EECS 105, Fall 1993
Midterm #2
Professor R. T. Howe

Ground Rules:

- Closed book and notes; one formula sheet (both sides)
- Do all work on exam pages
- Answers accurate to within 10% will receive full credit
- Default bipolar transistoe parameters:

  npn: $\beta_n = 100$, $V_{An} = 50$ V, $I_{Sn} = 10^{-16}$ A.

  pnp: $\beta_p = 50$, $V_{Ap} = 25$ V, $I_{Sp} = 10^{-16}$ A.

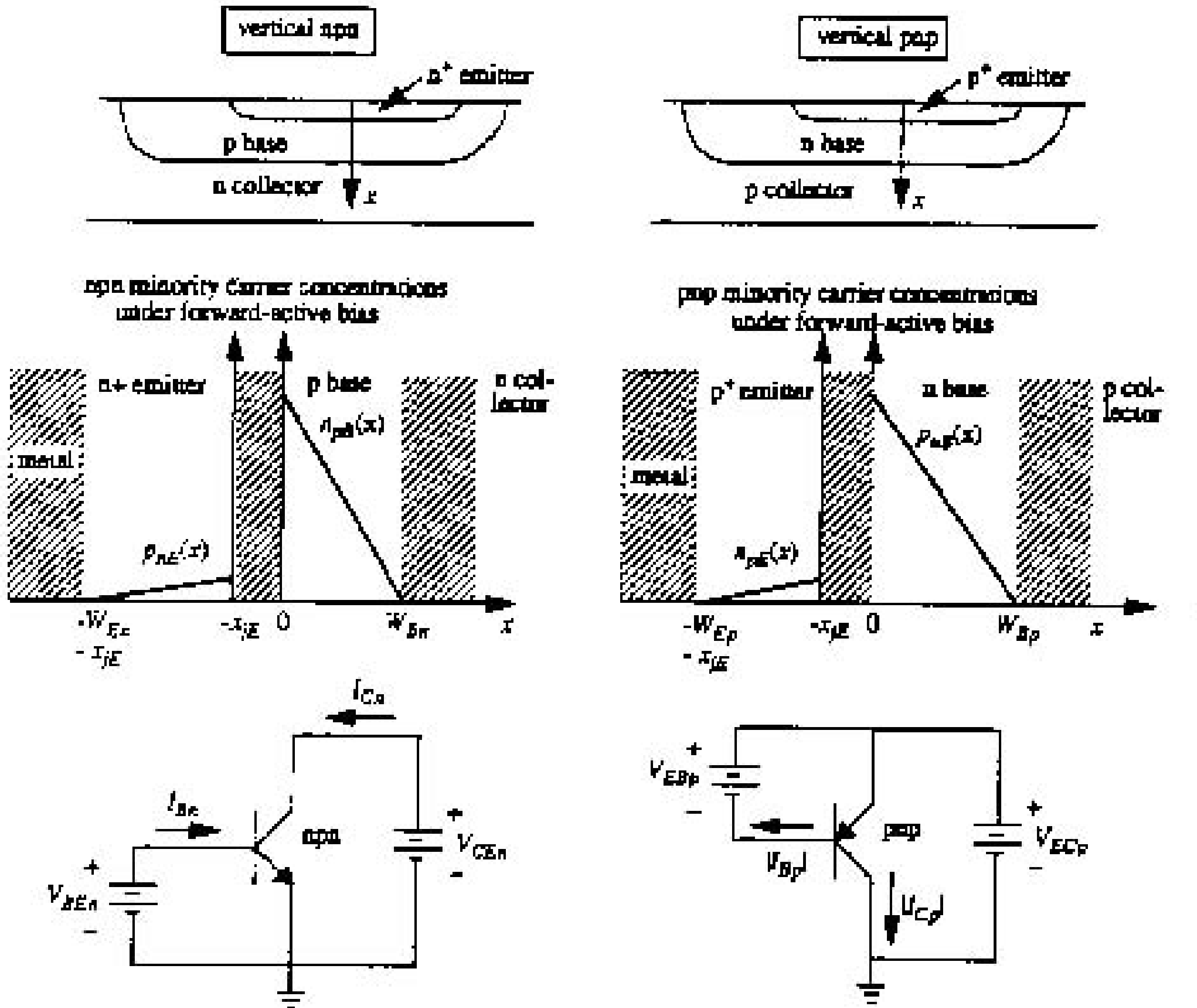
- Default MOS transistor parameters:

  NMOS: $\mu_n C_{ox} = 50\ \mu AV^{-2}$, $\lambda_n = 0.02 V^{-1}$, $V_{Tn} = 1$ V.

  PMOS: $\mu_p C_{ox} = 25\ \mu AV^{-2}$, $\lambda_p = 0.02 V^{-1}$, $V_{Tp} = -1$ V.

Problem #1. Matched Complementary Bipolar Transistor Design [12 points]

The cross sections, minority carrier concentrations, and circuit schematics are shown for matched npn and pnp vertical BJTs, operated in the forward-active region.



Given: all doping levels are matched and the emitter areas are identical

- N_{dE} (npn) = N_{aE} (pnp)
- N_{aB} (npn) = N_{dB} (pnp)
- N_{dC} (npn) = N_{aC} (pnp)
- A_E (npn) = A_E (pnp)

Given: the bias volatages for the two transistors are matched and both are in the forward-active region

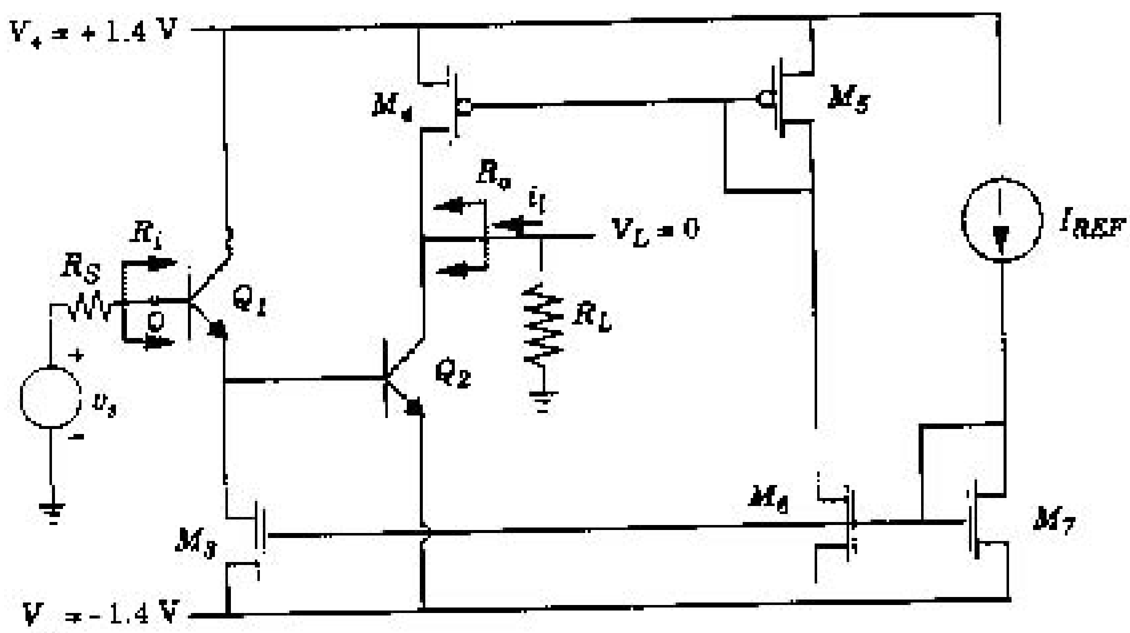
- $V_{BEn} = V_{EBp}$
- $V_{CEn} = V_{ECp}$

(a) [5 pts.] In order for the npn and the pnp transistors to have *matched collector currents*, $I_{Cn} = |I_{Cp}|$, determine the numerical value of the *base width of the pnp*, W_{Bp}.
Given: the base width of the npn is W_{Bn} = 0.2 (mu)m, the electron diffusion coefficient (diffusivity) is $D_n = 20\ \text{cm}^2\text{s}^{-1}$, and the hole diffusivity is $D_p = 10\ \text{cm}^2\text{s}^{-1}$ -- these are valid for the emitter, base, and collector of each transistor.

(b) [5 pts.] In order for the npn and the pnp transistors to *matched base currents*, $I_{Bbn} = |I_{Bp}|$, determine the numerical value of the *emitter width of the pnp*, W_{Ep}. This part is independent of part (a).
Given: the emitter width of the npn is W_{En} = 0.1 (mu)m, and $D_n = 20\ \text{cm}^2\text{s}^{-1}$, $D_p = 10\ \text{cm}^2\text{s}^{-1}$.

(c) [2 pts.] Which transistor has the smaller Early voltage, V_A? Explain why in one sentence.

Problem #2. Two-Stage Transconductance Amplifier [24 points]



Given: I_{REF} = 100 (mu)A, V_L = 0(DC), R_S = 1 k(omega), R_L = 400 k(omega)
MOSEFTs: $(W/L)_{3,5,6,7} = 10$ and $(W/L)_4 = 25$

(a) [4 pts.] Find the collector currents I_{C1} and I_{C2}. You can neglect the base currents I_{B1} and I_{B2}, as is customary for hand calculations.

(b) [4 pts.] Find the numerical value of the input resistance, R_i of this amplifier. If you couldn't answer part (a), you can assume that I_{C1} = 50 (mu)A and that I_{C2} = 75 (mu)A for this part.

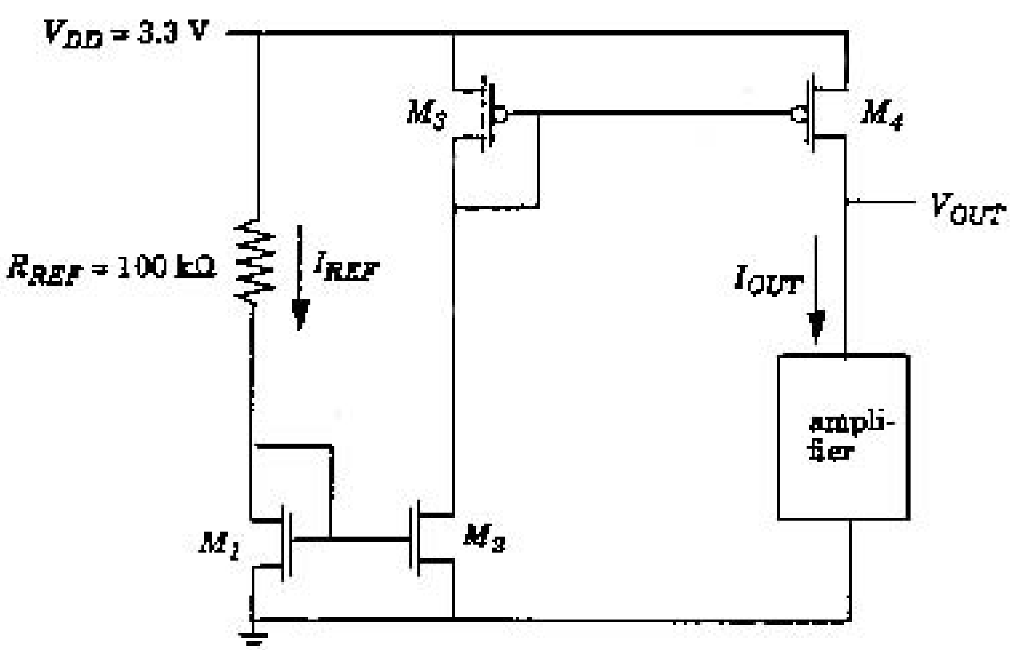
(c) [4 pts.] Find the numerical answer value of the output resistance, R_o of this amplifier. If you couldn't answer part (a), you can assume that I_{C1} = 50 (mu)A and that I_{C2} = 75 (mu)A for this part.

(d) [4 pts.] Find the numerical value of the short-circuit transconductance G_m of the amplifier. Again, if you couldn't answer part (a), you can assume that I_{C1} = 50 (mu)A and that I_{C2} = 75 (mu)A for this part.

(e) [5 pts.] Find the numerical value of the laod current i_l, for a small-signal input voltage v_s = 2 mV. If you couldn't solve parts (b), (c), and (d), asumme for this part that R_i = 80 k(omega), R_o = 500 k (omega), and G_m = 7.5 mS.

(f) [3 pts.] What is the DC voltage at the base Q_1? You can assume that V_{BE} = 0.7V for the transistors in the forward-active region.

Problem #3. Current-Source Design [14 points]



Given: $(W/L)_1 = (W/L)_2 = (W/L)_3$

(a) [5 pts.] Find $(W/L)_1$ such that I_{REF} = 20 (mu)A.

(b) [3 pts.] Find $(W/L)_4$ such that I_{OUT} = 50 (mu)A. If you couldn't solve part (a), assume that $(W/L)_1$ = 10.

(c) [3 pts.] Find the numerical value of r_{oc} for this current source, assuming that I_{OUT} = 50 (mu)A.

(d) [3 pts.] Assuming that the source-gate voltage for transistor M_4 is V_{SG4} = 1.4V. What is the largest DC output voltage V_{OUT} for which transistor M_4 remains in the saturation region?
