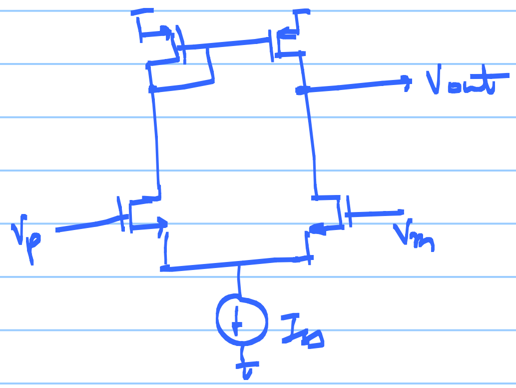
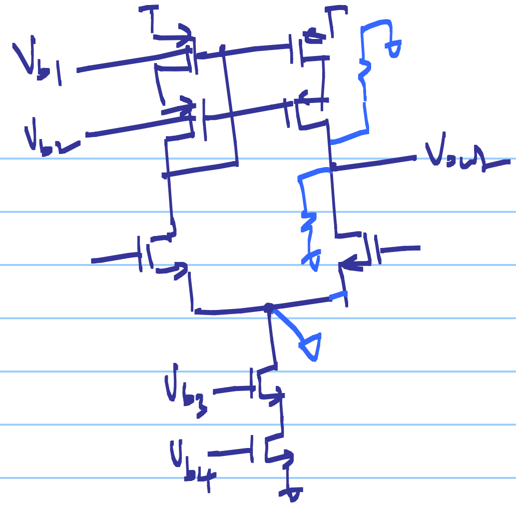
ECE 511 - Lecture 21

Note Title 4/11/2013



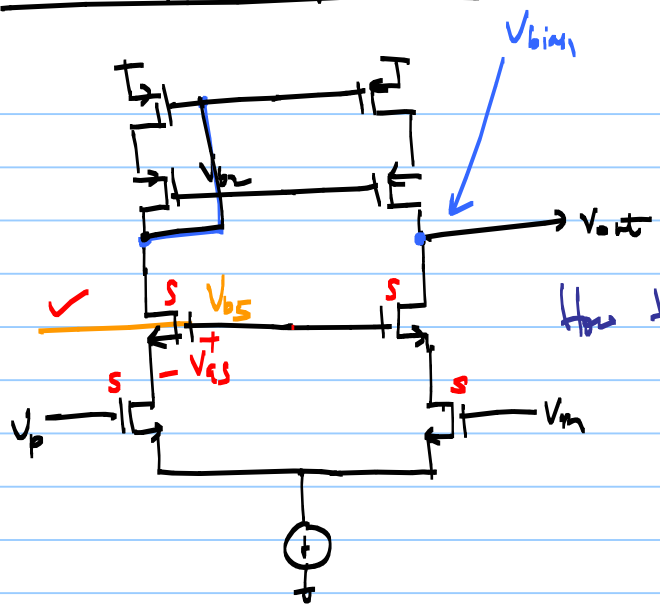
$A_{v,DM} = g_{m_n} \cdot (r_{op} \| r_{on}) \simeq g_m r_o$



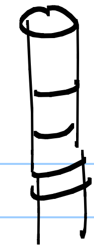
$$A_{v,DM} = g_{mn} \cdot \left(r_{on} \parallel \left(g_{mp} r_{op}^2 \right) \right)$$

$$\approx g_{mn} r_{on}$$

Telescopic Amplifier

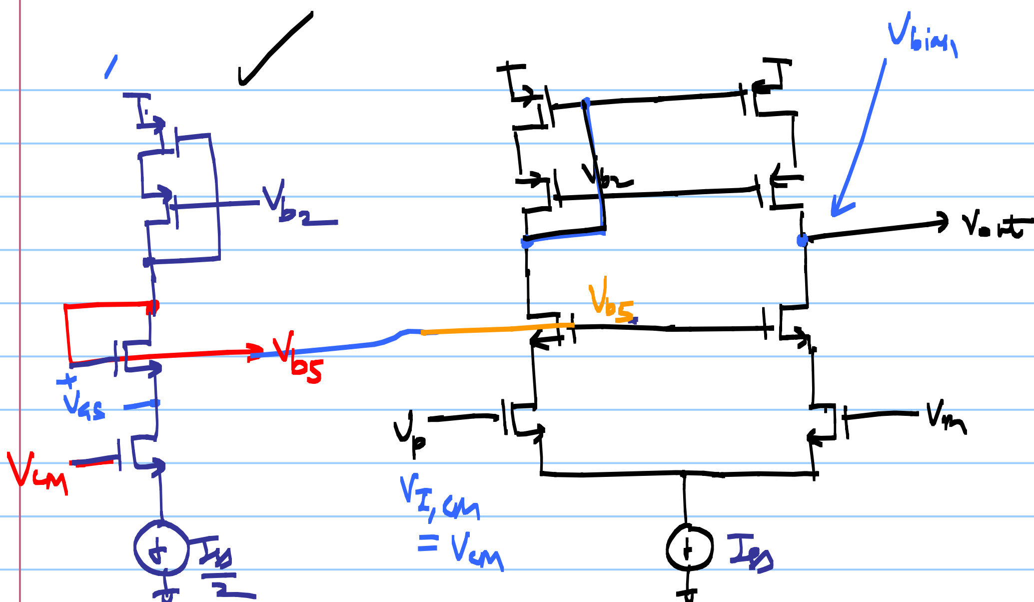


How to generate V_{b5}?



"Telescope"

"Replica Biasing"



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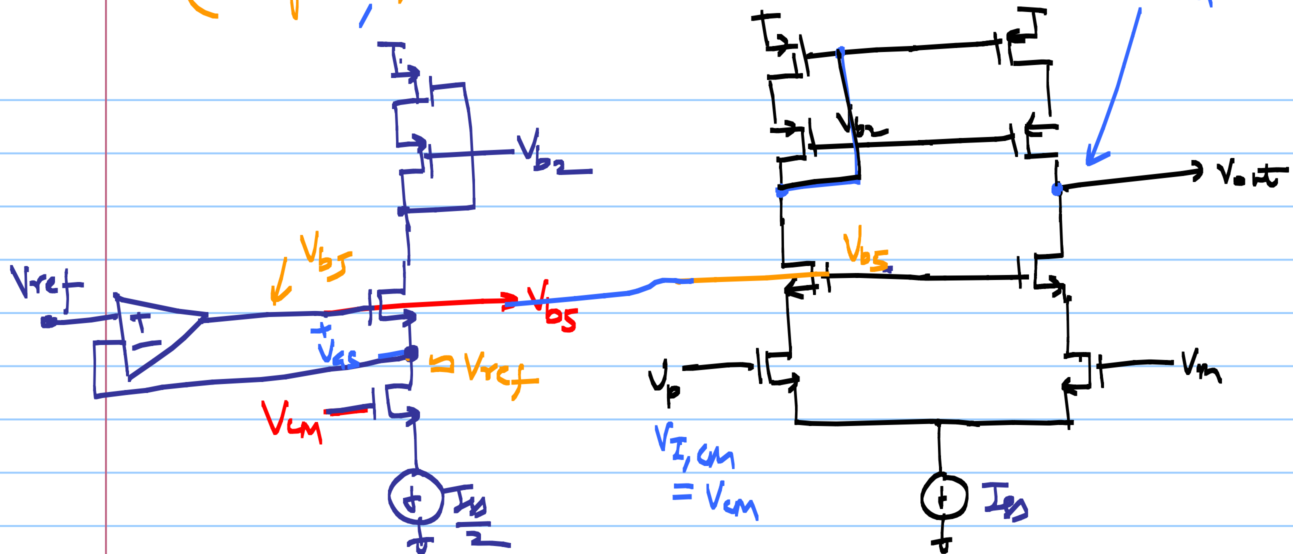
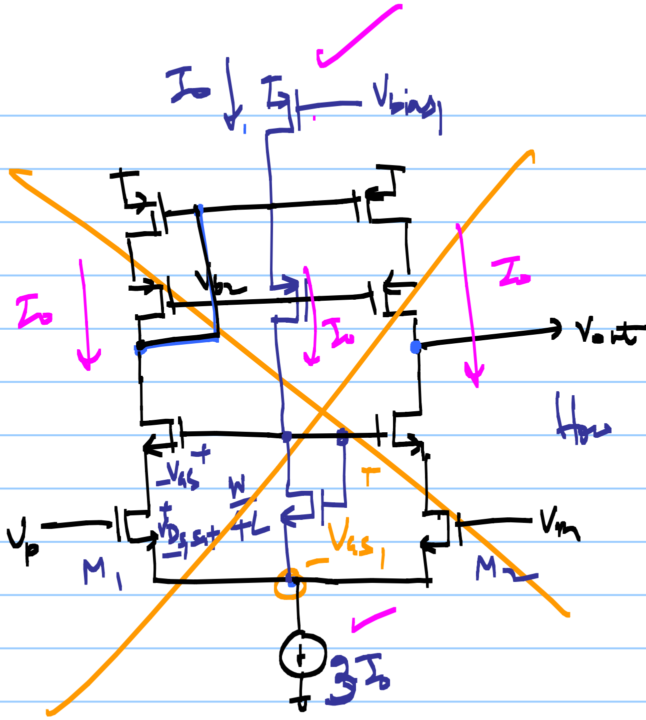


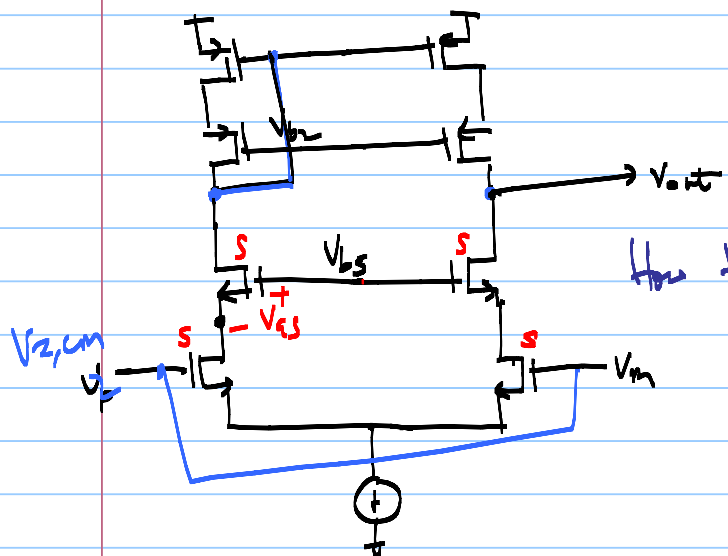
V_{ref}
V_{b5}
V_{b2}
V_{b5}
V_{GS}
$= V_{ref}$
V_{CM}
$\frac{I_{SS}}{2}$
V_{b2}
V_{b5}
V_{bias}
V_{out}
V_p
V_m
$V_{I,CM} = V_{CM}$
I_{SS}



" Bias Stick disturbs biasing of the ~~diff pair~~ "

How to generate V_{b2}?

$$A_v = g_{mn} \cdot (R_{ncas} \,||\, R_{pcas})$$



How to generate V_{bs}?

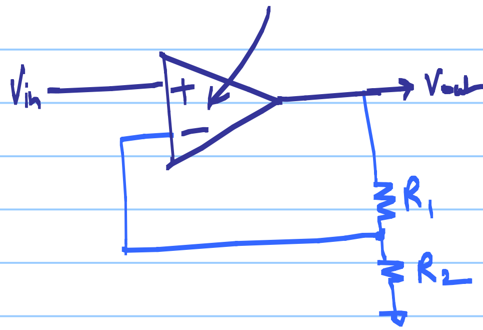
$$V_{in,cm} \geq V_{GS} + V_{CCS} = V_{GS} + 2V_{DS,sat}$$
$$= 3V_{DS,sat} + V_{THN}$$

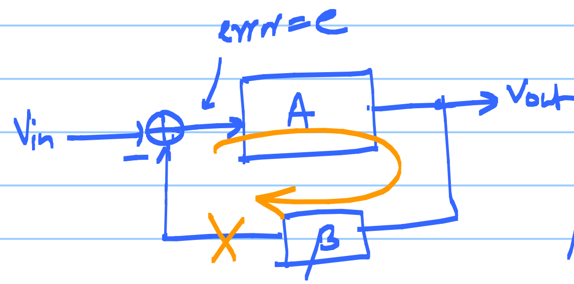
$$V_{in,cm} \leq V_{DD} - \underbrace{V_{SG} - V_{DS,sat}}_{} + V_{THN}$$

"input CMR is limited"

Opamp performance Metrics

① Gain   ideal opamp, A, (no pole) — DC gain





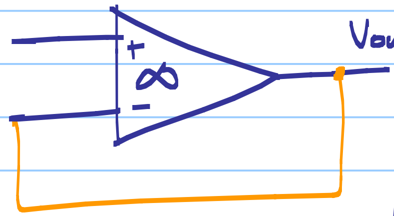
$\beta \leq 1$

$$\beta = \frac{R_2}{R_1 + R_2}$$

$$L = A\beta$$

Loop-gain $L = A\beta$

Aside (Ideal opamp)



Vout — finite voltage

$V_{out} = A \cdot (V_p - V_m)$

$\infty \cdot 0$

$\Rightarrow V_p \simeq V_m$

GBW = gain × BW = constant

$$\frac{G}{1+GH}$$

from controls

$$H_{CL} = \frac{V_{out}}{V_{in}} = \frac{A}{1+L} = \frac{A}{1+A\beta}$$

$$= \frac{1}{\frac{1}{A}+\beta}$$

if $A \to \infty$

$\simeq 1/\beta \longrightarrow$ ideal closed-loop gain

$$\frac{R_1+R_2}{R_2} = 1+\frac{R_1}{R_2}$$

$$= \frac{1}{\beta}\cdot\frac{A\beta}{1+A\beta}$$

$$= \frac{1}{\beta}\cdot\frac{1}{1+\frac{1}{A\beta}}$$

$|x| \ll 1$

$$(1+x)^{-1} \simeq 1-x$$

$$= 1 - x + \cancel{\frac{x^2}{2}} - \cancel{\frac{x^3}{3}} + \cancel{\frac{x^4}{4}}$$

$$= \frac{1}{\beta}\cdot\left(1+\frac{1}{A\beta}\right)^{-1}$$

$$= \frac{1}{\beta}\left(1-\frac{1}{A\beta}\right)$$

ideal closed-loop gain

$$\frac{v_{out}}{v_{in}} = \frac{1}{\beta}\left(1 - \underbrace{\frac{1}{A\beta}}_{\text{Error} \Rightarrow \epsilon}\right) \longrightarrow \text{relative gain error}$$

for $\epsilon \to 0$

$A\beta \gg 1$

$\epsilon = \frac{1}{A\beta}$ for $\frac{1}{\beta} = 10$

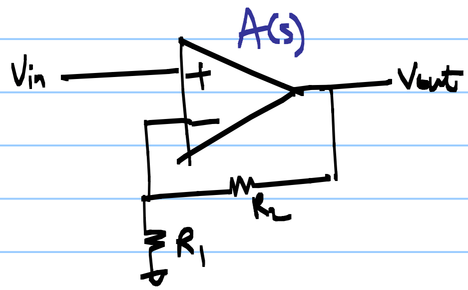
for $\epsilon < 1\% \Rightarrow A > 1000 = 60\ \text{dB}$

gain error

A sets the precision requirements

② Small-signal BW

$$A(s) = \frac{A_0}{\left(1+\frac{s}{\omega_0}\right)} \longrightarrow \text{dominant pole model}$$



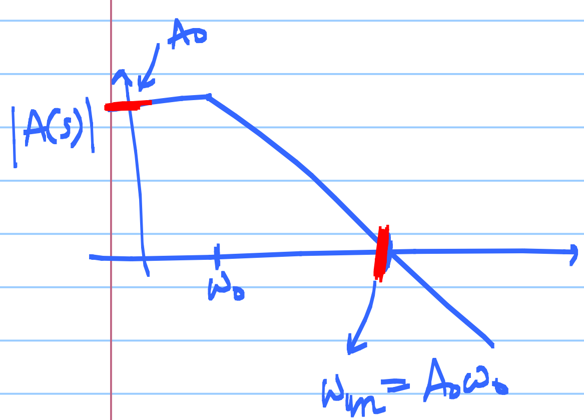
$$\text{Loop gain} = \overbrace{\beta A(s)}^{L(s)} = \frac{A_0\beta}{1+\frac{s}{\omega_0}}$$

$$A_{CL}(s) = \frac{V_{out}}{V_{in}}(s) = \frac{A(s)}{1+L(s)} =$$

$$= \frac{\frac{A_0}{(1+s/\omega_0)}}{1+\frac{A_0\beta}{(1+s/\omega_0)}} = \frac{A_0}{1+\frac{s}{\omega_0}+\beta A_0}$$

$$= \frac{A_0}{(1+\beta A_0) + \frac{s}{\omega_0}} = \underbrace{\left(\frac{A_0}{1+A_0\beta}\right)} \cdot \frac{1}{1 + \frac{s}{\omega_0(1+\beta A_0)}}$$

$$= A_{CL} \cdot \frac{1}{\left(1 + \frac{s}{\omega_{3dB}}\right)}$$



$$-3dB \ BW = \omega_{3dB} = \omega_0(1+\beta A_0)$$

$$\simeq \omega_0 \beta A_0$$

$$= \beta(A_0\omega_0)$$

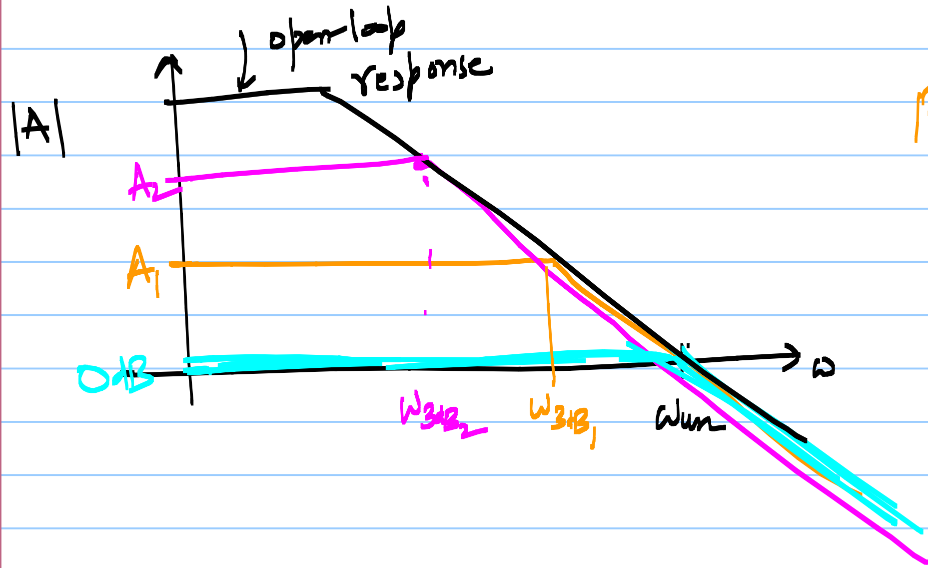
$$= \beta \cdot \omega_{un}$$

$$\omega_{3dB} = \beta \cdot \omega_{un}$$

$$\Rightarrow \quad \omega_{un} = \frac{1}{\beta} \cdot \omega_{3dB} = A_{CL} \cdot \omega_{3dB}$$

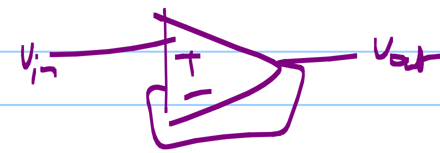
$$\boxed{\omega_{un} = \text{Gain} \times BW}$$ Trade-off

$$\boxed{\omega_{3dB} \cdot A_{CL} = \omega_{un}} \longrightarrow$$ Exactly true for dominant-pole opamp



$\beta < \frac{1}{2}$

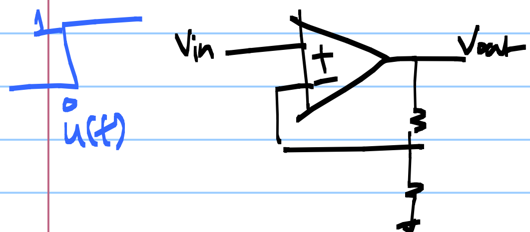
$\beta = 1 \Rightarrow \omega_{3dB} = \omega_{un}$

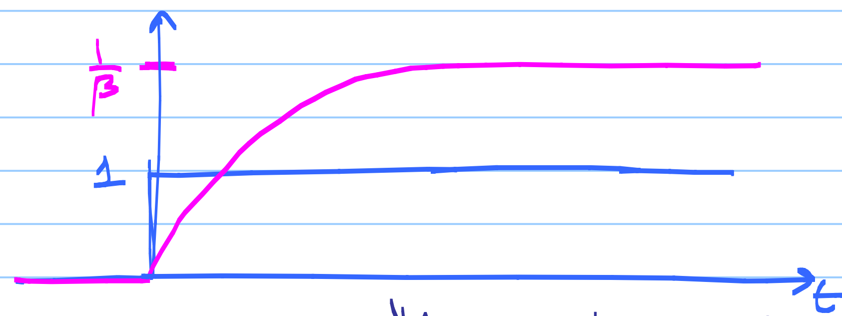


$$A_{CL}(s) = \frac{1}{\beta} \cdot \frac{1}{1 + s/\omega_{3dB}} ,$$

$$\tau = \frac{1}{\omega_{3dB}}$$

$$V_{out}(t) = \frac{1}{\beta} \cdot \left(1 - e^{-t/\tau}\right) u(t)$$





"Assumed linear settling"

* Settling accuracy

$$V_{out} = \frac{1}{\beta}\left(1 - e^{-t/\tau}\right) ,$$

allow T_1 to settle

settling error $= e^{-T_1/\tau}$

For 1% settling accuracy

$$1 - e^{-T_1/\tau} = 0.99$$

$$\Rightarrow \quad T_1 = 4.6\tau \simeq 5\tau$$

Ex. For 1% settling with a gain of 10 of 5ns $\Rightarrow$ $\tau = 1.09\ ns \simeq 1ns$

$$\omega_{3dB} = \frac{1}{\tau} = 1\ G\ rad/s$$

$$Gain = \frac{1}{\beta} = 10 \Rightarrow \omega_{un} = 10 \times \omega_{3dB}$$

$$\omega_{un} = 10 \times 10^9$$

$$\boxed{f_{un} = \frac{\omega_{un}}{2\pi} = 1.47\ GHz}$$