ECE 3040B Microelectronic Circuits

Exam 2

March 15, 2001

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Print your name clearly and largely: Key

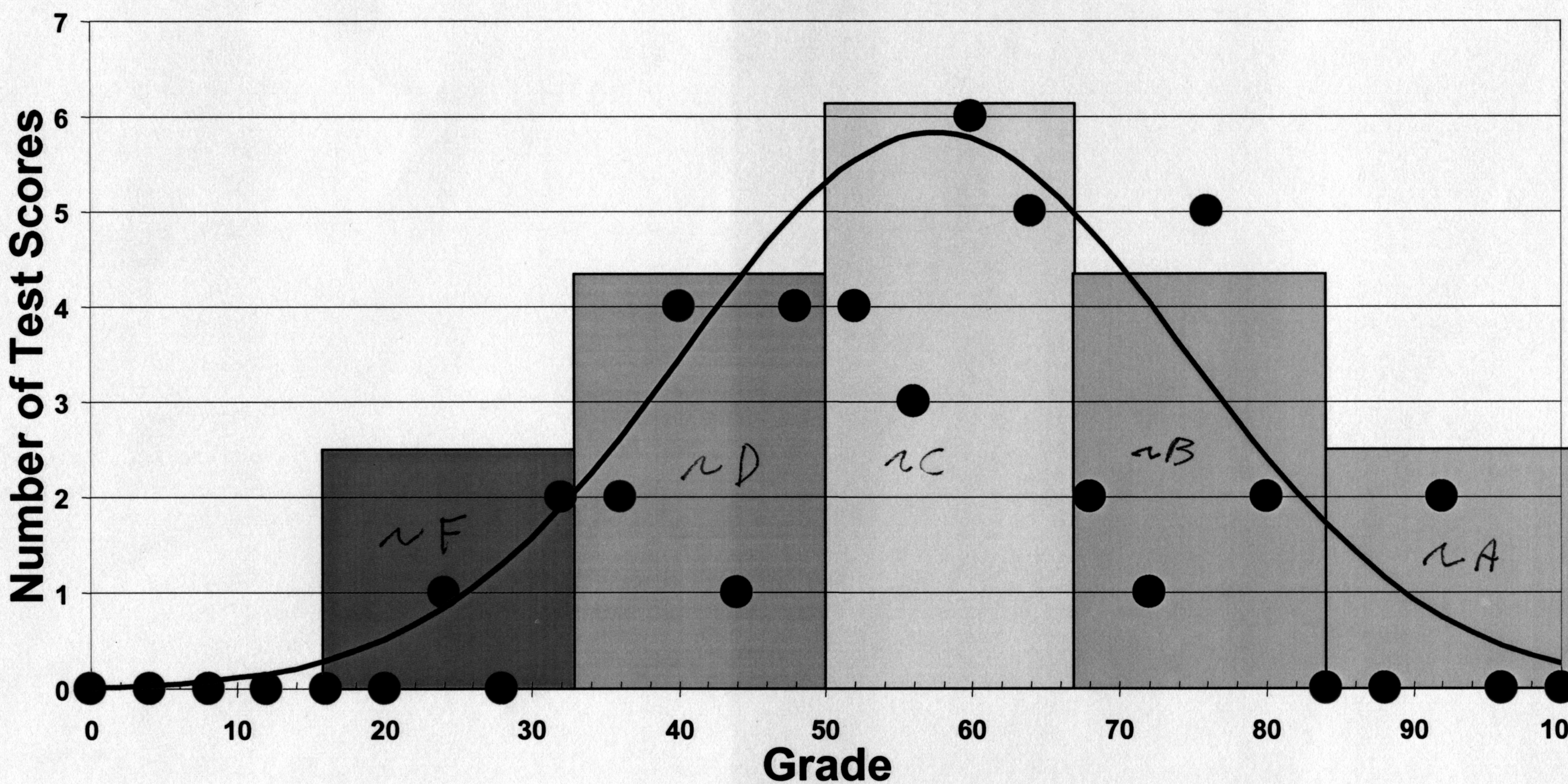
Instructions:
Read all the problems carefully and thoroughly before you begin working. You are allowed to use 1 new sheet of notes (1 page front and back), your note sheet from the previous exam as well as a calculator. There are 100 total points in this exam. Observe the point value of each problem 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:

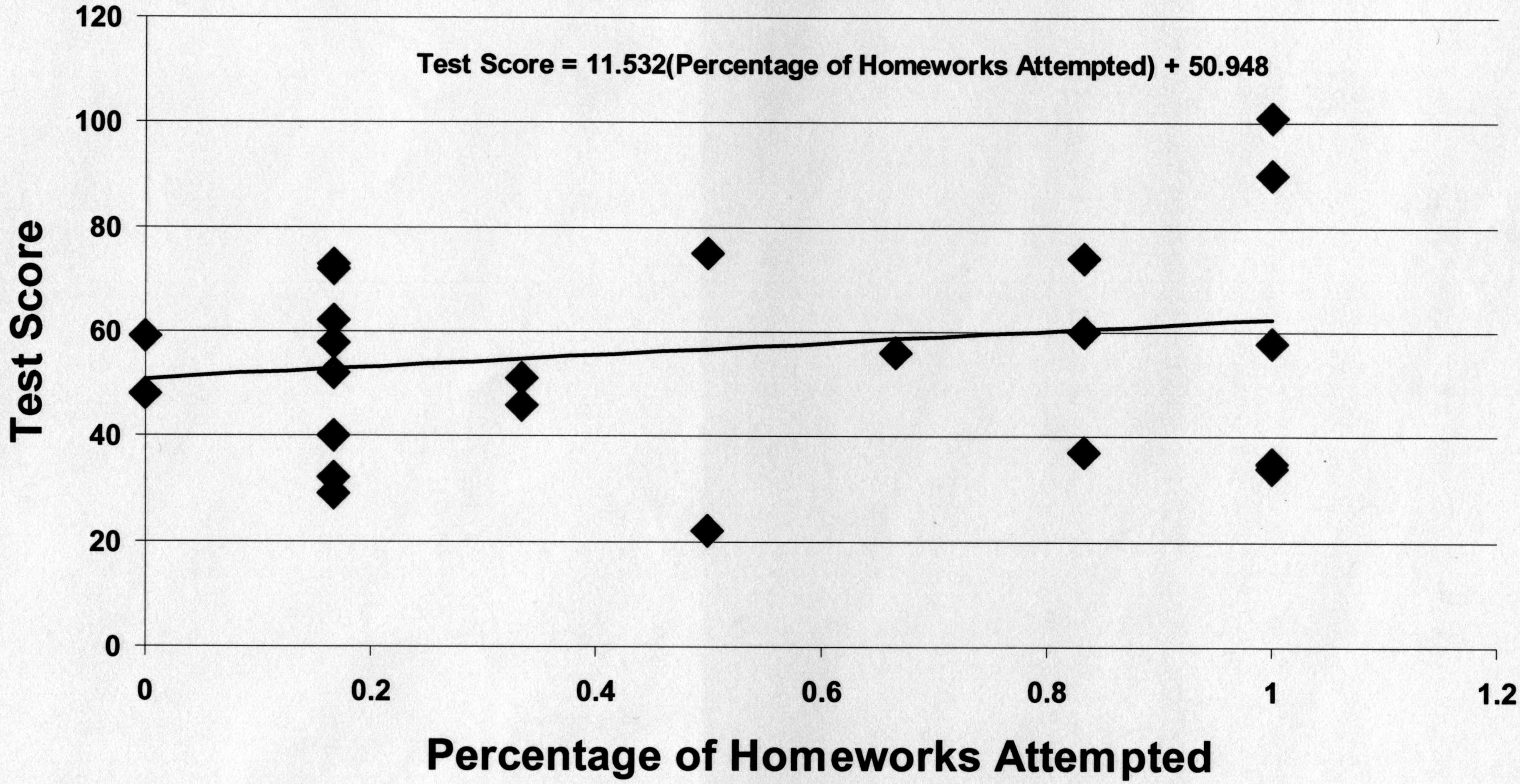
I DID NOT observe any ethical violations during this exam: ______________________

I observed an ethical violation during this exam: ______________________

Test Average	57.5
Standard Deviation	17.0
Max	101
Min	22



		Broken down by question								
Question	1	2	3	4	5	6	7	8	9	10
% Score per Question	84.44444	60	88.9	53.3	20	83.6	67	80.2	58.1	23.5
1st 25%	61.9065									
2nd 25%	75.31339									
3rd 25%	69.15242									
4th 25%	23.46667									



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

1.) (5-points) An n-type region of silicon material is brought into contact with a p-type region of silicon. Which of the following is true:

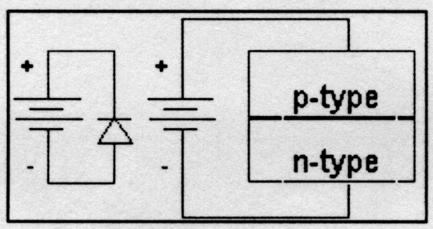
a.) A diode results from this process.
b.) A transistor results from this process.
c.) The transistor is cutoff.
d.) The diode is reverse biased
e.) None of the above.

2.) (5-points) Base transport factor, α_T...

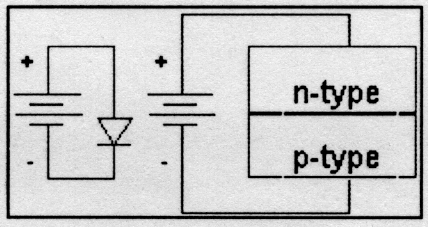
a.) ...characterizes the ability of a diode to handle large currents.
b.) ...characterizes the ability of a transistor to handle large currents.
c.) ... characterizes the percentage of minority carriers in the base that make it to the collector.
d.) ... characterizes how effectively the emitter can inject carriers into the base
e.) ... characterizes how effectively the collector can inject carriers into the base

3.) (5-points) Which of the following bias diagrams is consistent with forward bias (both the schematic symbols and the material drawing must have the correct polarity)?

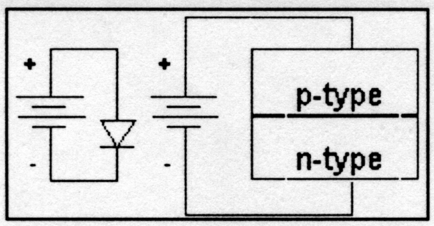
a.)



b.)



c.)



4.) (5-points) A reverse biased pn diode junction...

a.) ...conducts a very large current.
b.) ...conducts absolutely zero current.
c.) ...has a smaller capacitance than when the diode is unbiased ($V_{applied}$=0V).
d.) ...could be conducting a large current if biased into breakdown.
e.) c and d.
f.) None of the above.

5.) (5-points) The built in voltage of a junction...

a.) ...is determined by the doping on the heaviest doped side of the junction.
b.) ...is the voltage at which the device turns on.
c.) ... is always larger than $-E_G/q$ where E_G is the bandgap and q is the electronic charge.
d.) ...is always negative
e.) None of the above.

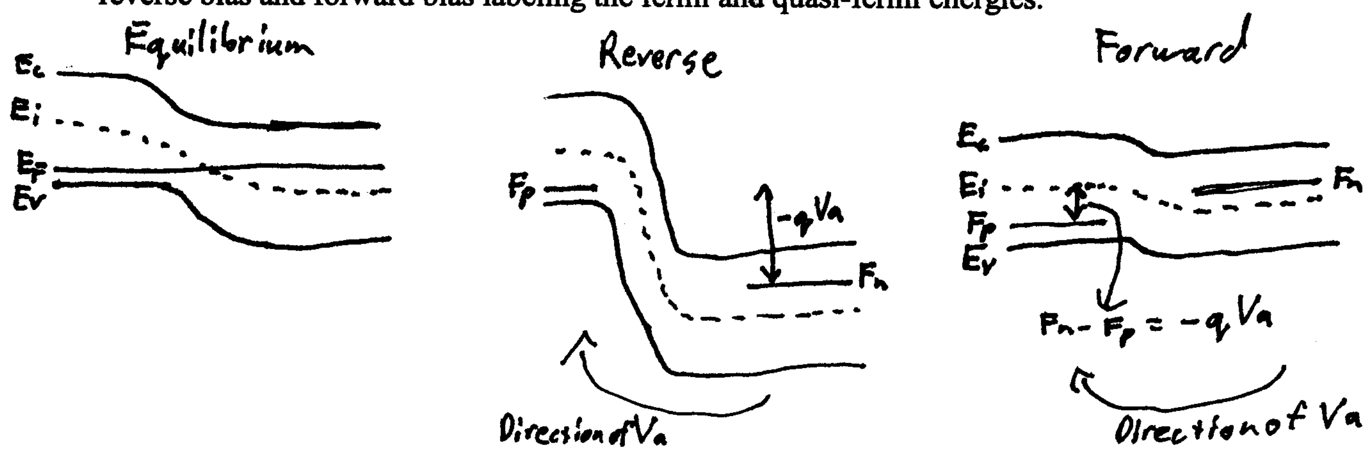
Second 25% Short Answer:

6.) (12-points total) (a 8-points) Calculate the DC common emitter current gain of a bipolar junction transistor with an emitter diffusion coefficient of 6.81 cm^2/Sec, emitter diffusion length of 8.25 um, emitter doping of 1e18 cm^{-3}, base width of 2 um, base diffusion coefficient of 11.3 cm^2/Sec, base diffusion length of 33.6 um, base doping of 1e16 cm^{-3} . (b 4-points) Why does the collector material parameters not matter to this calculation?

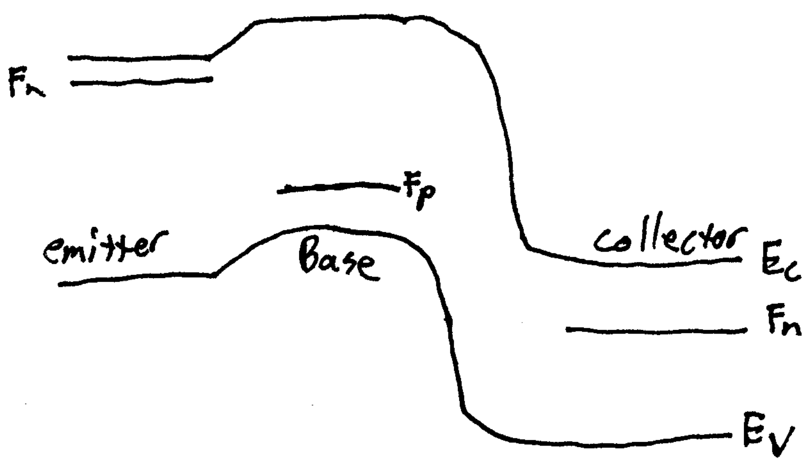
$$\beta_{DC} = \frac{1}{\frac{D_E N_B W}{D_B N_E L_E} + \frac{1}{2}\left(\frac{W}{L_B}\right)^2} = \frac{1}{\frac{(6.81)(1e16)(2\times10^{-4})}{(11.3)(1e18)(8.25\times10^{-4})} + \frac{1}{2}\left(\frac{2\times10^{-4}}{3.36\times10^{-3}}\right)^2}$$

$$= 309$$

7.) (7-points) Draw and label the energy band diagram of a p+ n diode in equilibrium, reverse bias and forward bias labeling the fermi and quasi-fermi energies.



8.) (6-points) Draw the energy band diagram of a npn bipolar transistor biased into active mode. Label the three regions of the device.



Third 25% Problems (3rd 25%)

9.) (12-points) Describe the function of each of the three regions of a bipolar junction transistor biased in the forward active mode. Be as detailed as possible. (Bonus points are available for subtle details.)

1.) The emitter "emits" or "injects" it's majority carriers in to the base. ~~These~~

2.) These carriers are now minority carriers in the base. They diffuse through the base ~~am~~ and ...

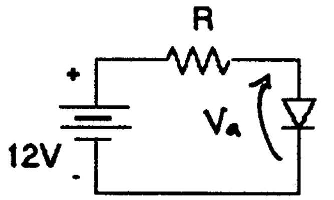
3.) Are collected by the strong electric fields of the base - collector junction. Once in the collector, the carriers are once again majority carriers.

4.) The base - emitter is forward biased.

5.) The base - collector is reverse biased.

Bonus points awarded for all important statements beyond these 5 points.

9.) (13-points) A GaAs p+ n diode has the following parameters: intrinsic concentration= 2e6 cm^{-3}, Area= 100 um^2, diffusion coefficient in the p side of 5 cm^2/Sec, diffusion length in the p-side of 0.1 um, p+ doping of 1e19 cm^{-3}, diffusion coefficient in the n side of 10 cm^2/Sec, diffusion length in the n-side of 0.5 um, n-type doping of 1e15 cm^{-3}. The diode is to be used as a light emitting diode (LED) that must be biased with the following circuit at 20 mA to obtain the desired amount of light out. Use the full diode current equation, $I=I_S(e^{V_a/V_t}-1)$ to find the value of the resistor that achieves this bias current (do not assume a "turn on voltage" in this particular case).



$$I = I_o\left(e^{V_a/V_T} - 1\right) = 20mA$$

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

$$= 1.6\times10^{-19}\,(1\times10^{-6}cm^2)\left[\frac{10cm^2/s}{(5e\text{-}5cm)}\frac{(2\times10^6)^2 cm^{-6}}{1e19cm^{-3}} + \ldots \right.$$

$$\left. \ldots \frac{5cm^2/s\,(2\times10^6)^2 cm^{-6}}{(1e\text{-}5cm)\,1e15}\right]$$

$$I_o = 3.2\,e\text{-}22 \text{ Amps}$$

$$V_a = \left[\ln\left(\frac{20mA}{3.2\times10^{-22}} + 1\right)\right]0.0259 = 1.18\,V$$

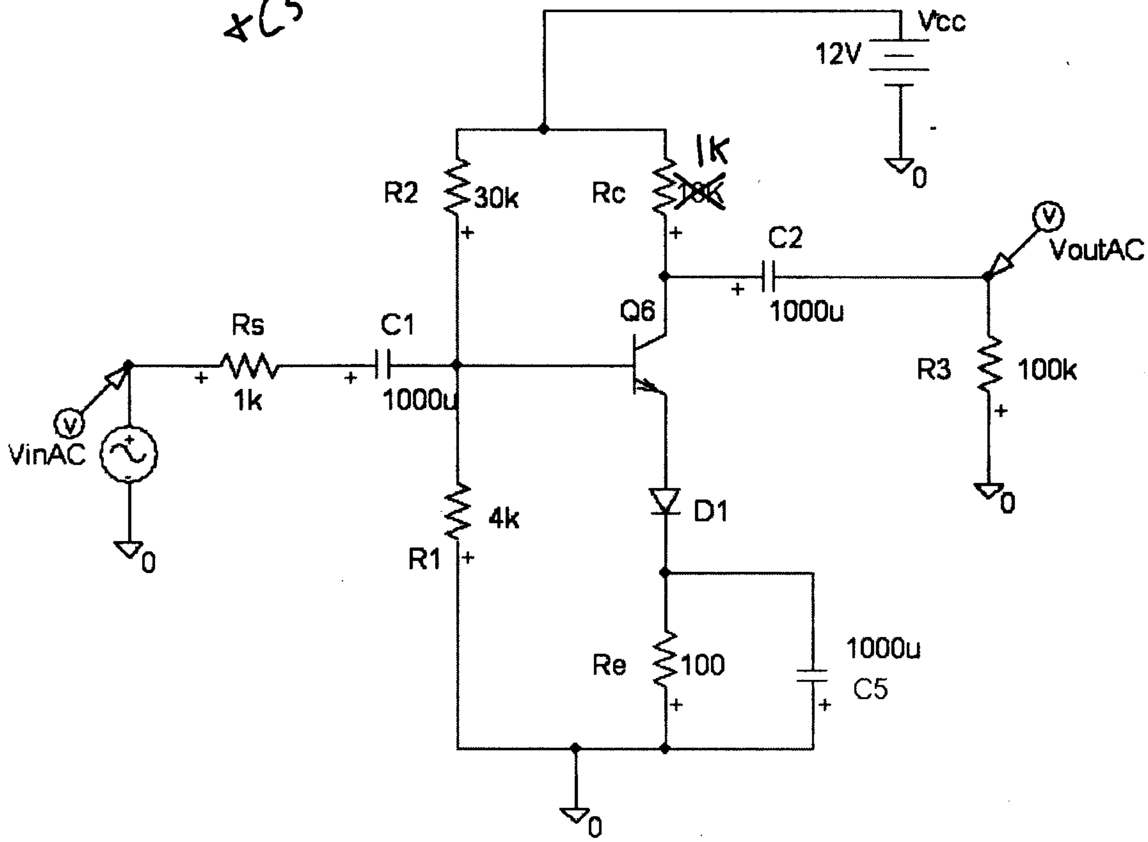
$$\frac{12V - 1.18V}{R} = 20mA$$

$$\boxed{R = 541\,\Omega}$$

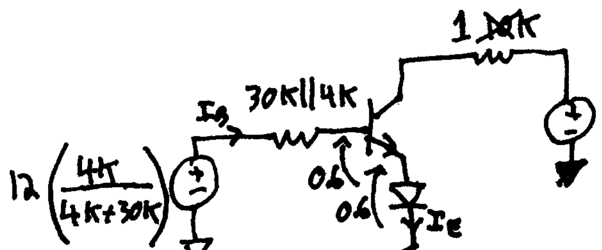
Pulling all the concepts together for a useful purpose: (4^{th} 25%)

12.) (25-points) Given the following circuit and BJT Parameters, what is the AC voltage gain, VoutAC/VinAC? β_{DC}=416, turn on voltages for all forward biased junctions are 0.6 V. You may assume C1 and C2 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.

x C5



Bias Circuit



$$12\left(\frac{4k}{4k+30k}\right) = I_B(30k\|4k) + 0.6 + 0.6 + I_E\,100$$

$$\Rightarrow \quad 1.41\,V = I_B(3.5k) + 1.2 + \underset{416}{(\beta+1)}\,I_B(100)$$

$$I_B = \frac{0.21}{45{,}210} = 4.6e\text{-}6\ A$$

$$I_C = \cancel{1.9\,mA}\ \ 1.93\ mA$$

$$I_E = (\beta+1)\,I_B = 1.94\ mA$$

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

AC Anaylsis:

Transistor: $g_{m_{trans}} = \frac{I_c}{V_T} = \frac{1.93e{-3}}{0.0259} = 0.0745\,[S]$

$$r_\pi = \frac{\beta}{g_{m_{trans}}} = \frac{416}{0.0745} = 5582\,[\Omega]$$

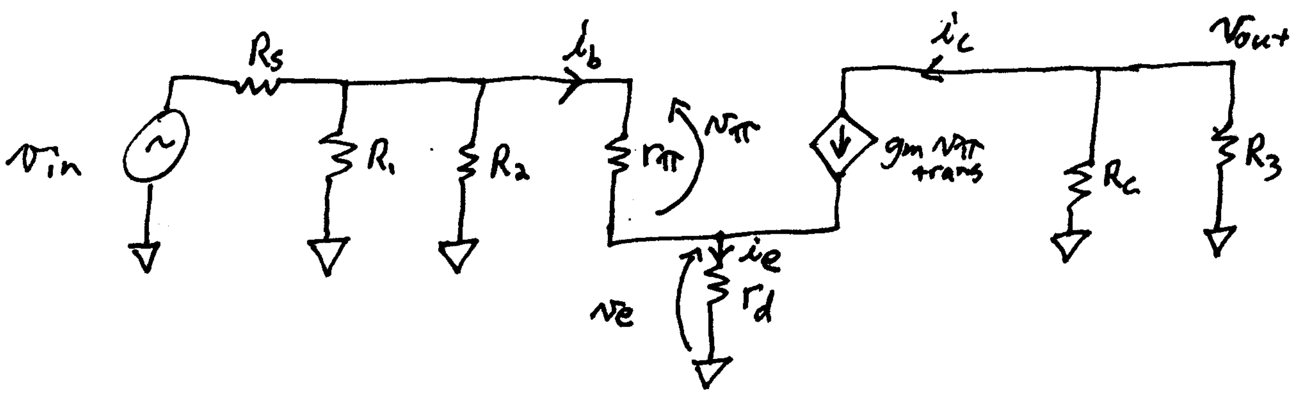
$$r_o = \frac{V_A + V_{CE}}{I_c} = \infty$$

Diode: $g_{m_{Diode}} = \frac{I_d + \cancel{I_s}}{V_T}$ neglect due to magnitudes as discussed in class and homework

$$= \frac{I_E}{V_T} = \frac{1.94e{-3}}{0.0259} = 0.075\,[S]$$

$$r_{diode} = r_d = \frac{1}{g_{m_{diode}}} = 13.35\,[\Omega]$$

Small Signal Model:

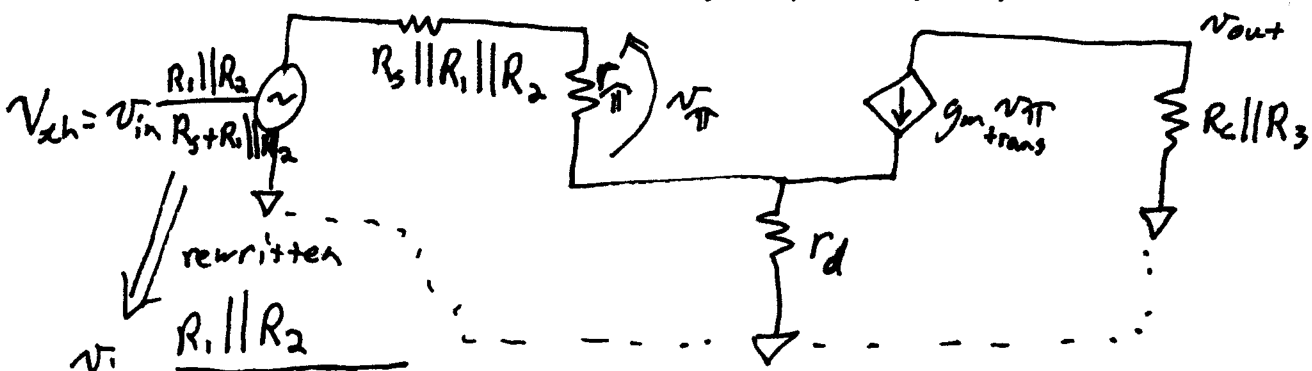


$$i_e = i_c + i_b$$
$$= g_m v_\pi + \frac{v_\pi}{r_\pi}$$

$$v_e = i_e r_d$$

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

Thevenin on each leg of transistor. (what equivalent circuit does the transistor see?



$$v_{in} \frac{R_1||R_2}{R_s + R_1||R_2}$$

You can simply do Mesh analysis

or ...

$$A_v = \frac{v_{out}}{v_{in}} = \frac{v_o}{v_\pi} \frac{v_\pi}{v_{th}} \frac{v_{th}}{v_{in}}$$

(1) (2) (3)

$$v_{out} = -(R_c||R_3)\, g_{m_{trans}} v_\pi$$

$$\Rightarrow (1) \quad \frac{v_{out}}{v_\pi} = -(R_c||R_3)\, g_{m_{trans}}$$

$$v_{th} = v_{in} \frac{R_1||R_2}{R_s + R_1||R_2}$$

$$\Rightarrow (3) \quad \frac{v_{th}}{v_{in}} = \frac{R_1||R_2}{R_s + R_1||R_2}$$

$$v_{th} = i_b (R_s||R_1||R_2) + v_\pi + i_e r_d$$
$$= \frac{v_\pi}{r_\pi}(R_s||R_1||R_2) + v_\pi + \left(g_{m_{trans}} v_\pi + \frac{v_\pi}{r_\pi}\right) r_d$$

$$\Rightarrow (2) \quad \frac{v_\pi}{v_{th}} = \frac{1}{\frac{R_s||R_1||R_2}{r_\pi} + 1 + \left(g_{m_{trans}} + \frac{1}{r_\pi}\right) r_d}$$

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

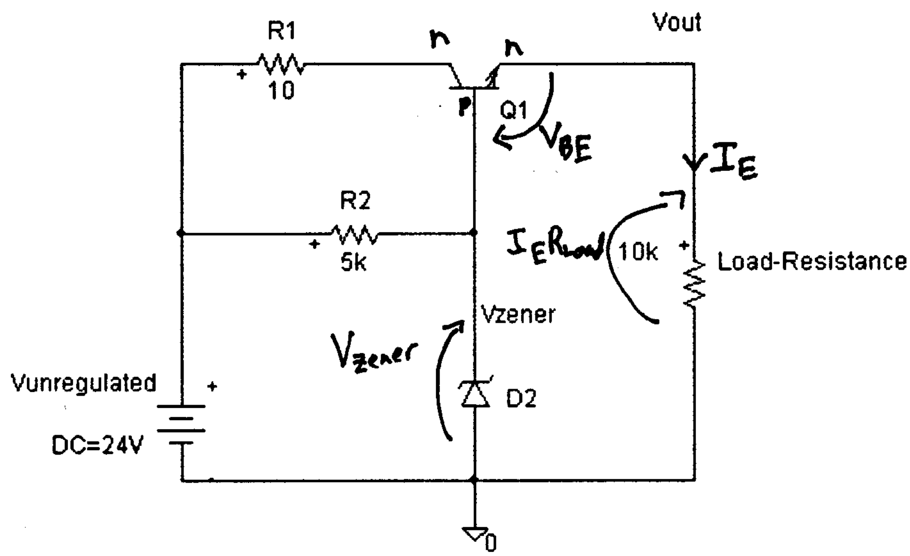
$$\therefore \quad A_v = \frac{v_{out}}{v_{in}} = \frac{v_o}{v_\pi} \frac{v_\pi}{v_{th}} \frac{v_{th}}{v_{in}}$$

$$= \frac{-\left[\left(R_c \| R_3\right) g_{m_{trans}}\right]\left[\dfrac{R_1 \| R_2}{R_s + R_1 \| R_2}\right]}{\dfrac{R_s \| R_1 \| R_2}{r_\pi} + 1 + \left(g_m + \dfrac{1}{r_\pi}\right) r_d}$$

$$= \frac{-\left[\left(\overset{990}{\cancel{9090}}\right)(0.0745)\right]\left[\dfrac{3529}{1000+3529}\right]}{\dfrac{779}{5582} + 1 + \left(0.0745 + \dfrac{1}{5582}\right) 13.35}$$

$$\boxed{\frac{v_{out}}{v_{in}} = \overset{-26.9}{\cancel{-247}} \quad [V/V]}$$

Bonus of 15 points total:
As we saw in our full wave rectifier homework problem, load resistances can change the output of the rectifier. Thus, the following circuit acts as a voltage regulator, meaning regardless of the load resistance, the output voltage, V_{out}, is fixed at a fixed value. Given that the transistor operates in the forward active mode, the Zener diode has a break down voltage of 5.7 V, and assuming a turn on voltage of 0.7 V; (a-5 points) What is the value of V_{out}? (b-10 points) Describe how the circuit would operate (i.e. how the voltage remains constant regardless of load resistance). (Hint: R2 simply supplies bias current to the Zener diode and Base of the transistor. It's value is not critical.)



a). Since Q1 is in forward active mode, the base-emitter is forward biased. Thus, $V_{out} = V_{zener} - V_{BE}$

$$\Rightarrow V_{out} = 5.7V - 0.7V$$

$$\boxed{V_{out} = 5.0V}$$

b.) $\underbrace{V_{zener} - V_{BE}}$ $= I_E R_{Load}$

As Long as the transistor is in active mode, this is a constant!

$$\Longrightarrow I_E = \frac{K}{R_{Load}}$$

Constant

Thus, the voltage regulator adjusts it's output current as R_{Load} changes to maintain a constant output voltage.