UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Electrical Engineering
and Computer Sciences

Professor Oldham

Fall 2000

EECS 40 — MIDTERM #2 SOLUTIONS

13 November 2000

Name: ______________________________

Last, First

Student ID: _________

Signature: ____________________________

TA: ❏ Ben
❏ Warren
❏ Naratip

Guidelines:

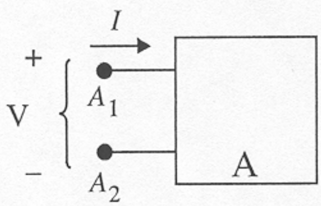
1. Closed book and notes except 1 page of formulas.
2. You may use a calculator.
3. Do not unstaple the exam.
4. Show ***all your work and reasoning on the exam*** in order to receive full or partial credit.
5. This exam contains 8 problems and corresponding worksheets plus the cover page.

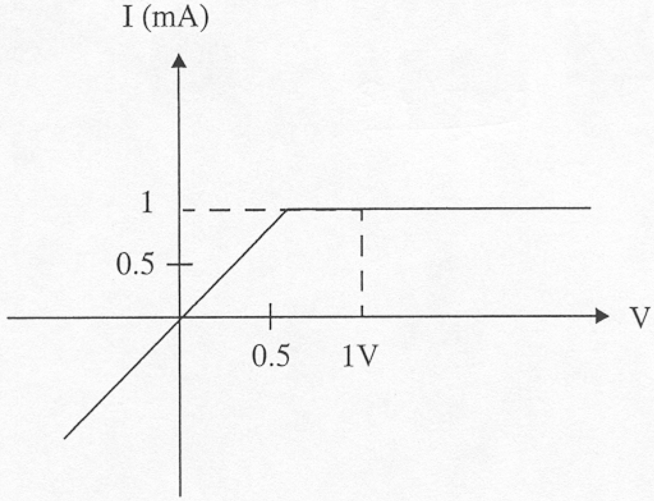
Problem	**Points Possible**	**Your Score**
1	12	
2	12	
3	10	
4	16	
5	12	
6	12	
7	12	
8	14	
Total	**100**	

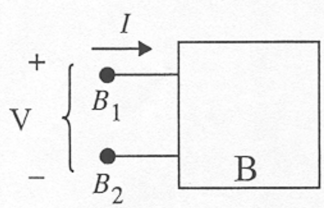
$f = 10^{-15}$
$p = 10^{-12}$
$n = 10^{-9}$
$\mu = 10^{-6}$
$m = 10^{-3}$
$K = 10^{3}$
$M = 10^{6}$

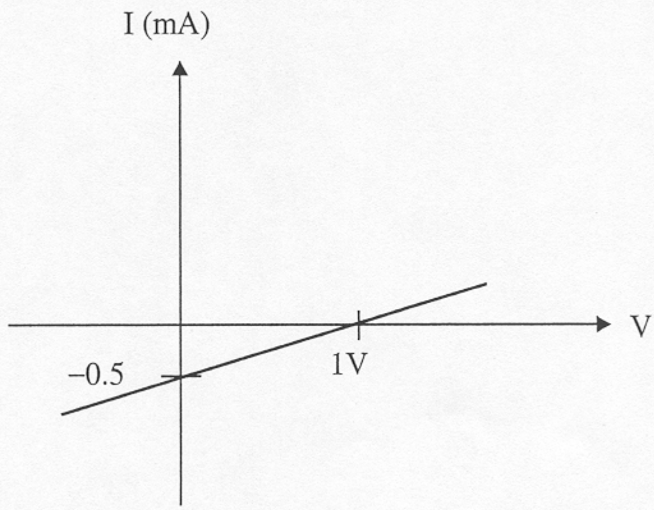
Problem 1 (12 points)

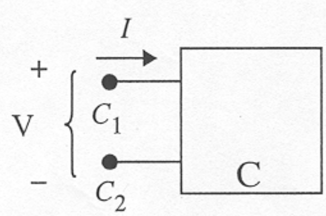
The boxes A, B, C have the following I-V characteristics:.

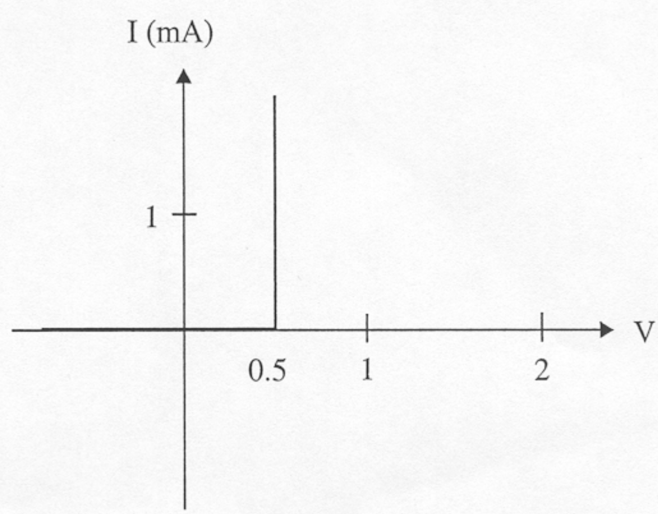






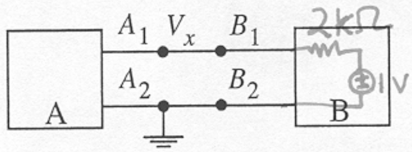






Problem 1 Answer sheet

[10 pts.] a) Find V_x.



For A, R = slope = ~~2kΩ~~ 500 Ω

For B, R = slope = 2 kΩ
V = 1 V

V_x = 0.2V

$I_A = -I_B$

So V_x should be the point of intersection of the two curves with I_B reversed

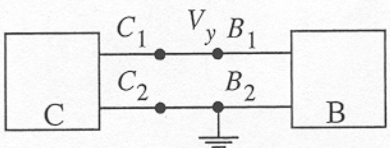
$I_A = 2 V_x$

$I_B = \frac{V_x - 1}{2}$

$I_A = -I_B \Rightarrow 2 V_x = \frac{1 - V_x}{2} \Rightarrow \frac{5}{2} V_x = \frac{1}{2}$

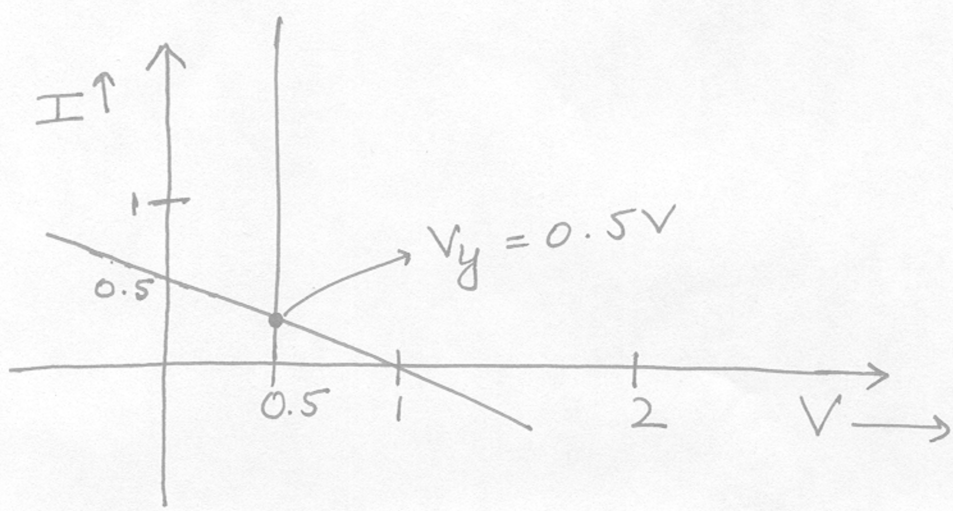
$\Rightarrow V_x = \frac{1}{5} = 0.2\text{V}$

[10 pts.] b) Find V_y.



V_y = 0.5 V

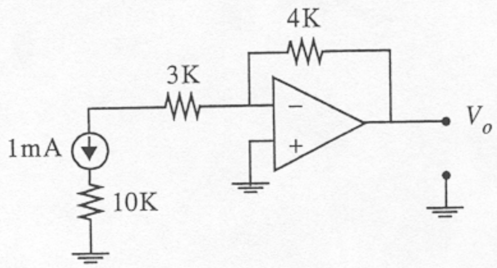
For the point of intersection of curves of B and C with $I_C = -I_B$



Problem 2 (12 points)

In this problem, assume that the op-amps are nearly ideal but with output voltages limited by ±5V rails.

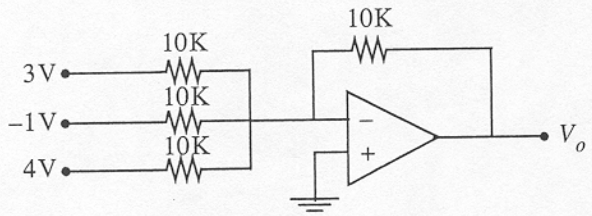
[4 pts.] a) Find V_o.



$4k\Omega \cdot 1m = 4V$

$V_o =$ 4V (V)

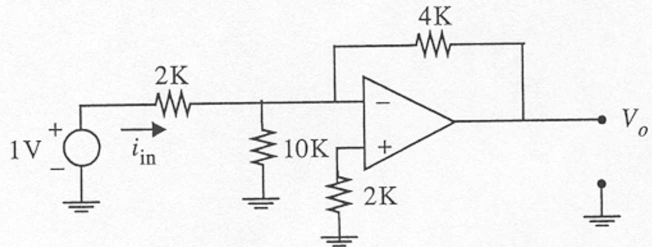
[4 pts.] b) Find V_o.



$V_o =$ −5 (V)

$-3+1-4=-6 \Rightarrow -5V$

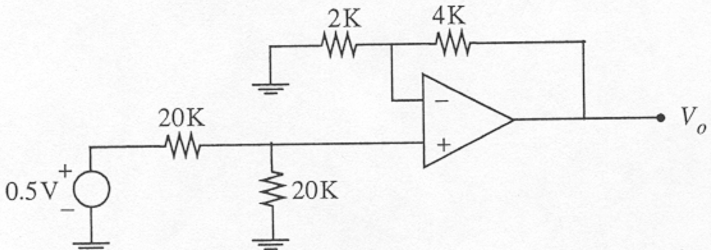
[4 pts.] c) Find i_{in}.



$i_{in} =$ .5 (mA)

$\frac{1V}{2k\Omega} = .5mA$

[4 pts.] d) Find V_o.

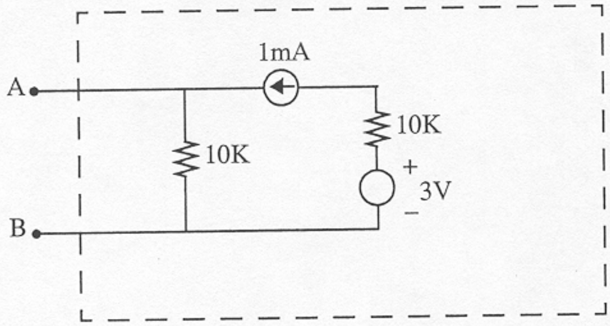


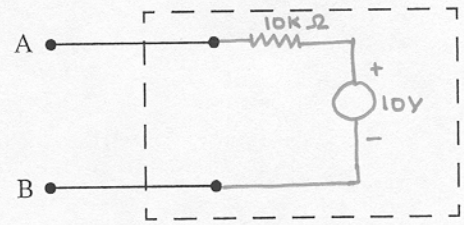
$V_o =$ .75 (V)

$\frac{1}{2}(.5)\cdot\left(\frac{4}{2}+1\right) = .75V$

Problem 3 (10 points)

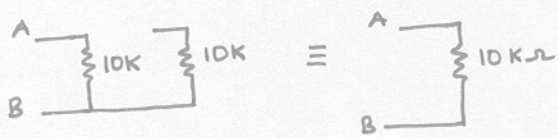
[5 pts.] **a)** Find the Thévénin Equivalent circuit of the stuff in the box. Draw this Thévénin circuit in the answer box. **Note**: No credit unless the circuit is drawn in the answer box.





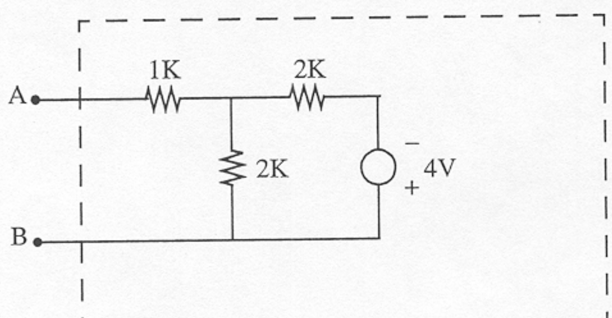
Thévénin EQ
ANSWER

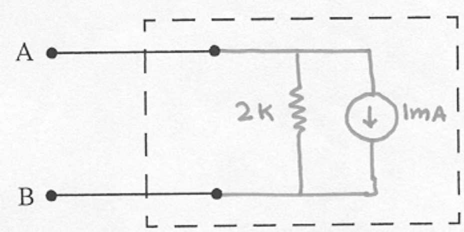
$R_{eq} = 10K\Omega$



$V_{oc} = 1mA \times 10K\Omega = 10V$

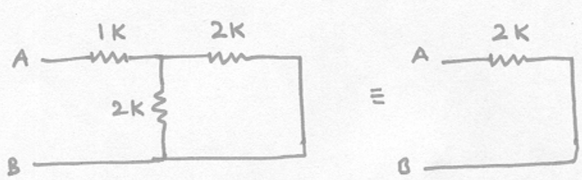
[5 pts.] **b)** Find the Norton Equivalent circuit of the stuff in the box. Draw this Norton circuit in the answer box. Again, no credit unless the answer appears in the answer box.



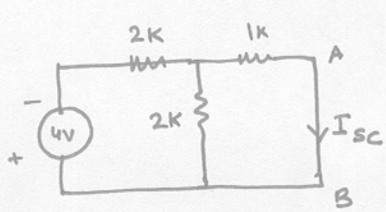


Norton EQ
ANSWER

$R_{eq} = 2K\Omega$



$I_{sc} = -1mA$



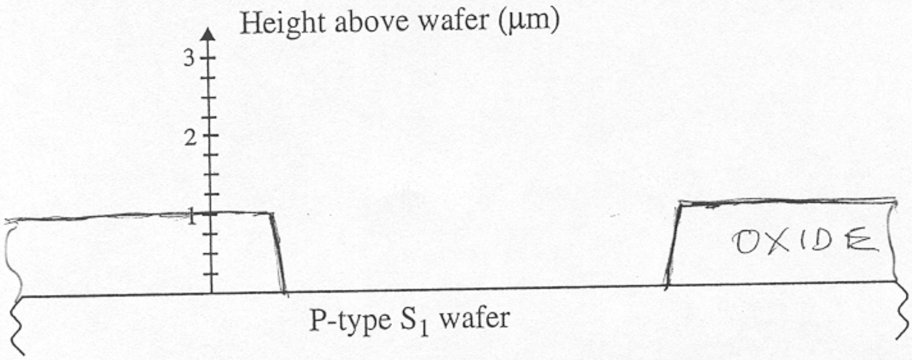
$I_{sc} = \left(\frac{2}{3}\right)\left(\frac{-4}{2K + \frac{2}{3}K}\right) = -1mA$

Problem 4 (16 points)

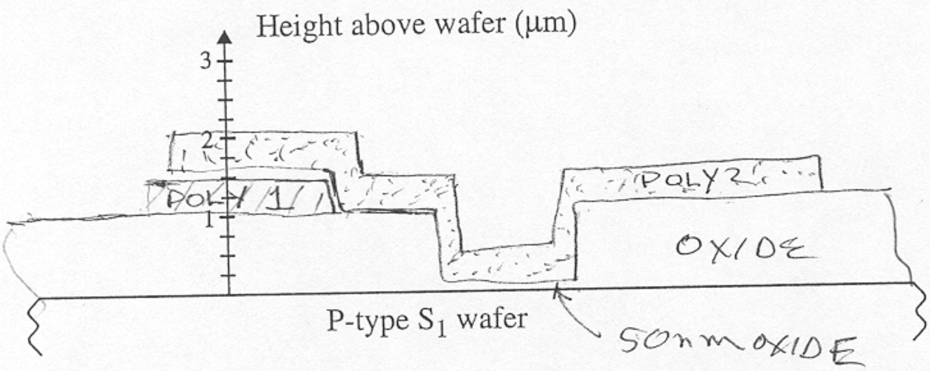
Consider the following process that refers to the figure on the opposite page.

(1) Start with p-type wafer.
(2) Deposit 1μm (1000nm) oxide.
(3) Deposit 0.5μm polysilicon. ("Poly 1")
(4) Pattern polysilicon with mask (P1). (clearfield)
(5) Pattern oxide with mask (OX). (darkfield)
(6) Deposit 50nm oxide.
(7) Deposit 0.5μm polysilicon ("poly 2").
(8) Pattern poly 2 with mask (P2). (clearfield)
(9) Implant donors $10^{14}/cm^2$ and anneal to depth of 0.25μm.
(10) Deposit 0.5μm oxide.
(11) Pattern oxide with mask (C). (darkfield)
(12) Deposit 0.5μm Al.
(13) Pattern Al with mask (M). ~~(darkfield)~~ CLEARFIELD

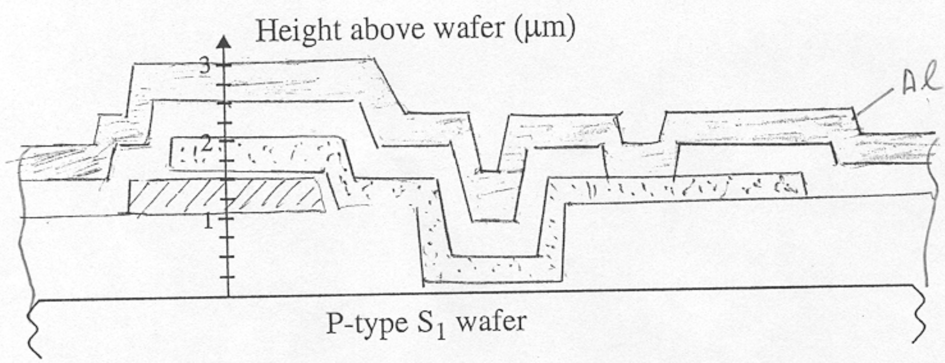
[5 pts.] a) Show cross-section A-A after completion of Step 5.



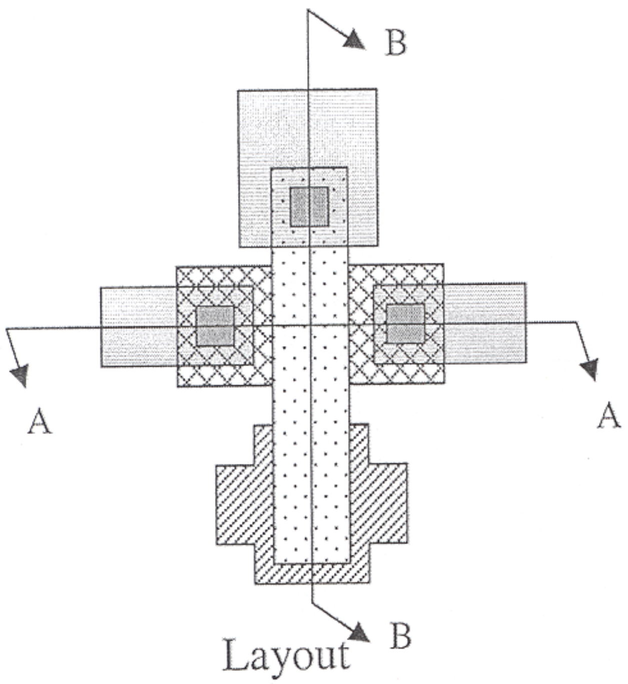
[5 pts.] b) Show cross-section B-B after completion of Step 9.

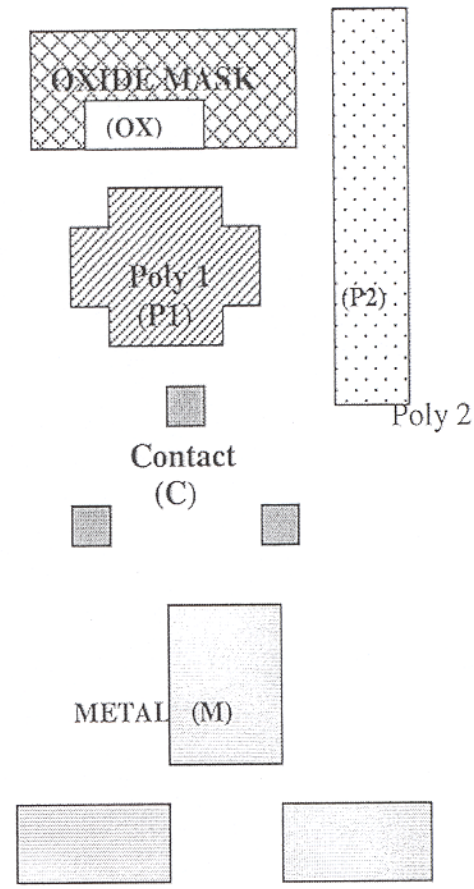


[6 pts.] c) Show cross-section B-B after completion of Step 12.



Problem 4 Figure





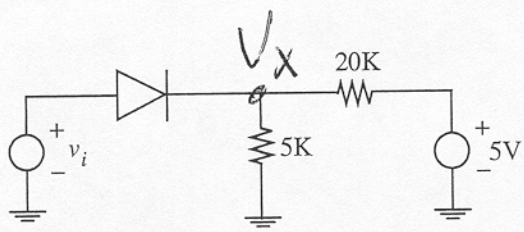
Problem 5 (12 points)

Assume in this problem that all diodes are perfect rectifiers.

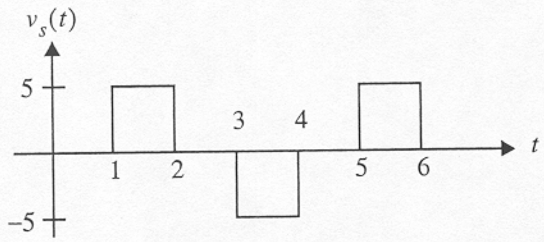
[6 pts.] a) Find V_x when:

a.1 $v_i = 9\text{V}$ a.1 ___9V___ (V)

a.2 $v_i = -5\text{V}$ a.2 ___1V___ (V)

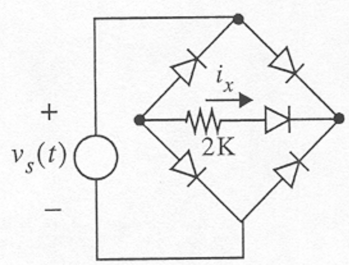


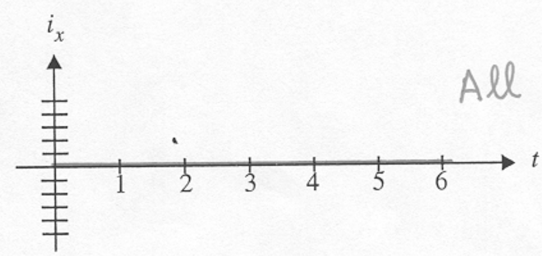
[6 pts.] b)



Sketch the unknown i_x or V_x for the following circuits with the input waveform shown above.

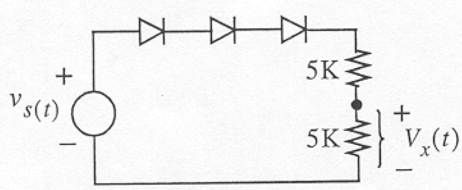
b.1

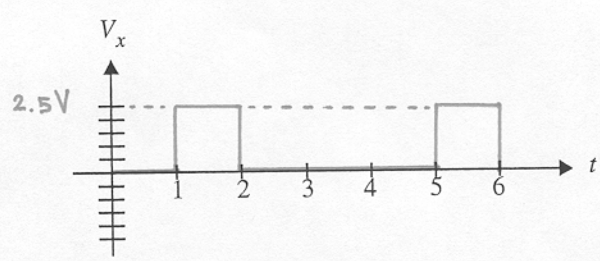




All zero

b.2

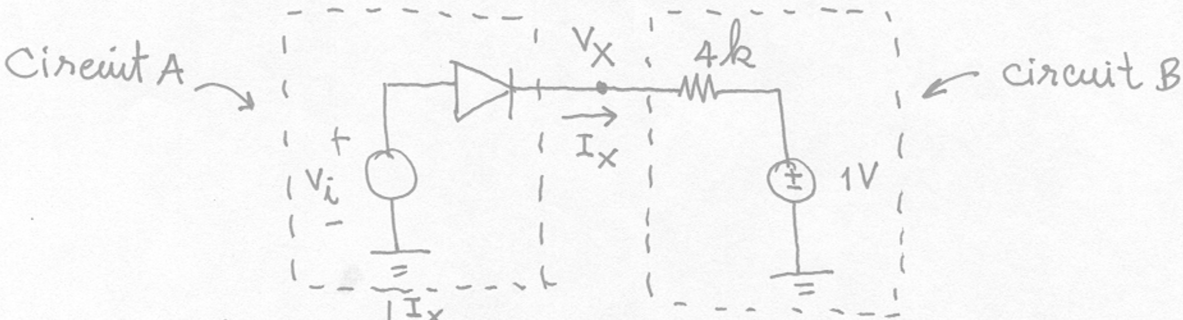


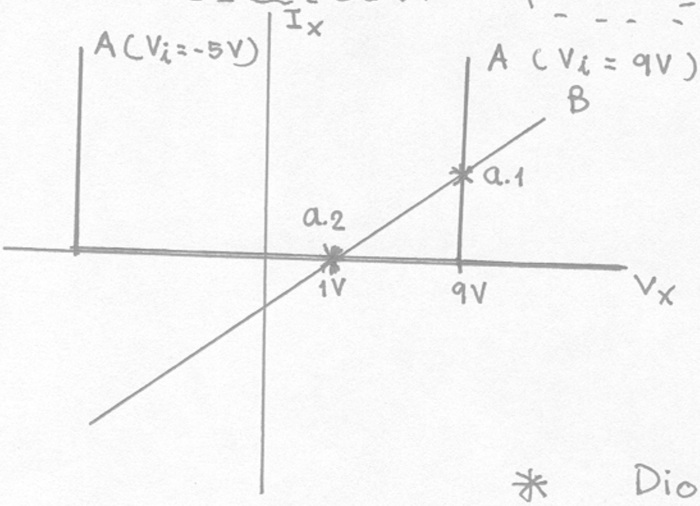


$$V_x(t) = \begin{cases} \frac{5k}{5k+5k} V_s(t) = \frac{1}{2} V_s(t) & \text{when } V_s(t) \geq 0 \\ 0 & \text{when } V_s(t) < 0 \end{cases}$$

Problem 5 Worksheet

a) find Thevenin equivalent of the right side of the circuit (linear part)





Therefore

a.1) $V_X = 9V$

a.2) $V_X = 1V$

* Diode is a nonlinear device. Superposition can't be used.

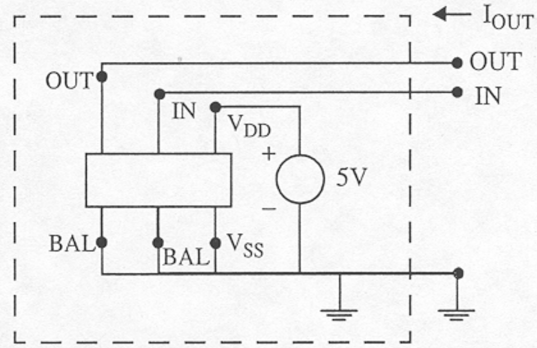
b) b.1) There is no path for the current to flow regardless of the polarity of $V_s(t)$. Therefore, i_x is always zero.

b.2) Since we assume all diodes are perfect rectifiers, it doesn't matter how many diodes are put in series (in the same direction). Current can flow only when $V_s(t)$ is positive.

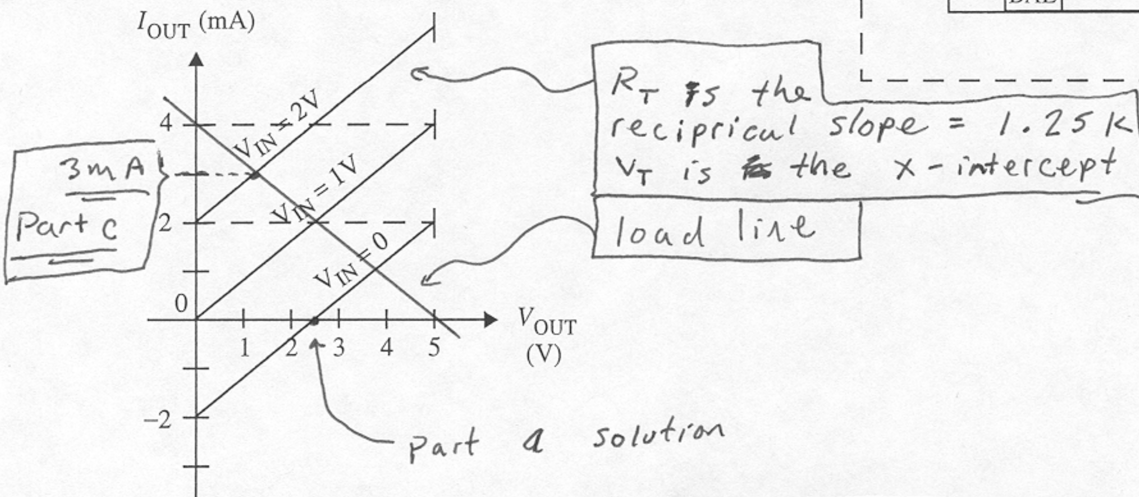
Problem 6 (12 points)

In the lab you encounter a 6-terminal device labeled as follows: One terminal is labeled "V_{SS}", so you ground it. Another is labeled "V_{DD}", so you hook it to a +5V supply. Two are labeled "Bal", and not knowing what they might be, you simply ground them. The remaining two terminals are labeled "IN" and "OUT".

So what you now have is essentially a 3-terminal device to study. You proceed to take a series of I-V measurements between V_{OUT} and ground, each set of measurements at one value of v_{IN}.

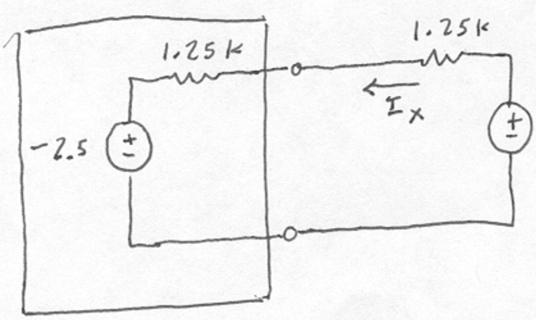


You obtain:



Alternate solution to part c

$$I_X = \frac{5v - (-2.5)}{2.5\,k} = 3\,mA$$



Equivalent circuit when $V_{in} = 2V$

Problem 6 Answer Sheet

[4 pts.] a) What is the open circuit value of V_{OUT} for V_{IN} = 0V ?

Check that if $V_{in} = 0$ and $I_{out} = 0$

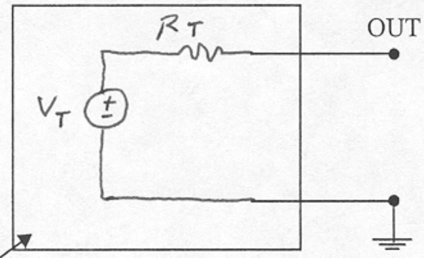
$V_{out} \approx 2.5v$ (see facing page.)

V_{OUT} = 2.5v

[4 pts.] b) Draw the Thévénin Equivalent circuit of the output for each of the input values given (R_{TH} and V_{TH} may be a function of the input voltage), and fill out the table.

All slopes are the same

X-intercepts

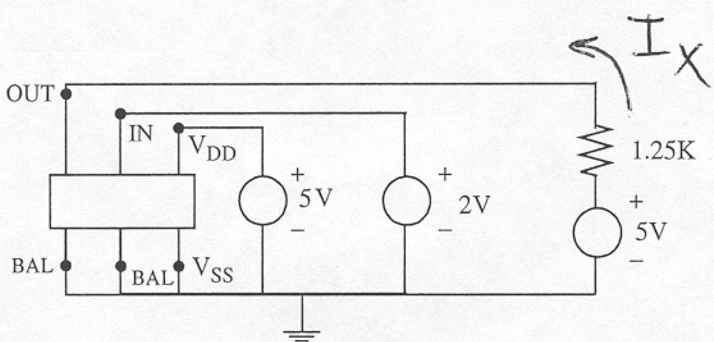


Draw circuit here

V_{IN}	R_T	V_T
0	1.25K	2.5v
1	1.25K	0
2	1.25K	-2.5v

Fill out table

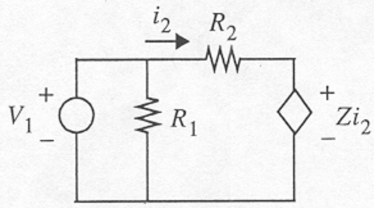
[4 pts.] c) Find I_x (10% accuracy is good enough).



See facing Page

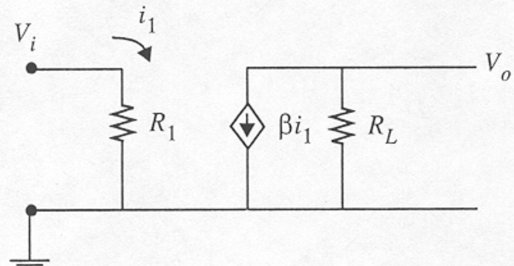
Problem 7 (12 points)

a) Find i_2 in terms of R_1, R_2, Z, and V_1.



i_2 = $\dfrac{V_1}{R_2 + Z}$

b) Find V_o in terms of R_1, R_L, β, and v_i.



V_o = $-\beta \dfrac{R_L}{R_1} \cdot V_i$

c) In the same circuit as (b), if $R_1 = 10\text{K}$, $\beta = 100$, $R_L = 10\text{K}$, and $V_i = 0.01\text{V}$, what is V_o?

V_o = -1 V

Solution

Problem 8 (14 points)

Scientists at Stanford are excited about discovering a new low-mobility semiconductor "Xanium." The electron mobility in Xanium is 0.5 cm^2/V sec and the saturation drift velocity is 10^6 cm/sec.

They construct a field effect transistor with this material using an insulator of such a thickness that the capacitance per unit area is 10^{-7} ~~coul~~ F/cm^2. The transistor length L is 0.5μm and the width W is 10μm. They find that the threshold voltage is 2.0 V. Your job is to predict their experimental results.

a) What is the induced charge per unit area in the channel at a gate-source voltage V_{GS} of 5V?

$$Q = C(V_G - V_{th}) = \left(10^{-7}\frac{F}{cm^2}\right)(3V)$$

Q = $3\times10^{-7}\frac{F}{cm^2}$ (units?)

b) What is the source-drain resistance at V_{GS} = 1 V?

$V_{GS} < V_{th}$

No Channel

R = ∞ Ω

c) What is the source-drain resistance at V_{GS} = 5 V?

$$R_\square = \frac{1}{Q\mu_n} = \frac{1}{\left(3\times10^{-7}\frac{F}{cm^2}\right)\left(0.5\frac{cm^2}{Vs}\right)} = 6.67M\Omega$$

we have $R = R_\square\left(\frac{L}{W}\right) = 333.3K$

R = 333.3 K Ω

d) In a bulk n-type sample of Xanium that is 0.5μm long (in the direction of current flow), how large a voltage would be required to observe velocity saturation? (HINT: Do NOT be too surprised by the answer.)

$$V_{SAT} = \frac{\langle v\rangle L}{\mu} = \frac{(10^6 cm/s)(0.5\mu m)}{0.5\ cm^2/Vs}$$

$0.5\mu m = .5\times10^{-4} cm$

V = 100 (V)

e) Would velocity saturation be observed in this transistor (for drain voltages of 5 V or less)?

Y or (N) N

Why? Need $V_{DS} > V_{SAT}$