ECE 3040 Microelectronic Circuits

Exam 2

July 2, 2002

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Note: The length of this exam was adjusted for the summer semester (1 hr 10 min)

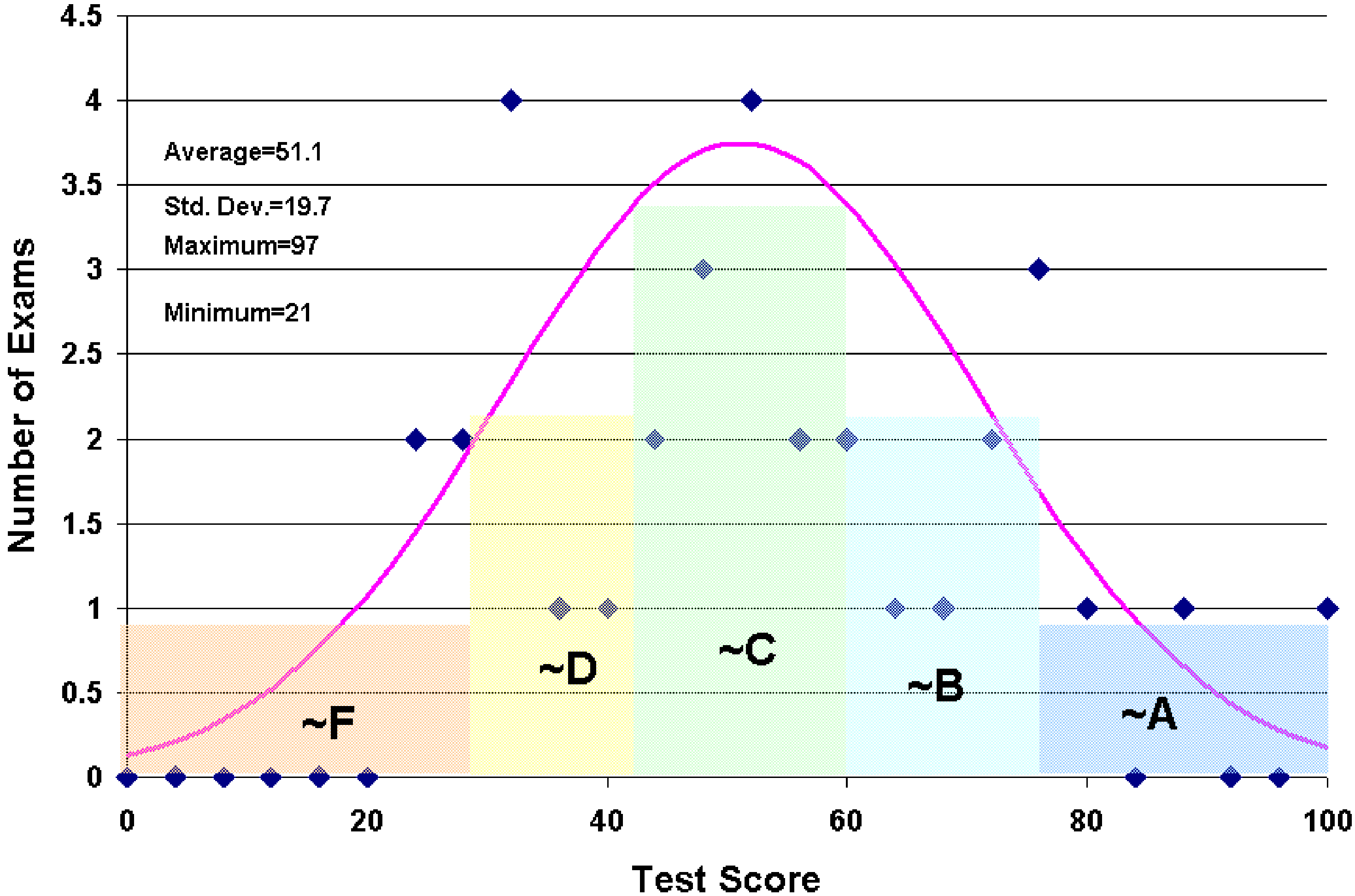
Print your name clearly and largely: Solutions

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:



4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Number of Exams
Average=51.1
Std. Dev.=19.7
Maximum=97
Minimum=21
~F
~D
~C
~B
~A
0
20
40
60
80
100
Test Score

***First ~1/3%* Multiple Choice (Select the most correct answer)**

1.) (5-points) When a diode is reverse biased, the net current that flows is a result of:
- a.) Minority carriers that are collected by the large electric field, better known as diffusion current
- b.) Minority carriers that are collected by the large electric field, better known as drift current
- c.) Majority carriers that surmount the energy barriers, better known as diffusion current
- d.) Majority carriers that surmount the energy barriers, better known as drift current
- e.) None of the above because no current flows in reverse bias.

2.) (5-points) The Early Voltage…
- a.) …results from the 8:00 AM start time of our class
- b.) …results from the base-collector depletion region overlapping the base-emitter depletion region
- c.) …results from the base-collector depletion region "consuming" part of the base quasi-neutral region width making W a function of V_{BC}
- d.) … is kT/q
- e.) both c and d

3.) (5-points) When a BJT is to be used as a switch that is conducting (on) which bias mode is required?

a.) Forward bias	b.) Reverse bias	c.) Forward Active
d.) Inverse Active	e.) Saturation	f.) Cutoff

4.) (5-points) When a BJT is to be used as a switch that is not conducting (off) which bias mode is required?

a.) Forward bias	b.) Reverse bias	c.) Forward Active
d.) Inverse Active	e.) Saturation	f.) Cutoff

5.) (5-points) When a BJT is to be used as an amplifier which bias mode is required?

a.) Forward bias	b.) Reverse bias	c.) Forward Active
d.) Inverse Active	e.) Saturation	f.) Cutoff

6.) (5-points) For a given power supply voltage (one single supply) which mode of operation has the smallest magnitude of collector to emitter voltage?

a.) Forward bias	b.) Reverse bias	c.) Forward Active
d.) Inverse Active	e.) Saturation	f.) Cutoff

7.) (5-points) When using the small signal analysis, …
- a.) Diodes are replaced by resistors
- b.) BJT's are replaced by the hybrid Pi model
- c.) Only small inputs are valid
- d.) You must first solve the DC solution
- e.) All of the above

8.) (5-points) When using the small signal analysis, …
- a.) is only useful for voltages greater than kT/q (~26 mV at room temperature).
- b.) The model can often still be used for large signals but results in the introduction of distortion
- c.) Must be replaced by the large signal model if distortion is to be analyzed
- d.) Is a simpler "linearized" version of the large signal model valid for only small perturbations around the DC operating point.
- e.) Both a and b
- f.) Both c and d

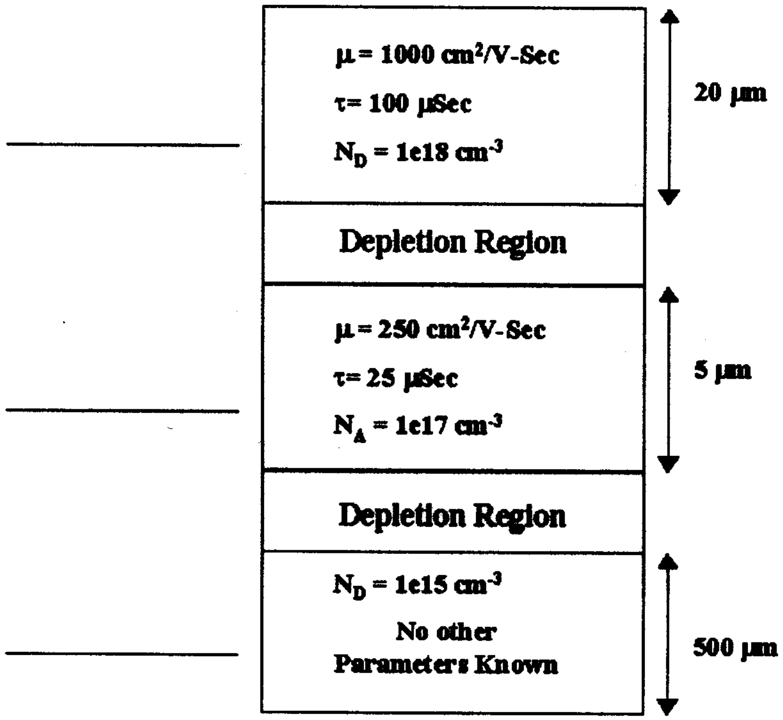
Third 20%

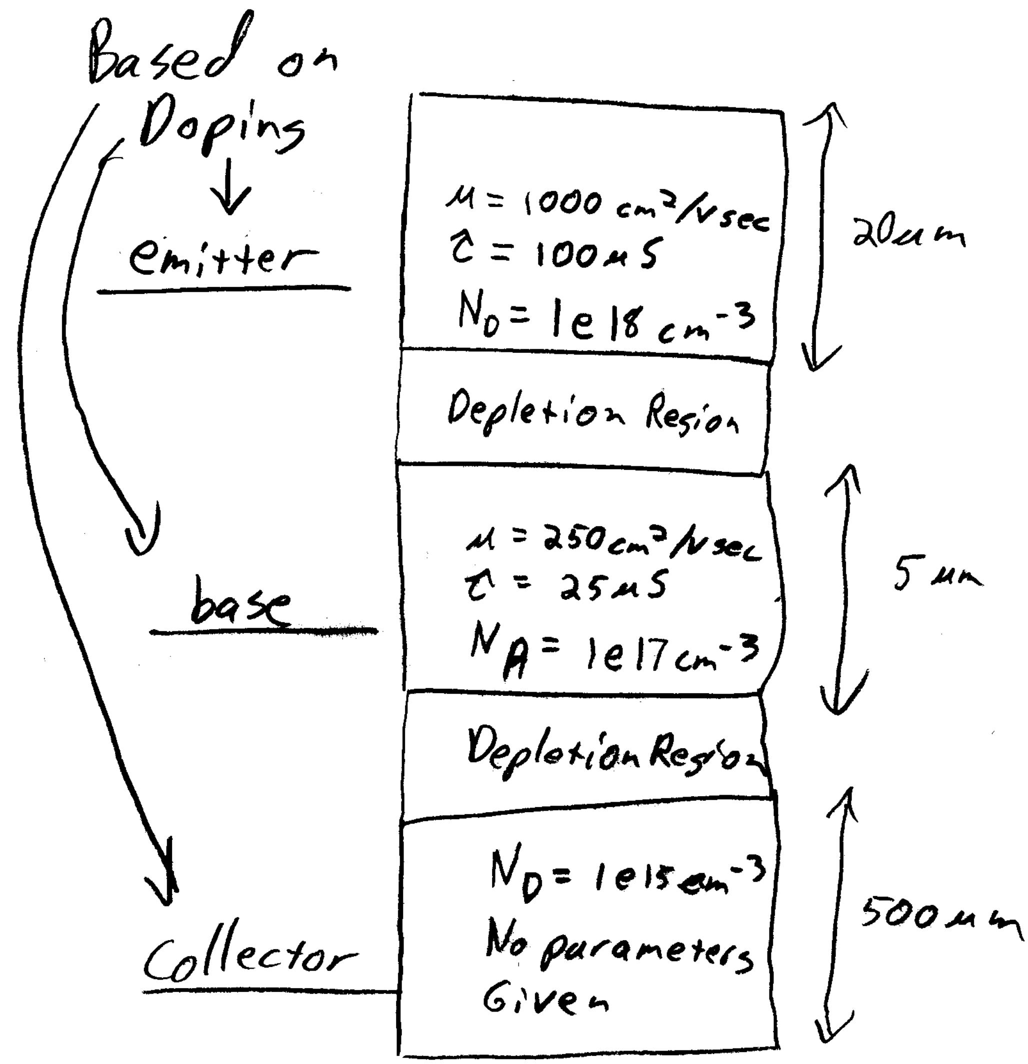
9.)(20-points total in three parts) Given the following BJT structure,

(a- 3 points) Label the emitter, base and collector

(b- 12 points) Find the DC common emitter (β_{DC}) and common base current gains (α_{DC}).

(c- 5 points) Determine three parameters that you can change that increase BOTH the DC common emitter current gain (β_{DC}) and the operational speed of the BJT.





$$D_E = \frac{kT}{q}\mu_{Emitter} = 0.0259(1000) = 25.9\ cm^2/sec$$

$$D_B = \frac{kT}{q}\mu_{Base} = 0.0259(250) = 6.48\ cm^2/sec$$

$$L_E = \sqrt{D_E \tau_E} = \sqrt{25.9(100e\text{-}6)} = 0.05089\ cm$$

or $508.9\ \mu m$

$$\beta_{DC} = \frac{D_B L_E N_E}{D_E W N_B} = \frac{6.48(0.05089)1E18}{25.9(5e\text{-}4 cm)1E17} = 254.6$$

$$\alpha_{DC} = \frac{\beta_{DC}}{\beta_{DC}+1} = \frac{254.6}{255.6} = 0.996$$

Can increase mobility or τ in base

Since $\quad \beta_{DC} = \dfrac{D_B L_E N_E}{D_E \, W \, N_B}$ → Can raise Emitter Doping

→ Can Lower base doping

→ Can Shrink base width

can kill mobility or τ in emitter

but $\quad \tau_F = \dfrac{W^2}{2 D_B}$ is the base transport time

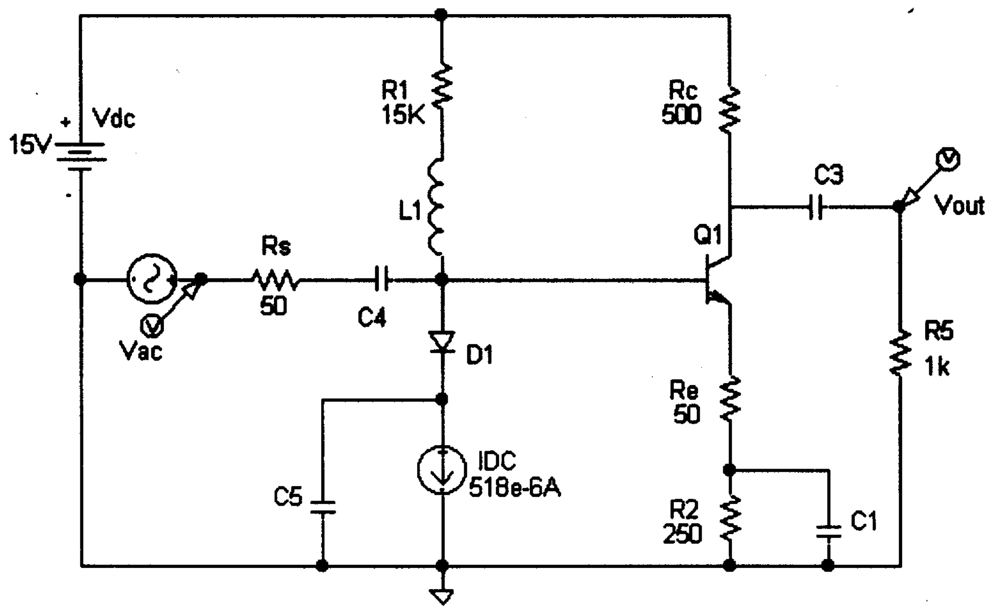
Thus our only 3 choices are to increase μ_{Base} or τ_{Base} to increase D_B or decrease W (Base quasi neutral width).

Note: since lowering N_B lowers μ_{Base} due to decreased ionized impurity scattering lowering N_B was accepted as well.

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

10.) (40-points) Given the following amplifier circuit and BJT Parameters, what is the AC voltage gain, Vout/Vac? Assume: β_{DC}=100, Early voltage is infinite, and the 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 and any inductors are very large values, and thus AC opens. 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. For full Credit, be sure to check your assumptions on the mode of operation of the transistor.

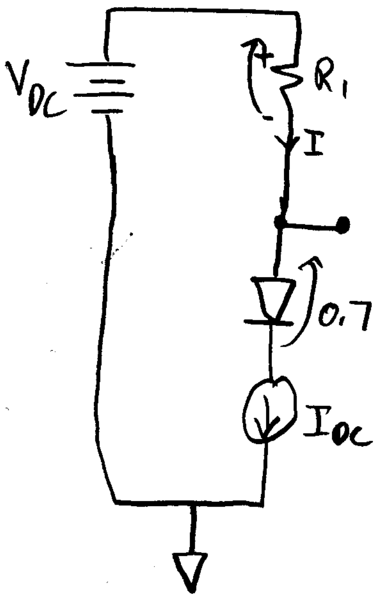
Hint: Use the CVD/Beta analysis for the DC solution. Then apply your results to convert to the small signal model for both the BJT and diode (i.e. do not ignore the small signal model of the diode).



Extra work space. Show your work clearly and label which problem this page contains.

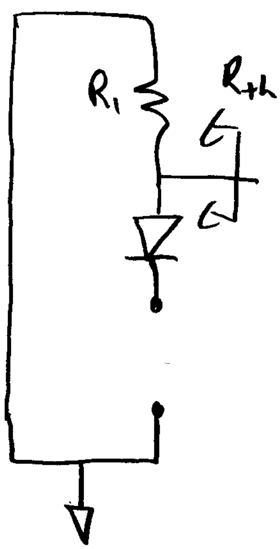
DC Solution: Thevenize base circuit

V_{th} :



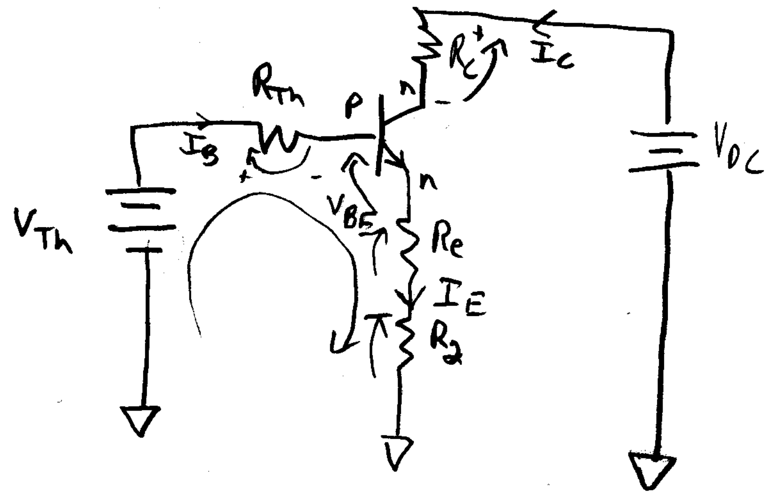
$$V_{th} = V_{oc} - I_{oc} R_1$$
$$= 15 - (5.18e-4) 15K$$
$$= 7.23 \text{ V}$$

R_{th} :



$$R_{th} = R_1 = 15K$$

Extra work space. Show your work clearly and label which problem this page contains.



$$V_{Th} - I_B R_{th} - V_{BE} - I_E(R_e + R_2) = 0$$

$$V_{Th} - V_{BE} = I_B\left[R_{Th} + (\beta+1)(R_e+R_2)\right]$$

$$I_B = \frac{7.23-0.7}{15K+(101)(50+250)} = 144\,\mu A$$

$$I_c = \beta I_\beta = 14.4\,mA$$

$$I_E = (\beta+1)I_\beta = 14.56\,mA$$

Check Assumption of Forward Active:

$$V_B = V_{Th} - I_B R_{Th} = 5.07\,V$$

$$V_C = V_{DC} - I_c R_c = 7.8\,V$$

$$V_E = I_E(R_e + R_2) = 4.37\,V$$

$$\left.\begin{array}{l} V_B > V_E \checkmark \\ V_c > V_B \checkmark \end{array}\right\}\ \text{Assumption verified}$$

Extra work space. Show your work clearly and label which problem this page contains.

AC Solution:

$L \to \infty \Rightarrow$ open

$C \to \infty \Rightarrow$ short

$I_{DC} \to$ open

$V_{DC} \to$ short

BJT

$r_\pi = \frac{\beta}{g_m} = \frac{100}{0.556} = 179.9\ \Omega$

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

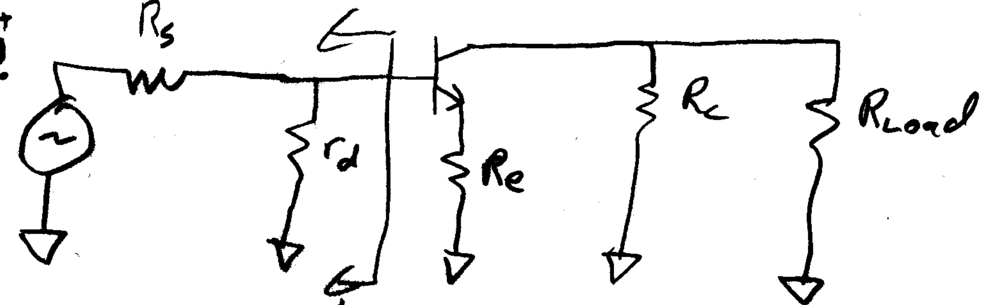
$g_m = \frac{I_c}{V_T} = \frac{14.4mA}{0.0259} = 0.556\ \Omega^{-1}$

Diode

$r_d = \frac{V_T}{I_{DC}} = \frac{0.0259}{518\mu A} = 50\ \Omega$

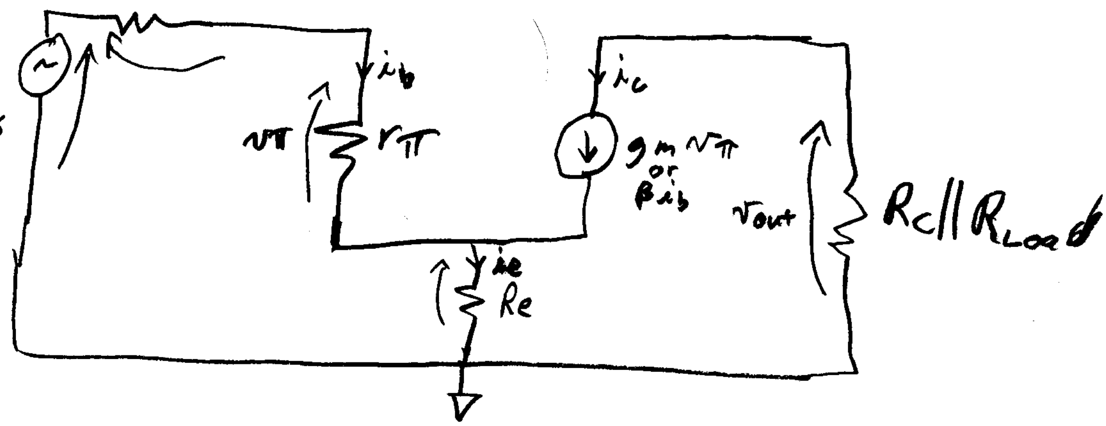
Current through diode is the current source current!

Thevenize base circuit



$r_{th} = R_s || r_d$

$v_{th} = v_{ac} \frac{r_d}{r_d + R_s}$ (4)



(1) $v_{out} = -i_c (R_c || R_{Load}) = -g_m v_\pi (R_c || R_{Load})$

(2) $i_c = \beta i_b$

(3) $v_{th} = i_e R_e + i_b r_\pi + i_b R_s || r_d$

$= \left[(\beta+1) R_e + r_\pi + R_s || r_d \right] i_b$

$\frac{v_{out}}{v_{ac}} = \left(\frac{v_{out}}{i_c}\right)\left(\frac{i_c}{i_b}\right)\left(\frac{i_b}{v_{th}}\right)\left(\frac{v_{th}}{v_{ac}}\right)$

$\Rightarrow$ cont'd on next page

Extra work space. Show your work clearly and label which problem this page contains.

$$\frac{v_{out}}{v_{ac}} = -\underbrace{(R_C \| R_{Load})}_{1}\underbrace{(\beta)}_{2}\underbrace{\left[\frac{1}{r_\pi + (\beta+1)R_e + (R_S \| r_d)}\right]}_{3}\underbrace{\left[\frac{r_d}{r_d + R_S}\right]}_{4}$$

$$= (500 \| 1K)\, 100 \left[\frac{1}{179.9 + 101(50) + (50\|50)}\right]\left[\frac{50}{50+50}\right]$$

$$\boxed{\frac{v_{out}}{v_{ac}} \simeq -3.17 \text{ V/V}}$$