

# VE311 FINAL RC - Single Stage Amplifier

Runxi Wang

UM-SJTU JI

*wangrunxi@sjtu.edu.cn*

December 9, 2021

# Overview

## Basics

DC

$g_m$  &  $r_o$  &  $g_{mb}$

$G_m$  &  $R_{out}$  &  $A_v$

## Circuits and Formulas

Common Source

Source Degradation

Source Follower

Common Gate

## Tips



## DC Calculation

### Current (NMOS)

Non-saturation region:

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

Saturation region:

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

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



## $gm$ & $r_o$ & $gmb$

For NMOS,

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

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

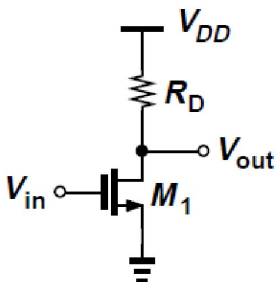
$$gmb = \frac{\partial I_D}{\partial V_{SB}} = -\mu_n C_{ox} \frac{W}{L_{eff}} (V_{GS} - V_{TH}) \cdot \frac{\gamma}{2} \cdot \frac{1}{\sqrt{|2\phi_F + V_{SB}|}}$$

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

$G_m$  &  $R_{out}$  &  $A_v$

## Common Source with Resistive Load

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



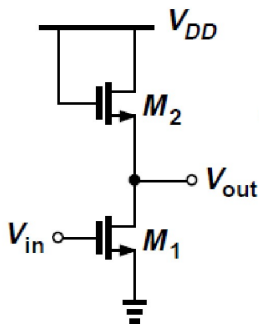
$$G_m = -g_{m1}$$

$$R_{out} = r_o \parallel R_D$$

$$A_v = -g_{m1}(r_o \parallel R_D)$$

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

### c Circuit ( $\lambda, \gamma \neq 0$ )



$$\Rightarrow \frac{1}{g_{m2}} \parallel \frac{1}{g_{mb2}} \parallel r_{o2}$$

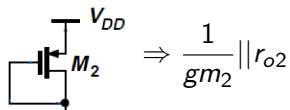
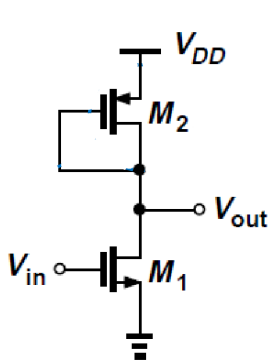
$$Gm = -gm_1$$

$$R_{out} = r_{o1} || \frac{1}{g_{m2}} || \frac{1}{g_{mb2}} || r_{o2}$$

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

# Common Source with Diode-Connected Load (Cont.)

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



$$G_m = -g_{m1}$$

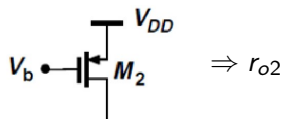
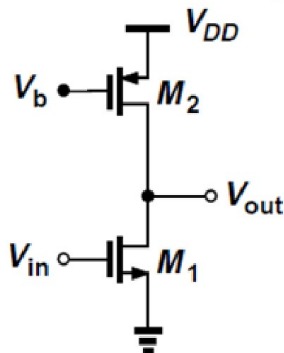
$$R_{out} = r_{o1} \parallel \frac{1}{g_{m2}} \parallel r_{o2}$$

$$A_v = -g_{m1} \left( r_{o1} \parallel \frac{1}{g_{m2}} \parallel r_{o2} \right)$$



# Common Source with Current-Source Load

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



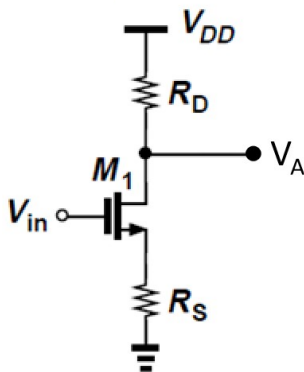
$$G_m = -g_{m1}$$

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

$$A_v = -g_{m1} (r_{o1} || r_{o2})$$

## Common Source with Source Degradation

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



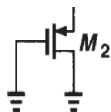
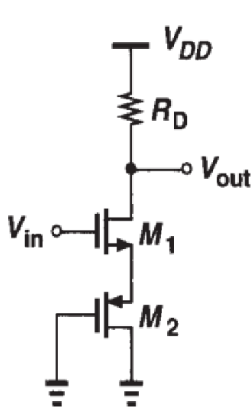
$$G_m = \frac{-g_{m1} r_{o1}}{R_S + r_{o1} + (g_{m1} + g_{mb1}) r_{o1} R_S}$$

$$R_{out} = [R_S + r_{o1} + (g_{m1} + g_{mb1}) r_{o1} R_S] \parallel R_D$$

\* What if  $M_1$  is a PMOS?

# Common Source with Source Degradation (Cont.)

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



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

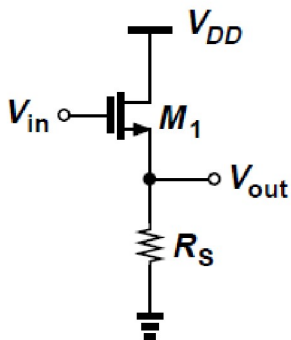
$$G_m = \frac{-gm_1 r_{o1}}{R_S + r_{o1} + (gm_1 + gmb_1) r_{o1} R_S}$$

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

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

## Source Follower

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

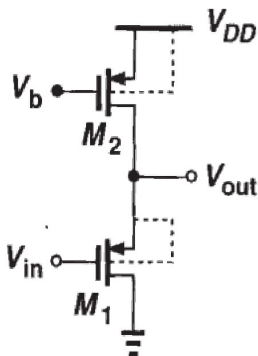


$$Gm = gm_1$$
$$R_{out} = r_{o1} || R_S || \left( \frac{1}{gm_1 + gmb_1} \right)$$

\* What if  $M_1$  is replaced by a PMOS?

# Source Follower with Current Source

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



The small-signal equivalent circuit shows the PMOS transistor  $M_2$  as a dependent current source  $g_{m2}v_b$  in parallel with its output resistance  $r_{o2}$ . The NMOS transistor  $M_1$  is represented by its transconductance  $g_{m1}$  and output resistance  $r_{o1}$  in parallel. The input voltage  $V_{in}$  is applied to the gate of  $M_1$ . The output resistance is the parallel combination of  $r_{o1}$ ,  $1/g_{m1}$ , and  $r_{o2}$ .

$$\Rightarrow r_{o2}$$

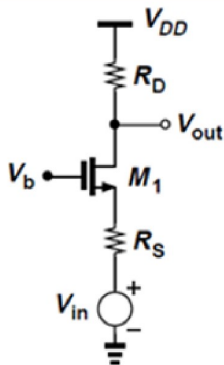
$$\Rightarrow r_{o1} \parallel \frac{1}{g_{m1}}$$

$$R_{out} = r_{o1} \parallel \frac{1}{g_{m1}} \parallel r_{o2}$$

$$Gm = g_{m1}$$

## Common Gate

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



$$G_m = \frac{(g_{m1} + g_{mb1})r_{o1} + 1}{r_{o1} + R_S + (g_{m1} + g_{mb1})r_{o1}R_S}$$

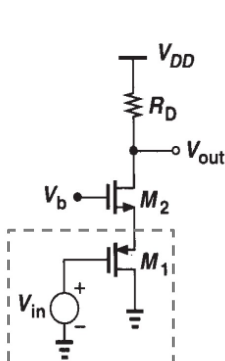
$$R_{out} = R_D \parallel [r_{o1} + R_S + (g_{m1} + g_{mb1})r_{o1}R_S]$$

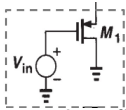
$$\Rightarrow \frac{R_D + r_{o1}}{1 + (g_{m1} + g_{mb1})r_{o1}}$$

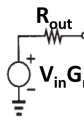
\* What if  $M_1$  is replaced by PMOS?

## Complex Common Gate

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



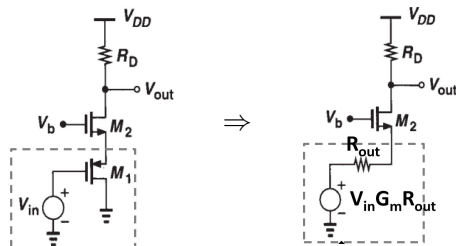
For , take it as a source follower with infinity source resistance. Then we get



$$\left\{ \begin{array}{l} G_m = g_{m1} \\ R_{out} = r_{o1} \parallel \frac{1}{g_{m1}} \parallel \frac{1}{g_{mb1}} \end{array} \right.$$

## Complex Common Gate (Cont.)

Then



with

$$G_m = \frac{(g_{m2} + g_{mb2})r_{o2} + 1}{r_{o2} + R_S + (g_{m2} + g_{mb2})r_{o2}R_S} \cdot g_{m1} \left( r_{o1} \parallel \frac{1}{g_{m1}} \parallel \frac{1}{g_{mb1}} \right)$$

$$R_{out} = R_D \parallel [r_{o2} + R_S + (g_{m2} + g_{mb2})r_{o2}R_S]$$

$$\text{where } R_S = r_{o1} \parallel \frac{1}{g_{m1}} \parallel \frac{1}{g_{mb1}}$$



## Some Tips qwq

- Understand all the formulas will help.
- Please write down partial steps in the exam.
- When plotting, please mark your diagram well (peak values, period. . . ).

# Good Luck for Your Mid!