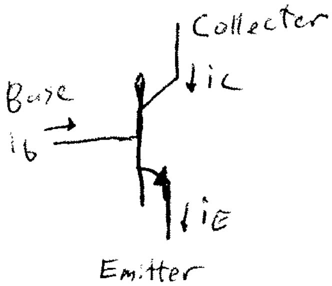
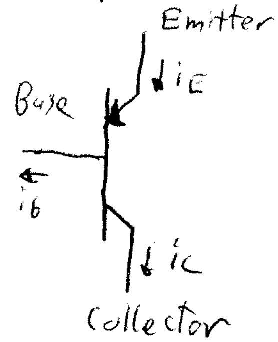
R2.1

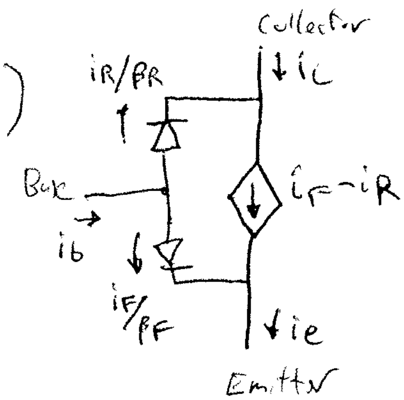
NPN | PNP

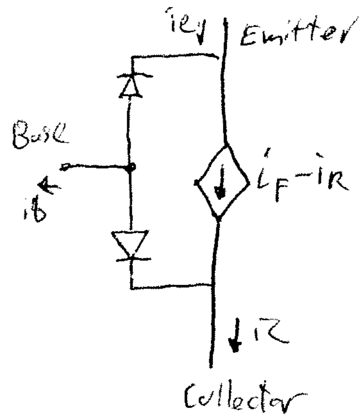
a)



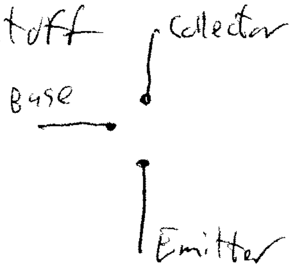


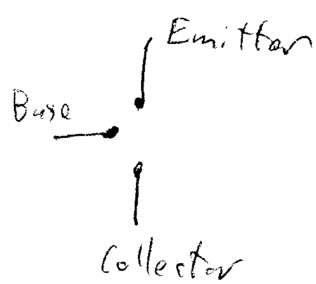
b)



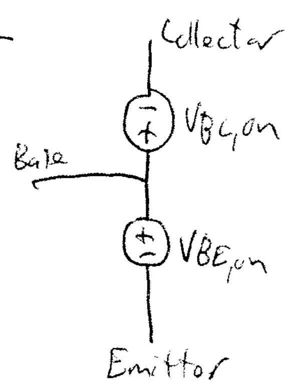


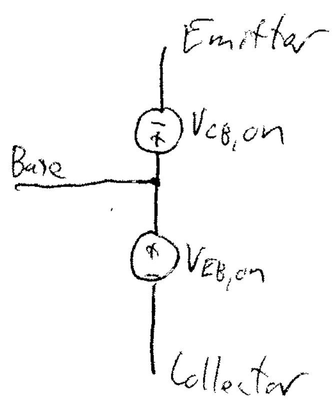
c) Cutoff



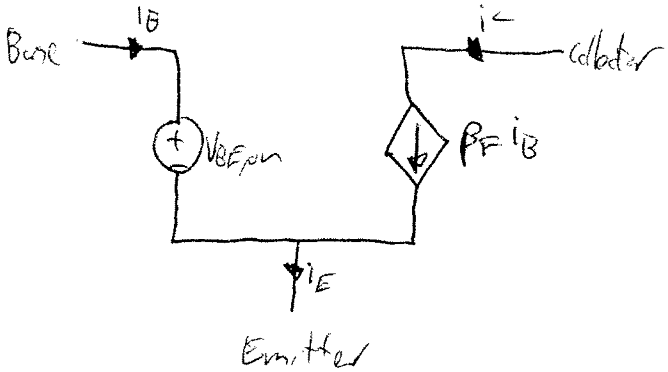


SAT

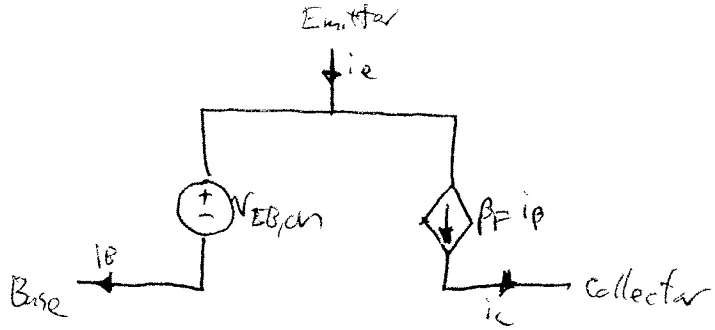




FAR

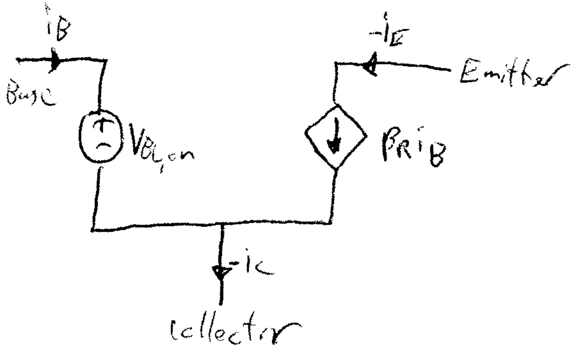


Base
i_B
i_C
Collector
$V_{BE,on}$
$\beta_F i_B$
i_E
Emitter

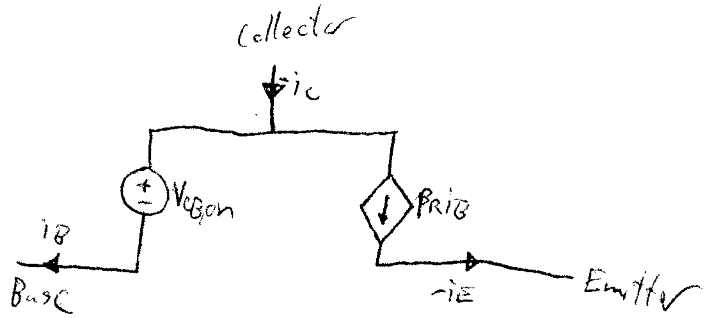


Emitter
i_E
$V_{EB,on}$
$\beta_F i_B$
i_B
Base
Collector
i_C

RAR

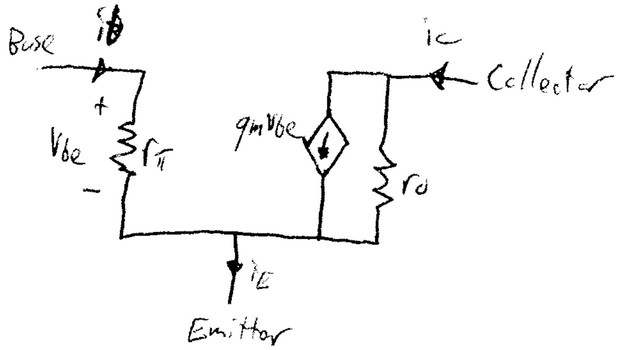


i_B
Base
$-i_E$
Emitter
$V_{BC,on}$
$\beta_R i_B$
$-i_C$
Collector

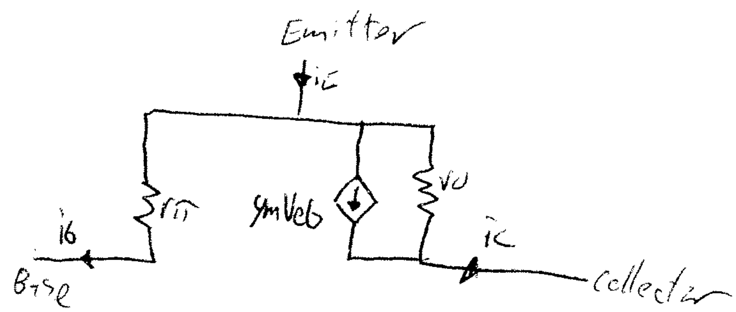


Collector
i_C
$V_{CB,on}$
$\beta_R i_B$
i_B
Base
$-i_E$
Emitter

d)

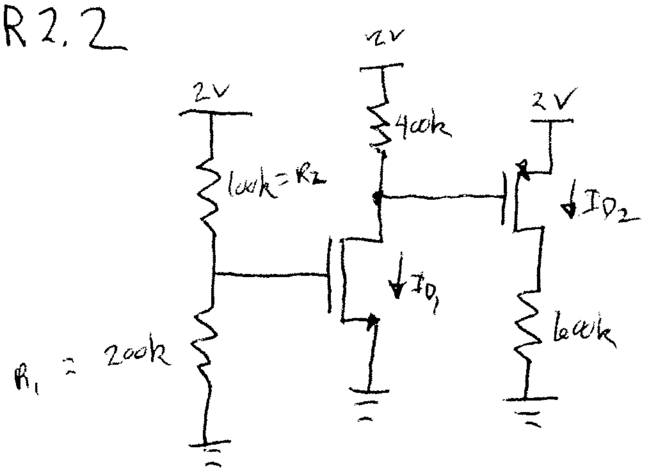


Base
i_B
i_C
Collector
+
V_{be}
−
r_π
$g_m V_{be}$
r_o
i_E
Emitter



Emitter
i_E
r_π
$g_m V_{eb}$
r_o
i_B
Base
i_C
Collector

R2.2



$V_{Tn} = 1V$

$V_{Tp} = -1V$

$K_n = 60\mu A/V^2$

$K_p = 40\mu A/V^2$

Assume SAT for Both

$$I_{D_1} = \frac{V_{DD} - V_{D_1}}{400k} = \frac{1}{2} K_n (V_{gs_1} - V_{TN})^2 \qquad V_{gs_1} = V_{DD} \frac{R_1}{R_1 + R_2}$$

$$I_{D_2} = \frac{V_{D_2}}{600k} = \frac{1}{2} K_p (V_{gs_2} - V_{Tp})^2 \qquad V_{gs_2} = V_{D_1} - V_{DD}$$

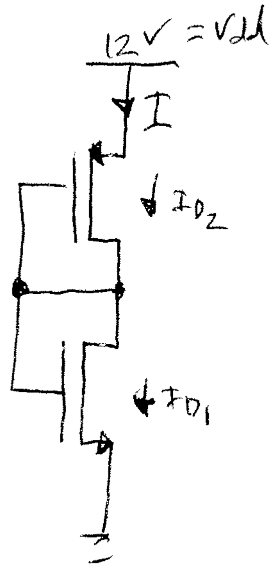
$V_{D_1} = 0.6667V = V_{DS_1}$ $\qquad$ $V_{gs_1} = 1.333V$

$V_{D_2} = 1.333\ V \longrightarrow V_{DS_2} = V_{D_2} - V_{DD} = -0.6667V$ $\qquad$ $V_{gs_2} = -1.333V$

$V_{DS_1} \geq V_{gs_1} - V_{TN}$ ✓ $\qquad$ $V_{DS_2} \leq V_{gs_2} - V_{Tp}$ ✓

$\boxed{I_{D_1} = 3.333\mu A}$ $\qquad$ $\boxed{I_{D_2} = 2.222\mu A}$

R2.3



$V_{TN} = 1V$

$V_{TP} = -1V$

$K_n = 60 \mu A/V^2$

$K_p = 40 \mu A/V^2$

Both Gates connected to Drains $\rightarrow$ Both always in SAT

$$I_{D_1} = I_{D_2} = I$$

$$K_n(V_{gs_1} - V_{TN})^2 = K_p(V_{gs_2} - V_{Tp})^2$$

$$\downarrow$$

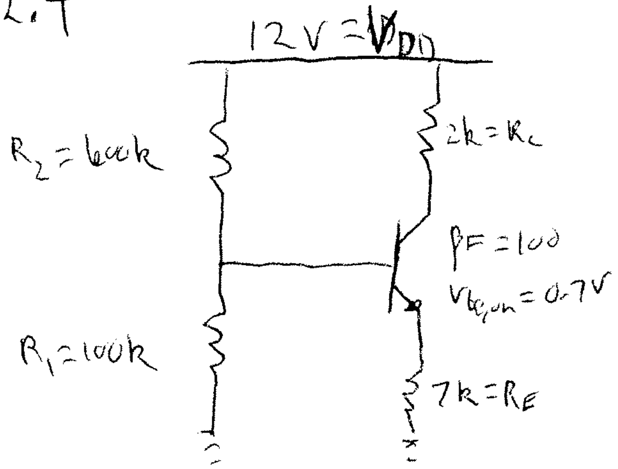
$$V_{gs_2} = V_{gs_1} - V_{DD}$$

$$V_{gs_1} = \frac{K_n \cdot V_{TN} \pm \sqrt{K_n K_p}(Vdd - V_{TN} + V_{Tp}) - K_p(Vdd + V_{Tp})}{K_n - K_p}$$

$$= \boxed{5.4949V} \text{ or } \cancel{-43.4949 V}$$

$$I = \frac{1}{2}K_n(V_{gs_1} - V_{TN})^2 = \boxed{606.12 \mu A}$$

R2.4



$\beta_F \uparrow 10\%$

$$\% \text{ Error } I_C = \left| \frac{I_{C\,change} - I_{C\,nom}}{I_{C\,nom}} \right| = \frac{\Delta I_C}{I_{C\,nom}}$$

1st way

$$\text{KVL} \longrightarrow I_C = \beta_F \frac{V_{DD}\frac{R_1}{R_1+R_2} - V_{BE,on}}{R_1 // R_2 + (\beta_F+1)R_E}$$

$\to \beta_F = 100 \to I_C = 127.95\,\mu A$

$\to \beta_F \approx 110 \to I_C = 129.37\,\mu A$

$\% \text{ Error } I_C = 1.0747\%$

$R_E = 0$

$\to \beta_F = 100 \to I_C = 1.183\,mA$

$\to \beta_F = 110 \to I_C = 1.302\,mA$

$\% \text{ Error } I_C = 10.1\%$

2nd way

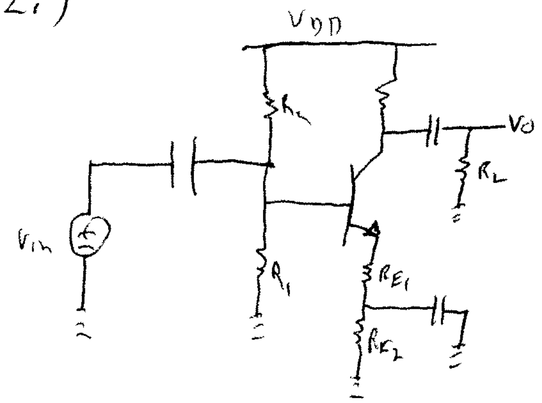
$$\frac{\partial I_C / \partial \beta_F}{I_{C\,nom}} = \frac{\Delta I_C / \Delta \beta_F}{I_{C\,nom}} \approx \frac{1}{\beta_F}\left(1 - \frac{I_C R_E}{I_B R_1 // R_2 + I_C R_E}\right) \approx \frac{\% \text{ Error } I_C}{\% \text{ Error } \beta_F} \cdot \frac{1}{\beta_F}$$

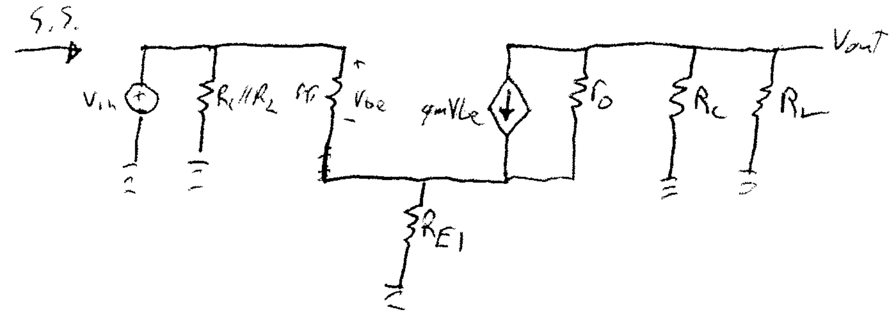
$R_E = 7k \longrightarrow \% \text{ Error } I_C \approx 1.0813\%$

$R_E \approx 0 \longrightarrow \% \text{ Error } I_C \approx \% \text{ Error } \beta_F \approx 10\%$

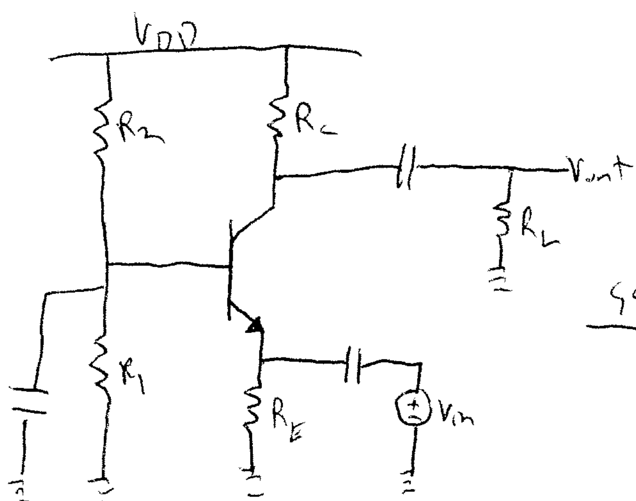
R 2.5

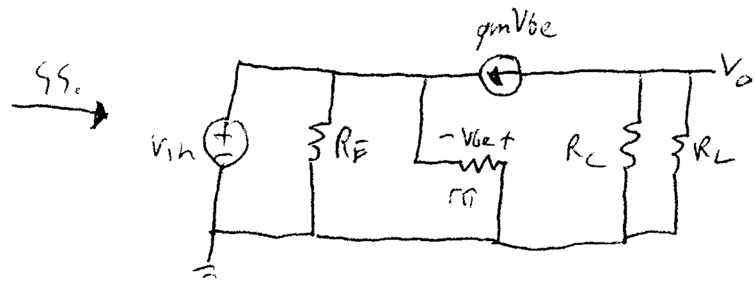
a)





b)





R 2.6

$$V_o = -g_m V_{be} \cdot R_C // R_L$$

$$= g_m V_{in} R_C // R_L$$

$$\frac{V_o}{V_{in}} = +g_m R_C // R_L$$