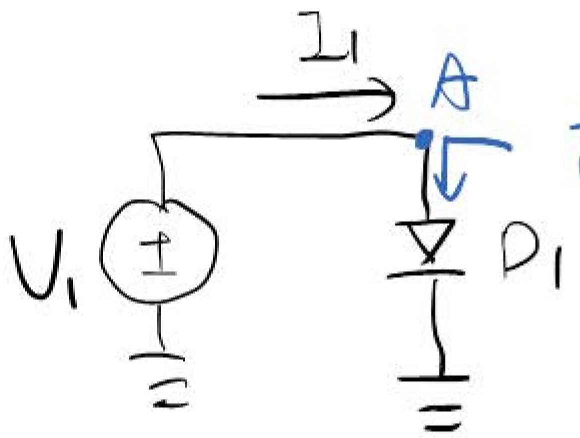
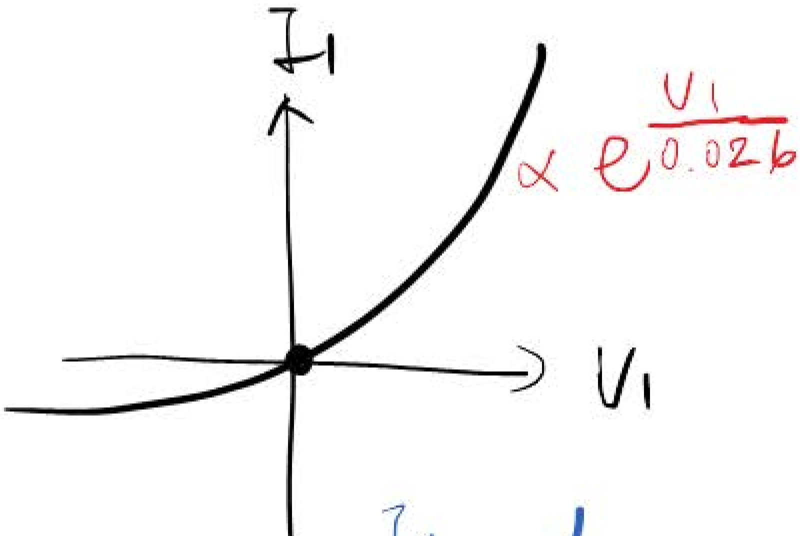
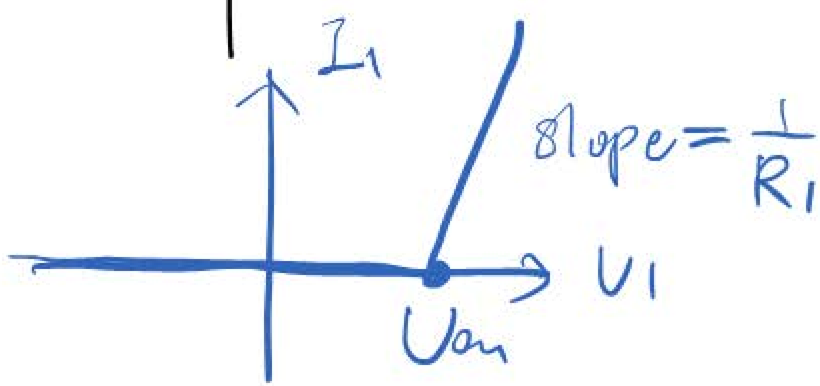
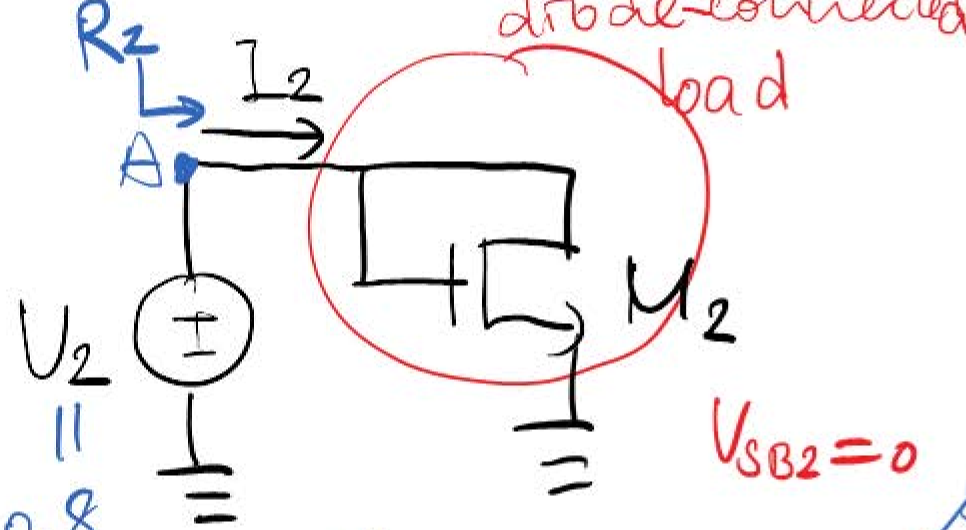


$\frac{1}{R_1}$ (the small signal impedence from node A to small signal ground)



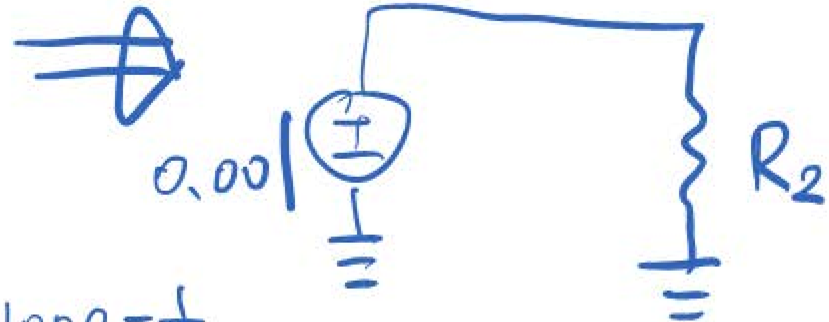


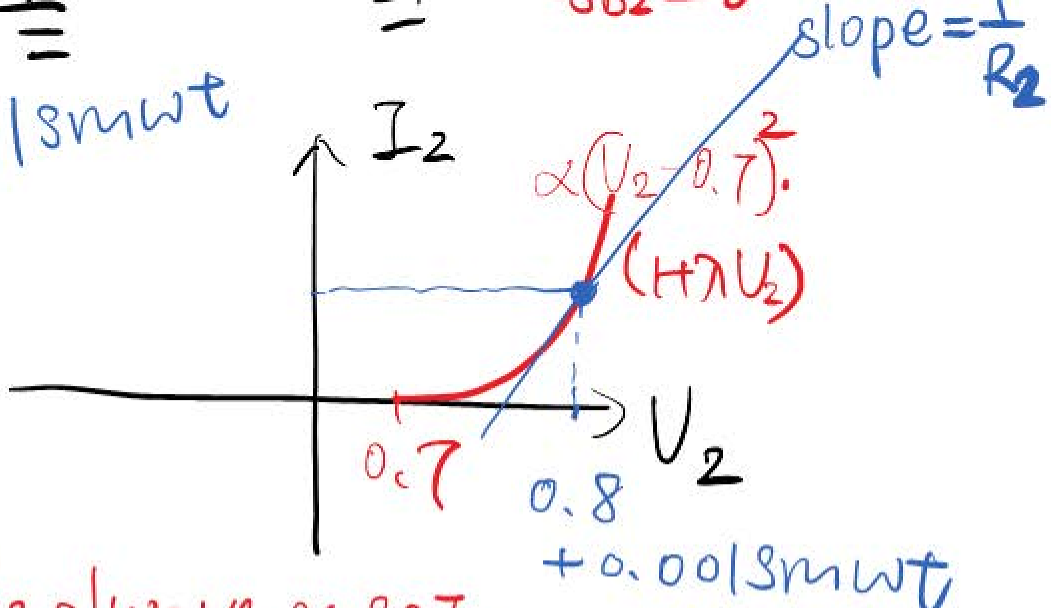
Small signal



$V_2 = 0.8 + 0.001 \sin \omega t$

$V_{SB2} = 0$

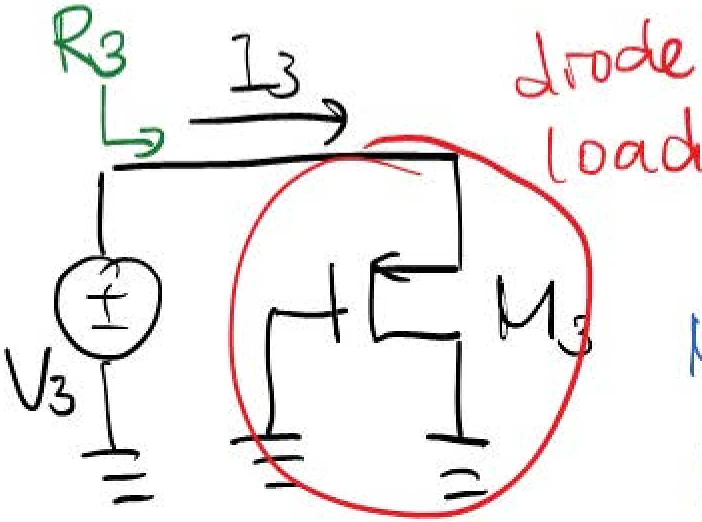




$$R_2 = r_{o2} \,/\!/\, \frac{1}{g_{m2}}$$

M_2 always in sat.

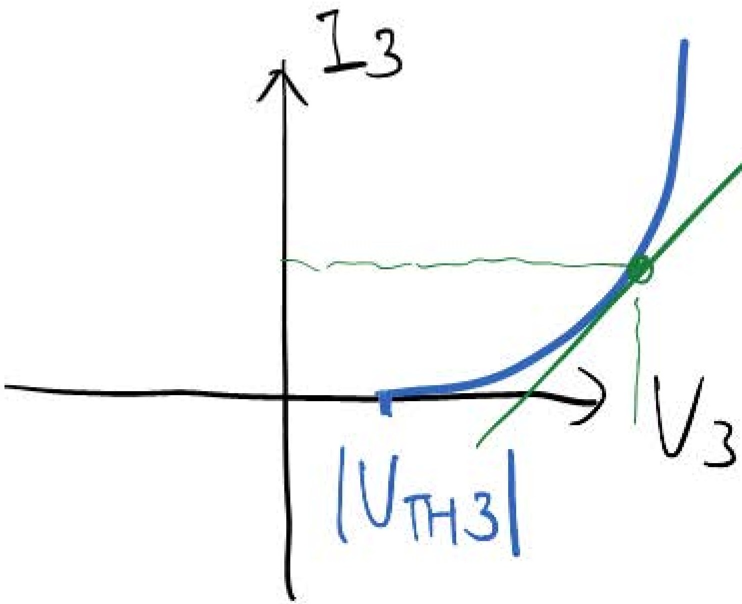
$$I_2 = \frac{1}{2} \mu_n C_{ox} \frac{W}{L_{eff}} (V_2 - 0.7)^2 (1+\lambda V_2)$$



$$R_3 = r_{o3} \,//\, \left(\frac{1}{g_{m3}+g_{mb3}}\right)$$

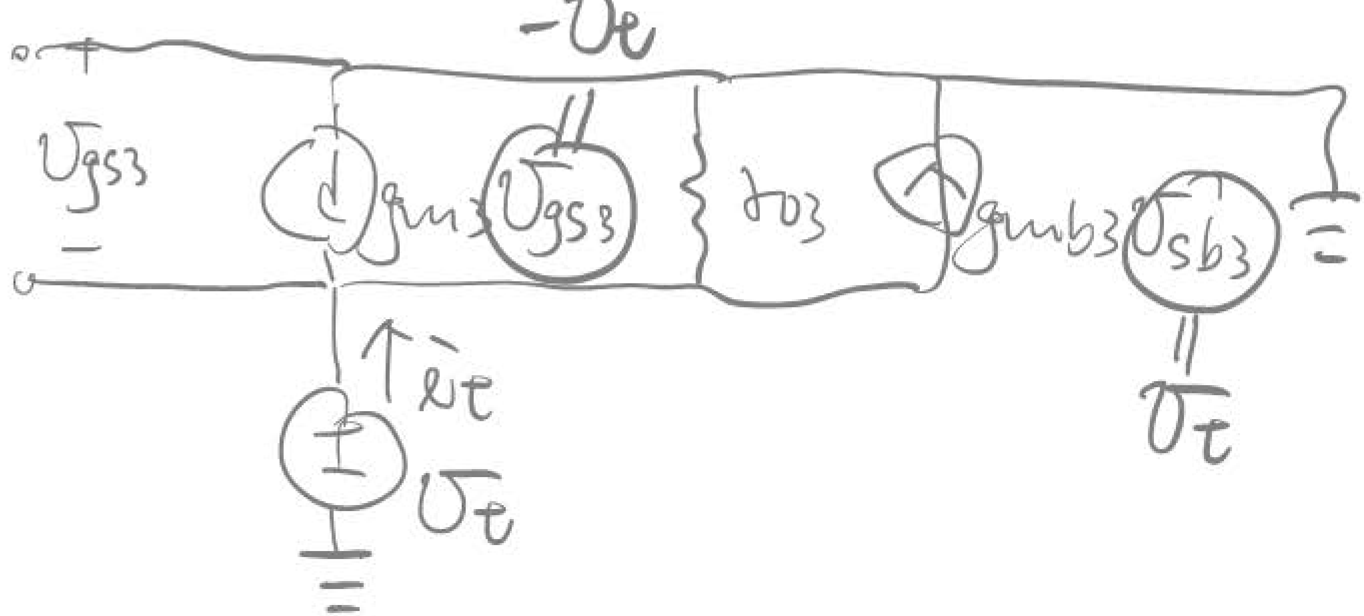
M_3 always in Sat.

$$V_{BS3} = V_{DD} - V_3 > 0, \quad |V_{TH3}| > 0.8$$



$$\text{slope} = \frac{1}{R_3}$$

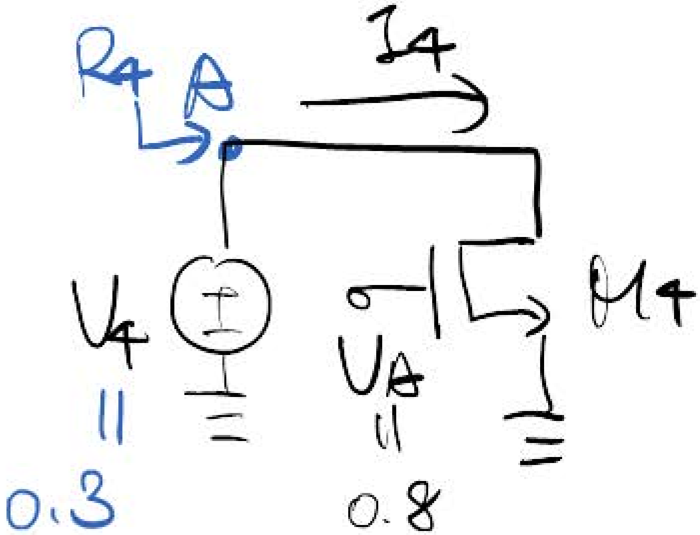
$$I_3 = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L_{eff}}\right)_3 \cdot (V_3 - |V_{TH3}|)^2 (1+\lambda V_3)$$

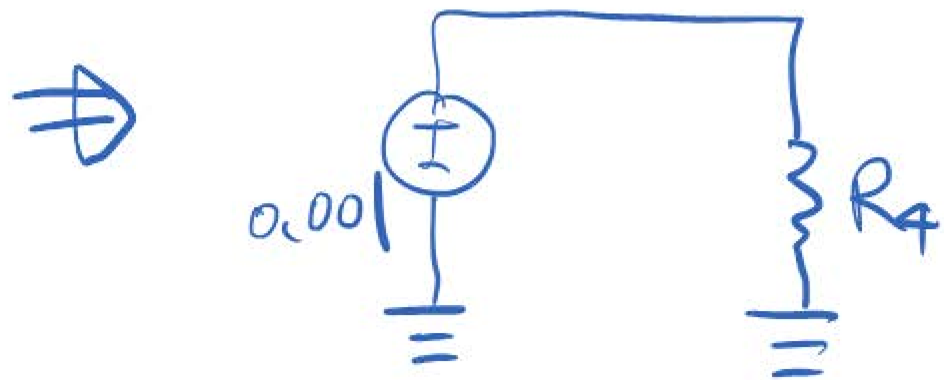


$$i_t = (g_{m3} + g_{mb3}) v_t + \frac{v_t}{r_{o3}}$$

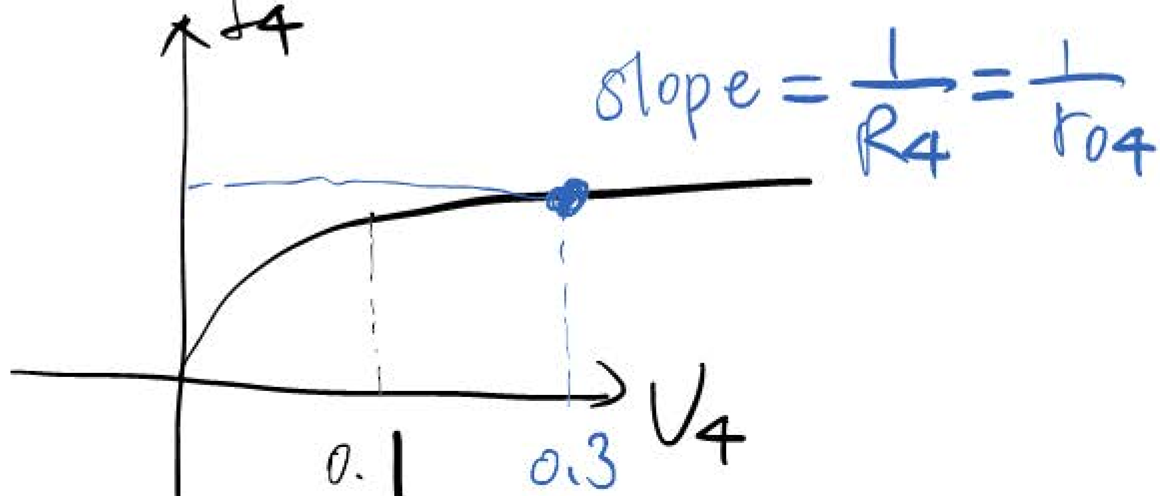
$$R_3 = v_t / i_t = r_{o3} \parallel \left(\frac{1}{g_{m3} + g_{mb3}} \right)$$

small signal



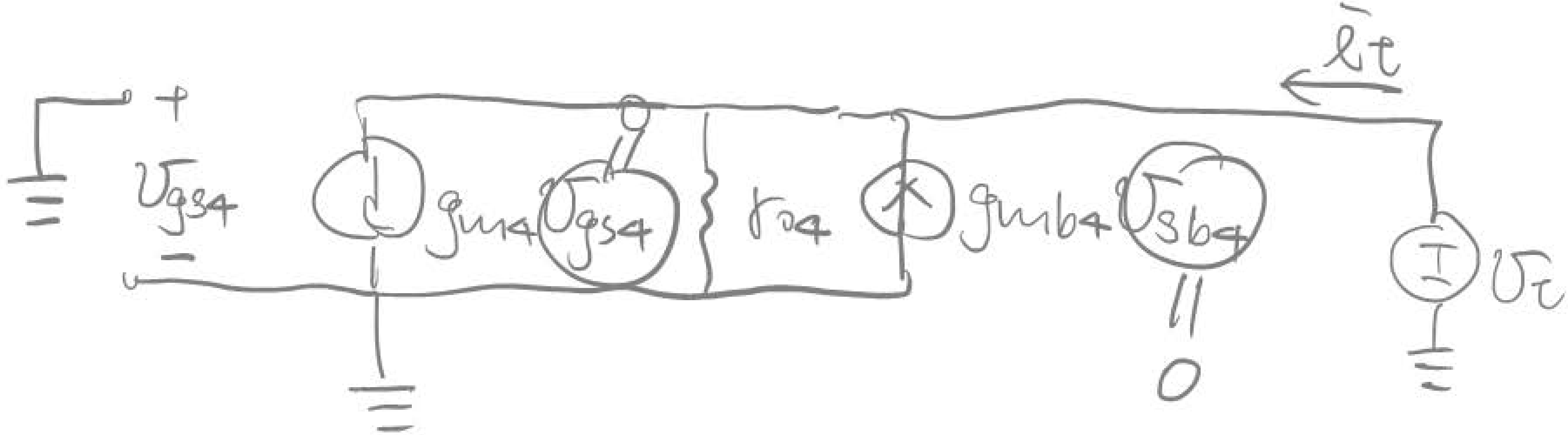


$+0.001 \sin \omega t$

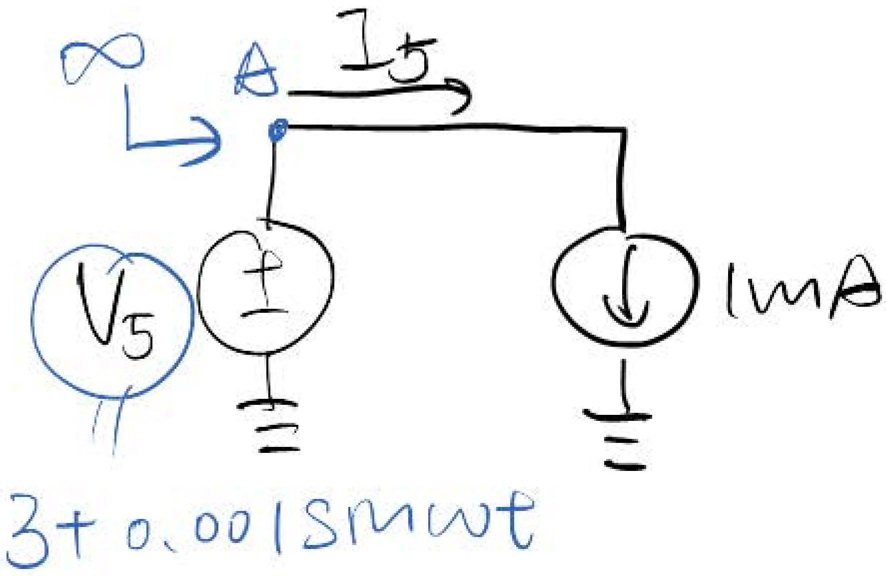


$= V_{GS4} - V_{TH4}$

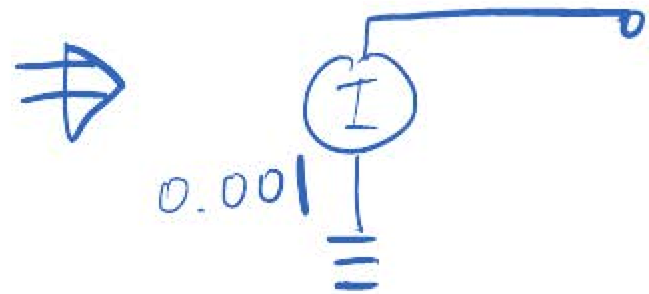
$= 0.8 - 0.7$

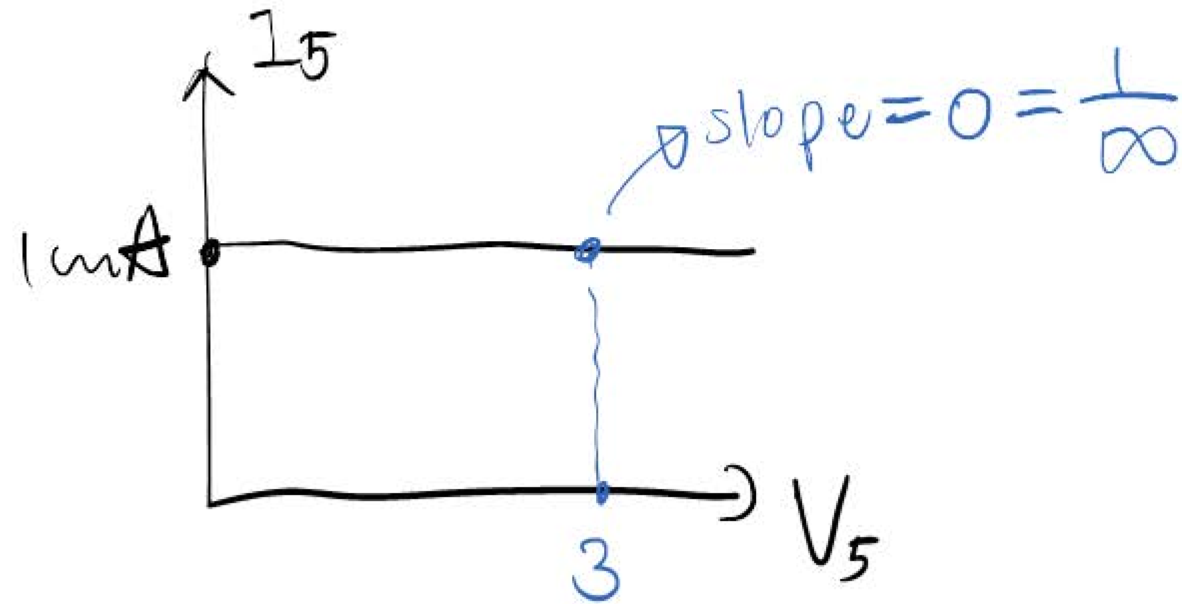


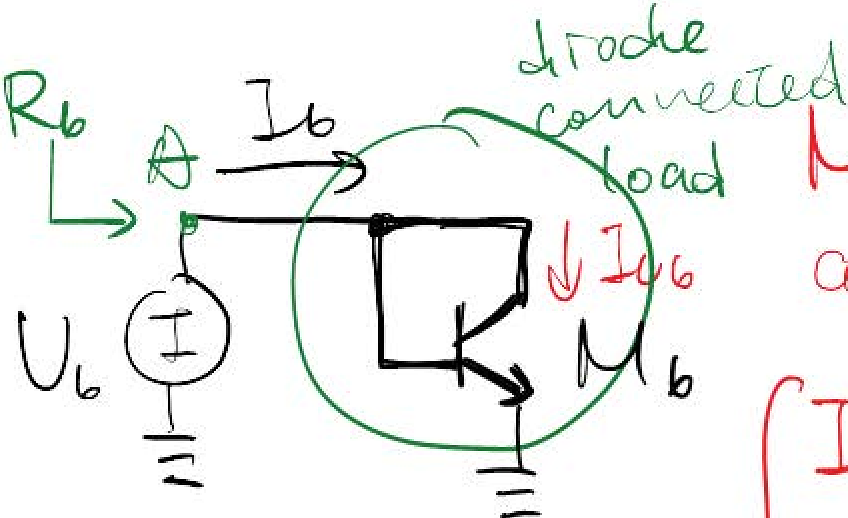
$$R_4 = \frac{v_t}{i_t} = r_{o4}$$



small signal

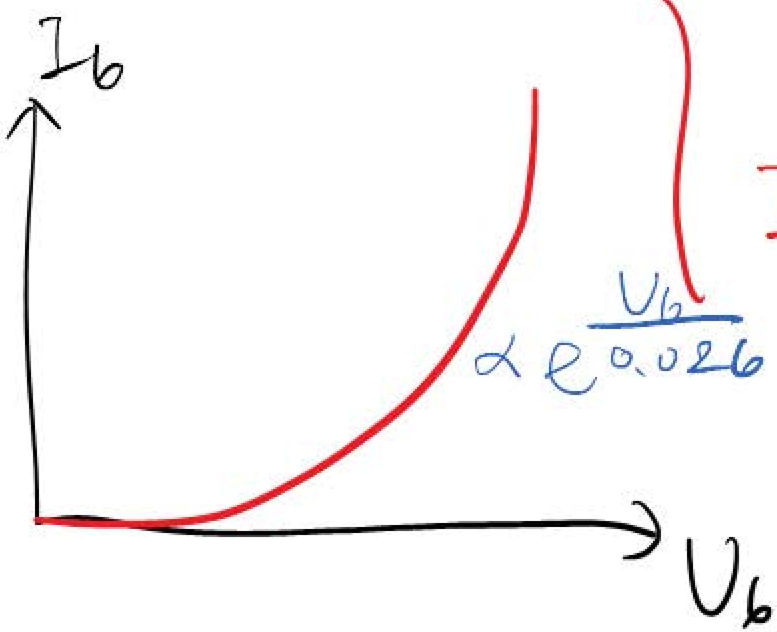




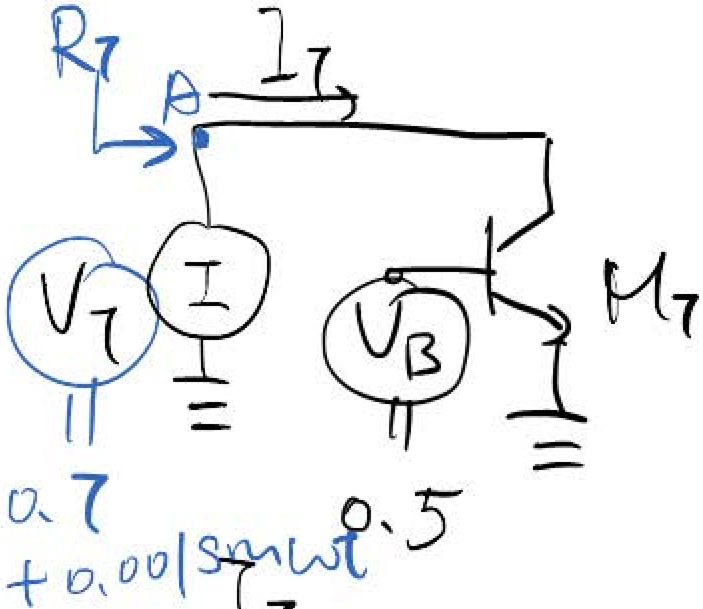


M_6 always in forward-active region

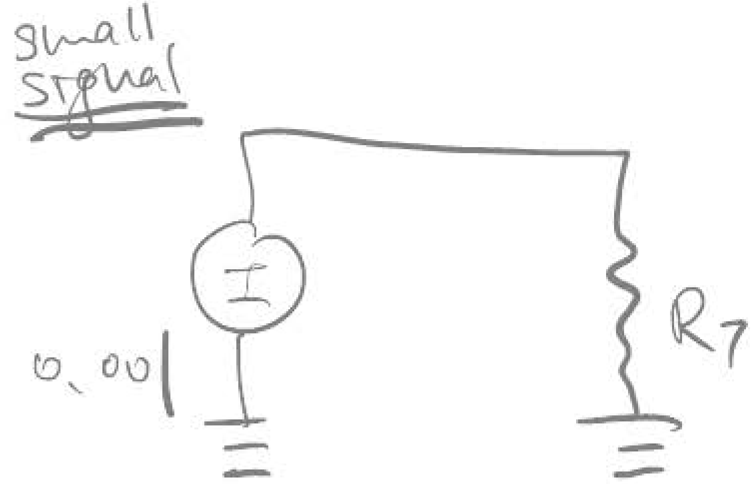
$$\begin{cases} I_{c6} = I_s\left(e^{\frac{U_6}{0.026}} - 1\right) \cdot \left(1 + \frac{U_6}{U_A}\right) \\ I_6 = I_{c6} + \frac{I_{c6}}{\beta} \end{cases}$$

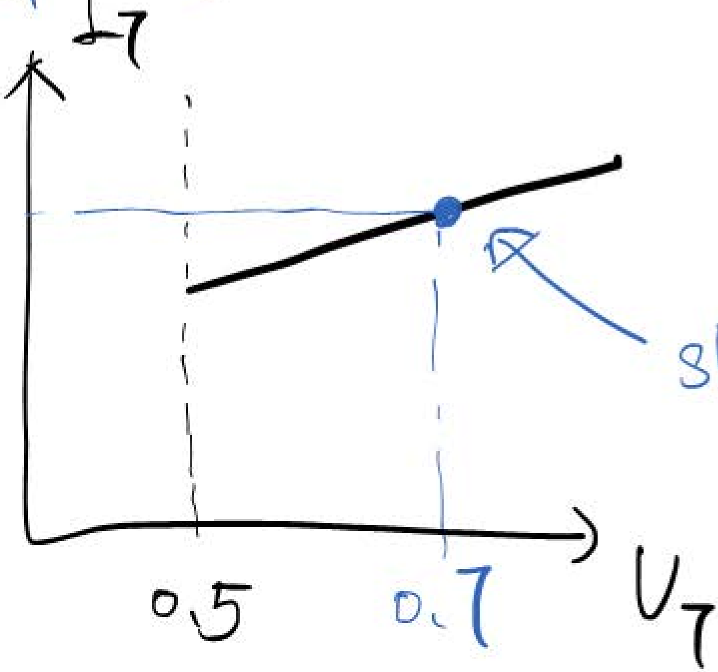


$$R_6 = \frac{v_t}{i_t} = r_{\pi 6} \,/\!/\, r_{o6} \,/\!/\, \frac{1}{g_{m6}}$$



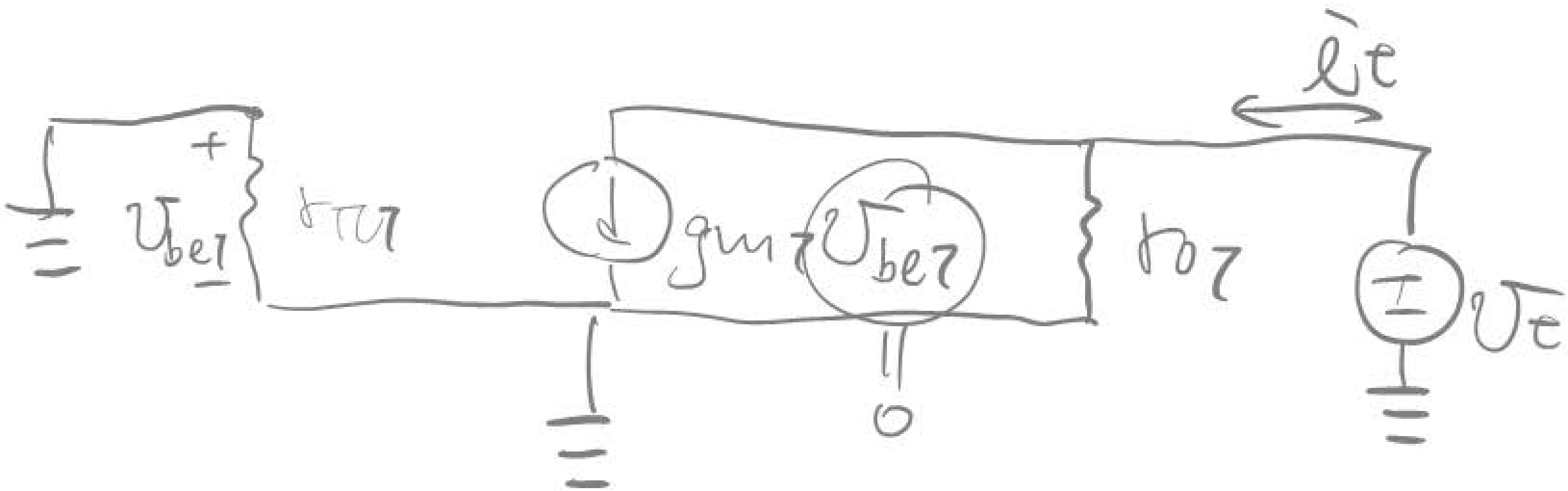
$\Rightarrow$





$$I_7 = I_S\left(e^{\frac{0.5}{0.026}} - 1\right)\left(1 + \frac{V_7}{V_A}\right)$$

$$\text{slope} = \frac{1}{R_7} = \frac{1}{r_{o7}}$$

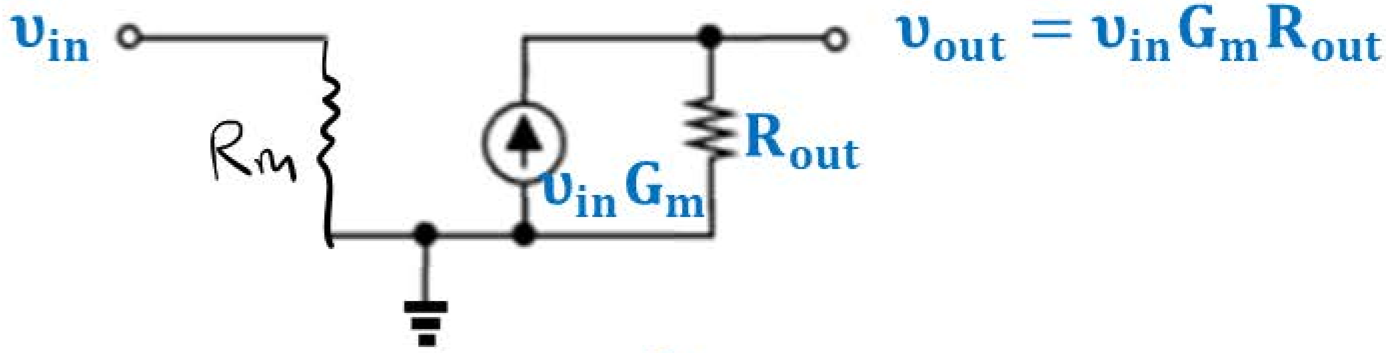


$$R_7 = \frac{v_t}{i_t} = r_{o7}$$

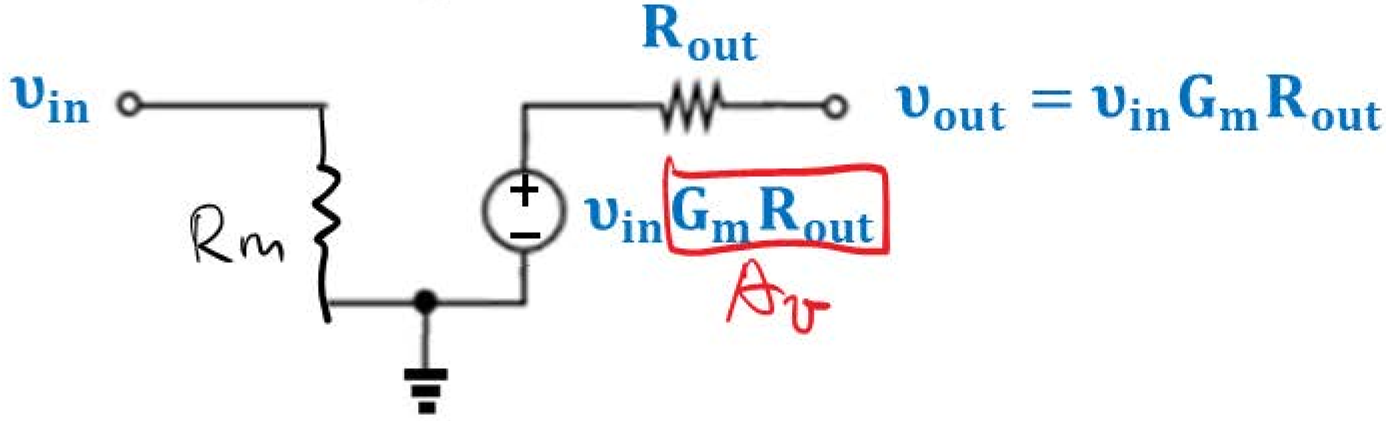
Degeneration

Common-Source with Source Degradation

Amplifier Equivalent Circuit

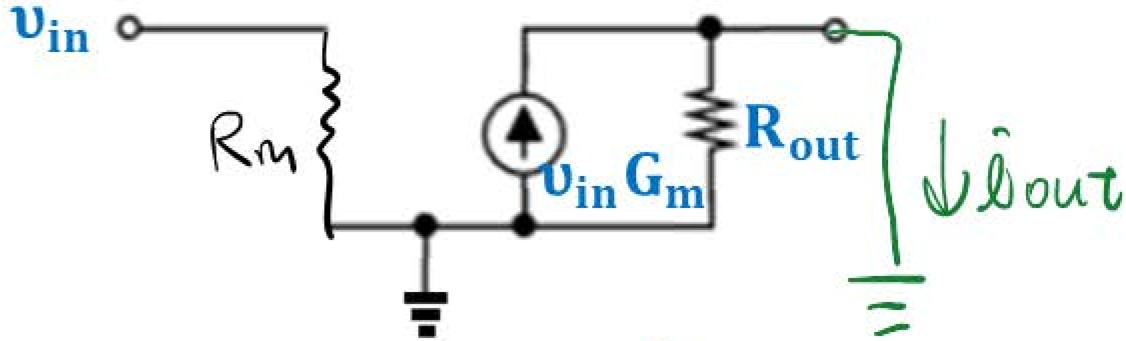


=



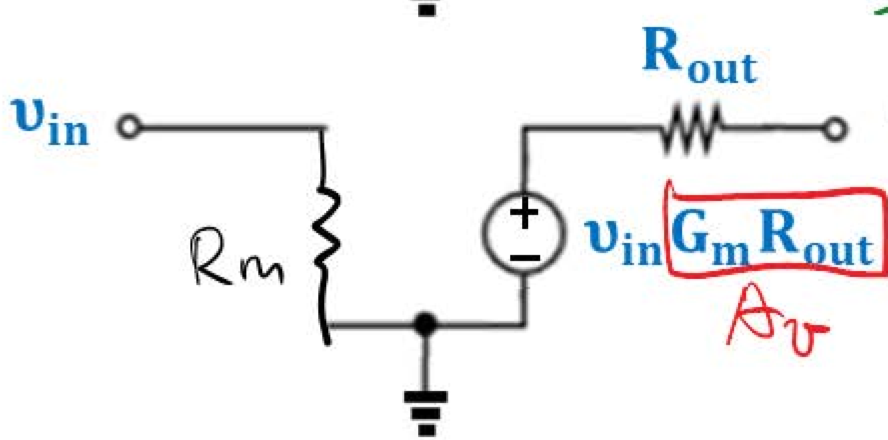
- How to calculate G_m? υ_{out} shorted to ground. $\mathbf{G_m = i_{out}/\upsilon_{in}}$
- How to calculate R_{out}? υ_{in} shorted to ground and υ_{out} connected to υ_{test}. $\mathbf{R_{out} = \upsilon_{test}/i_{test}}$

Amplifier Equivalent Circuit



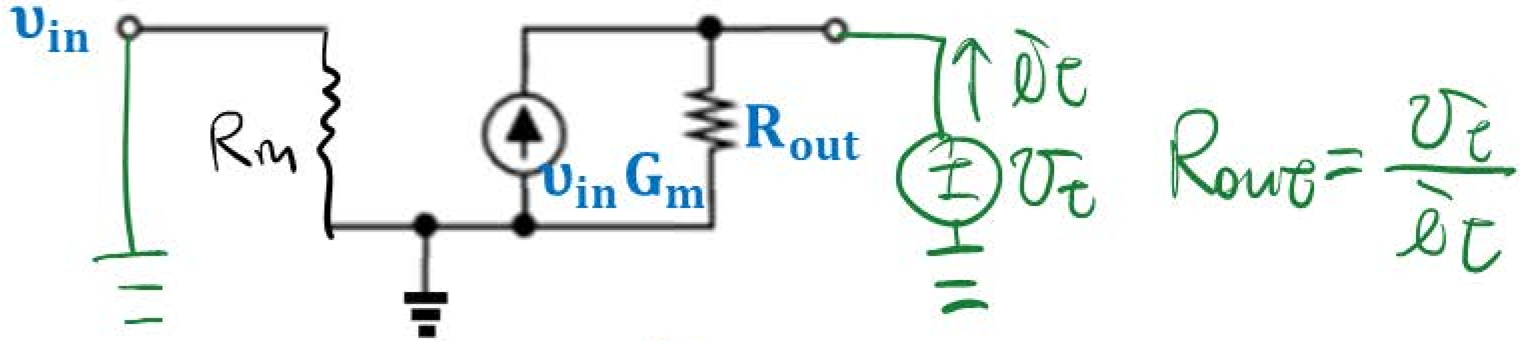
$$G_m = \frac{i_{out}}{\upsilon_{in}}$$

=

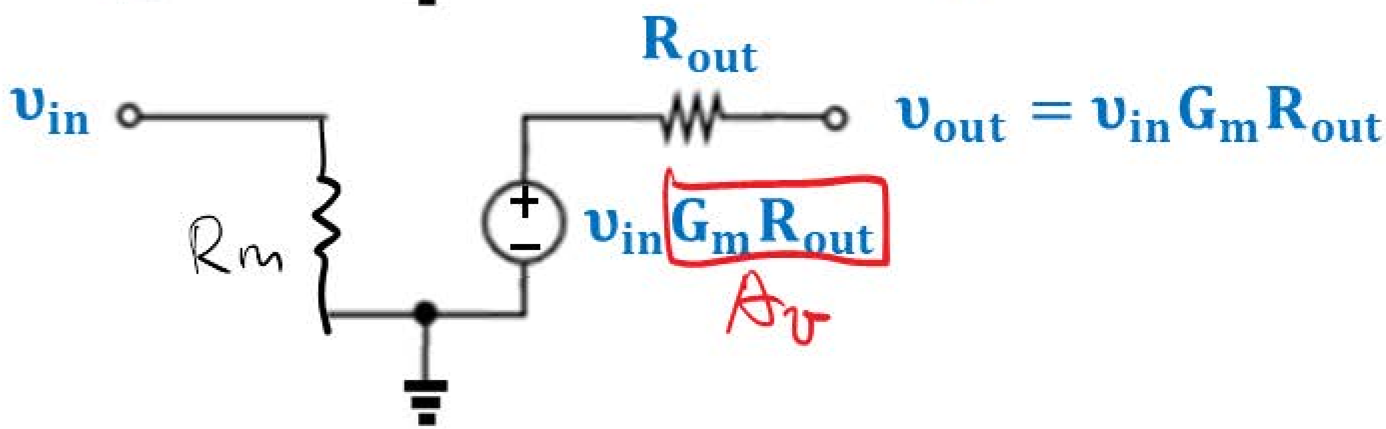


$$\upsilon_{out} = \upsilon_{in} G_m R_{out}$$

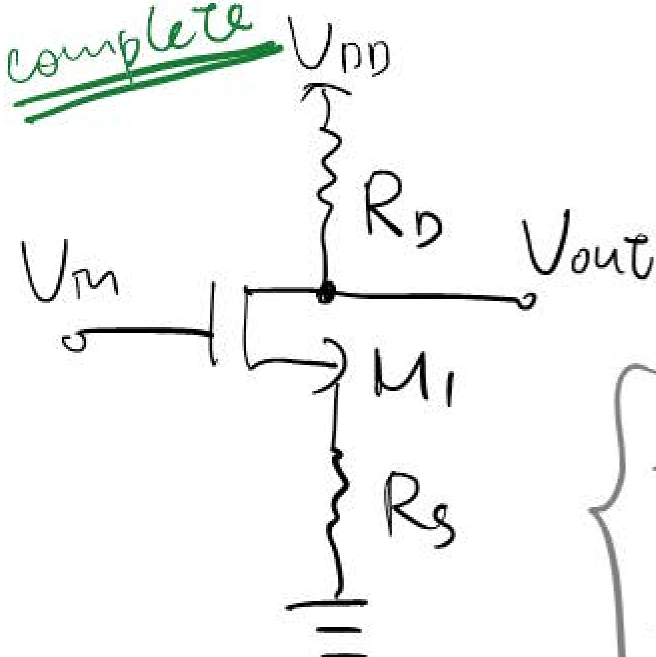
Amplifier Equivalent Circuit



=



complete



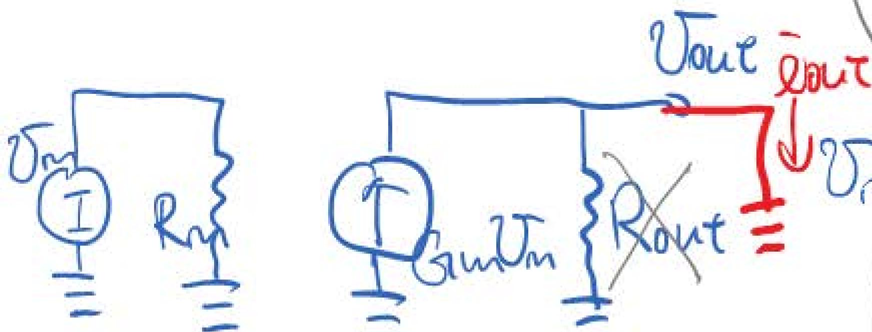
$\lambda \neq 0,\ \gamma \neq 0$

$A_v = ?$

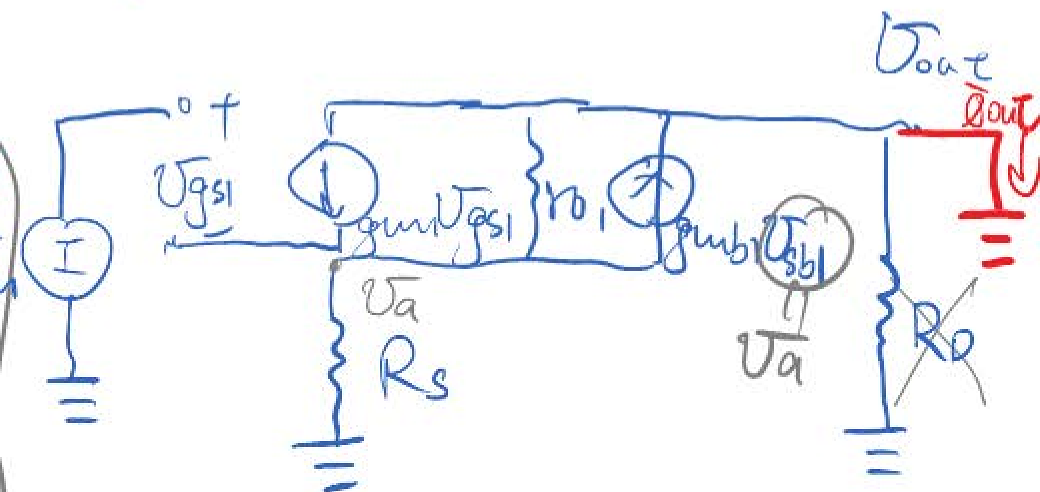
$G_m = i_{out} / v_{in}$

$$\begin{cases} \dfrac{v_a}{R_S} + (v_a - v_{in}) g_{m1} + \dfrac{v_a}{r_{o1}} + g_{mb1} v_a = 0 \\ -\dfrac{v_a}{R_S} = i_{out} \end{cases}$$

Equivalent small signal



small signal

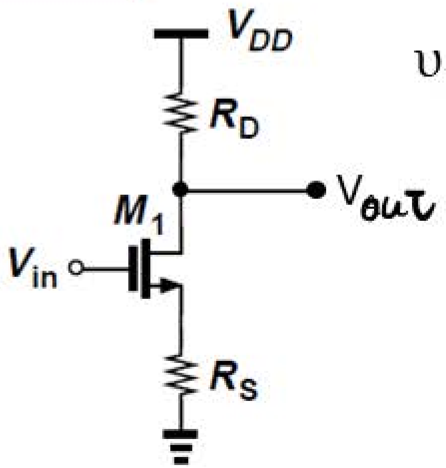


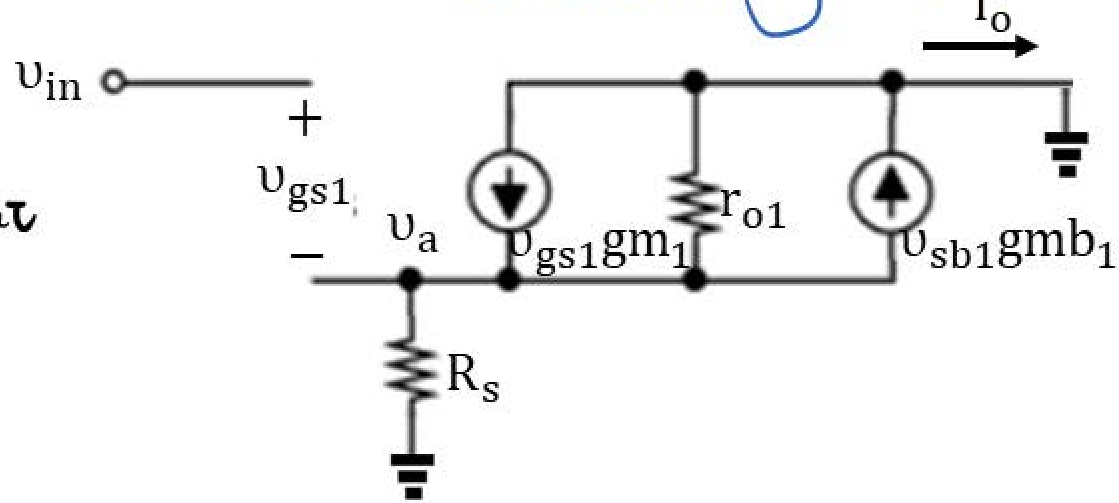
Common-Source with Source Degradation

Small-signal Analysis

$\lambda \neq 0 \quad \gamma \neq 0$

small signal circuit for calculating Gm





$$\begin{cases} i_o = \dfrac{-\upsilon_a}{R_S} \\ (\upsilon_{in} - \upsilon_a)gm_1 + i_o = \dfrac{\upsilon_a}{r_{o1}} + \upsilon_a gmb_1 \end{cases}$$

$$\boxed{G_m = \frac{i_o}{\upsilon_{in}} = \frac{-gm_1 r_{o1}}{R_S + r_{o1} + \boxed{(gm_1 + gmb_1)r_{o1}}R_S} \approx -\frac{1}{R_S}}$$

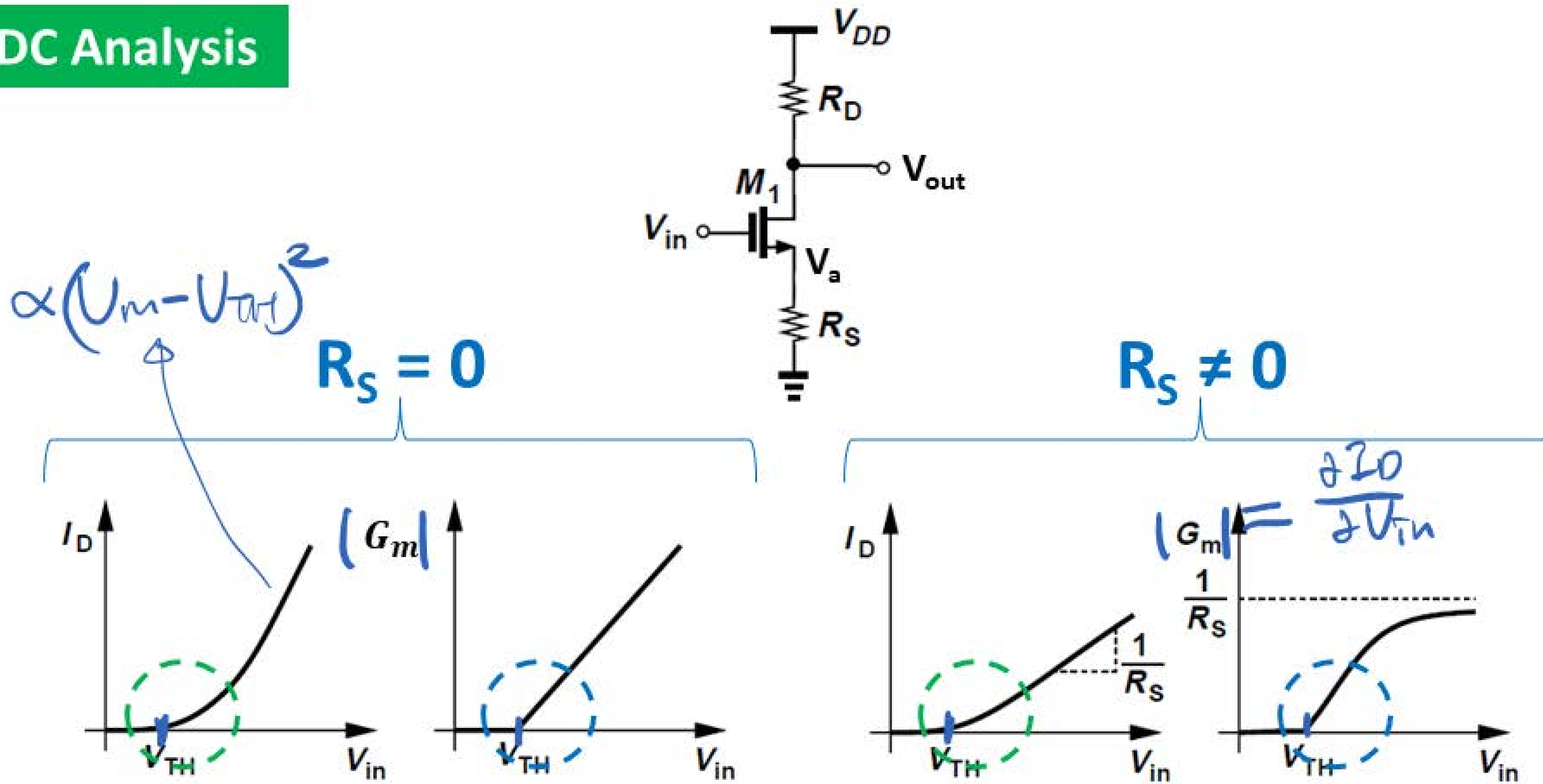
intrinsic gain of M1

if $gmb_1 \ll gm_1$

If $(gm_1 + gmb_1)r_{o1}R_S$ >> r_{o1} and R_S

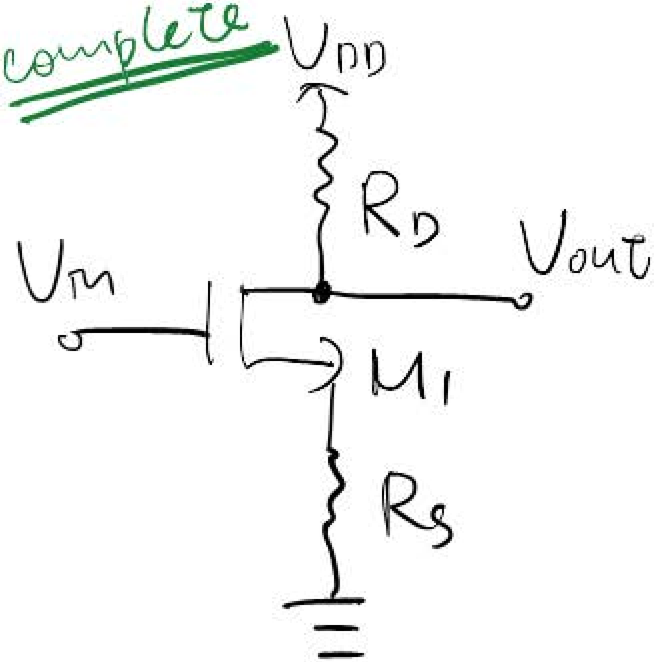
Common-Source with Source Degradation

DC Analysis



- At low V_{in} (gm small), turn-on behavior of $R_S \neq 0$ is similar to that of $R_S = 0$.
- At large V_{in} (gm large), the effect of R_s, i.e. degradation, becomes more significant.
- V_{in} = 0 V → M_1 off, no current flowing → V_a = 0 V and V_{out} = V_{DD}

complete

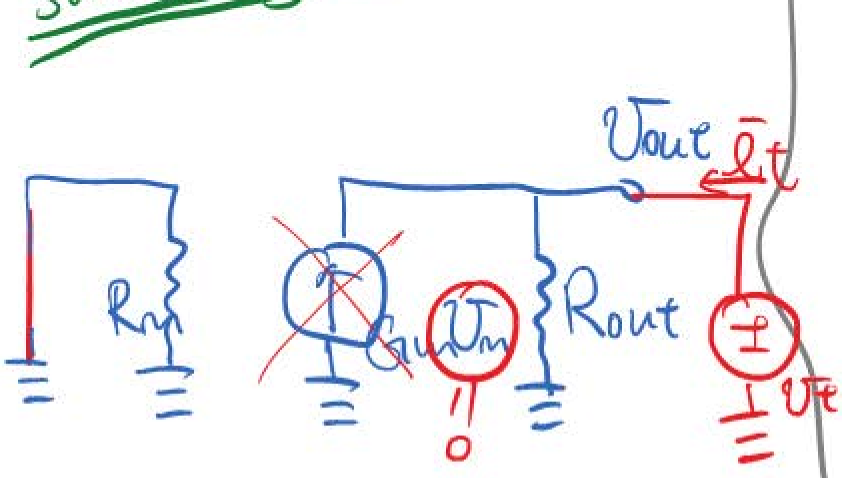


$\lambda \neq 0, \gamma \neq 0$

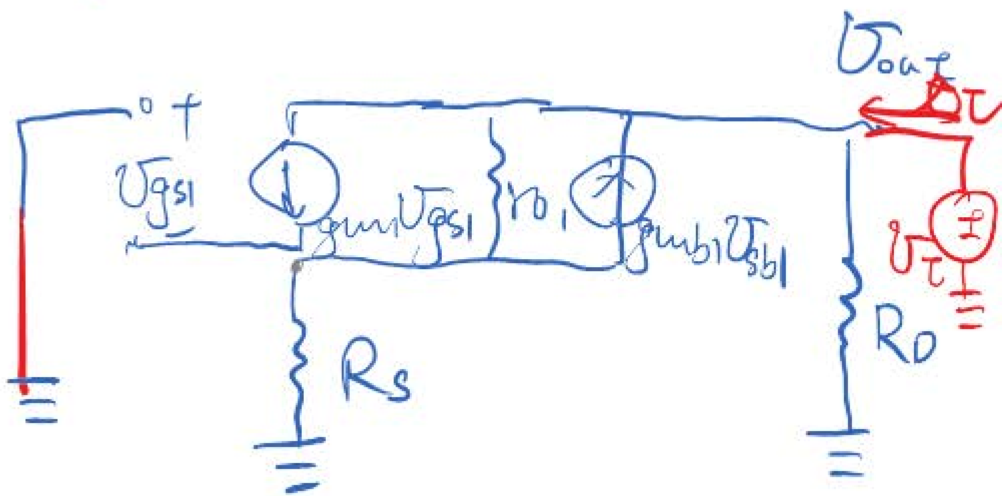
$A_v = ?$

$R_{out} = v_t / i_t$

Equivalent small signal



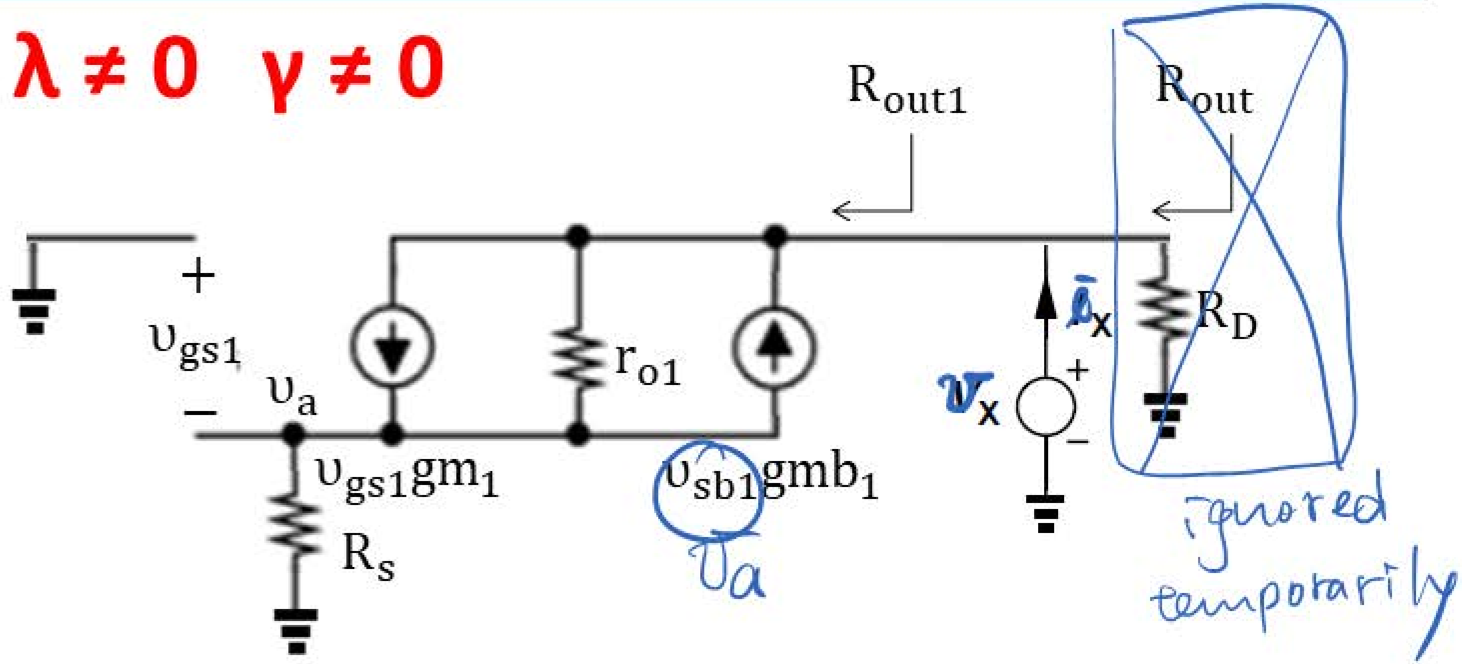
Small signal



Common-Source with Source Degradation

Small-signal Analysis

$\lambda \neq 0 \quad \gamma \neq 0$



$$\begin{cases} i_x = \dfrac{\upsilon_a}{R_S} \\ \upsilon_a gm_1 + \upsilon_a gmb_1 + \dfrac{\upsilon_a - \upsilon_x}{r_o} + i_x = 0 \end{cases}$$

$$R_{out} = R_{out1} \parallel R_D = \boxed{[R_S + r_{o1} + (gm_1 + gmb_1) r_{o1} R_S]} \parallel R_D \approx R_D$$

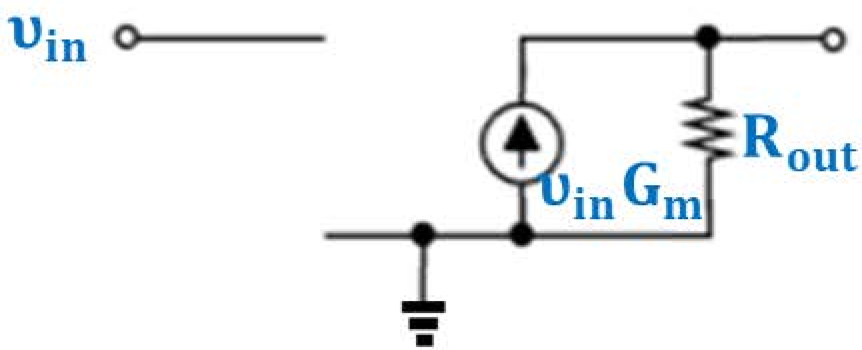
$= \upsilon_x / i_x = R_{out1}$

If $(gm_1 + gmb_1) r_{o1} R_S >> R_D$

Common-Source with Source Degradation

Small-signal Analysis

$\lambda \neq 0 \quad \gamma \neq 0$



$v_{out} = v_{in} G_m R_{out}$

$$A_v = \frac{v_{out}}{v_{in}} = G_m R_{out}$$

$$= \frac{-gm_1 r_{o1}}{\cancel{R_S + r_{o1} + (gm_1 + gmb_1) r_{o1} R_S}} \cdot \frac{\cancel{[R_S + r_{o1} + (gm_1 + gmb_1) r_{o1} R_S]} R_D}{[R_S + r_{o1} + (gm_1 + gmb_1) r_{o1} R_S] + R_D}$$

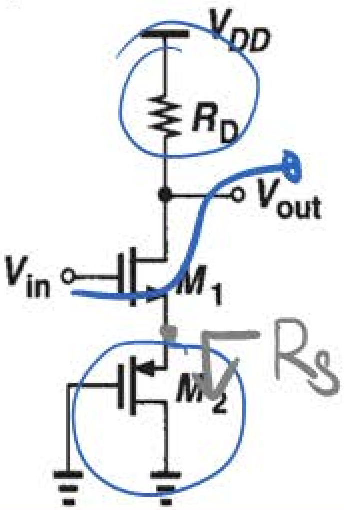
$$\approx -\frac{R_D}{R_S}$$

If $(gm_1 + gmb_1) r_{o1}$, the intrinsic gain, is large.

if $gmb \ll gm$

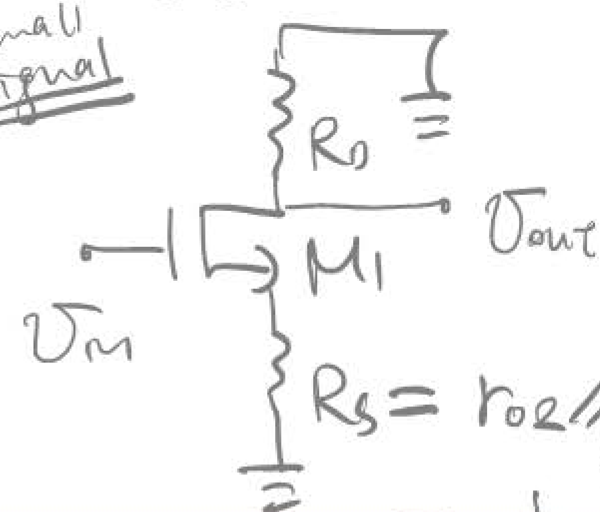
Example

Assuming λ = γ = 0, calculate the small signal voltage gain of the circuit below.



⇒

small signal



$$R_S = r_{o2} \parallel \left(\frac{1}{g_{m2}+g_{mb2}}\right) = \frac{1}{g_{m2}}$$

Solution:

$$G_m = -\frac{1}{\frac{1}{gm_1}+\frac{1}{gm_2}}$$

$$R_{out} = R_D$$

$$A_v = G_m R_{out}$$