NAME: KEY STUDENT NO.:

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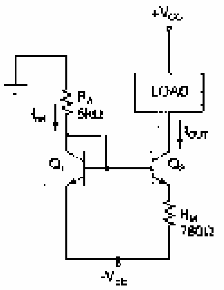
Electrical and Computer Engineering Department
INEL 4202 - Electronics II - Fall 2002 - Exam 3b - Prof. M. Toledo
THERE ARE THREE PROBLEMS - WORK CLEARLY OR LOOSE POINTS

1. The following sketch shows a Widlar current source connected to a load. Assume that the load is a resistor R_{LOAD}. Assume the collector-emitter saturation voltage to be 0V. Use $V_{CC} = V_{EE} = 10V$. The transistors are matched and have the same area.

 (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) $I_{ref} = \dfrac{0-0.7-(-10)V}{5k\Omega} = \dfrac{9.3V}{5k} = 1.86mA$

$$I_o = \frac{V_T}{R_M}\ln\left(\frac{I_{ref}}{I_o}\right) = \underbrace{\frac{25mV}{780\Omega}}_{32\mu A}\ln\left(\frac{1860\mu A}{I_o}\right)$$

Solving iteratively yields $\boxed{I_o = 95\mu A}$

(b) $V_{CC} - I_{out} \times R_{LOAD} - V_{CESAT} - I_{out} \times 780\Omega - (-V_{EE}) = 0$

$10 - 95\mu A(780 + R_{LOAD}) - 0 - (-10) = 0$

$780 + R_{LOAD} = \dfrac{20V}{95\mu A} = 210.5K\Omega$

$$\boxed{R_{LOAD} \approx 210K\Omega}$$

2. 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 $V_{CC} = V_{EE} = 10V$.

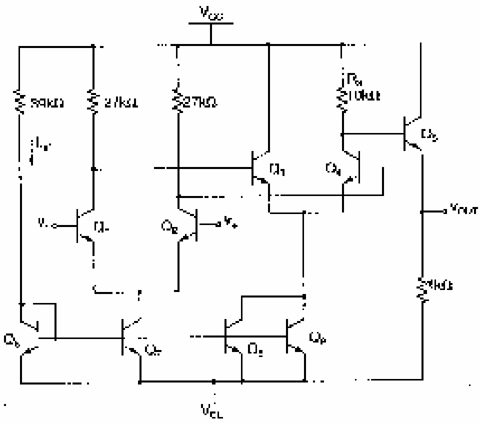
   (a) Determine each transistors' collector d.c. current and collector-to-emitter d.c. voltages, present when $v_+ = v_- = 0$. Neglect the base currents. Write your results in the table below. (25 points)

   (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. Assume $V_A = 100V$. (10 points)

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



transistor	I_C (mA)	V_{CE} (V)
1	.25	3.95
2	.25	3.95
3	.5	7.45
4	.5	2.45
5	14.3	5.7
6	.5	.7
7	.5	9.3
8	.5	12.5

(a) $I_{ref} = \frac{20V - 0.7}{39k\Omega} = 0.5mA \cong I_{C6} = I_{C7} = I_{C8} = I_{C9}$

$I_{C1} = I_{C2} = \frac{1}{2} I_{C7} = 0.25mA$

$I_{C3} = I_{C9} = I_{C8} = 0.5mA \Rightarrow V_{B5} = V_{CC} - I_{C9} \times 10K = 5V$

$I_{C5} = \frac{V_{E5} - (-V_{EE})}{1k} = 14.3mA \Leftarrow V_{E5} = 4.3V$

$V_{C1} = V_{C2} = V_{CC} - 27k\Omega \times I_{C1} = 10V - \frac{27k}{4} 1mA = 3.25V$

$V_{E1} = V_{E2} = -0.7V \Rightarrow V_{CE1} = V_{CE2} = 3.25V - (-0.7V) = \boxed{3.95V}$

$V_{E4} = V_{E3} = V_{C1} - 0.7V = 3.25V - .7V = \boxed{2.55V}$

$V_{CE3} = 10V - 2.55V = \boxed{7.45V}$ $V_{CE4} = V_{B5} - V_{E4} = 5V - 2.55V = \boxed{2.45V}$

$V_{CE5} = 10V - 4.3V = \boxed{5.7V}$ $\boxed{V_{CE6} = 0.7V}$ $V_{CE7} = -0.7 - (-10) = \boxed{9.3V}$

$V_{CE8} = V_{CE9} = V_{E3} - (-V_{EE}) = 2.55 - (-10) = \boxed{12.55V}$

(b) $A_{V_1} = \frac{V_{C1} - V_{C2}}{V_+ - V_-} = +g_{m_1} R_{C_1} = \left(\frac{I_{C1}}{V_T}\right)(27k\Omega \| r_{\pi 3})$

$r_{\pi 3} = h_{fe} \times \frac{V_T}{I_{C3}} = 100 \times \frac{25mV}{.5mA} = 5k\Omega \Rightarrow A_{V_1} = +42.2 V/V$

$A_{V_2} = \frac{1}{2} g_{m_4} R_{C4} \Rightarrow R_{C4} = 10K \| [r_{\pi 5} + (h_{fe}+1) 1k] = 9.1k\Omega$

$A_{V_2} = \frac{1}{2}\left(\frac{.5mA}{25mV}\right)(9.1k\Omega) = +\frac{182}{2} V/V$

$A_{V_3} = \frac{V_{out}}{V_{b5}} = \frac{g_{m5} R_4}{1 + g_{m5} R_4} = \frac{\frac{14.3mA}{25mV} \times 1k}{1 + \frac{14.3mA}{25mV} \times 1k} \approx 1$

$A_V = \frac{V_{out}}{V_+ - V_-} = (42.2)\left(\frac{182}{2}\right)(1) = \boxed{7680.4 V/V} \div 2 = \boxed{3840 V/V}$

(c) $R_{in} = 2r_{\pi 1} = 2(100)\, 25mV/.25mA = \boxed{20k\Omega}$

$R_{out} = 1k \| \frac{r_{\pi 5} + R_{B5}}{101} = 1k \| 101\Omega = \boxed{92\Omega}$

(d) CMRR $= \infty$ because the 1st stage has differential output

otherwise $CMRR = \frac{1}{2}(1 + 2 g_{m_1} R_{TAIL}) \Rightarrow R_{TAIL} = r_o$ of C.S

(e) For $V_{out} = 0$, $V_{B5} = 0.7V$, $I_{C4} = \frac{10V - .7}{10K} = .93mA$

To obtain this current $\boxed{I_{ref} = I_{C4} = .93mA}$

3. (BONUS) For the circuit in problem 2, find the minimum and maximum common-mode voltage that can be applied to the input without driving any transistor into cutoff or saturation. (10 points)

$V_{C1} = V_{C2} = 3.25V$

$V_{E1} = V_{E2} = V_{CM} - 0.7$

$V_{CE} = 3.25V - (V_{cm} - 0.7) = 3.95 - V_{CM}$

This voltage must be larger than the saturation voltage. Thus

$\boxed{V_{CM} \le 3.95 - V_{CEsat}}$

On the negative side, a neg. voltage V_{CM} can drive Q_7 in to saturation. Since

$V_{CEQ7} = V_{E1} - (-V_{EE}) > V_{CEsat}$

we have that $V_{CM} - 0.7 + V_{EE} > V_{CEsat}$

or $\boxed{V_{CM} \ge V_{CEsat} + .7 - V_{EE}}$

Thus

$\boxed{3.95 - V_{CEsat} \ge V_{CM} \ge V_{CEsat} + .7 - V_{EE}}$

For $V_{CEsat} = 0V$, $V_{EE} = -10V$

$\boxed{3.95V \ge V_{CM} \ge -9.3V}$