VE311 FINAL RC - Single Stage Amplifier

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Overview

Basics

- DC
- gm & r_o & gmb
- Gm & R_{out} & R_{in} & A_v

Circuits and Formulas

- Common Source
- Source Degradation
- Source Follower
- Common Gate

Tips

DC Calculation

Current (NMOS)
Non-saturation region:

$$\boxed{I_D = \mu_n C_{ox} \frac{W}{L_{eff}} \left[(V_{GS} - V_{TH}) V_{DS} - \frac{1}{2} V_{DS}^2 \right]}$$

Saturation region:

$$\boxed{I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L_{eff}} (V_{GS} - V_{TH})^2 (1 + \lambda V_{DS})}$$

where $V_{TH} = VTO$, $\dfrac{W}{L_{eff}} = \dfrac{W_{drawn}}{L_{drawn} - 2LD}$, $C_{ox} = \dfrac{\epsilon_r \epsilon_0}{TOX}$, and $\mu_n = UO \times 10^{-4}$

gm & r_o & gmb

For NMOS,

$$\boxed{gm = \frac{\partial I_D}{\partial V_{GS}} = \frac{2I_D}{V_{GS} - V_{TH}}}$$

$$\boxed{r_o = \frac{\partial V_{DS}}{\partial I_D} \approx \frac{1}{I_D \lambda}}$$

$$\boxed{gmb = \frac{\partial I_D}{\partial V_{SB}} = -\mu_n C_{ox} \frac{W}{L_{eff}} (V_{GS} - V_{TH}) \cdot \frac{\gamma}{2} \cdot \frac{1}{\sqrt{|2\phi_F + V_{SB}|}}}$$

where $\lambda = LAMBDA$, $\gamma = GAMMA$, and $2\phi_F = PHI$.

Gm & R_{out}

How to calculate Gm?

1. Draw small signal model.
2. Connect port with V_{out} to ground.
3. Derive i_{out}.
4. Calculate $Gm = \frac{i_{out}}{v_{in}}$.

How to calculate R_{out}**?**

1. Draw small signal model.
2. Connect port with V_{in} to ground. Connect a test voltage v_t on port with V_{out}.
3. Derive i_t.
4. Calculate $R_{out} = \frac{v_t}{i_t}$.

R_{in} & A_v

How to calculate $\mathrm{R_{in}}$**?**

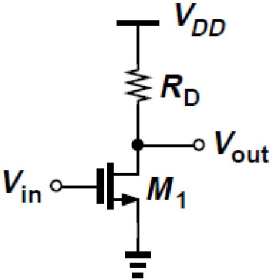
1. Draw small signal model.
2. Connect port with V_{out} to ground. Connect a test voltage v_t on port with V_{in}.
3. Derive i_t.
4. Calculate $R_{in} = \frac{v_t}{i_t}$.

How to calculate $\mathrm{A_v}$**?**

$$A_v = GmR_{out}$$

Common Source with Resistive Load

Basic Circuit $(\lambda, \gamma \neq 0)$



$$Gm = -gm_1$$

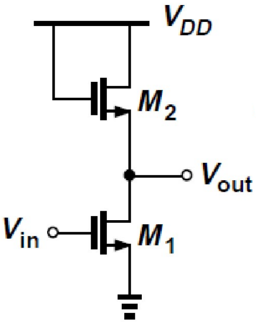
$$R_{out} = r_o || R_D$$

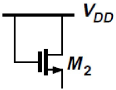
$$A_v = -gm_1(r_o || R_D)$$

* What if R_D is replaced by a DC current source? (slide page 9)
* What if M_1 is a PMOS?

Common Source with Diode-Connected Load

Basic Circuit $(\lambda, \gamma \neq 0)$





$$\Rightarrow \frac{1}{gm_2} || \frac{1}{gmb_2} || r_{o2}$$

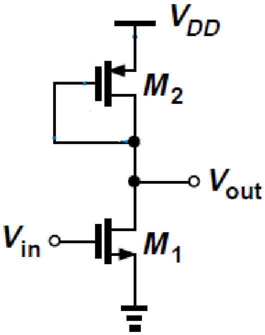
$$Gm = -gm_1$$

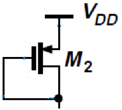
$$R_{out} = r_{o1} || \frac{1}{gm_2} || \frac{1}{gmb_2} || r_{o2}$$

$$A_v = -gm_1 \left(r_{o1} || \frac{1}{gm_2} || \frac{1}{gmb_2} || r_{o2} \right)$$

Common Source with Diode-Connected Load (Cont.)

Basic Circuit $(\lambda, \gamma \neq 0)$





$$\Rightarrow \frac{1}{gm_2}||r_{o2}$$

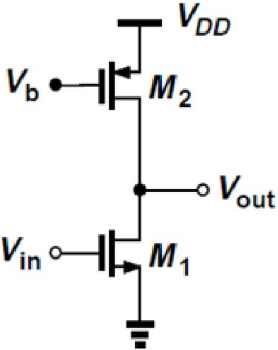
$$Gm = -gm_1$$

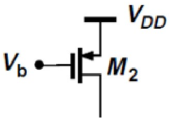
$$R_{out} = r_{o1}||\frac{1}{gm_2}||r_{o2}$$

$$A_v = -gm_1\left(r_{o1}||\frac{1}{gm_2}||r_{o2}\right)$$

Common Source with Current-Source Load

Basic Circuit ($\lambda, \gamma \neq 0$)





$\Rightarrow r_{o2}$

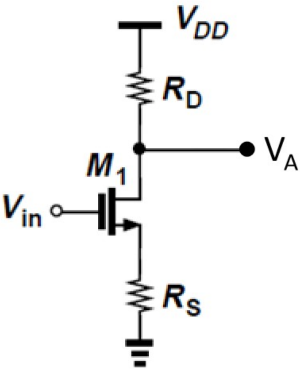
$$Gm = -gm_1$$

$$R_{out} = r_{o1}||r_{o2}$$

$$A_v = -gm_1\left(r_{o1}||r_{o2}\right)$$

Common Source with Source Degradation

Basic Circuit $(\lambda, \gamma \neq 0)$



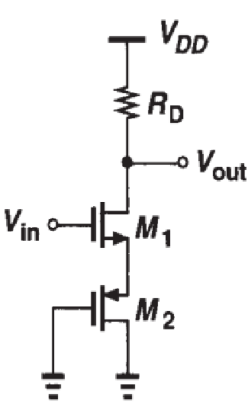
$$Gm = \frac{-gm_1 r_{o1}}{R_S + r_{o1} + (gm_1 + gmb_1)\, r_{o1} R_S}$$

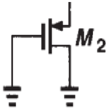
$$R_{out} = [R_S + r_{o1} + (gm_1 + gmb_1)\, r_{o1} R_S] \,||\, R_D$$

* What if M_1 is a PMOS?

Common Source with Source Degradation (Cont.)

Basic Circuit $(\lambda, \gamma \neq 0)$





$$\Rightarrow \frac{1}{gm_2} || \frac{1}{gmb_2} || r_{o2}$$

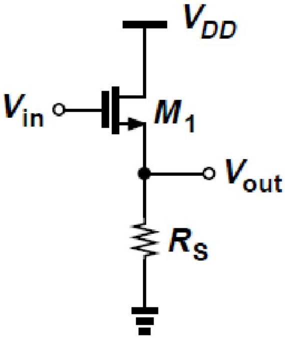
$$Gm = \frac{-gm_1 r_{o1}}{R_S + r_{o1} + (gm_1 + gmb_1)\, r_{o1} R_S}$$

$$R_{out} = [R_S + r_{o1} + (gm_1 + gmb_1)\, r_{o1} R_S] \, || R_D$$

with R_S replaced by $\frac{1}{gm_2} || \frac{1}{gmb_2} || r_{o2}$

Source Follower

Basic Circuit $(\lambda, \gamma \neq 0)$



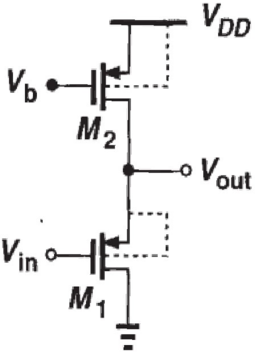
$$Gm = gm_1$$

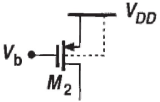
$$R_{out} = r_{o1}||R_S||(\frac{1}{gm_1 + gmb_1})$$

* What if M_1 is replaced by a PMOS?

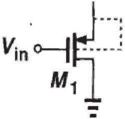
Source Follower with Current Source

Basic Circuit $(\lambda, \gamma \neq 0)$





$\Rightarrow r_{o2}$



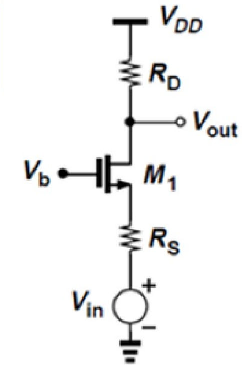
$\Rightarrow r_{o1} || \dfrac{1}{gm_1}$

$$R_{out} = r_o1 || \frac{1}{gm_1} || r_{o2}$$

$$Gm = gm_1$$

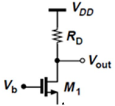
Common Gate

Basic Circuit ($\lambda, \gamma \neq 0$)



$$G_m = \frac{(gm_1 + gmb_1)r_{o1} + 1}{r_{o1} + R_S + (gm_1 + gmb_1)r_{o1}R_S}$$

$$R_{out} = R_D \| \left[r_{o1} + R_S + (gm_1 + gmb_1)r_{o1}R_S\right.$$

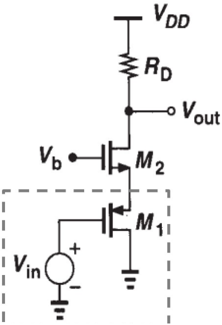


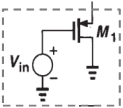
$$\Rightarrow \frac{R_D + r_{o1}}{1 + (gm_1 + gmb_1)r_{o1}}$$

* What if M_1 is replaced by PMOS?

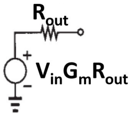
Complex Common Gate

$(\lambda, \gamma \neq 0)$



For 

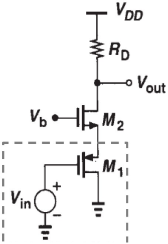
, take it as a source follower with infinity source resistance. Then we get



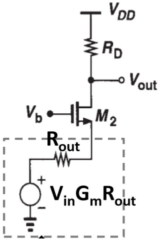
$$\begin{cases} G_m = gm_1 \\ R_{out} = r_{o1} \parallel \dfrac{1}{gm_1} \parallel \dfrac{1}{gmb_1} \end{cases}$$

Complex Common Gate (Cont.)

Then



$\Rightarrow$



with

$$G_m = \frac{(gm_2 + gmb_2)r_{o2} + 1}{r_{o2} + R_S + (gm_2 + gmb_2)r_{o2}R_S} \cdot gm_1 \left(r_{o1} || \frac{1}{gm_1} || \frac{1}{gmb_1} \right)$$

$$R_{out} = R_D || \left[r_{o2} + R_S + (gm_2 + gmb_2)r_{o2}R_S \right]$$

$$\text{where } R_S = r_{o1} || \frac{1}{gm_1} || \frac{1}{gmb_1}$$

Some Tips qwq

- Derive all the Gm and R_{out} yourself before the final.
- Small signal model!!!
- Small signal models, equations, and explanation do matter if you cannot guarantee your final result is correct.
- When plotting, please mark your diagram well!!!(peak values, period. . .).

Good Luck for Your FINAL!