University of Puerto Rico
Electrical and Computer Engineering Department
INEL 4202 - Electronics II - Fall 2002 - Exam 3a - Prof. M. Toledo
THERE ARE THREE PROBLEMS - WORK CLEARLY OR LOOSE POINTS

1. The circuit below represents the internal circuitry of a simple op-amp. You can neglect the base currents and use the concept of virtual ground in your analysis when appropriate. Assume all BJTs to be matched, of equal area and have $h_{fe} = 100$. Use $V_{CC} = V_{EE} = 5V$.

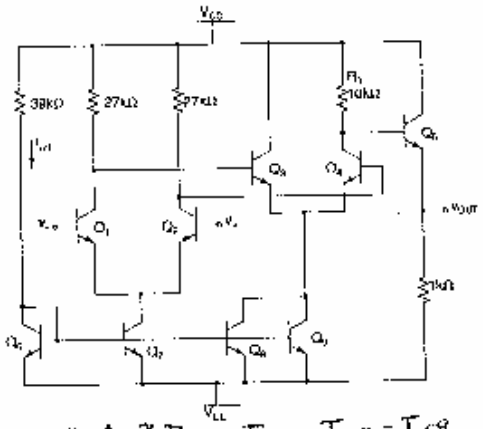
   (a) Determine each transistors' collector d.c. current and collector-to-emitter d.c. voltages, present when $v_+ = v_- = 0$. Neglect the base currents.Write your results in the table shown in the next page. (25 points)

   (b) Estimate the overall amplifier gain $A_v = \frac{v_{out}}{v_+ - v_-}$. (25 points)

   (c) Find the input and output resistances, R_{in} and R_{out}, seen between the input terminals and at the output terminal, respectively. (10 points)

   (d) Find the *common mode rejection ratio*, CMRR, assuming the differential amplifier's transistors are perfectly matched and all components ideal. Use $V_A = 100V$. (10 points)

   (e) Find a new value for I_{ref} that would make v_{OUT} to be zero when $v_- = v_+ = 0$. (5 points)



(a) $I_{ref} = \frac{10V - .7}{39k\Omega} \approx 0.25mA \cong I_{C6} = I_{C7} = I_{C8} = I_{C9}$

$I_{C1} = I_{C2} = \frac{1}{2} I_{C7} = 0.125mA$; $I_{C3} = I_{C4} = I_{C8} = 0.25mA$

$V_{B5} = V_{CC} - I_{C4} \times 10K = 5V - .25mA \times 10K = 2.5V$

$I_{C5} \approx [2.5V - (-5V)]/1K = \boxed{7.5mA}$

$V_{C1} = V_{C2} = V_{CC} - I_{C1} \times 17k\Omega = 5V - (27k\Omega)(.125mA) = 1.625V$

$V_{E1} = V_{E2} = -0.7V \Rightarrow V_{CE1} = V_{E2} = 1.625 - (-.7) = \boxed{2.325V}$

$V_{E3} = V_{E4} = V_{C1} - 0.7 = 1.625V - 0.7V = \boxed{0.55V}$

$V_{CC3} = +5 - .55 = \boxed{4.45V}$; $V_{B5} = 5 - (10K)(.25mA) = 2.5V$

$V_{CE4} = 2.5V - .55 = \boxed{1.95V}$ $V_{E5} = 2.5V - .7 = 1.8V$

$V_{CE5} = 5 - 1.8V = \boxed{3.2V}$ $\boxed{V_{CE6} = 0.7V}$ $V_{CE7} = .7 - (-5) = \boxed{4.3V}$

$V_{CE8} = V_{CE9} = 0.55V - (-5) = \boxed{5.55V}$

transistor	I_C (mA)	V_{CB} (V)
1	.125	2.325
2	.125	2.325
3	.25	4.45
4	.25	1.95
5	7.5	3.2
6	.25	.7
7	.25	4.3
8	.25	5.55

(b) $A_{v_1} = \frac{V_{c1} - V_{c2}}{V_+ - V_-} = g_{m_1} R_{c_1} = \left(\frac{I_{c_1}}{V_T}\right)(27k \| r_{\pi_3})$

$r_{\pi_3} = h_{fe} \times \frac{V_T}{I_{C3}} = 100 \times \frac{25mV}{.25mA} = \underline{10K\Omega}$

$A_{v_1} = \frac{.125mA}{25mV}(27k \| 10K) = \boxed{36.5\ V/V}$

$A_{v_2} = \frac{1}{2} g_{m_4} R_{c_4}$; $R_{c_4} = 10K \| [r_{\pi_5} + (h_{fe}+1)1K] = 9.1K$

$A_{v_2} = \frac{1}{2}\left(\frac{.125mA}{25mV}\right)(9102) = \boxed{45.5\ V/V}$

$A_{v_3} = \frac{g_{m_5}(1K)}{1 + g_{m_5}(1K)} = \frac{\frac{7.5mA}{25mV} 1K\Omega}{1 + \frac{7.5mA}{25mV} 1K\Omega} \approx 1$

$A_d = \frac{v_{out}}{v_+ - v_-} = (36.5)(45.5)(1) = \boxed{1661\ V/V}$

(c) $R_{in} = 2r_{\pi_1} = 2(100)\frac{25mV}{.125mA} = \boxed{40K\Omega}$

$R_{out} = 1K \| \frac{r_{\pi_5} + R_{BS}}{101} = 1K \| 102 = \boxed{92.8\Omega}$

(d) CMRR = ∞ because 1st stage output is differential

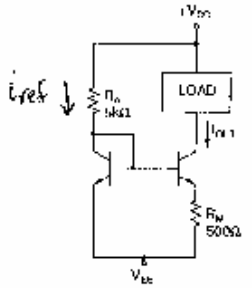
(e) For $V_{out} = 0$, $V_{BS} = 0.7V$

$I_{C4} = \frac{5V - 0.7V}{10K} = \boxed{0.43mA = I_{ref}}$

2. The following sketch shows a Widlar current source connected to a load. Assume that the load is a resistor R_{LOAD} and that the transistors are matched and have the same area. Assume the collector-emitter saturation voltage to be 0V. Use $V_{CC} = V_{EE} = 5V$.

   (a) Estimate the load current, i_{OUT}. (10 points)

   (b) Find the value of R_{LOAD} that will drive the transistor into saturation. (15 points)



(a) $I_{ref} = [V_{CC} - 0.7V - (-V_{EE})] / 5k\Omega = \frac{9.3V}{5k\Omega} = 1.86mA$

$$I_O = \frac{V_T}{R_E} \ln\left(\frac{I_{ref}}{I_O}\right)$$

$$I_O = \frac{25mV}{500\Omega} \ln\left(\frac{1860\mu A}{I_O}\right)$$

$$I_O = 50\mu A \ln\left(\frac{1860}{I_O}\right)$$

Successive approx. yields $\boxed{I_O = 132\mu A}$

(b) $V_{CC} - I_{out} R_{LOAD} - V_{CEsat} - I_{out} \times 500 - (-V_{EE}) = 0$

$$10 - I_{out}(R_{LOAD} + 500) - 0 = 0$$

$$R_{LOAD} = \frac{10V}{I_{out}} - 500 = \frac{10V}{132\mu A} - 500$$

$$\boxed{R_{LOAD} = 75.25k\Omega}$$

3. (BONUS) For the circuit in problem 1, find the minimum and maximum common-mode voltage that can be applied to the input without driving any transistor into cutoff or saturation. Assume $V_{in,dif} = 0$. (10 points)

$V_{C1} = V_{C2} = 1.625V$

$V_{CM_{max}} = 1.625V + 0.7V = 2.325V$

$V_{CM_{min}} = V_{EEsat} + .7V - V_{EE} = -4.3V$

$-4.3V \leq V_{CM} \leq 2.325V$