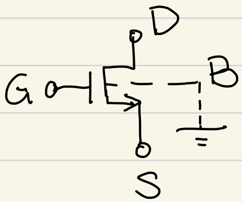
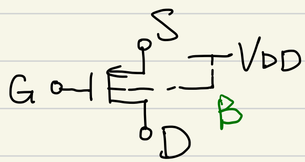
Single-Stage Amplifier RC

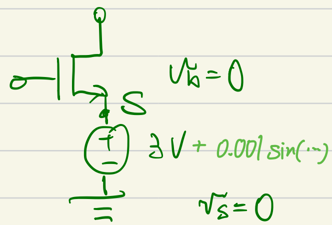
Recap from last RC:



NMOS



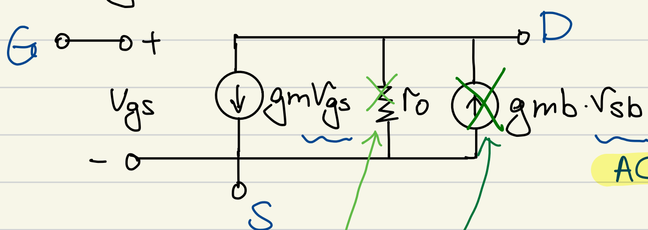
PMOS



$v_{sb} = 0$

则 $v_{sb} = 0.001$

small-signal model:



AC

Note: ① No body effect: 1° $\gamma = 0 \Rightarrow g_{mb} = 0$

2° $v_{sb} = 0$

② No channel length: $\lambda = 0 \Rightarrow r_o = \infty$

L: L_{eff}

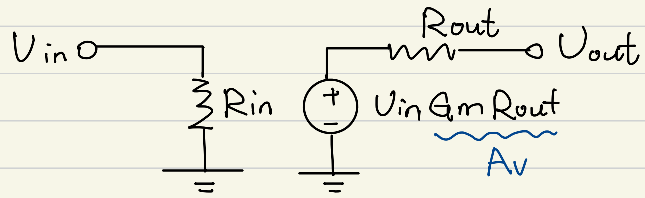
L': $L_{eff}(1+\lambda V_{DS})$.

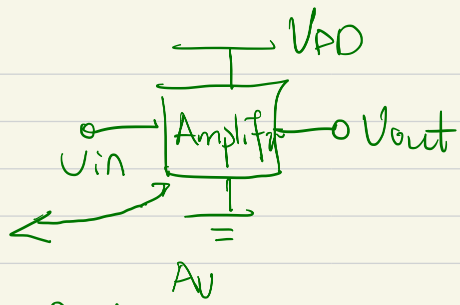
$$r_o = \frac{1}{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2 \cdot \lambda}$$

$$g_m = \mu_n C_{ox}\frac{W}{L'}(V_{GS}-V_{TH}) = \frac{2I_D}{V_{GS}-V_{TH}}$$

$$g_{mb} = -\mu_n C_{ox}\frac{W}{L'}(V_{GS}-V_{TH})\frac{\gamma}{2}\cdot\frac{1}{\sqrt{|2\phi_F + V_{SB}|}}$$

General Amplifier Model:





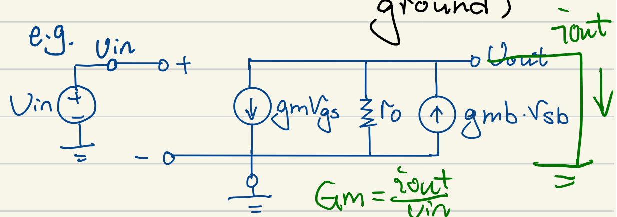
$V_{out} = V_{in} G_m \cdot R_{out}$

① To get G_m:

1° short V_{out} to small-signal ground. (i_{out} goes into ground)

2° $G_m = \dfrac{i_{out}}{V_{in}}$

e.g.



$G_m = \dfrac{i_{out}}{V_{in}}$

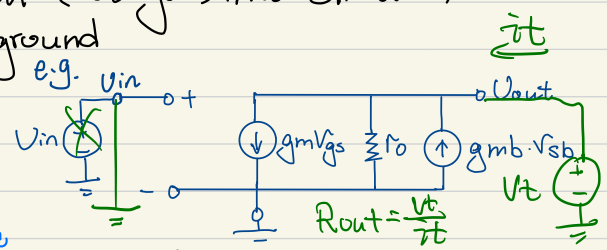
② To get R_{out}:

1° Put V_t at V_{out} (i_t goes into circuit)

2° Short V_{in} to ground

3° $R_{out} = \dfrac{V_t}{i_t}$

e.g.



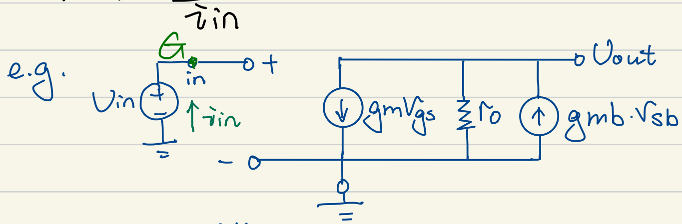
$R_{out} = \dfrac{V_t}{i_t}$

③ To get R_{in}:

1° Denote i_{in} goes into circuit (Do nothing else to current circuit) 流进电流

2° $R_{in} = \dfrac{V_{in}}{i_{in}}$

e.g.

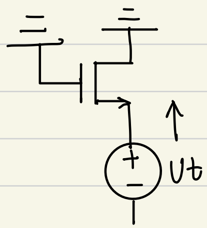


$R_{in} = \dfrac{V_{in}}{i_{in}} = \infty$

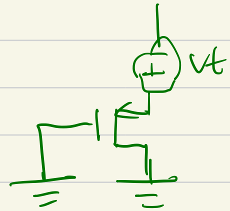
* How to obtain Rout for different circuit efficiently?

☆ 记住以下几个基本模型：（熟练运用！）

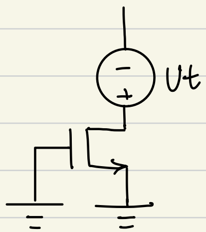
①



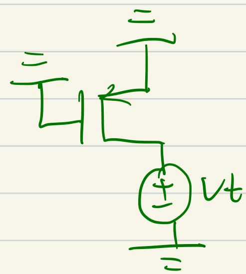
$$R_{out} = \frac{1}{g_m} \,//\, \frac{1}{g_{mb}} \,//\, r_o$$



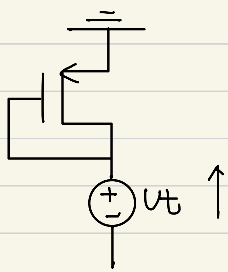
②



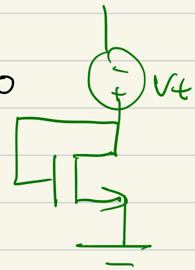
$$R_{out} = r_o$$



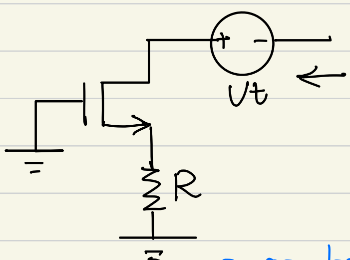
③



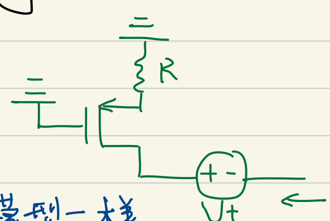
$$R_{out} = \frac{1}{g_m} \,//\, r_o$$



④



$$R_{out} = (g_m + g_{mb}) r_o R + r_o + R$$

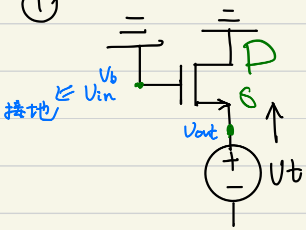


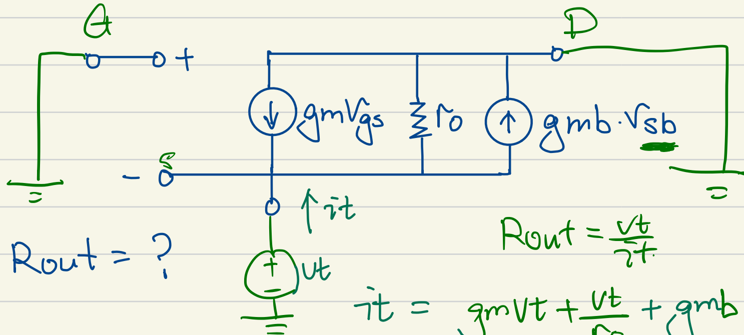
source degradulation：source有电阻

* PMOS 和 NMOS "上下翻转一样" 则模型一样

Analysis:

①





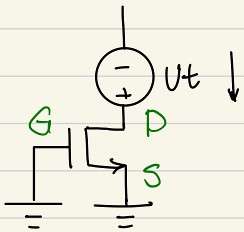
Rout = ?

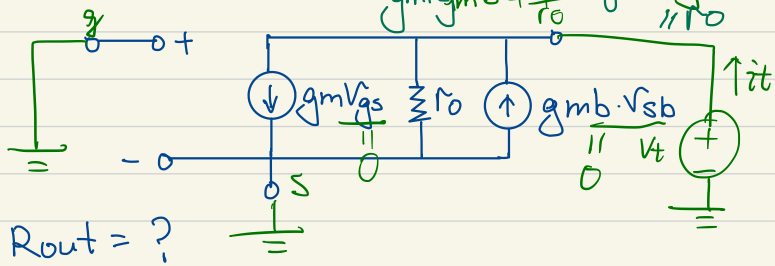
$$R_{out} = \frac{v_t}{i_t}$$

$$i_t = g_m v_t + \frac{v_t}{r_o} + g_{mb} v_t$$

$$R_{out} = \frac{1}{g_m + g_{mb} + \frac{1}{r_o}} = \frac{1}{g_m} // \frac{1}{g_{mb}} // r_o$$

②

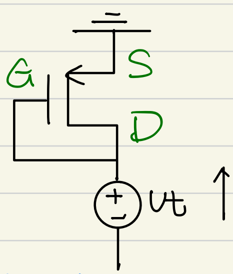




Rout = ?

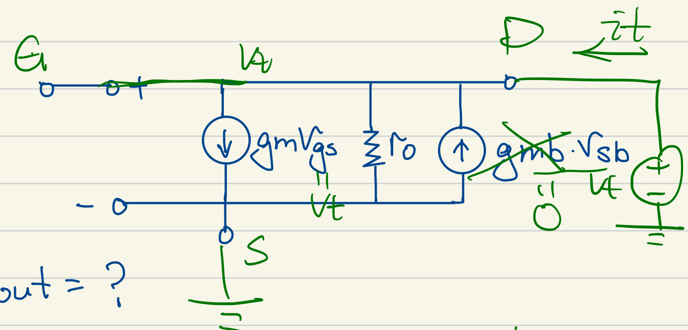
$$R_{out} = \frac{v_t}{i_t} = \frac{v_t}{\frac{v_t}{r_o}} = r_o$$

③



PMOS 默认接VDD

小信号中$V_b = 0$.



Rout = ?

$$R_{out} = \frac{v_t}{i_t} = \frac{v_t}{g_m v_t + \frac{v_t}{r_o}} = \frac{1}{g_m} // r_o$$

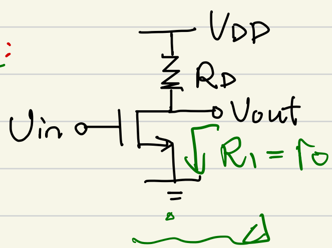
区分 Common Source, Source Follower, Common Gate:

看 signal path! (Vin 到 Vout 的 path)

	Vin	Vout	
CS	G	D	} $R_{in} = \infty$.
SF	G	S	
CG	S	D	

Common Source: Gate进 Drain出

*记:

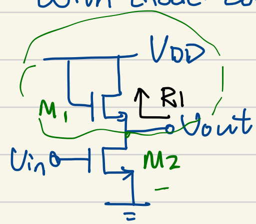


$R_{in} = \infty$

$R_{out} = R_D // r_o$

$G_m = -g_m$

*变型: 2° with diode-connected load, 写的时候注意 Vsb.



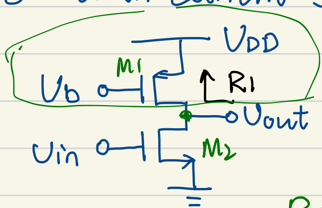
$R_1 = \frac{1}{g_{m1}} // \frac{1}{g_{mb}} // r_{o1}$

$G_m = ?\ -g_m$

$R_{out} = ?\ \frac{1}{g_{m1}} // \left[\frac{1}{g_{mb1}}\right] \cancel{\left[// r_{o1} // r_{o2}\right]}$

$[\lambda = 0]$ $[\gamma = 0]$

3° with current source load

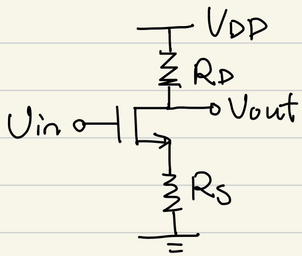


$G_m = -g_m$

$R_{out} = ?\ r_{o1} // r_{o2}$

$R_1 = r_{o1}$

*记: 4° with source degraduation



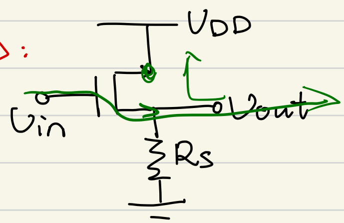
$R_{in} = \infty$

* $G_m = \dfrac{-g_m r_o}{R_s + r_o + (g_m + g_{mb}) r_o R_s}$

$R_{out} = [R_s + r_o + (g_m + g_{mb}) r_o R_s] // R_D$

Source Follower: Gate 进 source 出

*记:



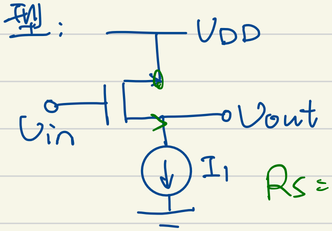
$R_{in} = \infty$

$G_m = g_m$

$R_{out} = r_o // R_s // \dfrac{1}{g_m} // \dfrac{1}{g_{mb}}$

*变型:

1°

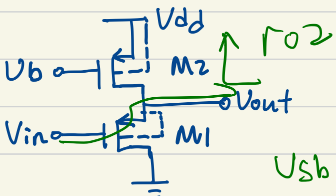


$R_s = \infty$

$G_m = ?$ g_m

$R_{out} = ?$ $r_o // \dfrac{1}{g_m} // \dfrac{1}{g_{mb}}$

2° with current source load

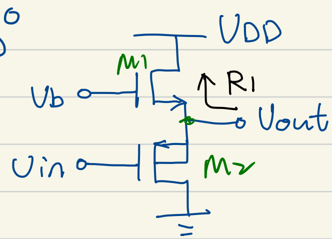


$R_{out} = ?$ $r_{o1} // r_{o2} // \dfrac{1}{g_{m1}}$

$V_{sb} = 0 \Rightarrow g_{mb1}$无

SF

3°



$$R_1 = \frac{1}{g_{m1}} \,//\, \frac{1}{g_{mb1}} \,//\, r_{o1}$$

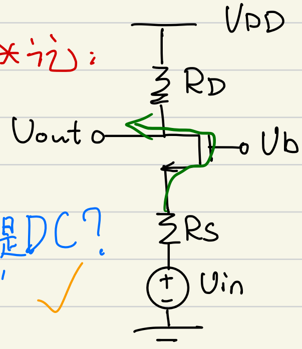
$$R_{out} = \;?\; \frac{1}{g_{m1}} \,//\, \frac{1}{g_{mb1}} \,//\, r_{o1} \,//\, r_{o2} \,//\, \frac{1}{g_{m2}}$$

"Rs"

Common-gate:

Source进 Drain出.

*记:



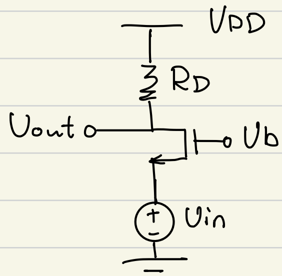
Vb是DC?

42' ✓

$$G_m = \frac{(g_m + g_{mb})r_o + 1}{r_o + R_S + (g_m + g_{mb})r_o R_S}$$

$$R_{out} = R_D \,//\, [r_o + R_S + (g_m + g_{mb})r_o R_S]$$

$$R_{in} = \frac{1 + R_S(g_m + g_{mb}) + \frac{1}{r_o}(R_S + R_D)}{g_m + g_{mb} + \frac{1}{r_o}}$$



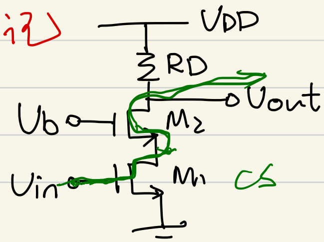
$$* \; R_{in} = \frac{R_D + r_o}{1 + (g_m + g_{mb})r_o}$$

P133?

Cascode

CS+CG:

*记



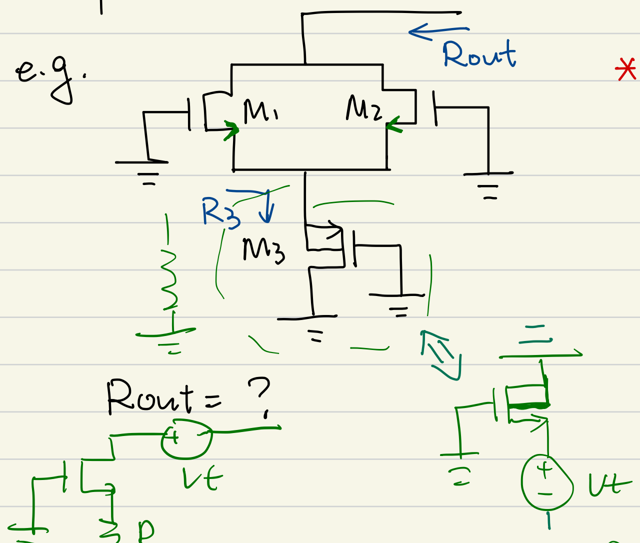
$$G_m = -g_{m1} \frac{r_{o1}}{r_{o1} + (r_{o2} \,//\, \frac{1}{g_{m2}} \,//\, \frac{1}{g_{mb2}})}$$

$$R_{out} = [r_{o1} + r_{o2} + (g_{m2} + g_{mb2})r_{o1}r_{o2}] \,//\, R_D$$

$$R_{in} = \infty$$

并联 MOS ;

e.g.



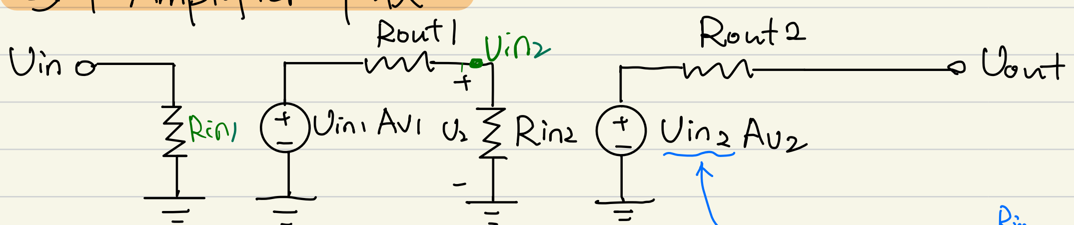
* 两个 MOS并联:

$$g_m = g_{m1} + g_{m2}$$
$$g_{mb} = g_{mb1} + g_{mb2}$$
$$r_o = r_{o1} // r_{o2}$$

$$R_3 = \frac{1}{g_{m3}} // r_{o3}$$

$$R_{out} = (g_m + g_{mb}) r_o \underbrace{R}_{R_3} + r_o + R$$

多个 Amplifier 串联:



$$V_2 = V_{in1} \cdot A_{V1} \cdot \frac{R_{in2}}{R_{out1} + R_{in2}} \cdot A_{V2} = V_{out}$$

$$A_V = \frac{V_{out}}{V_{in}} = A_{V1} \cdot \frac{R_{in2}}{R_{out1} + R_{in2}} \cdot A_{V2}$$

其中 $A_{V1} = G_{m1} \cdot R_{out1}$

$A_{V2} = G_{m2} \cdot R_{out2}$

假设100个 Amplifier 连在一起，Rin，Gm，Rout 均相等

$$A_V = A_{V1} \cdot \frac{R_{in}}{R_{out}+R_{in}} \cdot A_{V2} \cdot \frac{R_{in}}{R_{out}+R_{in}} \cdots A_{100}$$

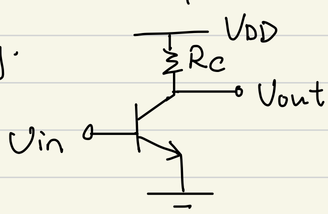
$$= G_m^{100} \frac{R_{out}^{100} \cdot R_{in}^{99}}{(R_{out}+R_{in})^{99}}$$

$$= G_m^{100} (R_{out} /\!/ R_{in})^{99} R_{out}$$

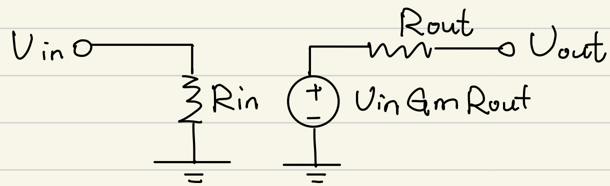
✡ If $R_{in} = \infty$, $A_V = A_{V1} \cdot A_{V2} \cdots A_{V100}$

* 记 BJT Amplifier

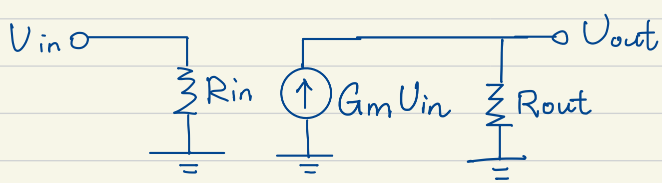
e.g.



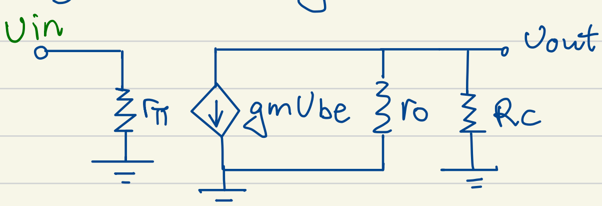
⇒



equivalent general amplifier model:



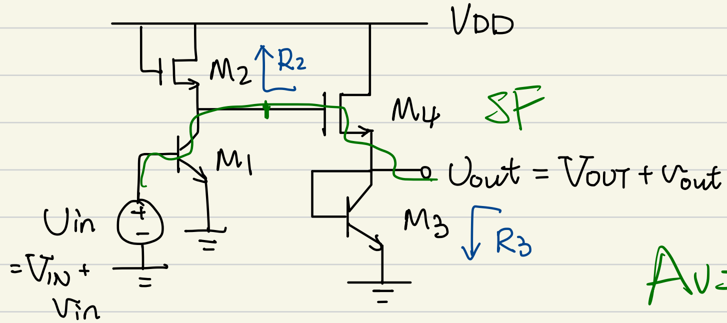
BJT's small-signal model:



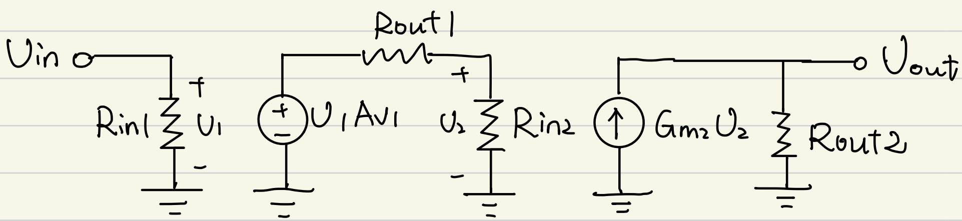
✡
$R_{in} = r_\pi$
$R_{out} = r_o /\!/ R_c$
$G_m = -g_m$

M_2 : Rout

Ex. (2020SU Final Exam)



$$A_v = A_{v1} \cdot \frac{R_{in2}}{R_{out1}+R_{in2}} \cdot A_{v2}$$



Derive analytical expressions for R_{in1}, R_{out1}, A_{v1}, R_{in2}, R_{out2}, G_{m2}

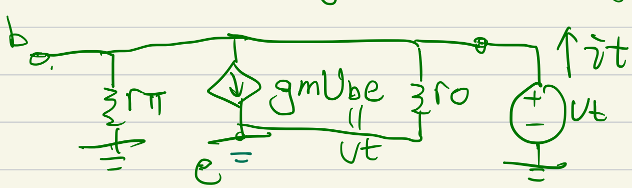
$$R_2 = \frac{1}{g_{m2}} // \frac{1}{g_{mb2}} // r_{o2}$$

$$R_{out1} = r_{o1} // R_2 = r_{o1} // r_{o2} // \frac{1}{g_{m2}} // \frac{1}{g_{mb2}}$$

$$R_{in1} = r_{\pi 1}$$

$$G_{m1} = -g_{m1}$$

$$A_{v1} = G_{m1} \cdot R_{out1} = -g_{m1}\left(r_{o1} // r_{o2} // \frac{1}{g_{m2}} // \frac{1}{g_{mb2}}\right)$$



$$R_3 = \frac{v_t}{i_t} \qquad i_t = \frac{v_t}{r_\pi} + \frac{v_t}{r_o} + g_m v_t \qquad R_3 = \frac{1}{g_{m3}} // r_{o3} // r_{\pi 3}$$

SF: $R_{in2} = \infty$

$G_{m2} = g_{m4}$

$$R_{out2} = R_3 // r_{o4} // \frac{1}{g_{m4}} // \frac{1}{g_{mb4}}$$

Solution:

① 1^{st} stage (M_1)

$$R_2 = \frac{1}{g_{m2}} // \frac{1}{g_{mb2}} // r_{o2}$$

$$R_{in1} = r_{\pi 1}$$

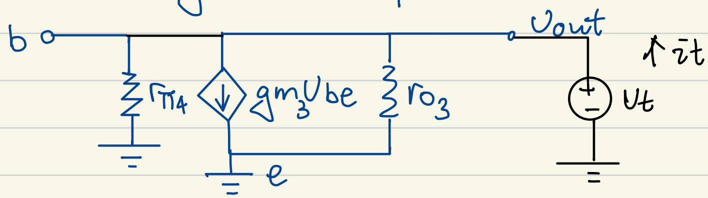
$$R_{out1} = r_{o1} // R_2 = r_{o1} // \frac{1}{g_{m2}} // \frac{1}{g_{mb2}} // r_{o2}$$

$$G_{m1} = -g_{m1}$$

$$A_{v1} = G_{m1} \cdot R_{out1} = -g_{m1} \cdot \left(r_{o1} // r_{o2} // \frac{1}{g_{m2}} // \frac{1}{g_{mb2}}\right)$$

② 2^{nd} stage (M_4)

1° R_3 用small-signal model 算（沒有模型可以套）：



$$R_3 = \frac{V_t}{i_t} \qquad i_t = g_{m3} V_t + \frac{V_t}{r_{\pi 3}} + \frac{V_t}{r_{o3}}$$

$$R_3 = \frac{1}{g_{m3}} // r_{\pi 3} // r_{o3}$$

2° M_4 is Source Follower

$$R_{in2} = \infty$$

$$G_{m2} = g_{m4}$$

$$R_{out2} = r_{o4} // \frac{1}{g_{m4}} // \frac{1}{g_{mb4}} // R_3$$

$$= r_{o4} // \frac{1}{g_{m4}} // \frac{1}{g_{mb4}} // \frac{1}{g_{m3}} // r_{\pi 3} // r_{o3}$$

$$A_v = ?$$