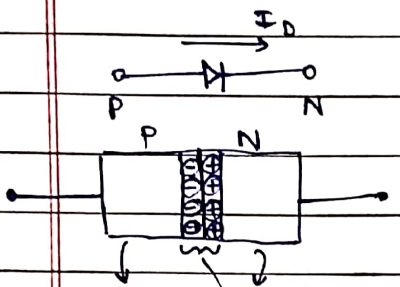
13/12/22

UNIT- 1

BIPOLAR JUNCTION TRANSISTORS.



unipolar device – one type of charge carriers → majority
two terminals.
one junction

holes are majority

electrons. are majority.

depletion layer

$I_D = I_S(e^{V_D/nV_T} - 1)$
↳ for both forward current/reverse

I_D = Diode current
I_S = Reverse saturation current
V_D = Forward voltage drop
n = material constant
V_T = Thermal voltage

$\therefore V_T$ at 27°C
⇒ 26mV

$V_T = \frac{KT}{q} = 0.0258\ V \approx 26mV$

$V_D = 0.1$ (Si)
$V_D = 0.3$ (Ge)

Reverse saturation current is Temperature dependent

K - Boltzmann's const = 1.38×10^{-23} J/K
T – Temperature in kelvin
q – Electron charge = 1.6×10^{-19} C

Q: calculate value of V_T at 57°C

~~$V_T = \frac{330 \times 1.38 \times 10^{-23}}{1.6 \times 10^{-19}}$~~

273
57
330

V_T ~~at~~ 57°C $= \frac{26}{300} \times 330$

$= \frac{11 \times 26}{10} = 28.6$ mV.

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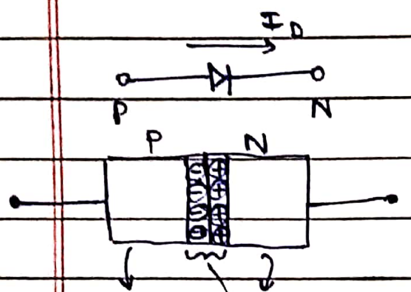
UNIT-1

BIPOLAR JUNCTION TRANSISTORS.



unipolar device – one type of charge carriers → majority
two terminals.
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holes are majority | electrons. are majority.

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↳ for both forward current / reverse

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I_S = Reverse saturation current
V_D = Forward voltage drop
n = material constant
V_T = Thermal voltage

$\therefore V_T$ at $27^\circ C$
$\Rightarrow 26mV$

$V_T = \frac{KT}{q} = 0.0258\ V \simeq 26mV$

$V_D = 0.1$ (Si)
$V_D = 0.3$ (Ge)

$\boxed{\text{Reverse saturation current is Temperature dependent}}$

K – Boltzmann's const = $\cancel{1.83}\ 1.38 \times 10^{-23}$ J/K
T – Temperature in kelvin
q – Electron charge = 1.6×10^{-19} C

Q: calculate value of V_T at $57^\circ C$

$\cancel{V_T = \frac{330 \times 1.26 \times 10^{-3}}{1.6 \times 10^{-19}}}$

273
57
———
330

V_T ~~at~~ $57^\circ C = \frac{26}{300} \times 330$

$= \frac{11 \times 26}{10} = 28.6\ mV.$

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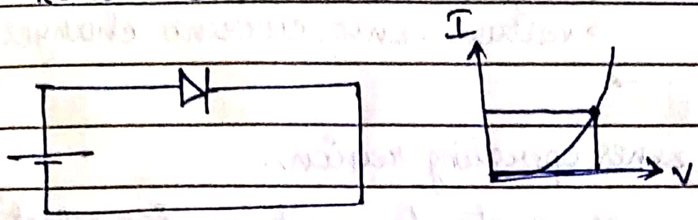
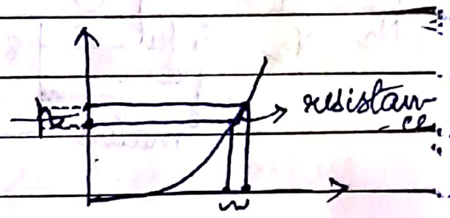
DC Resistance.



$$R_D = \frac{V}{I}$$

static resistance.

AC resistance.



for giving minimum voltage 0.7V

$$r_d = \frac{\Delta V}{\Delta I}$$

dynamic resistance

→ when we apply small AC signal diode behaves as resistance.

$$I_D = I_S \left(e^{V_d/nV_T} - 1\right)$$

diff :-

$$\frac{dI_D}{dV_D} = I_S \left(e^{V_D/nV_T} - 1\right) \times \frac{1}{nV_T}$$

$$\frac{1}{r_d} = I_D \left(\frac{1}{nV_T}\right)$$

$$\boxed{r_d = \frac{nV_T}{I_D}}$$

$$\frac{1}{r_d} = \frac{I_D}{nV_T}.$$

if $n=1$

$$\boxed{r_d = \frac{V_T}{I_D}}$$

Si: $n=2$

Ge: $n=1$

Date
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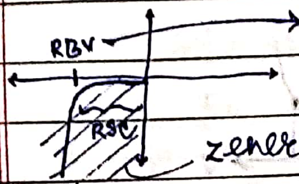
→ avalanche and zener breakdowns.



→ voltage=const, current changes

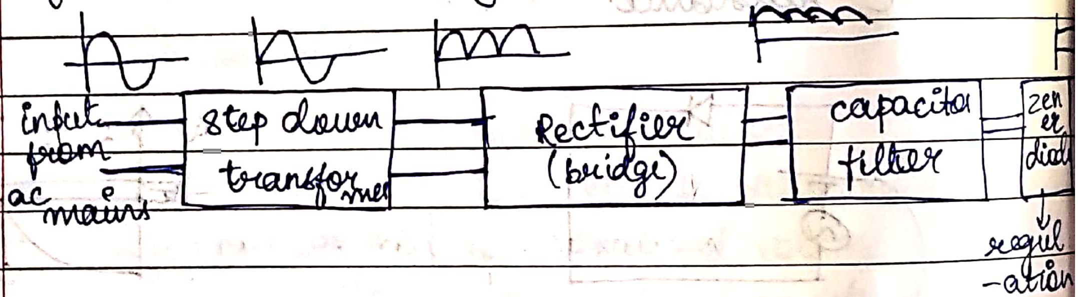
zener operating region.

Regulator gives constant voltage irrespective of change in line or change in load.

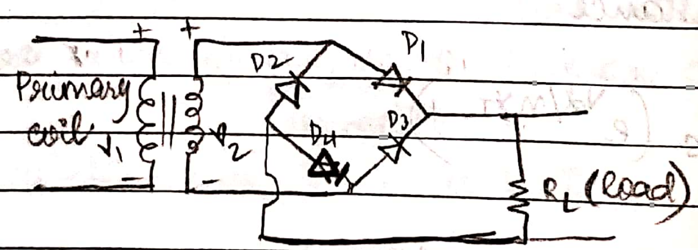
UNIT - 1

Regulated Power Supply (Block diagram)

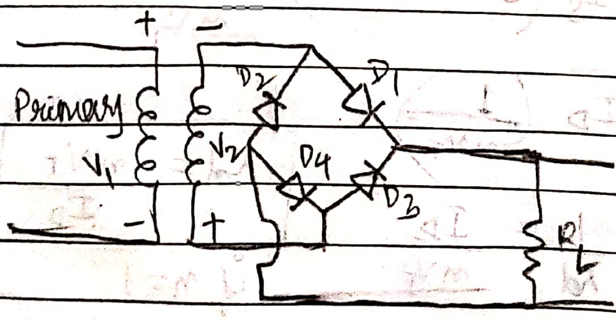
$\frac{N_1}{N_2} = \frac{V_1}{V_2}$



Rectifier → half wave (40%)
→ full wave (80%)
→ centre tapping (2 diodes)
→ bridge rectifier (4 diodes)



D_1 = on
D_2 = off
D_3 = off
D_4 = on



D_1 = off
D_2 = on
D_3 = on
D_4 = off

① NOTE: The diode is not behaving as a resistor as it behaves as resistor only for small AC signals. 5 V is huge AC signal

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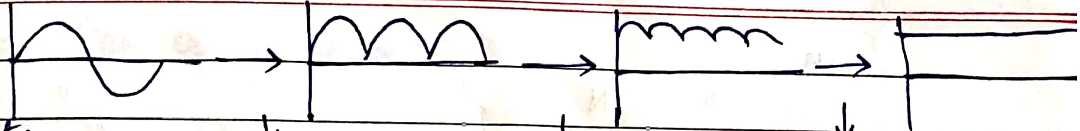


input; step down → rectifier → capacitor filter → zener diode (regulation)

→ zener works in breakdown region only
regulation starts only after reverse breakdown.

ripple $\gamma = \frac{1}{4\sqrt{3} f C R_L}$ (2% 3%)

value designed by engineer

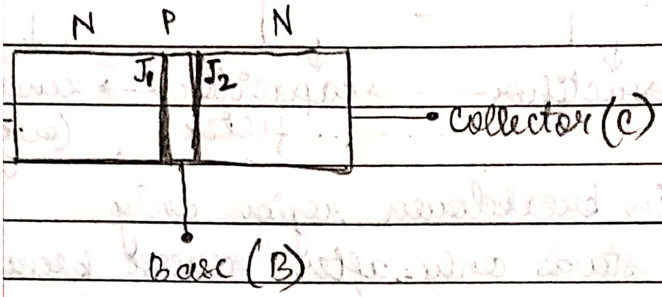
→ amount of AC content in ~~DC~~ the rectified output is called ripple factor.
→ in capacitor discharging rate is more than charging rate.

V_Z = zener voltage.
If $V_Z = 10V$, it means breakdown voltage is called zener voltage = 10V. Thus zener starts working as regulator.

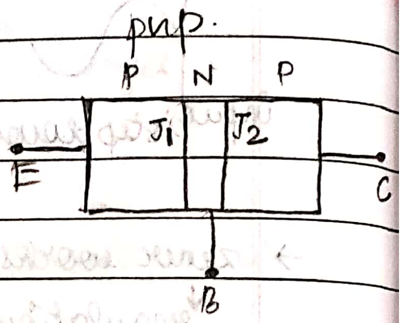
***
IMP Qs: Explain block diagram, explain what each component is used for. with diagrams to support your answer.

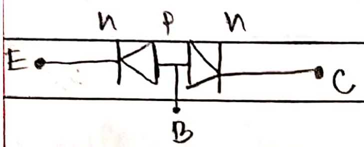
Bipolar Junction Transistor.
→ 2 junction
→ 3 terminal device.
Application: used for amplification of weak signals.
Can be used as switch.

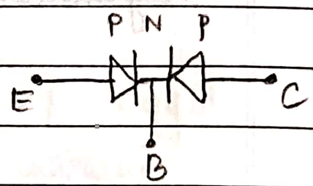
npn.



pnp.







J_1 = Emitter-base junction
J_2 = collector-base junction

C > E > B
E > C > B

Regions of operation.

J_1	J_2	Region	Application
FB	FB	Saturation	closed switch
FB	RB	Active	Amplifier
RB	FB	Inverse active	Attenuator
RB	RB	cut off	open switch

Transistor = Transfer + Resistor.
↓
signal is transferred from a region of low to high resistance. Thus voltage increases, hence ~~cable~~ used as amplifier.

$V = IR$.

$\left.\begin{array}{l} FB: R = 0 \\ RB: R = \infty \end{array}\right\}$ ideally

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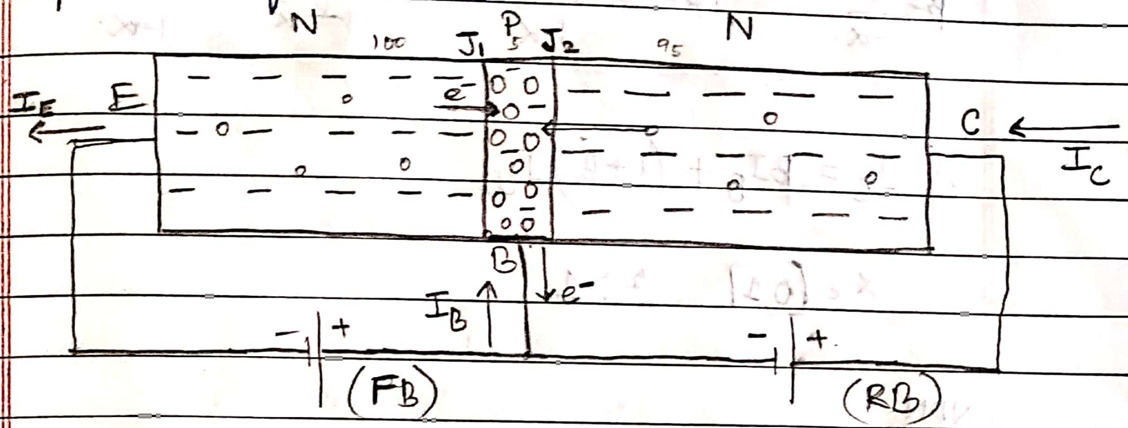
Operation of transistor.



$$\boxed{\overset{(mA)}{I_E} = \overset{(\mu A)}{I_B} + \overset{(mA)}{I_C}}$$ according to KCL.

I_E = emitter current
I_B = base current
I_C = collector current

$I_C \cong I_E$ (expectation)

α = current gain

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

Ideally $\alpha = 1$.

$\alpha = 0.95$ to 0.98

$$I_C = I_{C(majority)} + I_{CO(minority)}$$

I_{CO} = reverse saturation current / leakage current.

open ckt

20/12/22

$$I_E = I_B + I_C$$

$$I_C = I_{C(maj.)} + I_{CO}.$$

$$= \alpha I_E + I_{CO}.$$

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

$$I_C = \alpha I_B + \alpha I_C + I_{CO}$$

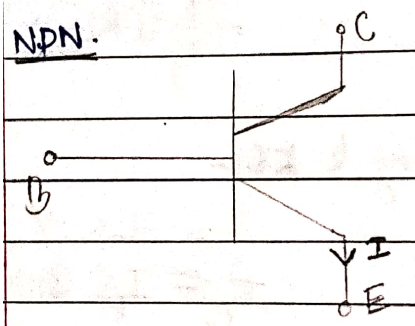
$$I_C[1-\alpha] = \alpha I_B + I_{CO}. \Rightarrow I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B + \left(\frac{1}{1-\alpha}\right) I_{CO}.$$

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

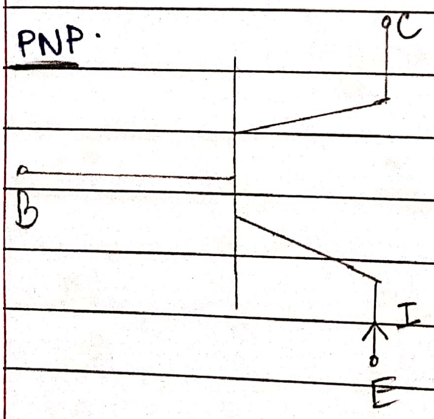
$$\therefore I_C = \beta I_B + (1+\beta) I_{CO}$$

$$\alpha \in [0,1] \quad , \beta > 1$$

NPN.



PNP.

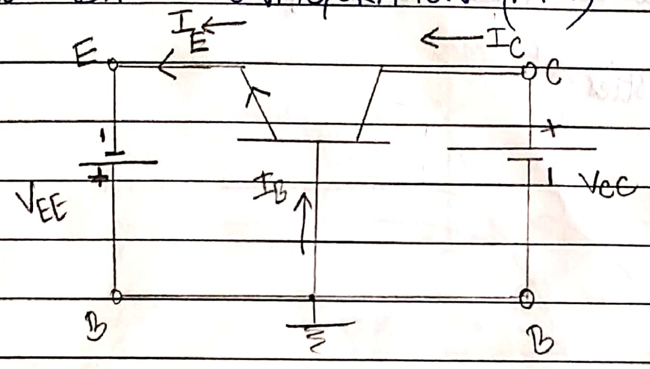


TRANSISTOR CONFIGURATION.

common base transistor configuration
common emitter transistor configuration
common collector transistor configuration.

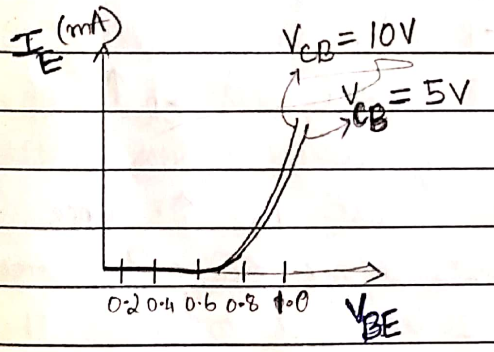
0/12/22.

COMMON BASE CONFIGURATION (NPN)



INPUT CURRENT = I_E
INPUT VOLTAGE = V_{BE}
OUTPUT CURRENT = I_C
OUTPUT VOLTAGE = V_{CB}

Input characteristics.



Input resistance = $\frac{\Delta V_{BE}}{\Delta I_E}$

For minor change in V_{BE}, the ΔI_E is huge. Hence input impedence is very low as Forward bias → R is very small.

(*) Input voltage v/s. input current for different values of output voltage

(*) As output voltage $V_{CB} \uparrow$, $I_E \uparrow$.

→ V_{CB} is the output voltage, when it is increased, the curve shifts leftwards and the emitter current also increases. The collector-base junction gets more reverse biased hence collector-base junction width increases, base width decreases hence less voltage is required for V_{BE} to maintain forward bias. I_E increases as $V_{CB} \uparrow$ ($I_C \uparrow$ and less e-h pairing in base).

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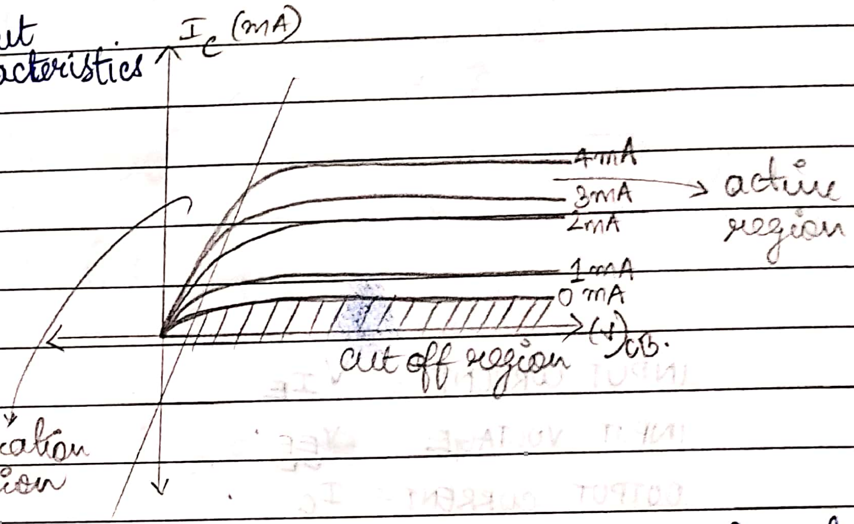
[Base width modulation]

output characteristics

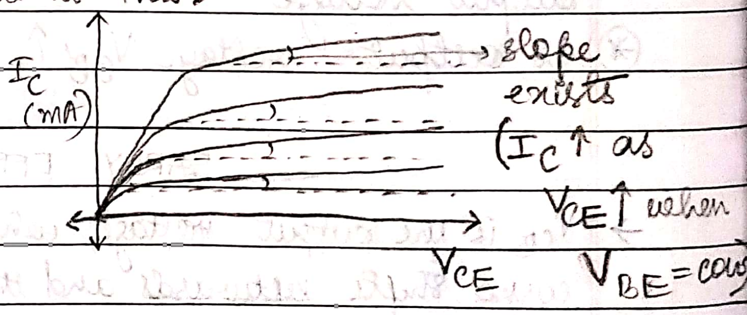


(*) output voltage v/s output current for different values of input current.

FORWARD ACTIVE REGION.

EARLY EFFECT :-

When V_{BE} is kept constant and $V_{CB}\uparrow$ (effectively $V_{CE}\uparrow$) the reverse nature of collector base increases, hence the depletion region width (BC) $\uparrow$. Hence base width decreases, hence less chance of e-h recombination. more e^- will thus be able to cross the base without recombination. Thus collector current will increase. Due to this:-



→ about output characteristics :-

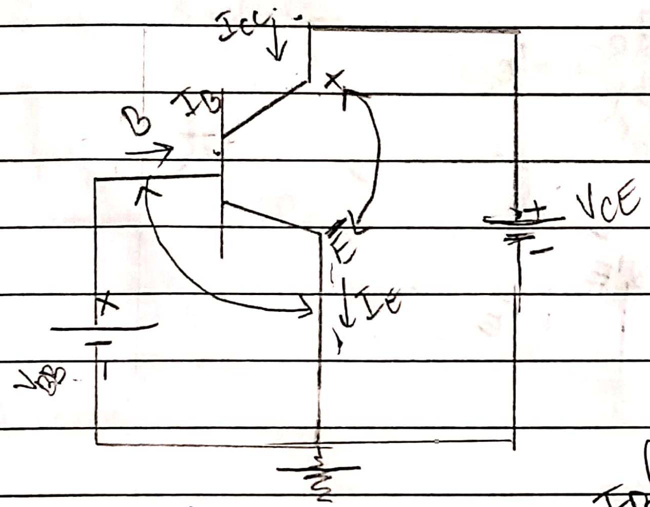
* Active region : Even if $V_{CB}\uparrow$, I_C remains almost constant
For fixed value of emitter current it is almost independent of V_{CB}.
$\boxed{I_C = \alpha I_E}$ → used for amplification as I_C only dependent on I_E

* Saturation region : As $V_{CB}\downarrow$, the $I_C\downarrow$

* cut-off region : $I_{CT} = I_C + I_{CO}$
when $I_E = 0$; $I_{CT} \simeq 0$

Reverse sat. current $\propto T$ ← reverse saturation current ← only due to minority charge carriers → I_{CO} / I_{CBO}

common emitter configuration



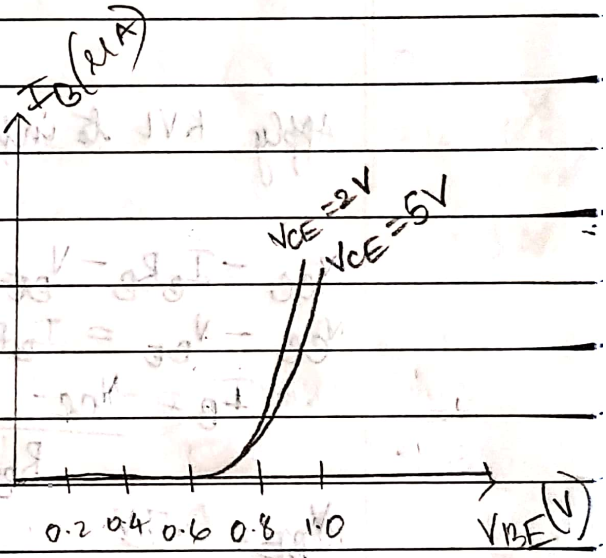
Input characteristics

I/p current = I_B

I/p voltage = V_{BE}

O/P current = I_C

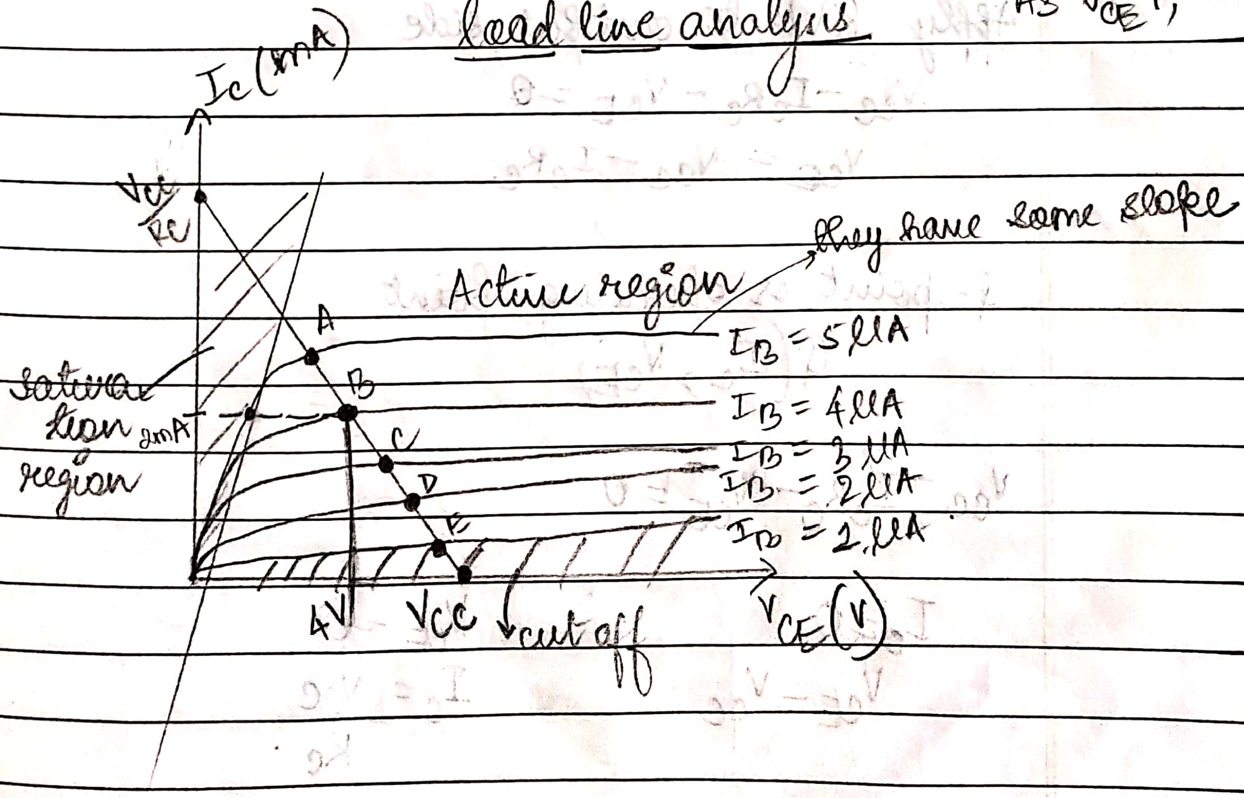
O/P voltage = V_{CE}



$I_C = \beta I_B$

load line analysis

As $V_{CE}\uparrow$,



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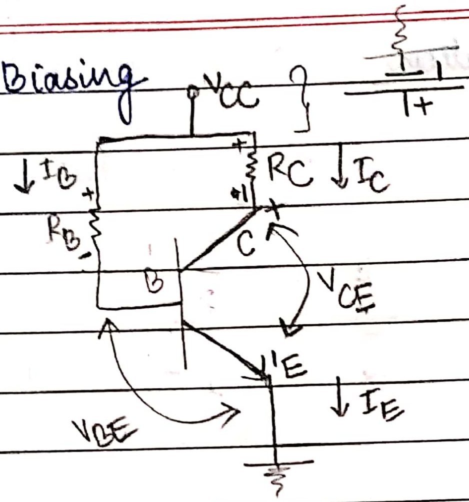
Biasing



Apply KVL to input side

$$V_{CC} - I_B R_B - V_{BE} = 0$$
$$V_{CC} - V_{BE} = I_B R_B$$
$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

$V_{BE} = 0.7V$

Apply KVL to output side.

$$V_{CC} - I_C R_C - V_{CE} = 0$$
$$V_{CE} = V_{CC} - I_C R_C$$

Q-point or operating point

$$Q(I_C, V_{CE})$$

$$V_{CC} - I_C R_C - V_{CE} = 0$$

$I_C = 0$ | $V_{CE} = 0$
$V_{CE} = V_{CC}$ | $I_C = \frac{V_{CC}}{R_C}$

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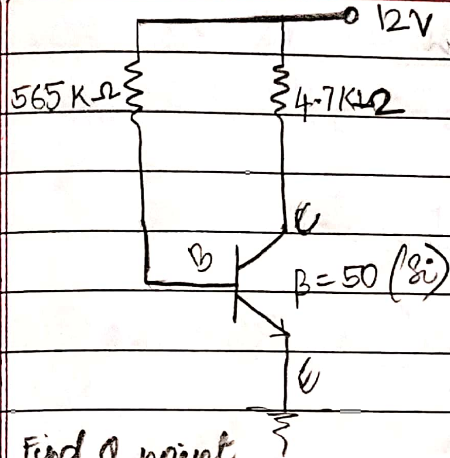


Find Q point

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

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12 - 0.7}{565}$$

$$I_C = \beta I_B = 50 \times \cancel{0}\, 20 \times 10^{-6}$$

$$= 1 \times 10^{-3}$$

$$= 1 mA$$

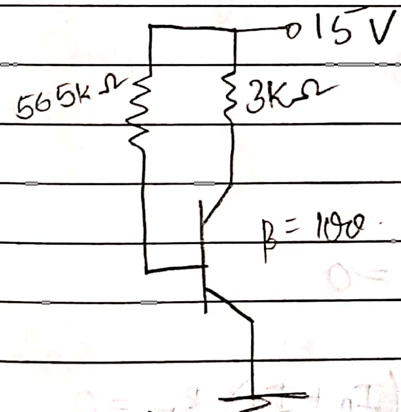
$$V_{CC} - I_C R_C - V_{CE} = 0$$

$$V_{CE} = V_{CC} - I_C R_C = 12 - 10^{-3} \times 4.7 \times 10^{3}$$

$$\cancel{7.3V}$$

$$= 7.3$$

Q point (1mA, 7.3V)



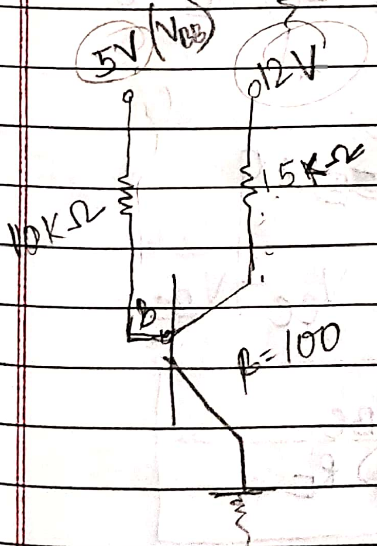
$$I_B = \frac{15 - 0.7}{565} = 25 \mu A.$$

$$I_C = 2.5 mA$$

$$V_{CE} = 7.5 V.$$

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

$$=$$



Find Q point

$$I_B = \frac{5 - 0.7}{10000} = 4.3 \times 10^{-4}$$

$$I_C = \beta I_B = 100 \times (4.3) \times 10^{-4}$$

$$= 4.3 \times 10^{-2}$$

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

$$= 12 - 10^{-2} \times 4.3 \times 15 \times 10^{3}$$

$$= 12 - 645.0$$

$$= -633 V$$

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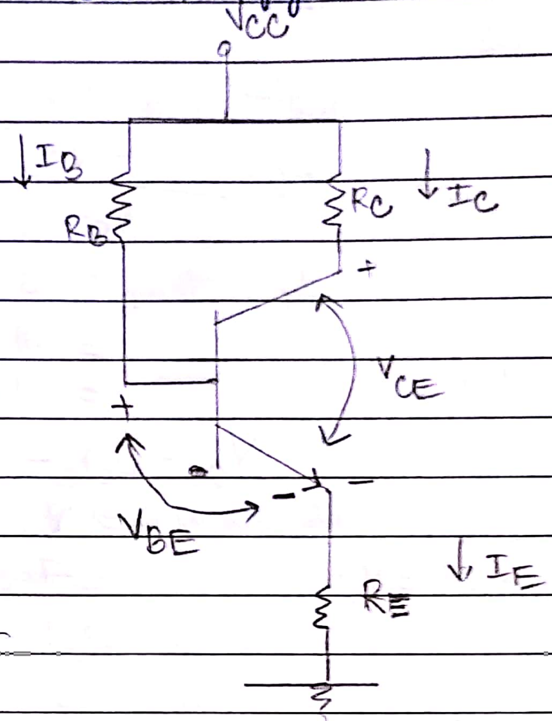
Emitter Bias configuration



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

depends on

$I_C = \beta I_B$

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

Q point

To avoid dependence on R_B.

Apply KVL to input loop.

$V_{CC} - I_B R_B - V_{BC} - I_E R_E = 0$

$V_{CC} - I_B R_B - V_{BC} - \cancel{I_E}(I_B + I_C) R_E = 0$

$\beta I_B = I_C$.

$V_{CC} - I_B R_B - V_{BC} - (1+\beta) I_B R_E = 0$

$[R_B + (1+\beta) R_E] I_B = V_{CC} - V_{BC}$

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

$I_C = \beta I_B$

$I_E = (1+\beta) I_B$

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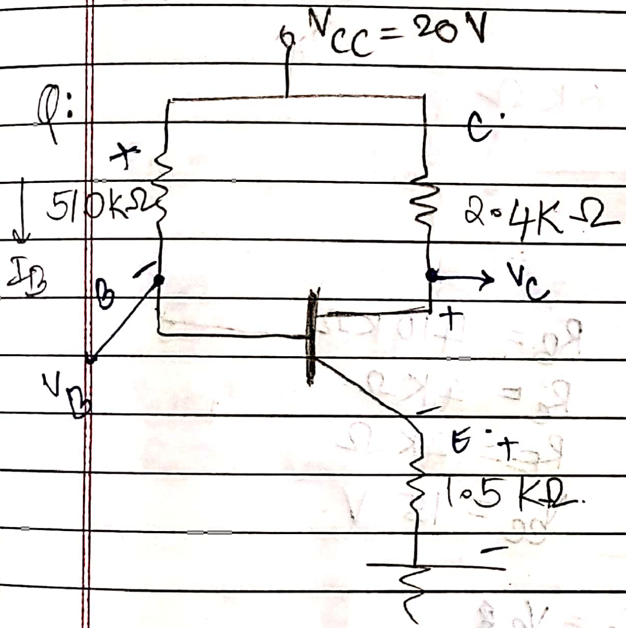
Apply KVL to output loop.

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

$V_{CE} = V_{CC} - I_C R_C - I_E R_E$.

Q point (I_C, V_{CE})

Q:



Find Q point, V_C, V_B, V_E

$V_C = V_{CC} - I_C R_C$

$V_B = V_{CC} - I_B R_B$

$V_{CE} = V_C - V_E$

$\therefore V_E = V_C - V_{CE}$

$= I_E R_E$.

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

$= \dfrac{20 - 0.7}{(510\,K\Omega + (1+100)\,1.5\,K\Omega) \times 10^3}$

$I_B = 29.17$ ~~μA~~ ~~0.02917~~ (0.02917×10^{-3})

29.17×10^{-6}.

$I_C = 100 \times 29.17$

$I_C = 2917\ \mu A$

$I_C = 2.9\ mA$

$V_C = 13.04\ V$.

$V_B =$ ~~13.04~~ 5.1233

$V_E = 4.410$

$I_E = (1+\beta) I_B = 2.94\ mA$

$V_{CE} = V_{CC} - I_C R_C - I_E R_E$

$= 20 - (2.9m)(2.4K\Omega) - 2.92m(1.5K)$

$V_{CE} = 8.66V$

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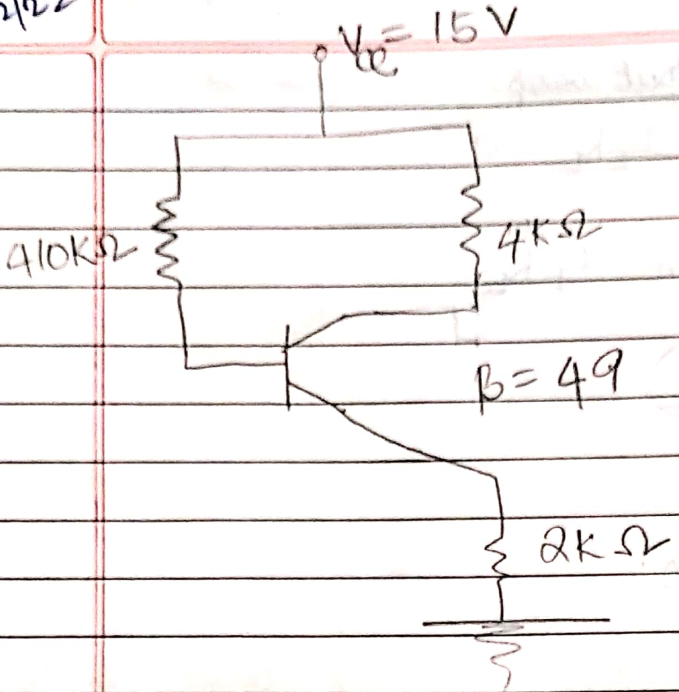

Q point = ?

$I_C = ?$

$V_{CE} = ?$

$R_B = 410 K\Omega$

$R_C = 4 K\Omega$

$R_E = 2 K\Omega$

$V_{CC} = 15 V.$

~~H/H~~

$$I_C = \frac{V_C}{R_C}.$$

$$\cancel{V_{CC} - I_C R_C = V_C}$$

$$I_B = \frac{V_{CC} - V_{BC}}{R_B + (1+\beta)R_E} = \frac{15 - 0.7}{410K + (50)(2K)}$$

$$I_E = (1+\beta) I_B = 1.4 \, mA \qquad = \frac{14.3}{510 K}$$

$$= 0.028 \, mA.$$

$$I_C = 49 \times 0.028 = 1.37 \, mA.$$

$$V_{CE} = \cancel{V_C - V_E} \; V_{CC} - I_C R_C - I_E R_E$$

$$= 15 - 1.37 \times 4 - 2 \times 1.4$$

$$V_{CE} = 6.72 V.$$

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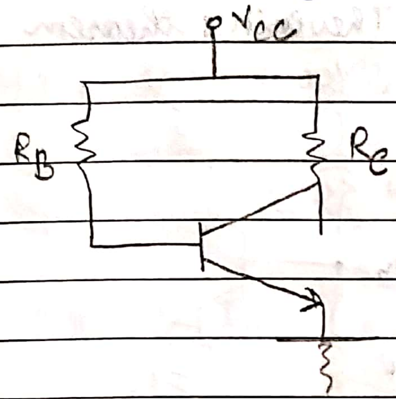
Q: Design value of R_B & R_C. $V_{CC} = 10V$, $I_C = 5mA$, $V_{CE} = 5V$. } fixed bias. $\beta = 100$.

Sol:



$R_B = ?$ $R_C = ?$

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

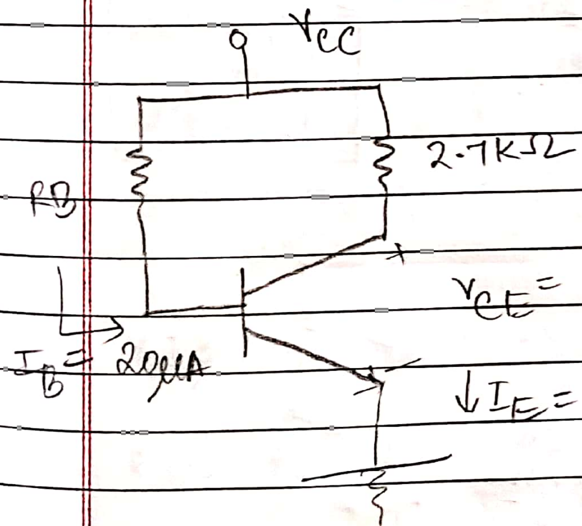
$I_B = \frac{I_C}{\beta} = 0.05mA$

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

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

$R_B = 186\ K\Omega$

$R_C = 1K\Omega$



calculate I_C, V_{CC}, β, R_B.

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

$V_{CC} - I_C R_C - V_{CE} \cancel{- I_E R_E} = 0$.

$V_{CC} =$

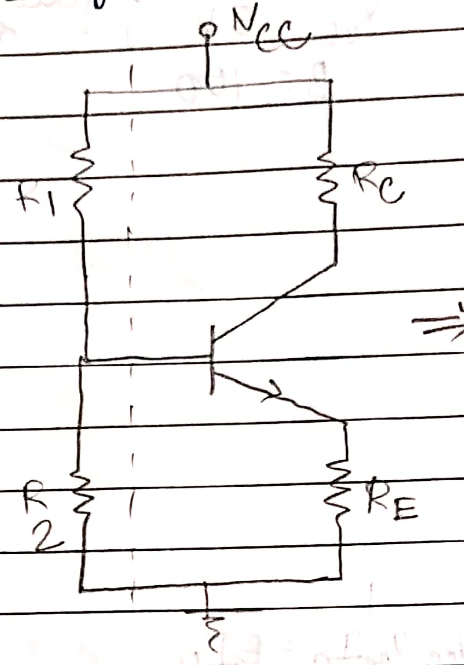
$I_C = I_E + I_B$

$= 4 + 20 \times 10^{-3}$

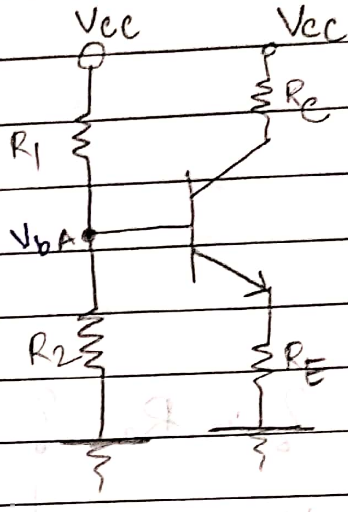
$I_C = 4.02\ mA$

28/12/22.

Voltage Divider biasing.



Thevenin's theorem.



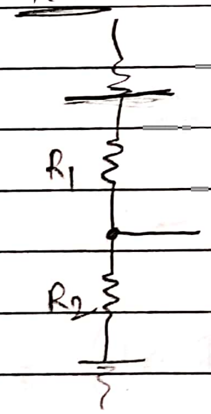
$$\boxed{V_{th} = \frac{V_{CC} \times R_2}{R_1 + R_2}}$$

Vcc is input voltage
R_1 and R_2 are in series.
R_2 is considered, as voltage at point A is same as voltage across R_2.

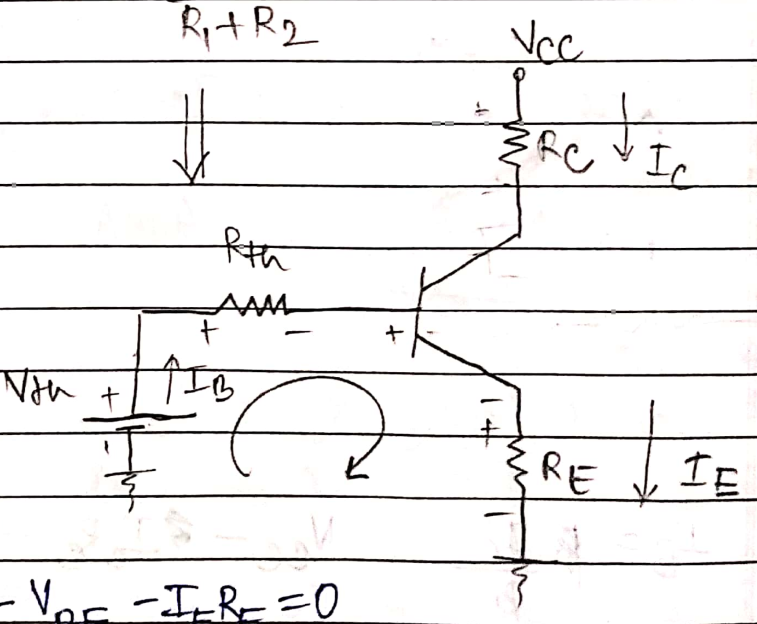
$$V_{R_1} = \left(\frac{V_{CC} \times R_1}{R_1 + R_2}\right)$$

$$V_{R_2} = \frac{V_{CC} \times R_2}{R_1 + R_2}$$

R_{th}



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



Apply KVL

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

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

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

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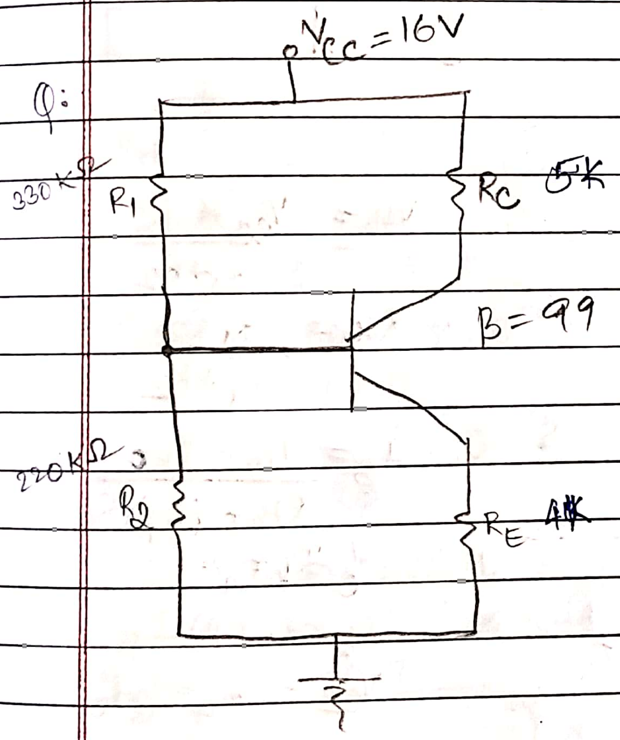
$I_C = \beta R_B$.
$I_E = (1+\beta) I_B$

Apply KVL to collector.
$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$
$V_{CE} = V_{CC} - I_C R_C - I_E R_E$

Q point (I_C, V_{CE}).

Q:



$$V_{th} = \frac{V_{CC} \times R_2}{R_1 + R_2} = \frac{16 \times 220K}{220K + 330K} = 6.4\ V$$

$$R_{th} = \frac{R_1 R_2}{R_1 + R_2} = \frac{330\cancel{K} \times 220\cancel{K}}{330\cancel{K} + 220\cancel{K}} = 132 \cancel{\times 10^3}\ K\Omega$$

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

$V_{CE} = V_{CC} - I_C R_C - I_E R_E$
$=$

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

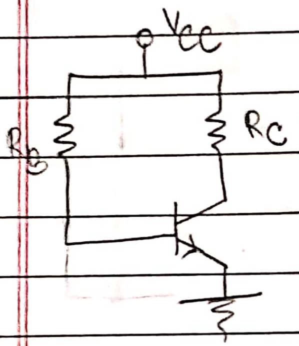
$I_B = 0.0107\ mA$
$= 10.7\ \mu A$.
$I_C = 1059.3\ \mu A = 1.0593\ mA$.
$I_E = 1070\ \mu A = 1.07\ mA$.

Q pt: (I_C, V_{CE})
: $(1.05\ mA, 6.47\ V)$

28/12/22

FIXED BIAS

CIRCUIT:



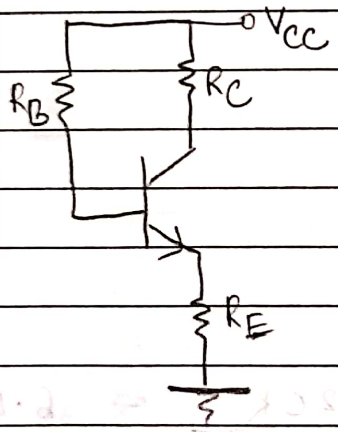
$$I_B = \frac{V_{CC} - V_{BC}}{R_B}$$

$$I_C = \beta I_B$$

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

EMITTER BIAS

CIRCUIT:



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

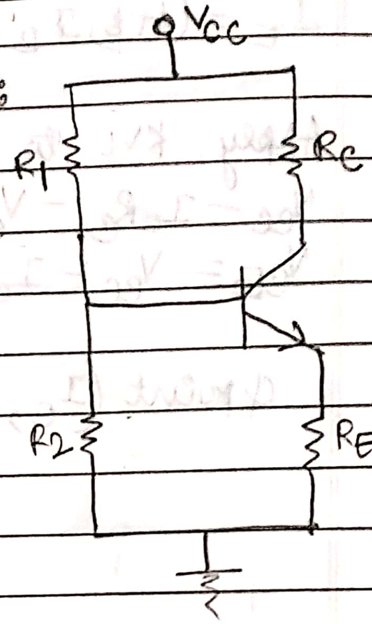
$$I_C = \beta I_B$$

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

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

VOLTAGE DIVIDER BIAS

CIRCUIT:



$$V_{th} = \frac{V_{CC} \times R_2}{R_1 + R_2}$$

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

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

$$I_C = \beta I_B$$

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

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

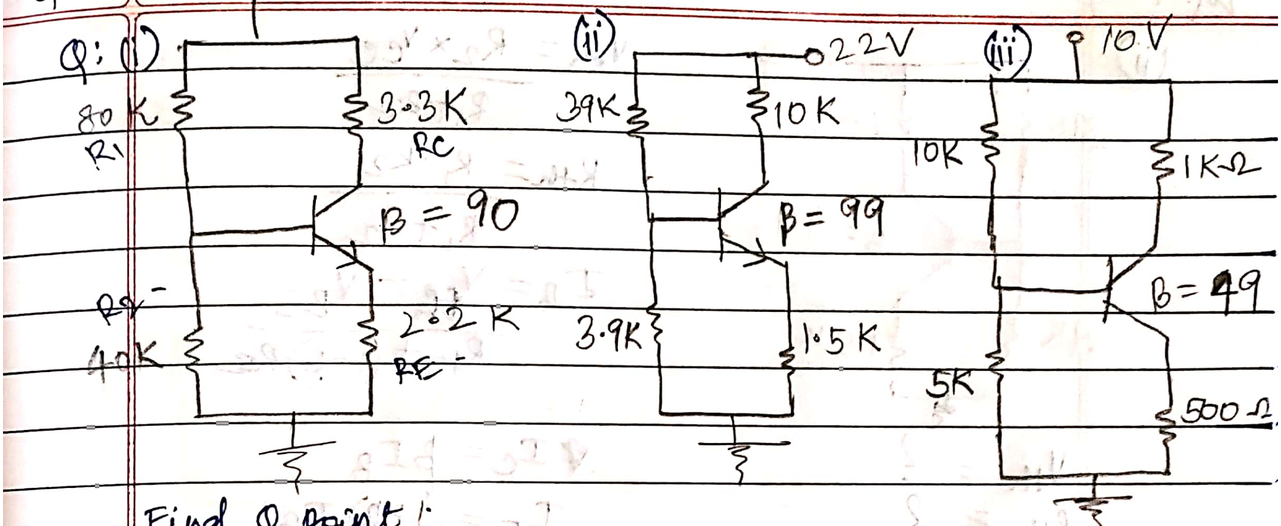
consider:-

$V_{BE} = 0.7V$ for Si transistor.

parameters of Q point (I_C, V_{CE})

28/12/22.

Q: (i)



Find Q point :

(i). $V_{th} = \dfrac{V_{cc} \cdot R_2}{R_1 + R_2}$

$= 4 V.$

$R_{th} = \dfrac{80 \times 40 \times 10^{-6}}{120 \times 10^{-3}}$

$= \dfrac{3200 \times 10^{-3}}{120}$

$= 26.6 \times 10^{-3}\ \Omega.$

$= 26.6\ K\Omega$

$I_B = \dfrac{4 - 0.7}{(26.6 + 91 \times 2.2) \times 10^{-3}}$

$= \cancel{0.0145\ mA}$

$= 14.5\ \mu A = 0.0145 mA$

$I_c = 90 \times 14.5$

$= 1.305\ mA.$

$I_E = 91 \times 0.0145.$

$= 1.3195\ mA.$

$V_{CE} = 12 - 1.305 \times 3.3 - 1.3195 \times 2.2$

$= 4.79\ V.$

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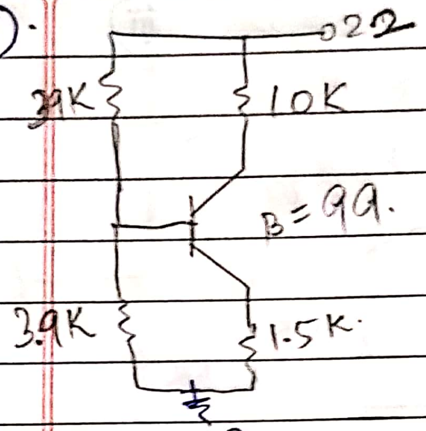
(ii).



$$V_{th} = \frac{R_2 \times V_{CC}}{R_1 + R_2}$$

$$R_{th} = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

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

$I_C = \beta I_B$

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

$V_{CE} = V_{CC} - I_C R_C - I_E R_E$

$V_{th} = ?$
$R_{th} = ?$
$I_B = ?$
$I_C = ?$
$I_E = ?$
$V_{CE} = ?$

$$V_{th} = \frac{3.9 \times 22}{3.9 + 39} = 2V.$$

$R_{th} = 3.54 K\Omega$

$$I_B = \frac{2 - 0.7}{3.54 + (100 \times 1.5)} = \cancel{8.41\ mA}\ 8.4\ \mu A.$$

$I_C = \cancel{8.18}\ 0.83\ mA.$

$I_E = \cancel{8.4\ 0.84\ mA}.\ 0.84\ mA.$

$V_{CE} = V_{CC} - I_C R_C - I_E R_E$

$= 22 - 0.83 \times 10 - \cancel{8}\ 0.84 \times 1.5$

$= 12.44\ V$

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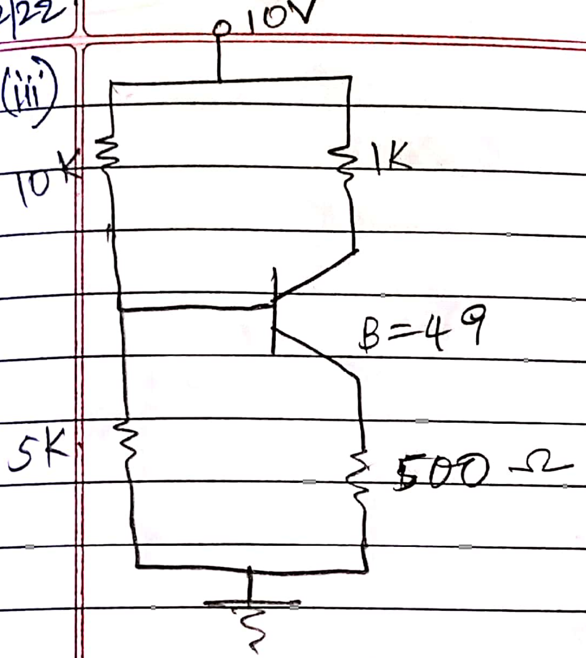
(iii)



$$V_{th} = \frac{5 \times 10}{5+10} = \frac{50}{15} = 3.33\,V.$$

$$R_{th} = \frac{10 \times 5}{10+5} = \frac{50}{15} = 3.33\,K\Omega.$$

$$I_B = \frac{V_{th} - V_{BE}}{R_{th} + (1+B)R_E}$$

$$I_B = \frac{3.33 - 0.7}{10^3 \times 3.33 + \underbrace{(50 \times 500)}_{25000}} \cancel{\times 10^{+3}3} = \frac{2.63}{3330 + 25000}$$

$$\cancel{I_B = 0.0001 \times 10^{-3}} \qquad = 92.8\,\mu A.$$

$$\cancel{= 0.1 \times 10^{-6}}$$

$$I_c = 49 \times 92.8\,\mu A$$

$$= 4.547\,mA.$$

$$I_E = \cancel{E}\ 50 \times 92.8\,\mu A = 4640.00\,\mu A = 4.64\,mA.$$

$$\cancel{V_{CE} = V_{CC} -}$$

$$= 3.133\,V.$$

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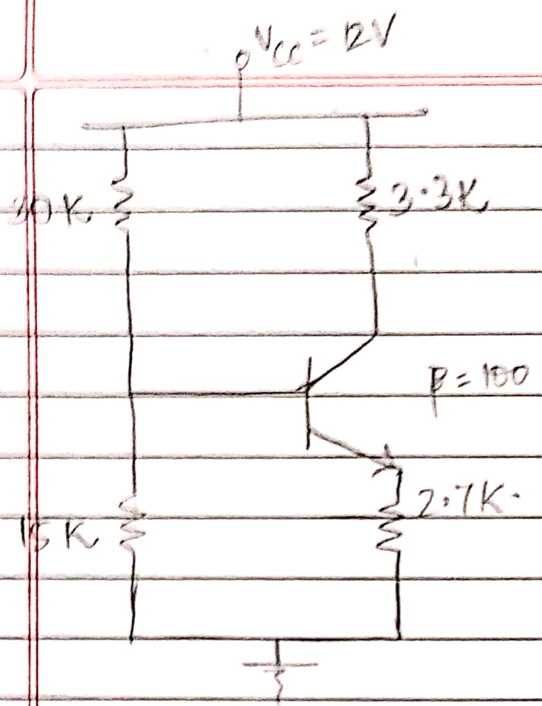
Q3



sol: $V_{th} = \dfrac{V_{cc} \times R_2}{R_1 + R_2} = \dfrac{12 \times 15}{15+30} = \dfrac{\cancel{180}}{\cancel{45}}$ $= 4V.$

$R_{th} = \dfrac{R_1 R_2}{R_1 + R_2} = \dfrac{30 \times 15}{45} = \dfrac{450}{45} = 10K$

$I_B = \dfrac{V_{th} - V_{BE}}{R_{th} + (1+\beta)R_E} = \dfrac{4 - 0.7}{10 + (101 \times 2.7)} = 0.0116\ mA = 11.673 \mu A.$

$I_C = 100 \times 11.673 = \cancel{1160 \mu A}.\ 1167.3$

$I_E = 101 \times 11.673 = \cancel{1171.6 \mu A}\ 1178.973.$

$V_{CE} = V_{cc} - I_C R_C - I_E R_E = \cancel{12 - 1.16 \times 3.3 - 1.1716 \times 2.7}$

$= V_{CE} = \cancel{5.0086V}\ 5.013V.$

$S(I_{CO}) = ?$

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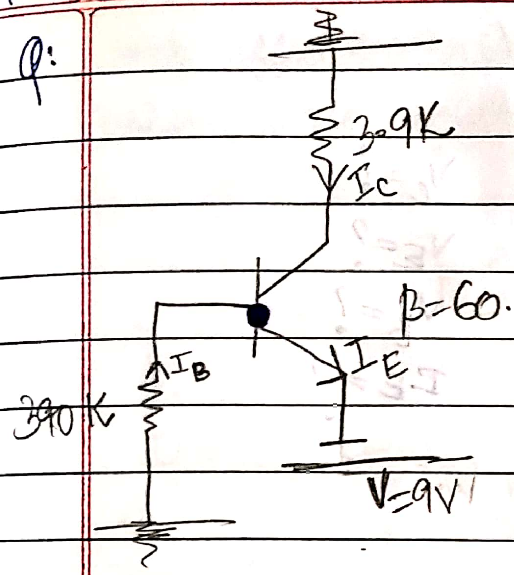
Q:



operation point = ?

$-I_B R_B + R_C I_C = 0$ — ①

$(-)\ -I_B R_B + 9 = 0$ — ②

$R_C I_C = 9$

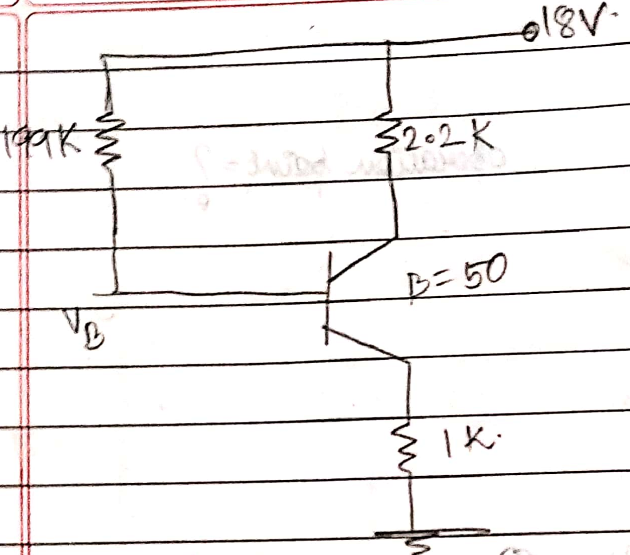
$I_C = \dfrac{9}{3.9} = 2.3\ mA$

$V_{CE} = -I_C R_C + 9$

$= -2.3 \times 3.9 + 9 = 0.03V$

30/12/22.

3.



$V_C = ?$

$V_E = ?$

$V_B = ?$

$I_E = ?$

$V_{CC} = 18V$.

$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta)R_E} = \frac{18 - 0.7}{199 + 51 \times 1} = \frac{17.3}{199 + 51}$

$= \frac{17.3}{250}$

$= 0.0692\ mA$

$= 69.2\ \mu A$.

$I_C = \beta I_B$

$= 50 \times 69.2$

$= 3460\ \mu A = 3.46\ mA$

$I_E = (1+\beta) I_B = 51 \times 69.2 = 3529.2\ \mu A$

$= 3.5292\ mA$.

$V_{CE} = V_{CC} - I_C R_C - I_E R_E$

$= 18 - 3.46 \times 2.2 - 3.5292 \times 1$

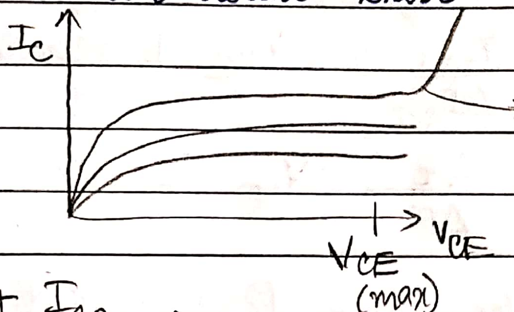
$= 18 - 7.612 - 3.5292$

$V_{CE} = 6.858\ V$.

$(I_C, V_{CE}) = (3.46\ mA, 6.858\ V)$

30/12/22.

Early effect → ↑ reverse voltage even more → Punchthrough when base width doesn't exist.



Punchthrough ↑ Breakdown condition ↓ when base no longer exists E and C come in contact - sudden ↑ in current.

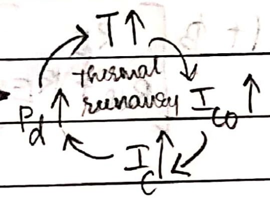
$I_c = I_{c(maj)} + I_{co\,(min)}$

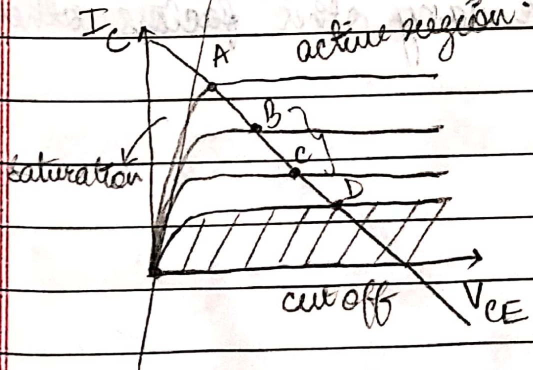
→ Thermal runaway:
usually I_{co} = constant
but when $T\uparrow$,
$I_{co}\uparrow \Rightarrow I_{C\,Total}\uparrow$

$I_{S_2} = I_{S_1} \times 2^{\frac{(T_2 - T_1)}{10}}$

→ For every 10°C rise in temp R.S.C doubles.

Thermal runaway ⇒ $\because P_d\uparrow = V_c \times I_c \uparrow$.
↳ power ↑ ⇒ Temperature ↑ of device ⟶ $I_{co}\uparrow \Rightarrow I_c\uparrow \Rightarrow P_d \Rightarrow$ T↑ and so on.





Q (I_c, V_{CE})

EARLY EFFECT ✓
PUNCH THROUGH ✓
THERMAL RUNAWAY ✓
BIAS STABILIZATION.

If operating point shifts, no faithful amplification as the points will not be optimum

1) V_{BE}
2) I_{CO}
3) β (material dependent)

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3/1/23

$$S_{(I_{CO})} = \frac{\Delta I_C}{\Delta V_{BE}} \quad , I_{CO}, \beta \rightarrow \text{constant}$$

$$S_{(I_{CO})} = \frac{\Delta I_C}{\Delta I_{CO}} \quad , V_{BE}, \beta \rightarrow \text{constant}$$

$$S_{(I_{CO})} = \frac{\Delta I_C}{\Delta \beta} \quad , V_{BE}, I_{CO} \rightarrow \text{constant}$$

$$I_B = \frac{V_{th} - V_{BE}}{R_{th} + (1+\beta)R_E} \; ; \; I_C = \beta I_B \; ; \; V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

→ Q point thus changes when V_{BE}, I_{CO} and β change

→ Stability factor:-

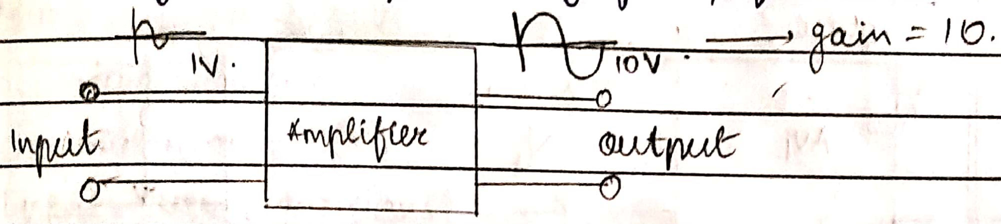
Fixed bias: $S_{(I_{CO})} = 1+\beta$

Voltage divider bias: $S_{(I_{CO})} = \dfrac{1+\beta}{1+\beta\left[\dfrac{R_E}{R_{th}+R_E}\right]}$

[→ This is more stable as Q factor is dependent on many other factors other than β.]

4/1/23.

→ Multistage amplifier / cascading of amplifier.



Gain = $\frac{\text{output}}{\text{input}}$

Gain → Actual number, dB

Eg: 10 X and X 20 dB
not same

Power gain $[A_P]$ = $\frac{\text{output power}}{\text{input power}} = \frac{P_o}{P_i}$

Voltage gain $[A_V]$ = $\frac{\text{output voltage}}{\text{input voltage}} = \frac{V_o}{V_i}$

current gain $[A_I]$ = $\frac{\text{output current}}{\text{input current}} = \frac{I_o}{I_i}$.

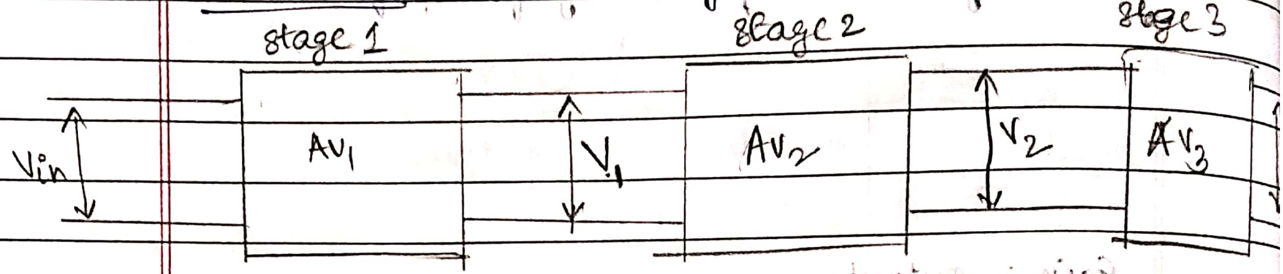
Power gain $[A_P]_{dB} = 10 \log\left[\frac{P_o}{P_i}\right]$ ← subst. — here $P = \frac{V^2}{R} = I^2R$.

Voltage gain $[A_V]_{dB} = 20 \log\left[\frac{V_o}{V_i}\right]$ — taken $R_i = R_L$

Current gain $[A_I]_{dB} = 20 \log\left[\frac{I_o}{I_i}\right]$

4/1/23.

MULTISTAGE: → (increase V gain)



Gain of stage 1 = $V_1/V_{in} = [AV_1]$

" " " 2 = $V_2/V_1 = [AV_2]$

" " " 3 = $V_0/V_2 = [AV_3]$

overall gain $[Av] = AV_1 \times AV_2 \times AV_3$

$= \frac{\cancel{V_1}}{V_{in}} \times \frac{\cancel{V_2}}{\cancel{V_1}} \times \frac{V_0}{\cancel{V_2}} = \frac{V_0}{V_{in}}$

overall gain $[Av]_{dB} = 20 \log [AV_1] + 20 \log [AV_2] + 20 \log [AV_3]$

$[Av]_{dB} = 20 \log \left[\frac{V_0}{V_{in}}\right]$

questions.

1. In a transistor if β changes from 99 to 199 then α changes from ___ to ___.

$\alpha_1 = \frac{\beta}{1+\beta}$ $\qquad \alpha_2 = \frac{199}{1+199}$

$= \frac{99}{100}$ $\qquad = \frac{199}{200}$

$= 0.99$ $\qquad = 0.995$

2. In pnp if B-E is reverse bias and CB = forward bias transistor is operating in <u>inverse active</u> region or <u>reverse active</u>

3. pnp transistor has $\alpha = 0.98$ and $I_B = 40\,\mu A$. calculate I_E.

$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{0.02} = 49$ $\boxed{2mA}$

$I_E = (1+\beta) I_B$

$= 50 \times 40$

$= 2000\,\mu A$

4/1/23

4. A Silicon transistor has $I_{CO} = 5nA$, $I_B = 0$, $I_C = 1\mu A$.
$\beta = ?$

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

$1\mu A = \cancel{\beta}\times 0 + \cancel{I_{CO}}\, 5n + \beta \times 5n$

$\cancel{1\,10^{-6}} = 5\times \cancel{10^{-9}}^{\,10^{-3}} + 5\times\cancel{10^{-9}}^{\,10^{-3}} \times \beta$

$\frac{1}{5\times10^{-3}} = (1+\beta)$

$\beta = \frac{1000}{5} - 1 = \frac{995}{5} = 199$

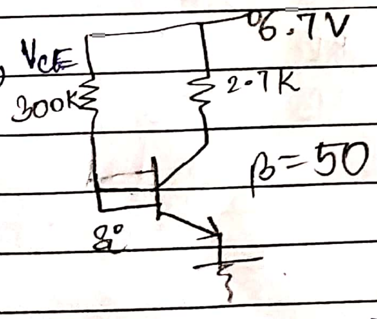
5. V-divider bias: $R_E = 4K\Omega$, $R_{th} = 60\,K\Omega$.
Find stability factor: $\beta = 49$

Sol: $S_{(I_{CO})} = \frac{1+\beta}{1+\beta\left[\frac{R_E}{R_{th}+R_E}\right]} = \frac{50}{1+49\times\left[\frac{4}{4+60}\right]}$

$= \frac{50}{1+\frac{49\times4}{64}}$

$S_{(I_{CO})} = 12.307$

6. Find I_C, V_{CE}



$I_B = \frac{V_{CC} - V_B}{R_B} = \frac{6.7 - 0.7}{300K} = \frac{6}{300}\times10^{-3} = 20\,A$

$I_C = 50\times20 = 10^{3}\,A$

$V_{CE} = 6.7 - \cancel{1000}\times 2.7\times\cancel{10^{-3}}$

$\boxed{V_{CE} = 4V}$

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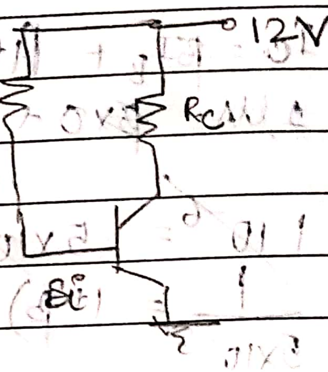
4/1/23

7. In the biasing circuit : design the values of R_B and R_C so that $V_{CE} = 5V$, $I_C = 1.5mA$ with $S_{(I_{CO})} = 51$ $V_{cc} = 12V$.



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

$= \frac{12 - 0.7}{I_B \rightarrow 30\mu A}$

$S = 1 + \beta$

$51 = 1 + \beta$

$\beta = 50$

$I_B = \frac{1.5}{50} = 30\mu A$

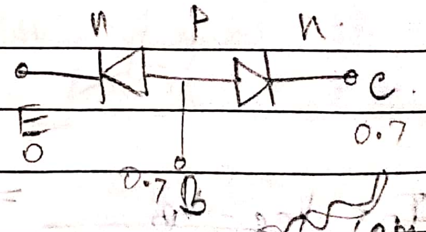
$R_B = 376.66 \, K\Omega$

$I_C R_C = V_{cc} - V_{CE}$

$R_C = \frac{12 - 5}{1.5} = 4.66 K\Omega$

8. If a ~~pnp~~ npn transistor

V_E	V_B	V_C	J_1	J_2	Region
0	0.7	0.7	FB	RB	active
0	0.8	0.1	FB	FB	saturation
-2.7	-2.0	0	FB	RB	active
0	0	0.3	RB	RB	cut off
0.7	0.7	0	RB	FB	reverse active



same potential
RB

8/1/23

Q: The output characteristics of a common emitter configuration can be obtained by plotting I_C vs V_{CE} by keeping I_B constant.

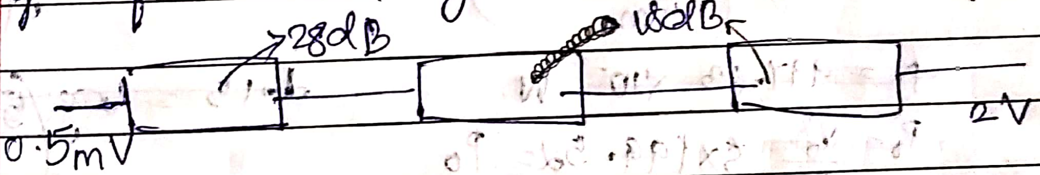
Q: Power gain of an amplifier is 20 dB. The input power required to obtain an output power of 100 watts = 1W.

$[A_p]_{dB} = 10 \log \left[\frac{P_o}{P_{in}}\right]$ $\quad 20\,dB = 10 \log_{10}\left[\frac{100}{P_{in}}\right]$

$P_{in} = \frac{100}{100} = 1W.$

Q: The output voltage of a cascaded chain of 3V amplifiers is 2V when input is 0.5 mV ~~with~~. If gain of 1st and 3rd stages are 28 dB and 18 dB. calculate the gain of middle stage.

sol:



$[A_v]_{dB} = 20 \log\left[\frac{2}{0.5m}\right]$

$= 20 \log \left[\frac{4000}{}\right]$

~~$= 60 \times 2 \log 2$~~

$= 72.04$

$72.4 = 28 + 18 + x$

$x = 26.4\,dB$

6/1/23.

Q: 3 voltage amplifiers are cascaded to provide an overall gain of 2000. The gains of first and last stages are 30dB & 30dB. calculate gain of middle stage.

Sol: $[A_v]_{dB} = 20\log(20000)$
$= 86.02\text{ dB} \; (-60\text{ dB})$
$[A_v]_{dB} = 26.02\text{ dB}$

Q: The input power to an amplifier with a power gain of 23dB is 5mW. If load resistance is 100 Ω calculate the output voltage.

Sol: $23 = 10\log\left(\frac{P_o}{5m}\right)$

$23\text{dB} = 20\log\left(\frac{P_o}{5\times10^{-3}}\right)$

$\cancel{P_o = 997.63\times10^{-3}\text{ W}}$

$\cancel{1.15 = \log\left(\frac{P_o}{5\times10^{-3}}\right)}$

$\cancel{P_o = \frac{V_o^2}{R}}$ $5\times199.52\times10^{-3} = P_o$

$\cancel{P_o = 14.12\times5\times10^{-3}}$

$\cancel{V_o = 315.85\text{ V}}$ $P_o = 997.63\times10^{-3}\text{ W}$

$\cancel{P_o = 70.62\times10^{-3}}$

$P_o = \frac{V_o^2}{R}$

$V_o = \sqrt{997.63\times10^{-3}\times10^{2}} = 9.988\text{ V}$

Q: An amplifier has voltage gain of 46dB to obtain an output of 2V. The input voltage should be = 0.01V

Q: The power gain of an amplifier is 23dB and the output resistance is 10KΩ. If the output voltage = 100V calculate the input power to the amplifier.

0.005 W.

Date
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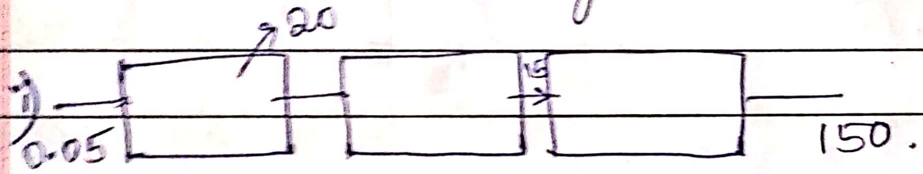
Q: 3 amplifier stages are in cascaded with 0.05 V input providing 150 V output. If voltage gain of first stage is 20 and input to the third stage is 15V.

Find i) overall gain
ii) voltage gain of second and third stage.
iii) input voltage of the second stage.
iv) decibel voltage gain at each stage
v) overall decibel gain

Sol: i)



overall gain = $\frac{150}{0.05} = 3000$.

ii) 15, 10

iii) 1

iv) 26.02 dB, 23.52, 20dB.

v) 69.54 dB

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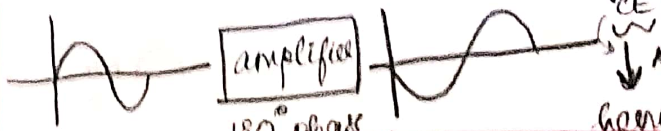
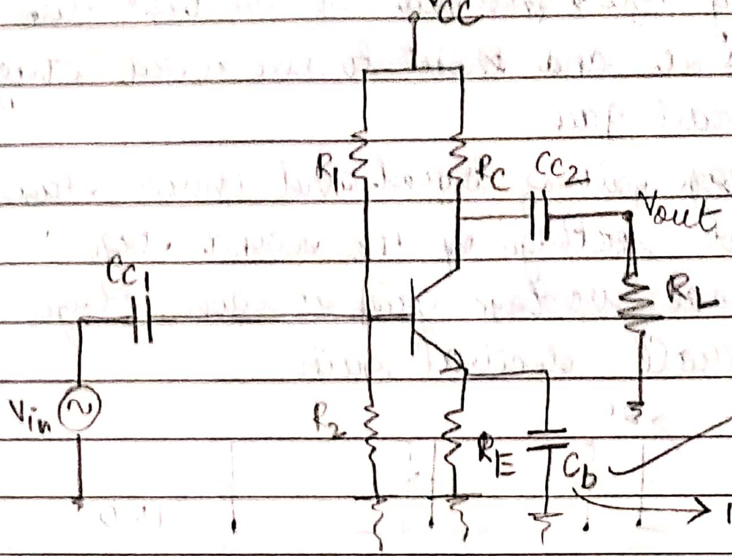


$V_{CE} = V_{CC} - I_C R_C - I_E R_E$

hence starts becoming -ve values.

RC coupled amplifier.



bypass capacitor

If no capacitor drop in R_E hence the $V_{CE} \downarrow$

makes sure no -ve feedback.
→ creates ac ground.

$V_{CE} = V_{CC} - I_C R_C - I_E R_E$

C_{C_1} and C_{C_2} – coupling capacitors

makes sure that no DC component goes into transistor's base

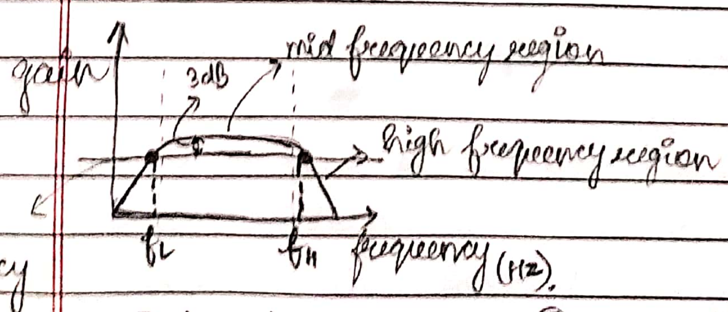
→ no DC component occurs across the load

DC: $f = 0 \Rightarrow X_C \Rightarrow \infty$
hence open circuit

C_{C_1} – input coupling capacitor
C_{C_2} – output coupling capacitor.

→ Frequency response of RC coupled amplifier.

AC analysis – capacitor → short circuited
DC source = 0



③ mid freq. region
gain is constant
↓
mid band gain
↓
AMPLIFIER
↓
constant gain

① low freq.

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

$f \downarrow \quad X_C \uparrow \quad gain \downarrow$

coupling & bypass drop in gain

② high freq.

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

junction capacitances dropping gain

10/1/23·

Band width

→ The range of frequencies over which the circuit operates as an amplifier satisfactorily.

f_L = lower cut off freq.

f_H = upper cut off freq.

$Bw = f_H - f_L$

→ Midband gain = V, gain at f_L & f_H = $\frac{V}{\sqrt{2}}$ at half power point

Q: An amplifier has a band width of 500 KHz. If the lower cut off frequency is 25Hz. What is the higher cut off frequency. Also find voltage gain at ~~low~~ f_L when the midband gain is 120.

Sol:
$$\Delta f = 500 \times 10^3 \text{ Hz}$$
$$f_L = 25 \text{ Hz}$$
$$f_H = (5\times10^5 + 25) \text{ Hz} = 500025 \text{ Hz}$$

$Vg_{(mb)} = 120$

3dB = 20 log 0.707

$$Vg \text{ at } f_L = \frac{120}{\sqrt{2}} \xrightarrow{} \text{3dB point}$$
$$= 84.85$$

Q: Gain of amplifier at $f_L = 100$. At mid band = ?

Sol:
$$\frac{Vg_{mb}}{\sqrt{2}} = Vg_{(f_L/f_H)}$$
$$\therefore Vg_{(mb)} = 100\sqrt{2}$$

S = mean time

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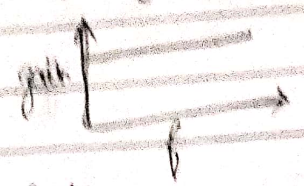
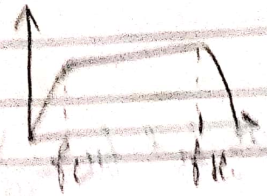
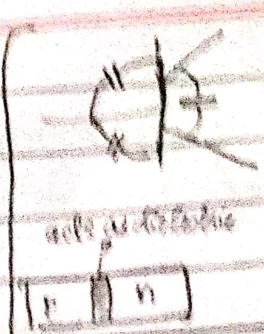
ideally amplifier



gain



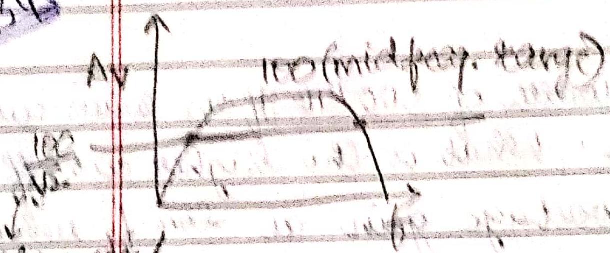


similar to capacitors
charging — less time
discharging — more time

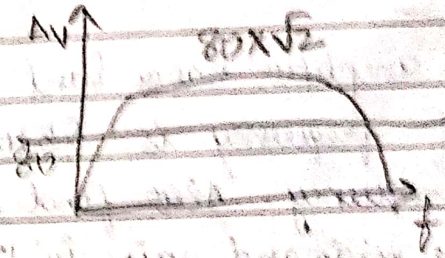
$\boxed{20\log(0.70) = -3dB}$

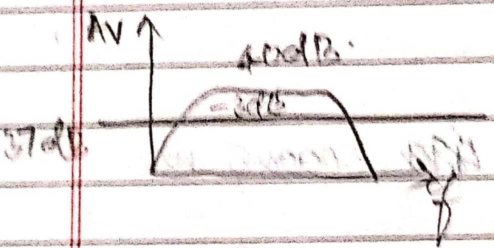
70%

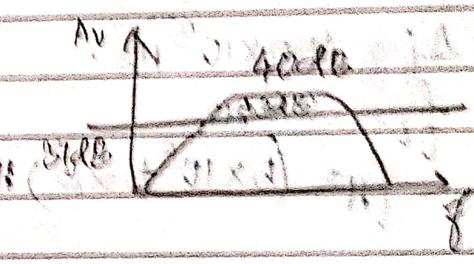
Quiz PS



half power/cut off







Q: The gain of an amplifier is 100 at mid frequency and the gain falls by 6dB at cut off frequencies calculate output voltage at cut off frequencies if input is 1mV.

Sol: $V_{in} = 1mV$

$V_g = 100$ (m-f)

$\Delta V = 6dB$.

$A = \frac{V_o}{V_{in}}$

~~$100 \times V_{in} = V_o$~~

~~$V_o = 40dB \times V_{in} = 40\times10^{-3}$~~

$V_{g(\text{cut off})} = 40 - 6 = 34$ dB

$\therefore V_g = 34 = \frac{V_o}{V_{in}}$

$V_o = \cancel{34} \times 34dB \times V_{in}$

$V_o = 50.11dB \times 1mV$

$V_o = 50.11$ mV

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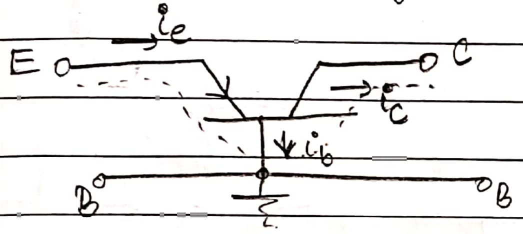
Q: Phase difference b/w input & output of CE amplifier is ___180°___.

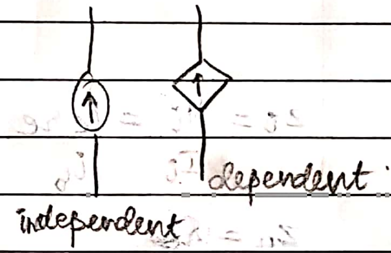
Re model (small AC signals)

common base configuration

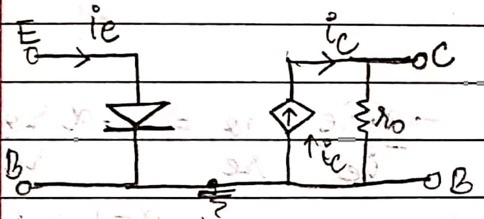


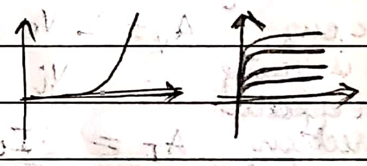
Z_i Z_o A_V A_I.

PNP



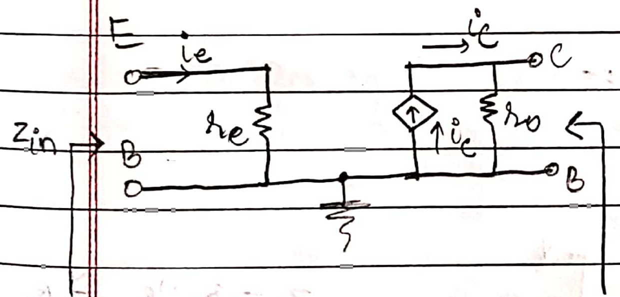
⇓





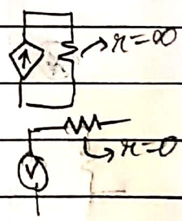
⇓

Small AC signals – small-change → Diode = resistance.



ideally

but



Input impedence $= \frac{V_{in}}{I_{in}} = \frac{i_e \cdot r_e}{i_e} = r_e = Z_{in}$

Output impedence $= \frac{V_o}{I_o} = \frac{i_c r_o}{i_c} = r_o = Z_o$.

Voltage gain $= A_V = \frac{V_o}{V_{in}} = \frac{i_c \cdot r_o}{i_e r_e} = \frac{\alpha i_e r_o}{i_e r_e} = \frac{\alpha r_o}{r_e}$

current gain $= A_I = \frac{I_o}{I_{in}} = \frac{i_c}{i_e} = \alpha$.

ideally $\alpha = 1$

$\therefore A_V = \frac{r_o}{r_e}$ ~~$\frac{Z_o}{Z_{in}}$~~

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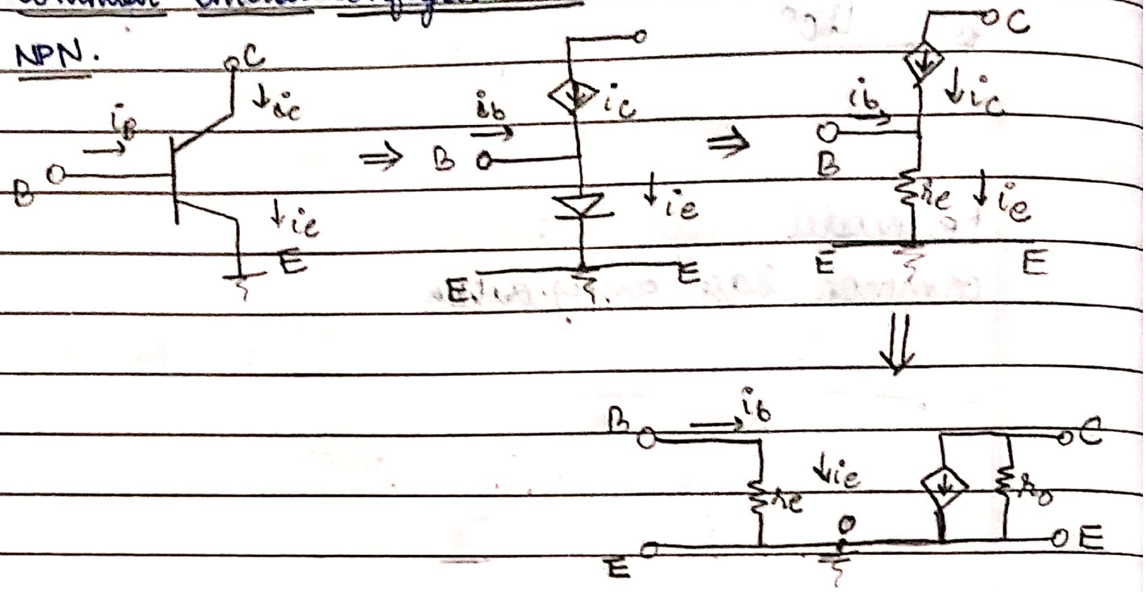
Common emitter configuration

NPN.



$$Z_i = \frac{V_i}{I_i} = \frac{i_e r_e}{i_b} = \frac{(1+\beta) i_b r_e}{i_b} = (1+\beta) r_e$$

$$Z_o = r_o$$

-ve cuz it is flowing in opposite direction wrt the ground

$$A_V = -\frac{V_o}{V_i} = \frac{-i_c \cdot r_o}{i_e \cdot r_e} = -\frac{\alpha i_e}{i_e} \cdot \frac{r_o}{r_e} = -\alpha \frac{r_o}{r_e}$$

$$A_I = \frac{I_o}{I_i} = \frac{i_c}{i_b} = \beta$$

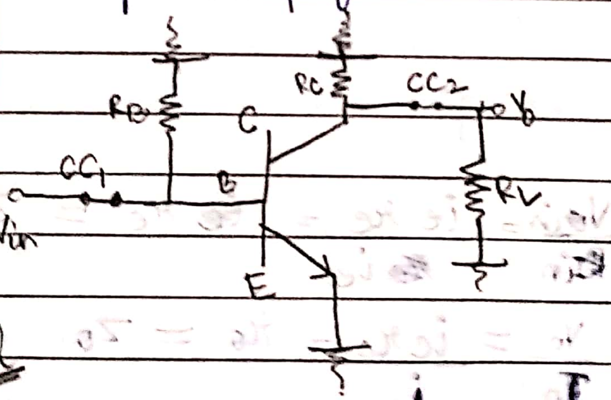
$$\alpha = 1 \Rightarrow A_V = -\frac{r_o}{r_e}$$

⊛ For fixed bias circuits:-

→ AC-capacitor - short circuited

RC coupled amplifier:-

→

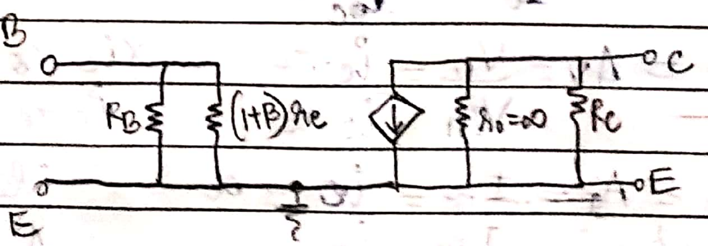


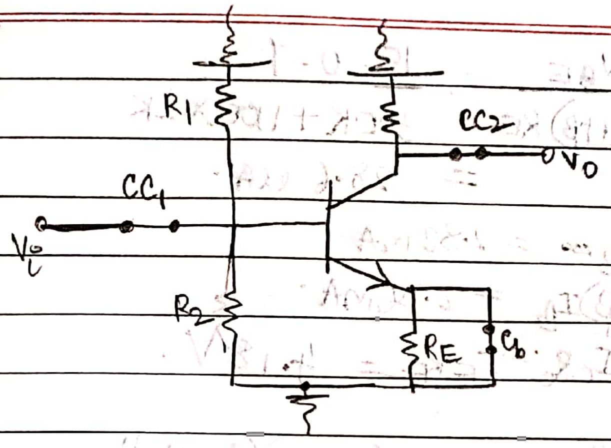
$$Z_o = r_o \| R_C \approxeq R_C \quad (r_o \to \infty)$$

$$A_V = -\frac{r_o \| R_C}{r_e} \approxeq -\frac{R_C \| R_L}{r_e}$$

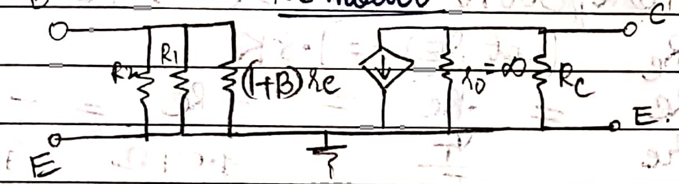
$$r_e = \frac{V_T}{I_E} = \frac{26mV}{I_E}$$

re model





re model.



$$Z_i = (1+\beta) r_e \,||\, R_1 \,||\, R_2$$

$$Z_o = \underset{\downarrow \infty}{r_o} \,||\, R_C \cong R_C$$

$$A_V = \frac{V_o}{V_{in}} = \frac{-r_o || R_C}{r_e} = \frac{-R_C}{r_e}$$

$$r_e = \frac{V_T}{I_E} = \frac{26mV}{I_E}$$

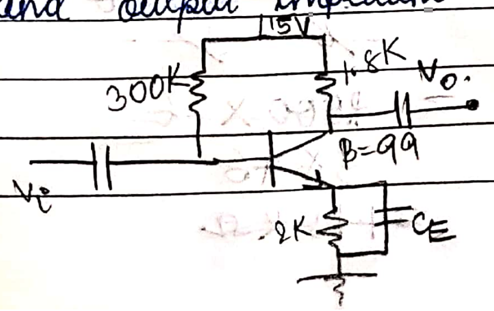
Q: Calculate the gain of an RC coupled amplifier given $R_C = 2k\Omega$ & $I_E = 2mA \rightarrow A_V = ?$

Sol: $$A_V = \frac{-R_C}{r_e} = \frac{-R_C \times I_E}{26 \times 10^{-3}} = \frac{-2 \times 10^3 \times 2 \times 10^{-3}}{26 \times 10^{-3}}$$

$$= \frac{-2}{13} \times 10^3 = -153.84$$

Q: Find operating point of Si transistor and also determine small signal voltage gain input impedance and output impedance. Sketch re model.

Sol:



$$I_B = \frac{V_{CC}-V_{BE}}{R_B+(1+\beta)R_E} = \frac{15-0.7}{300K+100\times 2K} = 28.6\ \mu A$$

$$I_C = \beta I_B = 2.83\,mA$$

$$I_E = (1+\beta)I_B = 2.86\,mA$$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E = 4.18\,V$$

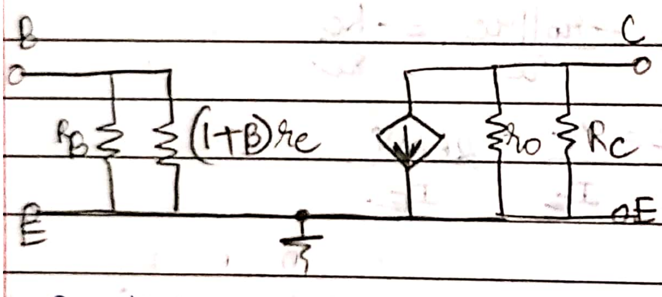
$Z_i \Rightarrow (1+\beta)r_e \| 300K = (1+99)(9.09) \| 300K = \cancel{225}$

$Z_o \Rightarrow R_C$ (not RE) $= 1.8K$

$$A_V = \frac{-R_C}{r_e} = \frac{-R_C}{\frac{V_T}{I_E}} = \frac{-R_C}{9.09\Omega} = \frac{-1.8}{9.09}$$

$$A_V = -198$$

$$\frac{909\times 300}{909+300} = 906\,\Omega$$



$R_1 = 10K\Omega$ $\quad I_E = 3mA$ $\quad \beta = 99.$

$R_2 = 20K\Omega$ $\quad R_C = 2K\Omega$

$R_L = 4K\Omega$

A_V, Z_o, Z_i $\qquad R_{th} = \frac{20\cancel{0}}{3\cancel{0}}$

$$r_e = \frac{26\times 10^{-3}}{3\times 10^{-3}} = 8.66\,\Omega$$

$$\frac{6.66\times 100\times 8.66}{6.66+8.66}$$

$Z_o = r_c \| R_L\ \cancel{2\times 10^3\,\Omega = 2K\Omega} = 1.33K\Omega$

$$Z_{in} = R_B \| (1+\beta) r_e = \frac{\frac{20}{\cancel{3}}\times 100\times\frac{26}{3}}{\frac{20}{\cancel{3}} + \frac{26\times 100}{\cancel{3}}} = \frac{2000\times 26}{3\times 46}$$

~~$A_V = \frac{-2.866\cdot 133}{3\ \ 3}$~~

~~$A_V = -288$~~

~~$= 1.13\,K\Omega$~~

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$R_B = \frac{20}{3} = 6.66\,K$

$\cancel{Z_{in} = \frac{6.66 \times 100 \times 8.66}{6.66 + 100 \times 8.66}} =$

$re = 8.66\,\Omega = \cancel{8.6}$

$re = (1+\beta)\, 8.66 \times 10^{-3}\ K\Omega$

$0.866\ K\Omega$

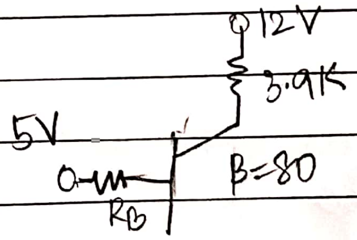
$\therefore R_B \,||\, re(1+\beta) \Rightarrow Z_{in} = 7.66$

Saturation Region

R_B minimum β minimum.

$[V_{CE} = 0.3\,V$ fixed$]$ $[$ideally $= 0]$

Q:



→ For inverter circuit determine minimum value of R_B.

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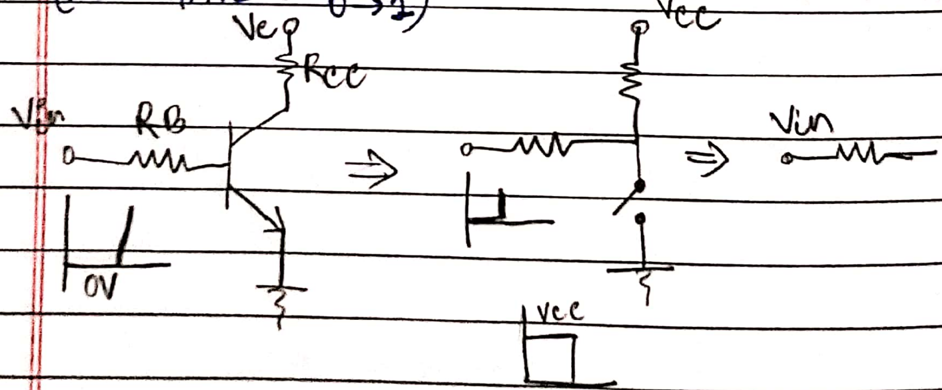
Q: In the inverter circuit of below figure determine minimum value of β.

sol:

→ Transistor as a switch
(NOT GATE → 1→0, 0→1)



Quiz question.

1. In a pnp transistor emitter-base junction is reverse biased and collector-base junction is forward biased, the transistor is operating in <u>Inverse Active region</u> region

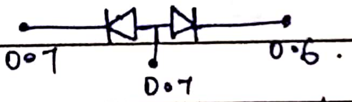
2. The transistor needs to be operated as amplifier it should operated in <u>active</u> region

3. For the given circuit if $V_B = 0.7$ V. Find region of operation.

<u>NPN</u>

$V_C = 0.6$ V

$V_E = 0.7$ V



same V means off state – reverse

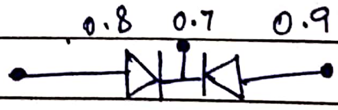
forward.

$\therefore$ ans = Inverse active region

4. <u>PNP</u> $V_E = 0.8$ V

$V_B = 0.7$ V

$V_C = 0.9$ V.



p → n n → p.

forward forward.

$\therefore$ It is in saturation.

WORKSHEET

1. a) $I_{CO} = 6nA$. $\alpha = 0.98$ $I_B = 0$ $V_{CE} = 4V$ $I_C = ?$

~~$I_C = \beta I_B$~~ $\alpha = \frac{I_C}{I_E}$

~~$I_C =$~~

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{0.02} = 49$$

$$I_C = \beta I_B + (1+\beta) I_{CO}.$$
$$= 49 \times 0 + 50 \times 6 \times 10^{-9}$$
$$I_C = 3 \times 10^{-7} = \cancel{30 \mu A} = 0.3 \times 10^{-6} = \underline{0.3 \mu A}$$

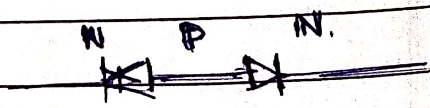
b) $I_{CO} = 30 \, nA$ $I_B = 0$ $V_{CE} = 4V$ $I_C = 30 \mu A$: $\beta = ?$

$$I_C = (1+\beta) I_{CO}.$$
$$\cancel{30 \times 10^{-6}} = I_{CO} + \beta I_{CO} = \cancel{30 \times 10^{-9}} + \beta \times \cancel{30 \times 10^{-9}}$$

(with 10^{-3} written over the struck terms)

$$1 = 10^{-3} + 10^{-3} \beta.$$
$$10^{3} = \beta + 1$$
$$\boxed{\beta = 999}$$

2.
1. F, R : active
2. F, F : saturation
3. F, R : active.
4. R, R : cut off.
5. R, F : reverse active



3. a) $\beta = \frac{\alpha}{1-\alpha}$

i) $\beta = \frac{0.5}{1-0.5} = 1$

ii) $\beta = \frac{0.8}{1-0.8} = 4$

iii) $\beta = \frac{0.96}{1-0.96} = 24$

iv) $\beta = \frac{0.98}{1-0.98} = 49$

v) ~~0.49~~ $\beta = 49$