EE 115A, Spring 2017, Midterm Exam – May 2, 2017

Instructions: This exam booklet consists of five problems, blank sheets for the solutions and additional blank sheets. Please follow these instructions while answering your exam:

1. You have 1 hour and 45 minutes to finish your exam.
2. Write your solutions in the provided blank space after each problem.
3. The sheets marked "Scratch Paper" at the end of the blanket will NOT be graded. These sheets are provided for your rough calculations only.
4. Write your solutions clearly. Illegible solutions will NOT be graded.
5. Be brief.
7. Write your name and student identification number below.

NAME: MIDTERM SOLUTIONS

STUDENT ID: ______

NAME OF STUDENT ON LEFT: ______

NAME OF STUDENT ON RIGHT: ______

Problem	Score
#1	10 /10
#2	10 /10
#3	25 /25
#4	40 /40 + 10 (Bonus)
#5	15 /15
Total	100 /100 (110)

Problem 1: For each of the following statements indicate whether it is true or false. Circle the appropriate response.

(a) An NPN BJT transistor is in the active region whenever its collector voltage is higher than its base voltage. **True [✓ False]** 5

(b) A resistor in parallel with a forward biased diode will not conduct any current. Assume that the diode is infinitely strong i.e. when it is forward biased, it carries infinite amount of current. **True [✓ False]** 5

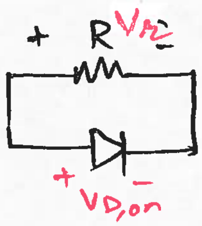
(5 + 5 = 10 points)

(a) For NPN BJT Transistor to be in Active region,

along with $V_{CE} > V_{BE}$ [Base-Collector Junction Reverse Biased]

we also need $V_{BE} \geq 0.8V$ [Base-Emitter Junction Forward Biased]

(b)



If the Diode is ON, Voltage across the resistor V_R will be $V_{D,on}$. Hence, it'll conduct the Current $\boxed{\frac{V_{D,on}}{R}}$

Problem 2: Consider the circuit shown in Figure 1.

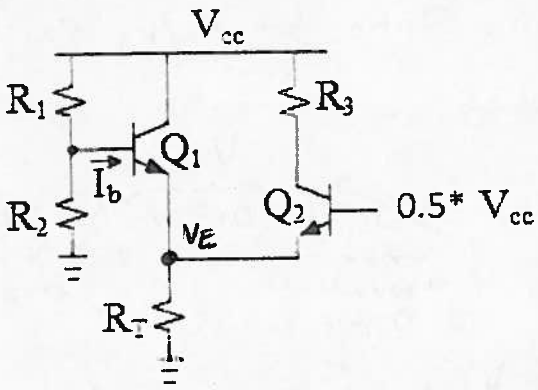


Figure 1

Determine the smallest ratio R_2/R_1 that still keeps the transistor Q_1 in the active region. Assume $V_{CC} = 2.5V$ and that both transistors need 0.8V forward bias on their base emitter junction to operate properly. Ignore I_b to simplify your calculations.
(10 points)

Solution:

Note: If $R_2=\infty$ then $V_{B_1} = V_{cc} - I_b R_1 \approx V_{cc}$ [∵ $I_b \approx 0$]

In this case Q_1 can easily be in Active region with $V_E \approx V_{cc} - 0.8V$ and Q_2 is off.

Now $V_{B_1} = \frac{R_2 V_{cc}}{R_1+R_2}$ [Ignoring I_b] ②

Hence, as $R_2 \downarrow$ $V_{B_1} \downarrow$

Clearly V_{B_1} can be decreased from V_{cc} [for $R_2=\infty$] till the point $V_{B_1} - \underbrace{V_{BE_1}}_{\text{around } 0.8V} \geq 0.5 V_{cc} - \underbrace{V_{BE_2}}_{\text{around } 0.8V}$ ④

Because if $V_{B_1} - V_{BE_1} < 0.5 V_{cc} - V_{BE_2}$ then Q_2 turns o

⇒ Current through $R_T = I_{E_1} + I_{E_2}$ ⇒ $V_E \uparrow$ as ② $V_E = (I_{E_1} + I_{E_2}) R_T$

P.T.O

Now if $V_E \uparrow$, clearly V_{B_1} needs to increase to keep Q_1 in Active region.

$\therefore$ Minimum Ratio for R_2/R_1 exists for the Case when

$$V_{B_1} - \underbrace{\cancel{V_{BE_1}}}_{\text{around } 0.8V} = \overbrace{0.5\,V_{cc}}^{V_{B_2}} - \underbrace{\cancel{V_{BE_2}}}_{\text{around } 0.8V}$$

$$\Rightarrow \quad V_{B_1} = 0.5\,V_{cc}$$

$$\Rightarrow \quad \frac{V_{cc} \times R_2}{R_1 + R_2} = 0.5 \times V_{cc}$$

$$\Rightarrow \quad \frac{R_2}{R_1 + R_2} = 0.5$$

$$\Rightarrow \quad \boxed{\left.\frac{R_2}{R_1}\right|_{\text{minimum}} = 1} \quad ②$$

Problem 3: Consider the level shifter circuit shown in Figure 2 below. It was designed to generate $V_{L.dc} = 1.2V$ across a load resistor, $R_L = 1.2$ kOhm by shifting down a constant 2V input by one forward diode drop, $V_{D.ON} = 0.8V$. Assume T = 300K.

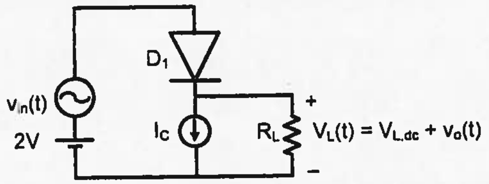
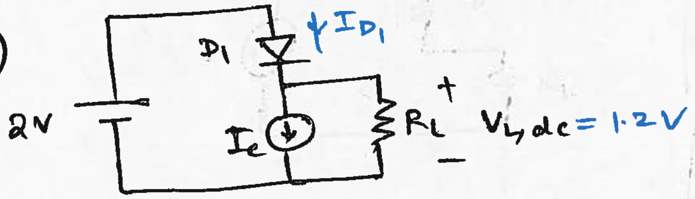


Figure 2

(a) Calculate the level shifter output, $v_o(t)$, if $v_{in}(t) = 10\sin(10t)$ mV. Assume $I_C = 9$mA.
(b) What should be the minimum value of I_C such that $|v_o(t)/v_{in}(t)| \geq 0.95$?
(10 + 15 = 25 points)
Solution:

(a)

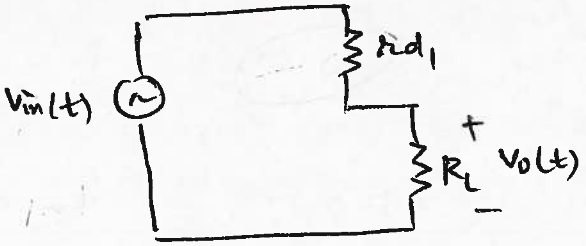
(Large Signal)



Here, $I_{D_1} = I_c + \frac{V_{L,dc}}{R_L}$

$= 9mA + 1mA = \boxed{10\ mA}$ ③

(Small-signal)



③

$V_o = V_{in}\frac{R_L}{R_L + r_{d_1}}$ where $r_{d_1} = \frac{V_T}{I_{D_1}} = \frac{26mV}{10mA} = \boxed{2.6\Omega}$

$v_{out}(t) = \left(\frac{1.2k}{1.2k + 2.6}\right) \times 10\sin(10t)\ mV = \boxed{9.978\sin(10t)\ mV}$

④

(b) find $I_{C\min}$ when $\left|\frac{V_{out}(t)}{V_{in}(t)}\right| \geq 0.95$

$$\frac{V_{out}(t)}{V_{in}(t)} = \frac{R_L}{R_L + r_{d_1}} \Rightarrow \frac{R_L}{R_L + r_{d_1}} \geq 0.95$$

$$\Rightarrow \frac{R_L + r_{d_1}}{R_L} \leq \frac{20}{19} \Rightarrow \boxed{\frac{r_{d_1}}{R_L} \leq \frac{1}{19}}$$ ⑤

$$\Rightarrow \frac{V_T}{I_{D_1}} \leq \frac{R_L}{19} \Rightarrow I_{D_1} \geq \underbrace{\frac{19 \times V_T}{R_L}}_{}$$

$$\Rightarrow I_{D_1} \geq \boxed{0.41167\,mA}$$ ⑤

where $I_{D_1} = I_c + 1mA$

$\Rightarrow$ Minimum value of $\boxed{I_c = 0\,mA}$ ⑤

Problem 4: Consider the circuit shown in Figure 3. Assume that the diodes are identical with $V_{D,ON} = 0.8V$, that $V_{ab}(t) = 5\cos(2\pi x 10^6 t)$ for all $t \geq 0$, and that all capacitors have zero initial charge.

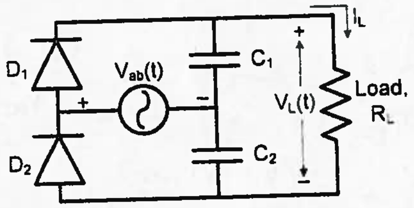


Figure 3

(a) What do you think is the purpose of this circuit? Limit your answer to one sentence.

(b) Sketch the output voltage waveform, $V_L(t)$, for the first two cycles of $V_{ab}(t)$ after t = 0. Assume that $C_1=C_2=C$ and that the time constant R_LC is much greater than the period of $V_{ab}(t)$.

(c) What is the minimum diode breakdown voltage magnitude to ensure proper operation?

(d) Calculate the ripple in $V_L(t)$ in the steady state, given that $C_1=C_2=100nF$ and R_L = 100kOhms.

(e) **(Bonus question: 10 points)** Due to inevitable errors in the printed circuit board assembly process, C_2 ended up being only half of C1 i.e. C_1 = 100nF, but C_2 = 50nF. Calculate the new steady state peak-to-peak value of $V_L(t)$.

Note: The bonus question will be graded only if you have made non-trivial attempts at all other parts of the Problem #4.

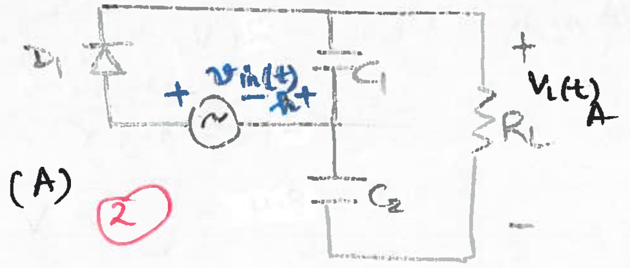
(5 + 10 + 10 + 15 = 40 points)

(10 bonus points)

5

Solution : (a) This circuit works as Voltage doubler & Full-Wave Rectifier.

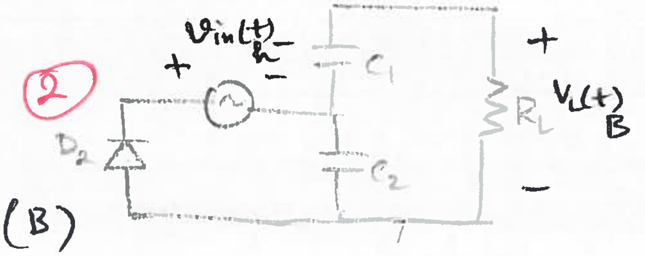
(b) This circuit can be Analyzed by partitioning into 2 halves :



2

Circuit valid for vin's positive half cycle

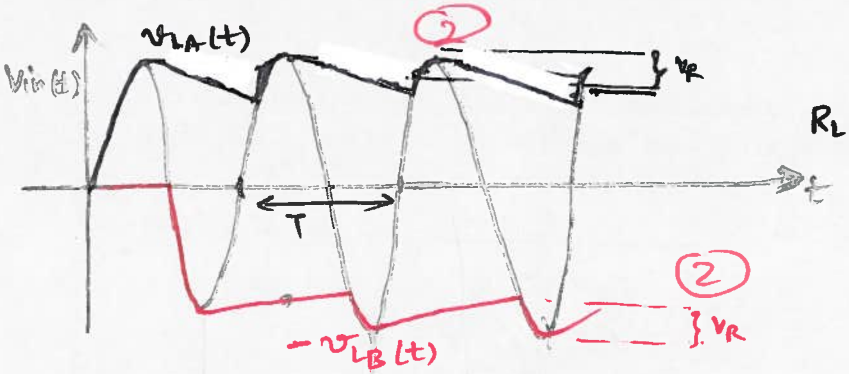
D₁ = ON D₂ = OFF



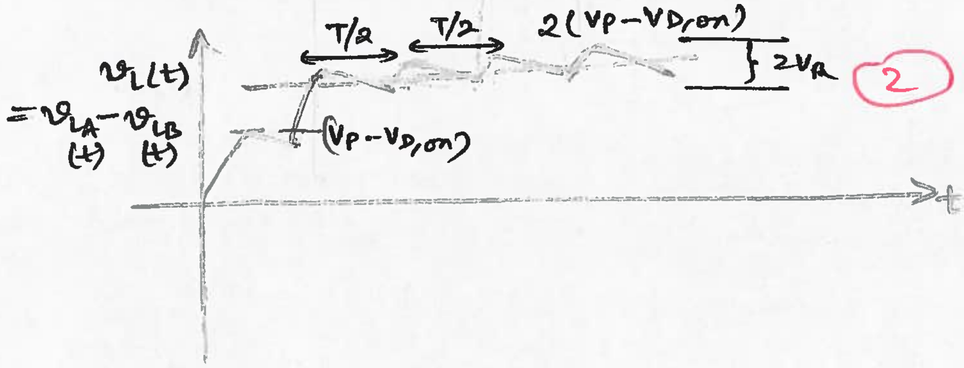
2

Circuit valid for vin's negative half cycle

D₁ = OFF D₂ = ON



$R_L C >> T$



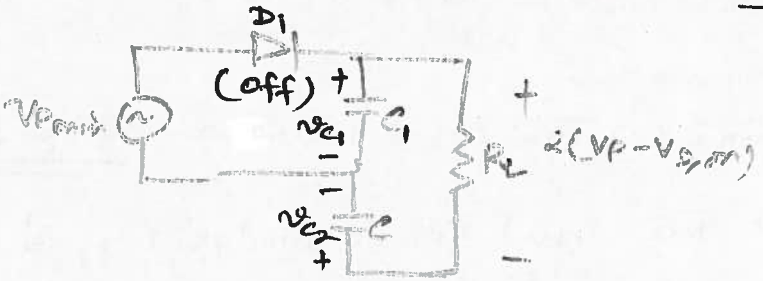
(c)

Minimum diode breakdown voltage

⇓

To calculate this, we need to ensure diode is reverse-biased

$v_{P_{min}} = -5V$



$$v_{breakdown,D_1} = v_{P,min} - \overbrace{(V_P - V_{D,on})}^{v_{C_1}}$$

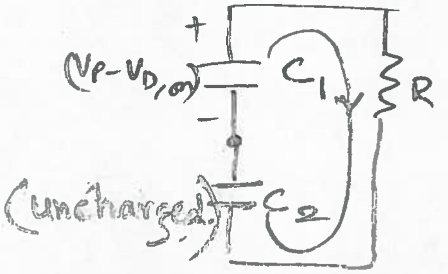
$$= -5 - \overbrace{(5 - 0.8)}^{v_{C_1}}$$

$$= -5 - 4.2 = \boxed{-9.2\,V}$$ ⑩

(d) find the ripple in steady state

$C_1 = C_2 = 100nF$ $R_L = 100\,k\Omega$

During discharge phase: $v_{LA} = (V_P - V_{D,on})\, e^{-\frac{T/2}{\underbrace{RC_1||C_2}_{\text{Effective Time Constant}}}}$



Similarly $v_{LB} = (V_P - V_{D,on})\, e^{-\frac{T/2}{RC_1||C_2}}$

Hence, $v_L = 2(V_P - V_{D,on})\, e^{-\frac{T/2}{RC_1||C_2}}$

$$\Rightarrow v_{ripple} = 2(V_P - V_{D,on}) - 2(V_P - V_{D,on})e^{-\frac{T/2}{RC_1||C_2}}$$

$$= 2(V_P - V_{D,on})\left[1 - e^{-\frac{T/2}{RC_1||C_2}}\right]$$

$$\simeq 2(V_P - V_{D,on})\left(1 - \left(1 - \frac{T/2}{RC_1||C_2}\right)\right] \quad \because RC_1||C_2 >>$$

$T = \frac{1}{10^6} = 1us$

$$\simeq \frac{2(V_P - V_{D,on})\,T/2}{R\,C_1||C_2} = \frac{(V_P - V_{D,on})\,T}{R\,C/2} \quad \because C_1 = C_2 =$$

⑫

$$\Rightarrow V_{ripple} = \frac{4.2 \times 1u}{100k \times (100nF/2)} = \frac{8.4 \times 1u}{100K \times 100n}$$

$$= \boxed{0.84\,mV}$$ ③

(e)

$$V_{ripple} = \frac{4.2 \times 1u}{100k \times (100n||50n)} = \frac{4.2 \times 1u \times 3}{100K \times 100n} = \boxed{1.26\,mV}$$

⑦ ③

Problem 5: Consider the diode-capacitor circuit shown in Figure 4. What is the steady state voltage, $V_C(t)$, on the capacitor if the following input is applied to it, assuming $V_{D,ON} = 0$:

$$v_{in}(t) = (1 + m(t))\sin(1000\,t),$$

where m(t) is a zero mean, square wave of amplitude 0.2, and a period of 1 second?

(15 points)

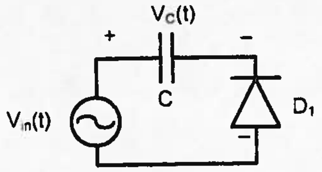
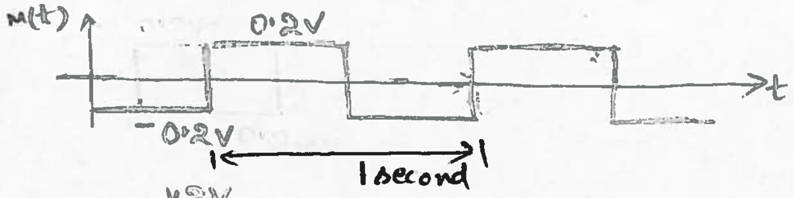


Figure 4

Solution:

Here m(t),



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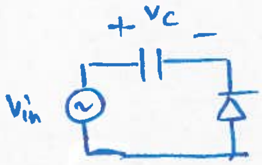
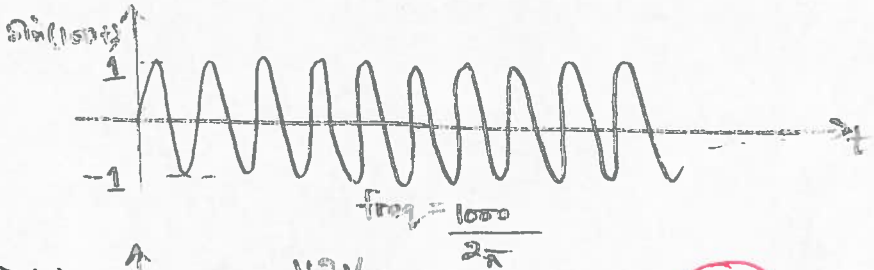
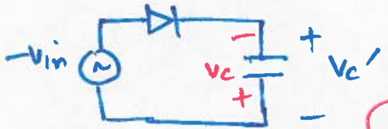




⇓

This can be modified as follows:



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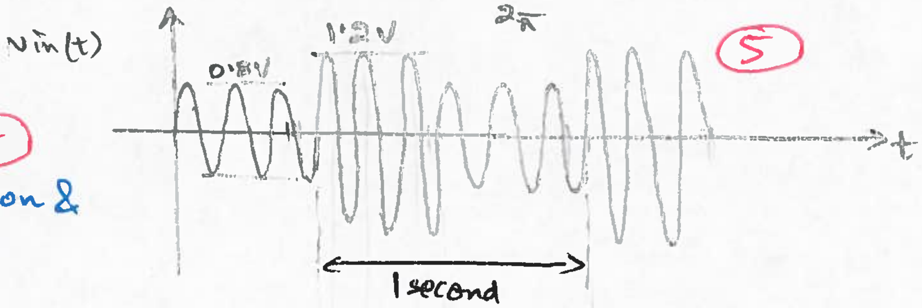

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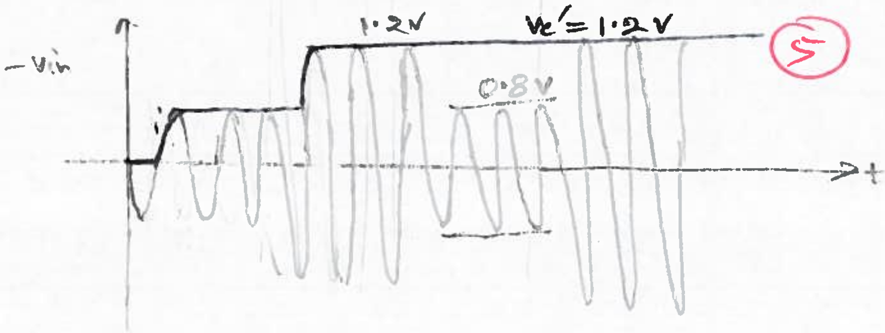
This circuit is common & is "peak detector"

Here, $V_c' = 1.2V$



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Note $V_c = -V_c'$

$= \boxed{-1.2V}$