Chap.2. MOS器件

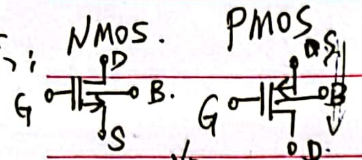
PVT: { process 工艺, Volutage 电压, Temperature 温度 }

思考：为什么常用 nMOS (p衬底)
① $\mu_p < \mu_n$ 迁移率

过程：V_{GS}↑ 耗尽 → 反型 → 面

$L_{eff} \approx L-2L_D$
阈值：$L_{eff}=L-2L_D$
三极：$L=L$

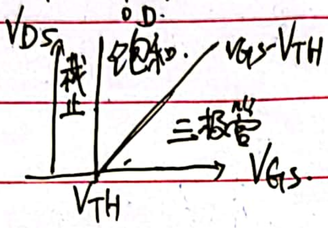
① 表示：



$A=\mu_n C_{ox}\frac{W}{L_{eff}}$

$V_{GS}-V_{TH}=V_{Dsat}$　长沟道 $L_{eff}\approx L$

② 分区：NMOS：



截止：$I_D=0$

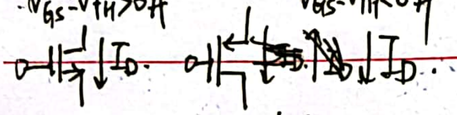
三极管：$I_D=A(\cancel{(V_{GS}-V_{TH})}V_{Dsat}V_{DS}-\frac{1}{2}V_{DS}^2)$

深三极管(电阻)：$I_D=AV_{Dsat}V_{DS}$，$g_{on}=AV_{Dsat}$　$g_m=AV_{DS}$

饱和：$I_D=\frac{1}{2}A\cdot V_{Dsat}^2$ } $\Rightarrow g_m=\sqrt{2AI_D}$

$g_m=\frac{\partial I_D}{\partial V_{GS}}=AV_{Dsat}$

I_D定义方向：



$I_D=+A\cdots$　　$I_D=+A\cdots$

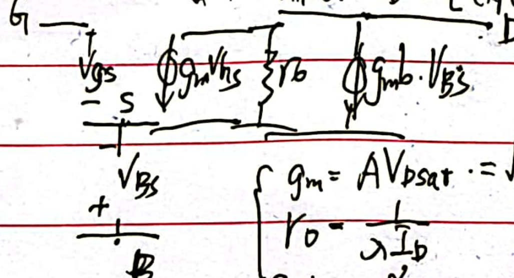
③ 二阶效应：1) 体效应 $V_{TH}'=V_{TH0}+\gamma(\sqrt{2\Phi_F+V_{SB}}-\sqrt{2\Phi_F})$　$\gamma=\sqrt{2q\varepsilon_{si}N_{sub}}/C_{ox}$

2) 沟道长度调制 (饱和区) $I_D=\frac{1}{2}AV_{Dsat}^2(1+\lambda V_{DS})$　$\lambda V_{DS}=\frac{\Delta L}{L}$

$g_m=AV_{Dsat}(1+\lambda V_{DS})$

3) 亚阈值导电：$V_{GS}=V_{TH}+0$，$I_D\propto\frac{W}{L}\exp(\frac{V_{GS}}{\xi V_T})$，$g_m=\frac{I_D}{\xi V_T}$

④ 小信号：饱和区



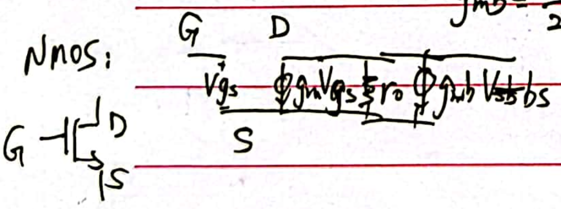
$g_m=AV_{Dsat}=\sqrt{2AI_D}$

$r_0=\frac{1}{\lambda I_D}$

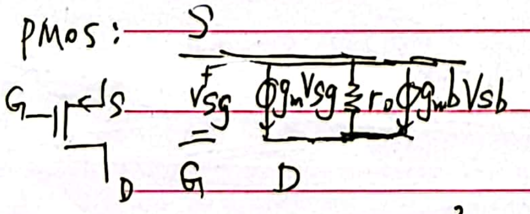
$g_{mb}=\frac{\gamma}{2\sqrt{2\Phi_F+V_{SB}}}g_m=\eta g_m$

μ_n：迁移率，载流子种类
C_{ox}：t_{ox}有关
W：
L：L & L_{eff} & L_D：$L_{eff}=L-2L_D$
λ：$\frac{\Delta L}{L}=\lambda V_{DS}$　$\lambda\propto\frac{1}{L}$
$\gamma=\sqrt{2q\varepsilon_{si}}\frac{\sqrt{N_{sub}}}{C_{ox}}$

NMOS：



PMOS：



常用数据：$\mu_nC_{ox}\frac{W}{L}=13.42\times10^{-3}$ $(\frac{5\mu m}{0.5\mu m})$
(L=0.5μm，t_{ox}=9nm)
$\mu_pC_{ox}\frac{W}{L}=3.835\times10^{-3}$ $(\frac{5}{0.5})$

$t_{ox}=20Å\rightarrow C_{ox}=17.2fF/\mu m^2$
$t_{ox}=90Å\rightarrow C_{ox}=3.83fF/\mu m^2$

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Chap.3 基本放大器.

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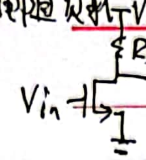
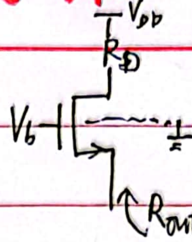
① 电阻负载 V_{DD} R_D V_{out} $A_V=-g_m(R_D//r_o)$



trade: ① $R_D\uparrow$. $A_V\uparrow$ 但 $V_{os}\downarrow$ 摆幅↓.

② $\frac{W}{L}\uparrow$ $g_m\uparrow$ ③ $R_D\uparrow$. $\tau=R_DC\uparrow$. 带宽↓.



增大 R_D

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

$R_D=0$. $\frac{1}{g_m+g_{mb}}//r_o$

$R_D\to\infty$. ∞

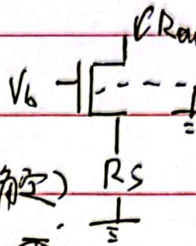
$\lambda=0$. $\approx\frac{1}{g_m+g_{mb}}$

② MOS负载. 问题: $A_V\propto\sqrt{(W/L)_1/(W/L)_2}$. 线性度好

$R_D=$ … $=R_D$. 修正: 电流源

输出摆幅↓. 增益↑.

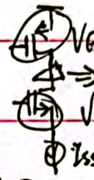
$R_{out}=R_S[1+(g_m+g_{mb})r_o]+r_o$ $\approx R_S[(g_m+g_{mb})r_o]+r_o$. $g_m r_o\gg1$. $\lambda=0$. $\approx\frac{1}{g_m}$.



增大 R_S.

③ 电流源负载. 问题: V_{out} 受 V_b 噪声影响大 (V_{out} 不容易确定)

$R_D=$ $I=V_b$ V_{DD} 修正: 反馈



V_{GS} 确定 ⇒ 电流确定. V_{GS} 确定 I_{SS}

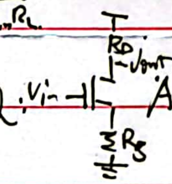
④ 反相器. 缺. ① I_D 受PVT. ② 电源噪声 ③ 输入范围窄

⑤ 源极负反馈. 线性度↑. 增益↓. (摆幅↓)

⑥ 源极跟随器. ~~破线性↓~~. 使电压余度↓. 驱动能力↓ ~~摆幅~~ ~~体效应~~ $I_D(V_{GS}-V_{TH}\downarrow)^2$. (∃输出阻抗) $\frac{g_m R_L}{1+g_m R_L}$

⑦ 共栅放大器.

⑧ 共源共栅放大器. $R_{out}\uparrow$ $A_V\uparrow$ 电压余度↓.

Q:  $A_V=\frac{-R_D}{R_S+\frac{1}{g_m}}$???

Chap.4. 差动放大器.

A: $V_{in\,CM}=\frac{V_{in1}+V_{in2}}{2}$ $V_{out\,CM}=\frac{V_{out1}+V_{out2}}{2}$

$V_{in\,DM}=V_{in1}-V_{in2}$ $V_{out\,DM}=V_{out1}-V_{out2}$.

$A_{DM}=\frac{V_{out\,DM}}{V_{in\,DM}}$. $CMRR=\left|\frac{A_{DM}}{A_{CM-DM}}\right|$

$A_{CM-DM}=\frac{V_{out\,DM}}{V_{in\,CM}}$.

Chap.5.

五管OTA缺点: ① CMRR有限. 理想仍∃ A_{CM-DM}

② 电源噪声

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小结

model

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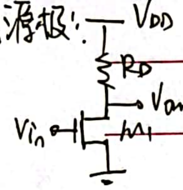
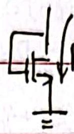
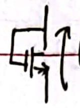
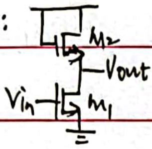
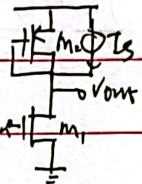
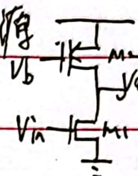
Chap.3.

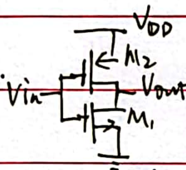
共源极：  $A_v=-g_mR_D$. $(\lambda=\gamma=0)$

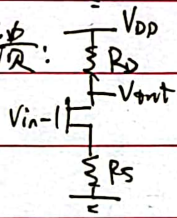
二极管联接：   $R=\frac{1}{g_m}//r_o \approx \frac{1}{g_m}(\lambda=0)$.  $R=\frac{1}{g_m}//r_o//\frac{1}{g_{mb}}$
$=\frac{1}{g_m+g_{mb}}(\lambda=0)$
$=\frac{1}{g_m}(\gamma=0)$.

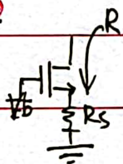
二极管联接共源：  $A_v=-\sqrt{\frac{(W/L)_1 I_{D1}}{(W/L)_2 I_{D2}}}\frac{1}{1+\eta}$
$=-\frac{g_{m1}}{g_{m2}+g_{mb2}}$

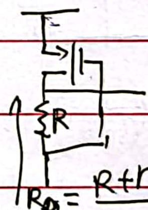
 $A_v=-\frac{g_{m1}}{g_{m2}}$
$=-\sqrt{\frac{\mu_n(W/L)_1 I_{D1}}{\mu_p(W/L)_2 I_{D2}}}$

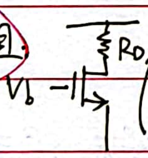
电流源  $A_v=-g_{m1}(r_{o1}//r_{o2})$

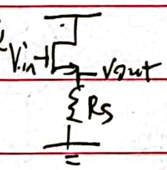
互补共源极  $A_v=-(g_{m1}+g_{m2})(r_{o1}//r_{o2})$.
$\frac{V_{out}}{V_{DD}}=(g_{m2}+\frac{1}{r_{o2}})(r_{o1}//r_{o2})$.

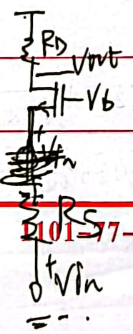
带源极负反馈：  $G_m=\frac{1}{R_S+\frac{1}{g_m}}$ $(\lambda=0,\gamma=0)$. $G_m=\frac{g_mr_o}{[1+(g_m+g_{mb})r_o]R_S+r_o}$ $(\lambda\neq0,\gamma\neq0)$.
$R_{out}=R_D$
$A_V=-G_mR_{out}=\frac{-g_mR_D}{1+g_mR_S}$ $(\lambda=0,\gamma=0)$.
$R_{out}=R_D//[[1+(g_m+g_{mb})r_o]R_S+r_o]$.
$A_v=\frac{-g_mr_oR_D}{R_D+R_S+r_o+(g_m+g_{mb})R_Sr_o}$ $(\lambda\neq0,\gamma\neq0)$.

源极加深电阻： 
$R=f(R_S)=R_S[1+(g_m+g_{mb})r_o]+r_o$ $(\lambda\neq0,\gamma\neq0)$.
$=R_S[1+g_mr_o]+r_o$ $(\lambda\neq0,\gamma=0)$.
$\approx R_S\cdot g_mr_o+r_o$. $(g_mr_o\gg1)$.
$\approx R_S\cdot g_mr_o$ = 断路 $(\lambda=\gamma=0)$.

 $R_{eq}=\frac{R+r_o}{1+g_mr_o}$

源极减小电阻  $R=f(R_D)=\frac{R_D+r_o}{1+(g_m+g_{mb})r_o}$ $(\lambda\neq0,\gamma\neq0)$.
$=\frac{1}{g_m+g_{mb}}$ $(\lambda=0,\gamma\neq0)$.
$=\frac{1}{g_m}$ $(\lambda=0,\gamma=0)$.

源跟随器  $A_v=\frac{g_mR_S}{1+(g_m+g_{mb})R_S}$ $(\lambda=0)$ $=\frac{R_{eq}}{R_{eq}+\frac{1}{g_m}}$. $R_{eq}=R_S//\frac{1}{g_{mb}}//r_o$ $(\lambda\neq0)$
$=\frac{1}{1+\eta}$ $(R_S\to\infty)$. $\to=\frac{R_S}{R_S+\frac{1}{g_m}}$ $(\lambda=\gamma=0)$.

共栅极  $A_v=\frac{(g_m+g_{mb})r_o+1}{r_o+(g_m+g_{mb})r_oR_S+R_S+R_D}R_D$.

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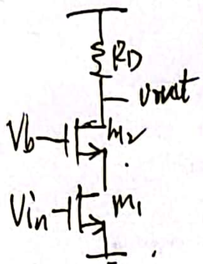
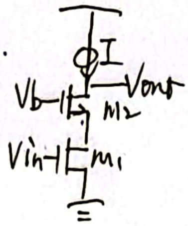
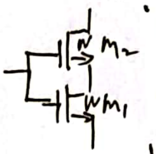
共源共栅.



$A_V = -g_{m1}R_D$. ~~RD~~

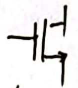


$A_V = g_{m1}r_{o1}[(g_{m2}+g_{mb2})r_{o2}+1]$



$(W/L)_1 = (W/L)_2$:

$=$

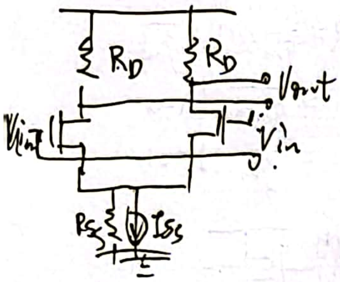


$2W/L$.

$V_{TH1} = V_{TH2}$:

M_1 线性区.

差动对.



① 完全对称: $A_V = -g_mR_D$. $A_{VCM} = \frac{R_D}{2R_{SS}+\frac{1}{g_m}}$

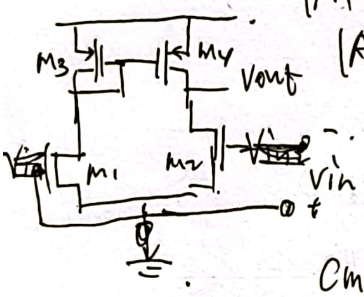
② $g_{m1} \neq g_{m2}$: $A_V \approx -2R_D(g_{m1}/g_{m2})$. $A_{CM-DM} = \frac{-\Delta g_m R_D}{(g_{m1}+g_{m2})R_{SS}+1}$

$= \frac{R_D}{2}\frac{g_{m1}+g_{m2}+4g_{m1}g_{m2}R_{SS}}{1+(g_{m1}+g_{m2})R_{SS}}$

$CMRR = \frac{g_{m1}+g_{m2}+4g_{m1}g_{m2}R_{SS}}{2\Delta g_m} \approx \frac{g_m}{\Delta g_m}(1+2g_mR_{SS})$.

③ $R_D \neq R_D$.

五管OTA. P133



~~$|A|$~~ ~~$\frac{g_{m1}}{2}[(2r_{o2})//r_{o4}]$~~

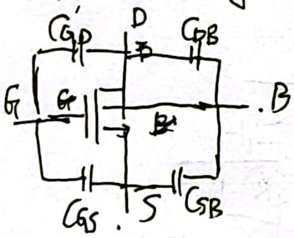
$|A_V| = g_{m1}(r_{o1}//r_{o4})\frac{2g_{m4}r_{o4}+1}{2(g_{m4}r_{o4}+1)}$.

$\approx g_{m1}(r_{o1}//r_{o4})$

$A_{cm} = \frac{-1}{1+2g_{m1,2}R_{SS}} \cdot \frac{g_{m1,2}}{g_{m3,4}}$.

$CMRR = (1+2g_{m1,2}R_{SS})g_{m3,4}(r_{o1,2}//r_{o3,4})$

密勒效应 P158



$\omega_n = [RC]^{-1}$.

源跟随 $L = \frac{C_{GS}}{g_m}(R_S - \frac{1}{g_m})$.

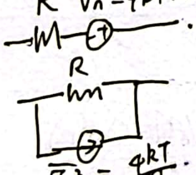
$H(s) = \frac{H_0}{(1+\frac{s}{\omega_1})(1+\frac{s}{\omega_2})\cdots}$

主极点近似: $\omega_p >> \omega_p$

$AS^2+BS+1 \Rightarrow \omega_1 = B^{-1}$

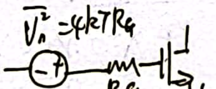
$\omega_p = \cancel{B/A}\ BA^{-1}$.

电阻热噪声: R $\overline{V_n^2} = 4kTR$

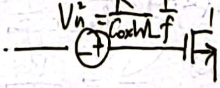


$\overline{I_n^2} = \frac{4kT}{R}$.

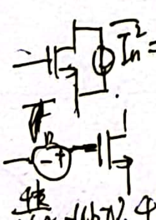
栅电阻 ~~闪烁~~噪声 $\overline{V_n^2} = 4kTR_G$



闪烁噪声 $\overline{V_n^2} = \frac{K}{C_{ox}WLf}$



MOS热噪声



$\overline{I_n^2} = 4kT\gamma g_m$

$\overline{V_n^2} = \frac{4kT\gamma}{g_m}$

电压噪声 ① V_{in}接地.

② $\overline{V_{nout}^2}$

③ $\overline{V_{nin}^2} = \frac{\overline{V_{nout}^2}}{|A_V|^2}$

电流噪声 ① V_{in}断开

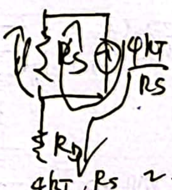
② $\overline{V_{nout}^2}$

③ $\overline{I_{nin}^2} = \frac{\overline{V_{nout}^2}}{R_m^2}$. $R_m = \frac{V_{out}}{I_{in}}$.

中间部分不贡献噪声

$\rightarrow \lambda=0$ 阻抗无穷 ~~极限~~

噪声分流:



$\frac{4kT}{R_S}\left(\frac{R_S}{R_D+R_S}\right)^2$.

V_{nin} 单位: $V/\sqrt{Hz}$.

差动两端噪声都要算

Lap Coa: $\delta(t)\to 1$
$u(t)\to \frac{1}{s}$
$e^{at}u(t)\to \frac{1}{s-a}$
$e^{-t/\tau}u(t) \leftrightarrow \frac{1}{s+\tau^{-1}} = \frac{\tau}{1+\tau s}$

备忘录

算增益别忘正负!

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注意一些特殊的把管子.

Chap.2.

亚阈值除非说明一般不考虑.

$V_{TH} = \Phi_{ms} + 2\Phi_F + \frac{Q_{dep}}{C_{ox}}$

$\Phi_F = V_T \ln\left(\frac{N_{sub}}{n_i}\right)$

NMOS:
判断工作区域: ① 化为: $V_S=0V$, 将 $V_D>0V$, $V_G>0V$.
② $V_{GS} \xrightarrow{>V_{TH}} V_{GD}$ $\xrightarrow{>V_{TH}}$ 线性区, $\xrightarrow{<V_{TH}}$ 饱和区; $V_{GS} \xrightarrow{<V_{TH}}$ 截止.

PMOS:
① 化为: $V_S=0V$, $V_D<0V$, $V_G\leq 0V$.
② $V_{SG} \xrightarrow{>V_{TH}} V_{DG}$ $\xrightarrow{>V_{TH}}$ 线性, $\xrightarrow{<V_{TH}}$ 饱和; $V_{SG} \xrightarrow{<V_{TH}}$ 截止.

Chap.3.

$A_V = -G_m R_{out}$ → V_{in} 接地

G_m: V_{out} 接地. $\frac{I_{out}(\text{流入})}{V_{in}}$

Chap.4.

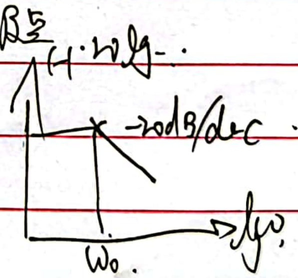
最大输入电压范围: 一边 I_{SS}, 也刚好要截止 ($V_{Dsat}=0$) 画半边电路.
差模
两种情况都要讨论.
差模
共模
最后答案 $\Delta V_{in1} \sim \Delta V_{in2}$. $\Delta V_{in} = V_{in1} - V_{in2}$.

最大输出电压摆幅: 管子刚好处于线性区 进行讨论.
答案: 差模: $(V_{1max}-V_{1min}) + (V_{2max}-V_{2min})$.
单端: $V_{max}-V_{min}$.

信噪比: $SNR = \left(\frac{信号幅度}{噪声}\right)^2 = \left(\frac{A_{DM} V_{inDM}}{A_{CM-DM} V_{inDM}}\right)^2$

再取功率分贝 = 10 lg SNR.

CMRR也取分贝 = 20 lg CMRR.



Chap.6.

当发现直流增益无限大, 不可用密勒.