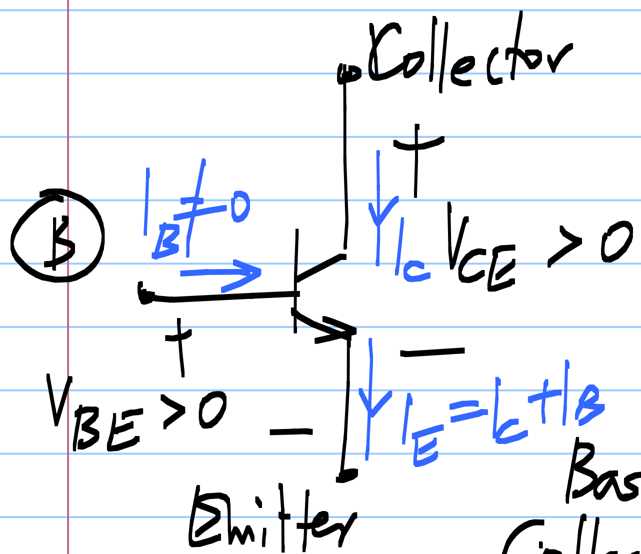
$$G_{m_2} - sC_3 \rightarrow G_{m_2} - \frac{sC_3}{1+sC_3R_3}$$

$$R_3 = \frac{1}{G_{m_2}}$$

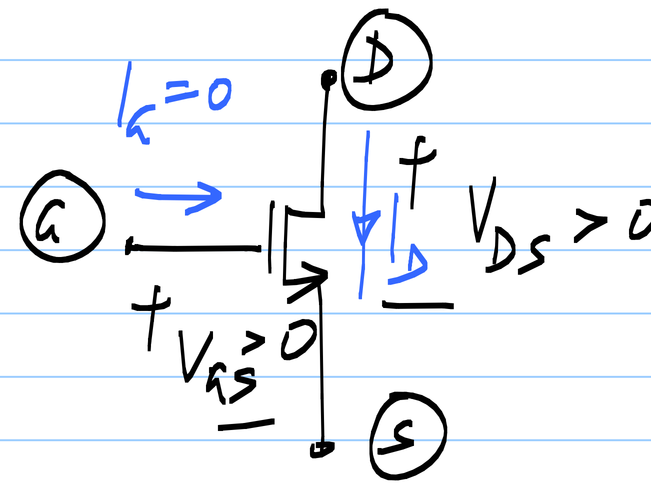
$$= \frac{\left[G_{m_2} + sC_3\left(G_{m_2}R_3 - 1\right)\right]}{\cancel{\left(1+sC_3R_3\right)}}$$

Bipolar junction transistor (BJT)

NPN

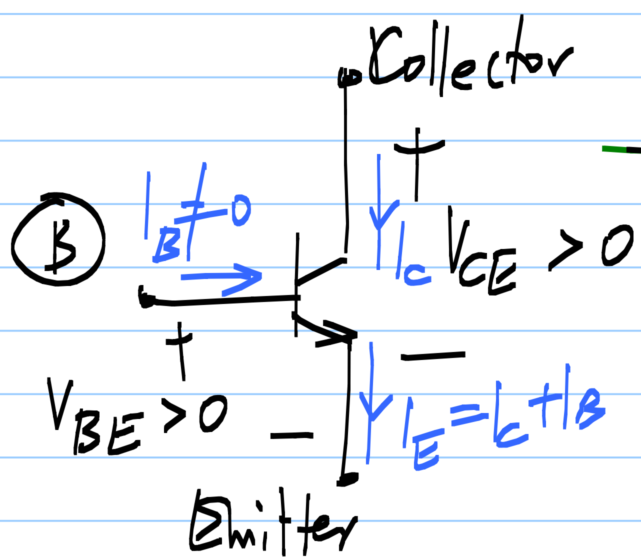


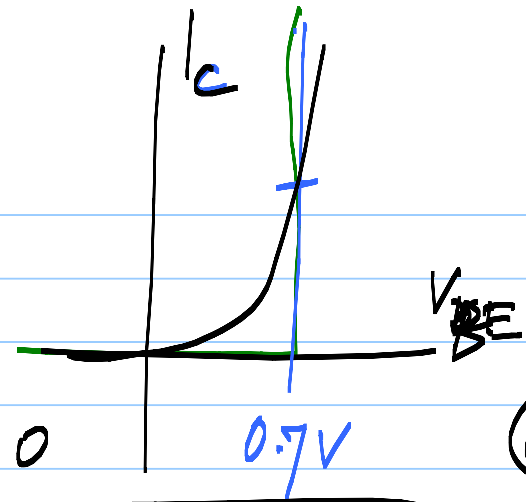
nMOS



Base ⟷ Gate
Collector ⟷ Drain
Emitter ⟷ Source

NPN





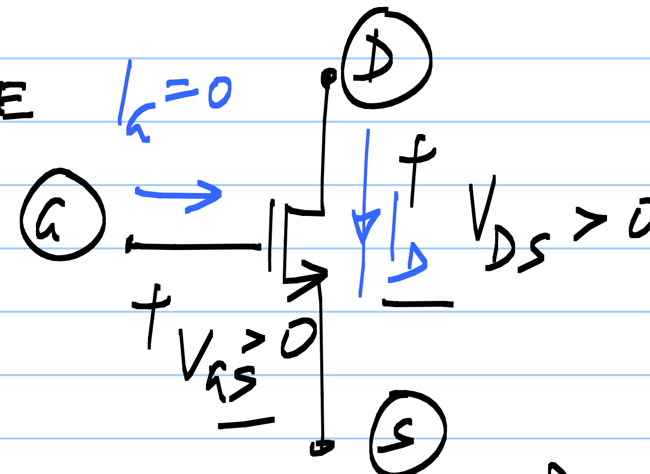
$$\boxed{V_{BE,on} = 0.7V}$$

$$I_C \simeq I_S \exp\left(\frac{V_{BE}}{V_t}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

Active region

$$V_{CE} > V_{CE,sat} = \underline{\underline{V_{BE,on} = 0.7V}}$$

nMOS



$$\underline{\underline{I_D = \frac{\mu C_{ox}}{2} \frac{W}{L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS})}}$$

Sat. region

$$V_{DS} > V_{GS} - V_T$$

$$I_B = \frac{I_C}{\beta} \qquad \beta \gg 1 \quad \sim 100$$

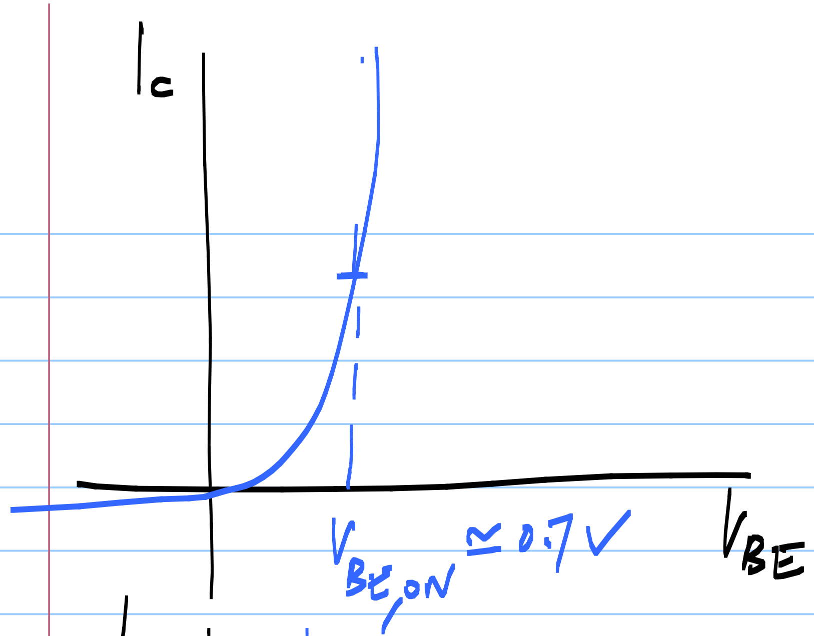
[For op. points, $\beta = \infty$]
i.e. $I_B = 0$

$$I_C = I_S \exp\left(\frac{V_{BE}}{V_t}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

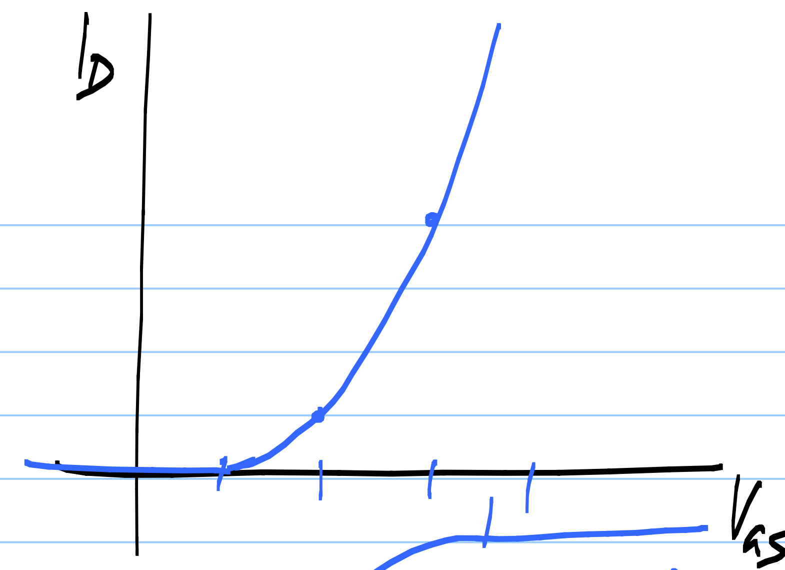
Saturation current

$$V_t = \frac{kT}{q} \simeq 25.9\,mV \text{ @ } 300K$$
$$\simeq 25\,mV$$

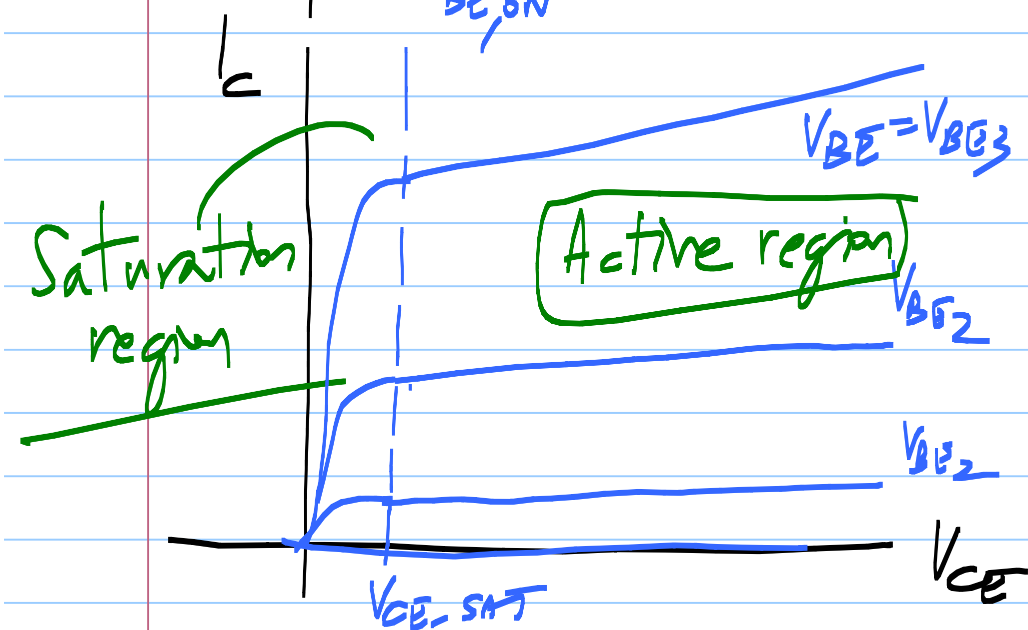
Early voltage



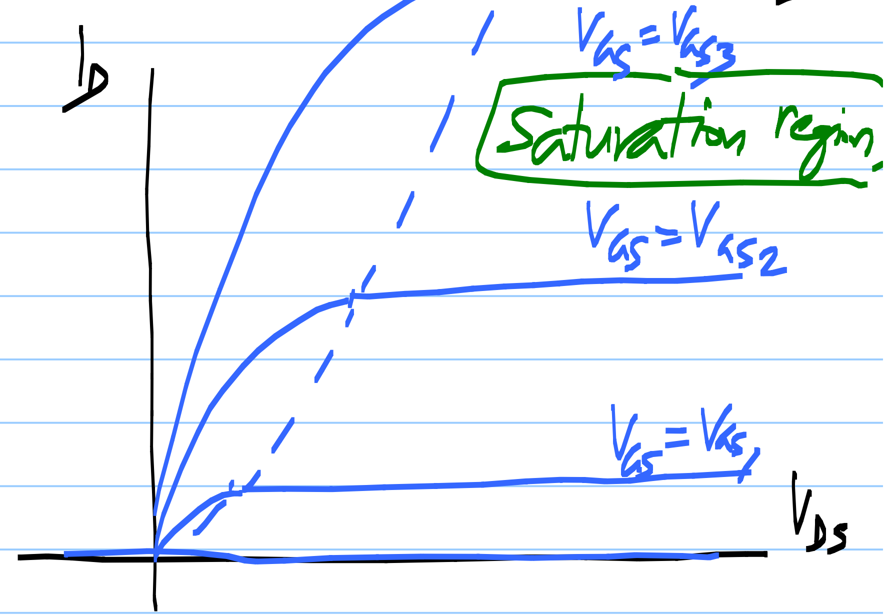
I_c
$V_{BE,ON} \simeq 0.7V$
V_{BE}



I_D
V_{GS}

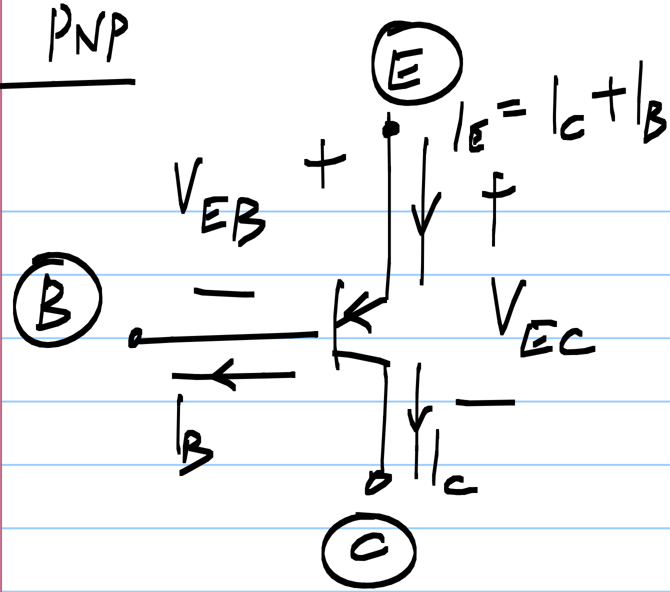


I_c
Saturation region
Active region
$V_{BE} = V_{BE3}$
V_{BE2}
V_{BE2}
V_{CE}
$V_{CE,SAT}$

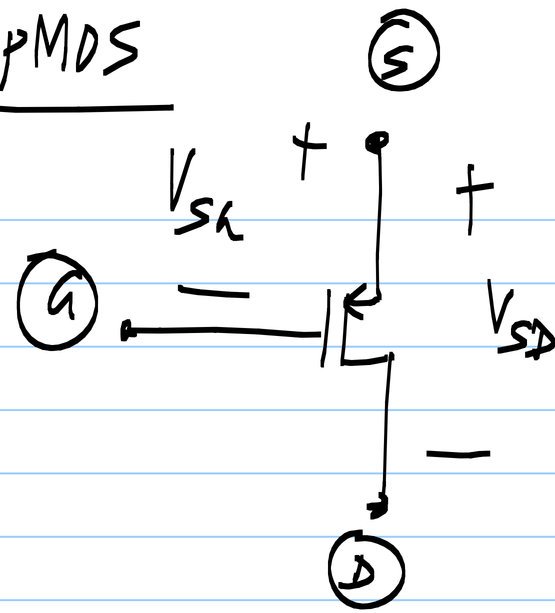


I_D
$V_{GS} = V_{GS3}$
Saturation region
$V_{GS} = V_{GS2}$
$V_{GS} = V_{GS1}$
V_{DS}

PNP



pMOS



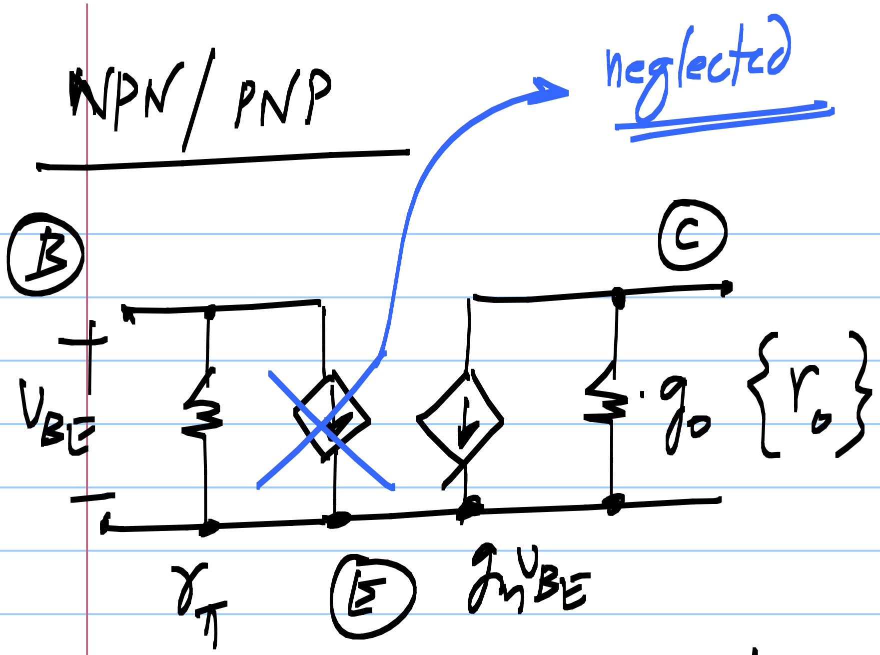
$$I_C = I_S \exp\left(\frac{V_{EB}}{V_t}\right)\left(1 + \frac{V_{EC}}{V_A}\right)$$

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

(Active region)

$V_{EB,ON} \simeq 0.7V$; $V_{EC} > V_{EC,SAT} \simeq 0.7V$

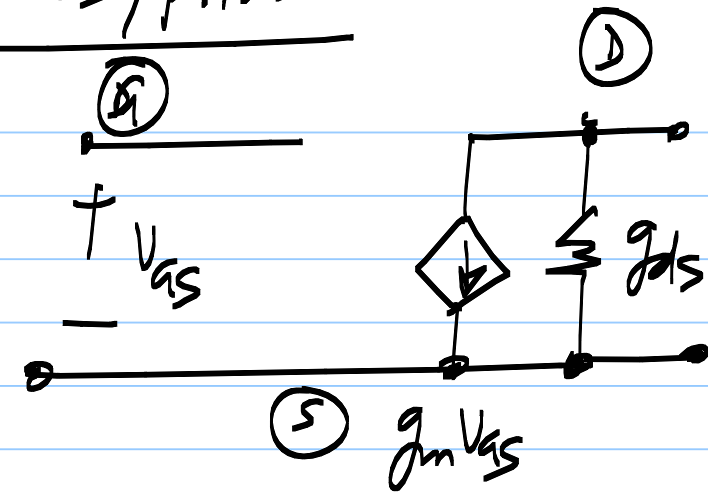
NPN / PNP



$$g_m = \frac{I_c}{V_t} \; ; \; g_o = \frac{I_C}{V_A} = \frac{1}{r_o}$$

$$\frac{1}{r_\pi} = \frac{g_m}{\beta} \qquad \boxed{r_\pi = \frac{\beta}{g_m}}$$

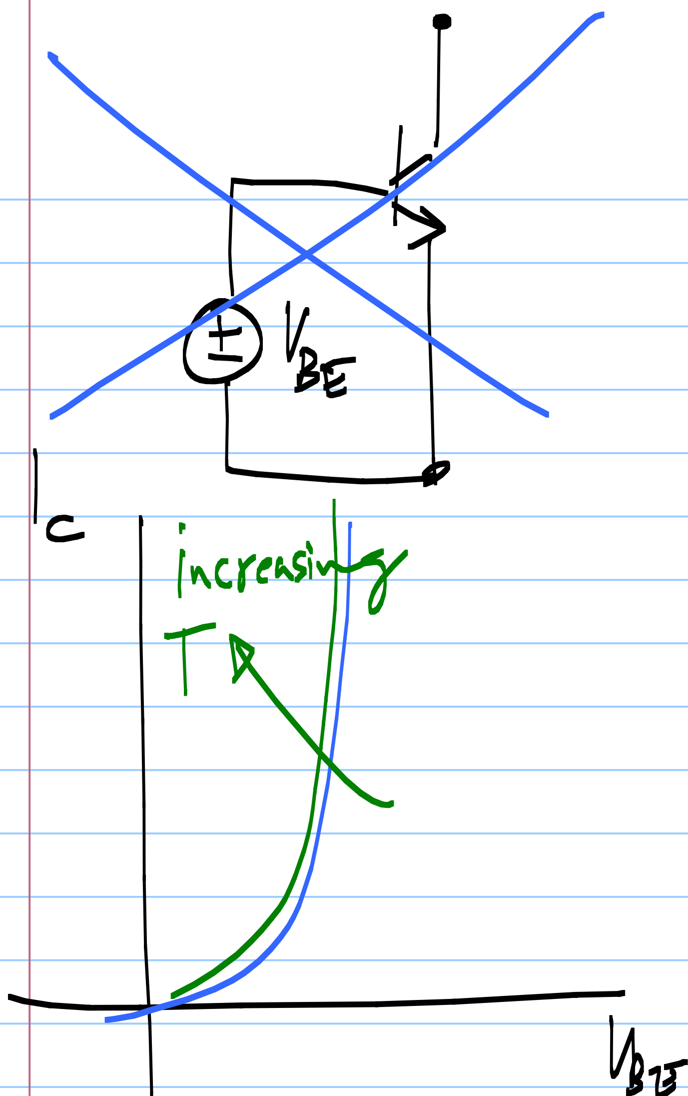
nMOS / pMOS



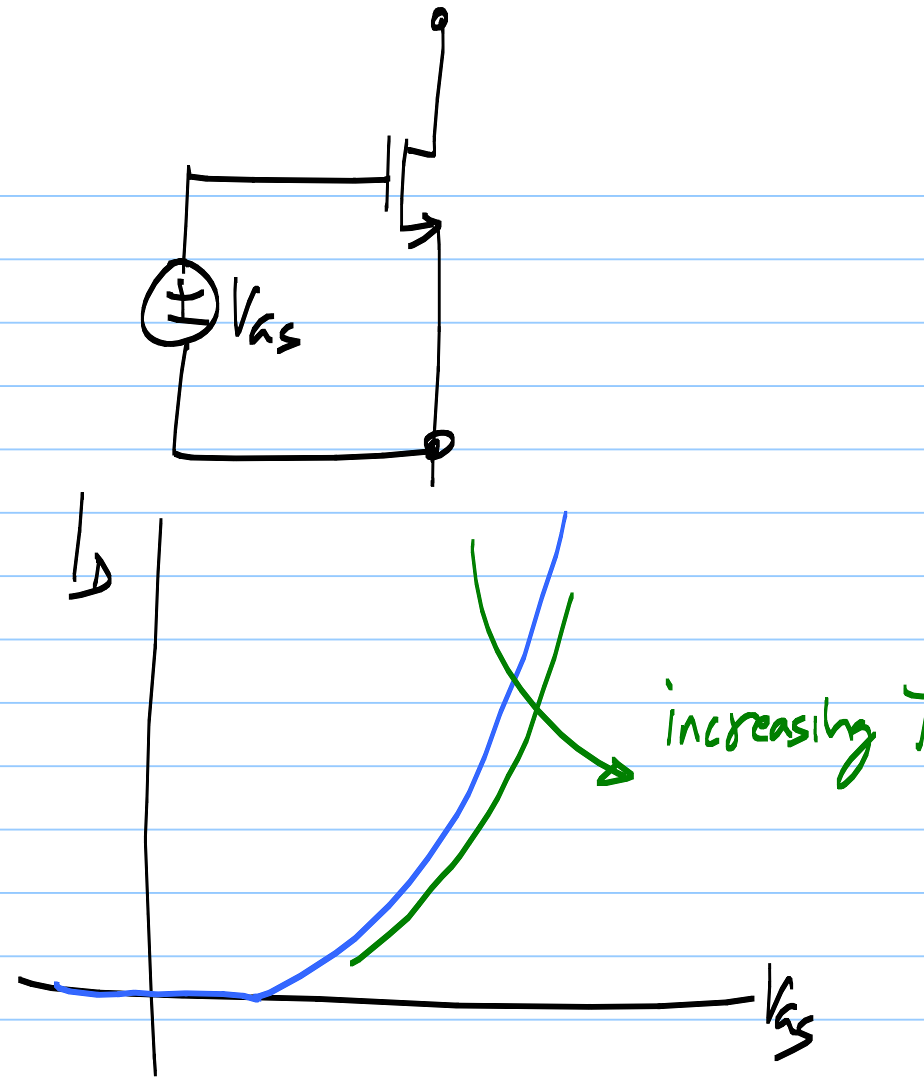
$$g_m = \mu C_{ox} \frac{W}{L} (V_{GS} - V_T)$$

$$= \frac{2 I_D}{V_{GS} - V_T} = \sqrt{2 \cdot \mu C_{ox} \frac{W}{L} I_D}$$

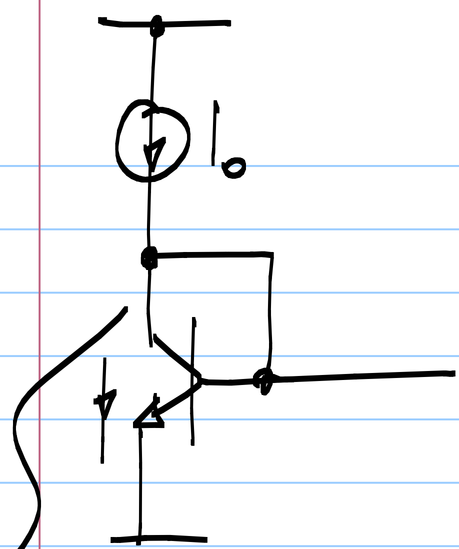
$$g_{ds} = \lambda I_D$$



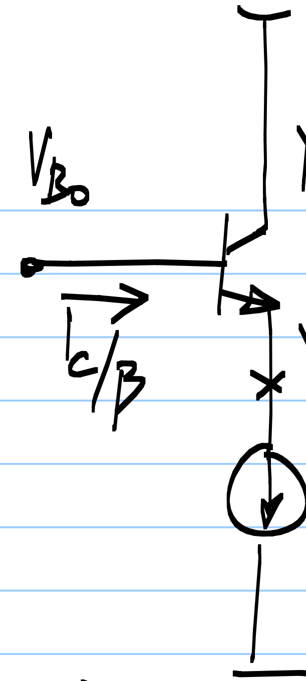
V_{BE}
I_C
increasing T
V_{BE}



V_{GS}
I_D
increasing T
V_{GS}



BJT biased at a fixed current using -ve fb.



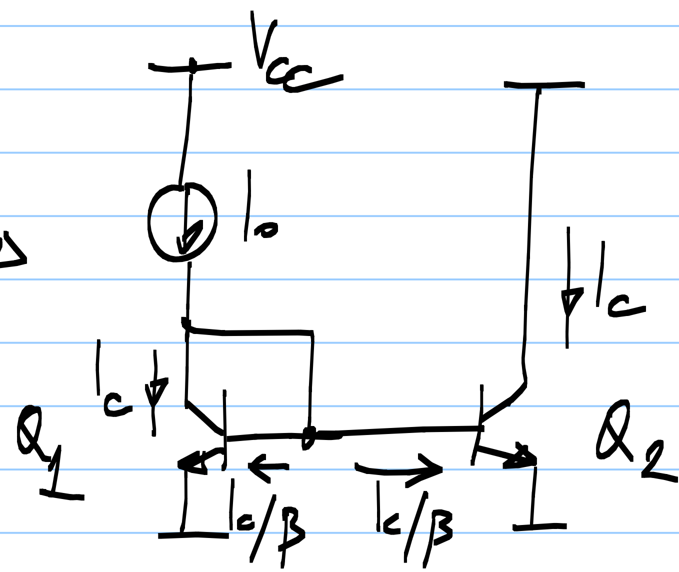
$I_o =$

$I_E = I_c + I_c/\beta$

$$I_c = \frac{I_E}{\underbrace{(1 + 1/\beta)}}$$

$$= \frac{I_o}{(1 + 1/\beta)}$$

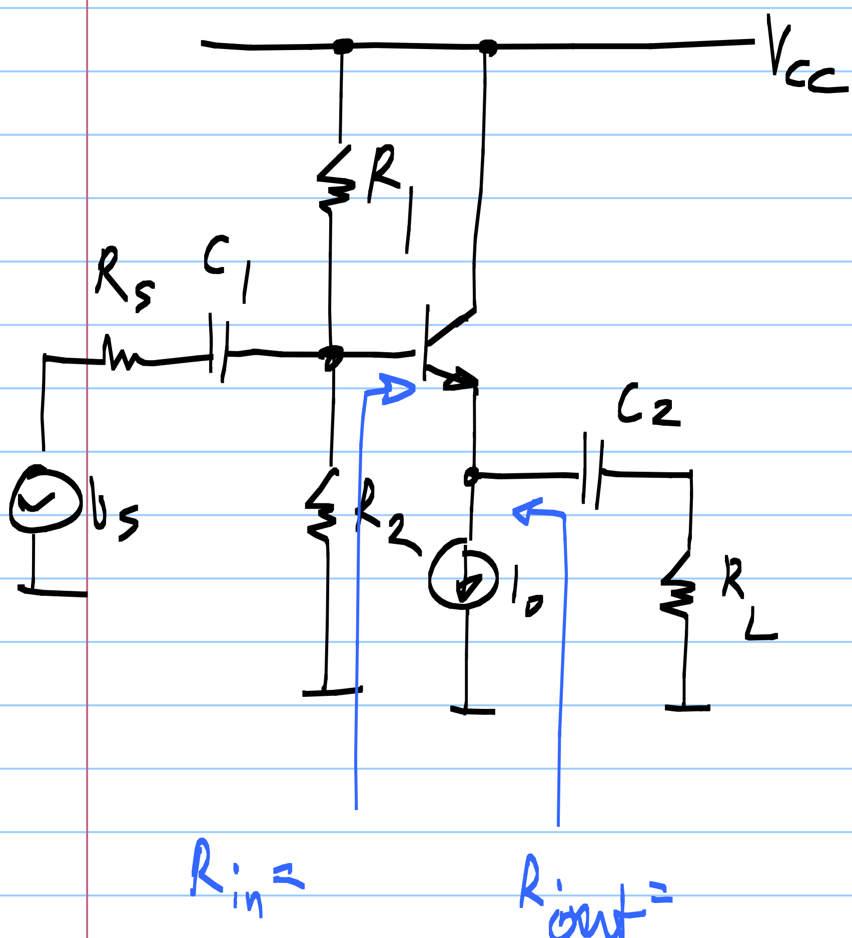
$I_c = \alpha \cdot I_E$

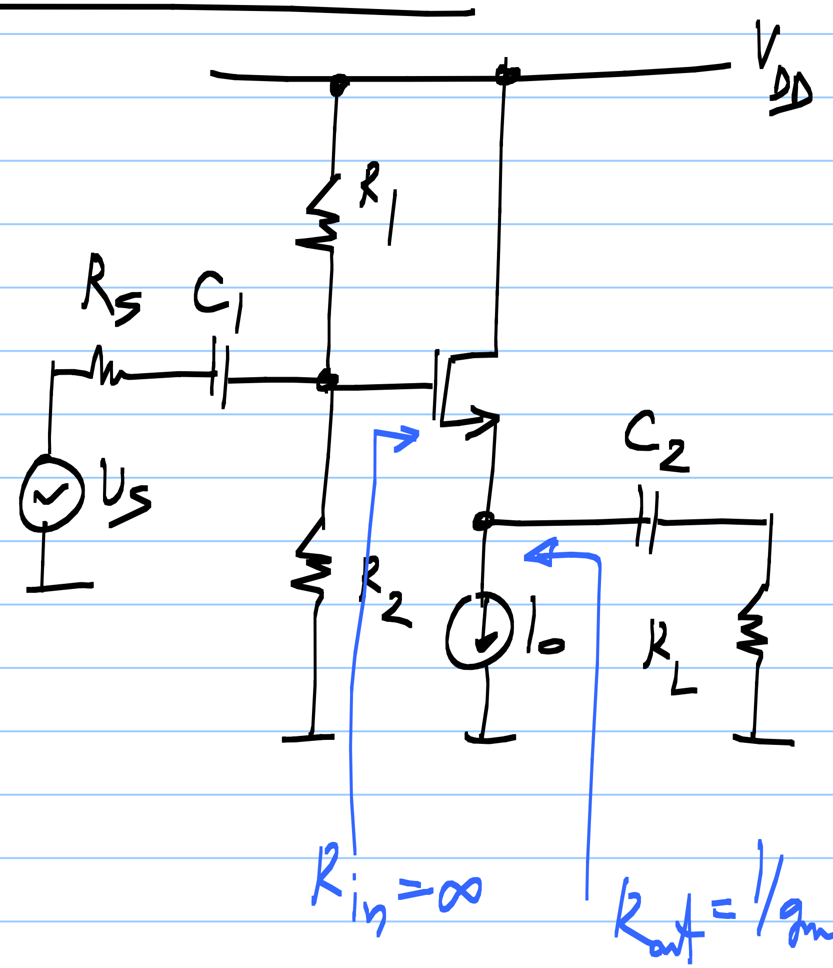


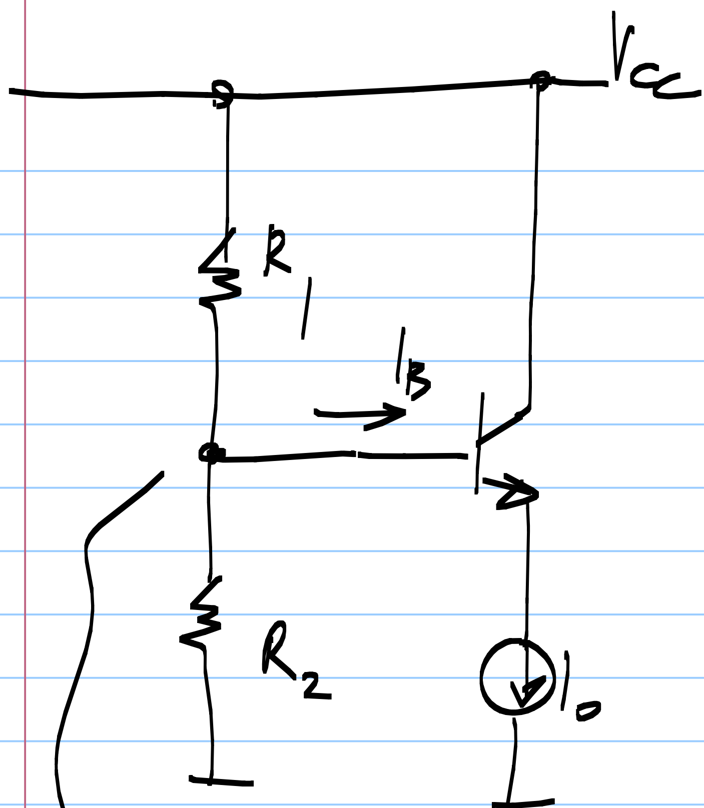
$$I_o = I_c + \frac{2I_c}{\beta}$$

$$I_c = \frac{I_o}{\left(1 + \frac{2}{\beta}\right)}$$

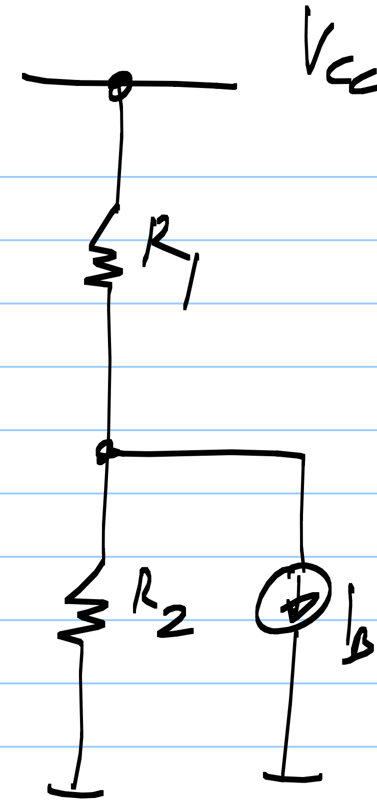
Common-drain amplifier (Collector) —— Emitter follower





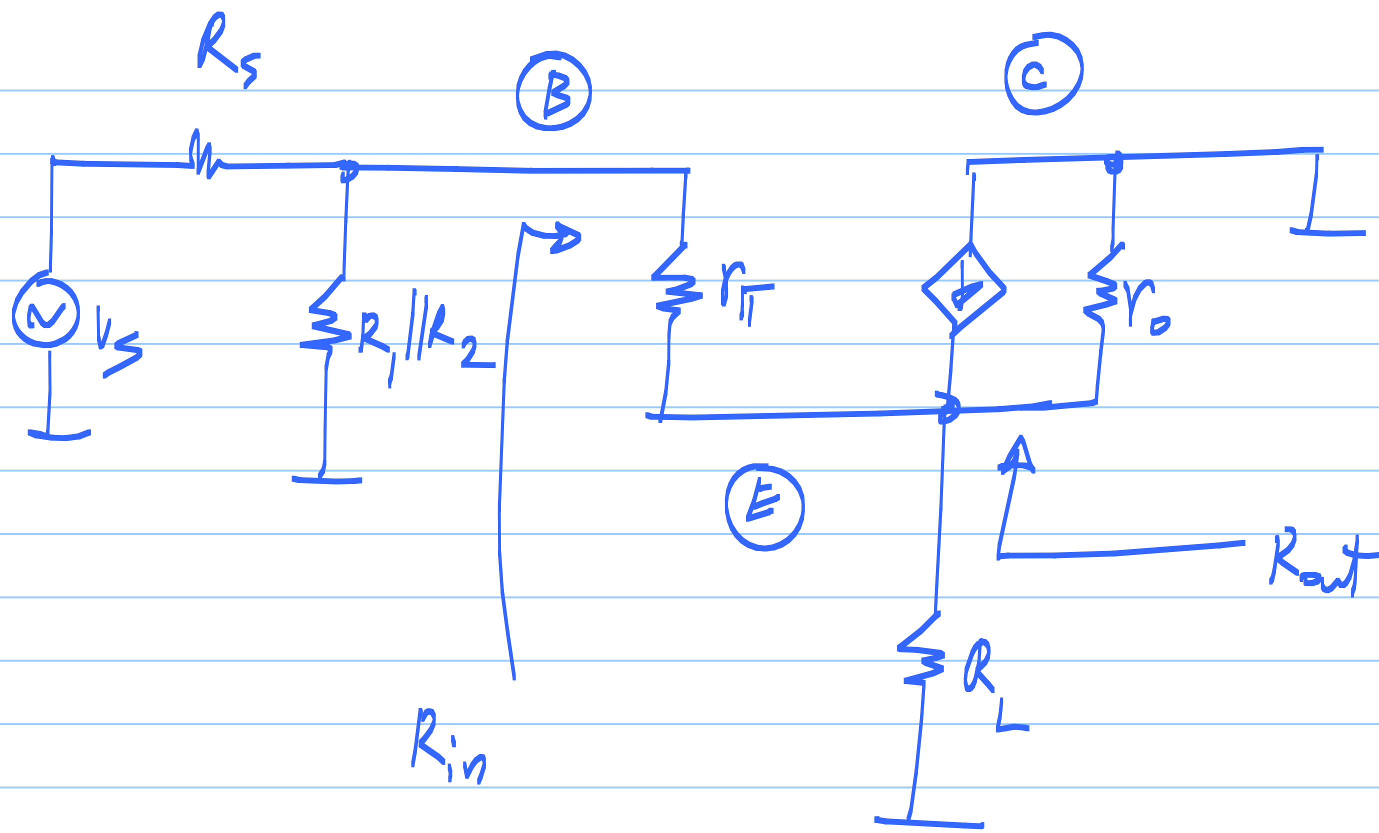


$$I_B = \frac{I_o}{\beta + 1}$$



$$\underbrace{V_{CC}\frac{R_2}{R_1 + R_2} - \underline{\underline{I_B(R_1 \| R_2)}}}$$

has to be small



R_s
B
C
v_s
$R_1 || R_2$
r_π
r_o
E
R_{out}
R_L
R_{in}