EECS 105, Fall 1992
Final Exam
Professor R. T. Howe

- Closed book; three 8&#189" x 11" crib sheets (both sides)
- Do all work on exam pages.
- Default bipolar transistor parameters:

npn: &#223$_n$ = 100, V_{An} = 100 V, $C_{[PI]}$ = 15pF, $C_{\&\#181}$ = 1pF.
pnp: &#223$_p$ = 50, V_{Ap} = 50 V, $C_{[PI]}$ = 30pF, $C_{\&\#181}$ = 2pF.

- Default MOS transistor parameters:

NMOS: &#181$_n$ C'_{ox} = 25 &#181AV^{-2}, [LAMBDA]$_n$ = 0.01 V^{-1}, V_{Tn} = 1V.
PMOS: &#181$_p$ C'_{ox} = 10 &#181AV^{-2}, [LAMBDA]$_p$ = 0.02 V^{-1}, V_{Tp} = -1V.

Problem #1 (Single-ended BJT amplifier) [20 points]
Picture of a circuit should be here!

Problem #1a [3 points]
Find the numerical value of the following resistors:

R_{E1}, R_{REF}, R_{E3}

such that the DC input voltage V_I, the DC output voltage V_O are both zero, and all bias currents are 100 &#181A.

Problem #1b [3 points]
Find the numerical value of the input resistance R_i of this amplifier. Use

R_{E1} = 5 k[OHM]s

if you couldn't do part (a)--not the correct answer for part (a), of course.

Problem #1c [4 points]
Find the numerical value of the output resistance R_o of this amplifier. Use

R_{E3} = 10 k[OHM]s

if you couldn't do part (a)--not the correct answer for part (a), of course.

Problem #1d [3 points]

Draw the 2-port small-signal model for this *three stage* amplifier. Label all input and output resistances and controlled sources.

Problem #1e [4 points]

What is the numerical value of the small-signal voltage gain, v_o / v_i ?

Problem #1f [3 points]

What is the maximum value the output voltage can reach and still have *all* devices operating in the forward active region?

Problem #2 (Electrostatics in Thermal Equilibrium) [18 points]
Picture of an n^+-p-n layer and 2 graphs should be here!

Given: the above n+-p-n is in *thermal equilibrium*. The donor and acceptor doping concentrations are shown below the structure. You can assume that the n+-p depletion layer has a total width of 0.5 &#181m and that the p-n depletion layer is 1 &#181m wide in your sketches.

Problem #2a [6 points]

Sketch the electrostatic potential [sPHI](x) along the x axis on the graph below; your values in the bulk regions (outside the depletion layers) should be accurate.

Problem #2b [6 points]

Sketch the electric field E(x) along the x axis on the graph below. Your field values should be accurate in the bulk regions (*hint*: this shouldn't be too hard if you recall the definition of bulk silicon!) and qualitatively correct in the depletion regions.

Problem #2c [6 points]

Plot (note: must be accurate!) the charge density, normalized by the electron charge, on the log plot below. *Hint*: recall that the depletion layer widths are given, along with the doping concentrations.

RE3 = 10 k[OHM]s

Problem #3 (Frequency Response) [16 points]
Picture of a circuit should be here!

Problem #3a [3 points]
Redraw the schematic with the transistor current sources replaced current-source symbols and find numerical values for the source/sink currents.

Problem #3b [4 points]
Find the numerical value of the voltage gain $A_v = v_o / v_s$.

Problem #3c [5 points]
Find the numerical value of the corner frequency of this amplifier, f_c. Note that the transistor capacitances are given on the first page.

Problem #3d [4 points]
Given: the amplifier has a second pole at 6.4 MHz. Plot the magnitude of the amplifier voltage gain in dB as a function of frequency on the graph below.

Problem #4 ("Interesting" BiMOS Logic Gate) [14 points]
Picture of a circuit should be here!

(W / L)=5. Other transistor parameters are given on the first page.

Problem #4a [2 points]
Plot the load characteristic i_L as a function of v_O for the npn transistor on the graph below.

Problem #4b [4 points]
Plot the driver characteristics $| i_D |$ on the same graph below, for v_I= 0, 1, 2, 3, 4, and 5 V.

Problem #4c [4 points]
From your results in part (b), plot the transfer curve v_O as a function of v_I on the graph below.

Problem #4d [4 points]

Label the operating regions for the p-channel MOSFET and for the npn BJT on the transfer curve. You need not find the exact breakpoints between the different segments, but the labels should be qualitatively correct.

Problem #5 (Two-stage differential amplifier) [20 points]
Picture of a circuit should be here!

Problem #5a [3 points]

Draw the 2-port small signal model for this op amp as a cascade of the two differential amplifiers. You need not evaluate all of the parameters in this part.

Problem #5b [3 points]

Find the numerical value for the transconductance of the first stage,

G_{m1}

Problem #5c [4 points]

Find the numerical value for the transconductance of the second stage,

G_{m2}

Problem #5d [3 points]

Find the numerical value of the differential input resistance of the second stage,

R_{id2}

Problem #5e [4 points]

Find the numerical value of the output resistance of the amplifier R_o.

Problem #5f [3 points]

Given that the two small-signal input voltage waveforms are:

v_{i1} = (-5&#181V)cos([sOMEGA]t) and

v_{i2} = (-8.5&#181V)cos([sOMEGA]t).

Find the output waveform $v_o(t)$. You can assume that [sOMEGA] is much less than the corner frequency of the differential amplifier.

Problem #6 (npn BJT and n-channel MOSFET Operating Regions) [12 points]

Problem #6a [6 points]

The plots below show the minority carrier concentrations in the emitter, base, and collector for six operating points, labeled *A*-*F* on the ouput characteristics. Fill in the table by correctly identifying which cross section corresponds with which operating point.

Picture of a bode plot, 6 cross sections and matching boxes should be here!

Problem #6b [6 points]

The device structures below show (qualitatively) the mobile electron charge $| Q_n(y) |$ in the channel of the MOSFET, along with the dotted outline of the edge of the depletion layer formed with the p-type substrate. Fill in the table by correctly identifying which device structure corresponds with which operating point *A*-*F* on the drain characteristics.

Picture of a bode plot, 6 device structures and matching boxes should be here!
