Name: ______________________________ (please print)

Signature: ___________________________

ECE 3455
Exam 2
November 20, 2010

Exam duration: 90 minutes

- You may have one 8 ½ x 11 in. "crib" sheet, written on both sides, during the quiz. You may have any calculator you choose, but no computers. No other notes or materials will be allowed.
- Show all work necessary to complete the problem on these pages. A solution without the work shown will receive no credit.
- Show units in intermediate and final results, and in figures.
- If your work is sloppy or difficult to follow, points will be subtracted.

This exam has 8 pages, including the cover sheet. Raise your hand if you are missing a page.

1 ________________/35

2 ________________/35

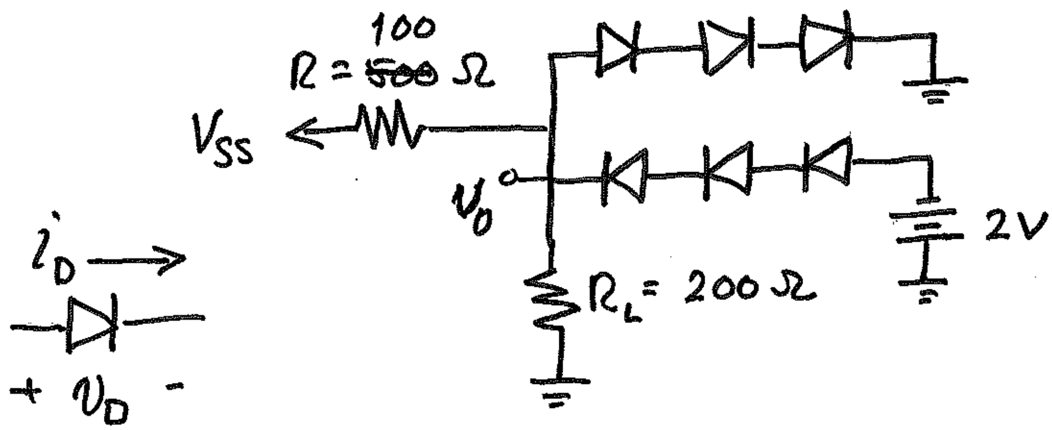
3 ________________/30

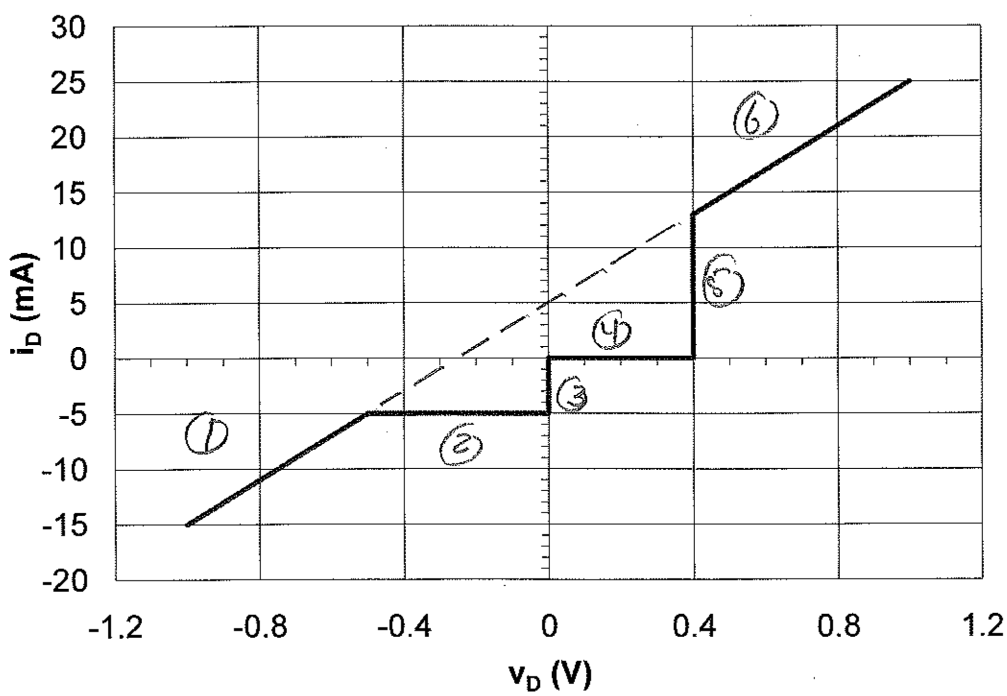
Total ________________/100

1. (**35 points**) The diodes in the circuit below can be characterized by the piecewise linear model shown in the figure below the circuit.

a) Find V_O if V_{SS} is 12 V.
b) If V_{SS} is 12 V +/- 1V (i.e., there is a variation of 1V), what is the corresponding variation in V_O?.

To receive full credit, you must state clearly which operating region each diode is assumed to be in, and what the test for that region is. Note also that you can receive significant credit for a single guess, even if it is wrong, if you correctly prove it is wrong.





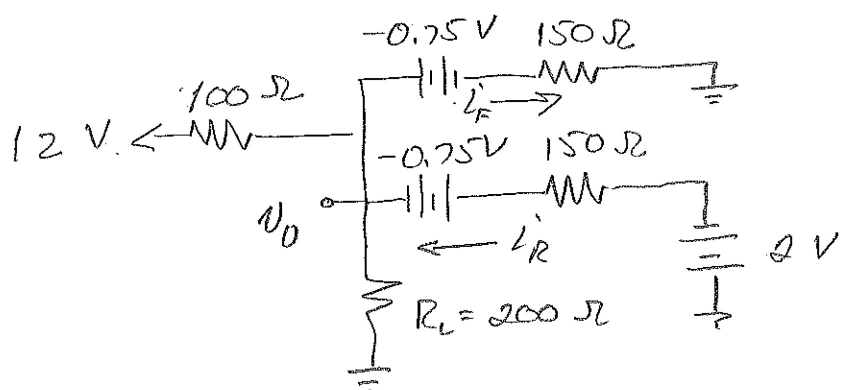
Room for extra work

a) With $V_{SS} = 12\,V$, we expect the upper diodes to be in forward bias, and the lower in reverse. We need models for regions ① and ⑥.

Extrapolating to the v_D axis, we see that both regions intercept at $v_D = -0.25\,V$ and have a slope

$$r_D^{-1} = \frac{\Delta i_D}{\Delta v_D} = \frac{(13-5)\,mA}{0.4\,V} \Rightarrow r_D = 50\,\Omega$$

So both regions have the same model! The difference will be in the testing: ① ⇒ $i_D \leq -5\,mA$; ⑥ ⇒ $i_D \geq 13\,mA$.



TEST:

$i_F \geq 13\,mA$

$i_R \leq -5\,mA$.

$$\frac{v_O + 2 - 0.75}{150} + \frac{v_O + 0.75}{150} + \frac{v_O - 12}{100} + \frac{v_O}{200} = 0$$

$$\Rightarrow v_O = 3.76\,V$$

i_F: $\dfrac{v_O + 0.75}{150} = 30.1\,mA$ ✓

i_R: $-\left(\dfrac{v_O + 1.25}{150}\right) = -33.4\,mA$ ✓

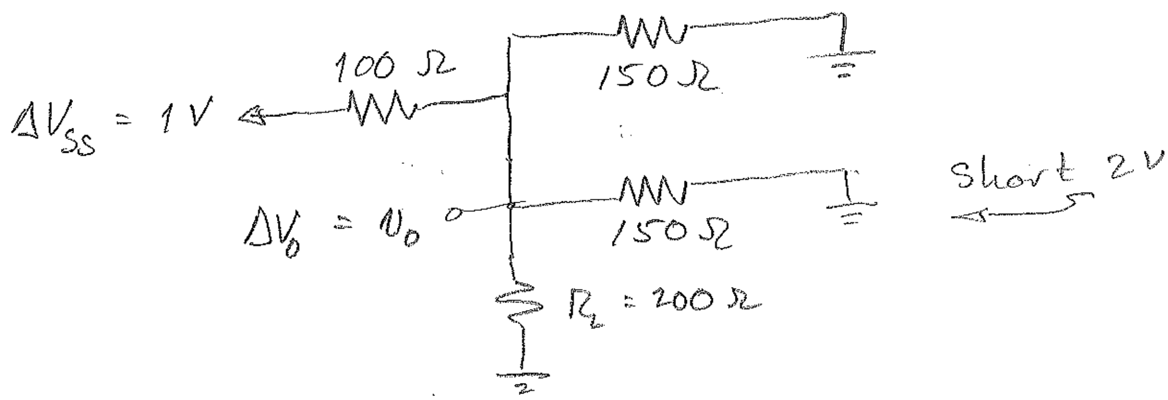
So these are the correct regions and

$v_O = 3.76\,V$

p.2 →

Room for Extra Work

b) The elegant way to solve this problem is to construct an ac model:



$$\frac{v_o}{150} + \frac{v_o}{200} + \frac{v_o - 1}{100} + \frac{v_o}{150} = 0 \Rightarrow v_o = 0.353\,V.$$

This is the amplitude of the variation in v_o due to the variation in V_{SS}.

Alternatively, we can solve for v_o when $V_{SS} = 13V$ and 11 V, and take the difference.

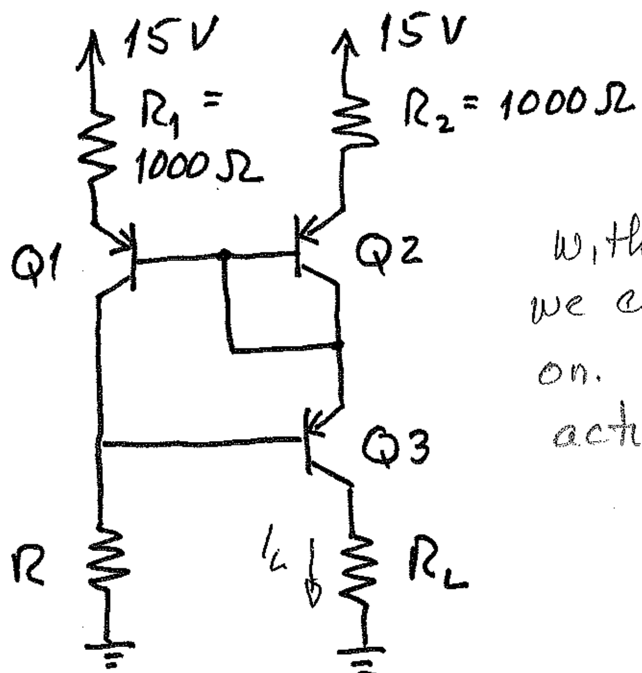
$V_{SS} = 13V \Rightarrow v_o = 4.118\,V$
$V_{SS} = 11V \Rightarrow v_o = 3.412$
$\Delta = 0.706\,V$

This is a "peak-to-peak" so $\Delta v_o = 0.353\,V$, as before.

2. (**35 points**) The circuit below is a *current mirror.* Its function is to deliver a fixed current to the load R_L. As long as R_L is in an appropriate range, the circuit will be a constant current source, with a current that can be varied by varying R. The BJTs are identical, with $\beta = 100$ and $V_{CE,sat} = -0.3$ V.

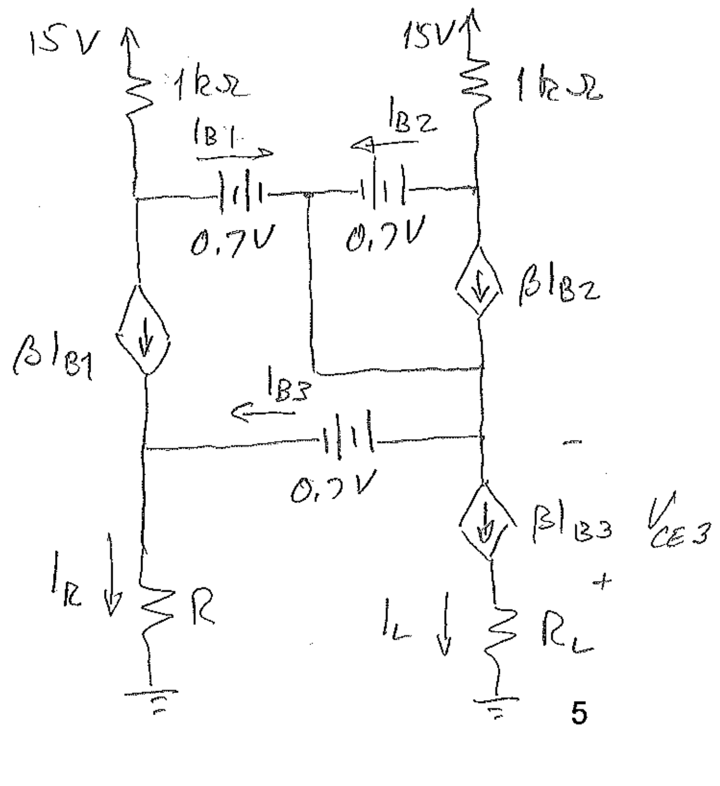
a) Choose R so that the load current I_L is 1 mA.

b) With the value of R you chose, over what range can R_L be varied so that the current mirror still delivers a constant current to R_L?



With 15 V at the source, we expect all BJTs to be on. We will guess active mode for each.

a)



KVL :

$-15 + (\beta+1) I_{B_1} \cdot 1000 + 0.7$

$- 0.7 - (\beta+1) I_{B_2} \cdot 1000 + 15 = 0$

$\therefore (\beta+1) I_{B_1} - (\beta+1) I_{B_2} = 0$

so $I_{B_1} = I_{B_2} \equiv I_B$

↗

Room for extra work

$$-I_R \cdot R - 0.7 - 0.7 - (\beta+1) I_B \cdot 1000 + 15 = 0$$

KCL: $I_R = \beta I_B + I_{B3}$

KCL: $(\beta+1) I_{B3} - (\beta+1) I_B - I_B = 0$

$$\Rightarrow (\beta+1) I_{B3} - (\beta+2) I_B = 0$$

$$I_{B3} = \frac{\beta+2}{\beta+1} I_B$$

So $I_{B3} \simeq I_B$ but we will continue with the "exact" value:

$I_L = \beta I_{B3} = 1 mA \Rightarrow I_{B3} = \frac{1 mA}{100} = 10 \mu A$

hence "current mirror"

$$\Rightarrow I_B = \frac{101}{102} I_{B3} = 9.9 \mu A$$

$$\Rightarrow I_R = 100 I_B + I_{B3} = 1 mA$$

$$\therefore R = \frac{15 - 1.4 - (\beta+1) I_B \cdot 1000}{I_R} = 12.6 k\Omega$$

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b) Note that for Q1, $V_{CE} = -1.4 V$ and for Q2, $V_{CE} = -0.7 V$, so these are fixed in active mode. But for Q3,

$$V_{CE3} = I_L R_L - (0.7 + I_R R).$$

This value needs to be less (more negative) than $-0.3 V$, so we have to limit R_L:

$$\underline{\underline{R_{L,max}}} = \frac{-0.3 + 0.7 + I_R R}{I_L} = \frac{0.4 + 10^{-3}(12.6 \times 10^3)}{10^{-3}} = \underline{\underline{13 k\Omega}}$$

3. (**30 points**) Using a 4-diode bridge configuration, design a dc power supply with the specifications given below. Assume the diodes are modeled by a constant voltage drop in forward bias of 0.7 V. In addition to the diodes, you have available a transformer, as well as capacitors and resistors of any number and value. No solid-state voltage regulators are available, unfortunately.

Specifications:

i) The output voltage will average 10 V, with a ripple voltage not to exceed 0.2 V in amplitude.

ii) The load resistor may vary between 150 and 300 Ω.

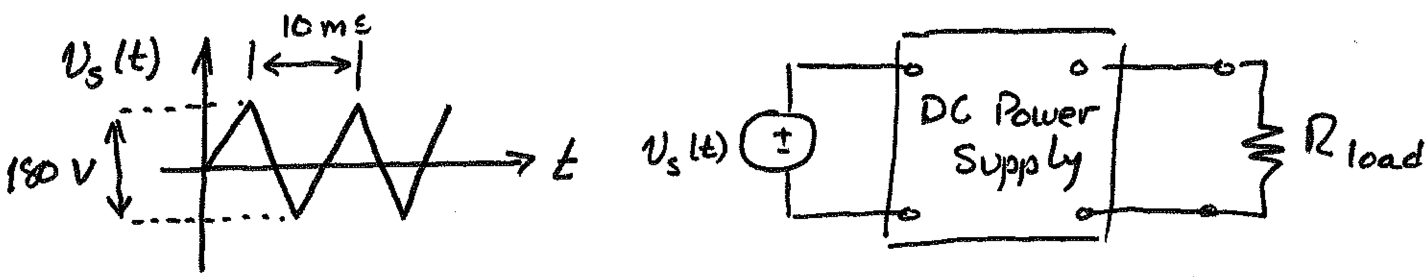
iii) Your power source will be a triangle wave of amplitude 90 V and period 10 ms. (In other words, it is <u>not</u> plugged into the wall.) This is illustrated in the figure below.

Draw your circuit, and clearly label all design values.

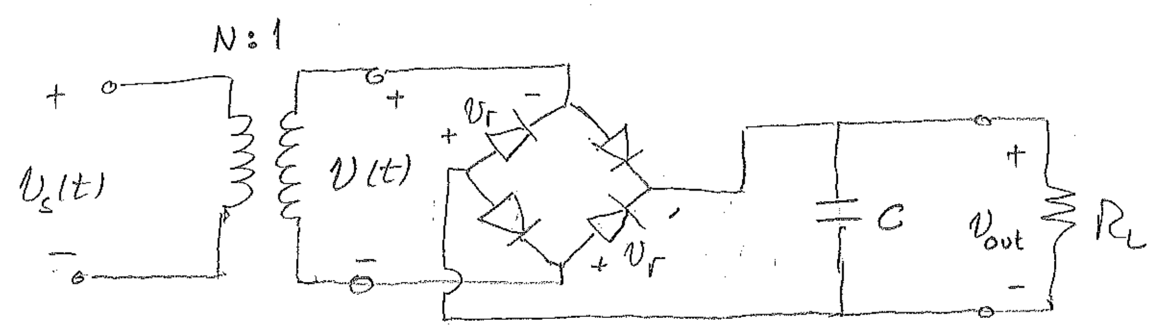
Bonus Questions (8 points total):

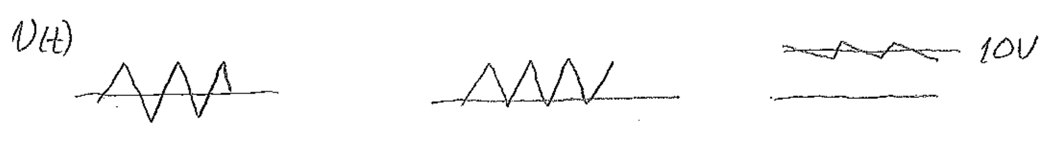
a) What is the largest reverse-bias voltage that will appear across any of the diodes?

b) What is the time interval over which the capacitor is charging? Assume $R_L = 150\ \Omega$



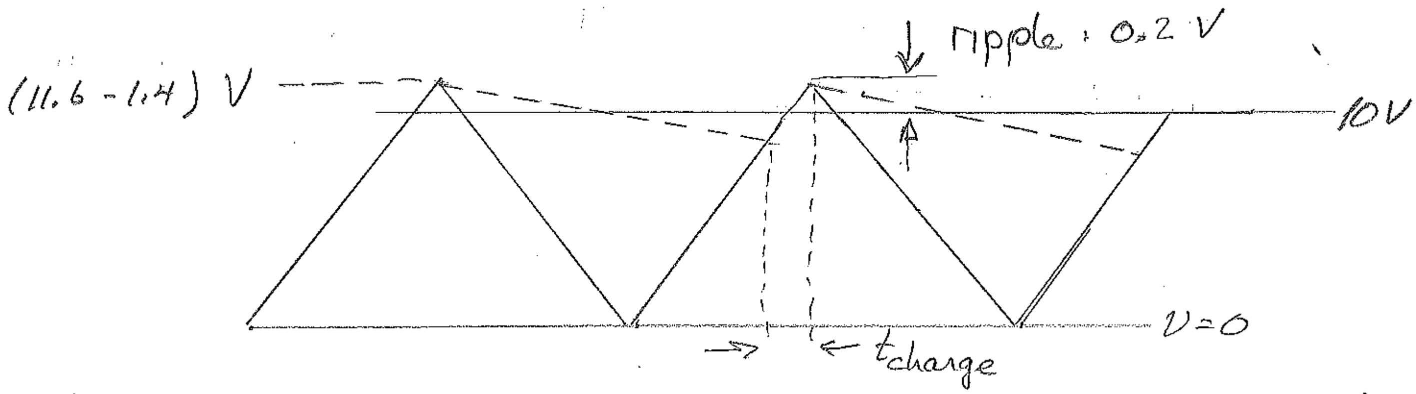
We will use a transformer to step down the voltage:





Room for extra work

Turns ratio: we will have a 1.4 V drop across the diodes, and a 0.2 V ripple amplitude.



Therefore we need 10 + 1.4 + 0.2 = 11.6 V at $v(t)$. The turns ratio is thus $N = \frac{90}{11.6} \simeq 8$ (7.76)

We will use the approximate formula for ripple voltage developed in class:

$$V_r = \frac{V_p}{2fR_LC} = \frac{(11.6 - 1.4)}{2\left(\frac{1}{10^{-2}}\right)(150)C} = 0.4 \quad \text{peak-peak}$$

We have used the worst-case R_L (larger R_L would give smaller ripple). Also note this formula is a peak-peak value. Then solving for C gives $C = 850\,\mu F$.

Bonus Q's →

a) If the source $v(t)$ is positive, the two diodes labeled $v_r(t)$ will be in reverse-bias. KVL gives

$$v_r + v_{out} + 0.7 = 0 \Rightarrow \underline{v_r \cong -10.7 \text{ V}}$$

So the peak-inverse voltage is -10.7 V.

b) The decay of the output voltage is

$$v_{out}(t) = V_p e^{-t/R_L C}$$

Then v_{out} intersects the full-wave rectified signal at t_0:

$$V_p e^{-t_0/R_L C} = \frac{10.2}{\frac{1}{4}T}\left(t_0 - \frac{1}{4}T\right)$$

$R_L = 150\ \Omega \Rightarrow$
$R_L C = 0.1275$ s.

Approximating the exponential as $(1 - t_0/R_L C)$ and solving for t_0 gives $t_0 = 4.9$ ms. Since the peak is reached at 5 ms, the capacitor charges for $0.1 \text{ ms} = 100\ \mu s = t_{charge}$.

An easier way:

The ramp-up to V_p happens at a rate of $\frac{10.2}{\frac{1}{4}T} \frac{V}{s}$, and we have to make up 0.4 V. So...

$$t_{charge} = \frac{0.4}{10.2/\frac{1}{4}T} = 98\ \mu s,$$ which is

about what we got before.