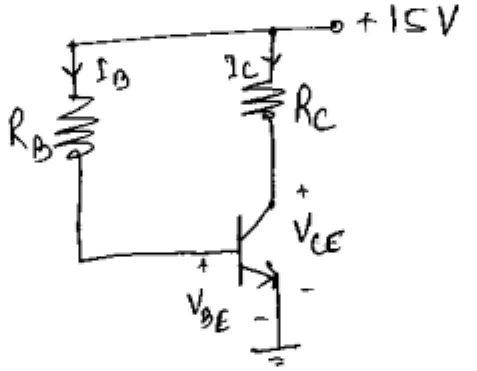
Chapter 3: Transistors:

① It is desired to amplify a weak signal using an appropriate circuit which can provide moderate bias stability. Which biasing arrangement would you prefer? Also design the circuit for an operating point of (5V, 5mA). Assume the supply voltage to be 15V, and the transistors provided have β of 100.

Soln: The biasing arrangement considered is fixed bias (also called base-bias), and is shown below.



Given data: $V_{cc} = +15V$, $V_{CE} = 5V$, $I_c = 5mA$, $\beta = 100$

Assume $V_{BE} = 0.7V$

Applying KVL to the ~~input~~ output loop.

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

$$\therefore R_c = \frac{V_{cc} - V_{CE}}{I_c} = \frac{15-5}{5\times10^{-3}} = 2000\,\Omega$$

$\therefore R_c = 2k\Omega$ //.

Applying KVL to input loop we get.

$$V_{ce} = I_B R_B + V_{BE} \qquad \therefore R_B = \frac{V_{cc} - V_{BE}}{I_B}.$$

$$\text{Now, } \beta = \frac{I_c}{I_B} \quad \therefore I_B = \frac{I_c}{\beta} = \frac{5\times10^{-3}}{100} = 50\times10^{-6}A = 50\mu A$$

$$\therefore R_B = \frac{15-0.7}{50\times10^{-6}} = 286\times10^{3}\,\Omega = 286\,k\Omega //.$$

$$\boxed{\therefore \text{ The design values are } R_B = 286\,k\Omega,\ R_c = 2\,k\Omega.}$$

② A single stage amplifier has equal input and output load resistances. If an audio signal of RMS value 100mV is applied, it produces an amplified output of 3V. Calculate the power gain and express it in decibels.

Soln: Given data: $V_{in} = 100\ mV$
$V_{out} = 3V$

$$\therefore \text{Power gain}\Big|_{dB} = 20 \log\left(\frac{V_{out}}{V_{in}}\right) = 20 \log\left(\frac{3}{100\times10^{-3}}\right) = 29.5\ dB$$

(2) The collector current and base current in a CE transistor configuration are 1mA and 20 μA respectively. Determine the emitter current, and express the parameters of this transistor in terms of various gain factors.

Soln: Given data: $I_C = 1mA$
$I_B = 20\ \mu A$

α_{dc}: Emitter to collector current gain.

$$\alpha_{dc} = \frac{I_C}{I_E}$$

Now, $I_E = I_C + I_B$
$= (1\times10^{-3}) + (20\times10^{-6}) = 1.02\times10^{-3}\ A$
$\therefore I_E = 1.02\ mA$

$$\therefore \alpha_{dc} = \frac{1\times10^{-3}}{1.02\times10^{-3}} = 0.98$$

β_{dc}: Base to Collector current gain.

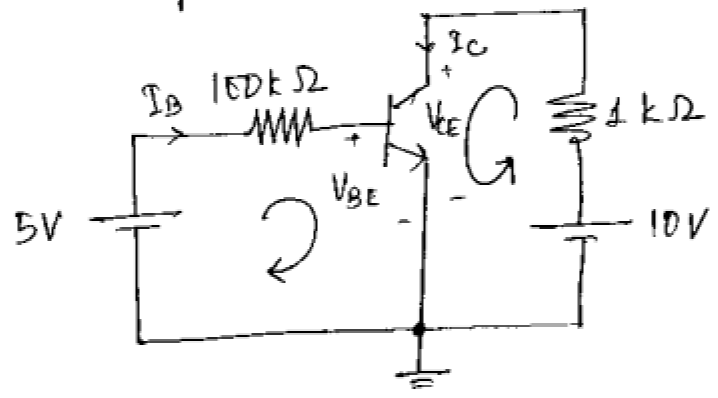
$$\beta_{dc} = \frac{I_C}{I_B} = \frac{1\times10^{-3}}{20\times10^{-6}} = 50$$

Alternatively: $\beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}} = \frac{0.98}{1-0.98} = 49$

why $\beta_{dc} = 49$ instead of 50??

$\because \alpha_{dc} = \frac{1\times10^{-3}}{1.02\times10^{-3}} = 0.98039$ $\quad \therefore \beta_{dc} = \frac{0.98039}{1-0.98039}$
$= 50$

(4) Why do we call base bias as fixed bias? Estimate the operating point for a transistor in fixed bias configuration as shown below. Assume $\beta = 100$.



Soln: Base bias is called "fixed bias", since the base current remains constant for a given value of supply voltage. In other bias configurations base current varies based on feedback. The biggest disadvantage of fixed bias is that the bias point (or Q-point) is largely dependent on β_{dc} of a transistor. β_{dc} varies with temperature, and also it is difficult to get two transistors of same β_{dc}, even if they are manufactured similarly. Usually β_{dc} varies from 50 to 200.

In the ckt given above,

$R_B = 100\ k\Omega$

$R_C = 1\ k\Omega$

For the input loop: $5 = (100\times10^3)I_B + V_{BE}$

Let's assume $V_{BE} = 0.7\,V$ $\therefore I_B = \dfrac{5-0.7}{100\times10^3} = 43\ \mu A$

$\therefore I_C = \beta I_B = (100)(43\times10^{-6}) = 4.3\ mA$

For the output loop: $10 = (1\times10^3)(4.3\times10^{-3}) + V_{CE}$

$\therefore V_{CE} = 5.7\ V$

$\therefore$ The operating point for the given circuit is,

$Q(V_{CE}, I_C) = Q(5.7V, 4.3mA)$.

(5) Analyze how the Q-point shifts for the base bias when β varies from 50 to 60. For circuit, $V_{CC} = 12\,V$, $R_C = 2k$, and $R_B = 150k$.

Soln: for base-bias the voltage & current equations are;

$$V_{CE} = V_{CC} - I_C R_C \quad \text{------} (1)$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \quad \text{------} (2)$$

and $$I_C = \beta I_B \quad \text{------} (3)$$

Let's assume $V_{BE} = 0.7\,V$.

i) when $\beta = 50$

$$I_B = \frac{12 - 0.7}{150 \times 10^3} = 75.33\,\mu A \qquad \therefore I_C = (50)(75.33 \times 10^{-6}) = 3.77\,mA$$

$$V_{CE} = 12 - (3.77 \times 10^{-3})(2 \times 10^3) = 4.46\,V$$

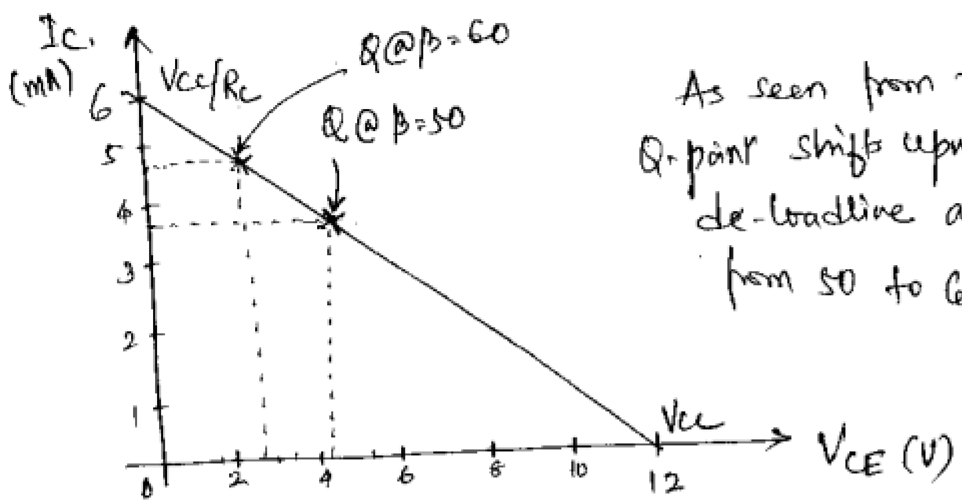
$$\therefore Q\Big|_{\beta=50} = (4.46V, 3.77\,mA)$$

ii) when $\beta = 60$

$$I_C = (60)(75.33 \times 10^{-6}) = 4.52\,mA$$

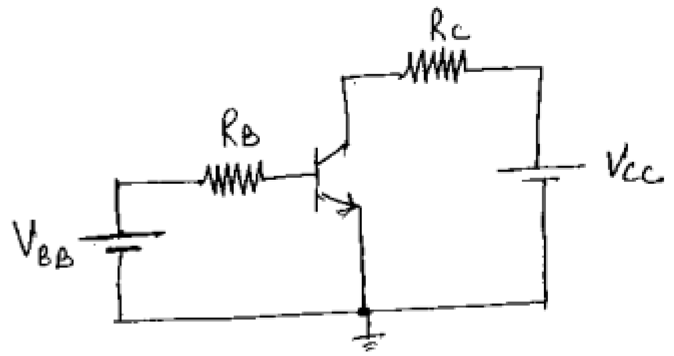
$$V_{CE} = 12 - (4.52 \times 10^{-3})(2 \times 10^3) = 2.96\,V$$

$$\therefore Q\Big|_{\beta=60} = (2.96V, 4.52\,mA)$$



As seen from the graph, the Q-point shifts upwards along the dc-loadline as β changes from 50 to 60.

⑥ For the circuit shown below find the values of α_{dc}, β_{dc} for a desired I_C of 5 mA, $I_B = 29\,\mu A$



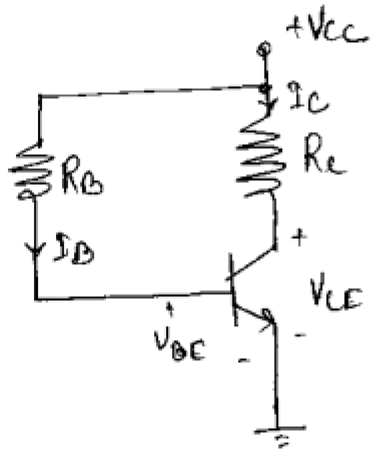
Soln: Given data: $I_C = 5\,mA$

$I_B = 29\,\mu A$

$\therefore I_E = I_C + I_B = 5.029\,mA.$

Now, $\alpha_{dc} = \dfrac{I_C}{I_E} = \dfrac{5\times10^{-3}}{5.029\times10^{-3}} = 0.99$ and $\beta_{dc} = \dfrac{I_C}{I_B} = 172.4.$

⑦ For the circuit shown below, find I_B, I_C and V_{CE} if $R_C = 2.2\,k$, $R_B = 470\,k$, $V_{CC} = 18\,V$, $h_{FE} = 100$ and $V_{BE} = 0.7\,V$. Also draw the dc load line and indicate the Q-point.



Soln: $I_B = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{18-0.7}{470\times10^3} = 36.81\,\mu A.$

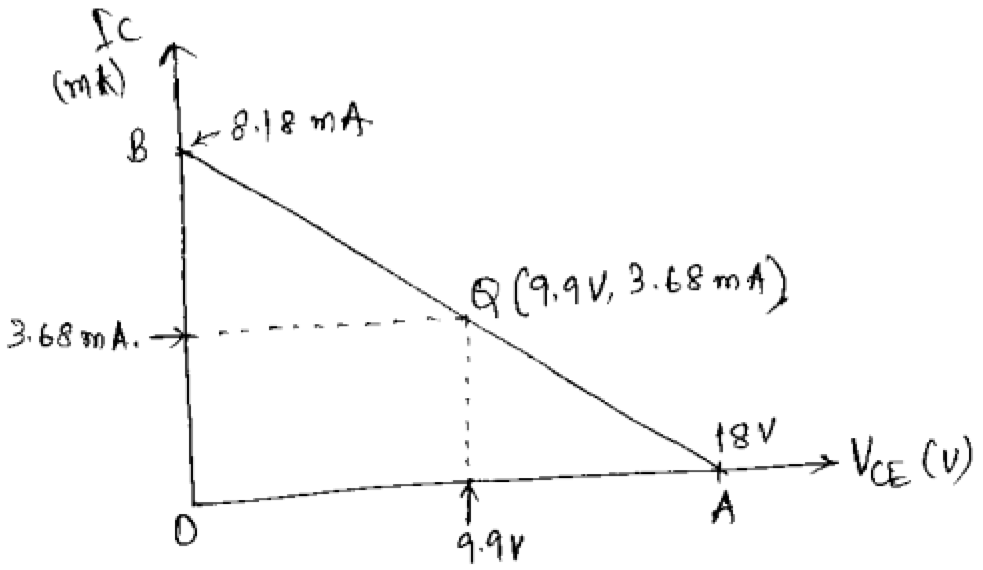
$I_C = \beta I_B = (100)(36.81\times10^{-6}) = 3.68\,mA.$

$V_{CE} = V_{CC} - I_C R_C = 18 - (3.68\times10^{-3})(2.2\times10^3) = 9.9\,V.$

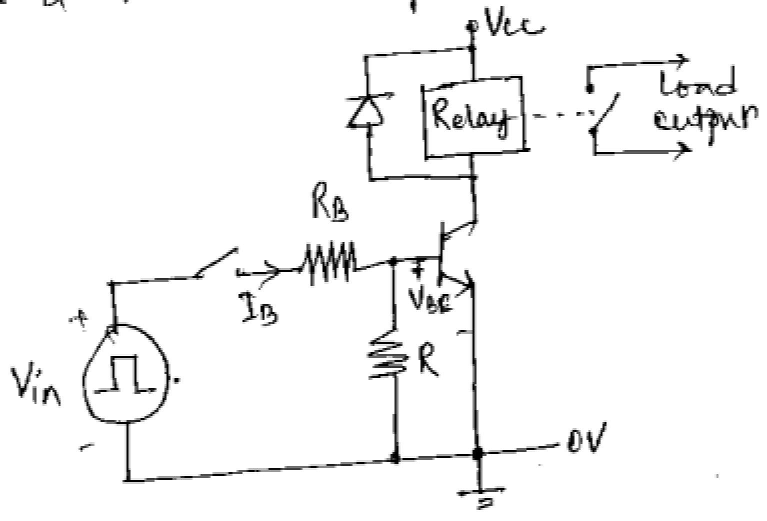
$\therefore Q(V_{CE}, I_C) = Q(9.9\,V, 3.68\,mA).$

Draw the dc load line with points A (V_{cc}, 0), and B(0, $\frac{V_{cc}}{R_C}$)

i.e. A(18V, 0) and B(0, 8.18 mA)



⑧ Identify the circuit shown below. find the value of base resistance to make the device fully ON when the input terminal voltage exceeds 2.5V. Assume $\beta = 200$, $I_c = 4mA$ and $I_B = 20\,\mu A$.



Soln: The circuit is "transistor as a switch" application, where the relay turns 'ON' when transistor is fully ON, and the relay turns OFF when transistor is in cut-off.

Given data: $I_c = 4\,mA$, $I_B = 20\,\mu A$, $V_{in} = 2.5V$, $\beta = 200$

~~Now due~~ Applying KVL to input loop, we get.

$V_{in} = I_B R_B + V_{BE}$. Let $V_{BE} = 0.7\,V$

$\therefore\ R_B = \dfrac{V_{in} - V_{BE}}{I_B} = \dfrac{2.5 - 0.7}{20\times10^{-6}} = 90\,k\Omega$

(9) For the fixed bias circuit, $V_{cc} = 18\,V$, $R_c = 2.2\,k\Omega$, $R_B = 470\,k\Omega$. $V_{BE} = 0.7V$. find the levels of I_c and V_{CE} when $\beta = 50$ and 200. Draw the dc loadline and indicate the operating points.

Soln:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{18 - 0.7}{470 \times 10^3} = 36.81\,\mu A.$$

i) when $\beta = 50$

$$I_C = \beta I_B = (50)(36.81\,\mu A) = 1.84\,mA.$$

$$V_{CE} = V_{cc} - I_c R_c = 18 - (1.84 \times 10^{-3})(2.2 \times 10^3) = 13.95\,V.$$

$$\therefore Q_1 (V_{CE}, I_c) = Q_1 (13.95V, 1.84\,mA)$$

ii) when $\beta = 200$

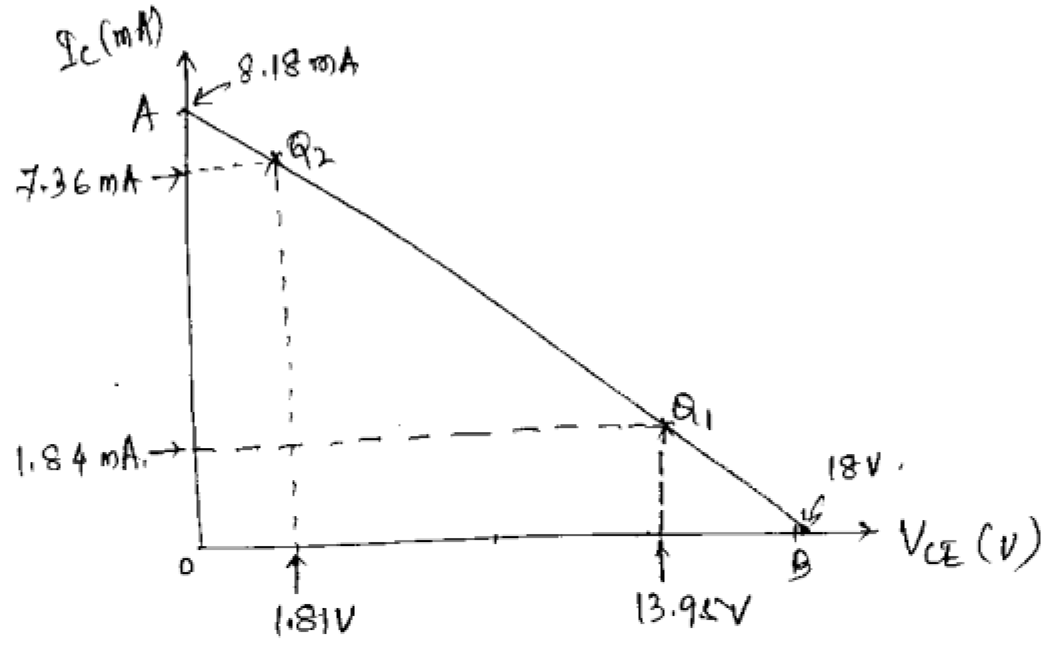
$$I_c = \beta I_B = (200)(36.81 \times 10^{-6}) = 7.36\,mA.$$

$$V_{CE} = V_{cc} - I_c R_c = 18 - (7.36 \times 10^{-3})(2.2 \times 10^3) = 1.81\,V.$$

$$\therefore Q_2 (V_{CE}, I_c) = Q_2 (1.81V, 7.36\,mA).$$

Dc-loadline is drawn with points $A(V_{cc}, 0)$ and $B(0, V_{cc}/R_c)$

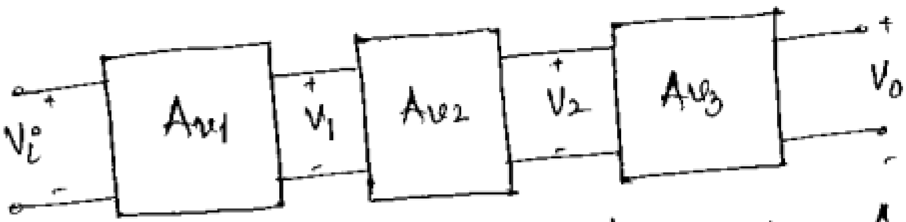
i.e. $A(18, 0)$ and $B(8.18, 0)$.



(10) In a three stage cascaded amplifier, the input voltage is 0.05 V_{p-p}, giving the output of 150 V_{p-p}. If the voltage gain of the first stage is 20 and the input to the third stage is 15 V_{p-p} then find:

i) The overall voltage gain
ii) Overall gain in dB
iii) Voltage gain of 2nd and 3rd stage
iv) Input voltage of 2nd stage.

Soln: The amplifier stages are shown below:



Given data: $V_i = 0.05\,V$, $V_o = 150\,V$ | and also $A_{v1} = 20$, $V_2 = 15\,V$

i) Overall voltage gain, $A_v = \dfrac{V_o}{V_i} = \dfrac{150}{0.05} = 3{,}000$

ii) Overall gain in dB, $A_{v,dB} = 20\log(3{,}000) = 69.54$ dB.

iii) Voltage gain of 2nd stage, $A_{v2} = \dfrac{V_2}{V_1}$

Now, $A_{v1} = \dfrac{V_1}{V_i}$ $\quad\therefore\quad V_1 = (A_{v1})\,V_i = (20)(0.05) = 1\,V$

$\therefore\ A_{v2} = \dfrac{V_2}{V_1} = \dfrac{15}{1} = 15$ //

Voltage gain of 3rd stage, $A_{v3} = \dfrac{V_o}{V_2} = \dfrac{150}{15} = 10$ //

Cross-check: $A_V = (A_{v1})(A_{v2})(A_{v3})$
$= (20)(15)(10)$
$= 3000$, which is same as (i)