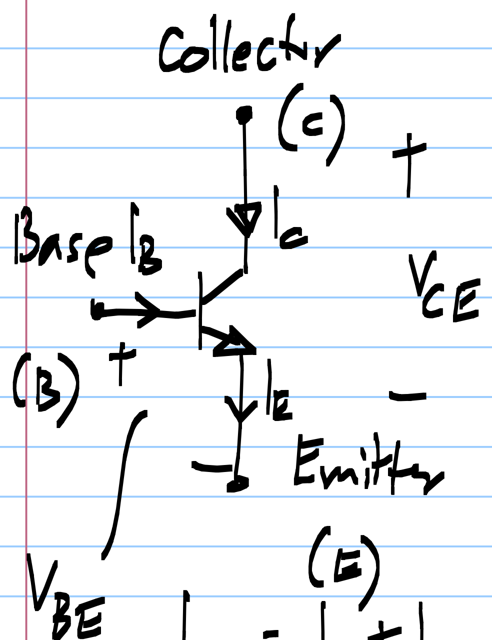
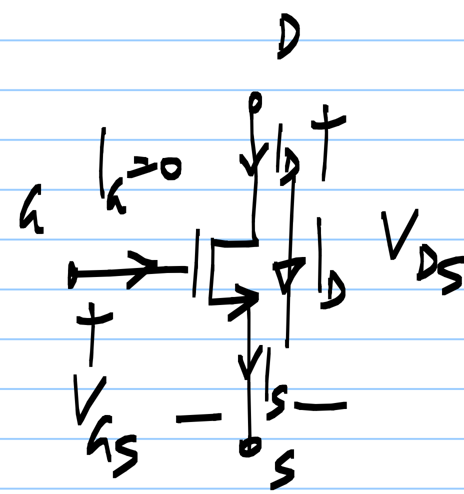
Bipolar junction transistor (BJT)



$$I_E = I_C + I_B$$

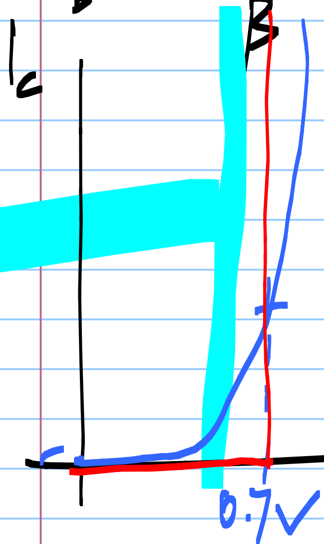


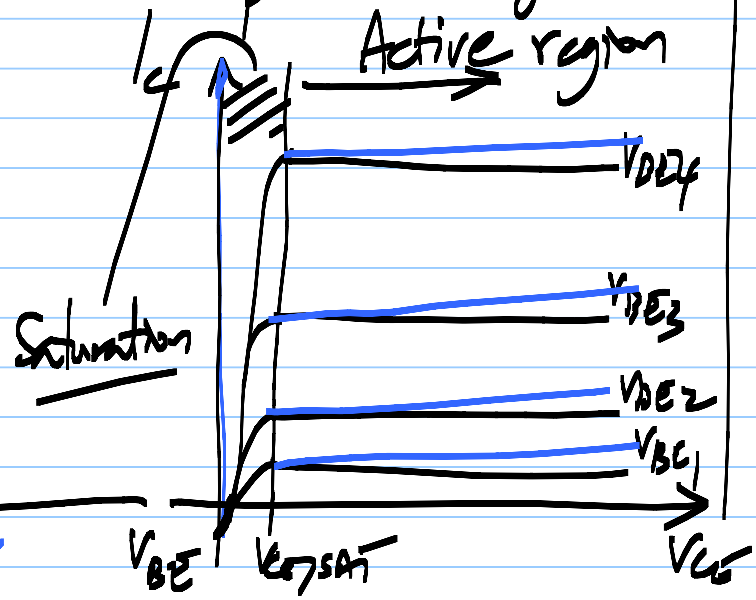
nMOS transistor

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

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

β: current gain



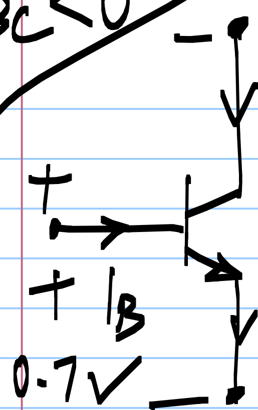


$I_D = \frac{\mu_n C_{ox}}{2}(V_{GS}-V_T)^2 (1+\lambda_n V_{DS})$

$V_{GS} > V_T$,

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

$V_{BC} < 0$



$I_C = I_s \exp\left(\frac{V_{BE}}{V_t}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$ $\Big|$ $V_{CE} > V_{CE,sat}$

$V_{CE} > 0.7V$ $I_B = \frac{I_C}{\beta}$

0.2V

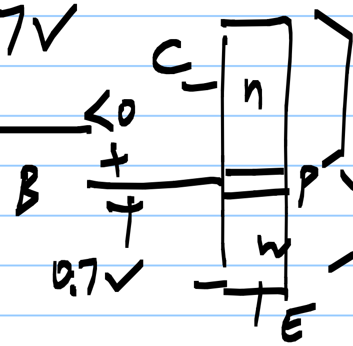
$V_{CE,sat} = V_{BE,on}$

$= 0.7V$

$I_E = I_C + I_B$

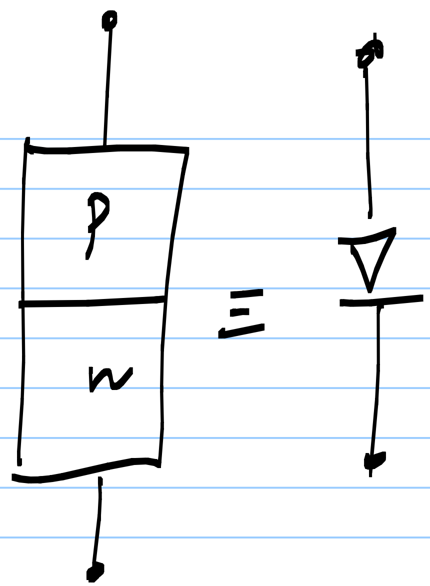
op. Point calculation:

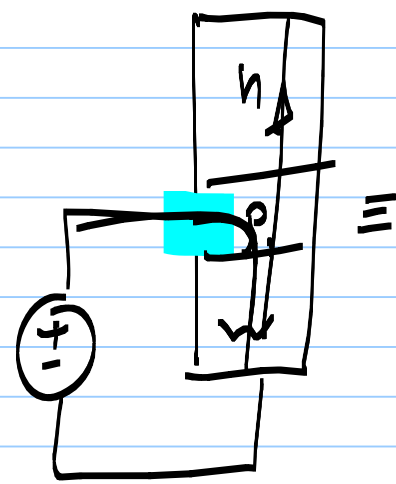
$V_{BE,on} = 0.7V$



CB jn: rev. biased

B-E jn fwd biased


p
n
≡


+
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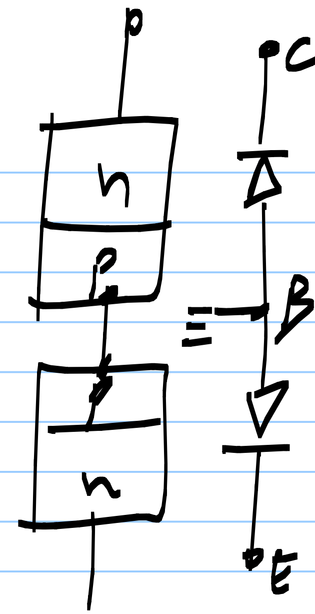
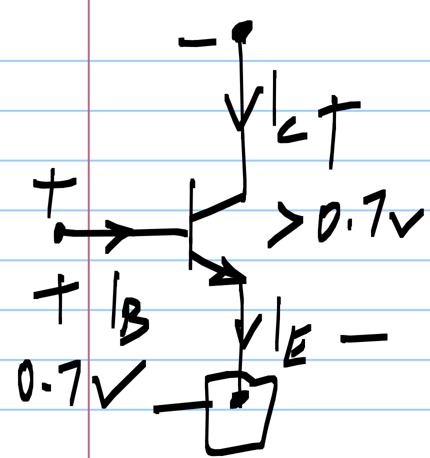
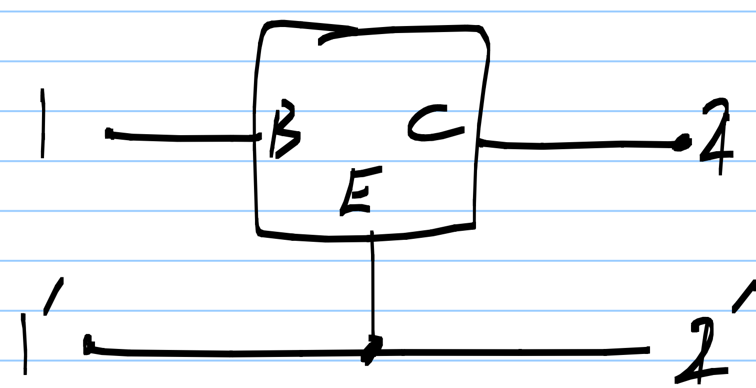

n
p
n
≡
C
B
E

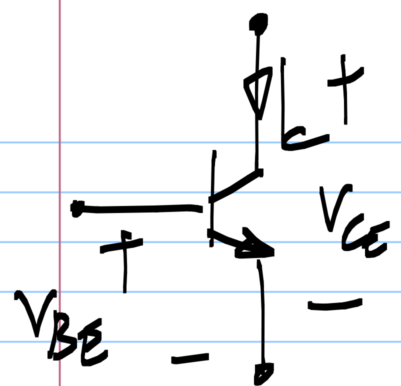


$$I_C = I_S \exp\left(\frac{V_{BE}}{V_t}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

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

$y_{11}, y_{12}, y_{21}, y_{22}$





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

$$\frac{\partial I_c}{\partial V_{BE}} = \frac{I_s}{V_t}\exp\left(\frac{V_{BE}}{V_t}\right)\cdot\left(1 + \frac{V_{CE}}{V_A}\right)$$

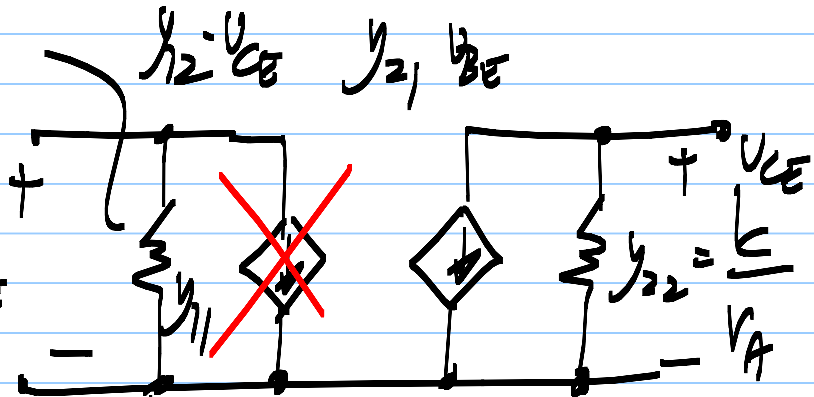
kT/q Thermal voltage

Early voltage

$$\frac{\partial I_c}{\partial V_{BE}} = \frac{I_c}{V_t}, \quad \frac{\partial I_c}{\partial V_{CE}} = \underbrace{I_s \exp\left(\frac{V_{BE}}{V_t}\right)}\cdot\frac{1}{V_A} \approx \frac{I_c}{V_A}$$

$$\frac{\partial I_B}{\partial V_{BE}} = \frac{1}{\beta}\frac{\partial I_C}{\partial V_{BE}} = \frac{I_C}{\beta V_t}, \qquad \frac{\partial I_B}{\partial V_{CE}} = \frac{1}{\beta}\frac{\partial I_C}{\partial V_{CE}} = \frac{I_C}{\beta V_A}$$

$$r_\pi = \frac{\beta V_t}{I_C} = 1/y_{11}$$

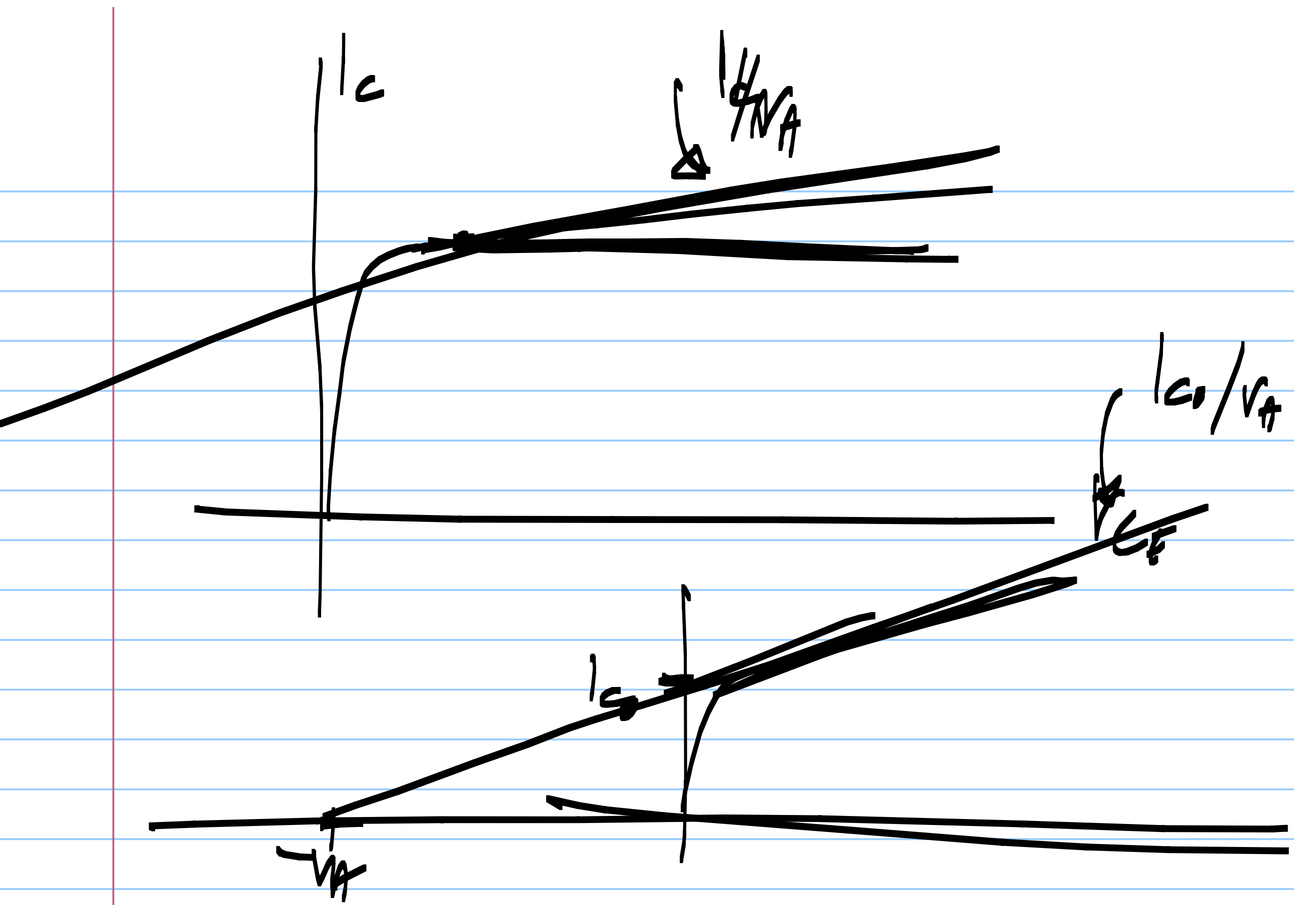


$$y_{22} = \frac{I_C}{V_A}$$

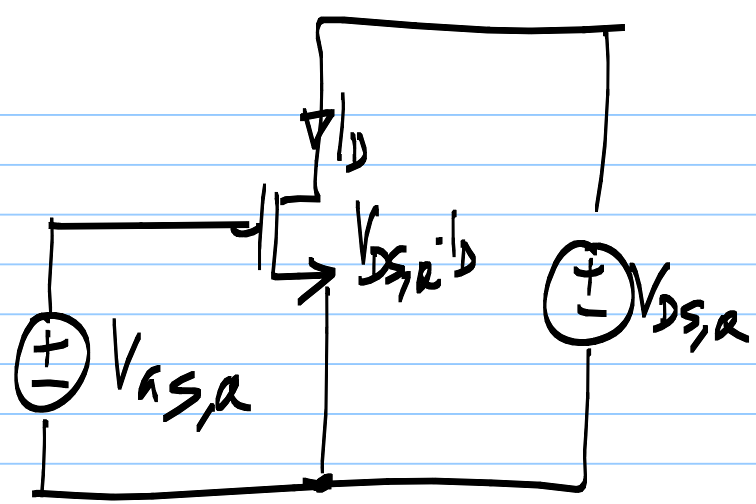
$$g_m = y_{21} = \frac{I_C}{V_t}$$

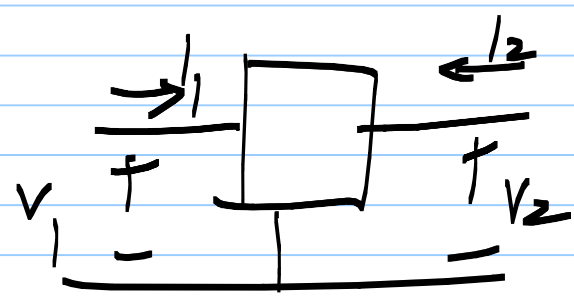
$$r_o = \frac{1}{y_{22}} = \frac{V_A}{I_C}$$

$$y_{12} = \frac{I_C}{\beta V_A} \qquad y_{11} = \frac{I_C}{\beta V_t} \qquad y_{21} = \frac{\partial I_C}{\partial V_{BE}}$$

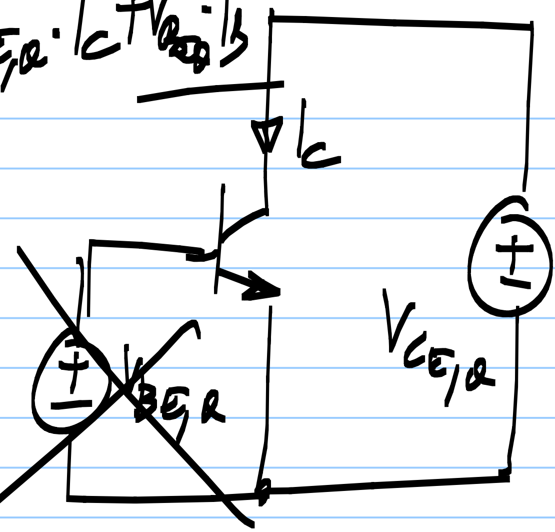


I_C
Δ
I_C/V_A
I_{C0}/V_A
V_{CE}
I_{C0}
$-V_A$





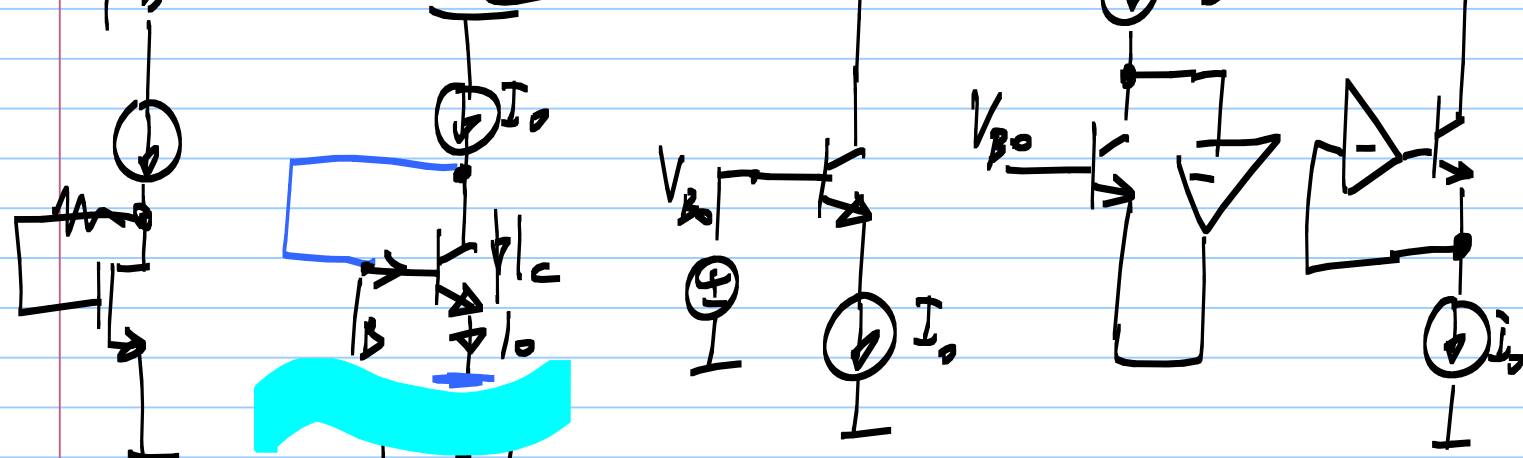
$V_{CE,Q} \cdot I_C + V_{BE,Q} \cdot I_B$



$\underbrace{I_s \exp\left(\frac{V_{BE}}{V_t}\right)}$

Const. current biasing:

Sense	collector	emitter	Collector	emitter
fb.	base	emitter	emitter	base

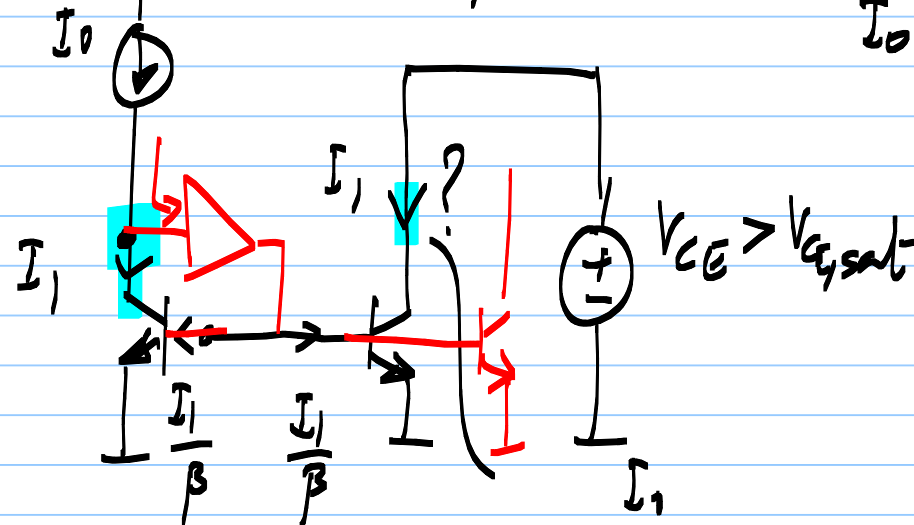


$I_E = I_0$

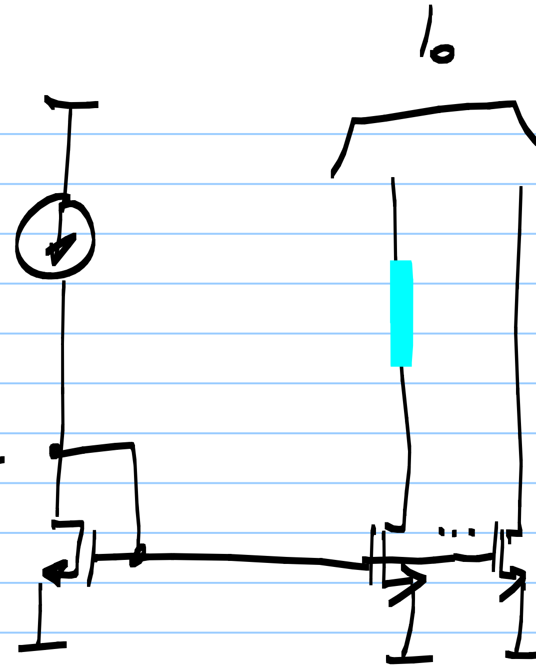
$I_C = \left(\frac{\beta}{1+\beta}\right) I_0 = \underline{\underline{\alpha I_0}}$

Collector feedback b'm :

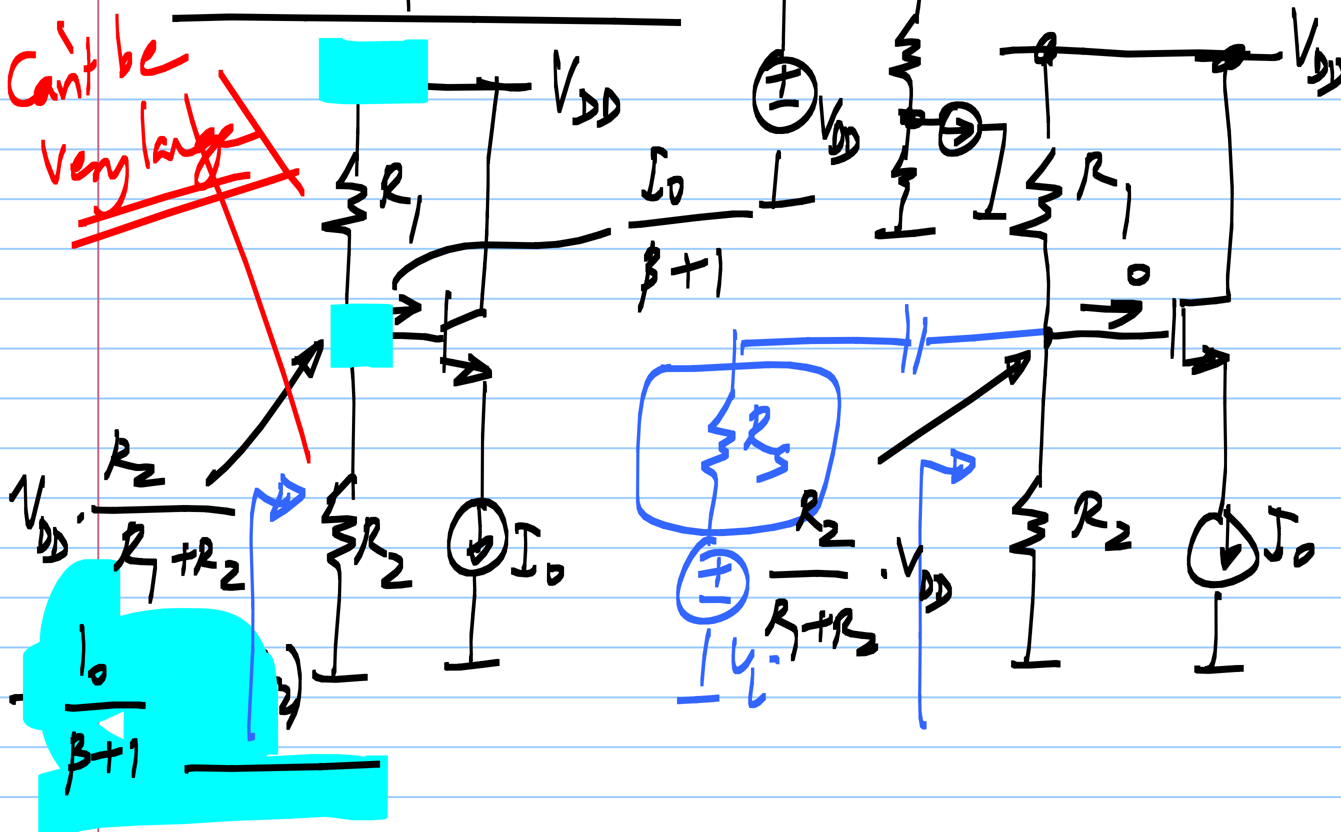
$$I_0 = I_1 + \frac{2I_1}{\beta}$$



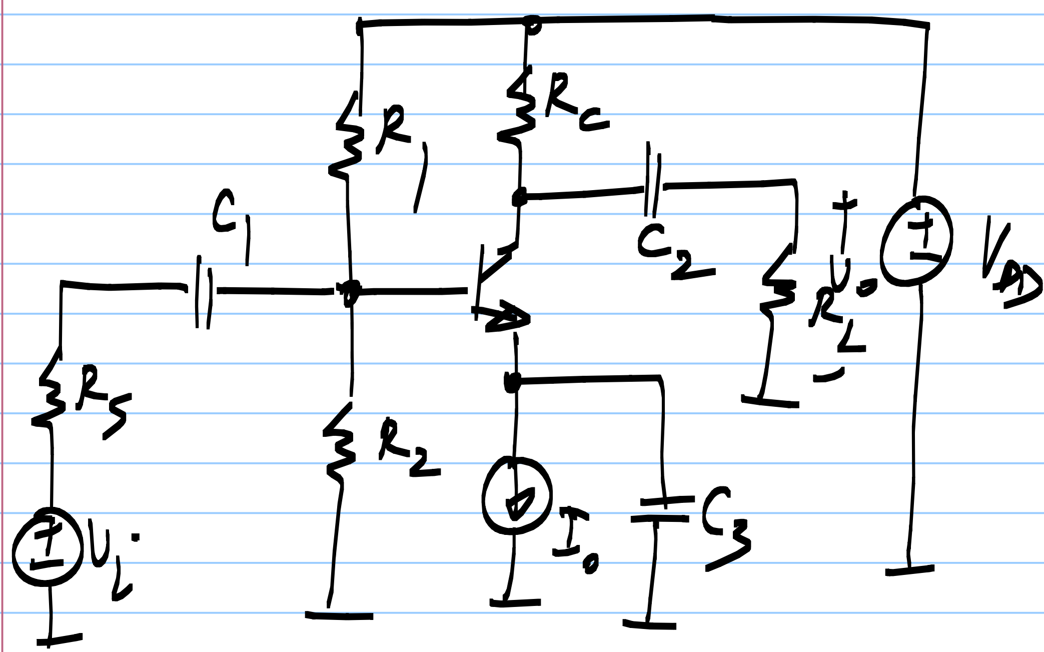
$$I_1 = \frac{I_1}{1 + 2/\beta}$$



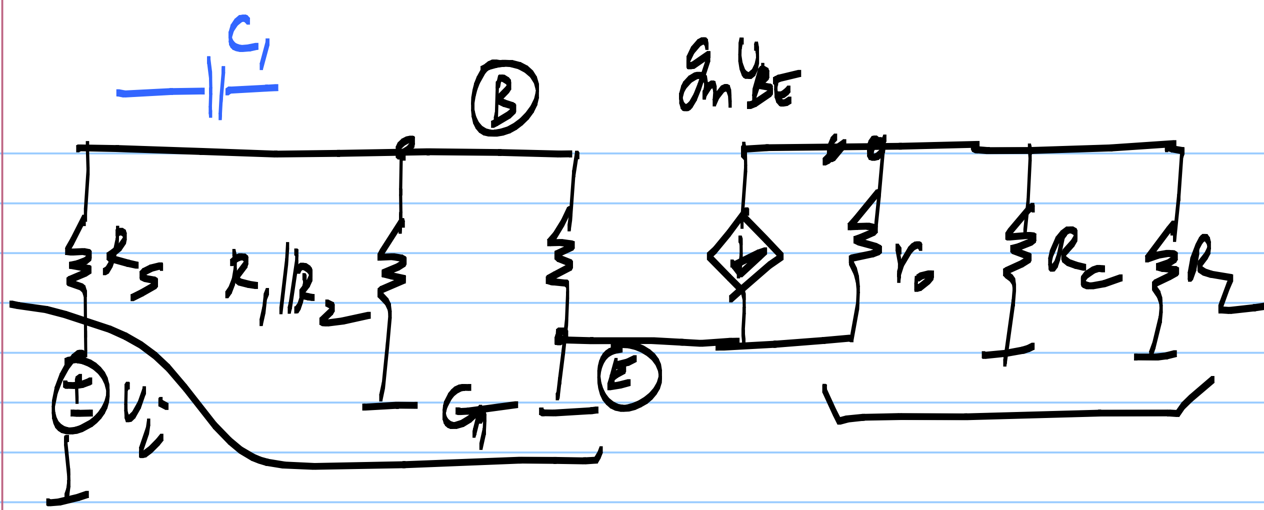
Emitter feedback



Bipolar Common Emitter amplifier

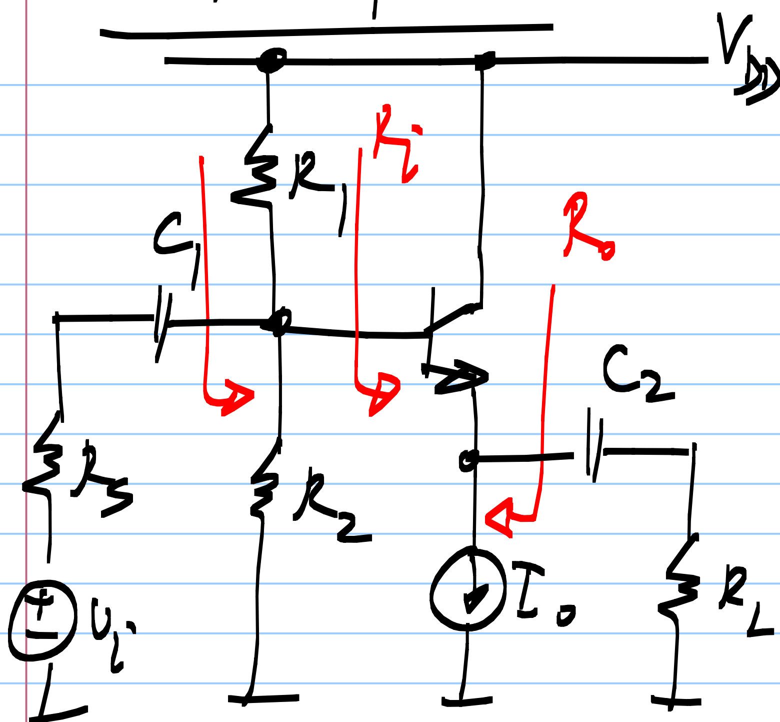


$$\frac{v_o}{v_i} =$$



$$\frac{v_o}{v_i} = -g_m \left(R_C || R_L || r_o\right) \cdot \frac{R_1 || R_2 || r_\pi}{R_1 || R_2 || r_\pi + R_S}$$

Emitter follower



Find R_i & R_o [neglect r_o]

MOS

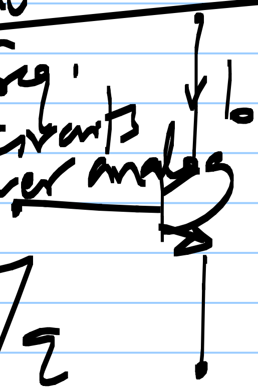
$R_i = \infty$

$R_o = 1/g_m$

Higher g_m for a given current

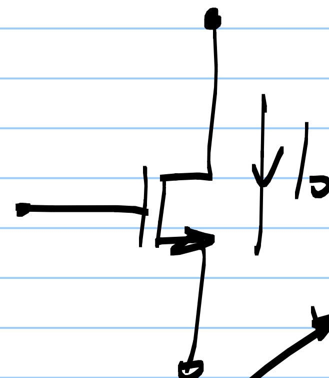
+ high freq. circuits

+ Low power analog circuits



$V_t = kT/q$

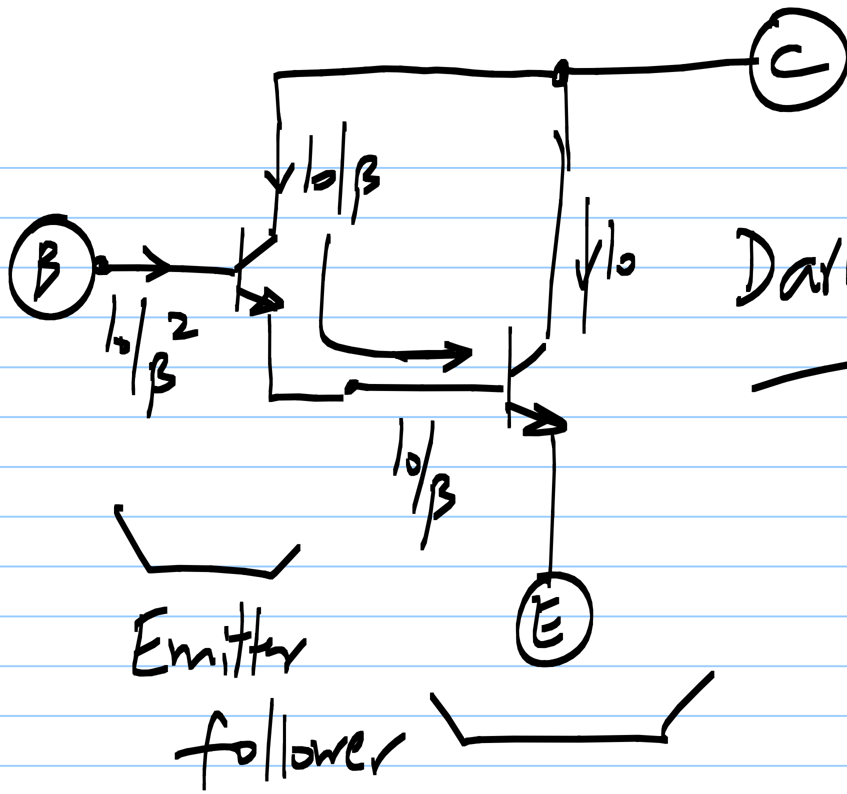
$$g_m = \frac{I_0}{V_t} = \frac{I_D}{25mV}$$



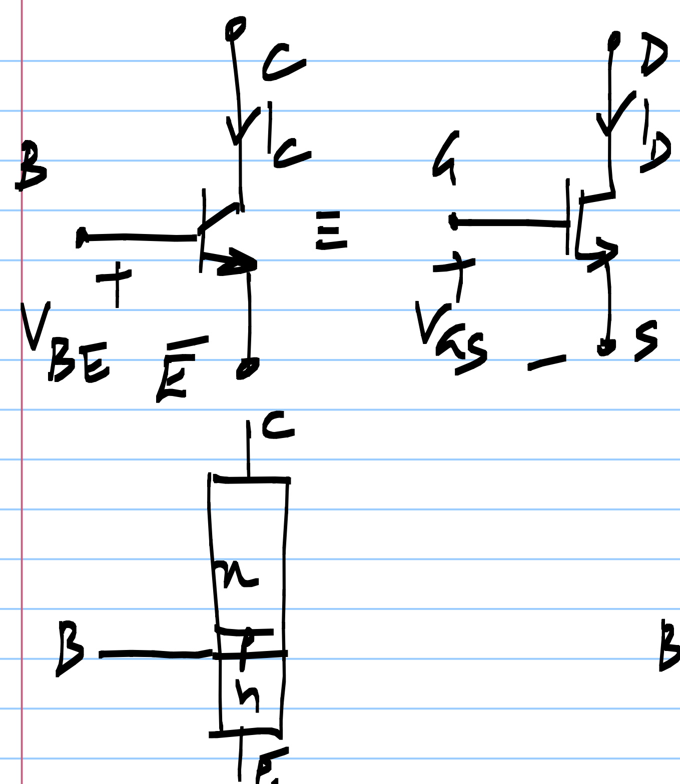
$$\frac{I_0}{100mV}$$

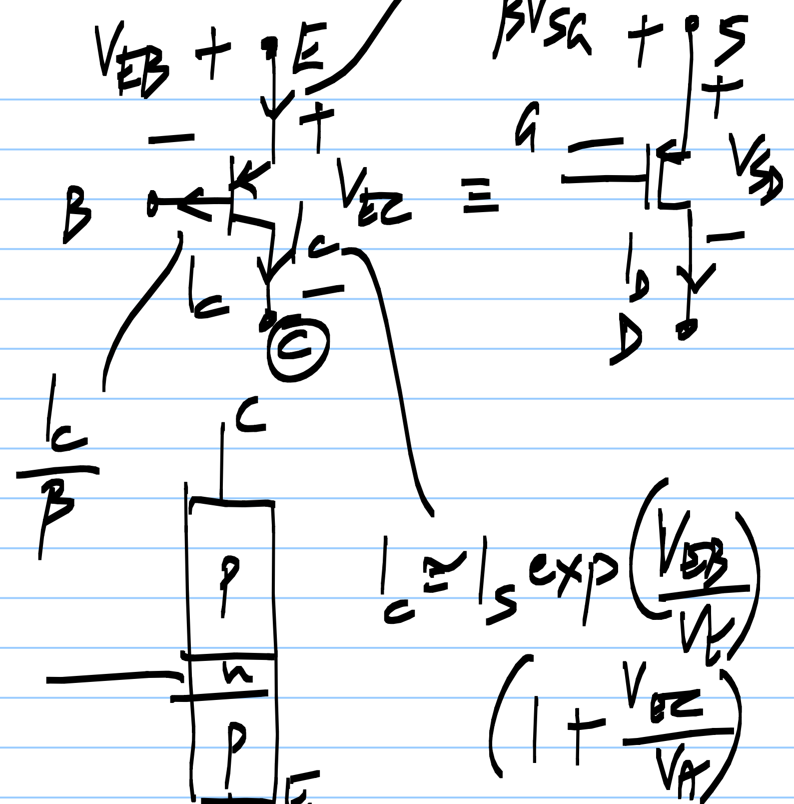
$$g_m = \frac{I_0}{\underbrace{(V_{GS}-V_T)}/2}$$

Darlington Pair



NPN nMOS PNP

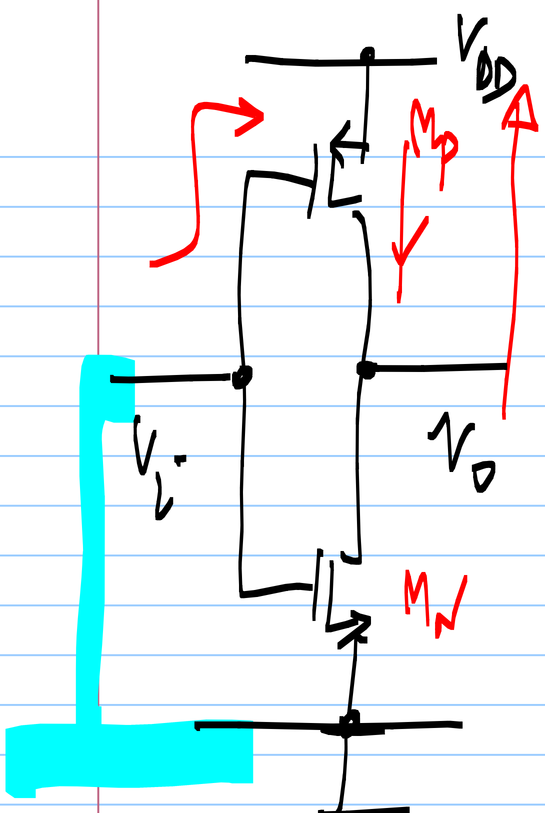


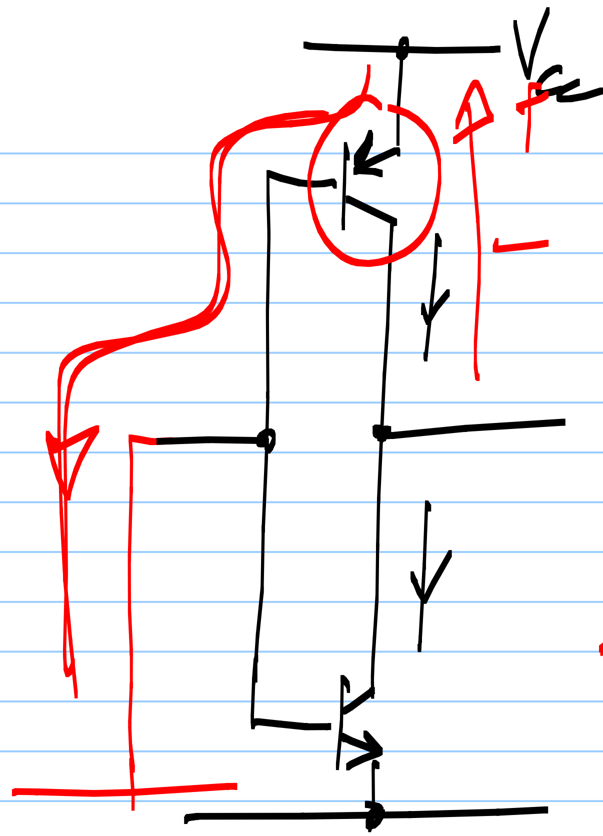


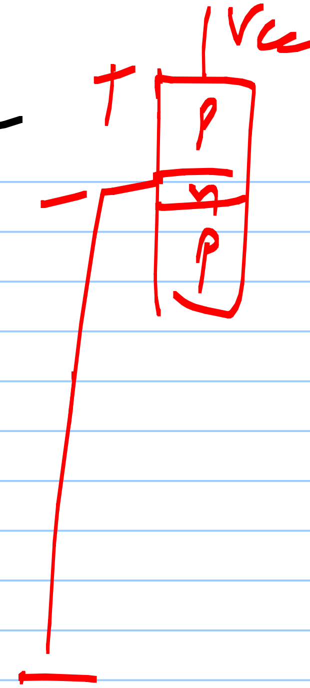
$I_c \cdot \frac{\beta+1}{\beta}$

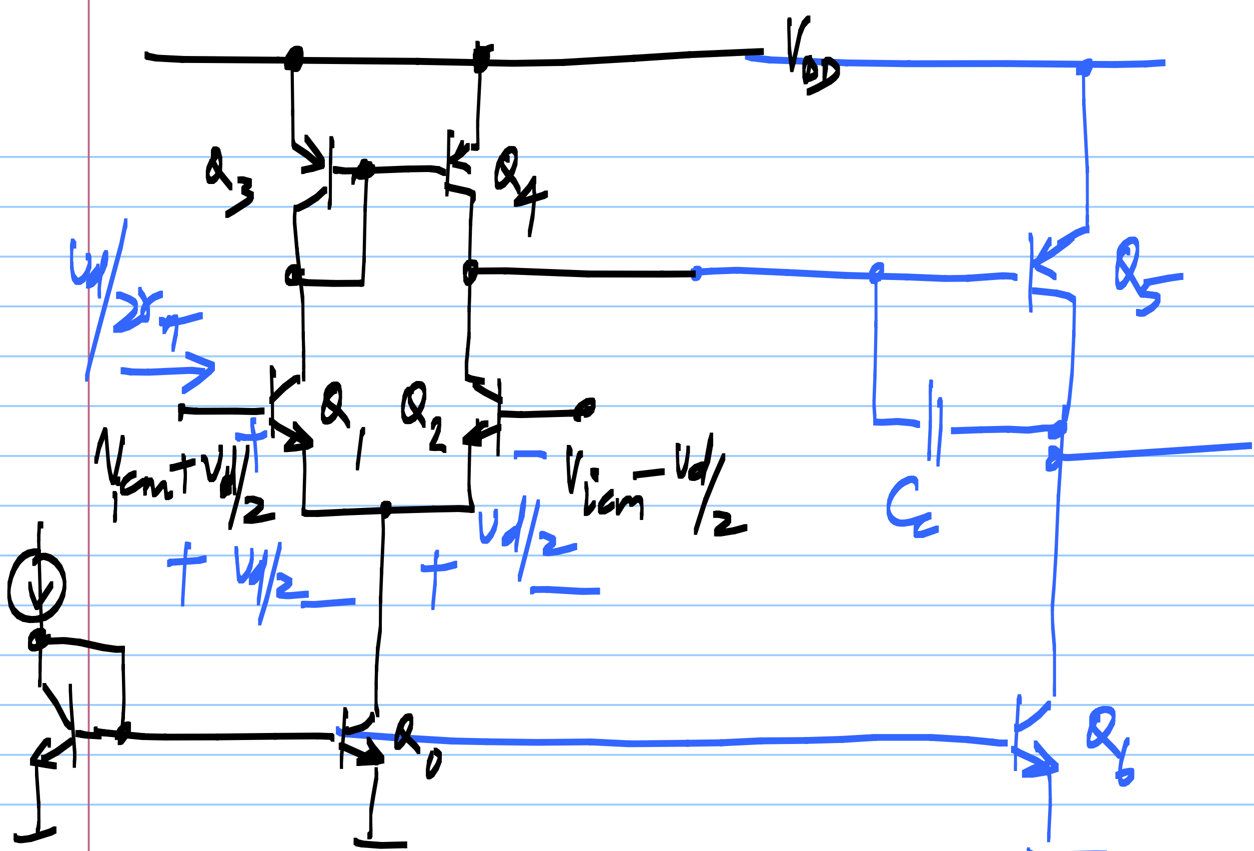
V_{SG}

$$I_c \simeq I_s \exp\left(\frac{V_{EB}}{V_t}\right)\left(1 + \frac{V_{EC}}{V_A}\right)$$


V_{DD}
M_P
V_i
V_o
M_N


V_{cc}


V_{cc}
p
n
p



V_{DD}
Q_3
Q_4
Q_5
Q_1
Q_2
Q_0
Q_6
$v_d/2r_\pi$
$V_{icm}+v_d/2$
$V_{icm}-v_d/2$
$+\ v_d/2\ -$
$+\ v_d/2\ -$
C_c