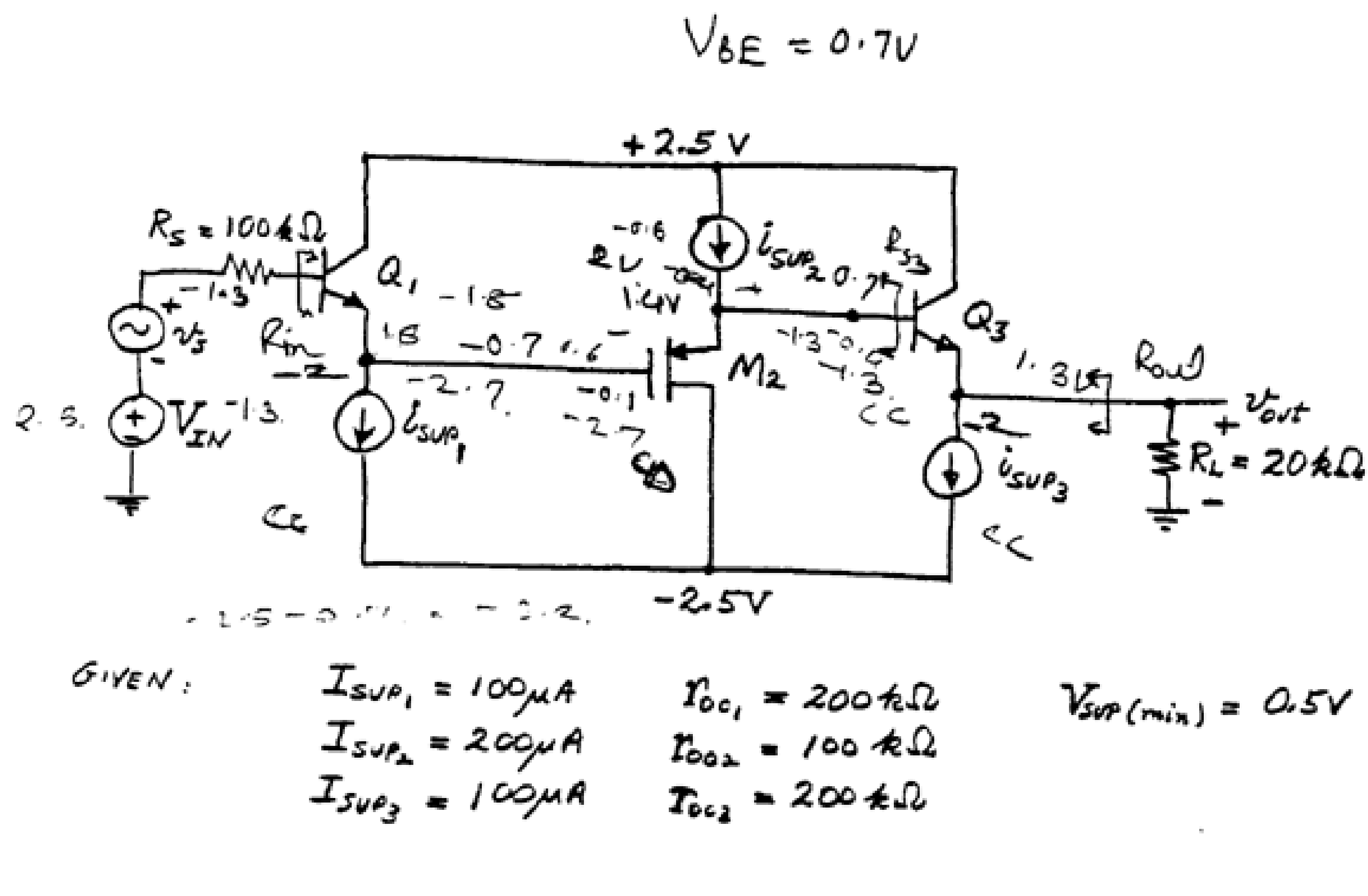
Ground Rules:

- Close book; one 8.5x11 crib sheet (both sides)
- Do all work on exam pages
- Default bipolar transistor parameters:
    - *npn:* $ß_n$=100, V_{An}=50 V, $V_{CE\text{-}sat}$=0.2 V
    - *pnp:* $ß_p$=50, V_{Ap}=25 V, $V_{EC\text{-}sat}$=0.2 V
- Default MOS transistor parameters: note LAMBDA depends on L!
    - NMOS: $MU_n C_{ox}$=100e-6 A/V^2, $LAMBDA_n$=[0.1/L] V^{-1} (L in micrometers) V_{Tp}=1 V
    - PMOS: $MU_p C_{ox}$=50e-6 A/V^2, $LAMBDA_p$=[0.1/L] V^{-1} (L in micrometers) V_{Tp}=-1 V

Problem #1: Small-Signal Amplifier [24 points]



a) [4 pts.] What is width of transistor M_2 such that the DC output voltage V_{out}=0 V for V_{IN}=0 V. Given: the length of M_2 is L_2=2e-6 m.

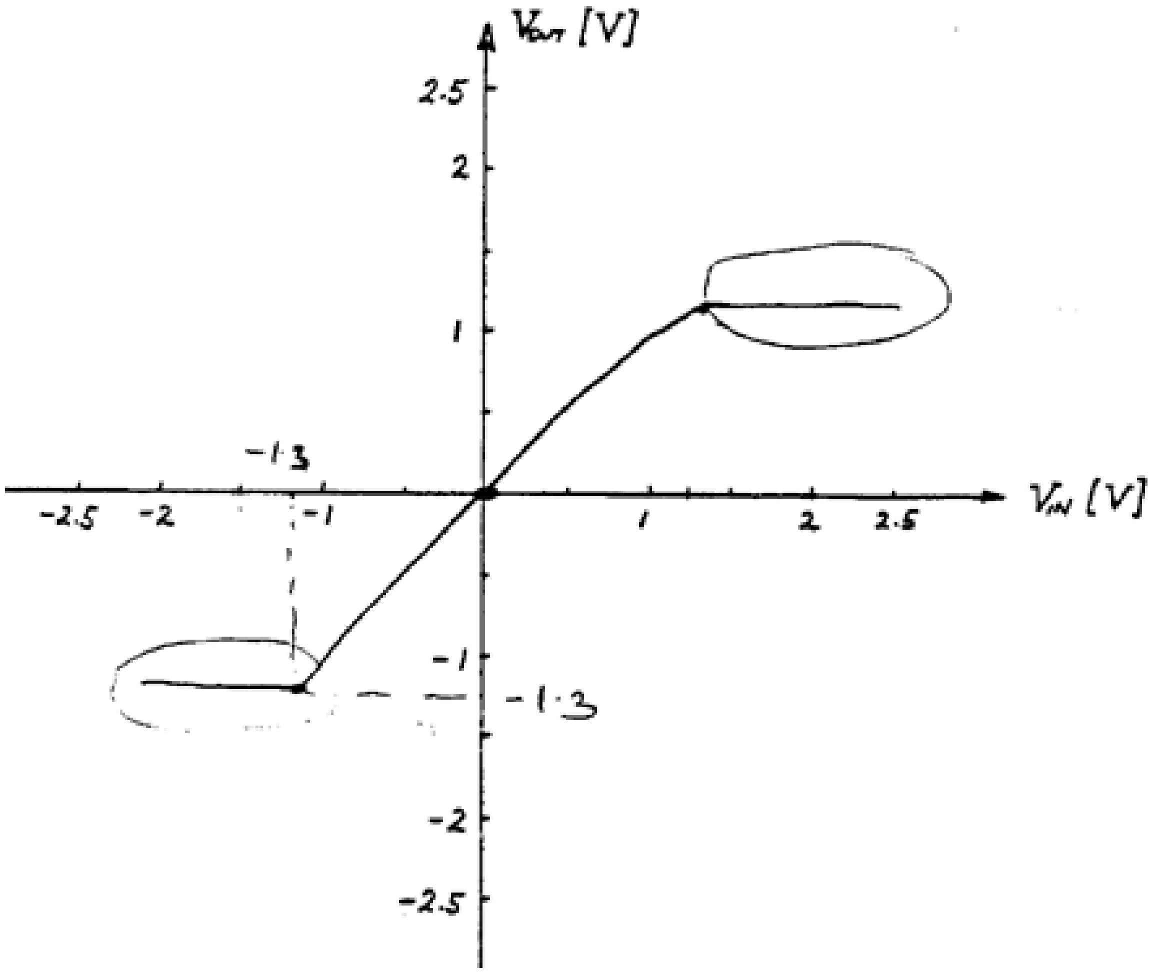
W=100 micrometers

b) [4 pts.] What is the numerical value of the input resistance R_{in} of this amplifier? Your answer should be correct to within +/- 5%.
If you couldn't solve (a) you can assume for this part that W_2=25e-6 m. Of course, this isn't the correct answer to part (a).
R_{in}=14.31 mega-ohms

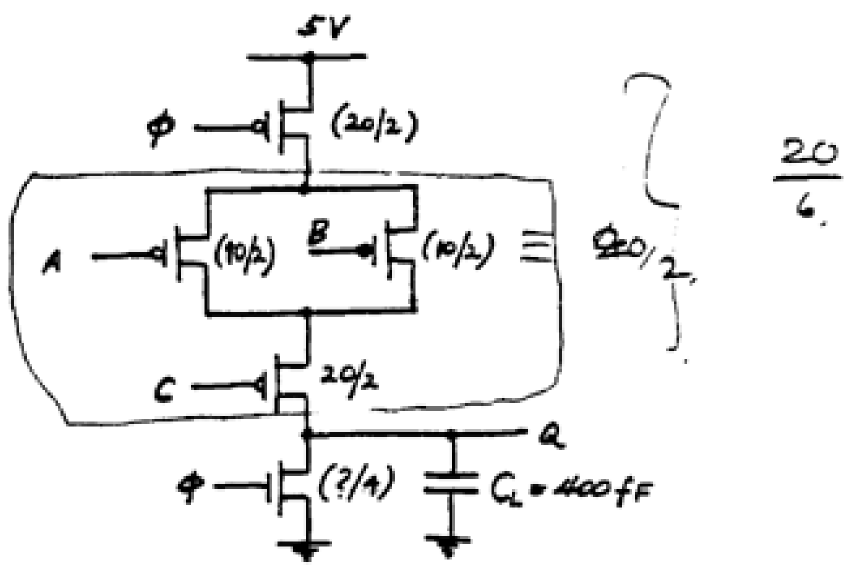
c) [4 pts.] What is the numerical value of the output resistance R_{out} of this amplifier? Your answer should be correct to within +/- 5%.
If you couldn't solve (a) you can assume for this part that W_2=25e-6 m. Of course, this isn't the correct answer to part (a).
R_{out}=260 ohms

d) [6 pts.] What is the numerical value of the overall voltage gain v_{out}/v_s, with R_s=100 kilo-ohms and R_L=20 kilo-ohms? Your answer should be correct to within +/- 5%.
Again, If you couldn't solve (a) you can assume for this part that W_2=25e-6 m. Of course, this isn't the correct answer to part (a).
$A_{v\text{-}overall}$=0.9804

e) [6 pts.] Sketch the transfer curve V_{OUT} versus V_{IN} for -2.5 <= V_{IN} <= +2.5 V on the graph below. For this part, R_L is infinity and R_S=0 V.
Hint: you should note that the current supplies each require at least $V_{SUP(min)}$=0.5 V in order to function.



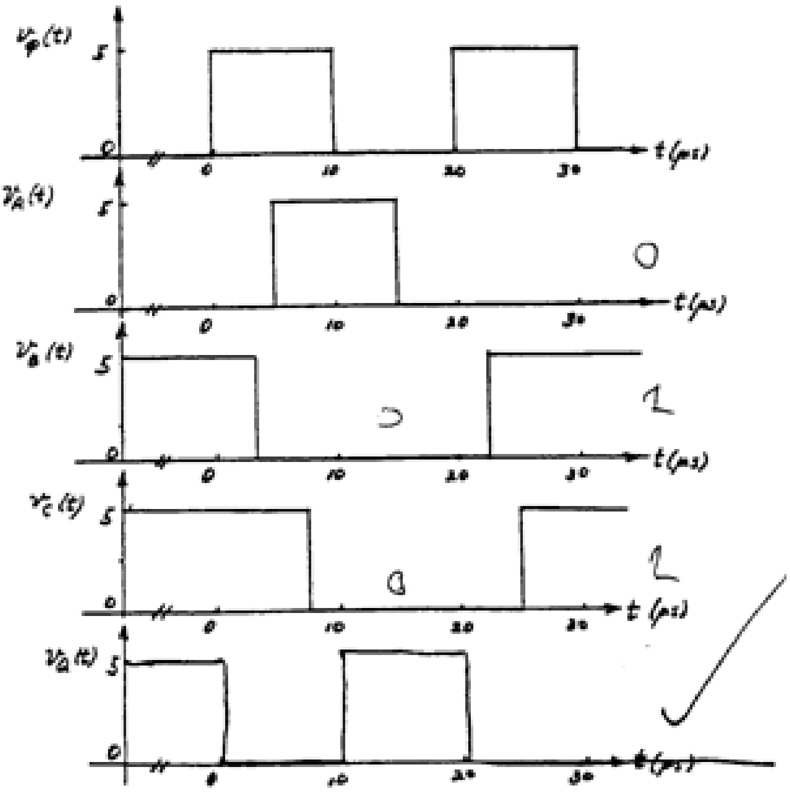
Problem #2: Digital Logic Gate [14 points]



a) [2 pts.] What is the logic operation performed by the above circuit? In other words, what is the logical expression for Q in terms of the three inputs A, B and C?

Q=(A-bar + B-bar) dot C-bar

b) [4 pts.] The graphs below plot the voltage waveforms over an interval of 35 microseconds. Fill in the output voltage waveform $v_Q(t)$ over 0 -=> 35e-6 s. Note that the rise and fall times are essentiall zero on this time scale.



c) [4 pts.] Find the numerical value of the **best case** low-to-high propagation delay (t_{PLH}) for this logic gate.

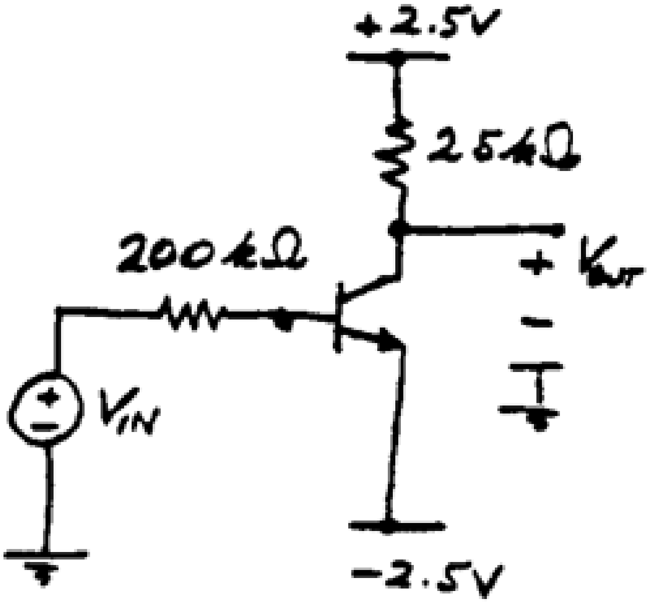
t_{PLH}=0.75 ns

d) [4 pts.] Find the width of the n-channel transistor such that the high-to-low propagation delay (t_{PLH}) is equal to your answer for part c). If you couldn't answer part c) you can assume for this part that $t_{PLH\ (best)}$ = 1 ns = 10^{-9}s.

W=6.665 micrometers

Problem #3: Bipolar Transistor Physics [12 points]

NOTE: The default npn transistors do not apply for this problem!



GIVEN:

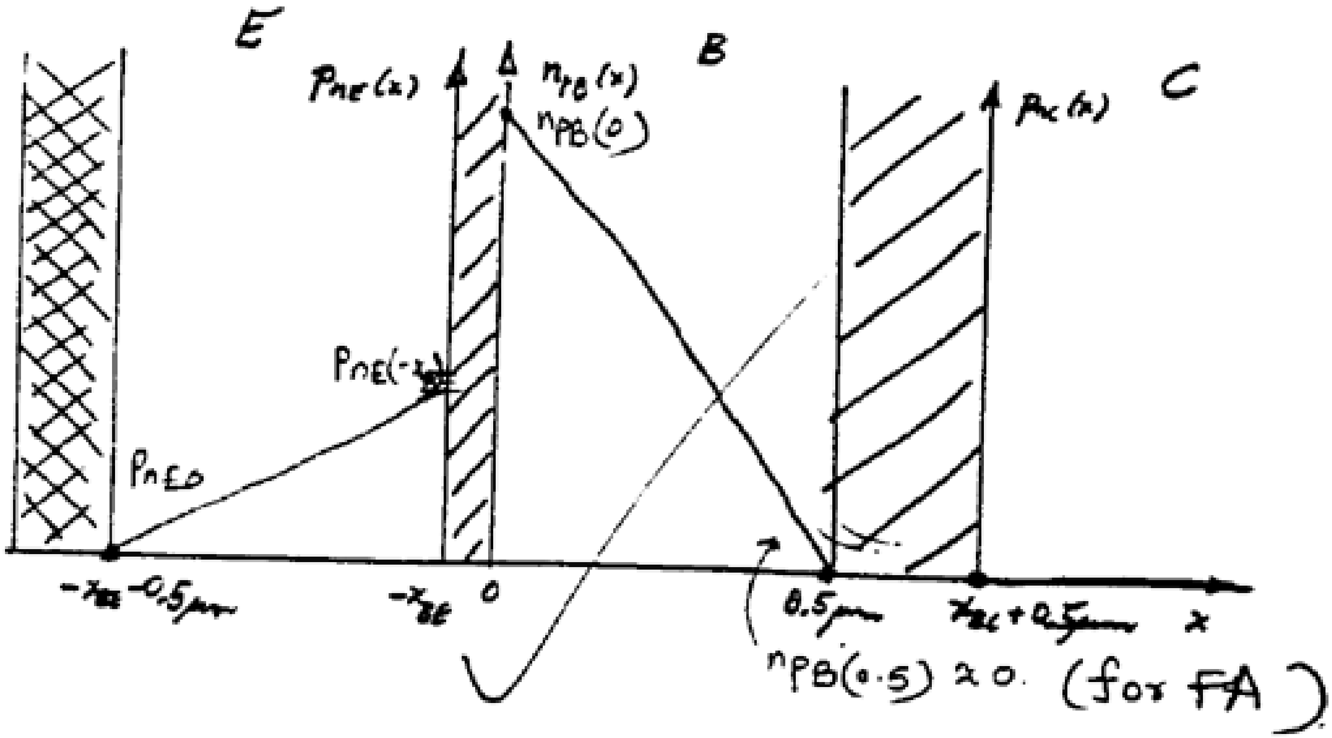
N_{dE}=2x10^{18} cm^{-3}

N_{dB}=10^{17} cm^{-3}

N_{dC}=10^{16} cm^{-3}

The base and emitter widths are W_B=W_E=0.5 micrometers. The electron diffusion coefficient in the base is D_{nB}=10 cm^2/s and the hole diffusion coefficient in the emitter is D_{pE}=5 cm^2/s.

a) [3 pts.] Qualitatively sketch the minority carrier concentrations in the emitter, base and collector on the graph below, assuming that the transistor is biased in the forward active region.



b) [3 pts.] For V_{OUT}=0 V what is the numerical value of the minority electron concentration at x=0, $n_{pB}(0)$? You can assume that the transistor is biased in the forward active region.
Not available

c) [3 pts.] What is the numerical value of the base current I_B for the bias condition in part b)? If you couldn't solve b) assume for this part that $n_{pB}(0) = 10^{15}$ cm^{-3} -- not the correct answer to b), of course.
I_B=2.5 micro-amps

d) [3 pts.] What is the numerical value of V_{IN} in order that the transistor is biased in the forward active region with V_{OUT}=0 V?
Notes: You cannot assume that V_{BE}=0.7 V for this part. If you couldn't solve parts b) and c) you can assume that $n_{pB}(0)=10^{15}$ cm^{-3} and that I_B=4 micro-amps. Neither of these answers are correct, of course.
V_{IN}=3.277 V
