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

EE40
Summer 09

SOLUTIONS

Frank Liao

MIDTERM EXAMINATION #2
Time allotted: 100 minutes

NAME: ______________________ ______________________ ______________________
(print) Last First Student ID#

LAB SECTION: ____________/____________
Days / Time

I acknowledge that the UC rules on academic honesty apply. ______________________
Signature

INSTRUCTIONS:

1. **SHOW YOUR WORK. Partial credit will be given only if your methods are clear to the grader.**
2. **Clearly mark (BOX or UNDERLINE) your answers.**
3. **Specify the units on answers whenever appropriate. Points will be deducted for missing units.**
4. **Closed book, closed notes. You are allowed ONE 8.5" x 11" sheet of notes. Calculators are allowed.**

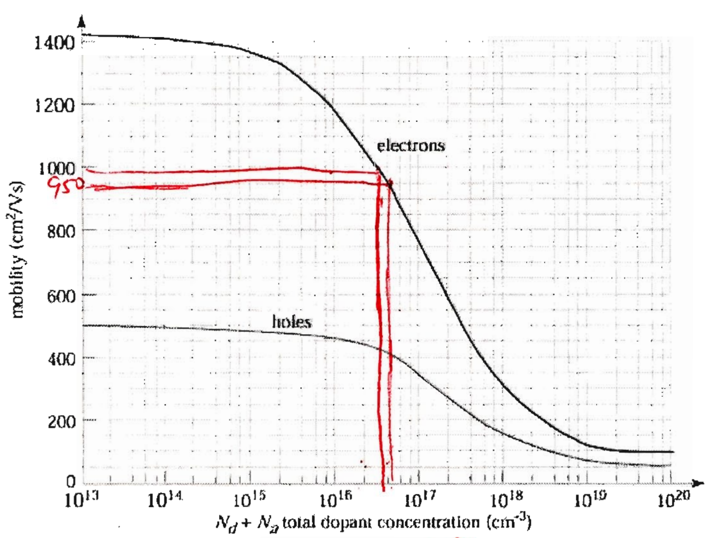
PHYSICAL CONSTANTS

Description	Symbol	Value
Electronic charge	q	1.6×10^{-19} C
Boltzmann's constant	k	8.62×10^{-5} eV/K
Thermal voltage at 300K	$V_T = kT/q$	0.026 V

PROPERTIES OF SILICON AT 300K

Description	Symbol	Value
Intrinsic carrier concentration	n_i	10^{10} cm^{-3}
Dielectric permittivity	ε_{Si}	1.0×10^{-12} F/cm

Electron and Hole Mobilities in Silicon at 300K



(For Prob 4)

SCORE:	1 ________	/ 10
	2 ________	/ 20
	3 ________	/ 30
	4 ________	/ 20
	5 ________	/ 20
	TOTAL: ________	/ 100

SOLUTIONS

Problem 1 [10 points]: Basic concepts and EE Technology
a) True/False and Multiple Choice. Select only ONE choice. No credit will be given to multiple answers. **[2 pts each]**

T F LCD stands for Liquid Capacitance Display.

T F The MEMS accelerometer uses a differential capacitance to detect motion.

T F If an RC circuit has a large time constant, τ, then it takes a long time for the capacitor in that circuit to charge and discharge.

4) What kind of filter is this?

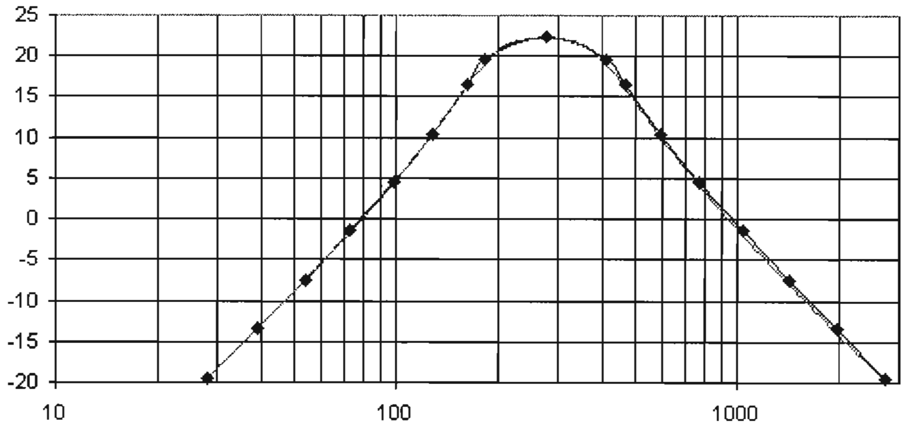
a) Lowpass

b) Highpass

c) Bandpass

d) Bandreject

Bode Plot of a Filter



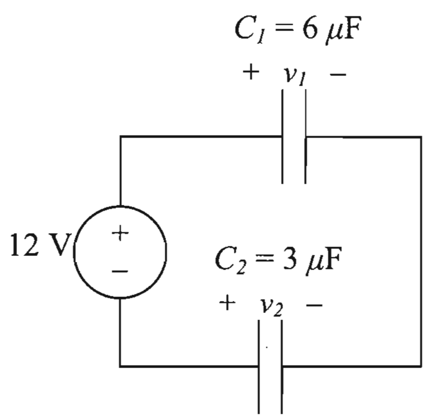
5) What is v_1, the voltage drop across C_1?

a) 4 V

b) 8 V

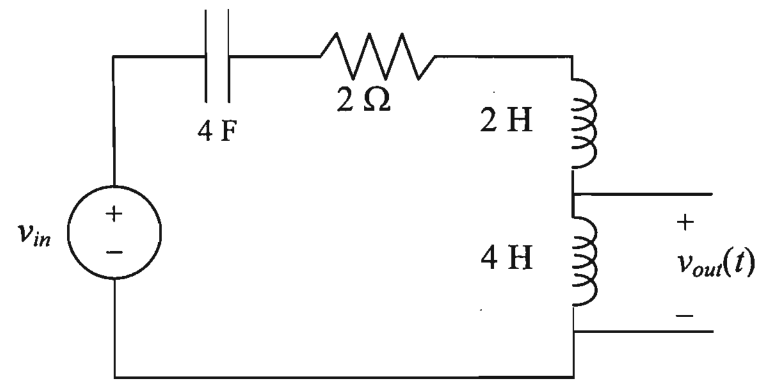
c) -4 V

d) -8 V



SOLUTIONS

Problem 2 [20 points]: Phasor Analysis
In the circuit below, $v_{in}(t) = 2\cos(0.1\,t + 30°)$.



a.) What is $v_{out}(t)$ in cosine form? **[10 pts]**

$$V_{out} = V_{in}\left(\frac{Z_{4H}}{Z_{4H} + Z_{2H} + Z_{4F} + Z_{2\Omega}}\right) = V_{in}\left(\frac{j(0.1)(4)}{j(0.1)(6) + \frac{1}{j(0.1)(4)} + 2}\right) = \left(\frac{j0.4}{2 - j1.9}\right)V_{in}$$

+5 for setup
+3 for phasor math
+2 expression

$$= (2\angle 30°)\left(\frac{0.4\angle 90°}{\sim 2\sqrt{2}\angle -43.5°}\right)$$

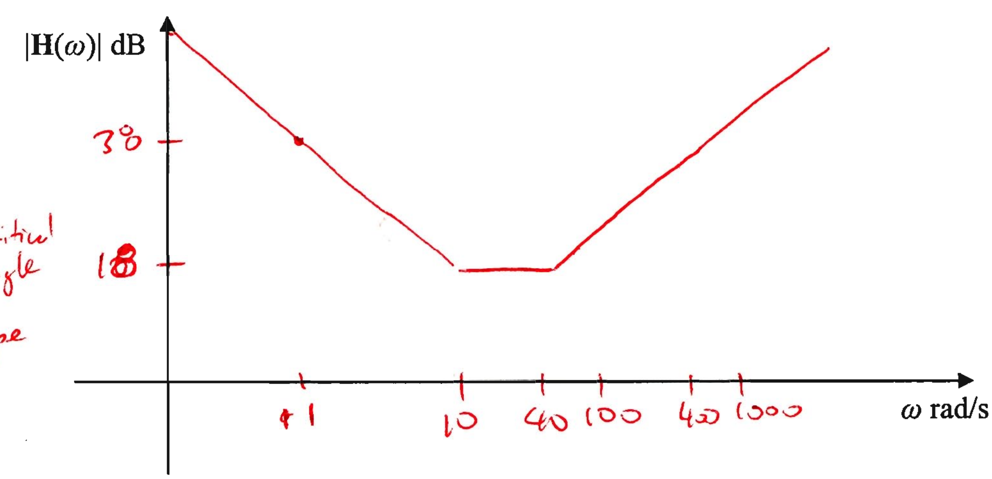
$$= 0.29\angle 163.5°$$

$$\Rightarrow \boxed{V_{out}(t) = 0.29\cos(0.1t + 163.5°)}$$

b.) If $v_{out} / v_{in} = (20 + j2\omega)(40 + j\omega) / j10\omega$, sketch the bode plot of the magnitude of the transfer function, $\mathbf{H}(\omega)$. Label the axes appropriately, denoting critical angles, slopes and plateau values. **[10 pts]**

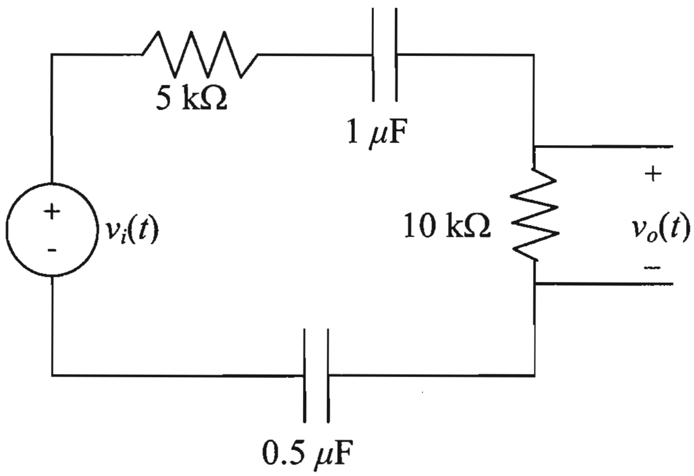
$$|H(\omega)| = 80\,\frac{\left(1+\frac{j\omega}{10}\right)\left(1+\frac{j\omega}{40}\right)}{j\omega} \Rightarrow 20\log 80 = 20(1.9) \approx 38$$

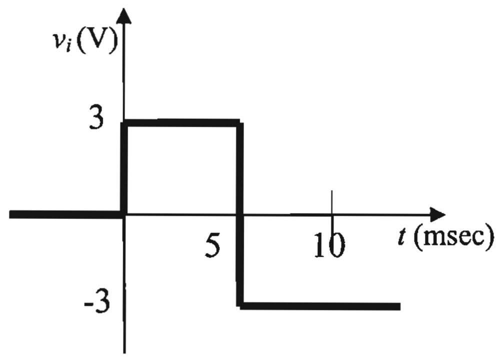
+1 plateau
+1 for each critical angle
+1 for each slope



SOLUTIONS

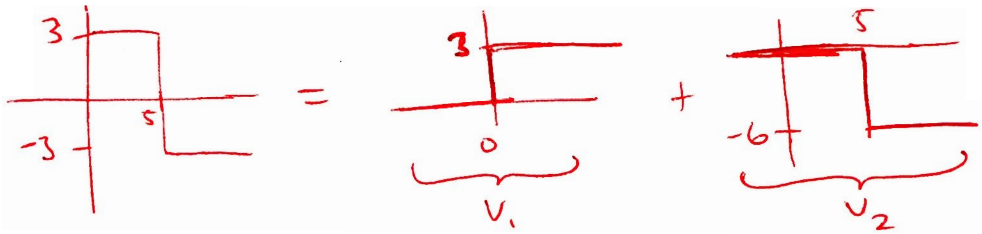
Problem 3 [30 points]: First-Order Transients
Consider the circuit below:



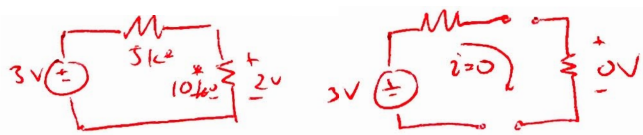


a.) Find the expression for $v_o(t)$ (piecewise expressions are acceptable) and plot $v_o(t)$ for 0 msec $\le t \le$ 10 msec. Label the values of $v_o(0^+)$, $v_o(5^-)$, and $v_o(5^+)$. **[20 pts]**

Show your work below. (Space for your answer is on the next page)



For V_1:



$v(0^+) = 2V$ $\qquad$ $v(\infty) = 0V$

$\tau = (5+10)k \times \left(\frac{0.5\mu}{1.5\mu}\right) = 5\,ms$

$\Rightarrow 0 \le t < 5m$

$v_o(t) = 2e^{-t/5m} = 2e^{-200t}$

+2 for initial value
+2 for final value
+2 for correct τ
+1 for expression

For V_2:

$v(5^+) = -4\,V$ $\qquad$ $v(\infty) = 0V$

$\tau = 15k \times \frac{1}{3}\mu = 5\,ms$

For V_2: $v_o(t) = -4e^{-t/5m}$

$\Rightarrow 5m \le t$

$v_o(t) = 2e^{-t/5m} - 4e^{-(t-5)/5m}$

+2 for initial value
+2 for final value
+1 for correct τ
+3 expression (and use of superposition)

Answer:

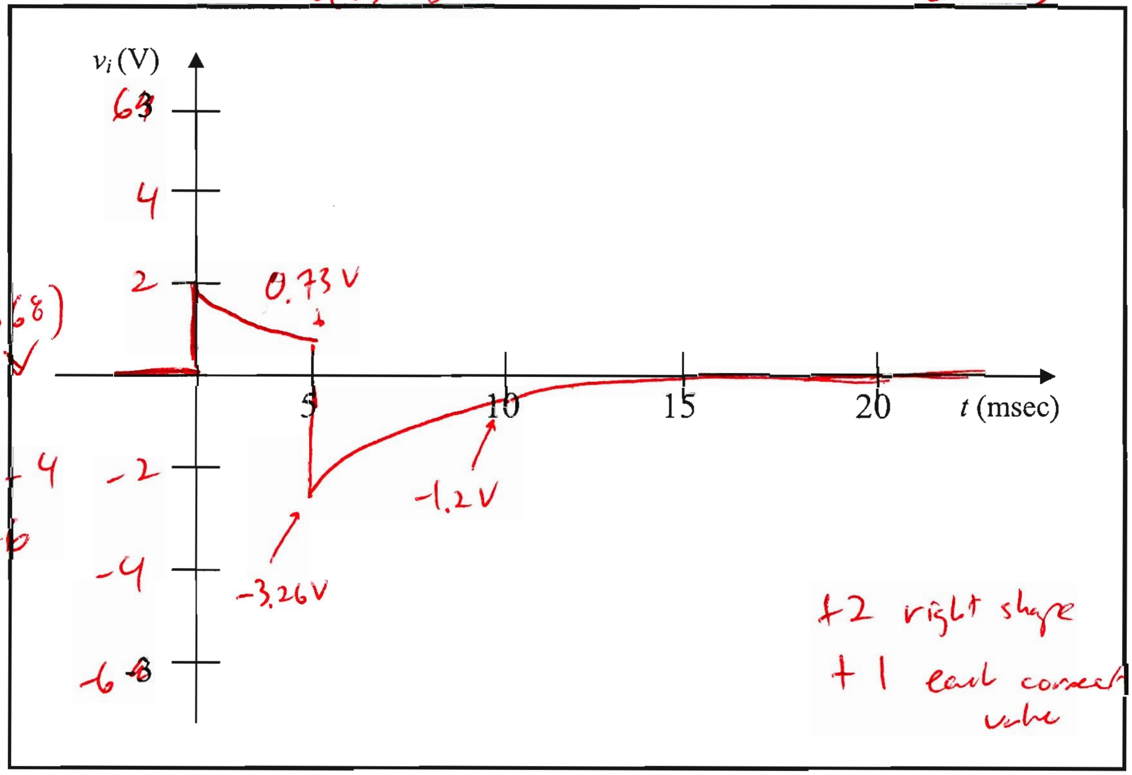
Expression for $v_o(t)$: $\begin{cases} 2e^{-t/5m} & 0 \le t < 5m \\ 2e^{-t/5m} - 4e^{-(t-5)/5m} & t \ge 5m \end{cases}$

$\overset{\shortparallel}{3.26}\, e^{-200t}$

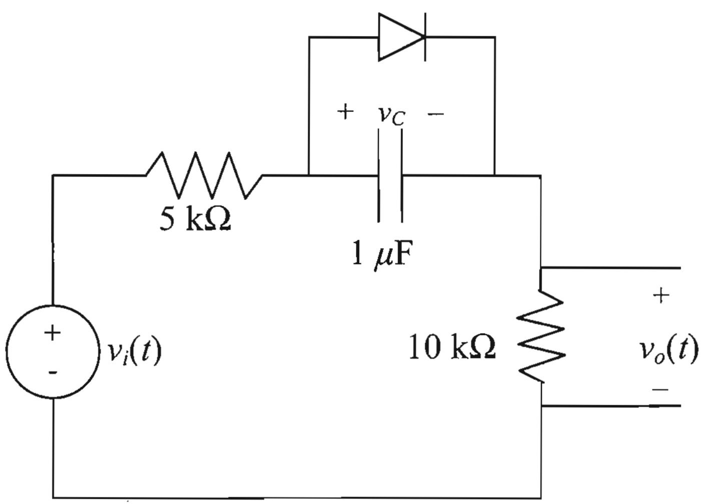
or $v_o(t) = 2e^{-200t} - 4e^{-200(t-5)} \cdot u(t-5)$

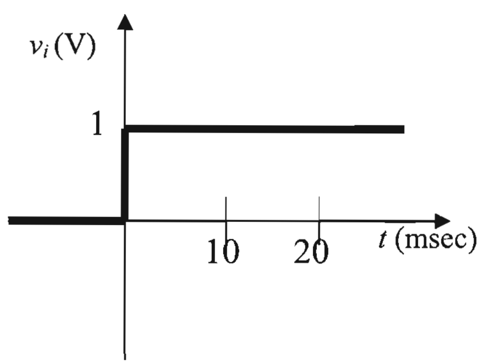
$v(5^-) = 2e^{-1}$
$= 2(0.368)$
$= 0.73\ V$

$v(5^+) = 0.73 - 4$
$= -3.26$



b.) Suppose we modify the circuit and apply a different input voltage.





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On the axes below, plot for $v_C(t)$ and $v_o(t)$. Use the large signal model for the diode with a turn-on voltage, V_D=0.7 V. Label the following values: (1) the final voltage of v_C, (2) the time, t, when v_C reaches its final voltage, (3) the final voltage of v_o, and (4) the time, t, when v_o reaches its final voltage. **[10 points]**

Space for work:

For v_c: $v_c(0^-) = v_c(0^+) = 0 \text{ V}$ $\quad v_c(\infty) = 1 \text{ V}$

$\tau = 15k \times 1\mu = 15 \text{ ms}$

$\Rightarrow v_c(t) = 1 - e^{-t/15m}$

at $v_c = 0.7$ V the diode will turn on and fix v_c at 0.7 V

this happens at $0.7 = 1 - e^{-t/15m}$

$\Rightarrow t = 18 \text{ ms}$

For v_o: $v_o(0^+) = 0.67 \text{ V}$ $\quad v_o(\infty) = 0 \text{ V}$ $\quad \tau = 15 \text{ ms}$

$\Rightarrow v_o(t) = 0.67\, e^{-t/15m}$ and at $t = 18$ ms, $v_o = 0.2$ V

at $t = 18$ ms,

$i = \frac{0.3}{15k} = 20\,\mu A$

$v_o = 20\,\mu A \times 10k$

$= 0.2$

+3 for shape

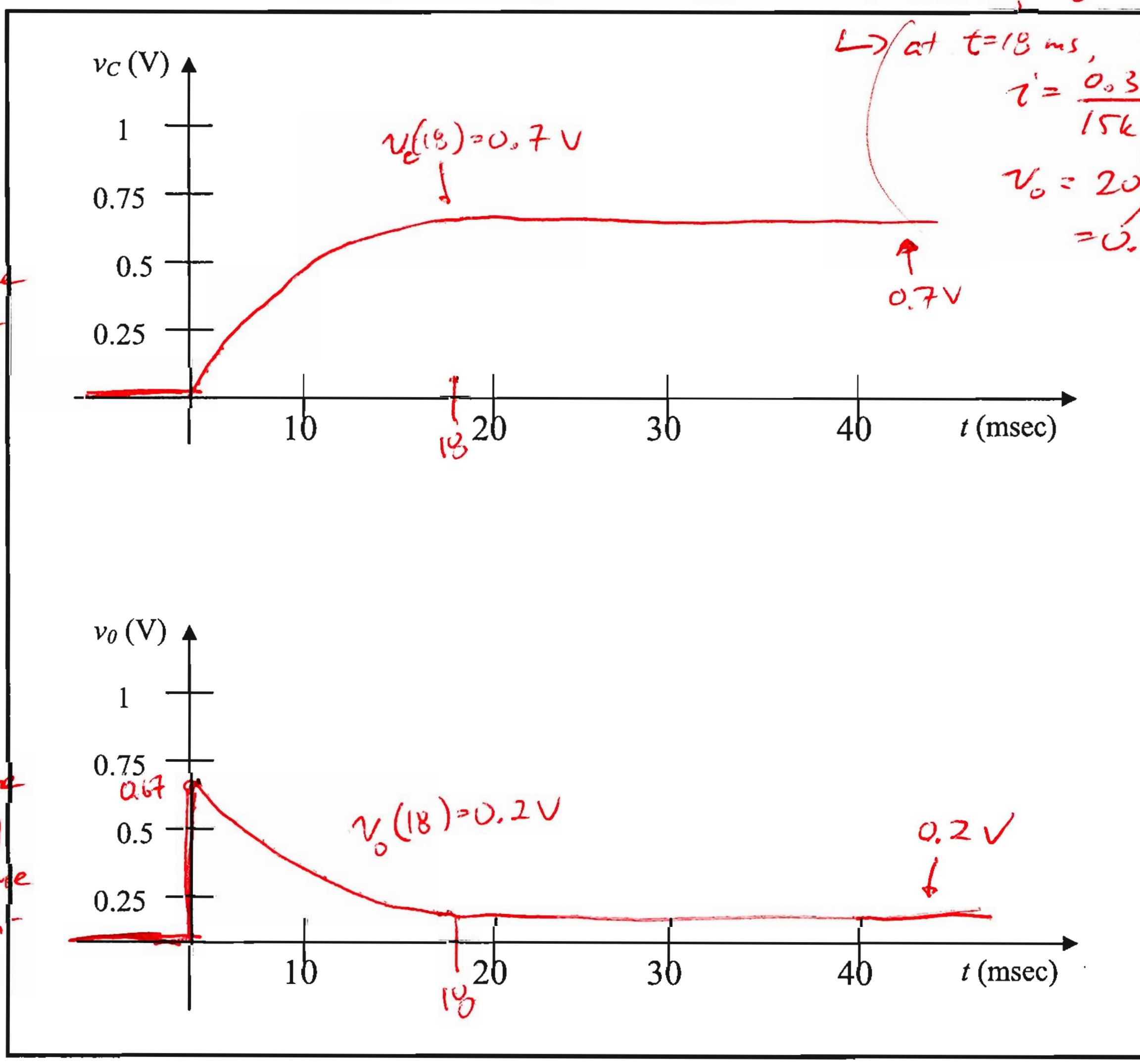
+1 for final value

+1 for right time

+2 for shape

+2 for final value

+1 for right time



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Problem 4 [20 points]: Doping and Carrier Concentrations

Consider a Si sample maintained under thermal equilibrium conditions at $T = 300\text{K}$, doped with phosphorous at a concentration of 2×10^{16} cm^{-3}.

a.) Is this material n-type or p-type? What are the majority and minority carrier concentrations? **[~~4~~ 6 pts]**

phosphorous = donor ⇒ n-type   majority – ~~holes~~ electrons
minority – ~~electrons~~ holes

$$n = N_D = 2\times10^{16}\ \text{cm}^{-3}$$

$$p = \frac{n_i^2}{N_D} = \frac{10^{20}}{2\times10^{16}} = 5\times10^{3}\ \text{cm}^{-3}$$

Write your answers here:

type:	n-type	+2
majority concentration:	$2\times10^{16}\ \text{cm}^{-3}$	+2
minority carrier concentration:	$5\times10^{3}\ \text{cm}^{-3}$	+2

b.) Suppose this sample is additionally doped with boron at a concentration of 10^{16} cm^{-3}. How will the carrier concentrations change? **[~~3~~ 2 pts]**

~~boron~~ boron is acceptor
but b/c $N_A < N_D$, material is still n-type ⇒ majority = electrons
minority = holes

$$n = N_D - N_A = 10^{16}\ \text{cm}^{-3}$$

$$p = \frac{n_i^2}{n} = \frac{10^{20}}{10^{16}} = 10^{4}\ \text{cm}^{-3}$$

Write your answers here:

new majority concentration:	$10^{16}\ \text{cm}^{-3}$	+1
new minority carrier concentration:	$10^{4}\ \text{cm}^{-3}$	+1

c.) Find the resistivity of this sample (with the boron doping). **[~~4~~ 12 pts]**

$$\rho = \frac{1}{qn\mu_n + qp\mu_p} \approx \frac{1}{qn\mu_n}$$

+7 for formula
+1 correct conc.
+3 for mobility
+1 for correct value

From the chart, using $N_D + N_A = 3\times10^{16}\ \text{cm}^{-3}$,

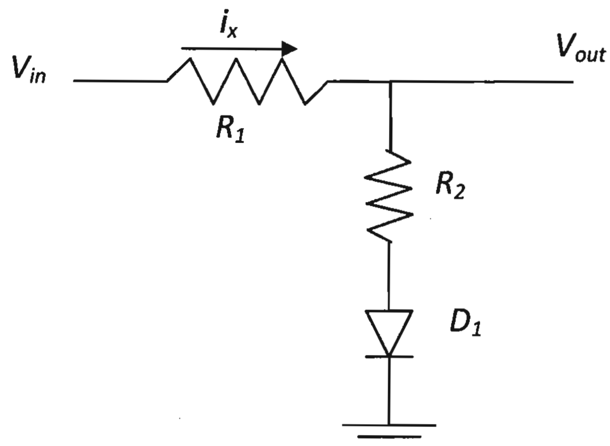
$$\mu_n \approx \cancel{1000}\ 950\ \text{cm}^2/\text{V/s}$$

$$\Rightarrow \rho = \frac{1}{(1.6\times10^{-19}\ \text{C})(10^{16}\ \text{cm}^{-3})(950\ \text{cm}^2/\text{V}\cdot\text{s})} = 0.66\ \Omega\text{-cm}$$

($\mu_n = 1000\ \text{cm}^2/\text{V/s}$ IS ACCEPTABLE ALSO
$\rho = 0.625\ \Omega\text{-cm}$)

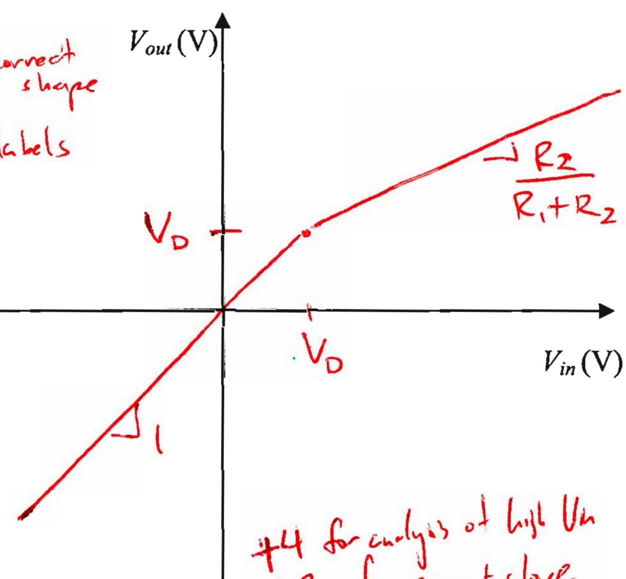
SOLUTIONS

Problem 5 [20 points]: Diode Circuits
Consider the following diode circuit:



a.) Using the large-signal model, plot V_{out} as function of V_{in} of the circuit below. Remember, a diode about to turn on carries zero current but sustains V_D. For full credit, you must label all important points on the graph (e.g. slope or cross-over points).

+1 correct shape
+1 labels



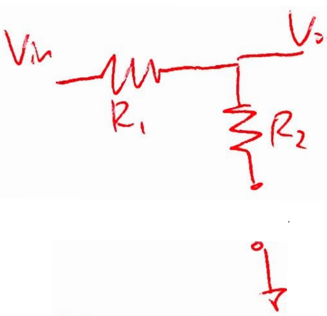
+2 for correct cross-over

Cross-over point:
$V_{in} = V_{out} = V_D$

+2 for analysis of low V_{in}
+1 for correct slope

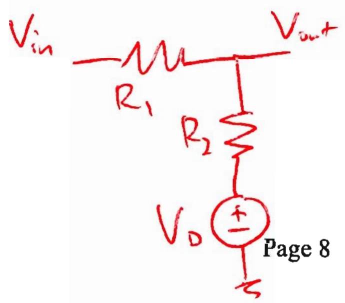
+4 for analysis of high V_{in}
+3 for correct slope

For low V_{in},
D_1 is off:



$V_{out} = V_{in}$

For high V_{in}
D_1 is on:



KCL:

$$\frac{V_{in} - V_{out}}{R_1} = \frac{V_{out} - V_D}{R_2}$$

$$\left(\frac{1}{R_1} + \frac{1}{R_2}\right) V_{out} = \frac{V_{in}}{R_1} + \frac{V_D}{R_2}$$

$$\Rightarrow V_{out} = \underbrace{\left(\frac{R_2}{R_1+R_2}\right)}_{\text{slope}} V_{in} + \left(\frac{R_1}{R_1+R_2}\right) V_D$$

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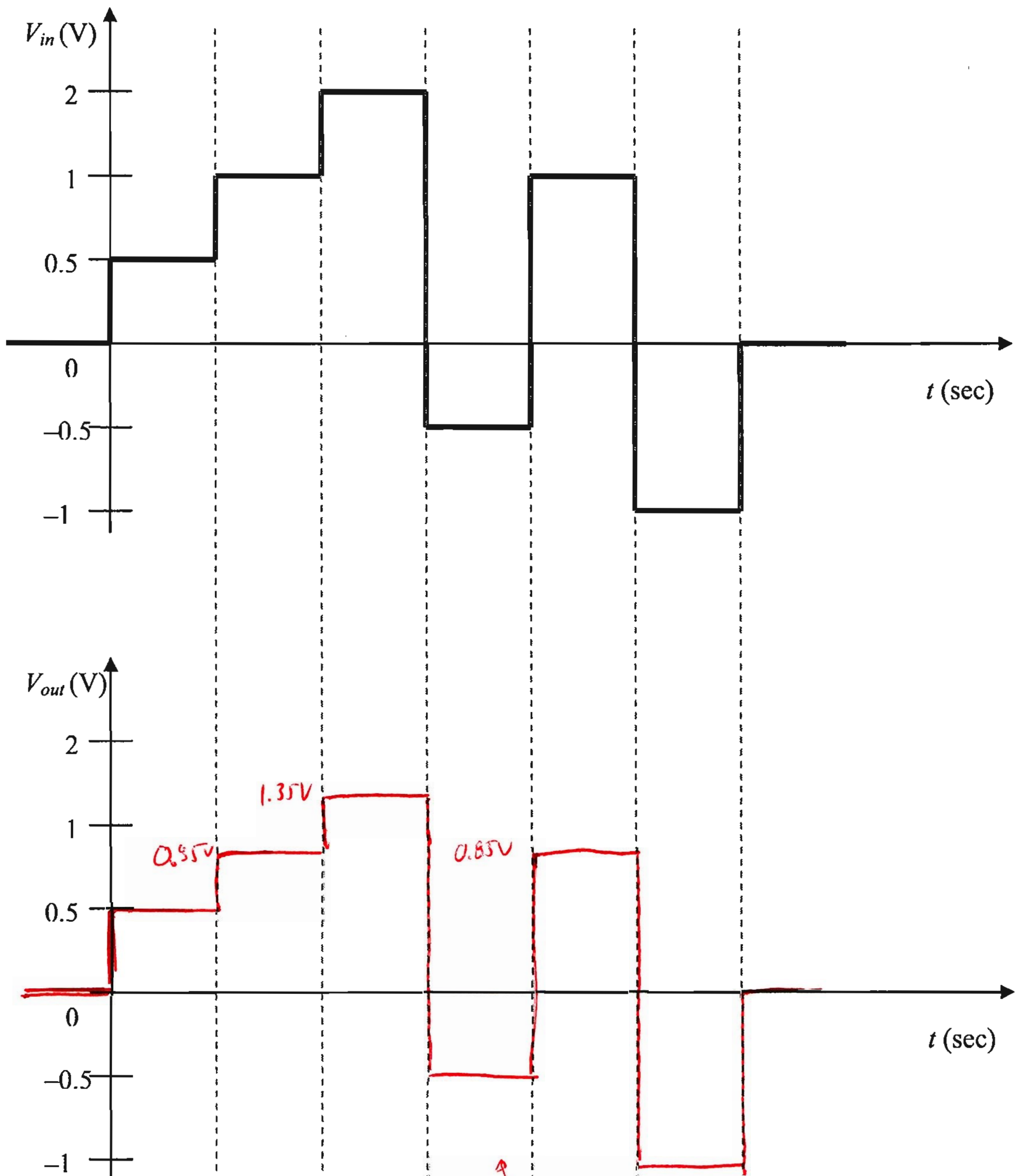
b.) Suppose $R_1 = 2\ \text{k}\Omega$, $R_2 = 2\ \text{k}\Omega$, and V_D=0.7 V and V_{in} is given by the waveform shown below. Plot V_{out} on the given axes.



+1 correct plot

For $V_{in} < 0.7\ V$

$$V_{out} = V_{in}$$

+2 correct analysis

For $V_{in} \geq 0.7\ V$

+3 correct analysis

$$V_{out} = \frac{1}{2}V_{in} + \frac{1}{2}(0.7)$$

$$= 0.5V_{in} + 0.35$$