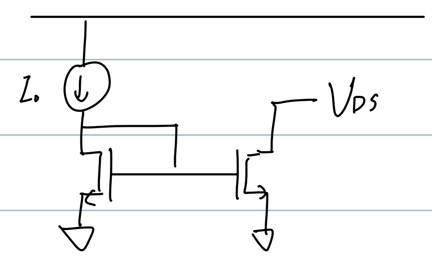
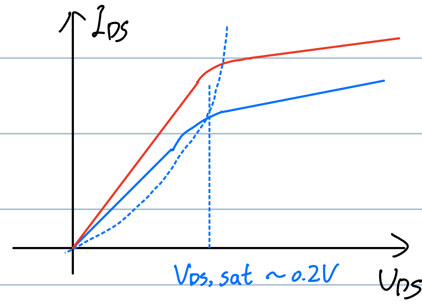
MOS $I_{DS} = \frac{\mu C_{ox}}{2}\frac{W}{L}(V_{GS}-V_T)^2(1-\lambda V_{DS}) \approx \frac{\beta}{2}(V_{GS}-V_T)^2$

if $V_{GS} = V_T + 0.2V$



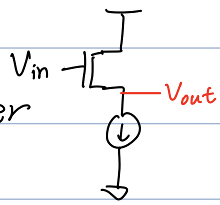


CM

Common drain

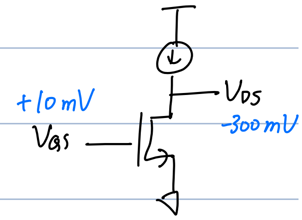
$V_G \uparrow$, $V_S \uparrow$ to follow G → src follower

good for buffer



Common source

$A_v = -\frac{g_m}{g_{ds}} = g_m r_o$

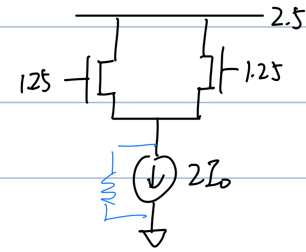


Diff pair

cm if $V_{cm} \uparrow$ → $V_{cmsrc} \uparrow$ lin.

reality, R ∥ ⓘ draws more I → $V_{out} \downarrow$ → $A_{cc} = \frac{-R_D}{2r_{o,src}}$

diff $A_{dd} = -g_m R_D$



+ pmos CM load (common source)

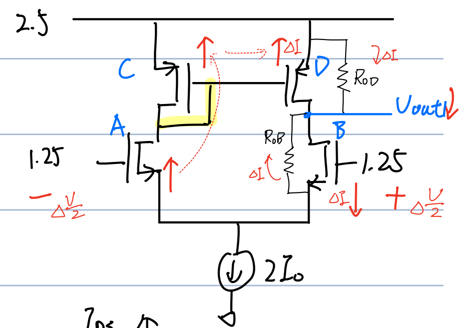
For M5, when $V_G \downarrow$ ($V_{SG} \uparrow$) → $V_{SD} \downarrow\downarrow$ → $V_o \uparrow\uparrow$

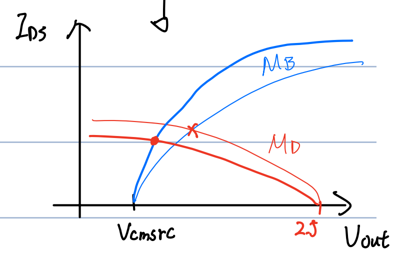
D wants $I_D \downarrow$, so $V_{SD,D} \uparrow\uparrow$, $V_{out1} \downarrow\downarrow$

$2\Delta I$ pulled from out1 , $R_{out1} = R_{OD} \parallel R_{OB}$

$\frac{\Delta V_{out1}}{R_{out1}} = -2\Delta I = -2g_m\frac{\Delta V}{2}$

$\frac{\Delta V_{out1}}{\Delta V} = -g_{m1} R_{out1}$

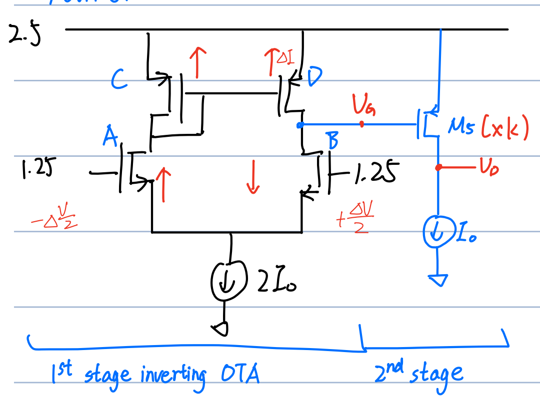


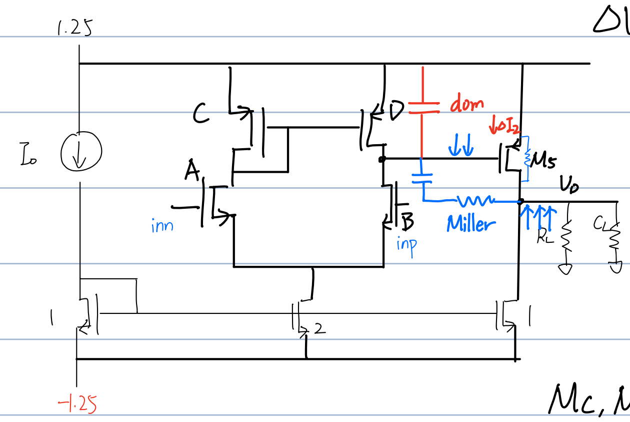


I_0 replace by CM

Dom-pole (better to put w/ vdd)

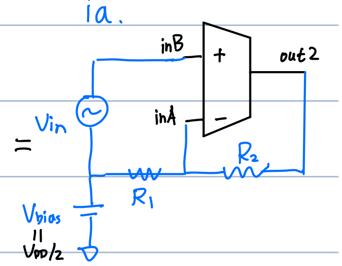
Miller





$\Delta V_{out2} = (-g_{m5} R_{o5})\Delta V_{out1}$

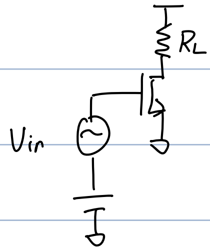
ia.

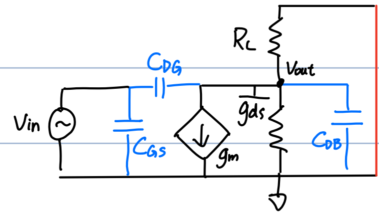


M_C, M_D, M_E same size → same ov

SS $\Delta I_{DS} = g_m \Delta V_{in} + g_{ds} \Delta V_{out}$

$$\frac{\Delta V_{out}}{\Delta V_{in}} = -g_m \left(R_L \,||\, \frac{1}{g_{ds}}\right)$$





Z_{out} Make $V_{in} = 0 \rightarrow g_m V_{in} = 0$. Add V_T @ output $\rightarrow Z_{out} = r_o \,||\, R_L$

$$A_v = -g_m Z_{out} = -g_m (r_o \,||\, R_L)$$

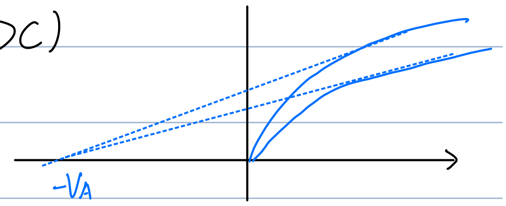
$R_L \gg r_o$ $\quad a_v = -g_m R_L = -\frac{g_m}{I_{DS}} \cdot R_L I_{DS}$

$$= \frac{-2}{V_{ov}} V_{DC,R_L} \rightarrow \text{limited by supply } (V_{DD} - V_{OUT} \text{ @ DC})$$

$R_L \ll r_o$ $\quad a_v = -\frac{g_m}{I_{DS}} \cdot \underbrace{r_o I_{DS}}_{\equiv V_A}$

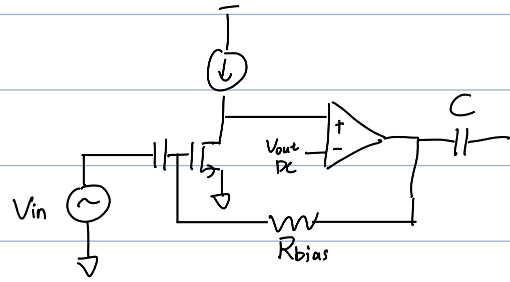
$$= \frac{-2}{V_{ov}} \cdot V_A \quad \sim 10V \qquad V_A \equiv V_{A,L} \cdot L$$

$$= \frac{-2}{V_{ov}} V_{A,L} \cdot L$$

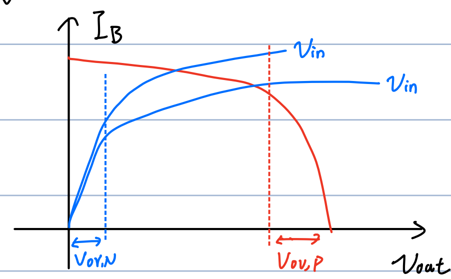


$V_A \overset{typ}{>} V_{R_L,DC}$, want $R_L \ll r_o \rightarrow$ ideal isrc

Self bias DC offset biased thru feedback



- V_{GS} self-biased thru I_B
- $V_{OUT,DC}$. Make it $\frac{V_{DD}}{2}$ for max sweep
- $\Delta V_{in,max} < \frac{V_{DD}/2 - V_{ov}}{A_v}$



Strong inv $V_{GS} = V_T + 0.2V$

$$I_{DS} = \frac{\mu C_{ox}}{2} \frac{W}{L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS})$$

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}} = \mu C_{ox} \frac{W}{L} (V_{GS} - V_T) = \sqrt{2\mu C_{ox} \frac{W}{L} I_{DS}} = \frac{2 I_{DS}}{V_{GS} - V_T}$$

Transconductance efficiency $\quad \frac{g_m}{I_{DS}} = \frac{2}{V_{GS} - V_T} \rightarrow$ want 10 $\quad$ Want $g_m \uparrow$, $I_{DS} \downarrow$, but not at sat.

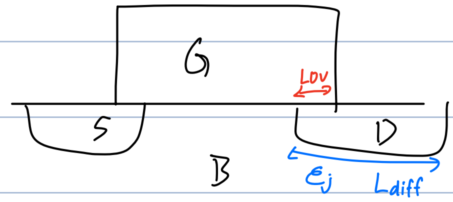
$$g_o = \frac{\partial I_{DS}}{\partial V_{DS}} \approx \lambda I_{DS} = \frac{I_{DS}}{V_{A,L} \cdot L}$$

Given C_L and desired $w_u \rightarrow$ can compute $g_m \xrightarrow{\frac{g_m}{I_{DS}} = 10} I_{DS} = \frac{g_m}{10}$

If $W \nearrow$, $I_{DS} \nearrow$, $g_m \nearrow$

Find a ref. case w/ $V_{ov} = 2V$, $\frac{g_m}{I_{DS}} = 10$, find its $\frac{W}{L}$ to produce the desired I_{DS}.

C : C_{gs}, C_{gd}, C_{db} at sat

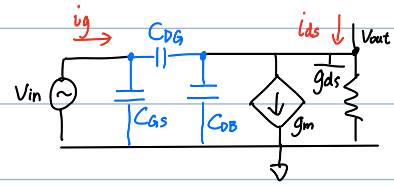


$C_{gs} = \frac{2}{3} C_{ox} W L$ $\sim W, L$

$C_{gd} = C_{ox} W L_{overlap}$ $\sim W$

$C_{db} = \frac{C_j}{A} W L_{diff} + \frac{C_{jsw}}{L}(2W + 2L_{diff})$ $\sim W$

jct side wall



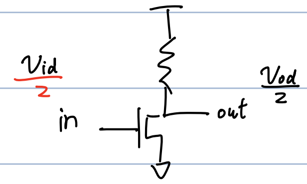
f_T is when $\frac{i_{ds}}{i_g} = 1$ (transit freq)

$f_T \stackrel{\cdot\cdot}{=} \frac{g_m}{2\pi(C_{gs}+C_{gd})} \propto \mu \frac{V_{GS}-V_T}{L^2}$

$A_V \propto r_o \propto \rightarrow f_T \downarrow$; $g_m \propto V_{ov}^{-1} \rightarrow f_T \downarrow \rightarrow$ speed vs gain tradeoff

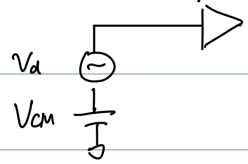
Digital uses min L and $V_{GS} = V_{DD} \rightarrow$ fast

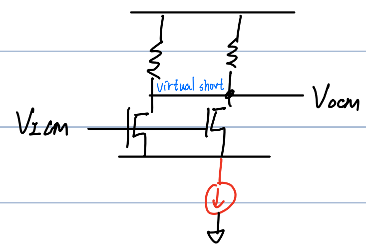
Half circuit (study half of diff pair)



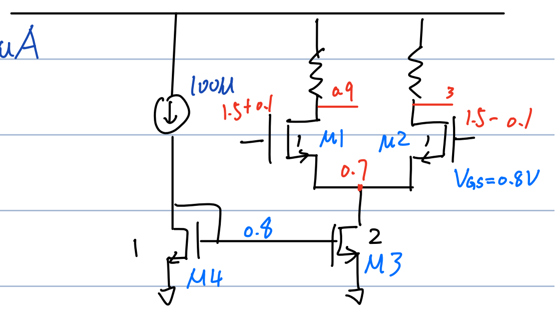
$A_{dd} = |-g_m R_L|$ (isrc is cm)

cm ideal $A_{cc} = 0$





E. $V_{DD} = 3V$, $V_T = 0.6V$, $V_{ov} = 0.2V$, real cm, R_L, $I_{BIAS} = 100\mu A$



$V_{CMSRC} > 0.2V$ for sat $\rightarrow V_{G1,2} > 1V$

$V_{D1,2} = 2V_{ov} = 0.4V$

Swing $\stackrel{\cdot}{=} 0.4 \sim 3V \rightarrow V_{BIAS} = 1.7V$

$V_{RL} = \frac{1}{R_L}(3V - 1.7V) = 100\mu A \rightarrow R_L = 13k$

$A = g_m R_L = \frac{g_m}{I_B} I_B R_L = \frac{2}{0.2V} \cdot 100\mu A \cdot 13k = 13$

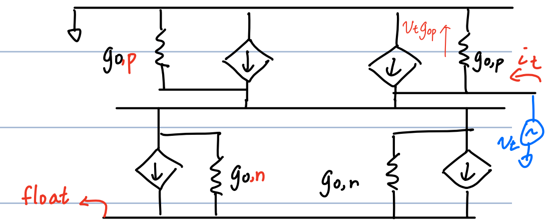
E. $V_G = 1.5V \rightarrow V_{out} > V_G - V_T = 0.9V$, range $(0.9, 3)$

$V_{RL} = \frac{1}{R_L}(3 - 1.95)V = 100\mu A$, $R_L = 10.5k$

$A = \frac{g_m}{I_B} I_B R_L \stackrel{\cdot\cdot}{=} 10.5k$ $(R_L \downarrow)$, input swing $100 mV_p$

PMOS load SS $V_{DD} = 2.5V$

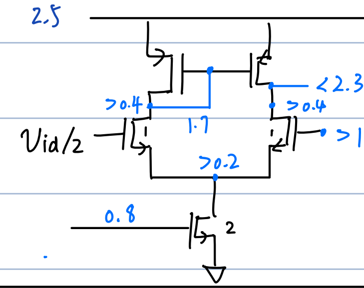
$V_{SG} = 0.8V$



G_M Short output, find i_{sc}

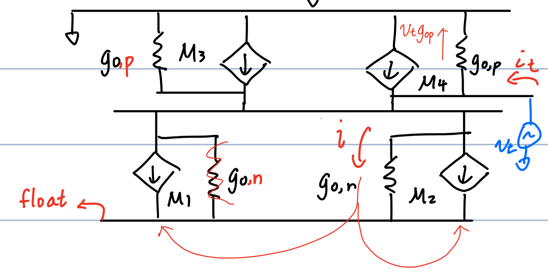
$\Delta i = g_m \frac{V_{id}}{2}$ $\quad i_{sc} = 2\Delta i = g_m V_{id}$

$G_M = \frac{i_{sc}}{V_{id}} = g_{m,M1}$

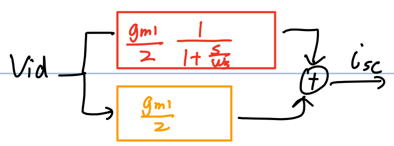


r_o Ground input, test V_{out} w/ V_t

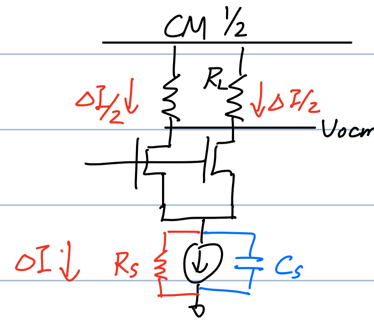
$g_{m1} >> g_{o1}$, ignore g_{o1}



Freq



Assume load has a dom. pole $\rightarrow$ 2p | z

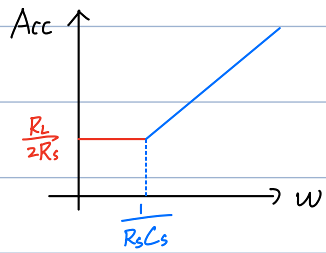


CM Ideal $A_{CM} = 0$ since $V_{cmsrc}\uparrow$

$\Delta I = \frac{\Delta V_{CM}}{R_s} \rightarrow \frac{\Delta V_{CM}}{2R_s}$ thru each M

$V_{ocm} = -\Delta V \frac{R_L}{2R_s}$

$+C_s$ $\quad A_{cc} = -\frac{R_L}{2}\left(\frac{1}{R_s} + sC_s\right)$

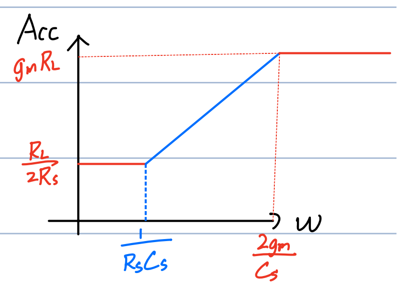


If $\Delta V_{CMSRC} \neq \Delta V_{CM}$, $\Delta I = g_m \Delta V_{GS}$

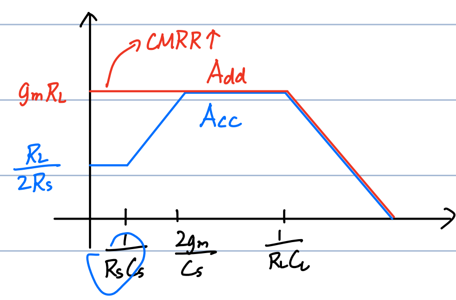
$\Delta V_{GS} = \frac{1}{g_m} \frac{sC_s}{2} \Delta V_{CM}$

when $s \approx \frac{2g_m}{C_s}$, $V_s \approx 0$ $\xrightarrow{\text{ana}}$ common source amp ($g_m R_L$)

(I_{src} is gnded)



Want $R_s\uparrow$ ($A_{cc,DC}\downarrow$); $C_s\downarrow$



PMOS load $A_{cc} \approx -\frac{1}{2g_m r_{o,cm}}$

Sizing

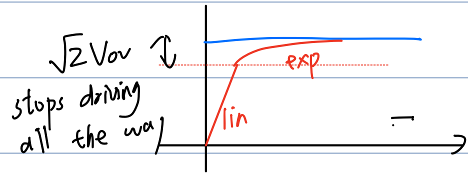
W	W	$2W$	$2W$	W
L	L	$2L$	L	L
I_{DS}	I_B	I_B	$2I_B$	$2I_B$
$V_{ov} = V_{DS,sat} = \sqrt{\frac{2I_{DS}}{\beta}}$	V_{ov}	V_{ov}	V_{ov}	$\sqrt{2}\,V_{ov}$
$g_m = \frac{2I_{DS}}{V_{ov}}$	g_m	g_m	$2g_m$	$\sqrt{2}\,g_m$
$\frac{g_m}{I_{DS}}$	$\frac{g_m}{I_B}$	$\frac{g_m}{I_B}$	$\frac{g_m}{I_B}$	$\frac{1}{\sqrt{2}}\frac{g_m}{I_B}$
$r_o \propto \frac{L}{I_{DS}}$	r_o	$2r_o$	$\frac{1}{2}r_o$	$\frac{1}{2}r_o$
A_o	$g_m r_o$	$2g_m r_o$	$g_m r_o$	$\frac{1}{\sqrt{2}}g_m r_o$
C_{gs}	—	$\times 4$	$\times 2$	—
f_T				

Non-idealities

SR on step input

$g_m V_{in} = I_{out} = C_L \dot{V}_{out} \rightarrow$ cap at $2 I_{BIAS}$

w/ more $C \rightarrow$ complex



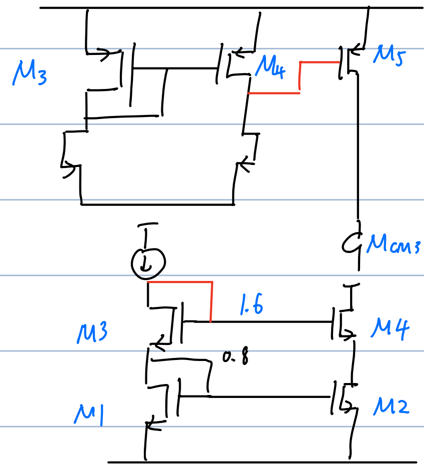
Offset For a CM, $\frac{I_{DS2}}{I_{DS1}} = \frac{1+\lambda V_{DS1}}{1+\lambda V_{DS2}} \approx 1 + \overbrace{\lambda (V_{DS2} - V_{DS1})}^{\varepsilon} \rightarrow$ error in CM

May from improper sizing

M_5, M_{CM3} need same sizing, so $V_{ov5} = V_{ov3}$

$\downarrow$

$V_{SD4} = V_{SD4}$



Cascaded cm

High $V_{out,min}$, but $R_{out} \uparrow$

ss $V_T = I_T r_{o2} + r_{o4} [I_T + g_{m4} r_{o2} I_T]$

$Z_{out} = r_{o2} + r_{o4} (1 + g_{m4} r_{o2})$