ECE 3040B Microelectronic Circuits

Exam 2

October 25, 2001

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Print your name clearly and largely: Solutions

Instructions:
Read all the problems carefully and thoroughly before you begin working. You are allowed to use 1 new sheet of notes (1 page front and back), your note sheet from the previous exam as well as a calculator. There are 100 total points in this exam. Observe the point value of each problem and allocate your time accordingly. SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED. Write legibly. If I can not read it, it will be considered to be a wrong answer. Do all work on the paper provided. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. Good luck!

Sign your name on **ONE** of the two following cases:

I DID NOT observe any ethical violations during this exam: ____________

I observed an ethical violation during this exam: ____________

First 25% Multiple Choice (Select the most correct answer)

1.) (5-points) When analyzing a circuit using the CVD diode model, which of the following is true:

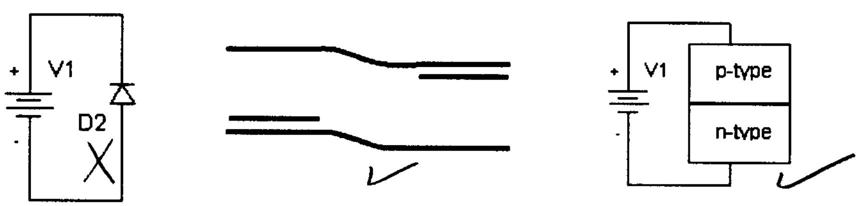
a.) The diode is replaced with either an open or a short circuit
b.) The diode is replaced with a battery plus a short circuit or open circuit
c.) The diode has a small non-zero leakage current flowing in reverse bias
d.) The diode has an offset voltage equal to the built in voltage of the diode
e.) None of the above.

2.) (5-points) The series resistance of a diode, r_s...

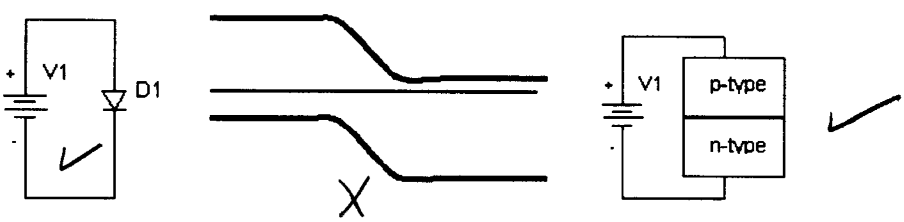
a.) ...results from the high resistance of the depletion region.
b.) ...results from the resistance of the quasi neutral region
c.) ...results from the resistance of the metal contacts
d.) both a and b
e.) both b and c

3.) (5-points) Which of the following bias diagrams is consistent with forward bias (all three diagrams must be correct, i.e. the schematic symbols, energy band diagrams and the material drawing must have the correct polarity)?

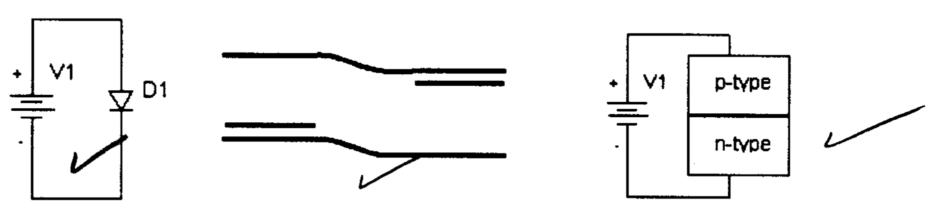
a.)



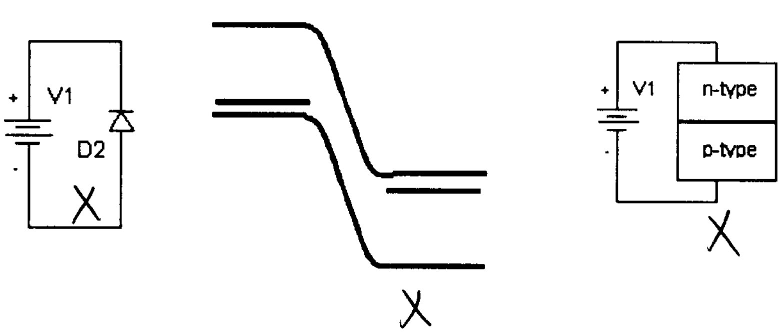
b.)



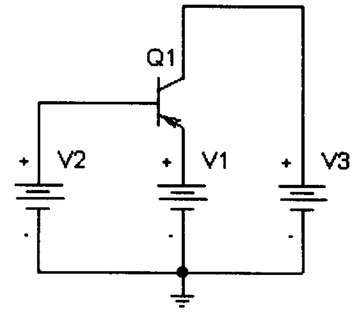
c.)



d.)



4.) (5-points) If we want to bias this transistor into saturation, which of the following is true?

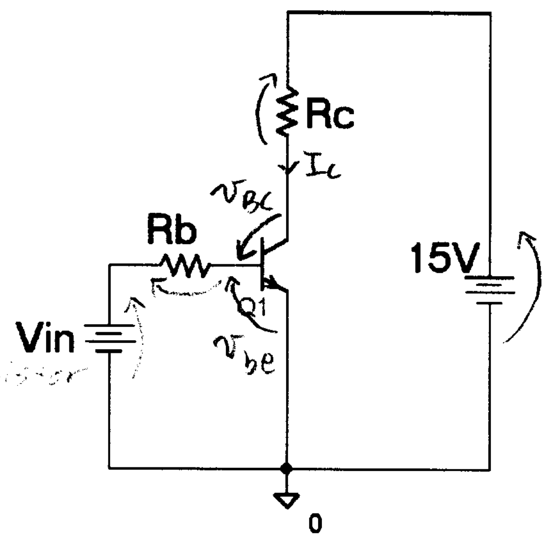


a. V3>V1 and V1>V3
b. V1>V2 and V3>V2
c. V2>V3 and V1>V3
d. V2>V1 and V2>V3
e. You cannot bias a transistor without resistors.

5.) (5–points) For a well designed BJT,
a. The emitter should always be p-type
b. The base should be thin if you want to have high voltage operation
c. The base should be thick if you want high frequency operation
d. Make the (emitter doping) > (base doping) > (collector doping)

Second 15% Short Answer and Fill in the blank:

6.) (15-points) For the following circuit, write out a set of non-linear equations (i.e. voltages appear in exponentials) that can be used to solve for currents and voltages of the circuit for large signal operation. ***DO NOT ATTEMPT TO SOLVE THE EQUATION SET!*** Hint: Use the Ebers-Moll equations and perform voltage summation loops in the base-emitter and collector emitter circuits. To get credit, a COMPLETE but not redundant set of equations is needed. Assume any transistor parameter you need is available.



5 Equations

1.) $V_{in} - i_B R_b - V_{BE} = 0$

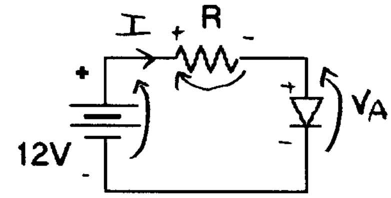
2.) $V_{BE} - V_{BC} + i_C R_C - 15\,V = 0$

3.) $i_B = i_E - i_C$

4.) $i_C = \alpha_F I_{Fo}\left(e^{v_{BE}/V_T} - 1\right) - I_{Ro}\left(e^{v_{BC}/V_T} - 1\right)$

5.) $i_E = I_{Fo}\left(e^{v_{BE}/V_T} - 1\right) - \alpha_R I_{Ro}\left(e^{v_{BC}/V_T} - 1\right)$

6.) (20-points total in two parts) A GaAs p+ n diode has the following parameters:



Intrinsic concentration n_i= 2e6 cm^{-3}

Relative dielectric constant, K_s (or ε_r)=13.1

Area=~~256~~ 625 um^2 (~~16~~ 25 um x ~~16~~ 25 um)

Minority carrier diffusion coefficient, D_p, in the n-side of 5 cm^2/Sec

Minority carrier diffusion length, L_p, in the n-side of 0.1 um

p-type doping of 1e19 cm^{-3}

Minority carrier diffusion coefficient, D_n, in the p-side of 10 cm^2/Sec

Minority carrier diffusion length, L_n, in the p-side of 0.5 um

n-type doping of 1e16 cm^{-3}.

The diode is to be used as a light emitting diode (LED) biased with the circuit shown. Find the value of the applied voltage, V_A, across the diode when R=200 Ω. Use the full mathematical diode model to solve this problem, NOT the ideal or CVD models.

Iterate to 2 decimals

$$12V - IR - V_A = 0$$

$$I = I_o\left(e^{V_A/0.0259} - 1\right)$$

$$I_o = qA\left(\frac{D_n}{L_n}\frac{n_i^2}{N_A} + \frac{D_p}{L_p}\frac{n_i^2}{N_D}\right)$$

$$= 1.6e\text{-}19\,(0.0025\,cm)^2\left[\frac{10\,cm^2/s}{0.00005\,cm}\left(\frac{(2e6\,cm^{-3})^2}{1e19\,cm^{-3}}\right) + \frac{5\,cm^2/s}{0.00001\,cm}\left(\frac{(2e6\,cm^{-3})^2}{1e16}\right)\right]$$

$$I_o = 2e\text{-}22\ A$$

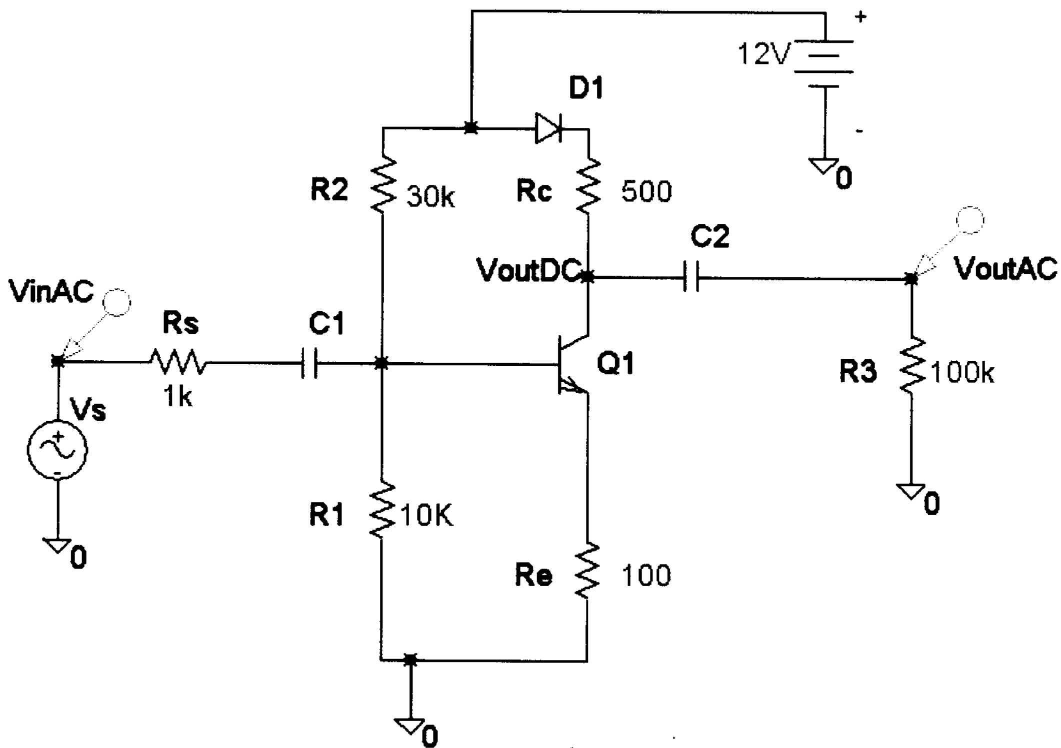
$$12V - 4e\text{-}20\left(e^{V_A/0.0259} - 1\right) - V_A \overset{?}{=} 0$$

V_A	
1V	11V
1.4V	-11,946
1.2V	5.5
1.3V	-240
1.25V	-25.8
1.22V	-0.684
1.215V	1.33
1.218V	0.169
actual → 1.219V	-0.249

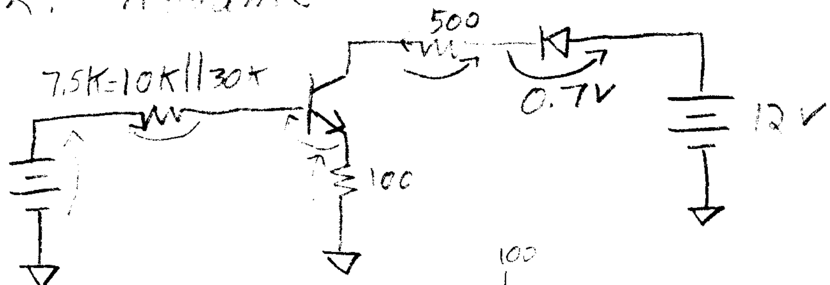
V_A = 1.21 V

(4th Section - 40%) Pulling all the concepts together for a useful purpose:

7.) (40-points) Given the following amplifier circuit and BJT Parameters, what is the AC voltage gain, VoutAC/VinAC? Assume: $\beta_{DC}=100$, Early voltage is infinite, turn on voltages for all forward biased junctions are 0.7 V. You may assume all capacitors are very large values and are thus, AC shorts. Additionally consider the circuit to be operated at low frequencies where you can neglect all small signal capacitances. Also, neglect all resistances that result from quasi-neutral regions. I_S of D1 = 1e-15 A



DC solution: Assume D1 is on.



$3V = 12V \frac{10K}{10K+30K}$

$3V - (I_B\ 7.5K) - 0.7 - (\beta+1) I_B (100) = 0$

$I_B = 130.7\ \mu A$

$I_C = (100) I_B = 13.07\ mA$

$I_E = (101) I_B = 13.2\ mA$

$V_B = 3 - (130.7e-6)(7.5K) = 2.02\ V$

$V_E = (13.2mA)\ 100 = 1.32\ V$

$V_C = 12V - 0.7 - (13.07mA)\ 500 = 4.765V$

Forward active verified: $V_B > V_E$ + $V_C > V_B$

Extra work can be done here, but clearly indicate with problem you are solving.

Small signal parameters

Diode

$$r_d = \frac{1}{g_d} = \frac{V_T}{I_D - I_S} = \frac{0.0259}{0.01307} = 2\,\Omega$$

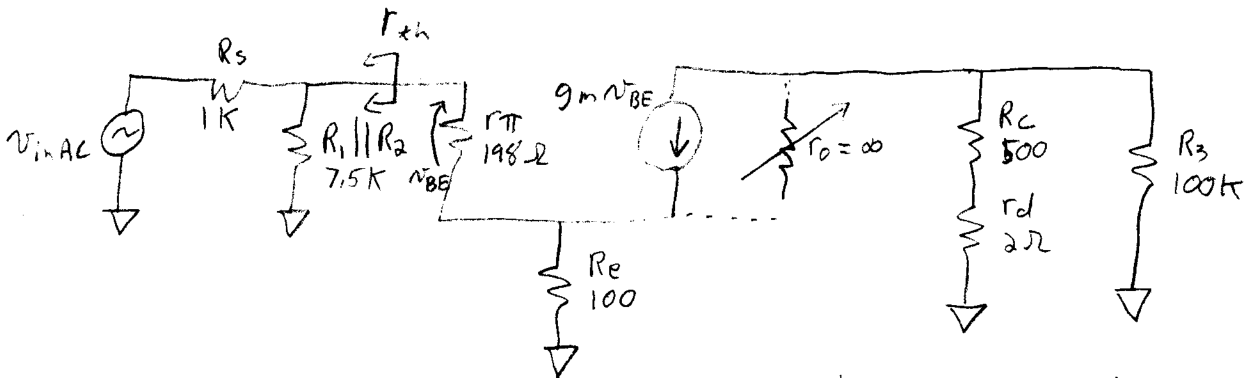
BJT

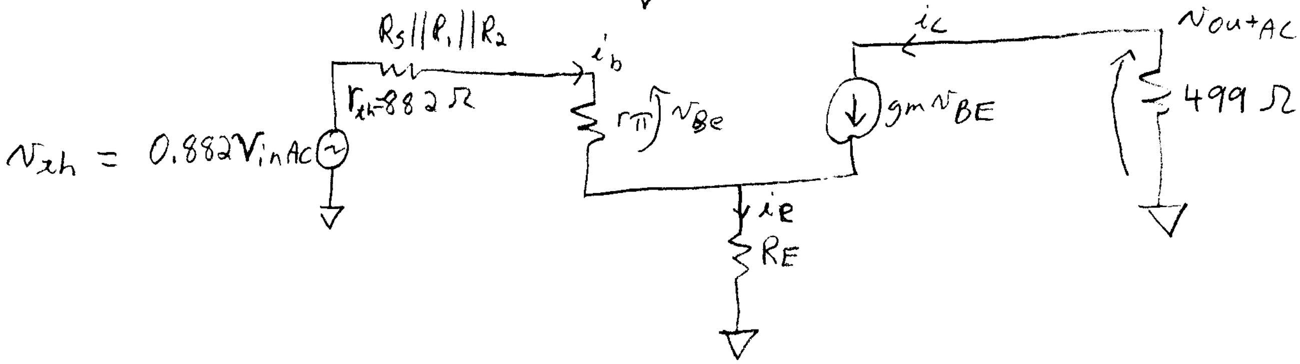
$$g_m = \frac{I_C}{V_T} = \frac{13.07\,mA}{0.0259} = 0.5046\ \Omega^{-1}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{0.5046} = 198\ \Omega$$

$$r_o = \frac{V_A + V_{CE}}{I_C} = \frac{\infty + V_{CE}}{13.07\,mA} = \infty\ \Omega$$

AC Small signal Conversion





$$A_v = \frac{v_{out\,AC}}{v_{inAC}} = \underbrace{\left(\frac{v_{out\,AC}}{v_{BE}}\right)}_{①} \underbrace{\left(\frac{v_{BE}}{v_{th}}\right)}_{②} \underbrace{\left(\frac{v_{th}}{v_{inAC}}\right)}_{③}$$

Term 1.) $v_{out\,AC} = -g_m v_{BE}\,(499\,\Omega) \Rightarrow \frac{v_{out\,AC}}{v_{BE}} = -g_m(499\ldots$ $= -251.8\ v/v$

Term 2.) $v_{th} = i_b\,(882\,\Omega) + v_{BE} + i_E R_E$, where $i_E \rightarrow (i_b + i_c)$

$$v_{th} = \frac{v_{BE}}{r_\pi}(882\,\Omega) + v_{BE} + \left(\frac{v_{BE}}{r_\pi} + g_m v_{BE}\right) R_E$$

Extra work can be done here, but clearly indicate with problem you are solving.

$$\frac{v_{BE}}{v_{th}} = \frac{1}{\frac{882\Omega}{r_\pi} + 1 + \left(\frac{1}{r_\pi} + g_m\right) R_E}$$

$$= 0.0177 \ V/V$$

Term 3) $v_{th} = 0.882 \ V_{in\,AC}$

$$\frac{v_{th}}{v_{in\,AC}} = 0.882 \ V/V$$

$$A_v = (-251.8)(0.0177)(0.882)$$

$$\boxed{A_v = -3.94 \ V/V}$$