6-3-12

Lec - 25

Telescopic opamp Discussion

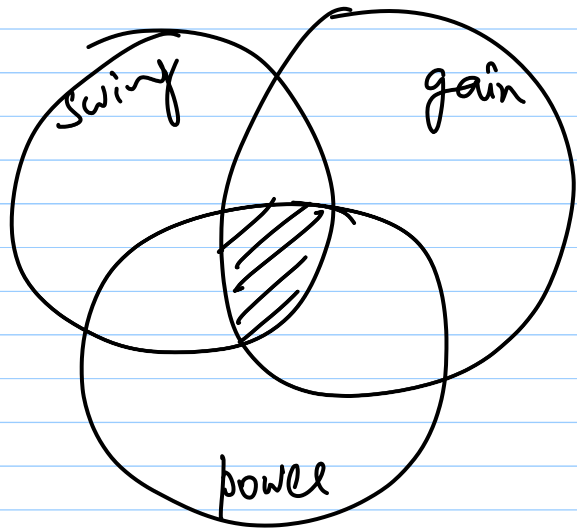
Design a telescopic opamp w/ the following specs:

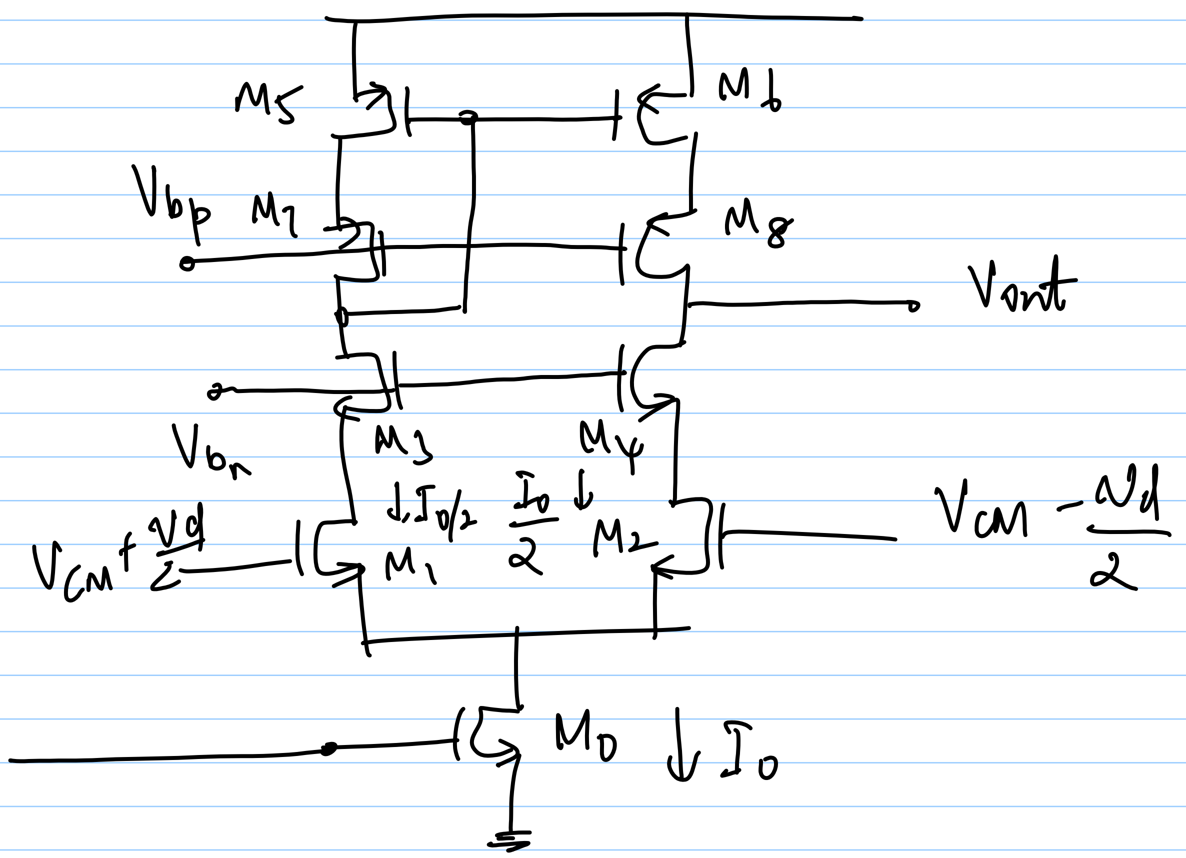
$V_{DD} = 3V$; Output swing $= 2V$ (pk-pk)

Voltage gain = 2000 ; Power diss. = 10mW

	NMOS	PMOS	
μC_{ox}	$60\ \mu A/V^2$	$30\ \mu A/V^2$	no backgate effect
$\lvert V_T \rvert$	0.7V	0.7V	
$L_{min.}$	0.5μm	0.5μm	
λ	$0.1V^{-1}$	$0.2V^{-1}$	

* Do not setup equations in 'n' variables
* There is no unique solution





<u>Simplify</u>: assume $M_1 - M_4$ identical

$M_5 - M_8$ "

$$V_{CM_{min.}} = V_{GS_1} + V_{DSAT_0}$$

$$V_{bn} = V_{DSAT_0} + V_{DS_1} + V_{GS_3}$$

$$V_{bn}(min.) = V_{DSAT_0} + V_T + 2V_{DSAT_n}$$

$$= V_T + 3V_{DSAT,n}$$

$$V_{out,max.} = V_{DD} - 2V_{DSAT_p}$$

$$V_{out,min.} = V_{bn} - V_T = 3V_{DSAT_n}$$

say, $V_{DSAT_p} = 250mV$

$\Rightarrow V_{out\,max.} = 2.5V$

say, $V_{DSAT,n} = 166.67mV$

$\Rightarrow V_{out\,(min.)} = 0.5V$

2V pk-pk swing

$Pd = 10mW \Rightarrow I_{tot.} = 3.33mA$

say $I_0 = 3mA$, $330\mu A$ for bias

$M_0 \Rightarrow V_{DSAT_0} = \sqrt{\dfrac{2 I_0}{\mu_n C_{ox} \left(\frac{W}{L}\right)_0}} \Rightarrow \left(\frac{W}{L}\right)_0 = 3600 = \dfrac{1800\mu m}{0.5\mu m}$

$$\left(\frac{W}{L}\right)_{1-4} = \frac{900\mu m}{0.5\mu m}$$

$$\left(\frac{W}{L}\right)_{5-8} = 1600 = \frac{800\mu m}{0.5\mu m}$$

$$r_{dsn} = \frac{1}{\lambda_n I_{Dn}} = 6.66k\Omega$$

$$r_{dsp} = \frac{1}{\lambda_p I_{Dp}} = 3.33k\Omega$$

$$g_{mn} = \mu_n C_{ox} \left(\frac{W}{L}\right)_n \cdot V_{DSAT_n} = 18e^{-3}S$$

$$g_{mp} = \mu_p C_{ox} \left(\frac{W}{L}\right)_p \cdot V_{DSATp} = 12e^{-3}\,S$$

$$A_o = g_{mn}\left[g_{mn} r_{dsn}^2 \,\|\, g_{mp} \cdot r_{dsp}^2\right]$$

$$= 18e^{-3}\left[18e^{-3} \cdot (6.66\,k)^2 \,\|\, 12e^{-3}(3.33\,k)^2\right]$$

$$= 18e^{-3}\left[798.4\,e^3 \,\|\, 133.07\,e^3\right]$$

$$= \underline{\underline{2053}}$$ meets spec.

If you need 2X gain (e.g. 4000)

1) $\frac{\Delta L}{L} = \lambda V_{DS} \Rightarrow \lambda L \simeq$ constant

$\Rightarrow \uparrow L \Rightarrow \downarrow \lambda \Rightarrow \uparrow r_{ds}$

keep (W/L) constant

here $\uparrow r_{dsp}$ is more important

e.g. $r_{dsp} = 798.4e^3 = r_{dsn}$

$\Rightarrow A_o = 7186$

2) $\downarrow I_o \Rightarrow$ $g_m \uparrow$ as $\sqrt{I_o}$) $A_o \uparrow$

$r_{ds} \downarrow$ as $1/I_o$

but $\omega_u \downarrow$ & SR $\downarrow$

here for 4X gain $\Rightarrow \downarrow I$ by 16X

3) $\uparrow g_{mn} \Rightarrow \uparrow \left(\frac{W}{L}\right)_n$

here $\uparrow \left(\frac{W}{L}\right)_n$ by 16X

$\Rightarrow$ non-dominant poles move in

2-stage opamp

$$|p_2| \approx \frac{G_{m2} \cdot \frac{C}{C+C_1} + \dots}{C_2 + \frac{CC_1}{C+C_1}} \approx \frac{G_{m2}}{C_2}$$

(LHP)

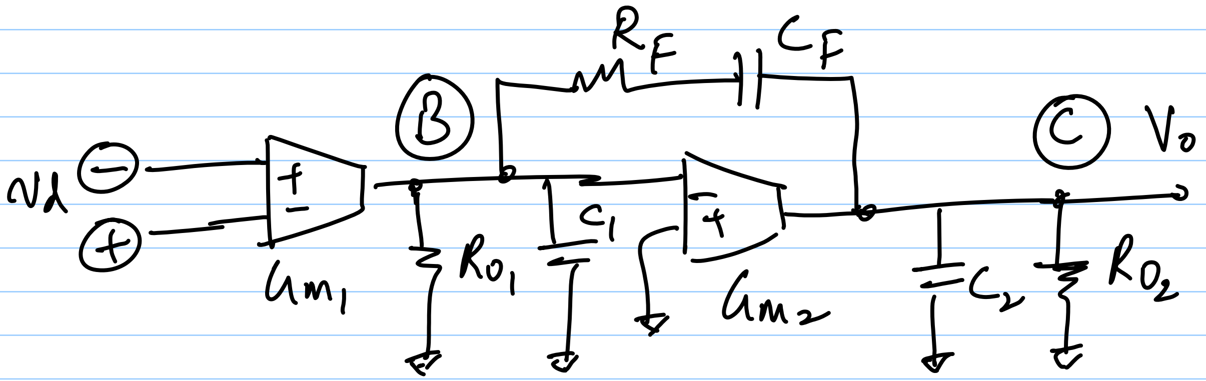
if $C_2 \gg C_1$ & $C \gg C_2, C_1$

For 45° PM, $p_2 = a_0 \cdot p_1 = \omega_u$

$$\frac{G_{m2}}{C_2} = \left(\frac{G_{m1}}{G_{o1}} \cdot \frac{G_{m2}}{G_{o2}}\right) \cdot \frac{G_{o1} G_{o2}}{G_{m2} C}$$

$$\Rightarrow \quad C = \left(G_{m1}/G_{m2}\right) \cdot C_2$$

RC - pole splitting compensation



Basic idea: @ high freq., develop a small-signal voltage across R_F that cancells small-signal voltage @ output

after long analysis:

$$p_1 = \frac{G_{o_1} \cdot G_{o_2}}{G_{m_2} \cdot C_F} ;$$

$$p_2 = \frac{G_{m_2} C_F}{C_1 C_2 + C_F(C_1 + C_2)} \approx \frac{G_{m_2}}{G_{o_2}} \cdot \frac{G_{o_2}}{C_2}$$

$$p_3 = \frac{1}{R_F C_1} ; \quad z_1 = \frac{1}{\left(\frac{C_F}{G_{m_2}} - R_F C_F\right)}$$

case (i) move Z_1 to infinity

$$\Rightarrow R_F = \frac{1}{G_{m2}}$$

$$p_1 \approx \frac{G_{o1} G_{o2}}{G_{m2} C_F} \; ; \; p_2 \approx \frac{G_{m2}}{G_{o2}} \cdot \frac{G_{o2}}{C_2}$$

$$p_3 \approx \frac{1}{R_F C_1} = \frac{G_{m2}}{C_1} \approx p_2 \cdot \frac{C_2}{C_1} \gg 1$$

due to load cap