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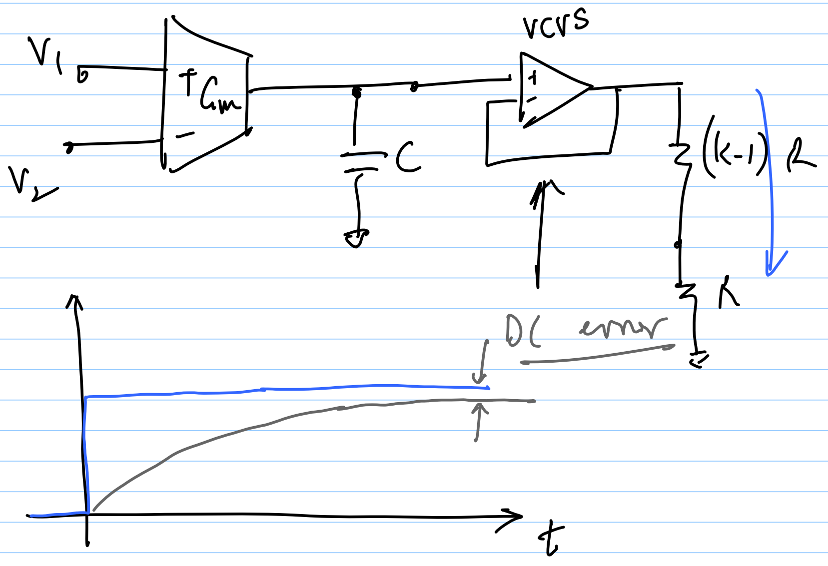
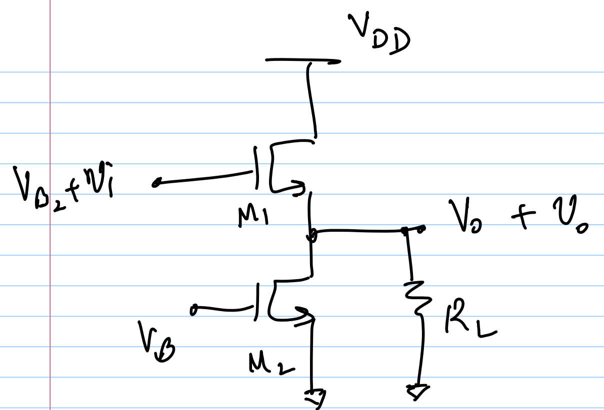
Lec 18





$V_{o_{min}} = V_{DSAT_2}$

$V_{o_{max}} = V_{DD}$ ~~$- V_{DSAT_1}$~~

$\hookrightarrow V_{G_1} = V_{DD} + V_{T_1}$

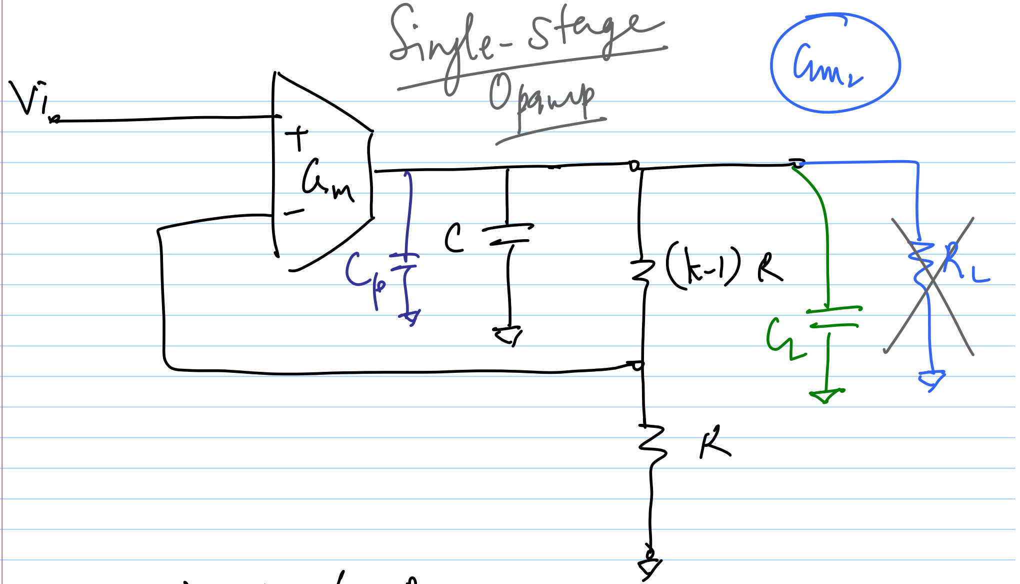
$V_{omax} = V_{DD} - V_{GS_1}$

* Increase R so that $G_m R$ is large enough

$G_m \uparrow \Rightarrow I_{bias} \uparrow$

$\Rightarrow W/L \uparrow$ { par Cap. ↑ / slower devices

Single-stage Opamp



DC gain $\simeq G_m R_L$

Single stage Opamp

1) DC gain $(G_m R_L)$ $\Rightarrow$ do not drive Resistive loads

2) $G_m = g_{m_1}$; $\omega_u = g_{m_1}/C_L$

3)

Load cap C_L

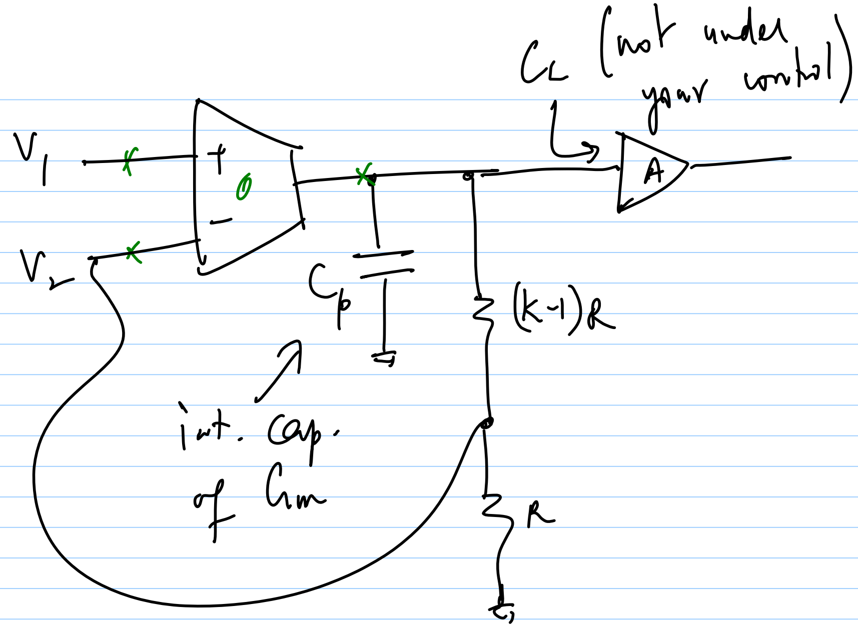
↳ acts as integrating cap

If you have $C + C_L$

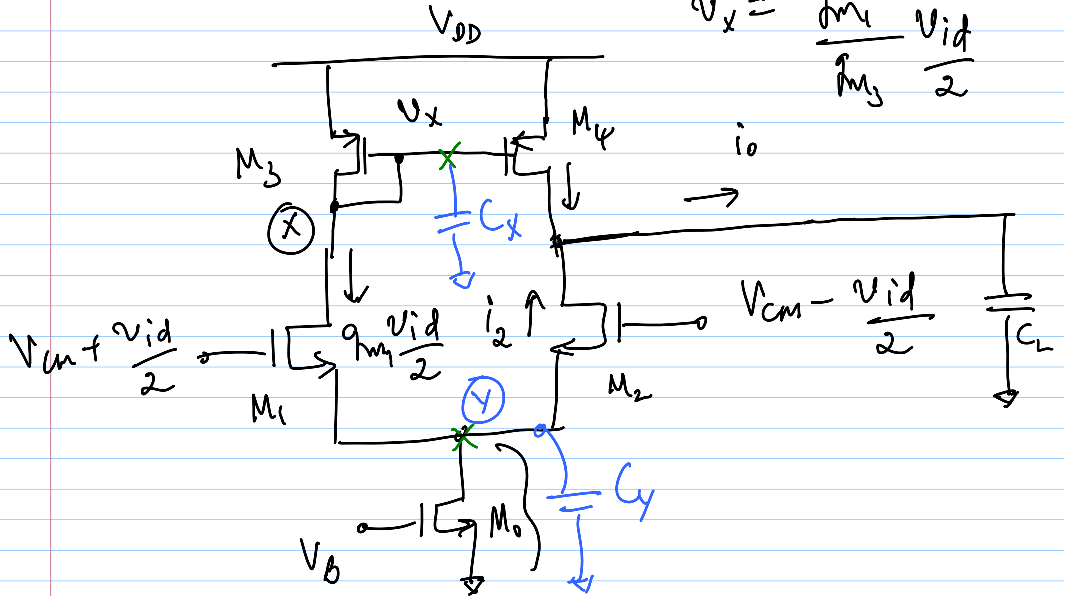
$$\omega_u = \frac{G_m'}{\cancel{C} + C_L}$$

$$G_m' > G_m$$

$$\boxed{\omega_u = \frac{G_m}{C_L}}$$



$$v_x = \frac{g_{m1}}{g_{m3}} \frac{v_{id}}{2}$$



$$i_4 = g_{m4} v_x$$

$$= g_{m1} \frac{v_{id}}{2} \qquad (g_{m4} = g_{m3})$$

$$i_2 = g_{m2} \frac{v_{id}}{2}$$

$$i_o = i_2 + i_4 = g_{m1} v_{id}$$

No C_L ⇒ $v_o = i_o \cdot r_o = g_{m1} v_{id} (r_{ds2} \| r_{ds4})$

No r_o ⇒ $v_o = i_o \cdot \frac{1}{sC_L}$

$$= \frac{g_{m1} v_{id}}{sC_L}$$

Actual ckt

$$\frac{v_o}{v_{id}}(s) = \frac{g_{m1}}{g_o + sC_L} = \frac{g_{m1} r_o}{1 + sC_L r_o}$$

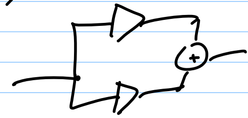
* finite dc gain = $g_m r_o = g_m / g_o$

* Swing limits
* noise
* slew rate
* Non-dominant poles & zeros

C_Y — No pole due to VG

C_X — $v_x = i_1 \left(\frac{1}{g_{m3}} \| \frac{1}{sC_X} \right)$

$$= \frac{i_1}{g_{m3} + sC_X}$$



$i_4 = g_{m4} \cdot v_x$

$$i_4 = \frac{g_{m4} \cdot g_{m1} v_{id}/2}{g_{m3} + sC_X}$$

$$i_2 = g_{m1} v_{id}/2$$

$$i_o = i_4 + i_2$$

$$= g_{m1} \frac{v_{id}}{2} \left[1 + \frac{g_{m4}}{g_{m3} + sC_X} \right]$$

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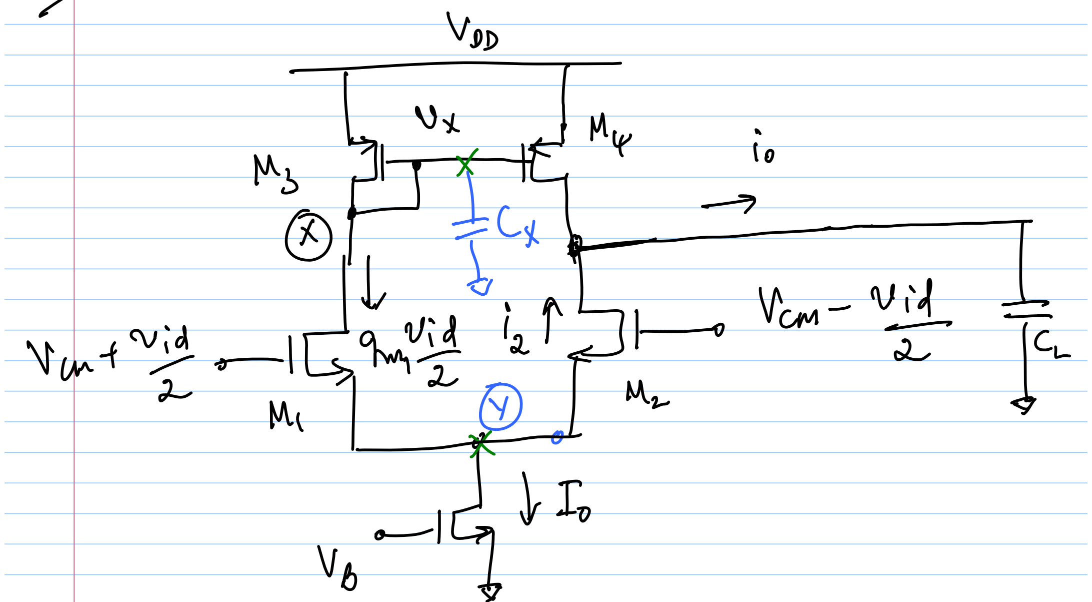


$$i_o = i_2 + i_4$$

$$= g_{m2}\frac{v_{id}}{2} + \frac{g_{m4}\, g_{m1} v_{id}/2}{g_{m3} + sC_x}$$

$$= g_{m1}\frac{v_{id}}{2}\left[1 + \frac{g_{m3}}{g_{m3} + sC_x}\right]$$

$$v_o = \frac{i_o}{g_o + sC_L}$$

$$\frac{v_o}{v_{id}} = \frac{g_{m1}}{2}\left[1 + \frac{g_{m3}}{g_{m3} + sC_x}\right] \cdot \frac{1}{(g_o + sC_L)}$$

$$= \frac{g_{m1}}{2} \cdot \frac{1}{g_o + sC_L} \cdot \frac{2g_{m3} + sC_x}{g_{m3} + sC_x}$$

Dominant pole (ω_D) $\qquad \omega_z, \omega_p$

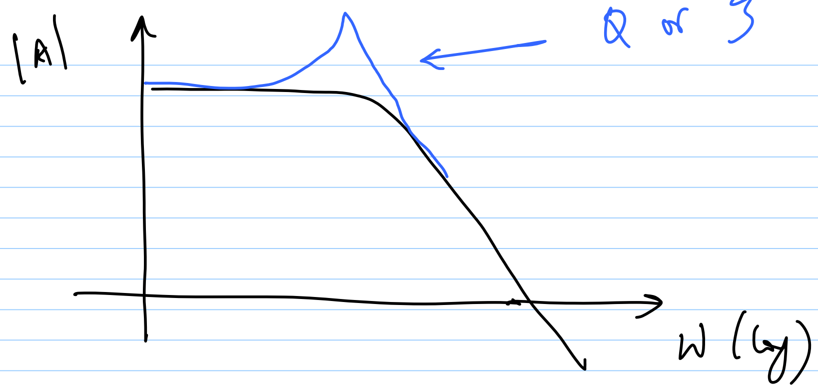
$$\omega_p = \frac{-g_{m3}}{C_x} \; ; \; \omega_z = \frac{-2g_{m3}}{C_x} = 2\omega_p$$

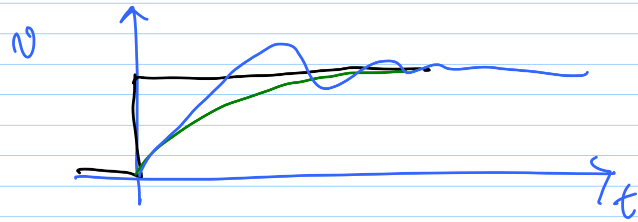
$$|\omega_u| = \frac{g_{m1}}{C_L} \; ; \; |\omega_D| = \frac{g_o}{C_L}$$

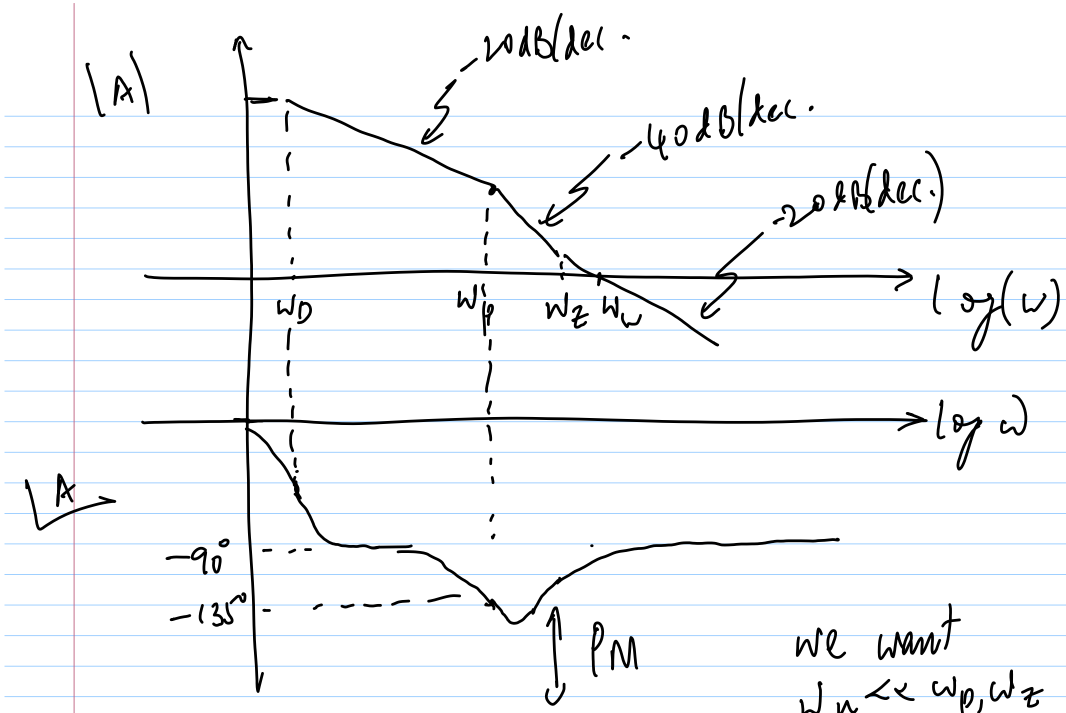
$$BW = \frac{\omega_u}{k} \; ;$$

$$\omega_p = \frac{-g_{m3}}{C_x} \; ; \; \omega_z = \frac{-2g_{m3}}{C_x} = 2\omega_p$$

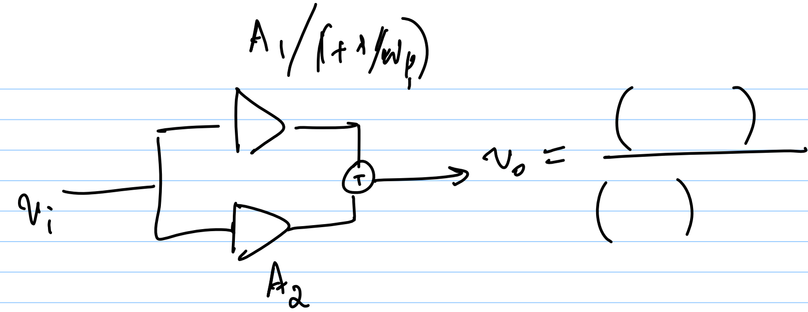
Unity gain $\Rightarrow \omega_p \gg \omega_u$







we want $\omega_u << \omega_p, \omega_z$



* Multiple paths w/ different freq. response w/ phase shifts

$$\omega_D = \frac{g_o}{C_L}, \quad \omega_u = \frac{g_{m1}}{C_L}$$

$$\omega_p = \frac{g_{m3}}{C_X}; \quad \omega_z = \frac{2 g_{m3}}{C_X}$$

$$\omega_p >> \omega_u$$

$$\boxed{\frac{g_{m3}}{C_X} >> \frac{g_{m1}}{C_L}}$$

1) $\uparrow C_L \Rightarrow \omega_u \downarrow$ ✗

2) $\uparrow g_{m3} \Rightarrow \uparrow \left(\frac{W}{L}\right)_3 \Rightarrow C_X \uparrow$ ✗

3) $\downarrow C_X \Rightarrow \left(\frac{W}{L}\right)_3 \downarrow$ @ same I_D

$V_{DSAT3,4} \uparrow$

hit swing limits

4) $\downarrow g_{m1} \Rightarrow \downarrow (W/L)_1 \Rightarrow \omega_u \downarrow$

↑ I_o is the only way to improve available BW of the opamp.

CM limits

1) Input CM:

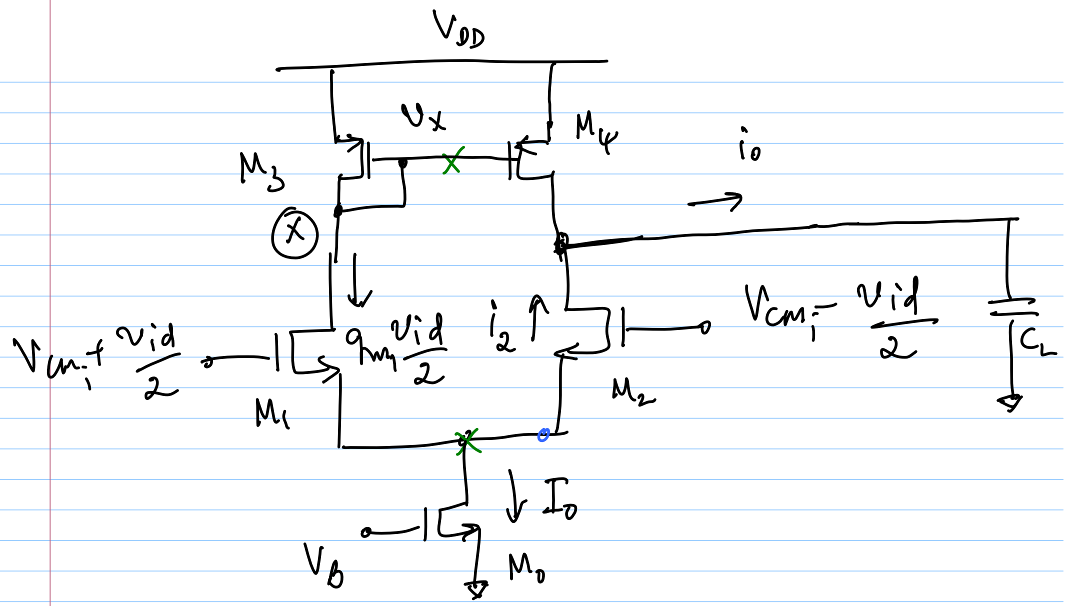
$$V_{CM_i}(min) = V_{DSAT_o} + V_{GS_1}$$

$$V_{CM_i}(max) = V_{DD} - V_{SG_3} + V_{T_1}$$

2) Output CM:

$$V_{CM_o}(min) = V_{CM_i} - V_{T_1}$$

$$V_{CM_o}(max) = V_{DD} - V_{DSAT_3}$$



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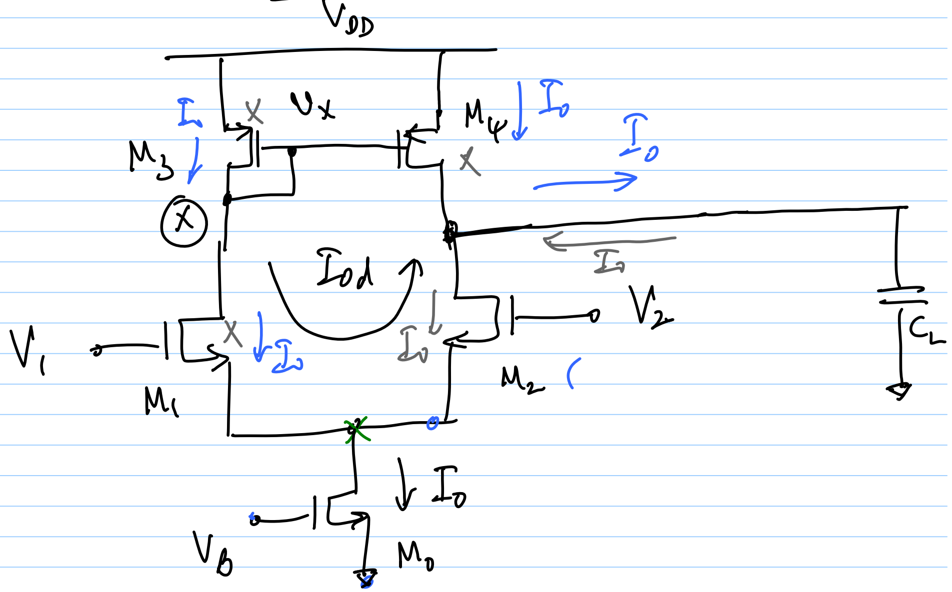
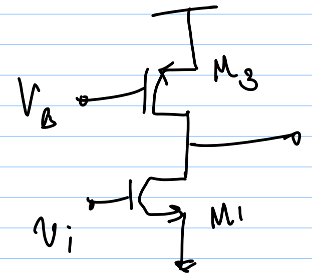
Lec 20



* Noise

$$\overline{e_n^2} = \frac{16kT}{3}\left[\frac{1}{g_{m_1}} + \frac{g_{m_3}}{g_{m_1}^2}\right]$$



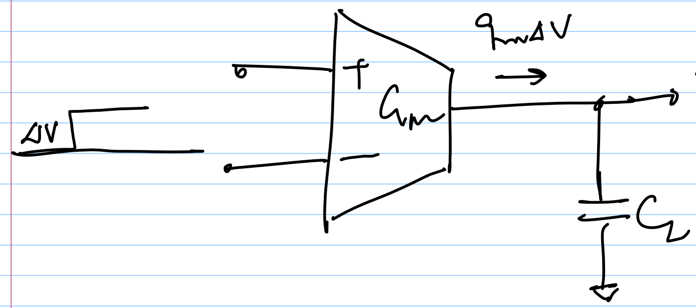
$$\frac{8kT}{3}\left[\frac{1}{g_{m_1}} + \frac{g_{m_3}}{g_{m_1}^2}\right]$$

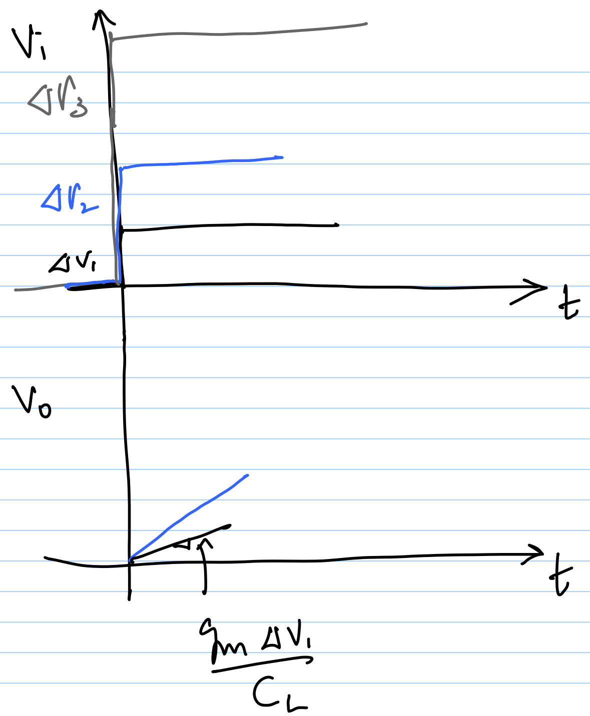
* Offset

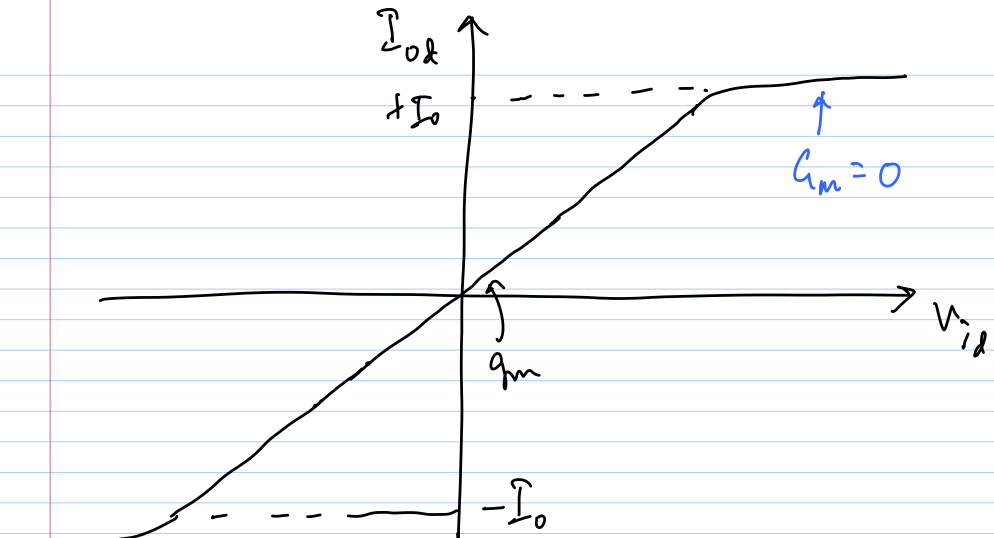
$$V_{os} = \Delta V_{T_{1,2}} + \frac{g_{m_3}}{g_{m_1}} \Delta V_{T_{3,4}}$$

$$\sigma_{os}^2 = \sigma_{V_{T_{1,2}}}^2 + \left(\frac{g_{m_3}}{g_{m_1}}\right)^2 \sigma_{V_{T_{3,4}}}^2$$

* Slew Rate $\frac{dV_o}{dt}$







$I_{out}(max) = I_0$

+ve Slew rate $= \frac{I_0}{C_L}$ (V/s)

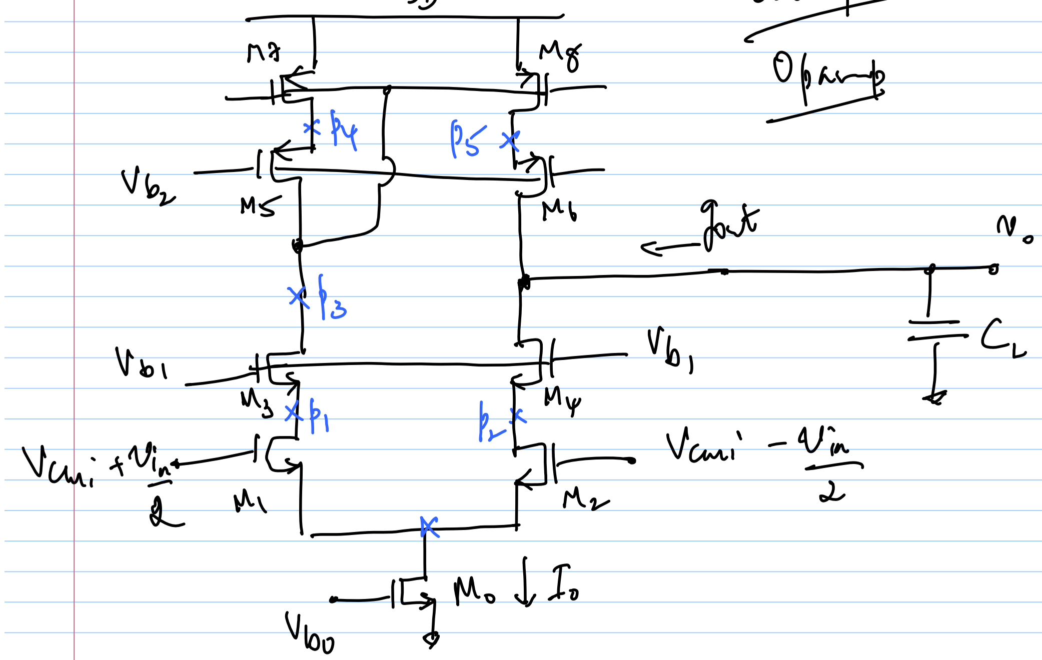
−ve SR $= -\frac{I_0}{C_L}$ (V/s)

3/3/14

Lec 21

* DC performance − R load
* DC gain − no DC error
  - g_m ⟵ affects ω_u
  - g_o ⟵ increased through cascode

Telescopic Op amp



1) $r_{out} = (g_{m_4} r_{ds_4}) r_{ds_2} \,||\, (g_{m_6} r_{ds_6}) r_{ds_8}$

DC gain $= g_{m_1} r_{out} \gg$ DC gain (1-stage opamp)

2) $\omega_u = g_{m_1}/C_L$; $\omega_{pole} = \frac{1}{r_{out} C_L} = \frac{g_{out}}{C_L}$

(Same) (much lower)

looks more like an ideal $\int$

3) $V_{cmi}\,(min) = V_{DSAT_0} + V_{GS_1}$

$V_{cmi}\,(max) = V_{b_1} - V_{GS_4} + V_{T_2}$

4) $V_{cm_o}\,(MAX) = V_{DD} - V_{DSAT_7} - V_{DSAT_5}$

$V_{cm_o}\,(MIN) = V_{b_1} - V_{T_4}$

5) Slew rate $= \pm \frac{I_0}{C_L}$

6) Noise : Almost the same @ low freq.

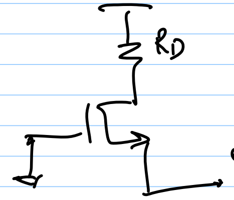
$$\frac{16kT}{3}\left[\frac{1}{g_{m1}} + \frac{g_{m7}}{g_{m1}^2}\right]$$

7) Offset

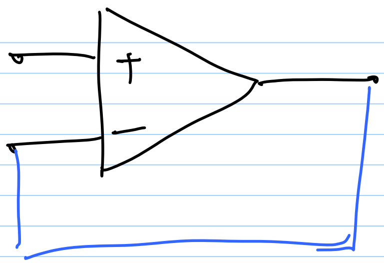
σ_{os}^2 = same as before

$$\sigma_{V_{T_{1,2}}}^2 + \left(\frac{g_{m7}}{g_{m1}}\right)^2 \sigma_{V_{T_{7,8}}}^2$$

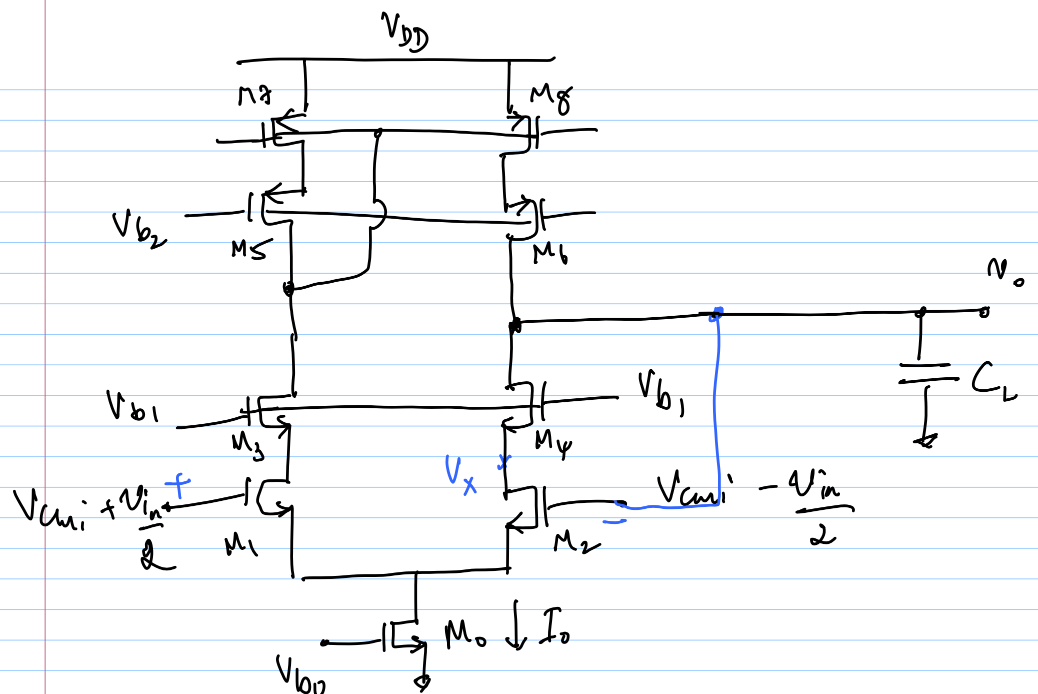
8) ND poles & zeros



$\leftarrow R_{out} = \frac{1}{g_m}$ only if $R_D \ll r_{ds}$



VG amp.



$V_{o_{min}}(V_{cm_{i,min}}) = V_{b_1} - V_{T_4}$

$V_{o_{max}}(V_{cm_{i,max}}) = V_X + V_{T_2} = V_{b_1} - V_{GS_4} + V_{T_2}$

$V_X = V_{b_1} - V_{GS_4}$

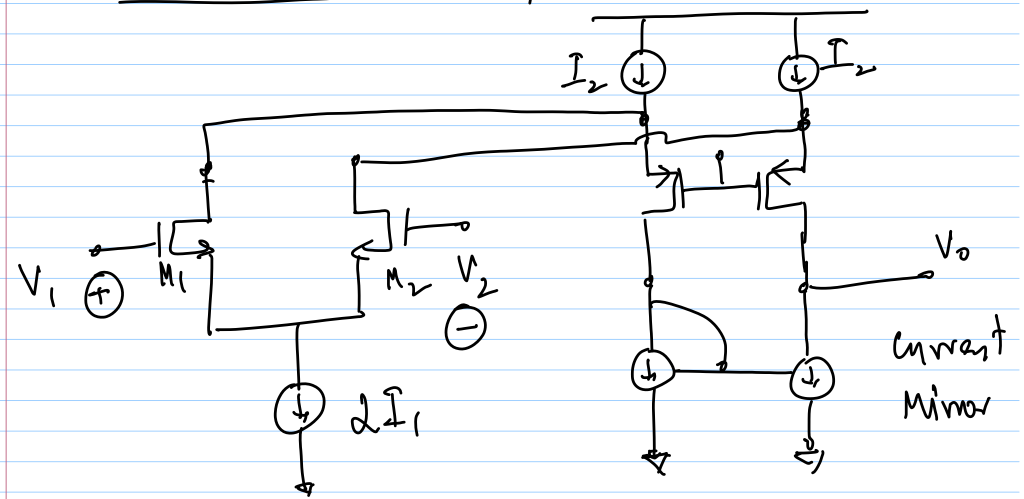
$\Delta V_o = V_{T_2} + V_{T_4} - V_{GS_4}$

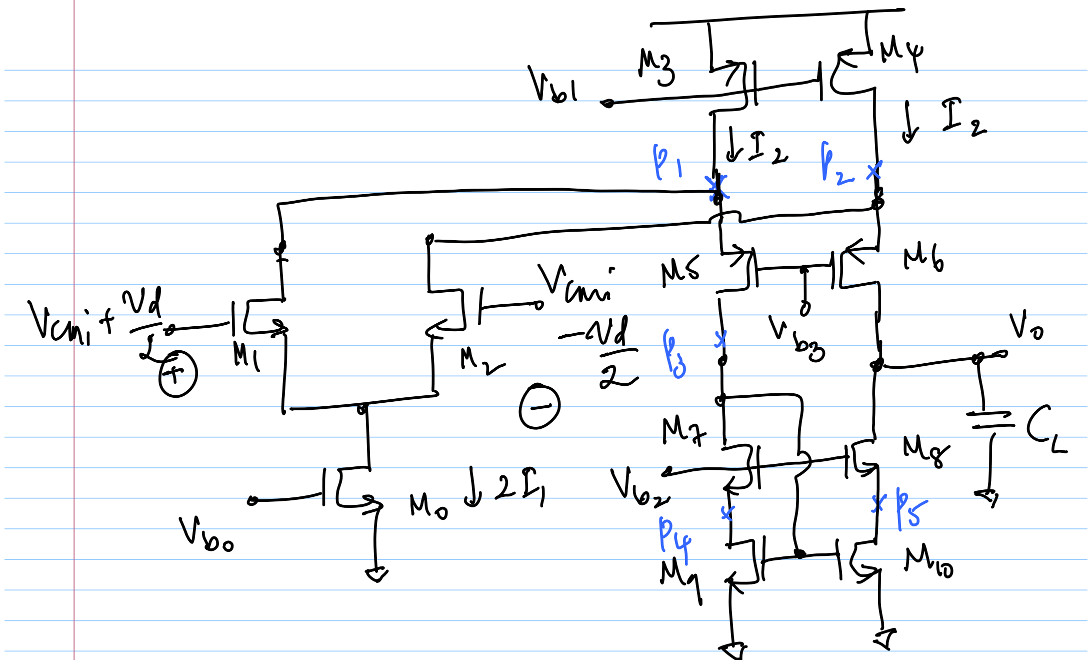
$\Delta V_o = V_{T_2} - V_{DSAT_4}$ ~ couple of 100 mV

4/3/14

Lec 22

Folded Cascode Opamp





1) DC gain:

$R_{out} = (g_{m_8} r_{ds_8}) r_{ds_{10}} \,\|\, (g_{m_6} r_{ds_6})(r_{ds_2} \| r_{ds_4})$

slightly lesser than telescopic opamp

DC gain = $g_{m_1} R_{out}$

2) $\omega_u = \frac{g_{m_1}}{C_L}$; $\omega_p = \frac{g_{out}}{C_L}$

3) ND poles & zeroes → $p_1 - p_5$

4) $V_{cmi}(min) = V_{DSAT_2} + V_{GS_1}$

$V_{cmi}(max) = V_{b_3} + V_{SG_5} + V_{T_1}$

5) $V_{cm_o}(min) = V_{DSAT_8} + V_{DSAT_{10}}$

$V_{cm_o}(max) = V_{b_3} + V_{T_6}$

6) <u>Noise</u>

$$\overline{e_n^2} = \frac{16kT}{3}\left[\frac{1}{g_{m_1}} + \frac{g_{m_3}}{g_{m_1}^2} + \frac{g_{m_9}}{g_{m_1}^2}\right]$$

7) <u>Offset</u> — HW

8) <u>Slew Rate</u> →