Lecture 22

April 13, 2015

EE 420 / ECE 620

Analog IC Design

A23.7

$$V_{D1} = nV_T \ln \frac{KI_{REF}}{I_S}$$

$$V_{D2} = nV_T \ln \frac{I_{REF}}{I_S}$$

$$I_{REF} = \frac{V_{D1} - V_{D2}}{R} = \frac{nV_T \ln K}{R}$$

$$V_{REF} = I_{REF} \cdot R + V_{D3}$$

$$V_{REF} = L \cdot \frac{kT}{q} \ln K + V_{D3}$$

is it a BGR? YES.

$$\frac{\delta V_{REF}}{\delta T} = L \cdot \frac{k}{q} \ln K + \frac{\delta V_{D3}}{\delta T}$$

$0.055 \frac{mV}{°C}$ $\quad -1.6 \frac{mV}{°C}$

$$TC_{V_{REF}} = \frac{1}{V_{REF}} \cdot \frac{\delta V_{REF}}{\delta T}$$

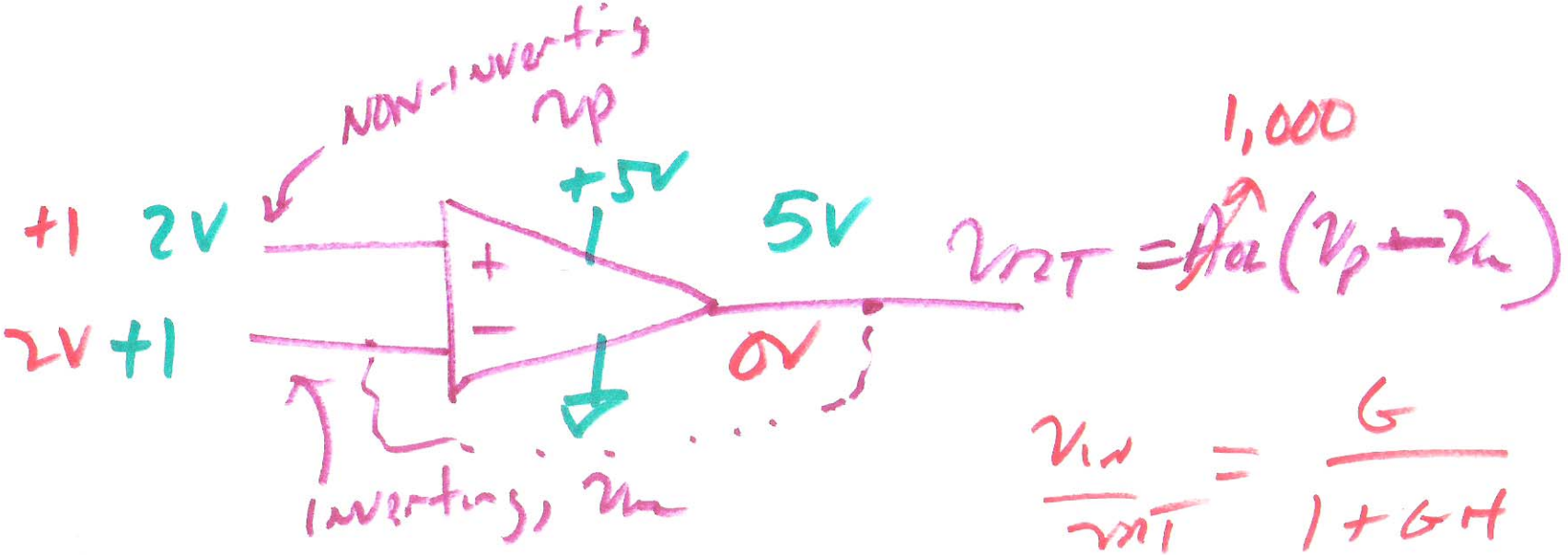
$$I_{REF} = R^{-1} N V_T \ln K = \frac{N V_T \ln K}{R}$$

$$\frac{\delta I_{REF}}{\delta T} = (-1) R^{-2} \frac{\delta R}{\delta T} N V_T \ln K + R^{-1} N \left(\frac{k}{q}\right) \ln K \qquad V_T = \frac{kT}{q}$$

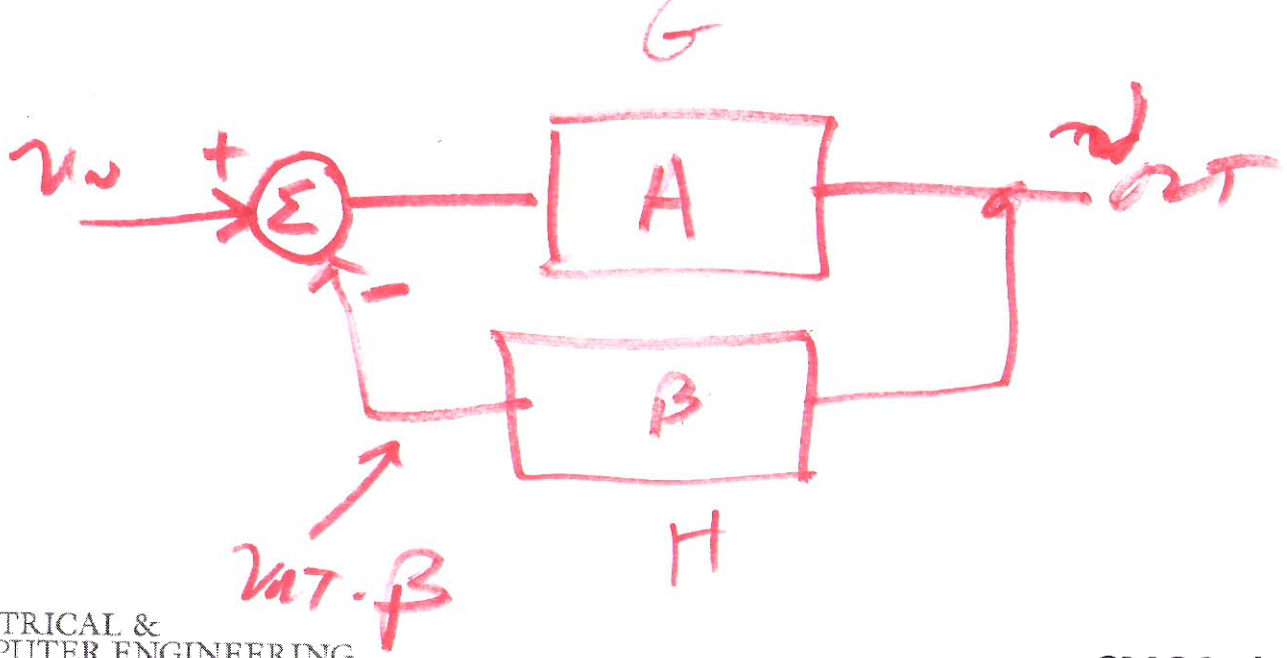
$$= \left(\frac{-1}{R} \frac{\delta R}{\delta T}\right) \underbrace{\frac{N V_T \ln K}{R}}_{I_{REF}} + \frac{N \left(\frac{k}{q}\right) \ln K}{R}$$

$$\frac{1}{I_{REF}} \frac{\delta I_{REF}}{\delta T} = -\frac{1}{R} \frac{\delta R}{\delta T} + \frac{1}{T} ?$$

Op-Amp Design



$$\frac{v_{IN}}{v_{OUT}} = \frac{G}{1+GH}$$



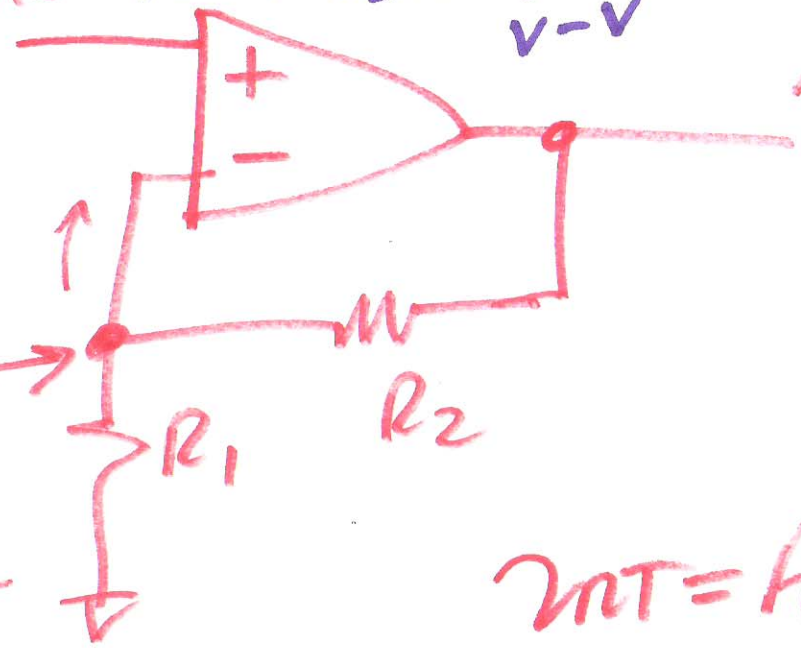
$\frac{v_{RT}}{v_i} = \frac{1}{\frac{1}{A_{OL}} + \beta}$

$\frac{1}{10^5} + \frac{1}{10}$

NON-INVERTING $= 1 + \frac{R_2}{R_1} = \frac{R_1 + R_2}{R_1}$

v_{in} SERIES-SHUNT

V-V



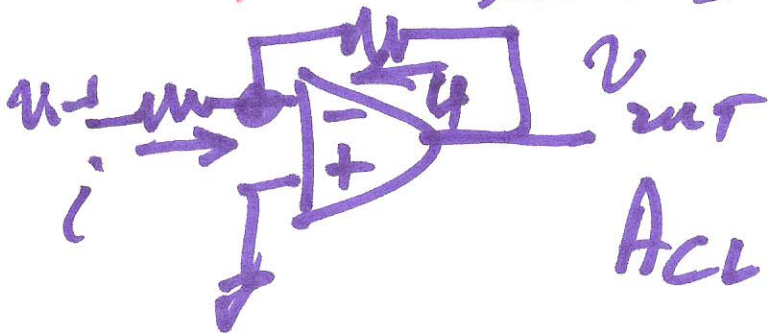
$v_{RT} = A_{OL(f)} \cdot (v_p - v_n)$

$v_f = v_{OUT} \cdot \frac{R_1}{R_1 + R_2} = \frac{v_{RT}}{\beta}$

$v_{RT} = A_{OL} \cdot (v_{in} - \beta v_{RT})$

$v_f = v_{RT} \cdot \beta$

SHUNT-SHUNT



$v_{RT} = (1 + \beta A_{OL}) = A_{OL} \cdot v_{in}$

$A_{CL} = \frac{v_{RT}}{v_{in}} = \frac{A_{OL}}{1 + \beta A_{OL}} \xrightarrow{A_{OL} \to \infty} = \frac{1}{\frac{1}{A_{OL}} + \beta}$

$A_{CL}\big|_{ideal, A_{OL} = \infty} = \frac{1}{\beta} = \frac{R_1 + R_2}{R_1}$

$$A_{CL} = \frac{v_{out}}{v_{in}} = \frac{A_{OL}}{1 + \beta A_{OL}}$$

When UNSTABLE

$\beta = 1$ worst case

$$\beta A_{OL} = -1 \rightarrow A_{OL} = -1$$

$$|\beta A_{OL}| = 1 \quad \angle \beta A_{OL} = \pm 180^\circ$$

$\beta = 1$ (All of the output feedback)

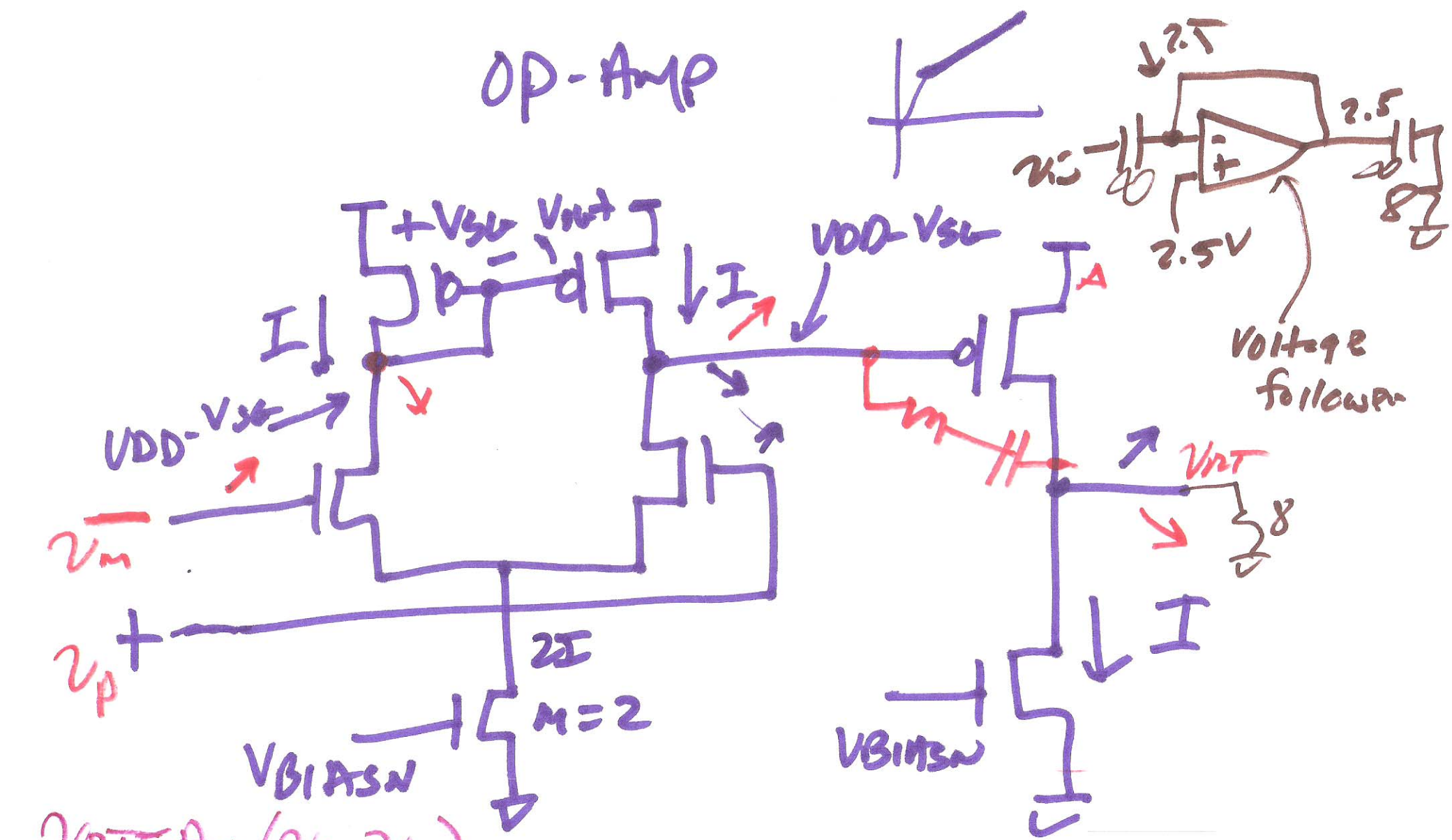
$|A_{OL}| = 1$

$\angle A_{OL} = 180^\circ$

Voltage follower

$$A_{CL} = \frac{1}{\beta} = 1$$

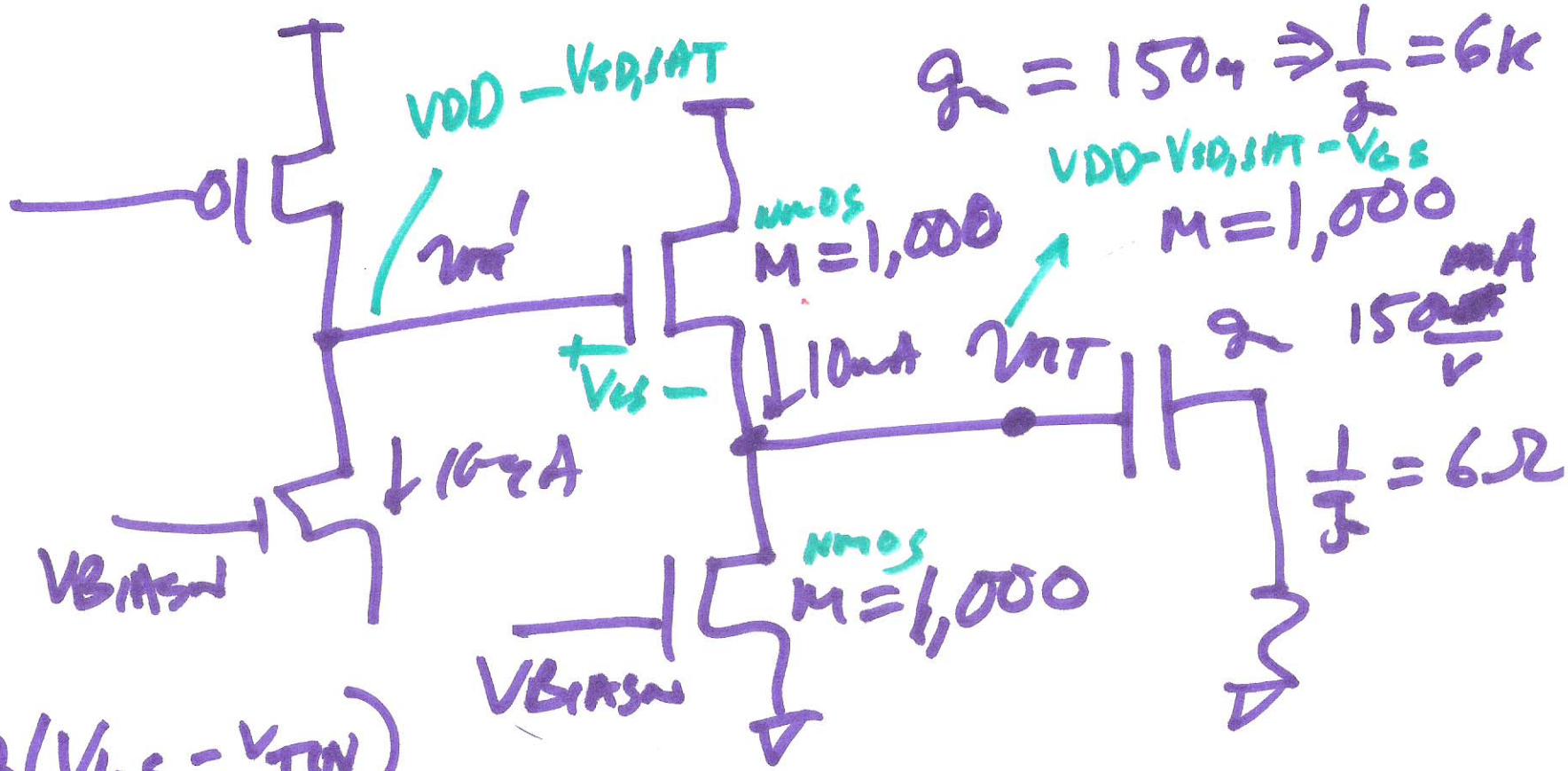
OP-AMP



$V_{OUT} = A_{OL}(V_p - V_m)$

$$A_{OL} = A_d \cdot A_{CS} = \frac{V_{OUT}}{V_p - V_m} = g_{mN} r_{ON} \| r_{OP} \cdot g_{mP} \cdot r_{ON} \| r_{OP}$$

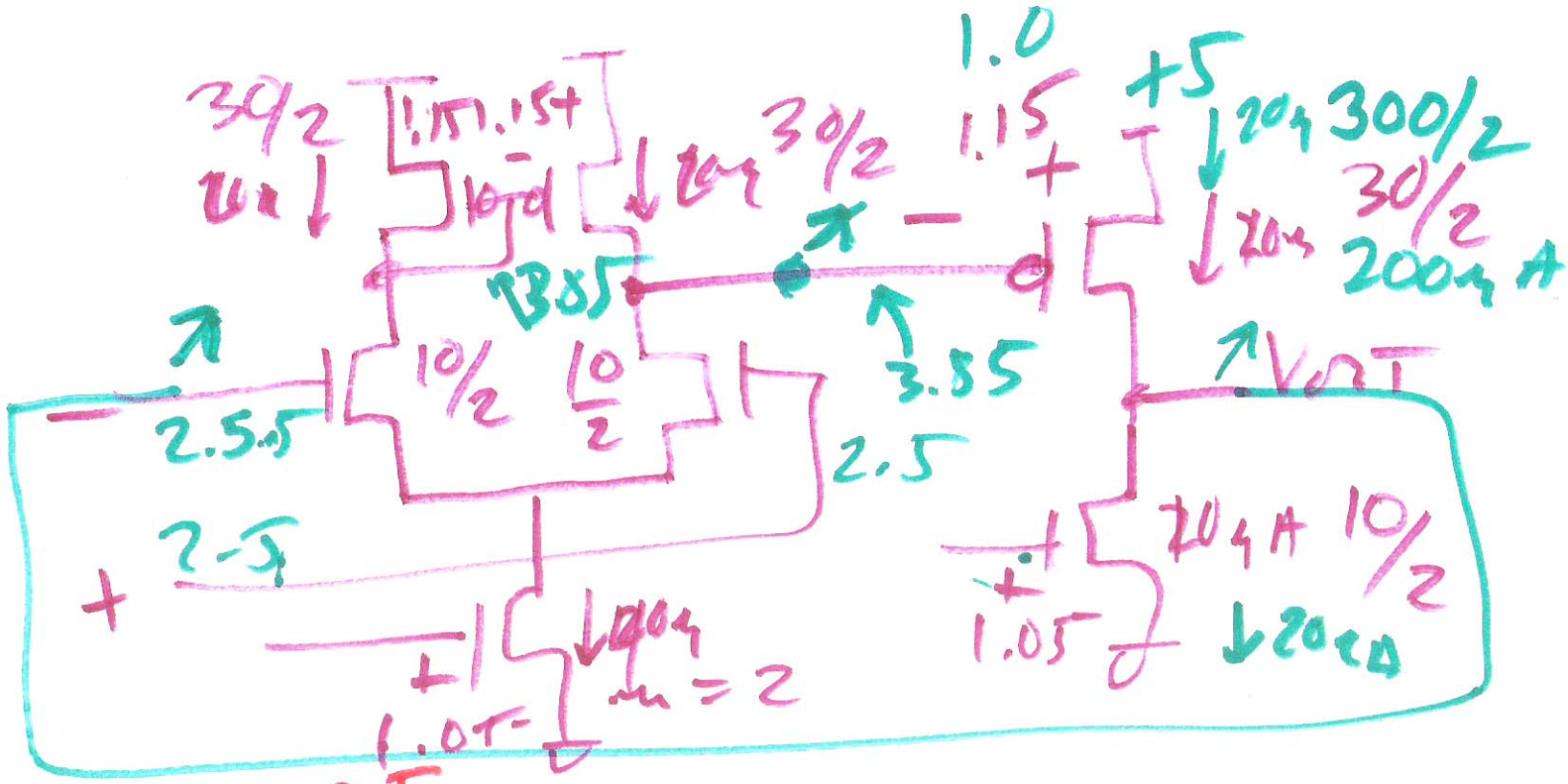
7)

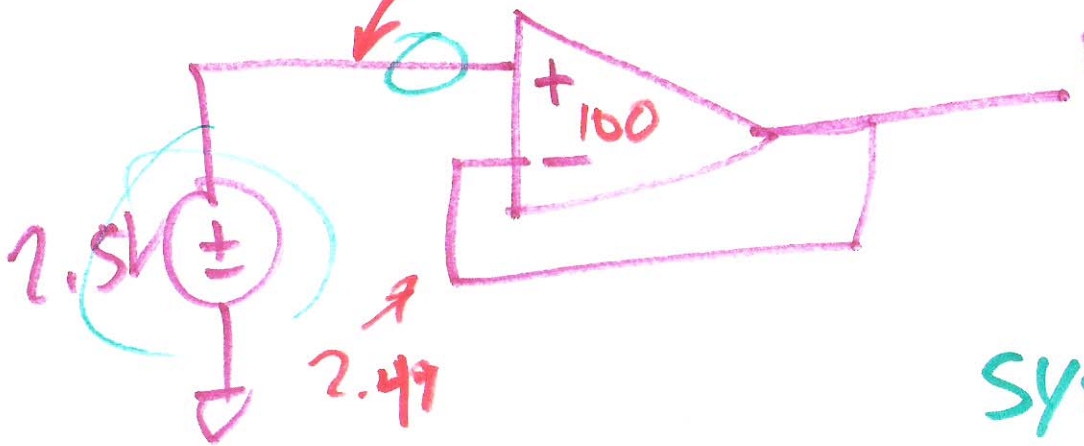


$g_2 = 150\mu \Rightarrow \frac{1}{J} = 6K$

$g_2 = \beta(V_{GS} - V_{TN})$

$g_2 = \sqrt{2 \cdot KP \cdot \frac{W}{L} \cdot I_D} \; \frac{2\mu/1\mu}{2\mu/1\mu} = \frac{8}{8 + \frac{1}{6}} \simeq \frac{1}{2}$





$V_{OUT} = 100 \cdot (2.5 - V_{OUT})$

$V_{OUT} \triangleq 2.49V$?

systematic offset