_{c\,sat} = \frac{V_{cc}}{R_c}$$

LOAD Line Analysis



$$I_c = \frac{V_{cc} - V_{CE}}{R_c}$$

$$\beta_{DC} = \frac{I_{CQ}}{I_{BQ}}$$

From Slide

$$\frac{V_{cc}}{R_c} = 10mA$$

$$V_{cc} = 20V$$

$$R_c = \frac{20}{10} = 2\,k\Omega$$

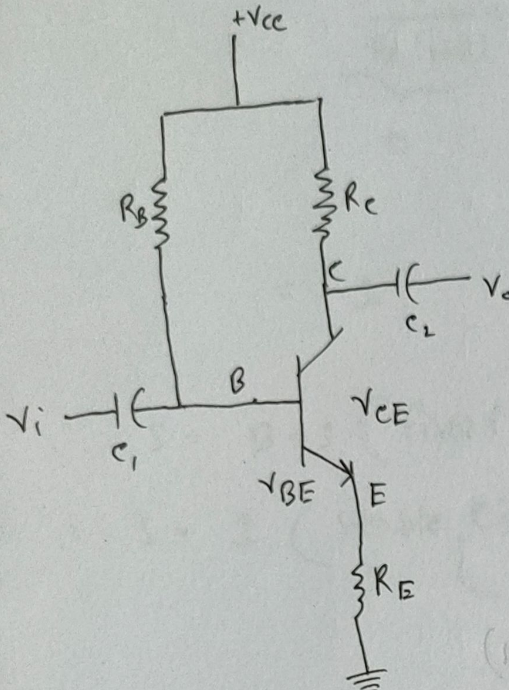
$$I_B = 25\ \mu A$$

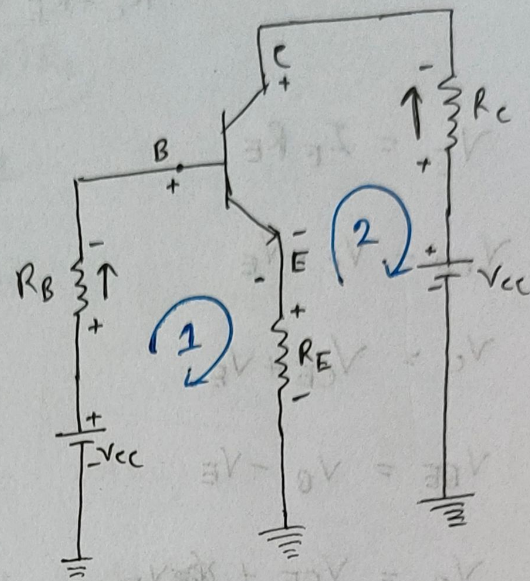
$$I_B = \frac{V_{cc} - V_{BE}}{R_B}$$

$$R_B = \frac{V_{cc} - V_{BE}}{I_B}$$

$$= \frac{20 - 0.7}{25\ \mu A} = 772\ k\Omega$$

⊛ Emitter Stabilized Bias Circuit





Loop-1:

$$V_{cc} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$I_E = I_B + I_C = I_B + \beta I_B = (\beta + 1) I_B$$

$$V_{cc} - I_B R_B - V_{BE} - (\beta+1) I_B R_B = 0$$

$$\boxed{\therefore I_B = \frac{V_{cc} - V_{BE}}{R_B + (\beta+1) R_E}}$$

Loop-2:

$$I_E R_E + V_{CE} + I_C R_C - V_{cc} = 0$$

$$I_C \cong I_E$$

$$I_C R_E + V_{CE} - I_C R_C - V_{cc} = 0$$

$$V_{CE} = V_{cc} - I_C (R_C + R_E)$$

or,

$$I_c = \frac{V_{cc} - V_{CE}}{R_c + R_E}$$

$\therefore$ $V_E = I_E R_E$

$V_{CE} = V_c - V_E$

$V_c = V_{CE} + V_E$

$V_{BE} = V_B - V_E$

$V_B = V_{BE} + V_E$

$$S = \frac{\partial I_c}{\partial I_{co}} = \frac{(\beta+1)}{1 - \beta \frac{\partial I_B}{\partial I_c}}$$

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

$$V_{cc} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$I_c \cong I_E$$

$$V_{cc} - I_B R_B - V_{BE} - I_c R_E = 0$$

$\frac{\partial I_B}{\partial I_c}$ /

$$R_B I_B = V_{cc} - V_{BE} - I_c R_E$$

$$I_B = \frac{V_{cc}}{R_B} - \frac{V_{BE}}{R_B} - \frac{I_c R_E}{R_B}$$

$$\frac{\partial I_B}{\partial I_c} = -\frac{R_E}{R_B}$$

$$\therefore S = \frac{\partial I_c}{\partial I_{co}} = \frac{\beta+1}{1 + \beta \frac{R_E}{R_B}} = \frac{(\beta+1) R_B}{R_B + \beta R_E}$$

$$\frac{1}{\underbrace{\frac{R_B}{R_B(1+\beta)}}_{0} + \underbrace{\frac{\beta R_E}{(1+\beta) R_B}}_{1}}$$

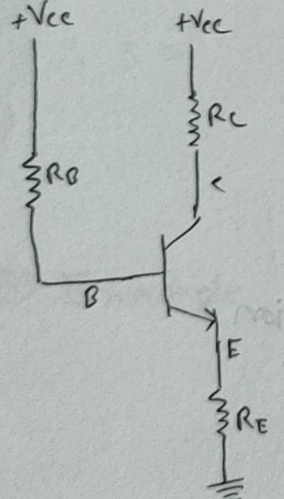
$= 1$

$\therefore$ $S = \beta + 1$ (fixed bias)

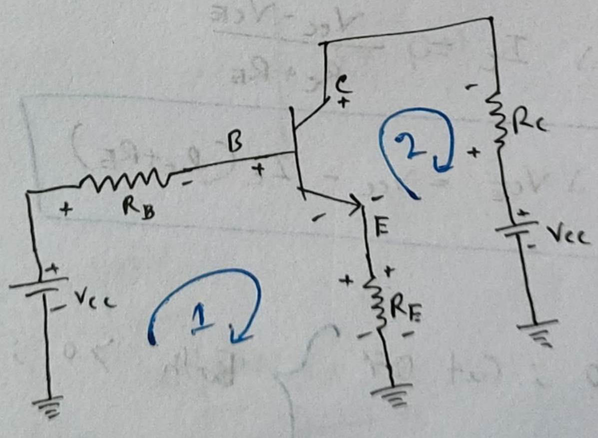
$\therefore$ $S = 1$ (Stable circuit) → independent.

L-19 / 05.10.2023

⊗ Emitter Stabilized Bias Circuit.



⇒



Loop-1 /

$$V_{cc} - R_B I_B - V_{BE} - R_E I_E = 0$$

$$I_E = I_c + I_B$$

$$= \beta I_B + I_B = I_B(\beta+1)$$

$$\boxed{I_c = \beta I_B}$$

$$\therefore V_{cc} - I_B R_B - V_{BE} - (\beta+1) I_B R_E = 0$$

$$\boxed{\therefore I_B = \frac{V_{cc} - V_{BE}}{R_B + (\beta+1) R_E}}$$

Loop-2 /

$$I_E R_E + V_{CE} + I_c R_c - V_{cc} = 0$$

$$I_c \cong I_E$$

$$\therefore I_c (R_c + R_E) + V_{CE} - V_{cc} = 0$$

$$\therefore I_c = \frac{V_{cc} - V_{CE}}{R_c + R_E}$$

$$\boxed{\therefore V_{CE} = V_{cc} - I_c (R_c + R_E)}$$

✱ $I_c = 0$; Cut Off
$V_{CE} = 0$; Saturation

} Both > 0 ; active region

⊛ Stability Factor for Emitter Bias Circuit

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

$$I_C = \beta I_B + (\beta+1) I_{CO}$$

$$\Rightarrow \boxed{S = \frac{\partial I_C}{\partial I_{CO}}}$$

$$S' = \frac{\partial I_C}{\partial \beta}$$

$$S'' = \frac{\partial I_C}{\partial V_{BE}}$$

for advance level, not in this course.

$$\therefore 1 = \beta \frac{\partial I_B}{\partial I_C} + (\beta+1) \frac{\partial I_{CO}}{\partial I_C}$$

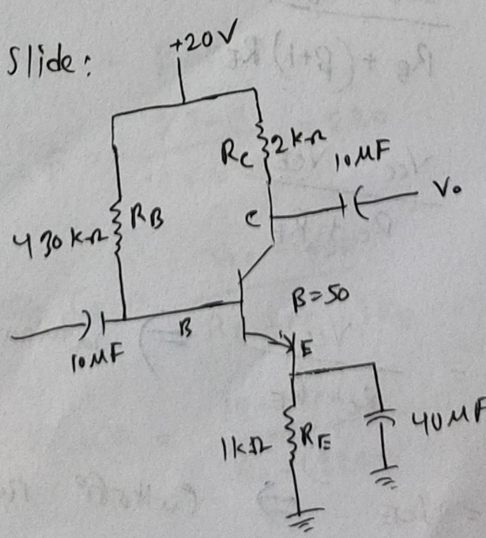
$$\therefore S =$$

fixed bias circuit,

$$\frac{\partial I_B}{\partial I_C} = 0$$

$$S = \beta + 1 .$$

⊛ Example from slide:



$$\therefore I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1) R_E} = \frac{20 - 0.7}{430\,k\Omega + (50+1) 1\,k\Omega}$$

always in micro

$$= 40.1\ \mu A$$

always in milli

$$I_C = \beta I_B = 50 \times (40.1\ \mu A)$$

$$= 2.006\ mA$$

$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$

$$= 20 - 2\,mA\,(2+1)\,k\Omega$$

$$= 13.982\,V$$

⇒ See Slide for more

L-20/07.10.2023

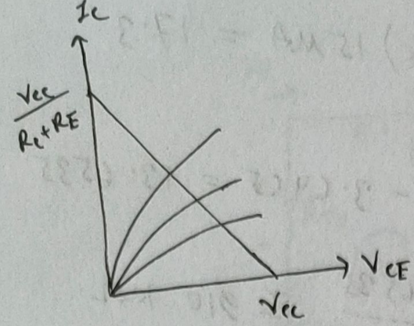
Load Line analysis for Emitter stabilized bias circuit

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

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

$$I_{C\,sat} = \frac{V_{CC}}{R_C + R_E} \Rightarrow \text{Saturation Region}$$

$$V_{CC} = V_{CE} \Rightarrow \text{Cuttoff region}$$



(*) Example from slide,

$V_{cc} = 18V$

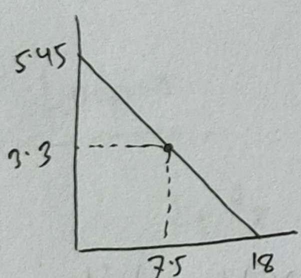
$R_C = 2.2 k\Omega$

$R_E = 1.1 k\Omega$

$R_B = ?$

$$I_{Csat} = \frac{V_{cc}}{R_C + R_E} = \frac{18}{2.2+1.1} = 5.45 mA$$

(*) Now plot load line and find out Q point. And I_{CQ} and V_{CEQ}



$\Rightarrow I_{CQ} = 3.3 mA$

$V_{CEQ} = 7.5 \mu A$

$I_{BQ} = 15 \mu A$

$I_C = \beta I_B$

$$\Rightarrow \beta = \frac{3.3mA}{15 \times 10^{-6} A} = 220$$

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

$$\Rightarrow 15 \mu A = \frac{18 - 0.7}{R_B + (220+1) 1.1k}$$

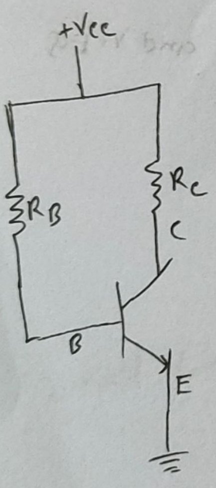
$\therefore 15\,\mu A\; R_B + (221 \times 1.1k)\, 15\,\mu A = 17.3$

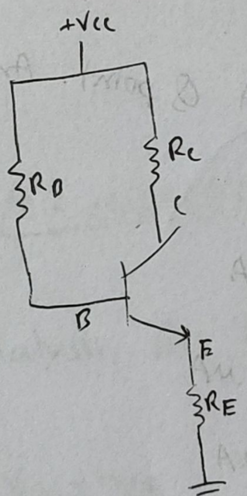
$\Rightarrow 15\,\mu A\; R_B = 17.3 - 3.6465 = 13.6535$

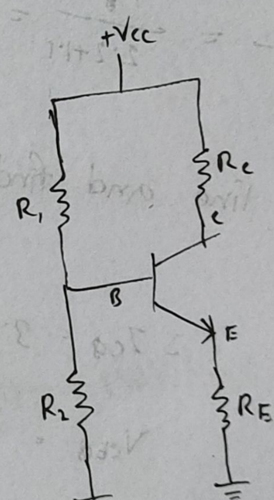
$\Rightarrow R_B = \dfrac{13.6535}{15\,\mu A} \simeq 910\; k\Omega$

Now reverse for this approximation, Q point will be shift. Reverse and find out Q point.

Voltage Divider Bias

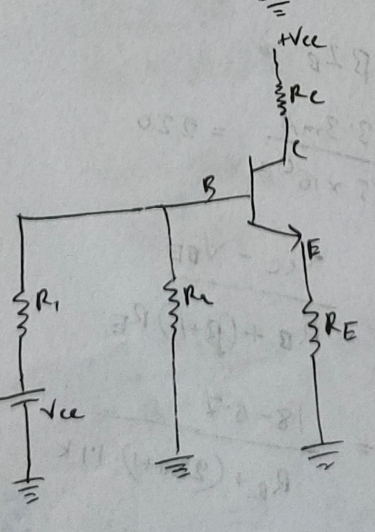






Voltage divider

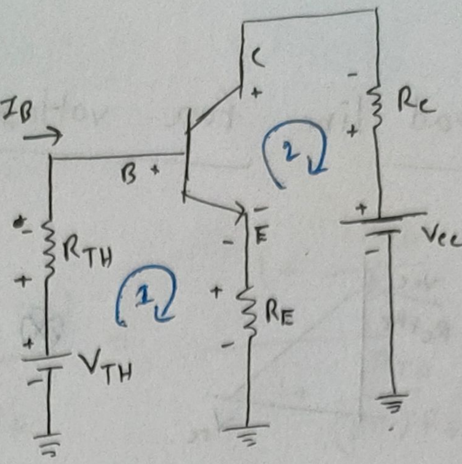
Simplify



$$R_{TH} = R_1 \parallel R_2$$

$$= \frac{R_1 R_2}{R_1 + R_2}$$

$$V_{TH} = \frac{R_2 \times V_{cc}}{R_1 + R_2}$$



Using KVL,

Loop-1,

$$V_{TH} - I_B R_{TH} - V_{BE} - I_E R_E = 0$$

$$I_E = (\beta + 1) I_B$$

$$\Rightarrow V_{TH} - I_B R_{TH} - V_{BE} - (\beta+1) I_B R_E = 0$$

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

Loop-2,

$$I_E R_E + V_{CE} + I_c R_c - V_{cc} = 0$$

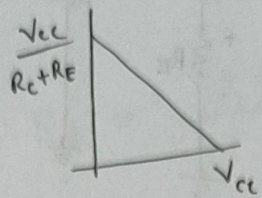
$$V_{CE} = V_{cc} - I_c R_c - I_E R_E$$

$$I_c \cong I_E$$

$$\Rightarrow V_{CE} = V_{cc} - I_c (R_c + R_E)$$

$$\Rightarrow I_c = \frac{V_{cc} - V_{CE}}{R_c + R_E}$$

⊛ DC Load line for voltage divider Bias Circuit



⊛ Do some example from slide.

⊛ Stability factor for voltage Divider Bias Circuit.

$$S = \frac{\beta + 1}{1 - \beta \frac{\partial I_B}{\partial I_C}}$$

$$* \Rightarrow V_{TH} - V_{BE} - R_{TH} I_B - I_E R_E = 0$$

$$I_E = I_B + I_C$$

$$V_{TH} - V_{BE} - R_{TH} I_B - I_C R_E - I_B R_E = 0$$

$$I_B (R_{TH} + R_E) = V_{TH} - V_{BE} - I_C R_E$$

$$\therefore I_B = \frac{V_{TH}}{R_{TH} + R_E} - \frac{V_{BE}}{R_{TH} + R_E} - \frac{I_C R_E}{R_{TH} + R_E}$$

$$\rightarrow \frac{\partial I_B}{\partial I_C} = - \frac{R_E}{R_{TH} + R_E}$$

$$\therefore S = \frac{\beta+1}{1+\beta\frac{R_E}{R_{TH}+R_E}}$$

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

$\therefore R_E >> R_{TH}$

$\therefore S = 1$ (Independent) (stable)

⊗ Collector Feedback config.

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Voltage divider Bias Circuit

Analysis

$$I_{c\,sat} = I_{c\,max} = \frac{V_{cc}}{R_c+R_E}$$

$$I_c = \frac{V_{cc}}{R_c+R_E}$$ [Now load Line analysis]

$V_{CE} = V_{cc}$

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Design Operation

From slide,

$V_{CC} = 20\,V$

$8mA = \frac{V_{CC}}{R_C}$

$R_C = \frac{20\,V}{8mA} = 2.5\,k\Omega$

$I_B = \frac{V_{CC} - V_{BE}}{R_B}$

$R_B = \frac{V_{CC} - V_{BE}}{I_B} = \frac{20 - 0.7}{40\,\mu A} = 482.5\,k\Omega$

But standard value of R,

$R_C = 2.4\,k\Omega$

$R_B = 470\,k\Omega$

$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{20 - 0.7}{470\,k\Omega} = 41.1\,\mu A \cong 40\,\mu A$

(We can consider upto 5%)

⊛ $I_{CQ} = \frac{1}{2} I_{c\,sat} = \frac{1}{2} \times 8mA$

$I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{4mA}{110} = 36.36\ \mu A$

$I_{BQ} = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1) R_E}$

$I_{RC} = \frac{V_{CC} - V_C}{R_C} = \frac{28-18}{R_C}$

$36.36\ \mu A = \frac{28-0.7}{R_B + (111 \times 1)\cdot \cancel{4mA}}$

$R_B = 639.8\ k\Omega$

$4mA = \frac{28-18}{R_C}$

$R_C = 2.5\ k\Omega$

$I_{c\,sat} = \frac{V_{CC}}{R_C + R_E}$

$R_E = \frac{V_{CC} - R_C I_{c\,sat}}{I_{c\,sat}}$

$= \frac{28 - 2.5 \cdot 8}{8}$

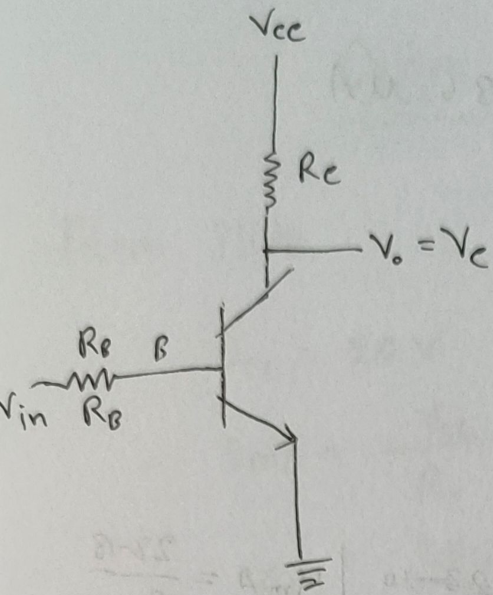
$= 1\ k\Omega$

∴ $R_B = 639.8k \cong$

$R_C = 2.5\ k\Omega \cong 2.4\ k\Omega$

$R_E = 1\ k\Omega$

Transistor Switching Networks



$$I_{C\,sat} = \frac{V_{CC}}{R_C}$$

$$I_B = \frac{I_{C\,sat}}{\beta} = 40$$

Assume

$$55 \leftarrow I_B > \frac{I_{C\,sat}}{\beta}$$

then

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

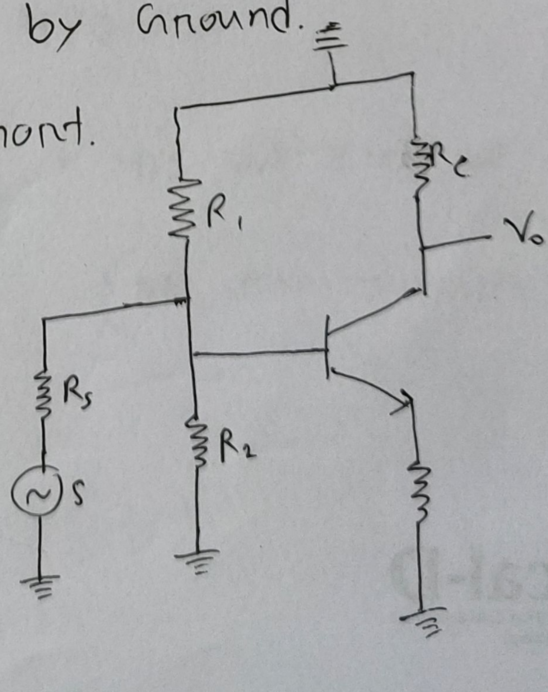
R_B → find out

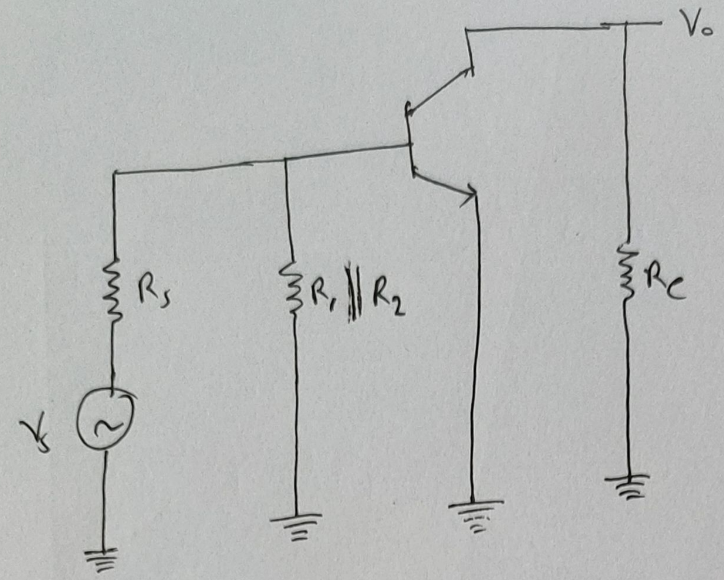
$h_{fe} \Rightarrow \beta_{DC}$

for PNP, just polarity will change

AC Analysis

- Replace DC source by Ground.
- Capacitor will be short.





$$\boxed{I_C = \beta I_B}$$

Why called - controlled - device?

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