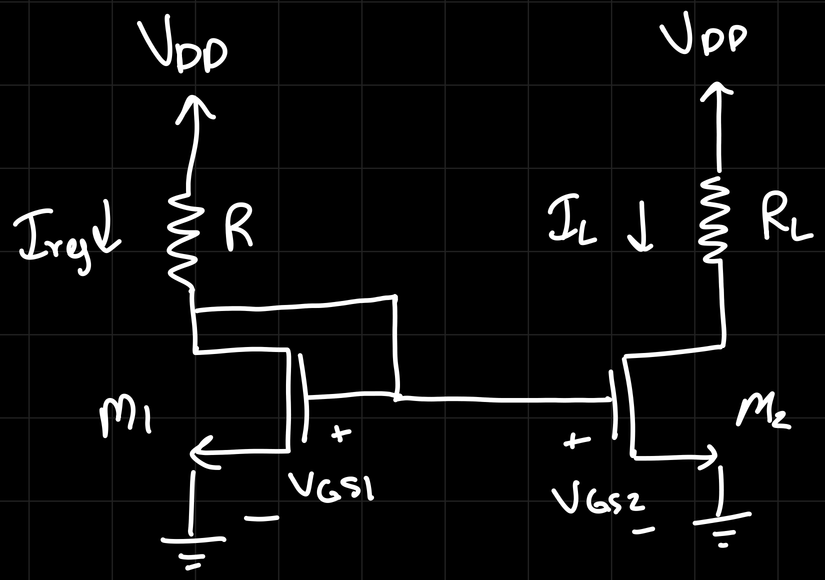
21st (monday) → Tut sim x2   5-7pm
↳ MOSFET Biasing
↳ current mirror / cascode

# lecture : current mirror




if $M_1$ and $M_2$ → $k_n$ and $V_T$ characteristics are same and they are in saturation,

$I_L = I_{ref}$

but is this true ∀ $R_L$?

NO

we require $M_2$ to be in saturation.

$V_{G2} > V_{T2}$

$V_{D2} > V_{G2} - V_{T2}$

for $M_1$,

$$I_{ref} = \frac{V_{DD} - V_{D1}}{R}$$

now since $V_{D1} = V_{G1}$

$$I_{ref} = \frac{V_{DD} - V_{G1}}{R}$$

$$V_{G1} = V_{DD} - I_{ref} R$$

for $M_2$ →

$$\left.\begin{aligned} V_{D2} &> V_{G2} - V_{T2} \\ V_{D2} &> V_{G1} - V_{T1} \end{aligned}\right\} \because M_1 \approx M_2$$

$$V_{DD} - IR_L > V_{G1} - V_{T1}$$

$$\left. V_{DD} - I_{ref} R_L > V_{G1} - V_{T1} \right\} I_{ref} = I_L$$

(we want this)

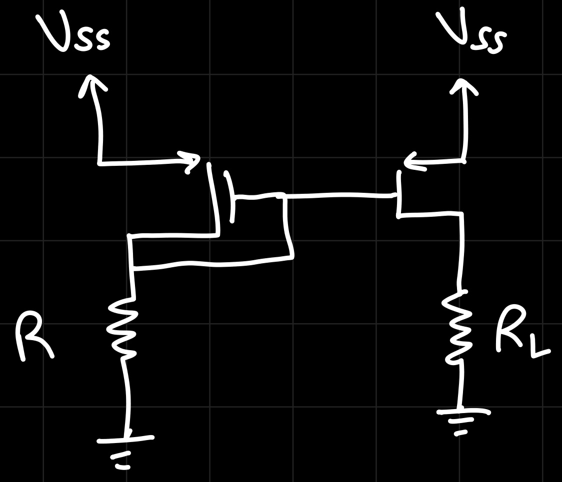
$$V_{G1} = V_{DD} - I_{ref} R$$

$$V_{DD} - I_{ref} R_L > V_{DD} - I_{ref} R - V_{T1}$$

$$I_{ref} R + V_{T1} > I_{ref} R_L$$

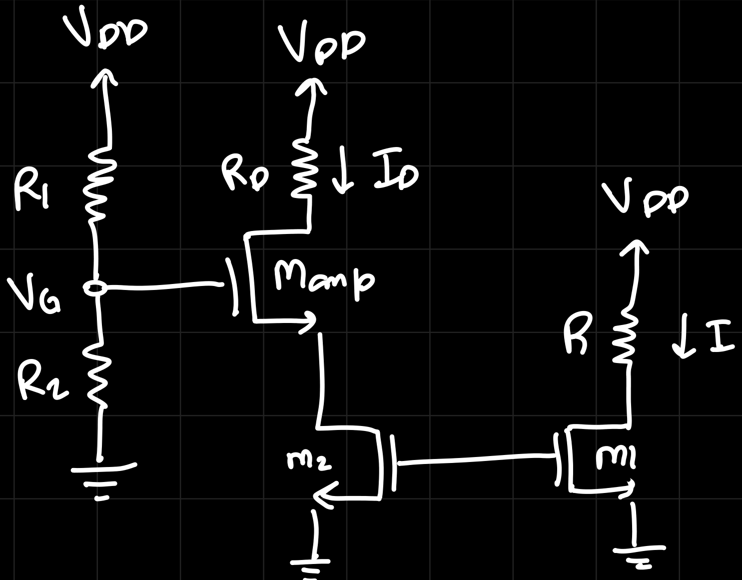
$$R_L < \frac{V_{T1}}{I_{ref}} + R$$

if $R_L < R + \frac{V_T}{I_{ref}}$ then $M_2$ would be in saturation and $I_L = I_{ref}$




Pmos current mirror

we can use a current source to bias a MOSFET and for that we use the current mirror circuit




if Mamp ≡ saturation
$I_d = k(V_{GS} - V_T)^2$

since $I_d = I \rightarrow V_{GS} = \sqrt{\frac{I}{k}} + V_T$

$$V_G = V_{DD} \times \frac{R_2}{R_1+R_2}$$

$$V_{GS} = V_G - V_S$$

$$V_S = V_G - V_{GS}$$

$$= V_{DD}\left(\frac{R_2}{R_1+R_2}\right) - \left(\sqrt{\frac{I}{k}} + V_T\right)$$

for saturation of Mamp: $V_{DS} > V_{GS} - V_T$

and to satisfy this, $V_{DS}\uparrow\uparrow \rightarrow V_S \downarrow\downarrow$

bias s.t. $V_S$ is small
by tweaking $R_2, R_1$,

but $V_S$ shouldn't be that small
because $V_S = V_{D2}$

{optimization problem}

Q// What is the limit to which we can reduce $V_S$?

for $M_2$ ≡ satration →

$$V_{DS2} > V_{GS2} - V_{T2}$$

since $V_{S2} = V_{S1} = 0$ →

$$V_{D2} > V_{G2} - V_{T2}$$

and since $V_S = V_{D2}$,

$$V_S^{min} = V_{G2} - V_{T2} = V_{G1} - V_{T1}$$

put $V_S^{min}$ in $V_G = V_{GS} + V_S$

$$V_G = V_{GS} + V_{G1} - V_{T1}$$

for $M_{amp}$: $V_{GS} = \sqrt{\frac{I}{k}} + V_T$

$$V_{GS1} = V_{G1} = V_{DD} - IR$$

$$V_G = \sqrt{\frac{I}{k}} + V_{T_{amp}} + V_{DD} - IR - V_{T1}$$

↳ and $V_G = V_{DD} \times \frac{R_2}{R_1 + R_2}$

This is the min value of $V_G$ we need to maintain

$R_1$ and $R_2$ are input impedence
and hence for the amp, $R_1$ and $R_2 >>>$
to prevent signal loss

$R_1, R_2$ : as high as possible

now what about $R_D = ?$

$M_{amp} \equiv$ should be in SATURATION

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

i.e. $V_D$ should $\uparrow$

and $V_D = V_{DD} - I_D R_D$

So, $R_D$ should be less

$V_S^{min} > V_{G1} - V_{T1}$

$V_D - V_S > \underbrace{V_{GS} - V_T}_{M_{amp}}$

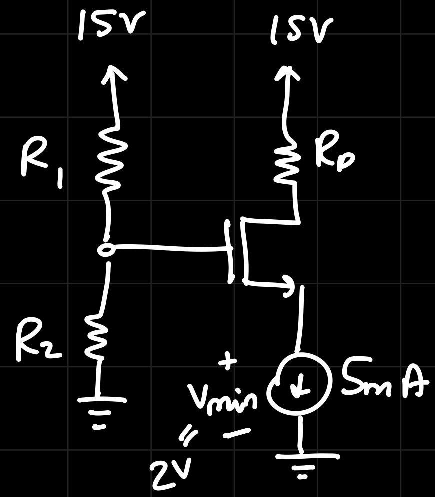
$V_{DD} - I_D R_D - V_{S1} > V_{GS} - V_T$

$$R_D < \frac{V_{DD} - V_S - V_{GS} + V_T}{I_D}$$

for $I_D = I$ (current mirror)

$$\boxed{R_D < \frac{V_{DD} - V_G + V_T}{I}}$$

Q3




$K = 0.2 \times 10^{-3}$

$V_t = 1V$

$$V_{GS} = \sqrt{\frac{I}{K}} + V_T$$

$$I_d = K(V_{GS} - V_T)^2$$

$$V_{GS} = \sqrt{\frac{5}{0.2}} + 1 = \underline{\underline{6V}}$$

$$V_S^{min} = 2V$$

$$V_G = \underline{\underline{8V}}$$

$$V_G = 15 \times \frac{R_2}{R_1 + R_2}$$

$$\frac{R_2}{R_1 + R_2} = \frac{8}{15}$$

$$8R_1 + 8R_2 = 15R_2$$

$$8R_1 = 7R_2$$

lets choose $R_1 = 7M\Omega \rightarrow R_2 = 8M\Omega$

$$R_D \leq \frac{V_{DD} - V_G - V_T}{I_D} = \frac{15 - 8 + 1}{5} k\Omega$$

$$= \frac{8}{5} k\Omega = \underline{1.6k\Omega}$$

$$\boxed{R_D \leq 1.6k\Omega}$$

check if Amp → saturation mode

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

$-15 + 8 + V_{DS} + 2 = 0$

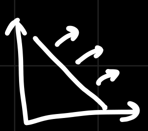
$V_{DS} = 5V$

$V_D = 7V$

$5 > 6 - 1$ ✓ but just at the edge of saturation for $R_D = 1.6k\Omega$

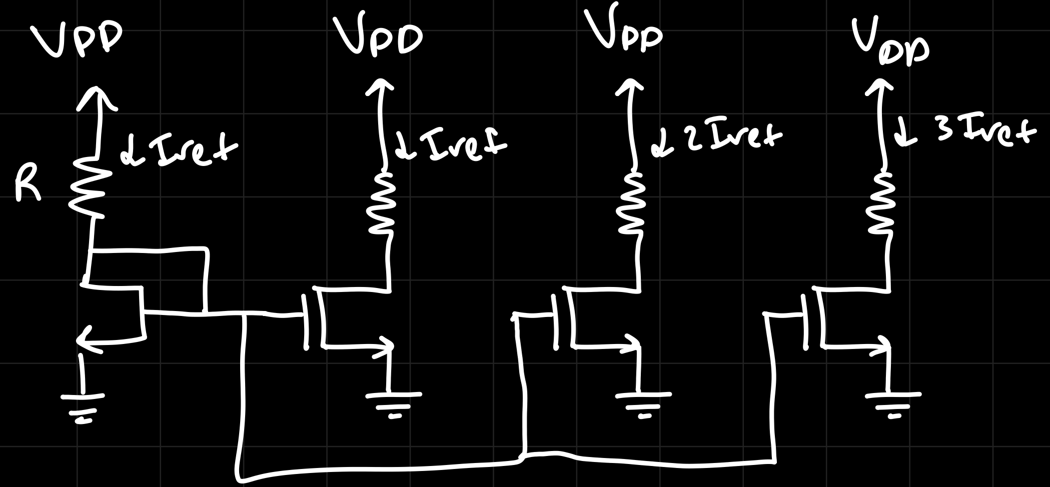
Choosing $R_D = 1k\Omega$ would be more suited.

⇒ $R_D$ will change the slope of the load line

$R_D \downarrow \rightarrow$  slope : $\frac{1}{R_D}$

# Current steering circuit

Create multiple I sources from a single reference current.




The current mirror ckt ensures $V_{GS}$ to be same as reference branch so that same ref current flows through each identical branch (MOSFETS)

$$V_{GS}^{ref} = V_{GS1} = V_{GS2} = \cdots$$

if mos are identical,

$$K_{ref} = K_1 = K_2 = \cdots$$

and $V_T^{ref} = V_{T1} = V_{T2} = \cdots$

now if i want scaled ref current for diff branches,

eg: for $n^{th}$ branch $\rightarrow I_{dn} = K_n (V_{GSn} - V_{Tn})^2$

we know $I_D = K_{ref}( V_{GS}^{ref} - V_T^2)$

if $K_{ref} \neq K_n$, $\frac{I_{dn}}{I_d} = \frac{K_n}{K_{ref}} \frac{\cancel{(V_{GSn} - V_{Tn})^2}}{\cancel{(V_{GS}^{ref} - V_T)^2}}$

scaling factor

$$\boxed{I_{dn} = \frac{K_n}{K_{ref}} I_d}$$

current steering

$I_{D1} = 25 \mu A$

$I_{D2} = 50 \mu A$

$I_{D3} = 125 \mu A$

$I_{D4} = 25 \mu A = I_{D5}$

$$V_{GS_1} = \sqrt{\frac{I}{k}} + V_T = \sqrt{\frac{25\mu}{5 \times 50\mu}} + 1$$

$$R = \frac{V_{G4} - V_{G1}}{I_{ref}}$$

PMOS : $M_4$

$V_{SD} = V_S - V_D$

$V_A = V_D = 5 - V_{SD} = 5 - V_{SG} = 5 + V_{GS}^p$

for $M_1$ : $V_{DS} = V_D - V_S$

$V_{DS} = V_D + 5$

$V_{GS} = V_D + 5$

$V_B = V_D = V_{GS}^n - 5$

$$R = \frac{V_A - V_B}{I_{ref}} = \frac{V_{GS}^n + 5 + 5 - V_{GS}^p}{25\mu A}$$

for $M_4 \rightarrow$ $I_{d4} = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)(V_T - V_{GS})^2$

for $M_1 \rightarrow$ $I_{d1} = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)(V_{GS} - V_T)^2$

$$(V_{GS}^p + 1)^2 = \frac{25\mu \times 2}{20\mu \times 5}$$