ECE 3040 Microelectronic Circuits

Exam 2

3

April ~~1~~, 2019

Dr. W. Alan Doolittle 19 minutes

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. **Turn in all note sheets with your exam.** 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 and ***DO NOT SEPARATE THE EXAM PAGES***. 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 **<u>ONE</u>** 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% **True /False and Multiple Choice - Select the most correct answer(s)**

1.) (2-points) True / False: In a short few months you will become a well-paid and thus, tax paying citizen making enough money to live very comfortably and support/help your family. This implies you will also become a republican when "those rich folks" becomes "you". ☺ (Lighten up! It is not that bad).

2.) (2-points) True / False: In the current equation of a diode, $I_D=I_o(e^{(V/0.0259)}-1)$, the V represents the turn on voltage.

3.) (2-points) True / False: Since a BJT transistor biased into saturation mode is turned on as hard as we can turn it on, it has a very large base-collector voltage.

4.) (2-points) True / False: The forward bias current of a BJT base-emitter junction operates via tunneling current just like a diode does.

5.) (2-points) True / False: A four diode, full wave rectifier provides a stable well regulated DC voltage output.

6.) (2-points) True / False: The BJT biased into forward active mode has a large base-collector capacitance dominated by diffusion capacitance.

7.) (2-points) True / False: The early voltage accounts for the breakdown of the base-collector junction at very high reverse biases. slope

False

8.) (2-points) Avalanche breakdown only occurs in diodes and does not apply to BJT junctions.

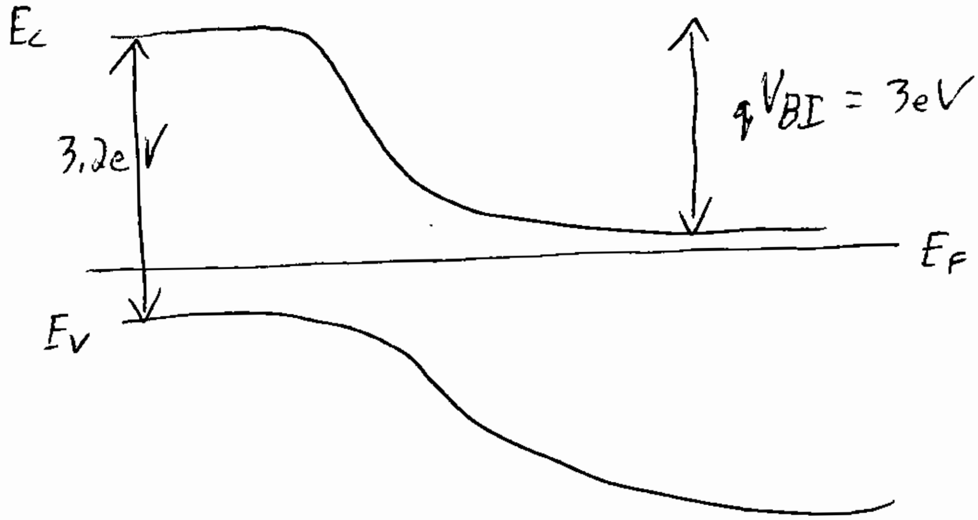
True

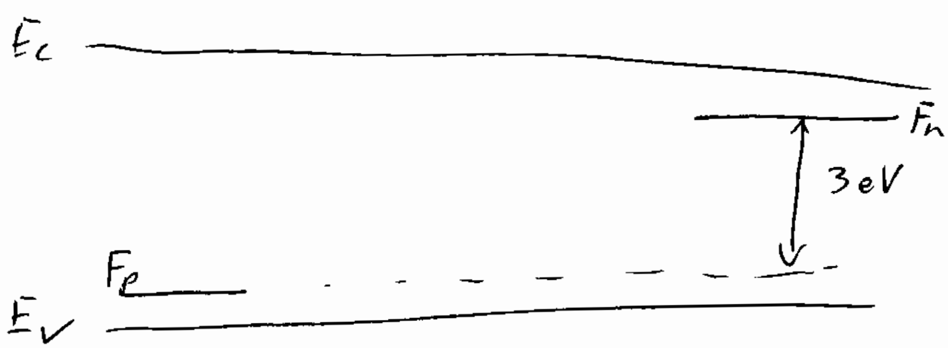
9.) (2-points) At high frequencies the BJT full small signal model (i.e. not merely the simple Hybrid pi model used for hand calculations) predicts the input base-emitter junction will become shorted, limiting the current flowing in the collector-emitter output stage.

10.) (2-points) The diode and BJT junctions operate as field control devices where the energy barrier setup by the built in voltage impedes or allows diffusion current flow depending on the sign and magnitude of the applied voltage.

True

11) (10 Points)
Draw the Energy band diagram of a SiC (Eg=3.2 eV, built in voltage =3V) power diode under equilibrium conditions and (separately) under 3 Volts forward bias. Label the p and n sides of the junction, the conduction band and fermi and quasi-fermi levels in the quasi neutral regions.

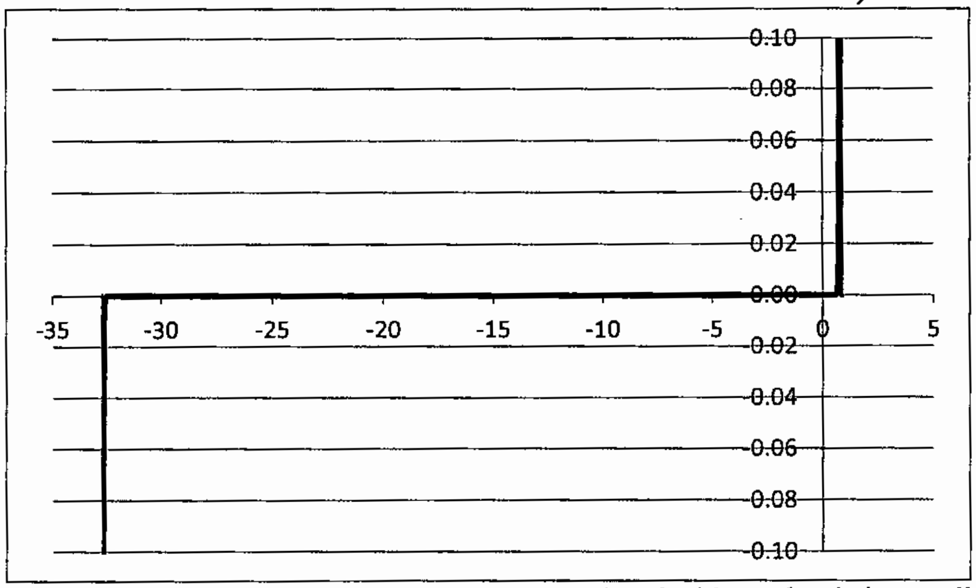




12.) (20 points total in 2 parts)

All parts refer to operation at room temperature.

A particular Zener Diode is found to have the following Current-Voltage relationship as described by the equation: $I_D=(1e\text{-}14)(e^{(V/0.0259)}-1) - (1e\text{-}12)(e^{((-32-V)/0.0259)})$ and shown below.



(a – 10 points) If the diode is operated at -32.6 Volts bias, what is its small signal conductance?

$$\left.\frac{dI}{dV}\right|_{V=-32.6V} = \left(\frac{1e\text{-}14}{0.0259}\right)e^{V/0.0259} - \left(\frac{1e\text{-}12}{0.0259}\right)e^{(-32-V)/0.0259}$$

$$g_d = 0.4442 \ \mho$$

or

$$r_d = \frac{1}{g_d} = 2.25\,\Omega$$

(b – 10 points)

For the Bias in part (A), specify the Zener break down voltage needed and the minimal power rating needed for the Zener diode.

→ ~0.6 below diode turn on

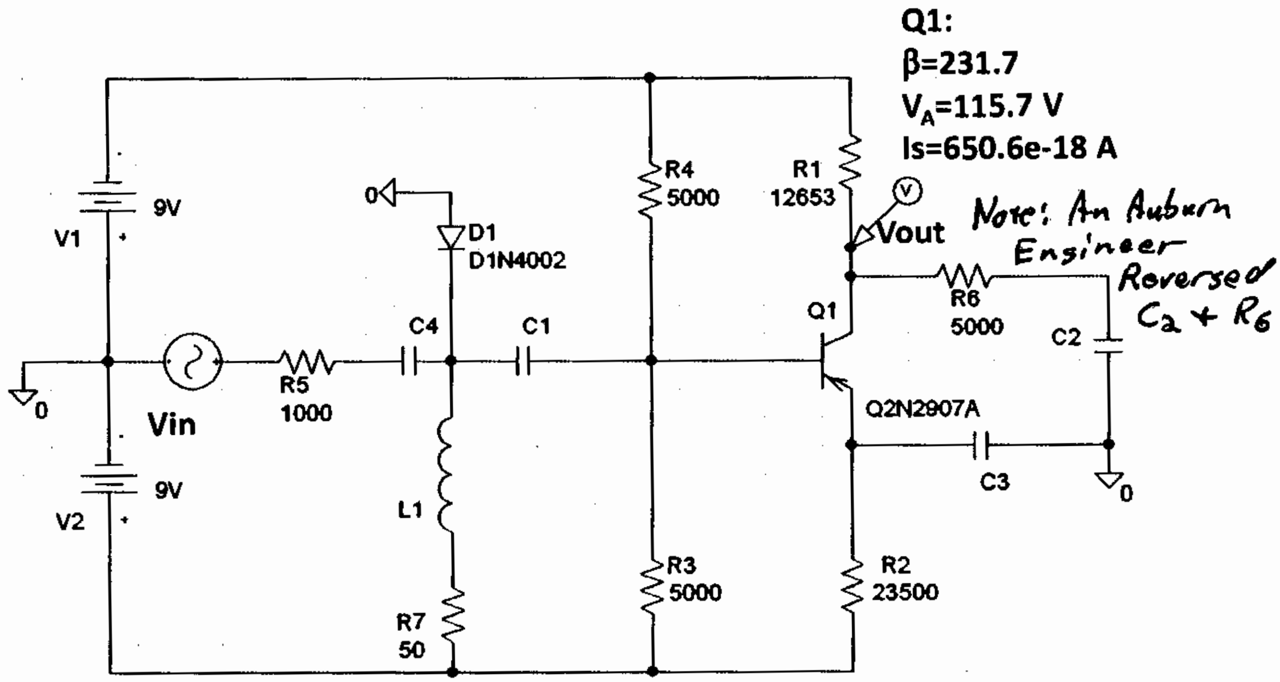
Zener breakdown Voltage -32.6 (or 32) → diode turn on

Minimal Zener Power Rating 0.375 W

$I|_{V=-32.V} = 0.0115\,A$

$P = V \times I$

13) **Pulling all the concepts together for a useful purpose:**
(50-points total: DC solution = 15 points, conversion to small signal model = 15 points, AC solution = 15 points and 5 points for accuracy of the graphs and 10 points for the bonus solution of the correct turn on voltage) .



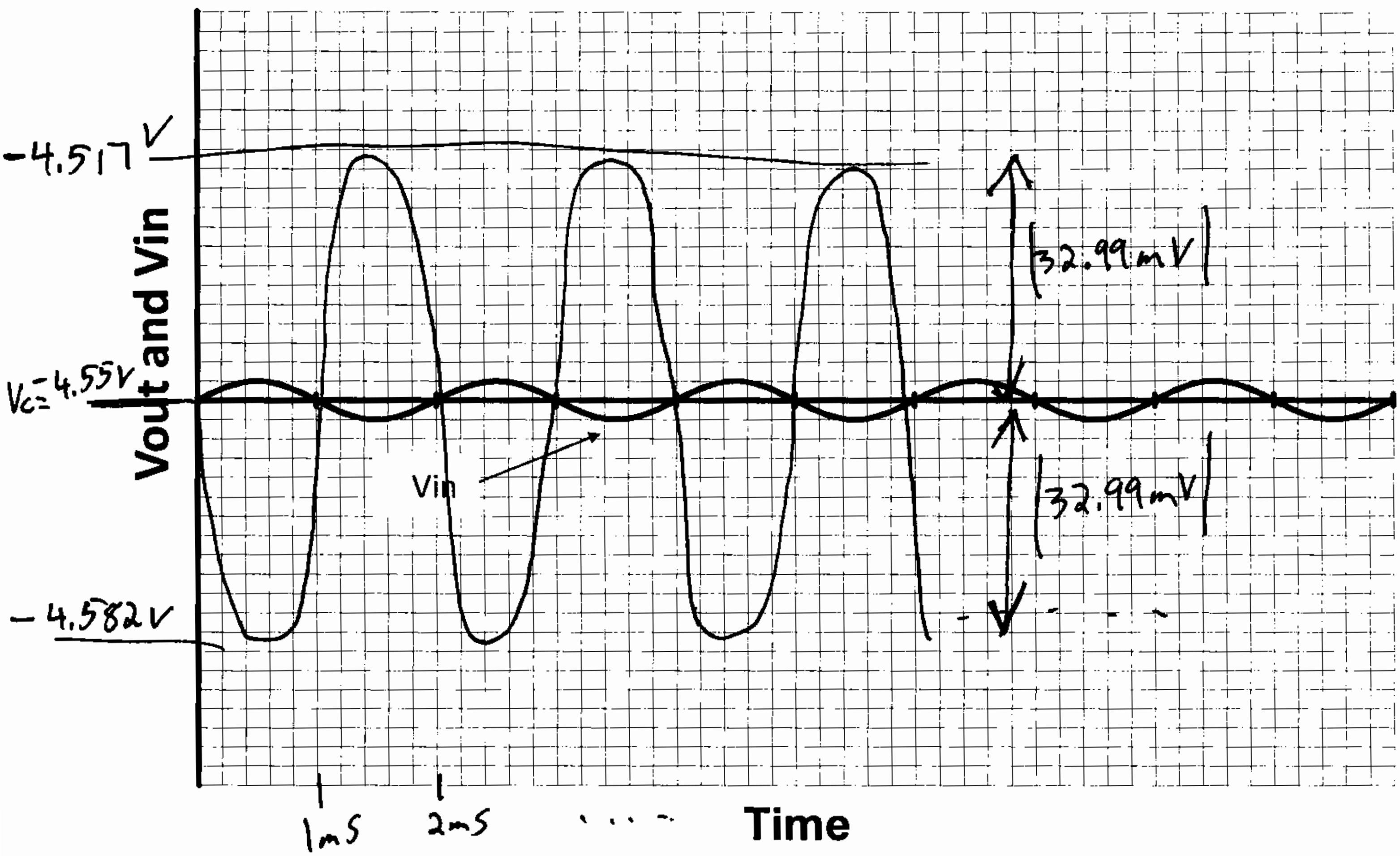
For the circuit above, you will be asked to solve for two cases, <u>the second being bonus points</u>:
<u>Part A</u>) The small signal gain of the amplifier, plot the small signal output waveforms AND
<u>Part B is a Bonus of 10 points</u>): Since in part A you assumed a turn on voltage of 0.7, using the Simplified Ebers Moll model (the model that we derived our small signal model from) determine the correct turn on voltage we should have used. DO NOT RESOLVE THE ENTIRE GAIN PROBLEM - JUST FIND THE TURN ON VOLTAGE WE SHOULD HAVE USED INSTEAD OF 0.7V.

Initially Assume Q1: $V_{\text{Base-Emitter turn on}}$=0.7 V, $V_{\text{Base-Collector turn on}}$=0.5 V,
β_{DC}=231.7, Early Voltage=115.7V, Is=650.6e-18 Amps

D1: $V_{\text{turn on}}$=0.7 V , Is=1e-14 amps
V_{inAC} = 1mV amplitude (i.e. 2mV peak to peak) at 1 KiloHertz

Part A) Given the above input voltage, V_{in}, sketch and accurately label a plot of the output waveforms V_{out} <u>on the graph paper provided on the next page</u>. Assume the turn on voltages for all forward biased junctions are as described above. You may assume all capacitors are very large values and any inductors are very large values. Additionally consider the circuit to be operated at low frequencies where you can neglect all small signal capacitances of transistors and diodes. Also, neglect all resistances that result from quasi-neutral regions. **For full Credit, be sure to check your assumptions on the mode of operation of the transistor and diode and to clearly label the axes of your plot.**

Small Signal answer Page



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

Part A:

Diode DC:

D_1 = Reverse biased

$I_D = -I_o = 1e{-14}A \approx 0$

Diode AC:

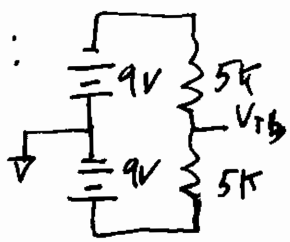
$$g_d = \frac{I_D + I_o}{V_T} = \frac{-I_o + I_o}{V_T} = 0$$

$$r_d = \infty = 1/g_d$$

DC BJT:

Assume F. Active.

V_{THB}:

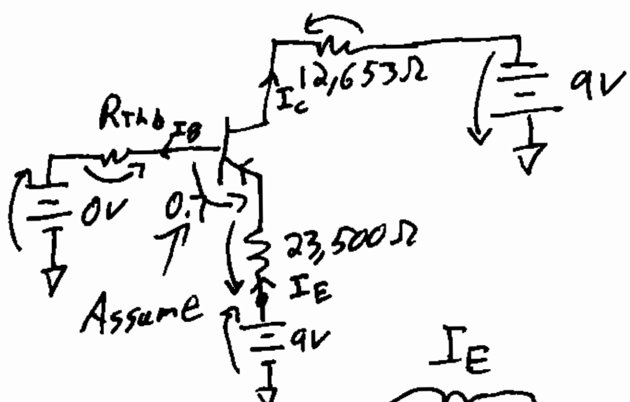


Superposition

$$V_{THb} = 9V\left(\frac{5K}{5K+5K}\right) - 9V\frac{5K}{(5K+5K)}$$

$$= 0V$$

$$R_{ThB} = 5K \| 5K = 2.5K$$



$$0V + I_B R_{THB} + 0.7V + \overbrace{I_B(1+\beta)}^{I_E}(23{,}500) - 9 = 0$$

$$I_B = \frac{8.3}{2.5K + 232.7(23{,}500)} = 1.52\,\mu A$$

$$I_C = \beta I_B = 351.5\,\mu A$$

$$I_E = (\beta+1)I_B = 353\,\mu A$$

$$V_B = I_B R_{THB} = 3.8\,mV$$

$$V_C = -9 + I_C\, 12{,}653 = -4.55V$$

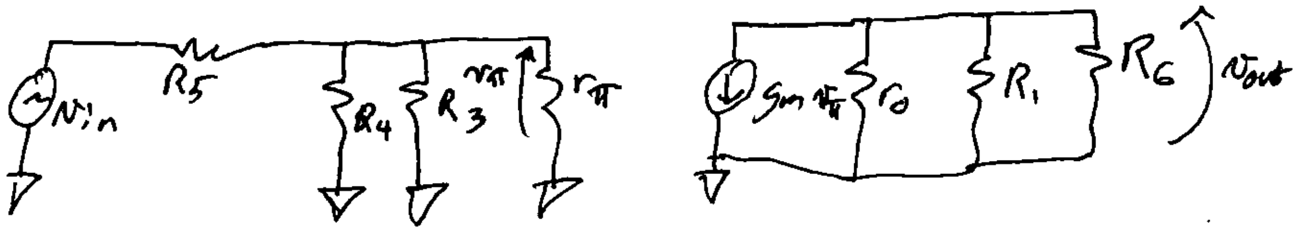
$$V_E = 9 - I_E\, 23{,}500 = 0.703V$$

$V_E > V_B > V_C$ ✓

F. A. Confirmed

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

AC Small Signal:



$$g_m = \frac{I_c}{V_T} = 0.01357\ \mho$$

$$r_\pi = \beta / g_m = 17{,}072\ \Omega$$

I did not count off for this pnp issue

$$r_o = \frac{V_A + |V_{CE}|}{I_c} = \frac{115.7 + (4.55 + 0.703)}{351.5\ \mu A}$$

$$r_o = 344{,}092\ \Omega$$

1) $$\frac{v_\pi}{v_{in}} = \frac{R_4 || R_3 || r_\pi}{R_5 + R_4 || R_3 || r_\pi} = \frac{2180}{1000 + 2180} = 0.685\ V/V$$

2) $$\frac{v_{out}}{v_\pi} = -g_m (r_o || R_1 || R_6) = -(0.01357)\,3546$$

$$= -48.13\ V/V$$

$$A_v = \overset{(2)}{\left(\frac{v_{out}}{v_\pi}\right)} \overset{(1)}{\left(\frac{v_\pi}{v_{in}}\right)} = -32.99\ V/V$$

Part B Bonus

$$I_c = I_s e^{V/V_T}$$

$$351.5\ \mu A = 650.6\text{e-}18\, e^{V/0.0259}$$

$$V_{Turnon} = 0.69969\ldots\ \text{Volts}$$