EE 422 ECG 622
Analog IC Design
April 3, 2013

Lecture 17

Cont'd from page 2

$$\frac{5 - V_x}{100K} = 1.2mA \cdot 0.3 \cdot V_x \quad \text{for } V_x \text{ small}$$

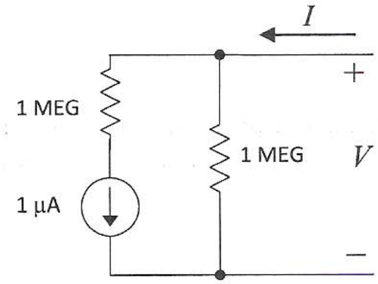
$$\underline{10^5 \cdot 360 \cdot 10^{-6}} = 36$$

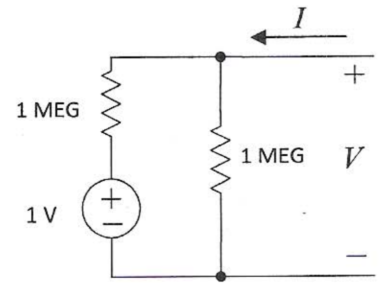
$$5 - V_x = 100K \cdot .36mA \cdot V_x$$

$$5 = (1 + 36) V_x$$

$$V_x = \frac{5}{37} \approx \underline{\underline{.13V}}$$

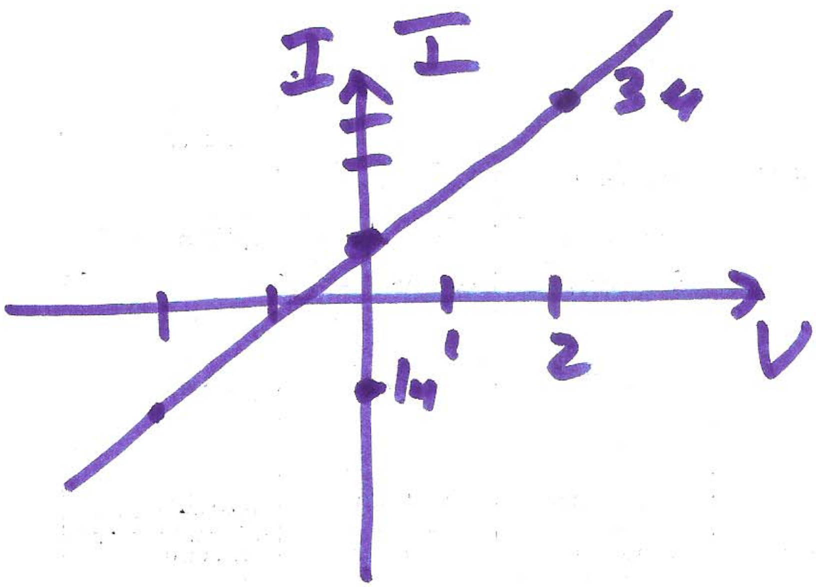
1. Determine equations for how the current, I in the following circuits, changes with changes in the voltage, V. Sketch the change in I for V changing from –2 V to +2 V. (20 points)

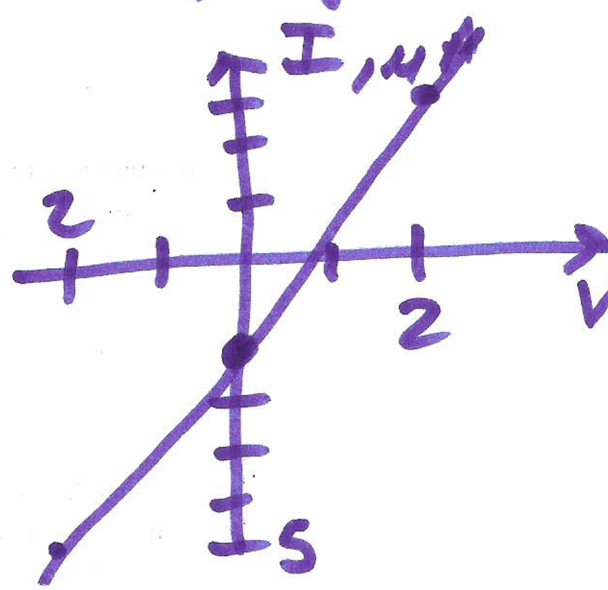




$$I = \frac{V}{10^6} + 10^{-6}$$
$$= 10^{-6}(V+1)$$

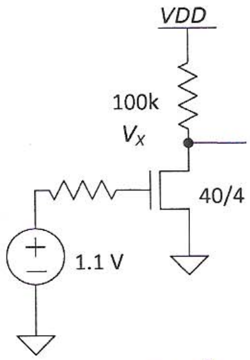
$$I = \frac{V}{10^6} + \frac{V-1}{10^6}$$
$$= 10^{-6}(2V-1)$$

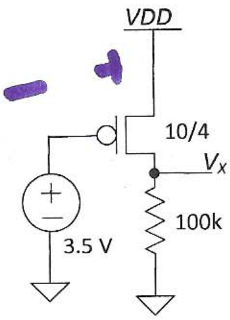




2)

2. Determine V_X in each of the following. Show your work for credit. (20 points)





$5 - V_O = I_O \cdot 100k$

$V_{GS} = 1.1$

ASSUME SAT.

$I_O = \frac{40}{4} \cdot \frac{120\mu A/V}{2} (1.1 - .8)^2$

$I_O = \frac{1.2mA}{2} \cdot .3^2 = 600\mu \cdot .09 = 540\mu A$

$V_O = 5 - 54\mu \cdot 100K < 0$

Not in saturation

in triode

$I_O = \frac{VDD - V_X}{100K} = \frac{120\mu}{V} \cdot \frac{40}{4} \left((1.1 - .8) V_X - \frac{V_X^2}{2} \right)$

3)

$V_X = I_O \cdot 100k$

$V_{SG} = 5 - 3.5 = 1.5$

$I_O = \frac{40\mu A/V}{2} \cdot \frac{10}{4} \cdot (1.5 - .9)^2$

$= 50\mu \cdot 0.36$

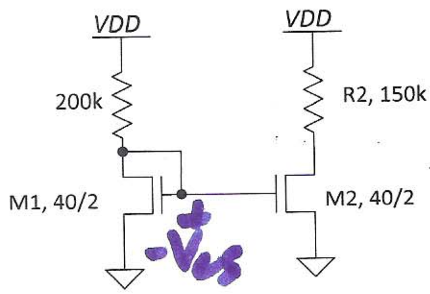
$= 18\mu A$

$V_X = 100K \cdot 18\mu A$

$= \underline{1.8V}$

yes $V_{SD} \geq V_{SG} - V_{THP}$

3. Calculate the currents and voltages in the following circuit. What is the maximum value allowed for R2 so that M2 remains operating in the saturation region? Show your work for credit. (20 points)



$240 \times .6 = 144.0$ $\qquad$ $240 + 144 = 384$ $\qquad$ $240 \times .6 = 144.0$ $\qquad$ $240 \times .04 = 9.60$

$$\frac{VDD - V_{GS}}{200k} = \frac{120\mu A/V}{2} \cdot \frac{40}{2}(V_{GS} - .8)^2$$

$$5 - V_{GS} = 1.2\frac{mA}{V}(V_{GS} - .8)^2 \cdot 200k$$

$$5 - V_{GS} = 240(V_{GS}^2 - 1.6V_{GS} + .64)$$

$153.6 + 148.8 - 5 = 148.6$

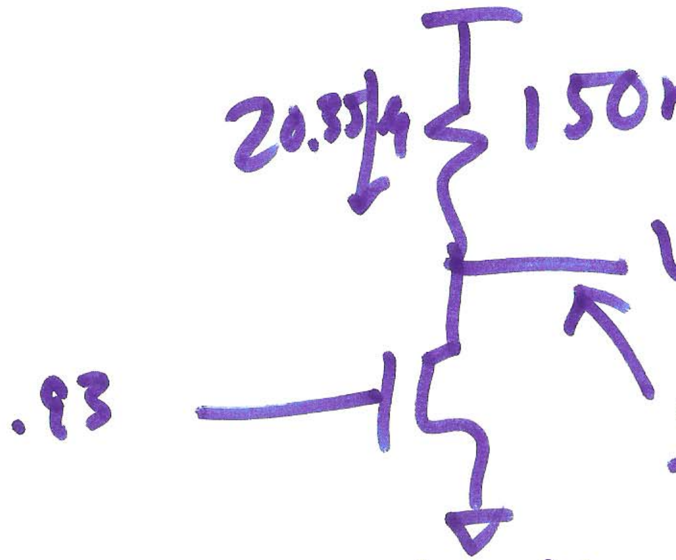
$$0 = 240V_{GS}^2 - 383V_{GS} + 148.6$$

$$V_{GS} = \frac{383 \pm \sqrt{(383)^2 - 4 \cdot 240 \cdot 148.6}}{2 \cdot 240}$$

$$\underline{\underline{V_{GS} = .93}}$$

4)

$$I_D = \frac{5 - .93}{200k} = \frac{4.07}{200k} = 20.35\,\mu A$$



$$150 \quad .35 \quad \overline{.45}$$

$$V_{OD} - 20.35\mu \cdot 150k =$$

$$5 - 3.04 = 1.89V$$

$$> .93 - .8 = .13 \qquad V_{O2} = 1.9V$$

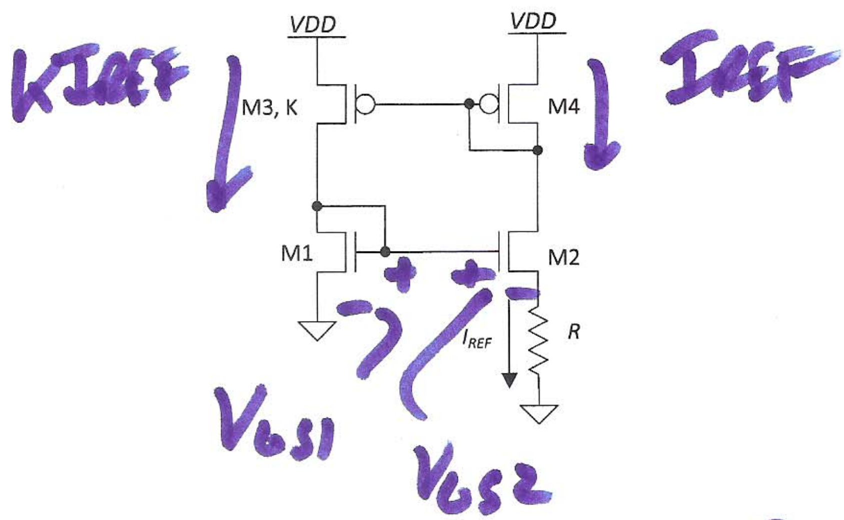
$$V_{DS} > V_{GS} - V_{THN}$$

$$\le \frac{5 - .13}{R_{D,MAX}} = I_D \rightarrow 20.35\mu$$

$$R_{DMAX} = \frac{5 - .13}{20.35\mu} = \frac{4.87}{20.35\mu} \approx 240k$$

$$\boxed{R_{DMAX} \approx 240k}$$

4. Derive an equation for I_{REF} in the following circuit. Note that M3 is K times wider than M4 and M1 and M2 are the same size. (20 points)



$$V_{GS1} = V_{GS2} + I_{REF} \cdot R$$

$$\sqrt{\frac{2KI_{REF}}{\beta_N}} + V_{THN} = \sqrt{\frac{2I_{REF}}{\beta_N}} + V_{THN} + I_{REF} \cdot R$$

$$\sqrt{\frac{2I_{REF}}{\beta_N}}\left(\sqrt{K} - 1\right) = I_{REF} \cdot R$$

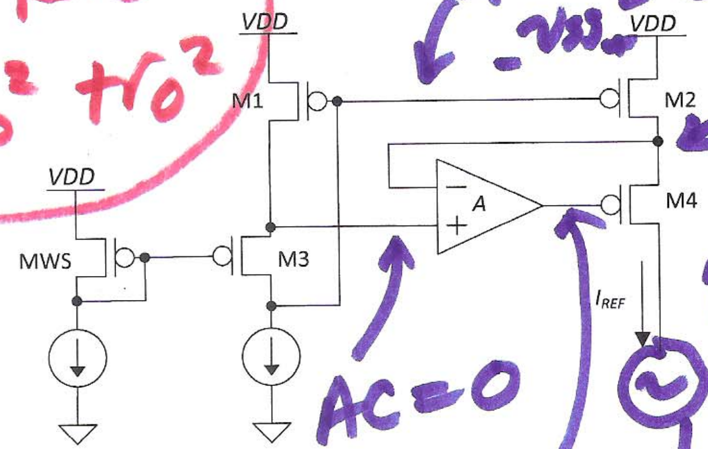
$$\sqrt{\frac{2}{\beta_N}}\left(\sqrt{K} - 1\right) = \sqrt{I_{REF}} \cdot R$$

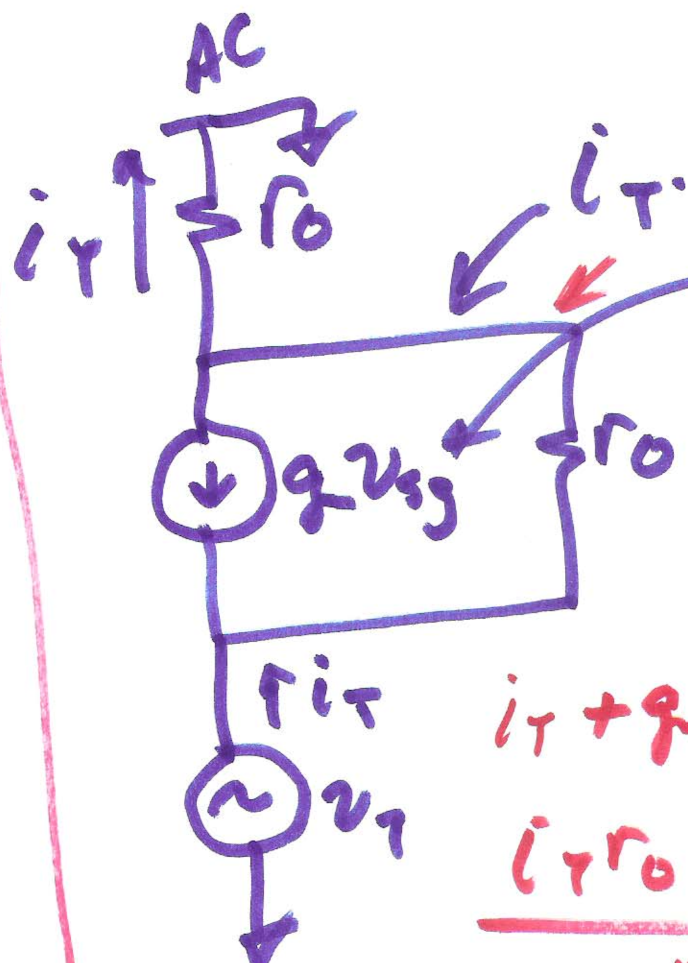
$$\frac{2}{\beta_N \cdot R^2}\left(\sqrt{K} - 1\right)^2 = I_{REF}$$

6)

5. Show how to determine the small-signal output resistance of the following current mirror. State all assumptions and show your work for credit. (20 points)

$$\frac{v_T}{i_T} = r_o + g_m r_o^2 + g_m A r_o^2 + r_o^2$$





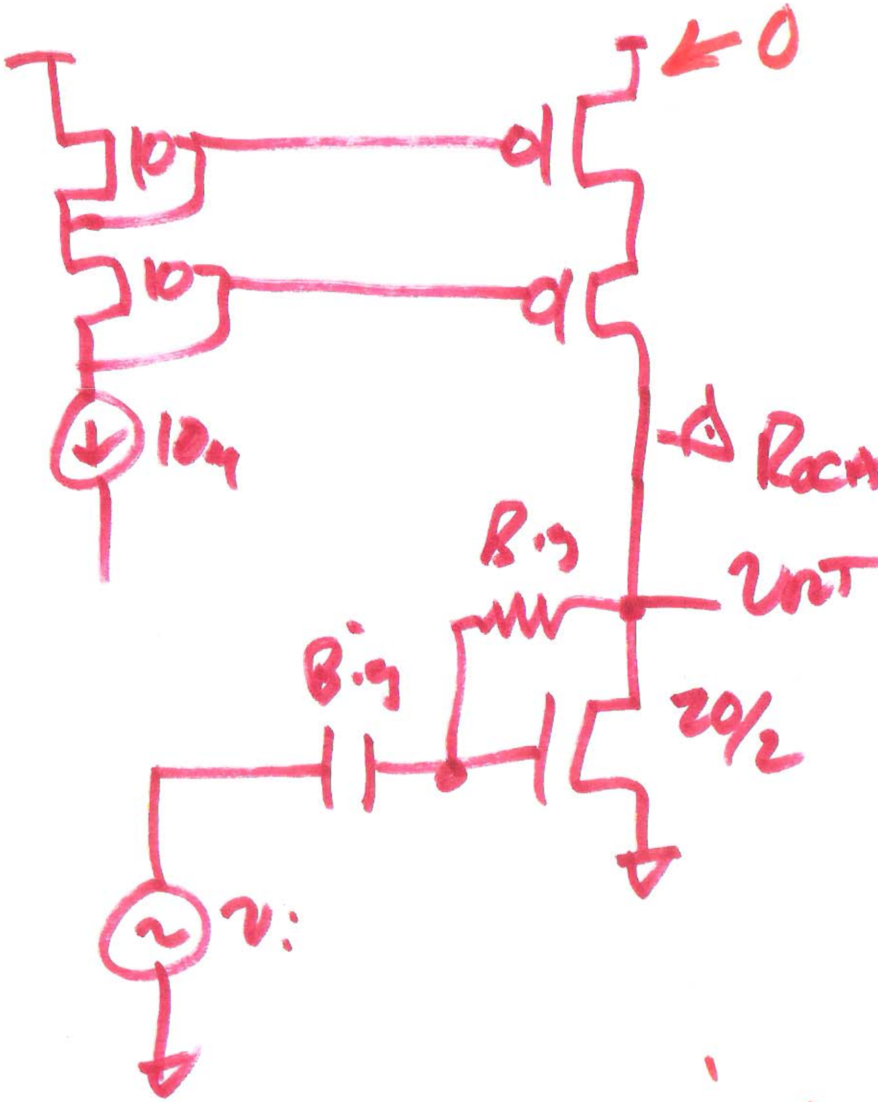
$v_{sg} = (i_T \cdot r_o + A i_T r_o)$

$$i_T + g_m(i_T r_o + A i_T r_o) + \frac{i_T r_o - v_T}{r_o} = 0$$

7)

$$v_T = r_o(i_T + i_T g_m r_o + i_T g_m A r_o + i_T r_o)$$

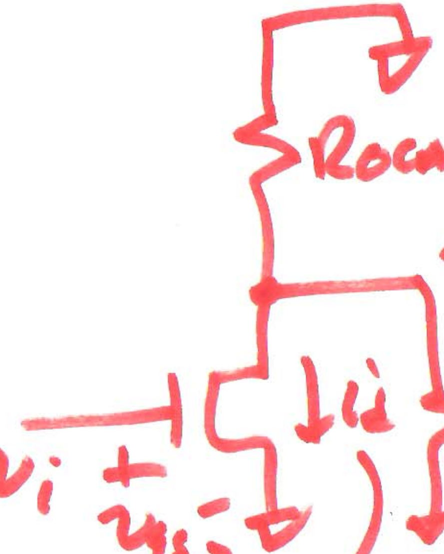
A21.6



$$g_m = \sqrt{2 I_D \cdot \beta_p}$$

$$r_o = \frac{1}{\lambda_p I_D}$$

$$R_{ocasp} = g_m r_o^2$$



$v_{OUT} = -i_d \cdot R_{ocas} \| r_{on} \approx -i_d \cdot r_{on}$

$v_{gs} = v_i$

$g_m v_i = i_d$

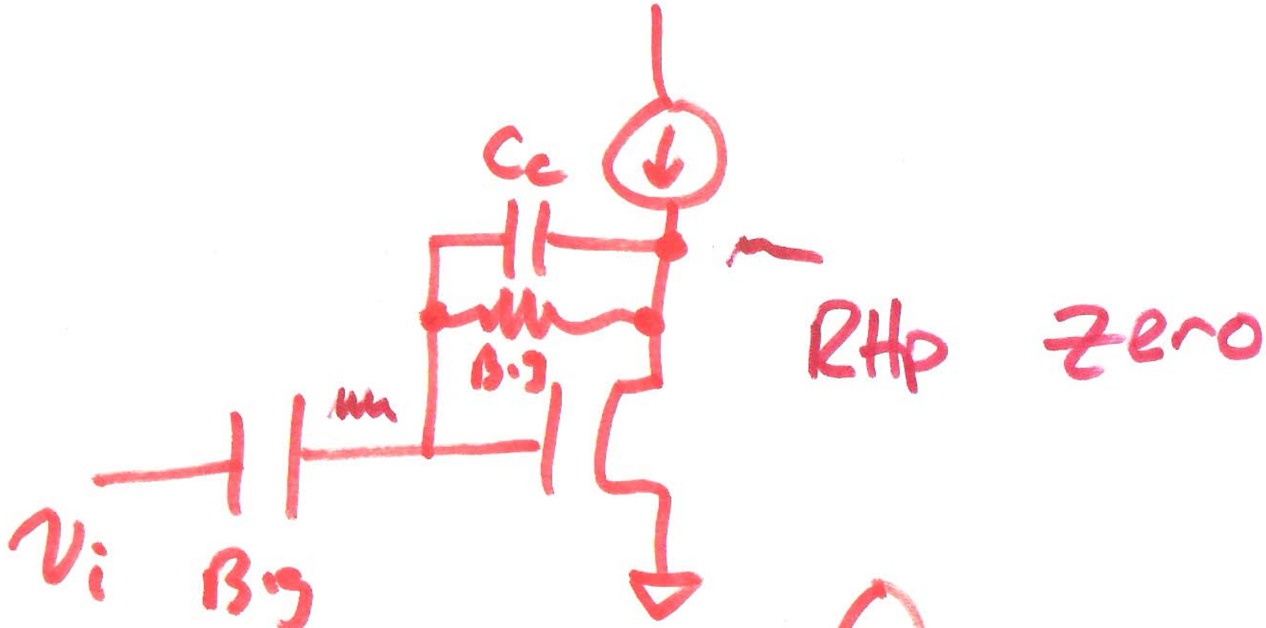
$\frac{i_d}{g_m} = v_i$

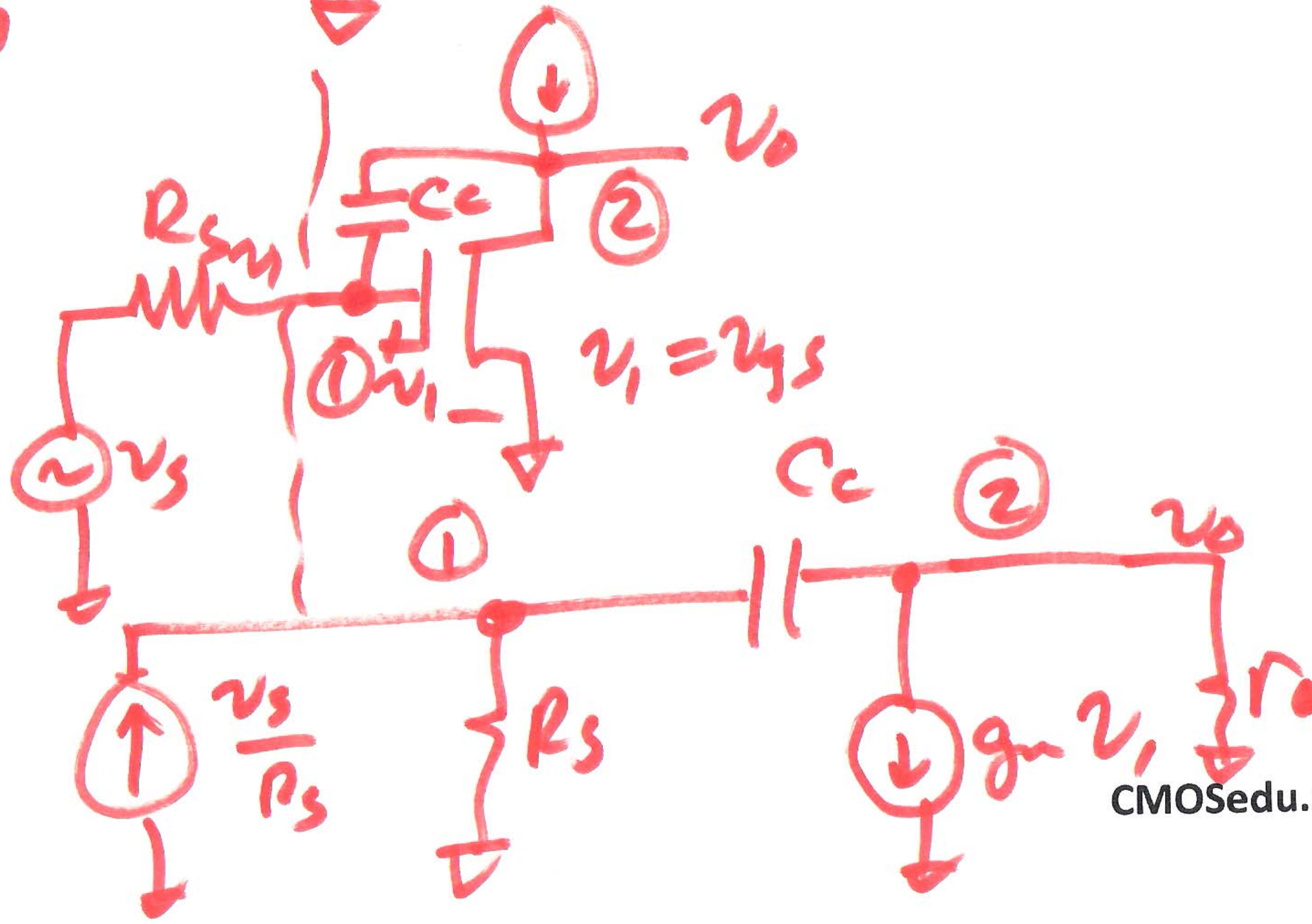
$$A_v = \frac{v_{OUT}}{v_i} = \frac{-i_d \cdot r_{on}}{i_d / g_m}$$

$$\boxed{A_v = -g_m r_{on} \| R_{ocas}}$$

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

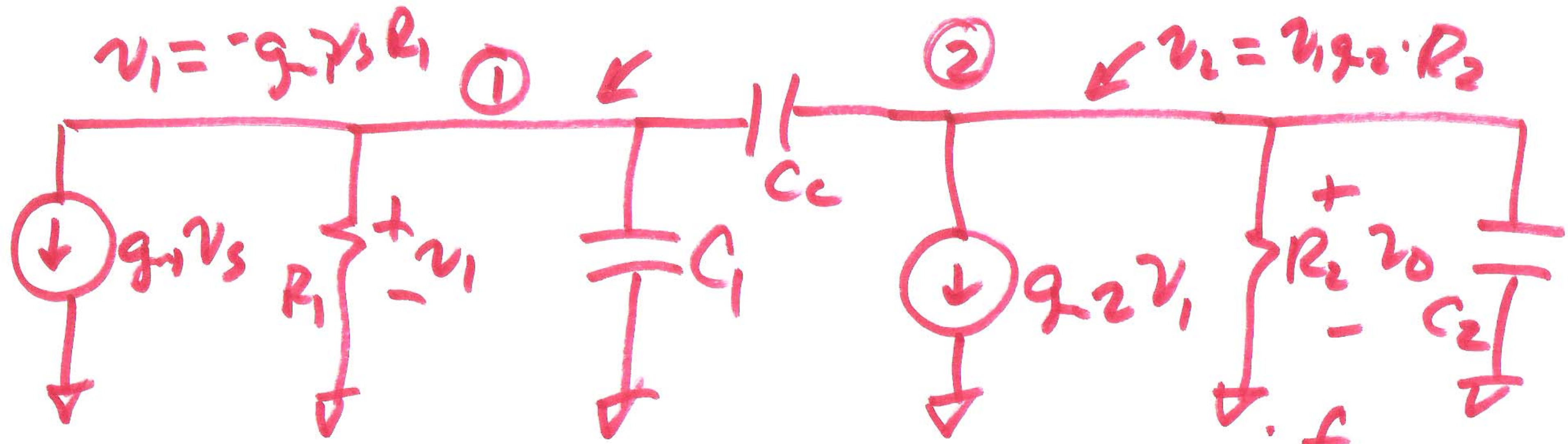
CMOSedu.com





UNLV
UNIVERSITY OF NEVADA LAS VEGAS

CMOSedu.com

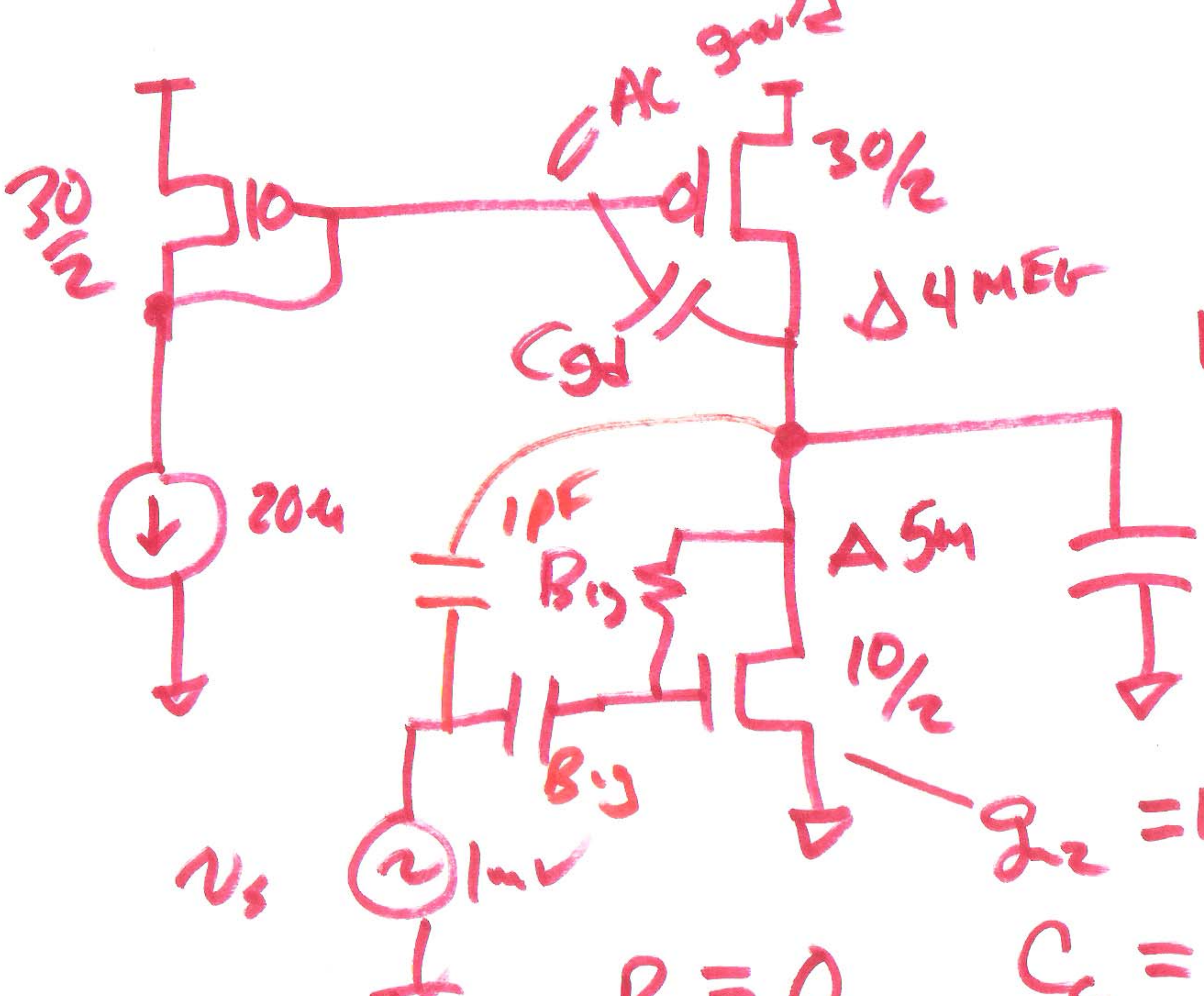


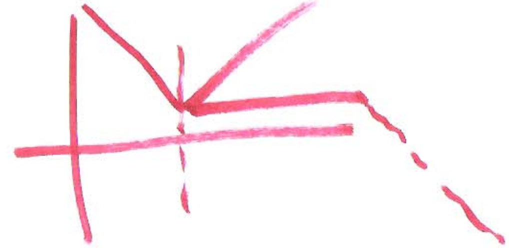
$$A_v(f) = \frac{v_{out}}{v_s} = g_{m1} R_1 \cdot g_{m2} \cdot R_2 \cdot \frac{1 - j\frac{f}{f_z}}{\left(1 + j\frac{f}{f_1}\right)\left(1 + j\frac{f}{f_2}\right)}$$

$$f_1 = \frac{1}{2\pi\left[(C_c + C_2)R_2 + (C_1 + C_c(1 + g_{m2}R_2)) \cdot R_1\right]}$$

$$\simeq \frac{1}{2\pi g_{m2} R_2 R_1 C_c}$$

$$f_2 \approx \frac{g_{m2} C_c}{2\pi (C_c C_1 + C_1 C_2 + C_c C_2)}$$





$R_2 = 4 \| 5$

$= 2.22\text{MEG}$

$\frac{1}{2\pi \cdot 6.5K \cdot 10pF}$

$=$

$\frac{1}{g_{m2}} = 6.5k$

$g_{m2} = 150\mu A/V$

$R_1 = 0$

$C_c = 1pF$

$C_2 = 10pF + C_{gdp}$

$$f_z = \frac{g_m}{2\pi C_c} = \frac{150\mu}{6.8 \cdot 1pF} = 23\text{MHZ}$$

$$f_2 = \frac{1}{2\pi \cdot \frac{1}{g_m} \cdot C_2} \rightarrow \frac{g_{m2}}{2\pi C_2} = 2.3\text{ MHz}$$

UNLV UNIVERSITY OF NEVADA LAS VEGAS

CMOSedu.com

$$f_1 = \frac{1}{2\pi R_2 C_c}$$

$$= \frac{1}{2\pi \cdot 2.2e6 \cdot 1pF}$$

$$= \frac{1}{2\pi \cdot 10^{-6} \cdot 2.2} = \frac{159kHz}{2.2}$$

$$\approx 72 \, kHz$$

$$\frac{1}{2}$$