Homework 7 – Due 11/9/2016

Problems (not review questions): 9.113, 9.114

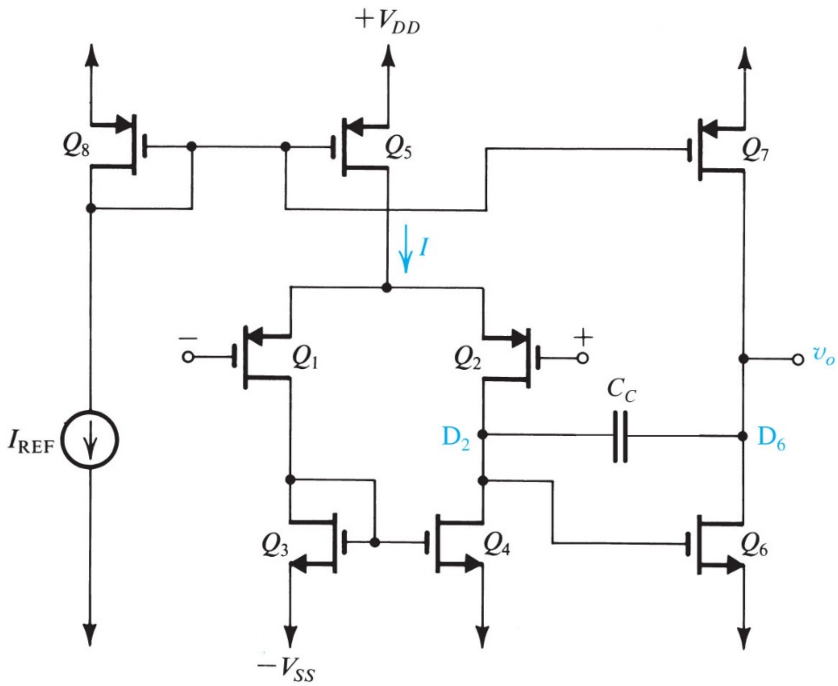

Figure 9.40 Two-stage CMOS op-amp configuration.

Answers for **9.113:** W = 20 µm, A_1 = -36 V/V, A_2 = -36 V/V, $-1.25\text{ V} \leq V_{ICM} \leq +0.25\text{ V}$, $-1.25\text{ V} \leq v_O \leq +1.25\text{ V}$

The results are summarized in the following table.

	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8
I_D (µA)	112.5	112.5	112.5	112.5	225	225	225	225
$\|V_{OV}\|$ (V)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
$\|V_{GS}\|$ (V)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
g_m (mA/V)	0.9	0.9	0.9	0.9	1.8	1.8	1.8	1.8
r_o (kΩ)	80	80	80	80	40	40	40	40

EE381 HOMEWORK FORMAT GUIDELINES

Things to remember

1) Re-Draw the Circuit on your homework sheet.
2) Show all work.
3) Final answer should be in decimal form.
4) Final answers should be boxed.
5) Your name should be on every page.

9.113 Refer to Fig. 9.40.

W_6 can be determined using Eq. (9.172):

$$\frac{(W/L)_6}{(W/L)_4} = 2\,\frac{(W/L)_7}{(W/L)_5}$$

$$\frac{(W/0.5)_6}{(10/0.5)} = 2\,\frac{(60/0.5)}{(60/0.5)}$$

$$\Rightarrow W_6 = 20\ \mu\text{m}$$

For all devices we can evaluate I_D as follows:

$$I_{D8} = I_{REF} = 225\ \mu\text{A}$$

$$I_{D5} = I_{REF}\frac{(W/L)_5}{(W/L)_8} = I_{REF} = 225\ \mu\text{A}$$

$$I = I_{D5} = 225\ \mu\text{A}$$

$$I_{D1} = I_{D2} = \frac{1}{2}I_{D5} = 112.5\ \mu\text{A}$$

$$I_{D3} = I_{D4} = I_{D1} = 112.5\ \mu\text{A}$$

$$I_{D6} = I_{D7} = I_{REF} = 225\ \mu\text{A}$$

With I_D in each device known, we can use

$$I_{Di} = \frac{1}{2}\mu C_{ox}\left(\frac{W}{L}\right)_i |V_{OVi}|^2$$

to determine $|V_{OVi}|$ and then

$$|V_{GSi}| = |V_{OVi}| + |V_t|$$

The values of g_{mi} and r_{oi} can then be determined from

$$g_{mi} = \frac{2I_{Di}}{|V_{OVi}|}$$

$$r_{oi} = \frac{|V_A|}{I_{Di}}$$

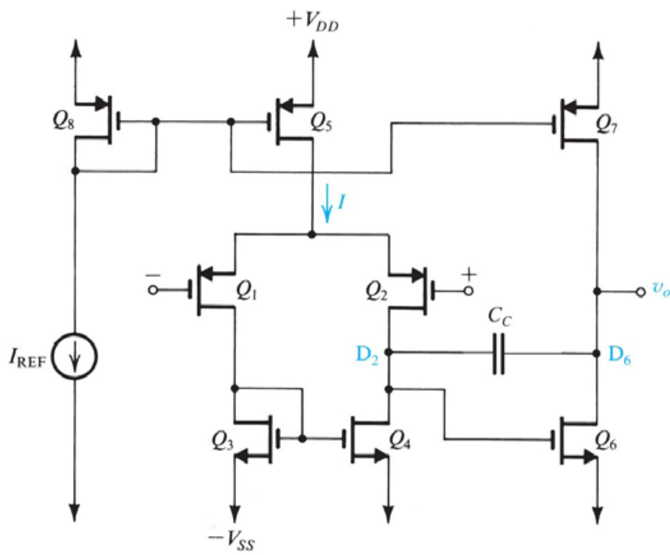

Figure 9.40 Two-stage CMOS op-amp configuration.

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I_D (µA)	112.5	112.5	112.5	112.5	225	225	225	225
$\lvert V_{OV}\rvert$ (V)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
$\lvert V_{GS}\rvert$ (V)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
g_m (mA/V)	0.9	0.9	0.9	0.9	1.8	1.8	1.8	1.8
r_o (kΩ)	80	80	80	80	40	40	40	40

$$A_1 = -g_{m1}(r_{o2} \parallel r_{o4})$$

$$= -0.9 \times (80 \parallel 80) = -36 \text{ V/V}$$

$$A_2 = -g_{m6}(r_{o6} \parallel r_{o7})$$

$$= -1.8 \times (40 \parallel 40) = -36 \text{ V/V}$$

$$A_0 = A_1 A_2 = -36 \times -36 = 1296 \text{ V/V}$$

The upper limit of V_{ICM} is determined by the need to keep Q_5 in saturation, thus

$$V_{ICM\max} = V_{DD} - |V_{OV5}| - |V_{SG1}|$$

$$= 1.5 - 0.25 - 1 = +0.25 \text{ V}$$

The lower limit of V_{ICM} is determined by the need to keep Q_1 and Q_2 in saturation, thus

$$V_{ICM\min} = V_{G3} - |V_t|$$

$$= -V_{SS} + |V_{GS3}| - |V_t|$$

$$= -1.5 + 1 - 0.75 = -1.25 \text{ V}$$

Thus

$$-1.25 \text{ V} \le V_{ICM} \le +0.25 \text{ V}$$

The output voltage range is

$$-V_{SS} + V_{OV6} \le v_O \le V_{DD} - |V_{OV7}|$$

that is,

$$-1.25 \text{ V} \le v_O \le +1.25 \text{ V}$$

9.114

(a) $I_{D1} = I_{D2} = 100 = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_{1,2} V_{OV}^2$

$$100 = \frac{1}{2} \times 400 \times \left(\frac{W}{L}\right)_{1,2} \times 0.04$$

$$\Rightarrow \left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = 12.5$$

$$I_{D3} = I_{D4} = 100 = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_{3,4} |V_{OV}|^2$$

$$100 = \frac{1}{2} \times 100 \times \left(\frac{W}{L}\right)_{3,4} \times 0.04$$

$$\Rightarrow \left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_4 = 50$$

$I_{D5} = I_{D7} = I_{D8} = 200\ \mu\text{A}$

Thus

$$200 = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_{5,7,8} V_{OV}^2$$

$$= \frac{1}{2} \times 400 \times \left(\frac{W}{L}\right)_{5,7,8} \times 0.04$$

$$\left(\frac{W}{L}\right)_5 = \left(\frac{W}{L}\right)_7 = \left(\frac{W}{L}\right)_8 = 25$$

$$I_{D6} = 200 = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_6 |V_{OV}|^2$$

$$200 = \frac{1}{2} \times 100 \times \left(\frac{W}{L}\right)_6 \times 0.04$$

$$\left(\frac{W}{L}\right)_6 = 100$$

The results are summarized in the following table:

Transistor	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8
W/L	12.5	12.5	50	50	25	100	25	25

Ideally, the dc voltage at the output is zero.

(b) The upper limit of V_{ICM} is determined by the need to keep Q_1 and Q_2 in saturation, thus

$$V_{ICM\max} = V_{D1} + V_t$$

$$= V_{DD} - |V_{SG4}| + V_t$$

$$= 0.9 - |V_t| - |V_{OV4}| + V_t$$

$$= 0.9 - 0.2 = +0.7\text{ V}$$

The lower limit of V_{ICM} is determined by the need to keep Q_5 in saturation,

$$V_{ICM\min} = -0.9 + |V_{OV5}| + |V_{GS1}|$$

$$= -0.9 + 0.2 + 0.2 + 0.4 = -0.1\text{ V}$$

Thus

$$-0.1\text{ V} \le V_{ICM} \le +0.7\text{ V}$$

(c) $v_{O\max} = V_{DD} - |V_{OV6}|$

$$= 0.9 - 0.2 = +0.7\text{ V}$$

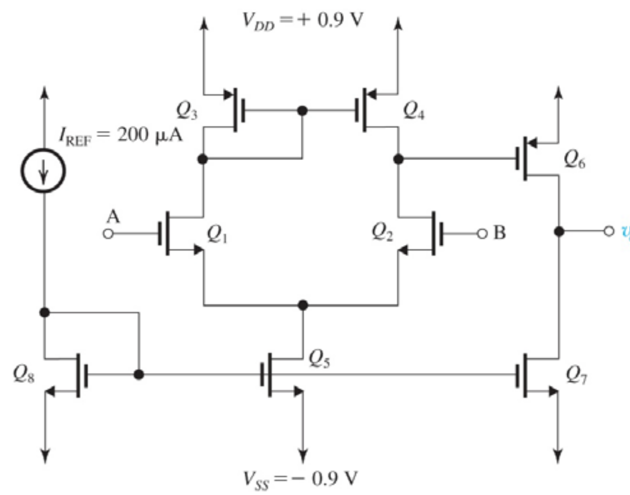

Figure P9.114

$$v_{O\min} = -V_{SS} + |V_{OV7}|$$

$$= -0.9 + 0.2 = -0.7\text{ V}$$

Thus

$$-0.7\text{ V} \le v_O \le +0.7\text{ V}$$

(d) $A_1 = -g_{m1,2}(r_{o2} \parallel r_{o4})$

where

$$g_{m1,2} = \frac{2 \times 0.1}{0.2} = 1\text{ mA/V}$$

$$r_{o2} = r_{o4} = \frac{|V_A|}{0.1\text{ mA}} = \frac{6}{0.1} = 60\text{ k}\Omega$$

$$A_1 = -1 \times (60 \parallel 60) = -30\text{ V/V}$$

$$A_2 = -g_{m6}(r_{o6} \parallel r_{o7})$$

where

$$g_{m6} = \frac{2 \times 0.2}{0.2} = 2\text{ mA/V}$$

$$r_{o6} = r_{o7} = \frac{|V_A|}{0.2} = \frac{6}{0.2} = 30\text{ k}\Omega$$

$$A_2 = -2 \times (30 \parallel 30) = -30\text{ V/V}$$

$$A_0 = A_1 A_2 = 30 \times 30 = 900\text{ V/V}$$