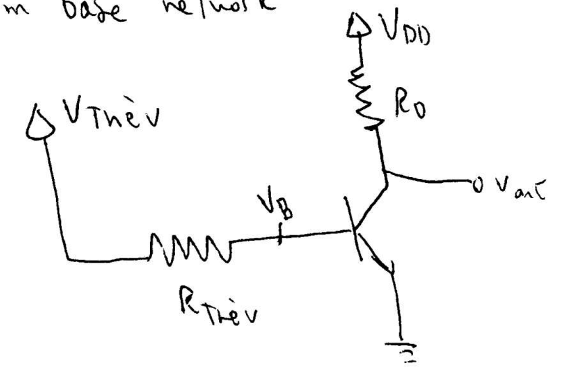
Q#1 design for max output swing: V_{C} halfway between V_{DD} & V_B

① Transform base network



$$V_{Thev} = V_{DD}\left(\frac{R_{B2}}{R_{B2}+R_{B1}}\right)$$

$$R_{Thev} = R_{B1} \| R_{B2}$$

$$V_D = V_{DD} - I_{C_1} R_D \quad \text{and} \quad I_{C_1} = \beta I_{B_1} = \beta \frac{(V_{Thev} - V_B)}{R_{Thev}}$$

design for $V_D = \dfrac{V_{DD}+V_B}{2} = V_{DD} - R_D \beta \left(\dfrac{V_{DD}\left(\frac{R_{B2}}{R_{B2}+R_{B1}}\right) - V_B}{R_{B1} \| R_{B2}} \right)$ and note $V_B = 0.7\,V$

choose R_{B2}, R_{B1} ... let's say we want a high input impedance

$$R_D = \left(\frac{V_{DD}}{2} - 0.45\right)\left[\frac{\beta}{R_{B1}}\left(V_{DD} - 0.7\left(\frac{R_{B1}+R_{B2}}{R_{B2}}\right)\right)\right]^{-1}$$

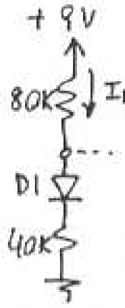
example: $V_{DD} = 10\,V$, $\beta = 100$, $R_{B1} = 9k$, $R_{B2} = 1k$

$$R_D = (4.55)\left[\frac{100}{9000}(10 - 7)\right]^{-1} = 136.5\,\Omega$$

5.83

For $\beta = \infty$ and R open:

$i_{B1} = i_{B2} = 0$, $\alpha_1 = \alpha_2 = 1$



$I_{D1} = \frac{9-0.7}{80K+40K} = 0.07mA$

$V_{B1} = 0.7 + 0.07m \times 40K$
$= \underline{\underline{3.5V}}$

$V_{E1} = V_{B1} - 0.7V$
$= 3.5 - 0.7 = \underline{\underline{2.8V}}$

$I_{E1} = \frac{2.8V}{2K} = 1.4mA$

$I_{E1} = I_{C1}$ since $\alpha = 1$

$V_{C1} = 9V - 2K \times 1.4m - 0.7 = \underline{\underline{5.5V}}$

$V_{CB} = 2V \rightarrow$ Transistor is in active mode.

$V_{B2} = V_{C1} = \underline{\underline{5.5V}}$

$V_{E2} = 5.5 + 0.7 = \underline{\underline{6.2V}}$

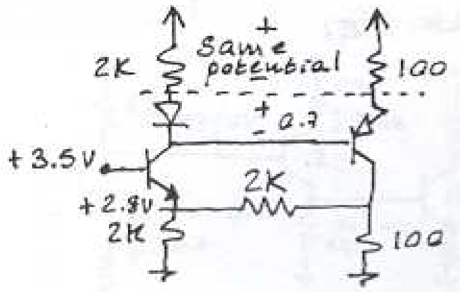
$I_{E2} = \frac{9-6.2}{100} = 28mA$

$I_{E2} = I_{C2}$ since $\alpha = 1$

$\rightarrow V_{C2} = 28mA \times 100\Omega = \underline{\underline{2.8V}}$

For $\beta = \infty$ and R connected:

Still: $\underline{\underline{V_{B1} = 3.5V}}$, $V_{E1} = \underline{\underline{2.8V}}$

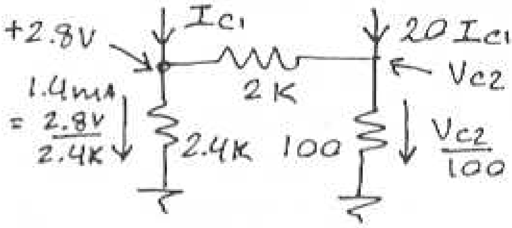


Since the voltage across the top two resistors is equal:

$I_{C1} \times 2K = I_{E2} \times 100$

$I_{E2} = 20 I_{C1}$

also: $I_{C1} = I_{E1}$, $I_{C2} = I_{E2}$



$1.4m - I_{C1} = 20 I_{C1} - \frac{V_{C2}}{100}$

$\rightarrow V_{C2} = 100 \times (21 \cdot I_{C1} - 1.4m)$ ①

also:

$\frac{V_{C2} - 2.8V}{2K\Omega} = 1.4mA - I_{C1}$

$\rightarrow V_{C2} = 5.6 - I_{C1} \times 2K$ ②

Solving for I_{C1} from ① & ②

$I_{C1} = 1.4mA$

Substituting in either ① v ②

$V_{C2} = \underline{\underline{2.8V}}$

and: $V_{E2} = 9 - 100 \times 1.4m$
$= \underline{\underline{8.86V}}$

$V_{B2} = V_{C1} = 8.86 - 0.7$
$= \underline{\underline{8.16V}}$

For $\beta = 100$ and R open:

In the previous two cases $I_{D1} = 0.07mA$, $I_{E1} = 1.4mA$

if $\beta = 100 \rightarrow I_{B1} \simeq 0.014mA$

which is a significant amount compared to 0.07m

$\rightarrow$ must be taken into account

The bottom two resistors have equal voltage drops thus,

CONT.

$2K \times I_{E1} = 40K \times I_{D1}$

$\rightarrow I_{D1} = 0.05 \times I_{E1}$ (3)

also: $\underbrace{I_{D1} + I_{B1}}_{\text{FROM (3)}} = \frac{9 - V_{B1}}{80K}$

$I_{E1}\left(\frac{1}{\beta+1} + 0.05\right)$

for $\beta = 100$:

$0.06 \times I_{E1} = \frac{9 - V_{B1}}{80K}$

$\rightarrow V_{B1} = 9 - 4800 \times I_{E1}$ (4)

also: $V_{B1} = 0.7 + I_{E1} \times 2K$ (5)

From (4) ∧ (5) $\begin{cases} V_{B1} = 3.14V \\ I_{E1} = 1.22mA \end{cases}$

$V_{E1} = 1.22m \times 2K \rightarrow V_{E1} = \underline{2.44V}$

$I_{C1} = \alpha I_E = 0.99 \times 1.22m = 1.2mA$

Again: voltage drop on top two resistors is equal

$2K . I_{D2} = 100 . I_{E2}$

$I_{D2} = 0.05\ I_{E2}$

but $I_{D2} = 1.2m - \frac{I_{E2}}{\beta+1}$

$\Rightarrow 1.2mA = \underbrace{\left(0.05 + \frac{1}{\beta+1}\right)}_{0.06} I_{E2}$

$I_{E2} = 20mA$

$V_{E2} = 9 - 100 \times 20m = \underline{7V}$

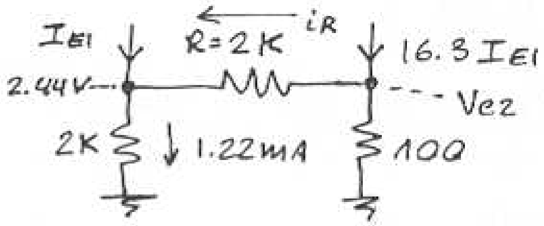
$V_{B2} = V_{C1} = 7 - 0.7 = \underline{6.3V}$

$I_{C1} = \alpha I_{E1} = 19.8mA$

$V_{C2} = 100 \times 19.8mA = \underline{1.98V}$

<u>For $\beta = 100$ and R connected:</u>

To simplify the solution: assume i on R is $<< I_{E1} \rightarrow V_{E1} = 2.44V$



From top of circuit:

$I_{E2} = I_{C1}/0.06$

$I_{C2} = \frac{\alpha^2}{0.06} . I_{E1}$

$I_{C2} = 16.3 \times I_{E1}$

To obtain I_{E1}:

$1.22m - I_{E1} = 16.3 I_{E1} - \frac{V_{C2}}{100}$

$V_{C2} = 100\,(17.2 I_{E1} - 1.22m)$ (6)

also:

$\frac{V_{C2} - 2.44}{2K} = 1.22m - I_{E1}$

$\rightarrow V_{C2} = 2.44 - 2000 I_{E1} + 2.44$

$= 4.88 - 2 \times 10^3 . I_{E1}$ (7)

From (7) ∧ (8): $I_{E1} = 1.34mA$

$V_{C2} = \underline{2.18V}$

thus,

$I_{C1} = 1.33mA$

$I_{E2} = 22.1mA$

$V_{E2} = 9 - 22.1m \times 100 = \underline{6.79V}$

$V_{B2} = 6.79 - 0.7 = \underline{6.09V}$

To confirm initial assumption on i of R:

$\frac{2.44 - 2.18}{2K} = 0.13mA$

which is 10 times smaller than I_{E1}

Q #3

$V_C \geq V_B$ is the condition

$$-0.7 - R_x I_{C_1} \geq -R_b I_{B_1}$$

and use $I_{B_1} = \frac{I_{C_1}}{\beta}$ and $I_{C_1} = \alpha I_{E_1} = \frac{\beta}{\beta+1} I_{E_1}$

$$-0.7 - 50\left(\frac{\beta}{\beta+1}\right)1mA \geq -70k\left(\frac{1mA}{\beta+1}\right)$$

$$-(\beta+1)\,0.7 - (50m)\beta \geq -70$$

$$\beta \leq 92.4$$