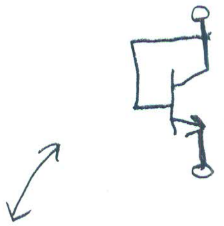
110B Midterm Sol'n
Sp 2012



1.

a) Select and circle the one best answer:

The approximate small-signal model for a diode-connected transistor is

2pts

i) a resistance of value V_A / I_C

ii) a resistance of value $\beta V_T / I_C$

[✓ iii)] a resistance of value V_T / I_C $= \frac{1}{g_m}$

b) Select and circle the one best answer:

A current mirror:

②

i) forces its input and output voltages to be nearly equal

[✓ ii)] forces its input and output currents to be nearly equal

iii) uses one NPN and one PNP transistor

c) If a differential amplifier has v_{in1} = 100mV·cos(10t) and v_{in2} = 200mV·cos(10t), what are the Common Mode Input Voltage (v_{ic}) and the Differential Mode Input Voltage (v_{id}) ?

④

v_{ic} = 150mV cos(10t)

||

$\frac{V_{in_1} + V_{in_2}}{2}$

v_{id} = −100mV cos(10t)

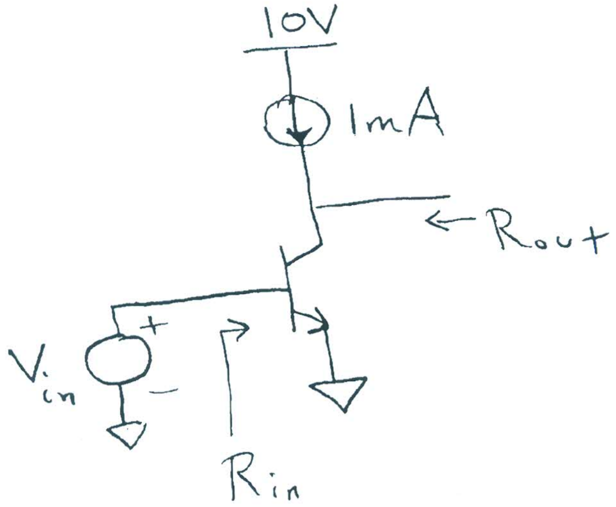
//

$V_{in_1} - V_{in_2}$

2. In the circuit below, R_{in} and R_{out} have been measured in the lab: R_{in} = 4k ohms and R_{out} = 112k ohms. Assuming the transistors is forward active and the DC collector current is 1 mA:

What is β for this transistor? β = 154

What is V_A for this transistor? V_A = 112 V



$$R_{in} = r_\pi = \frac{\beta V_T}{I_c} = \frac{\beta(26mV)}{1mA}$$

$$\overset{\parallel}{4k\Omega} \quad \Rightarrow \beta = 154$$

$$R_{OUT} = r_o = \frac{V_A}{I_c} = \frac{V_A}{1mA}$$

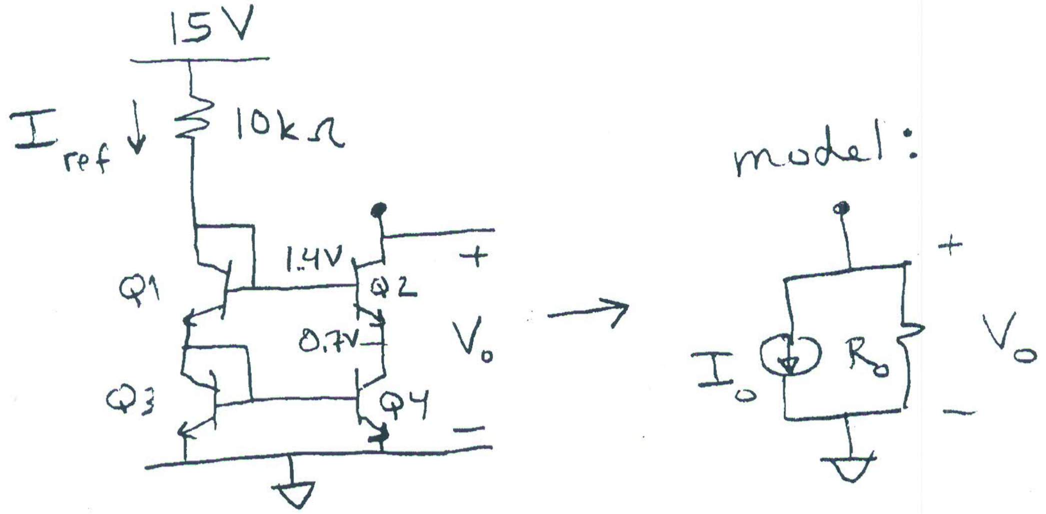
$$\overset{\parallel}{112k\Omega} \quad \Rightarrow V_A = 112V$$

3. a) A current source is shown below. All transistors are identical. Assume Q2 is forward active (its collector connects to other circuitry that is not shown). Find the value of I_O in the model shown.

I_O = 1.36 mA

b) What is the minimum value of the voltage at the collector of Q2 (V_O) for which Q2 remains forward active?

$V_O(\text{min})$ = 0.8V.



a) Q3-Q4 = current mirror

$$\Rightarrow I_{c_3} = I_{c_4} = I_{c_2} = I_o \quad (\text{ignoring } r_o)$$

$$I_{c_3} = I_{ref} = \frac{15V - 2V_{BE}}{10k\Omega}$$

$$\simeq \frac{15V - 2(0.7V)}{10k\Omega}$$

$$= 1.36 mA$$

b) $V_E(Q2) = V_{BE_1} + V_{BE_3} - V_{BE_2} \simeq 0.7V$

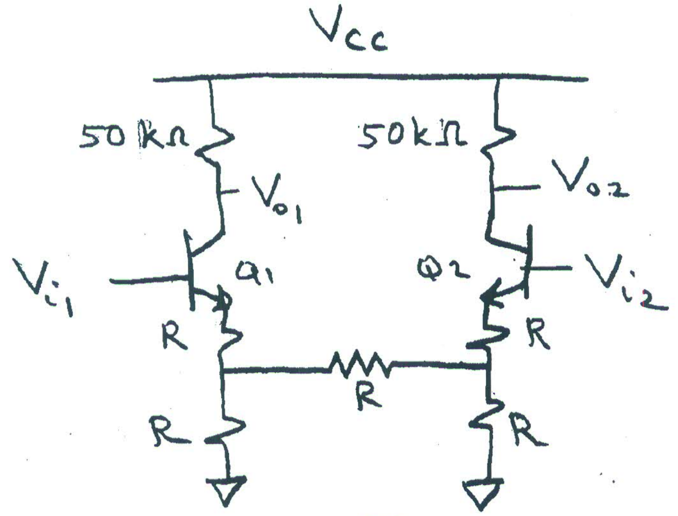
$V_o(\text{min}) \equiv 0.7V + V_{CE\,SAT}(Q2) = 0.8V$

12 pts

4. Find the DM and CM gains for the differential amplifier below. Assume all transistors are forward active; Q1 and Q2 are identical; and I_{C1}(D.C.) = I_{C2}(D.C.) = 1 mA. FOR THIS PROBLEM ONLY, ignore the transistor's output resistance (that is, take V_A = infinity).

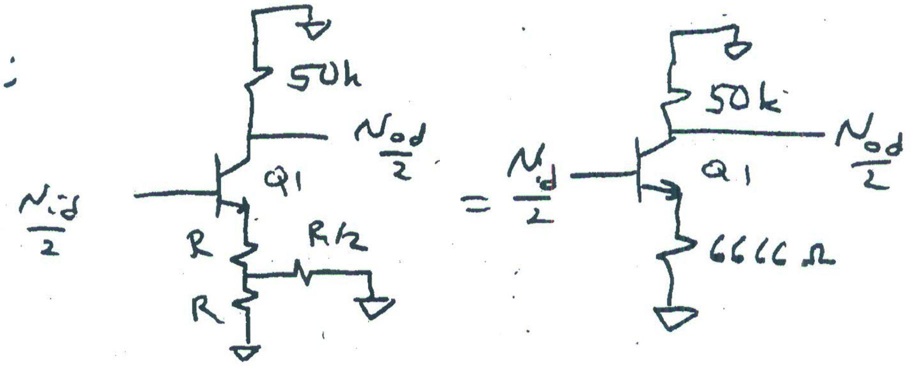
a) What is the Differential Mode (DM) gain? Vod/Vid = -7.5

b) What is the Common Mode (CM) gain? Voc/Vic = -5.



R = 5 kΩ

DM ½ ckt :

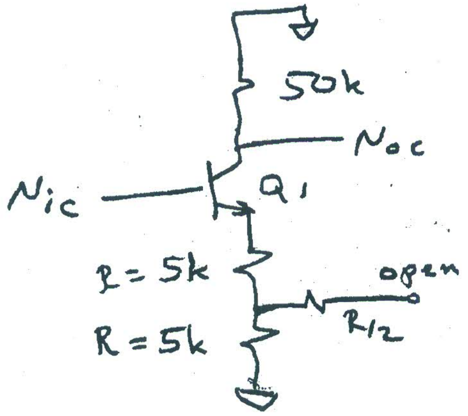


$$\frac{v_{od}}{v_{id}} = a_{DM} \simeq -G_{m_1}(50k) = \frac{-g_{m_1}}{1+g_{m_1}6666}\cdot(50k) =$$

$$= \frac{-\frac{1}{26}}{1+\frac{6666}{26}} 50k = -7.5$$

Extra work space for Problem 4.

cm $\frac{1}{2}$ ckt



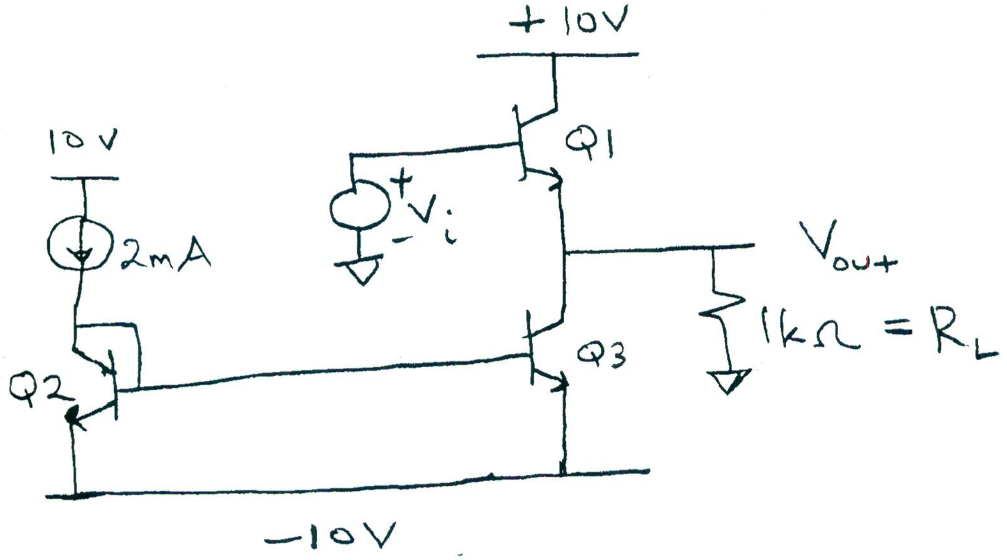
$$a_{cm} = \frac{v_{oc}}{v_{ic}} = -G_{m_1}(50k) = \frac{-g_{m_1}}{1+g_{m_1}(10k)}(50k)$$

$$= -5$$

5. A class A output stage is shown below.

a) What is the positive output swing limit? $V_{out(max)}$ = 9.9 V

b) What is the negative output swing limit? $V_{out(min)}$ = -2.0 V



Q1 = Q2 = Q3

Q2 - Q3 = current mirror $\Rightarrow I_{C_3} = 2mA$

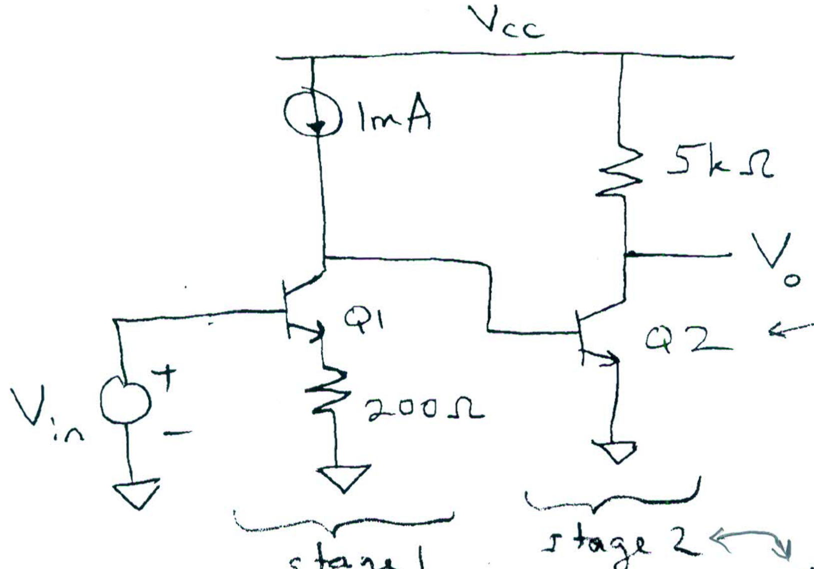
a) $V_o(\text{max}) = 10V - V_{CE_{SAT}}(Q1) = 9.9V$

b) $V_o(\text{min}) = \text{max}\left(\underbrace{-10V + V_{CE_{SAT}}(Q3)}_{-9.9V}, \underbrace{-I_{C_3}R_L}_{-2V}\right)$

$\rightarrow V_o(\text{min}) = -2V$

6. A two-transistor amplifier is shown below. ~~For simplicity, the DC sources are not shown.~~ Assume all transistors are forward active with $I_{C1} = I_{C2} = 1$ mA.

Find the small-signal voltage gain v_o/v_{in} = 4230.

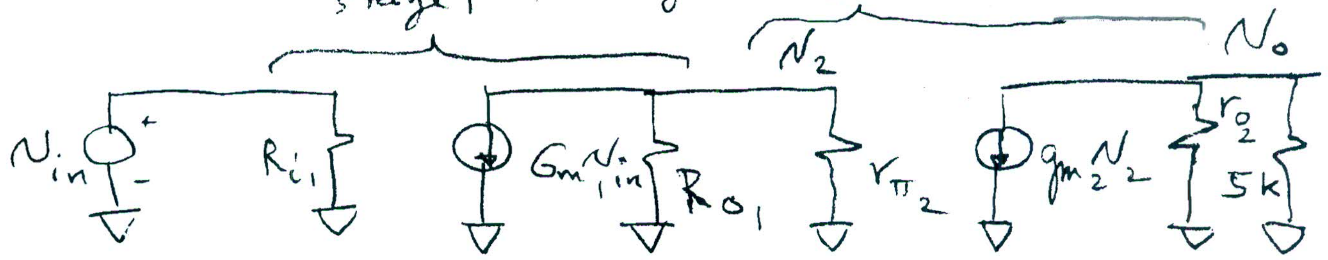


same values for Q1 & Q2

$$r_{\pi_2} = \frac{\beta V_T}{I_C} = 5.2k\Omega$$

$$g_{m_2} = \frac{I_C}{V_T} = \frac{1}{26}\frac{A}{V}$$

$$r_{o_2} = \frac{V_A}{I_C} = 130k\Omega$$



$$v_2 = -G_{m_1} v_{in} (R_{o_1} \| r_{\pi_2})$$

$$v_o = -g_{m_2} (r_{o_2} \| 5k\Omega) v_2$$

$$G_{m_1} = \frac{g_{m_1}}{1 + g_{m_1}(200\Omega)} = 4.4\frac{mA}{V}$$

$$R_{o_1} \simeq r_{o_1}(1 + g_{m_1}(200\Omega)) = 1.1M\Omega$$

So

$$\frac{v_o}{v_{in}} = +g_{m_2}(r_{o_2} \| 5k\Omega) G_{m_1} (R_{o_1} \| r_{\pi_2}) = \left(\frac{1}{26}\frac{mA}{V}\right)(\cancel{130k} \| 5k)\left(4.4\frac{mA}{V}\right)(\cancel{1.1M} \| 5k) \simeq 4230$$