Name Solutions

EE 42

Midterm 2

April 13, 2004

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PLEASE SHOW YOUR WORK TO RECEIVE PARTIAL CREDIT

Problem 1: 15 Points Possible ________

Problem 2: 15 Points Possible ________

Problem 3: 15 Points Possible ________

Problem 4: 15 Points Possible ________

Problem 5: 15 Points Possible ________

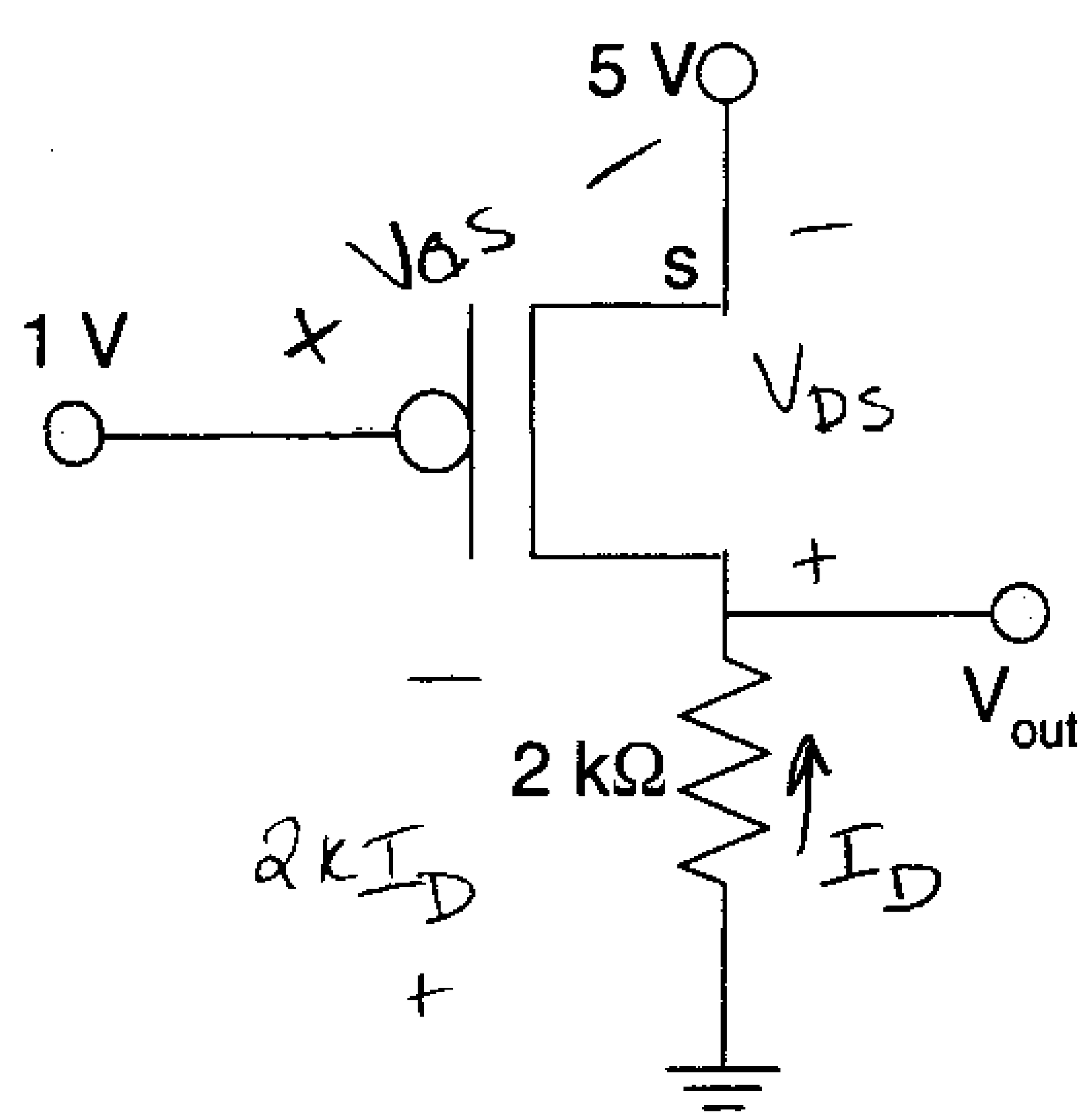
Problem 6: 15 Points Possible ________

Problem 7: 10 Points Possible ________

TOTAL: 100 Points Possible ________

Name Solutions.

Problem 1: 15 Points Possible



W/L μ_p C_{ox} = 1 mA/V^2

$\lambda_p = 0\ V^{-1}$

$V_{TH(p)} = -1\ V$

Find V_{out}.

$V_{GS} = -4V$ Not cutoff.

Guess saturation. $I_D = -1/2 \cdot 1mA/V^2 (-4V - -1V)^2 = -4.5\ mA$

$2kI_D + V_{DS} + 5V = 0$ $V_{DS} = 4V \not< \underbrace{V_{GS} - V_{TH(p)}}_{= -3V}$

Must be triode mode. (also, V_{DS} can't be positive for PMOS)

$I_D = -1mA/V^2(-4V - -1V - \frac{V_{DS}}{2}) V_{DS}$

$I_D = -\frac{5 + V_{DS}}{2k\Omega}$ from above

Simultaneously solve: $V_{DS} = \{-6.19, -0.81\}$

impossible for triode

$I_D = -\frac{5 + -0.81}{2k\Omega}$

$V_{OUT} = -2k\Omega I_D = \underline{4.19V}$

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Problem 2: 15 Points Possible

Inputs				Output
A	B	C	D	F
0	0	0	0	1
0	0	0	1	0
0	0	1	0	1
0	0	1	1	0
0	1	0	0	1
0	1	0	1	1
0	1	1	0	1
0	1	1	1	0
1	0	0	0	1
1	0	0	1	0
1	0	1	0	1
1	0	1	1	0
1	1	0	0	1
1	1	0	1	0
1	1	1	0	1
1	1	1	1	0

a) Write the simplest sum-of-products expression for F in terms of A, B, C, D.

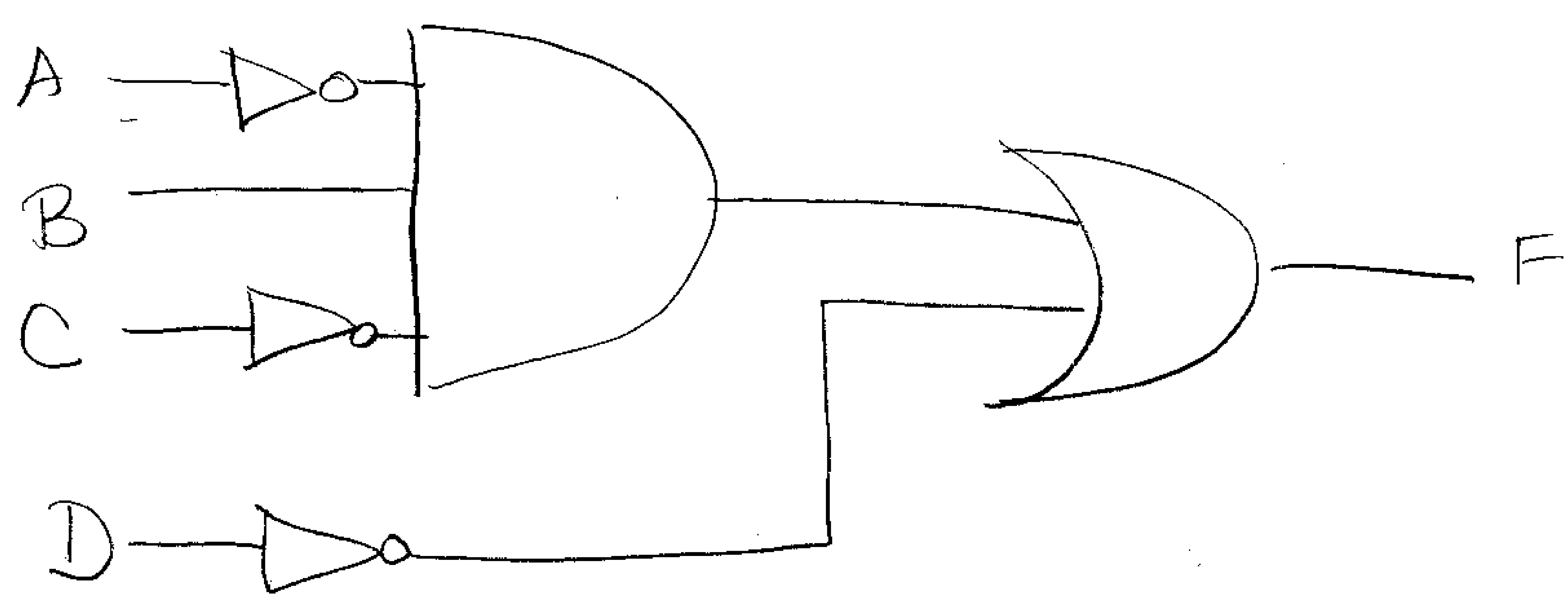
b) Draw the logic circuit for this function using only NAND gates.

AB \ CD	00	01	11	10
00	1	0	0	1
01	1	1	0	1
11	1	0	0	1
10	1	0	0	1

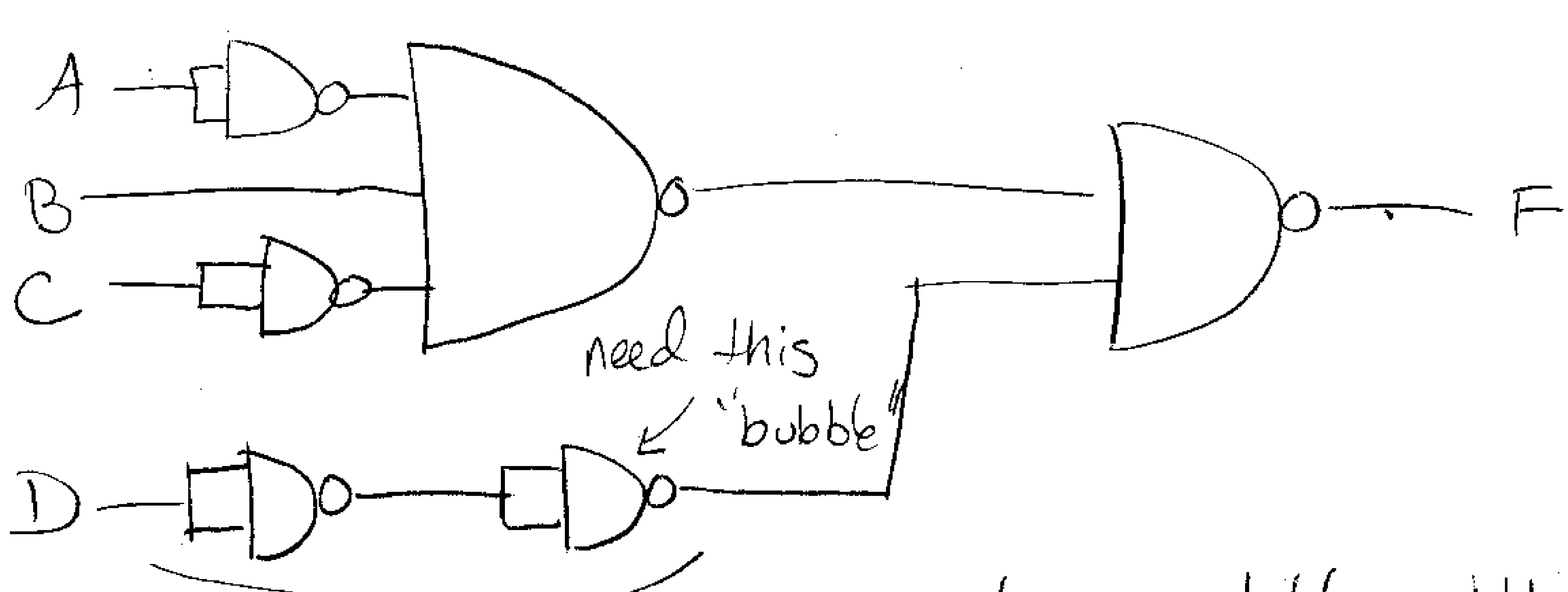
$\bar{A}B\bar{C}$

$\bar{D}$

Regular AND-OR gives us



So NAND-NAND is



these cancel; acceptable with both removed.

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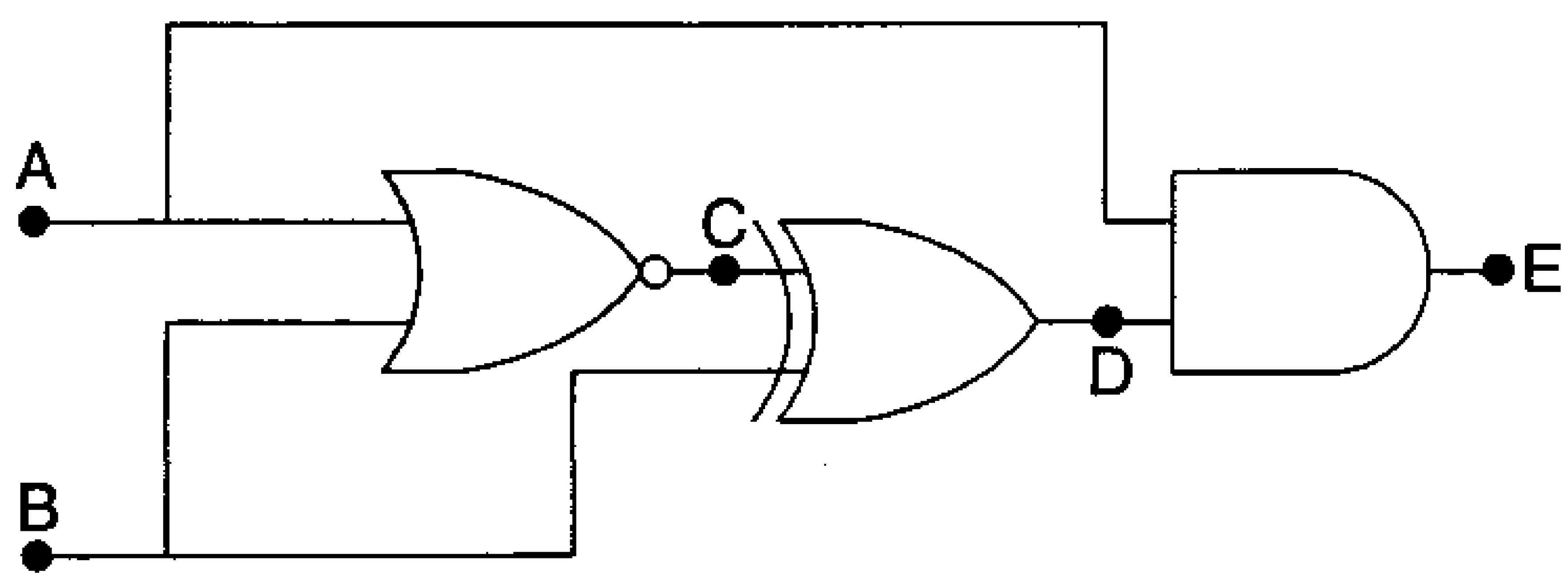
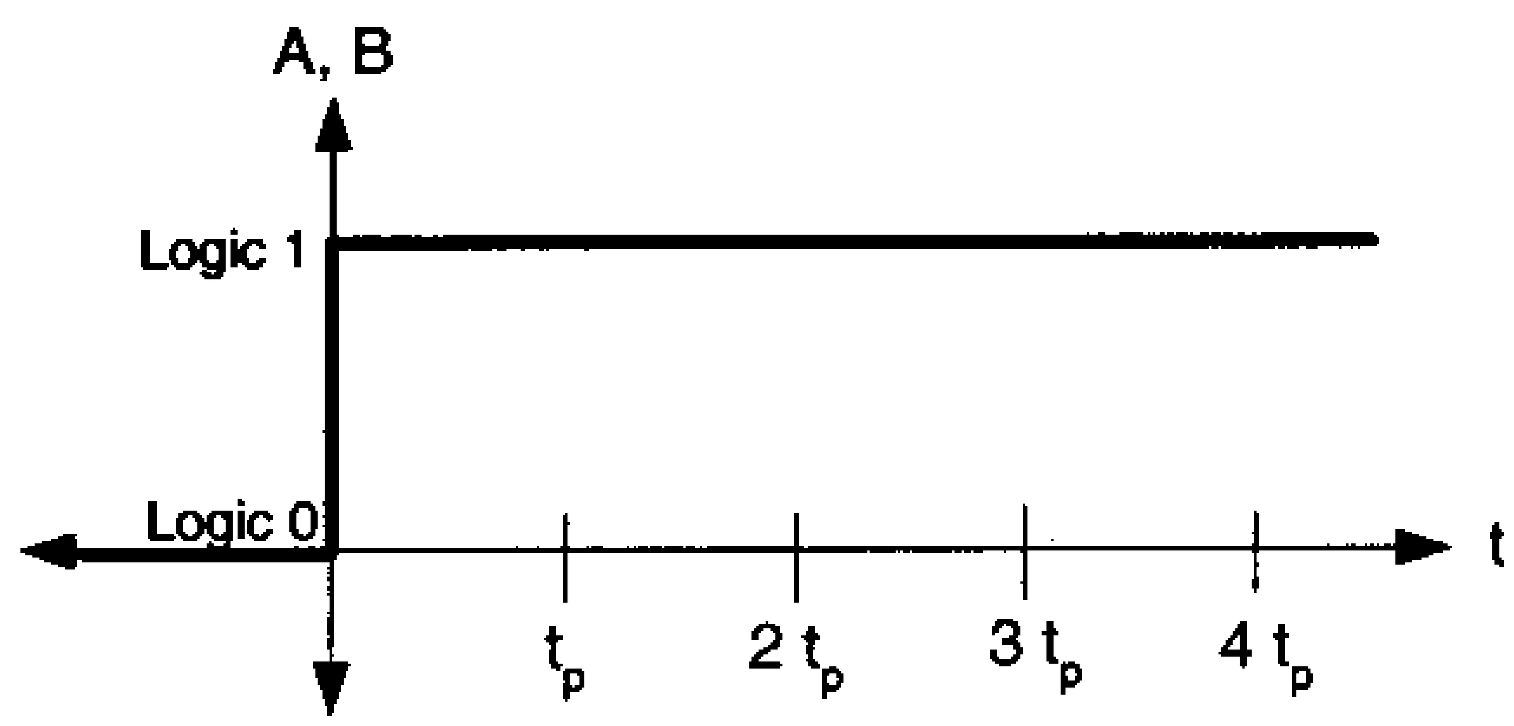
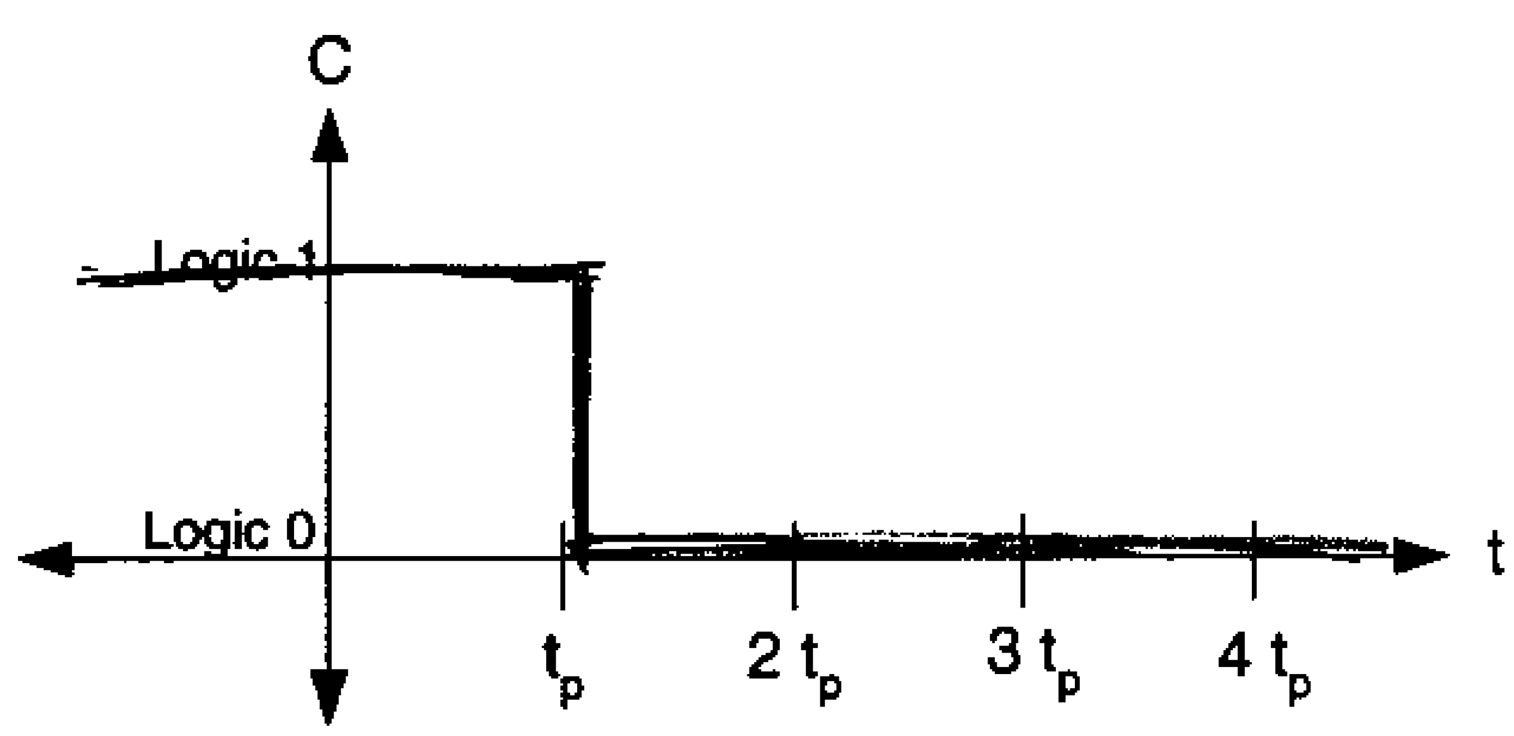
Problem 3: 15 Points Possible

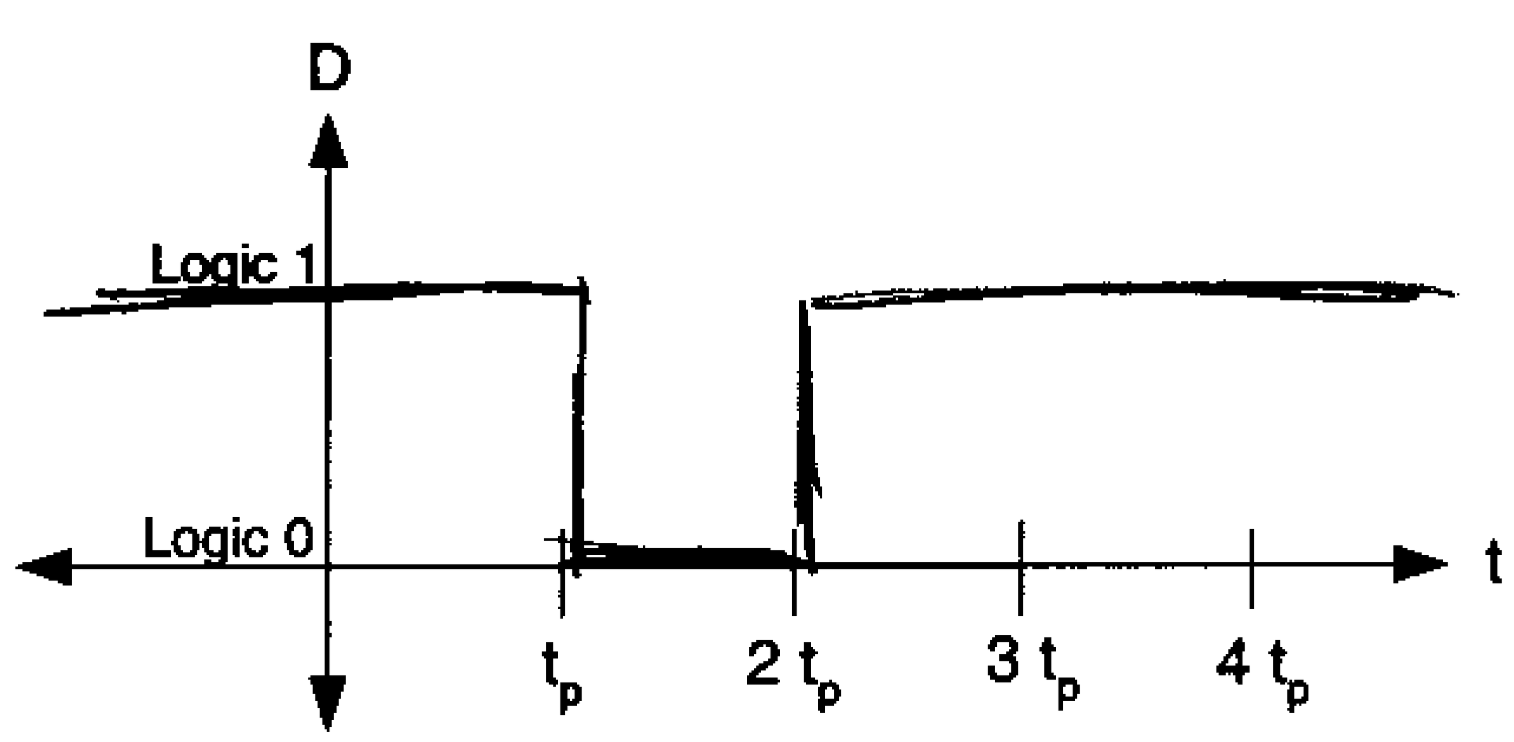


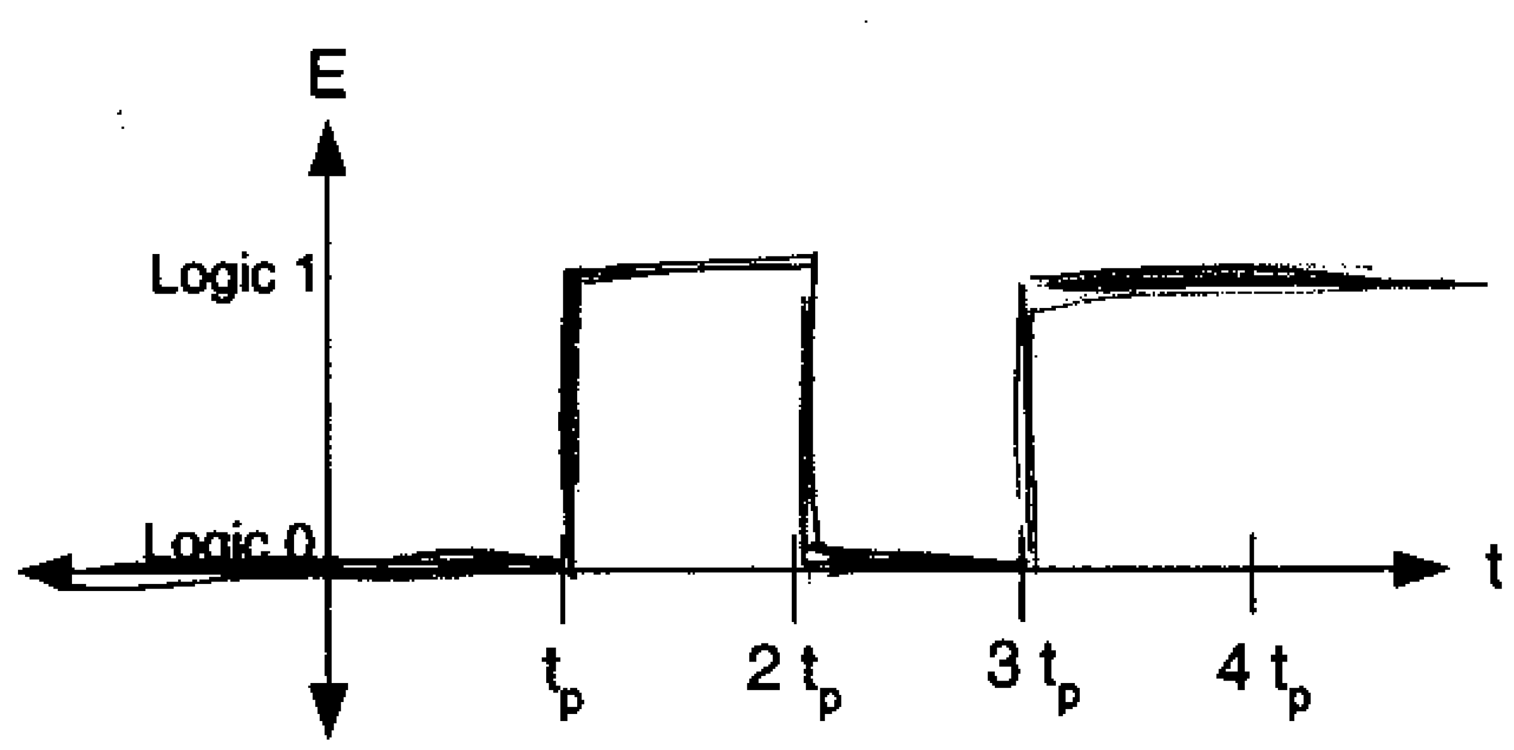
Assume that each gate shown has a propagation delay of t_p .

With signals A and B as shown below, sketch signals C, D, and E on the axes provided.









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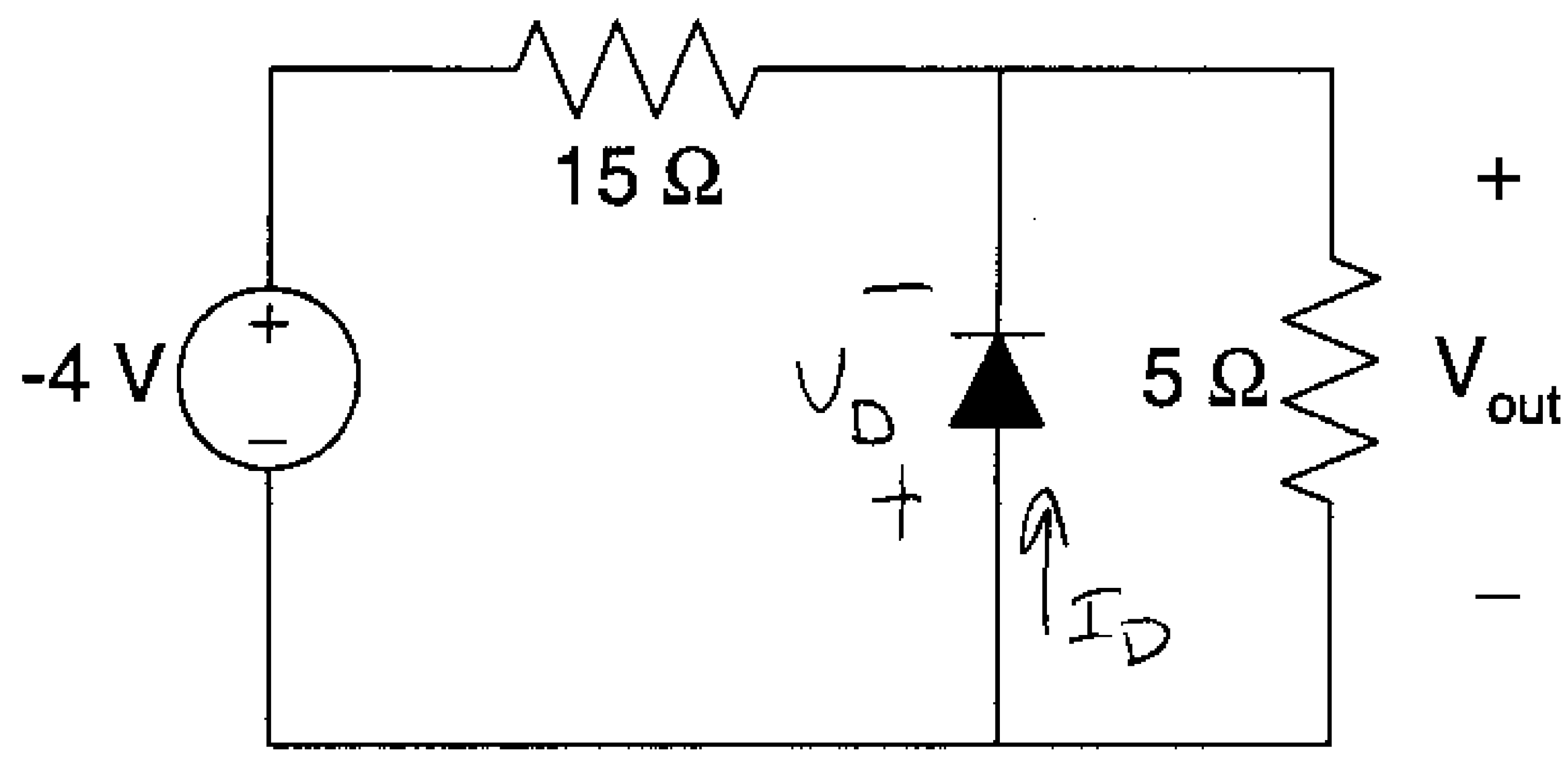
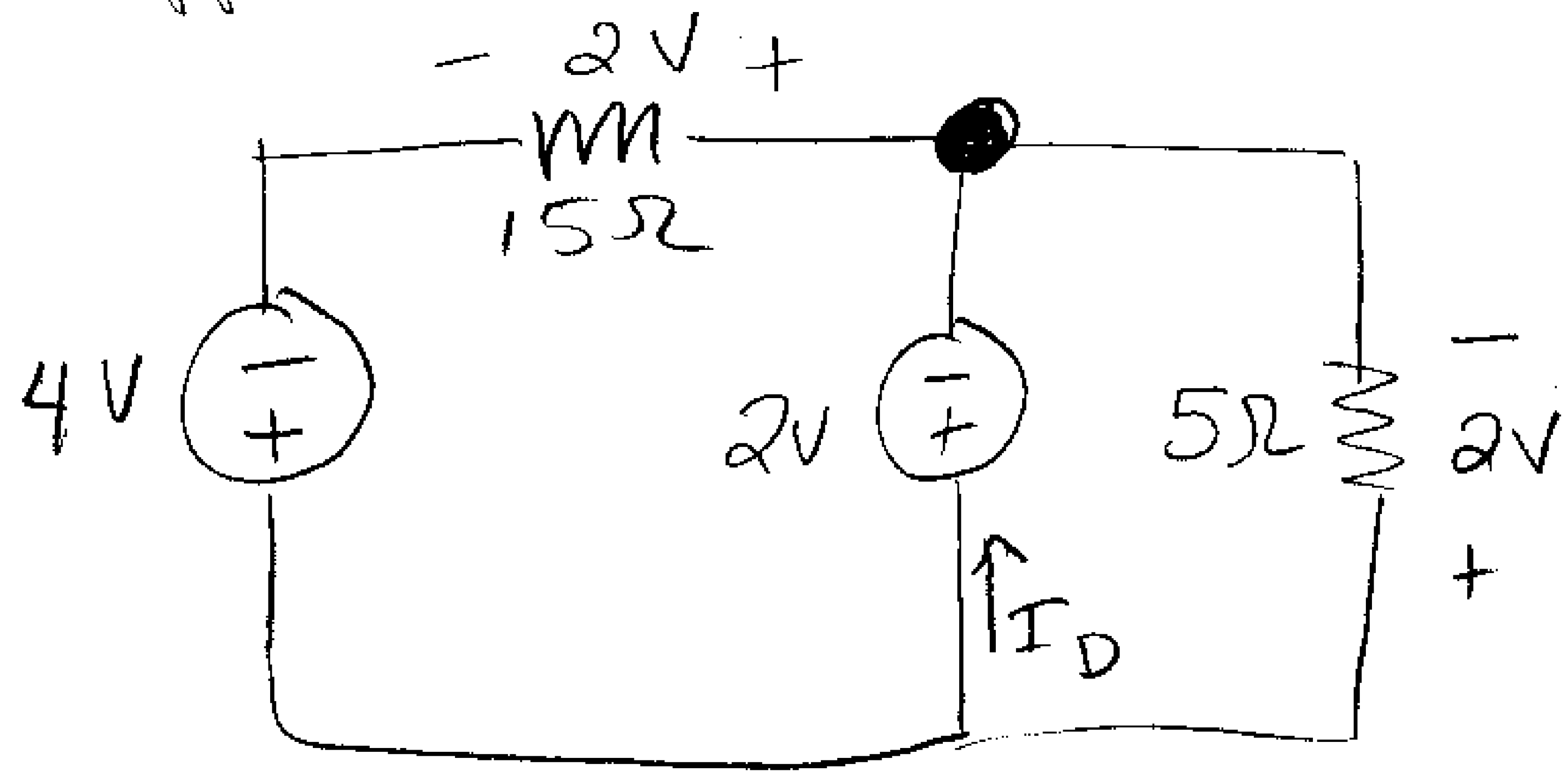
Problem 4: 15 Points Possible



Use the large-signal model for the diode, with V_F = 2 V.

Find V_{out}.

Suppose diode is forward biased. Verify $I_D \geq 0$.



By KVL, 15kΩ has 2V as shown.

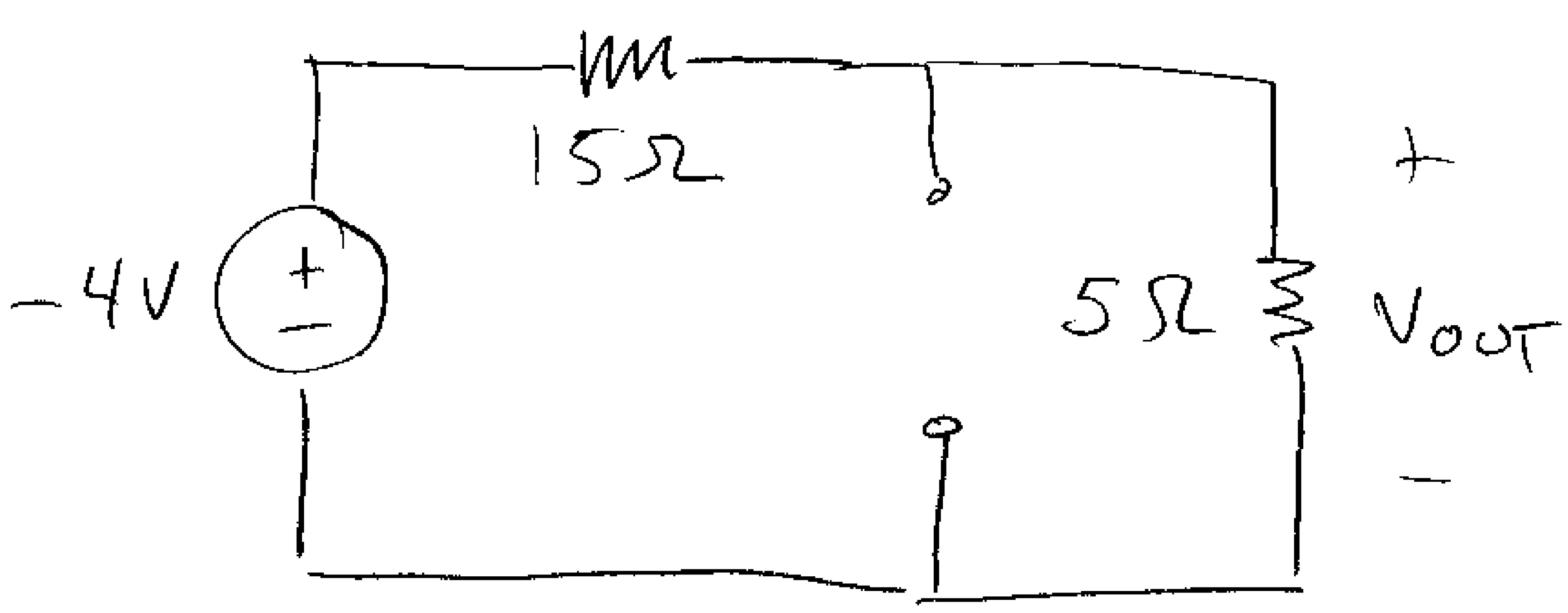
KCL at dot:

$$I_D + \frac{2V}{5\Omega} = \frac{2V}{15\Omega}$$

$$I_D = -\frac{4}{15} A$$

Not forward biased!

Must be reverse biased.



Resistors now in series,

By voltage division,

$$V_{OUT} = -4V \cdot \frac{5\Omega}{5\Omega + 15\Omega} = \boxed{-1V}$$

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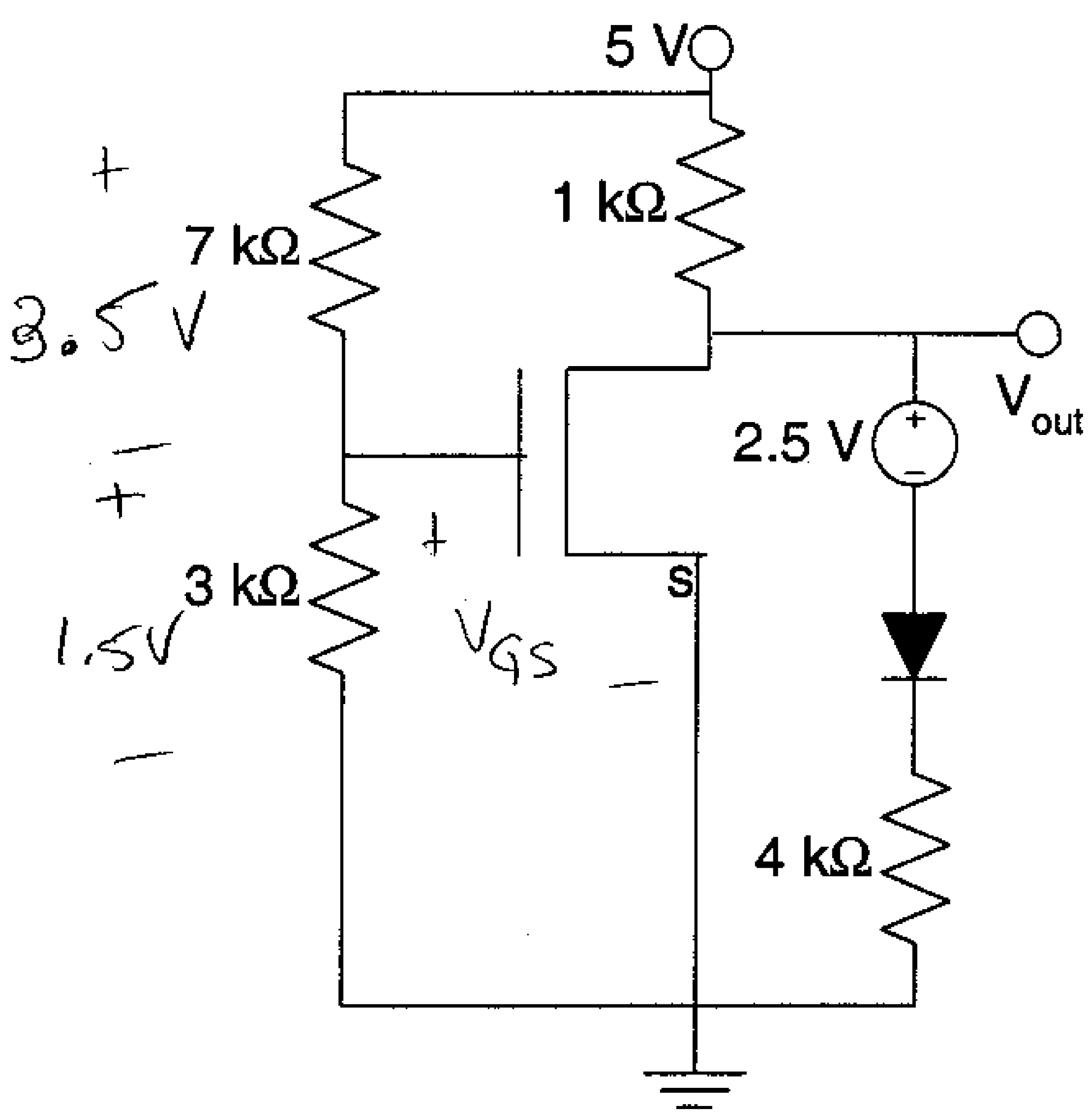
Problem 5: 15 Points Possible



$W/L\ \mu_n C_{ox} = 1\ mA/V^2$

$\lambda_n = 0\ V^{-1}$

$V_{TH(n)} = 1\ V$

Use the large-signal model for the diode with $V_F = 2$ V.

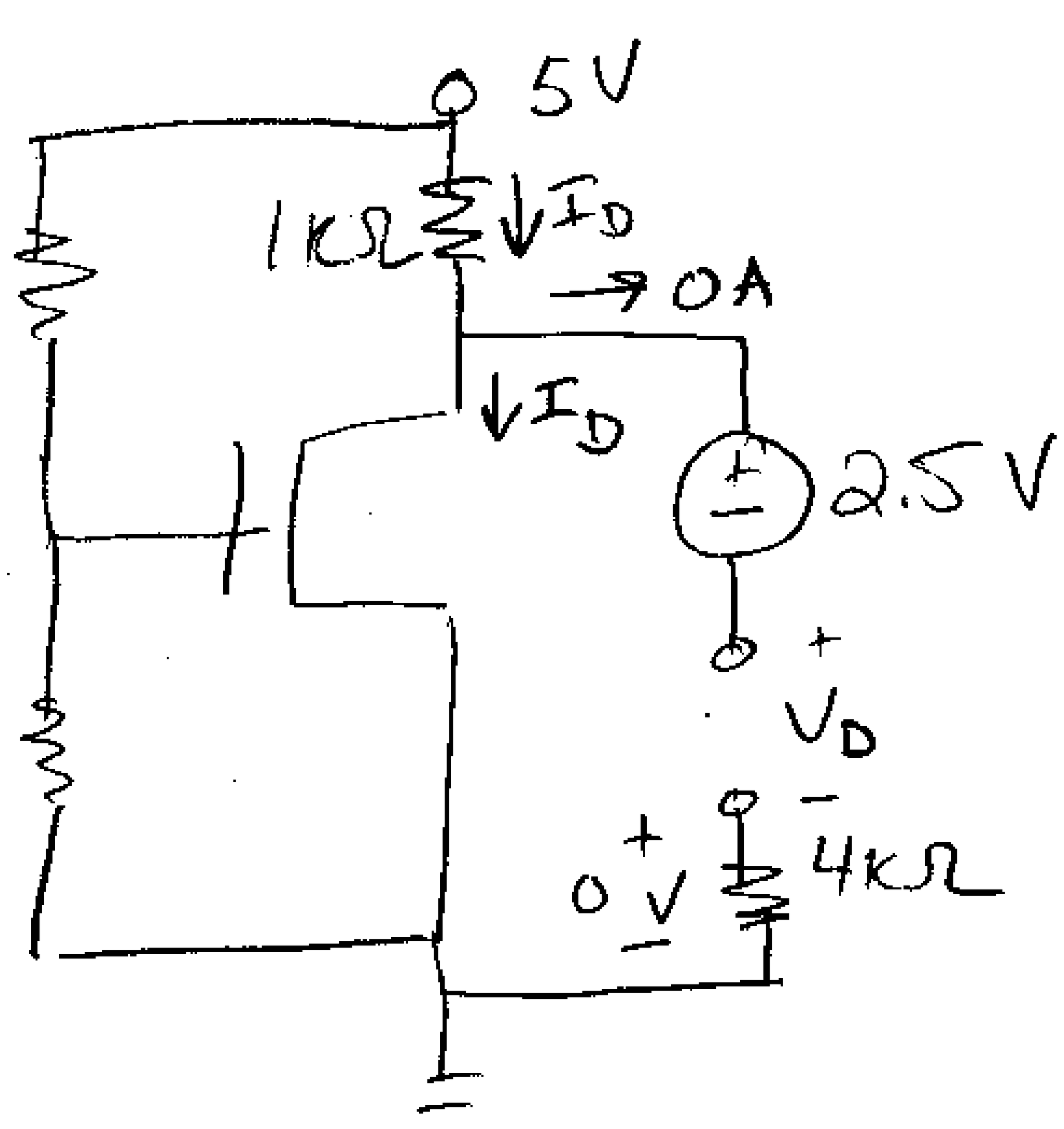
Find V_{out}.

By voltage division, 3kΩ resistor has 1.5 V.

$V_{GS} = 1.5\,V$ Not cutoff. Guess saturation.

$I_D = \frac{1}{2} \cdot 1mA/V^2 \left(1.5V - 1V\right)^2 = \frac{1}{8}\ mA$

Now find V_{DS} to verify saturation. Guess reverse bias for diode out of laziness. Must verify $V_D \leq 2V$.



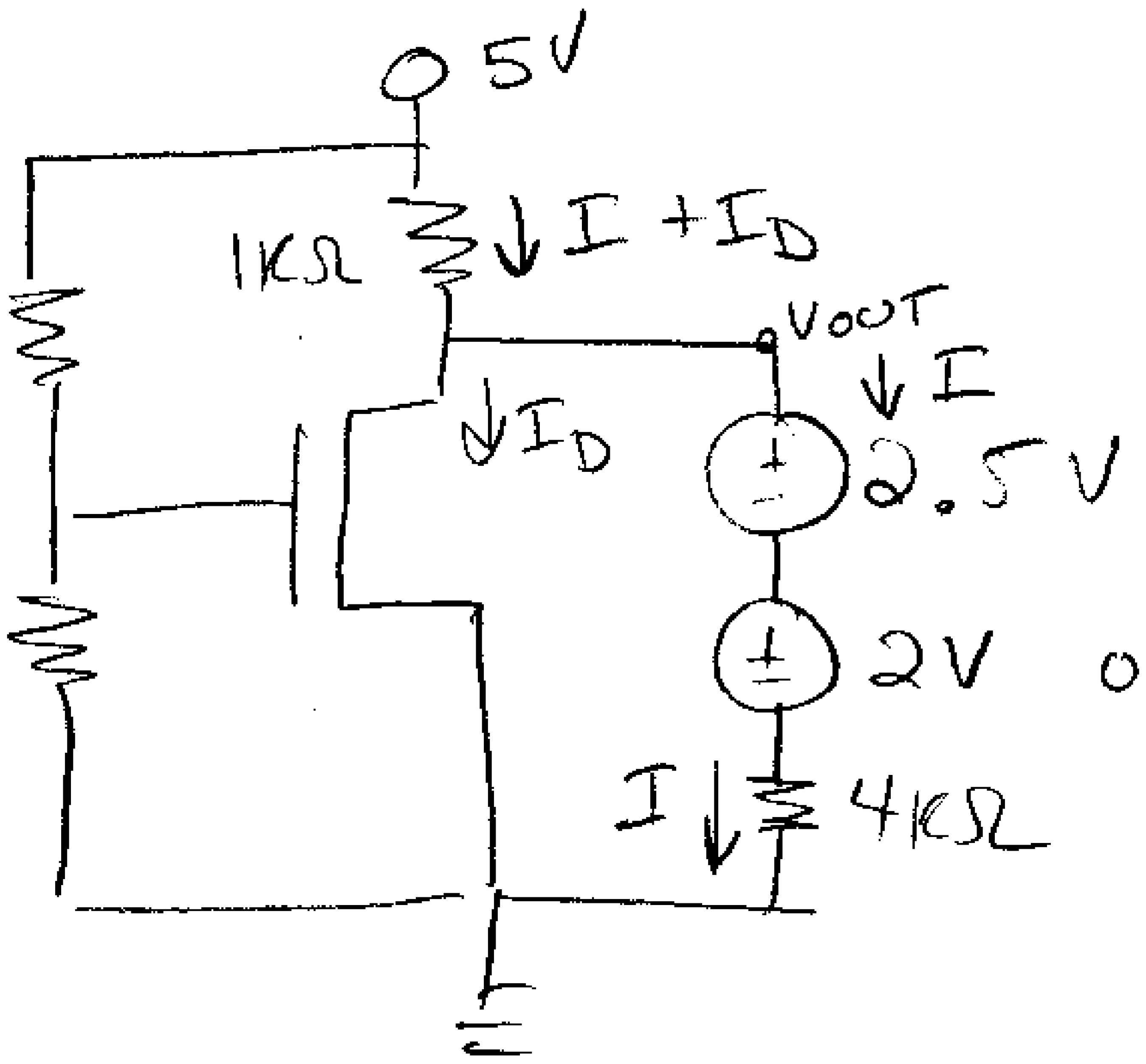
Since 0A thru open circuit, 1kΩ resistor carries I_D.
Also, 4kΩ resistor has 0V.

KVL:

$-0V - V_D - 2.5V - 1k\Omega I_D + 5V = 0$

$V_D = 2.375\,V$ not reverse biased!

Must be forward biased.



Now diode branch can conduct current. Call it I.

By KVL,

$$0 = -4k\Omega I - 2V - 2.5V - 1k\Omega(I + I_D) + 5V$$

$I_D = 1/8$ mA from saturation assumption

$$I = \frac{5V - 2V - 2.5V - 1/8\ V}{5k\Omega}$$

$$= \frac{3}{40}\ \text{mA}$$

Still need to verify $V_{DS} > \underbrace{V_{GS} - V_{TH}}_{1.5V - 1V = 0.5V}$ for saturation.

$V_{DS} = 2.5V + 2V + 4kI_D = 4.8V$ ok for saturation!

$V_{OUT} = V_{DS} = 4.8V$

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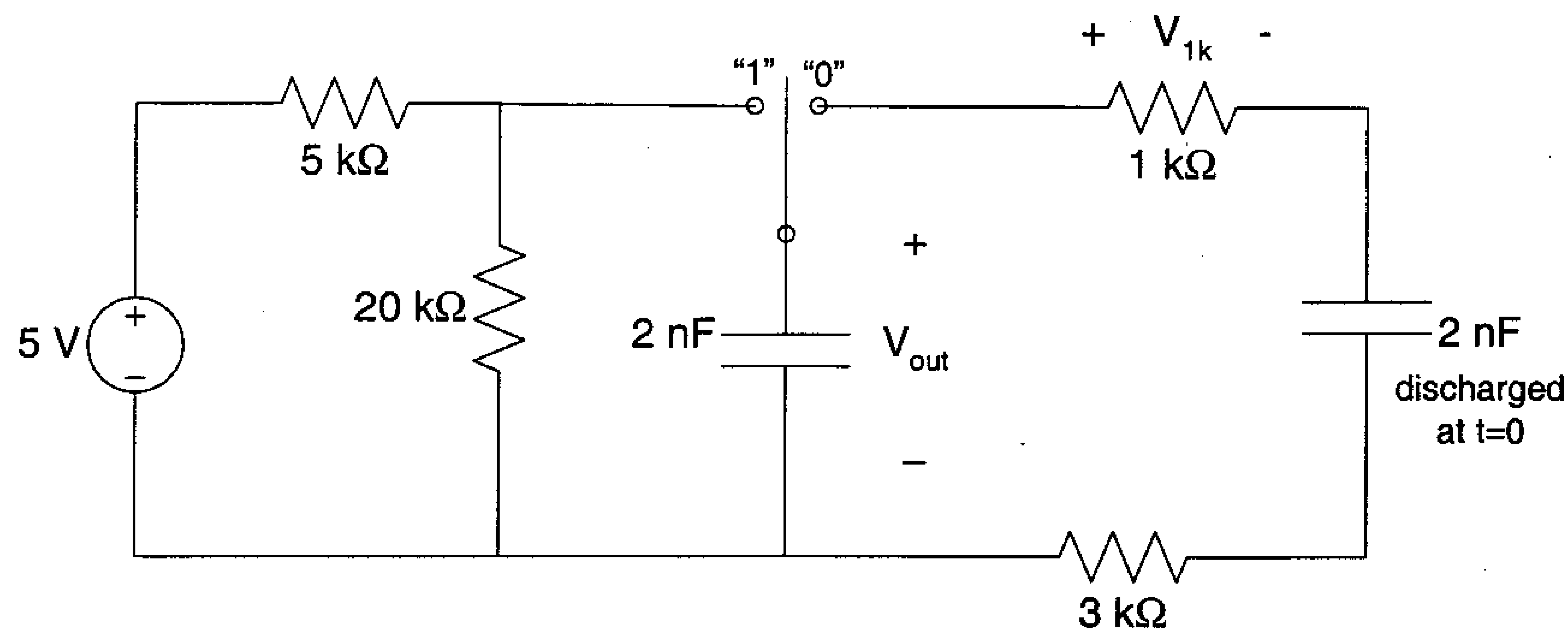
Problem 6: 15 Points Possible



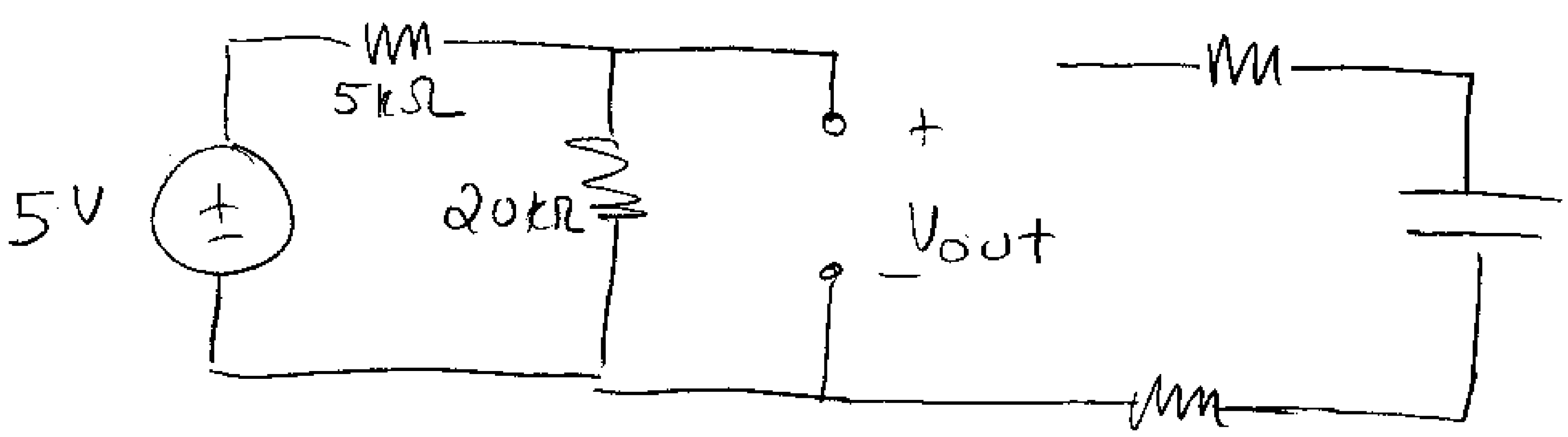
Suppose the circuit has been in position "1" for a long time.
At t = 0, it switches to position "0".
At t = 4 μs, it switches back to position "1".

a) Find $V_{out}(t)$ for all $t \geq 0$.

b) Find $V_{1k}(t)$ for all $t \geq 0$.

c) Find the total energy absorbed by the 1 kΩ resistor over the time period $t \geq 0$ (ending at ∞).

a) Use $t = 0^-$ circuit to find $V_{OUT}(0)$.



After a long time, Capacitor acts like open circuit.

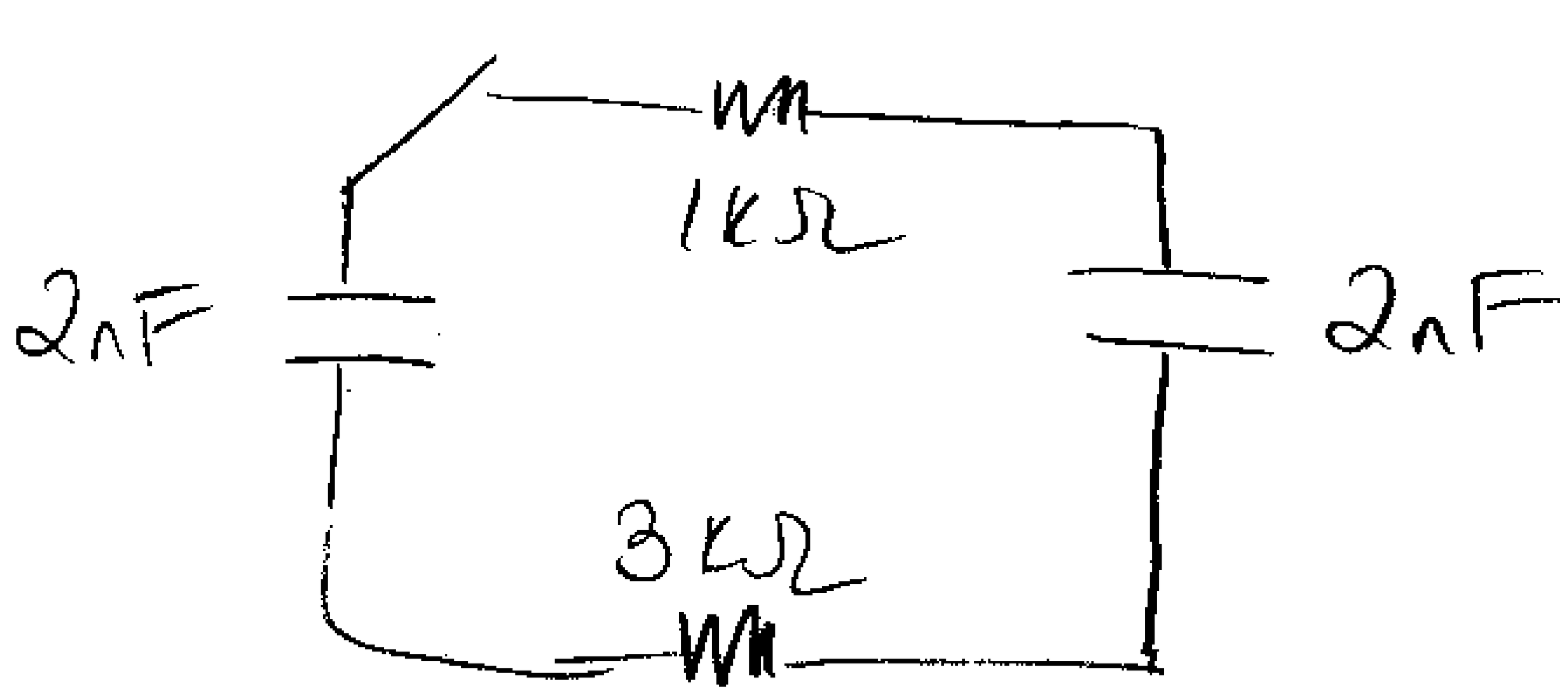
By voltage division, (5k + 20k act in series)

$V_{OUT}(0) = 4V$

V_{OUT} = Voltage over 20K

$= 5V \cdot \frac{20k\Omega}{20k\Omega + 5k\Omega} = 4V$

Use $t \geq 0$ circuit to find RC + $V_{OUT,f}$.



$RC = 4\mu s$

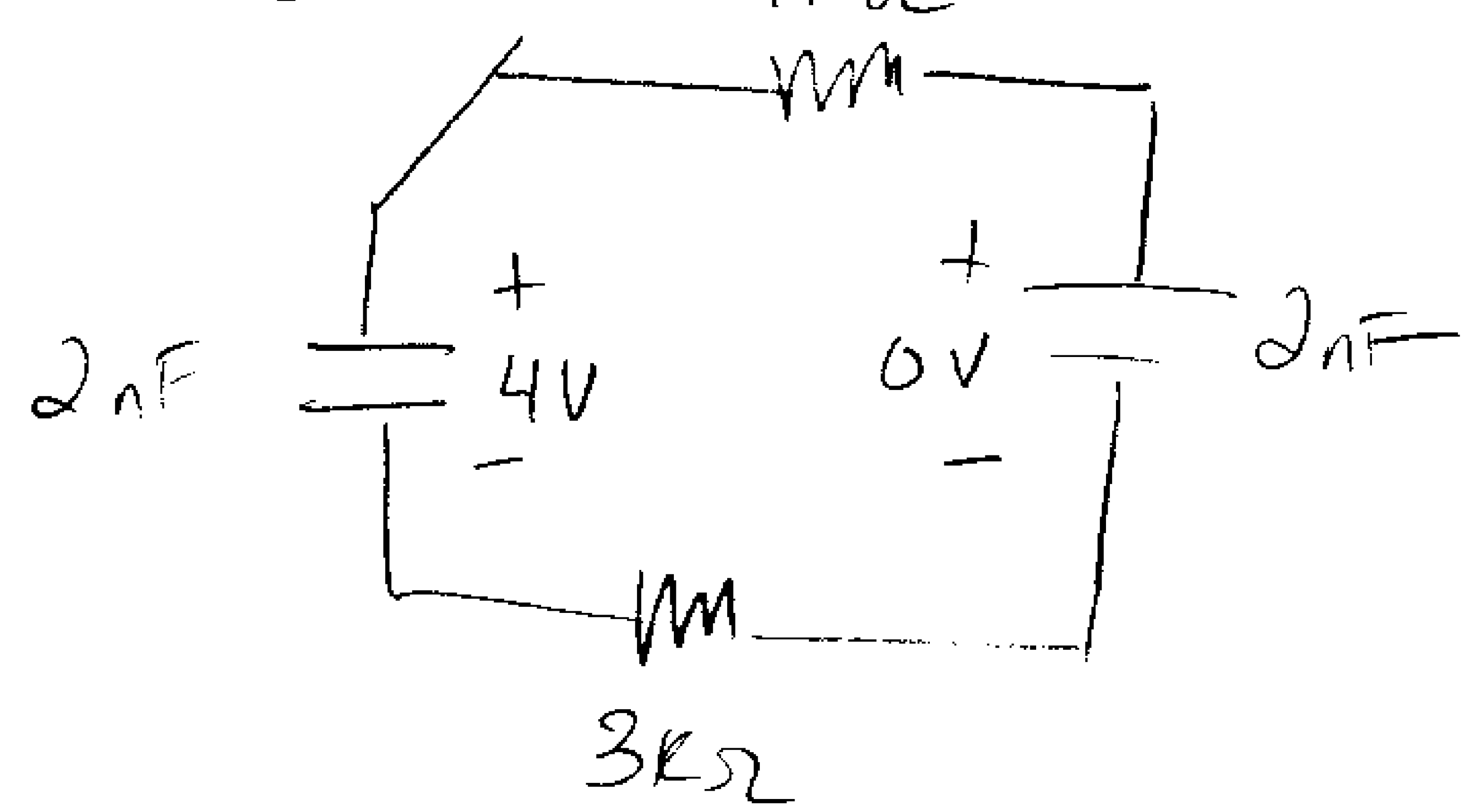
All in series.

$R = 1k + 3k = 4k\Omega$

$C = \left(\frac{1}{2nF} + \frac{1}{2nF}\right)^{-1} = 1nF$

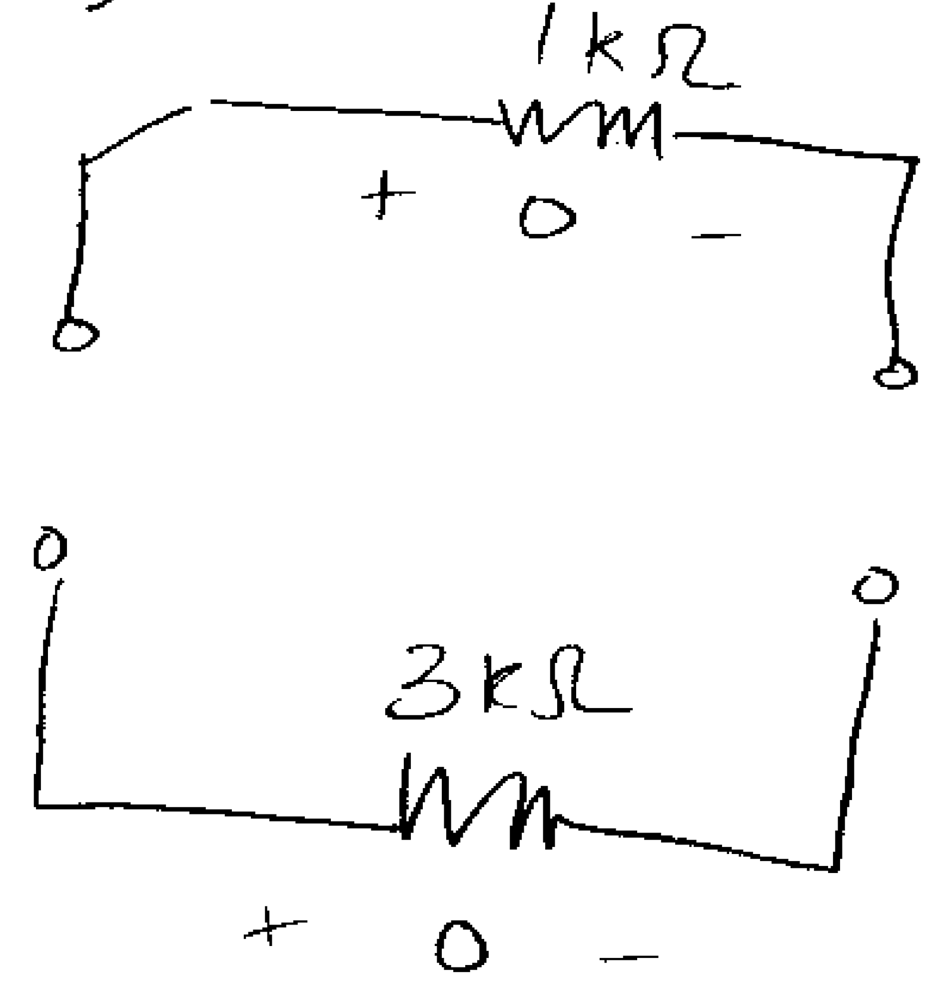
Problem 6, Page 2

$t = 0$:



Initially, left capacitor is charged & right is discharged.

$t \to \infty$:



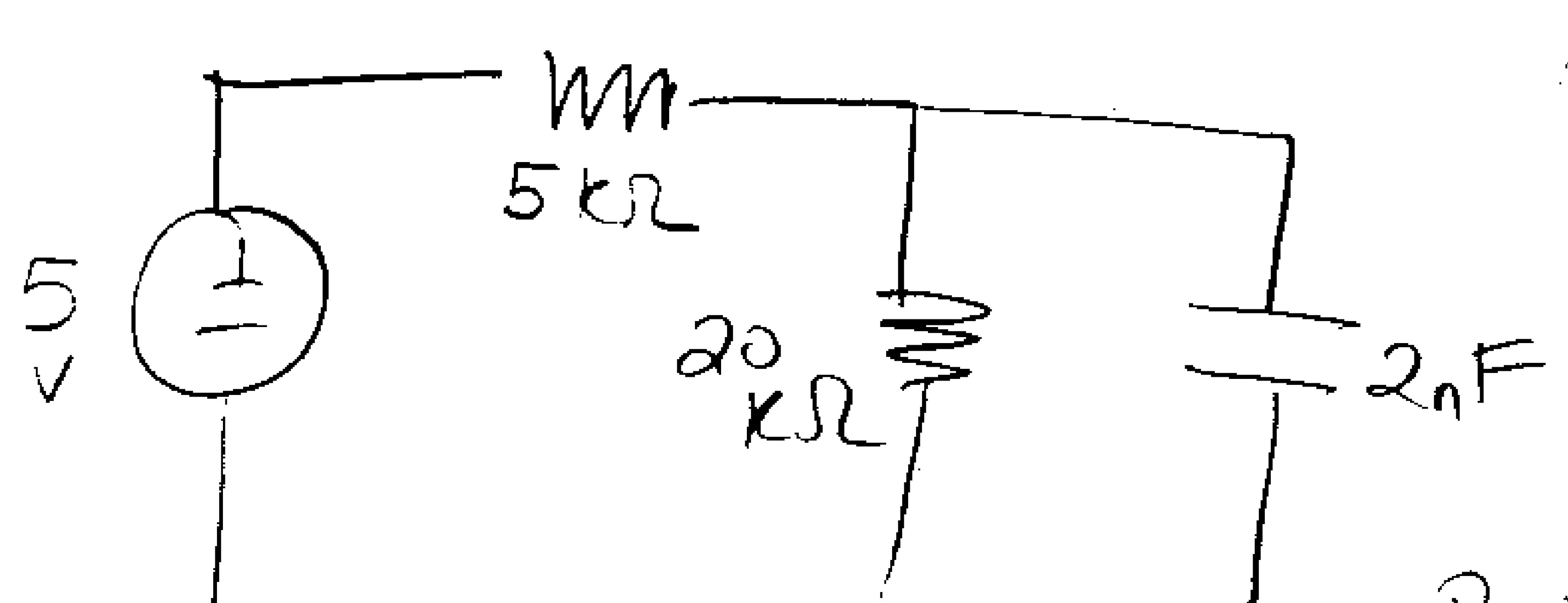
Eventually, both capacitors act as open circuits. So 0A flows, so both resistors have 0V. So both capacitors have equal voltage to satisfy KVL.

Left capacitor must give 1/2 its charge to right capacitor. Since capacitances equal, equal charge will result in equal voltage ($Q = CV$). $V_{OUT,f} = \frac{1}{2} V_{OUT}(0) = 2V$

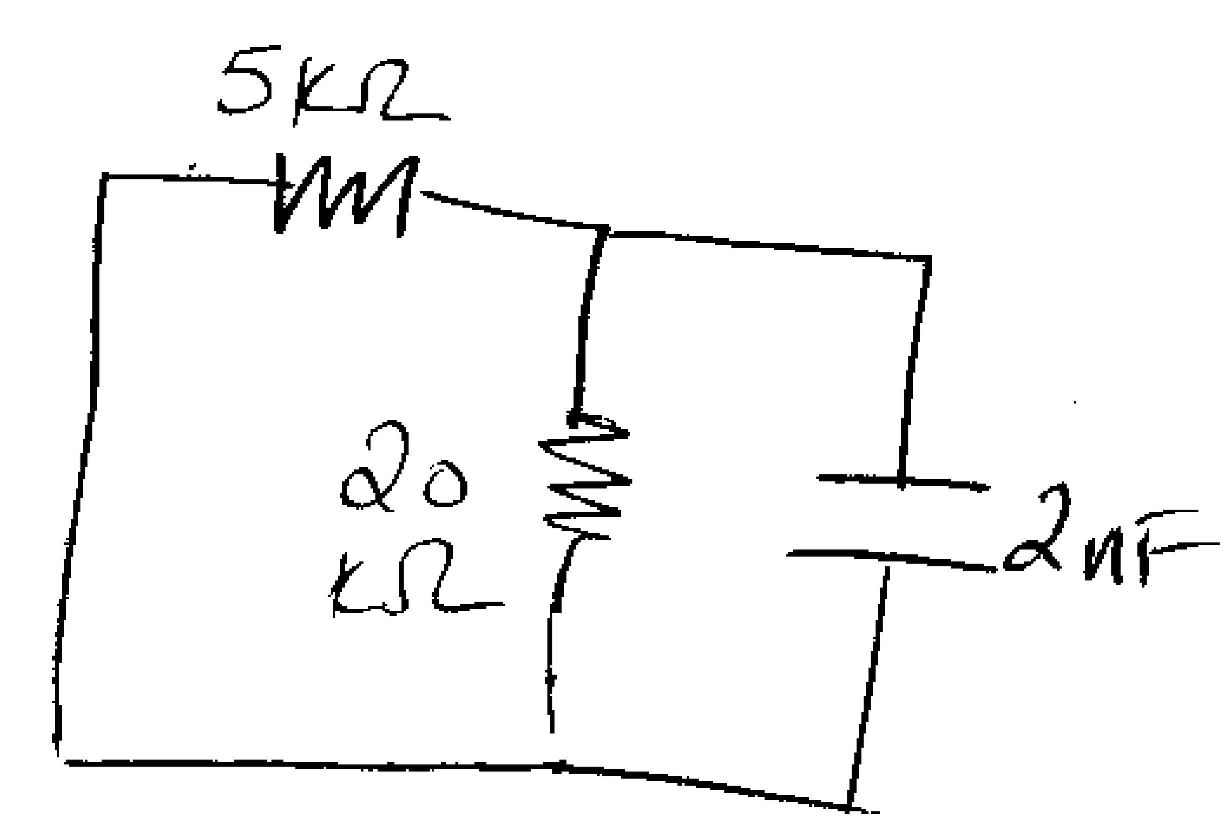
$$\boxed{\text{So until } t = 4\mu F, \quad V_{OUT}(t) = 2V + (4V - 2V)e^{-t/4\mu s} \text{ V.}}$$

At $t = 4\mu s$, switch occurs. $V_{OUT}(4\mu s) = 2V + 2Ve^{-\frac{4\mu s}{4\mu s}} = 2.74\ V$.

As $t \to \infty$, we go back to circuit at $t = 0^-$. $V_{out,f} = 4V$.



To see R_{eq}, kill voltage source. Resistors in parallel.



R_{eq} is $\left(\frac{1}{5k\Omega} + \frac{1}{20k\Omega}\right)^{-1} = 4k\Omega \quad RC = 8\mu s$

So after $t = 4\mu s$, $V_{OUT}(t) = 4V + (2.74 - 4V)\, e^{\frac{-(t-4\mu s)}{8\mu s}}$

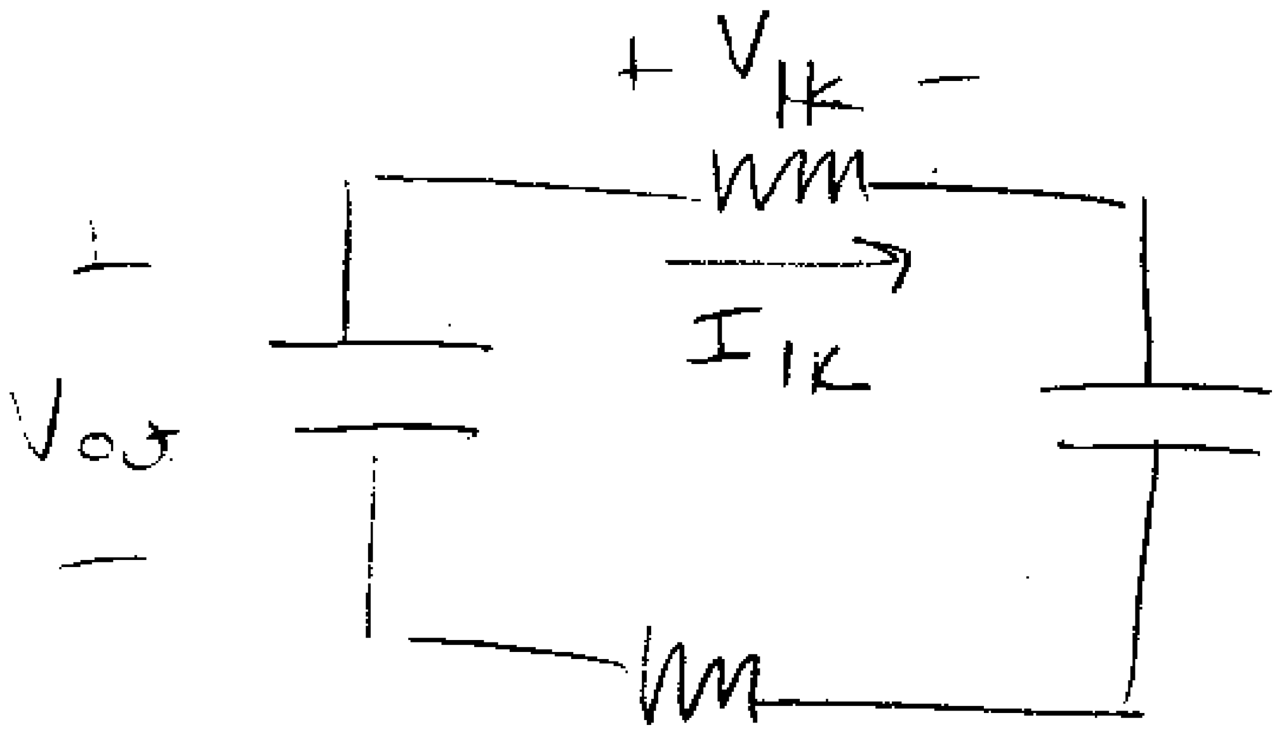
$$V_{out}(t) = \begin{cases} 2 + 2e^{-t/4\mu s}\ V & 0 \le t \le 4\mu s \\ 4 - 1.26\, e^{\frac{-(t-4\mu s)}{8\mu s}} & t > 4\mu s \end{cases}$$

b) We only have nonzero current through the $1k\Omega$ resistor when $0 \le t \le 4\mu s$ (resistor disconnected when in position "1").

$V_{1K}(t) = 0$ for $t > 4\mu s$.

When in position "0",

$$V_{1K}(t) = 1k\Omega\, I_{1K} = 1k\Omega\left(-2nF \frac{dV_{OUT}}{dt}\right)$$



$$= -(1\times10^{3})(2\times10^{-9})\left(\frac{-2}{4\times10^{-6}}\, e^{-t/4\mu s}\right) V$$

$$= e^{-t/4\mu s}\ V$$

So

$$V_{1K}(t) = \begin{cases} e^{-t/4\mu s}\ V & 0 \le t \le 4\mu s \\ 0 & t > 4\mu s \end{cases}$$

c) $$E = \int_0^{4\mu s} P(t)\,dt = \int_0^{4\mu s} V_{1K}(t)^2/1K\Omega\,dt$$

$$= \int_0^{\infty} e^{-\frac{2t}{4\mu s}}/1000\,dt$$

$$= \frac{1}{1000}\cdot\frac{-4\times10^{-6}}{2}\left(e^{-2t/4\mu s}\right)\Big|_0^{4\mu s}$$

$$= -\frac{4\times10^{-6}}{2000}\left(e^{-2}-1\right) = 1.7\,nW$$

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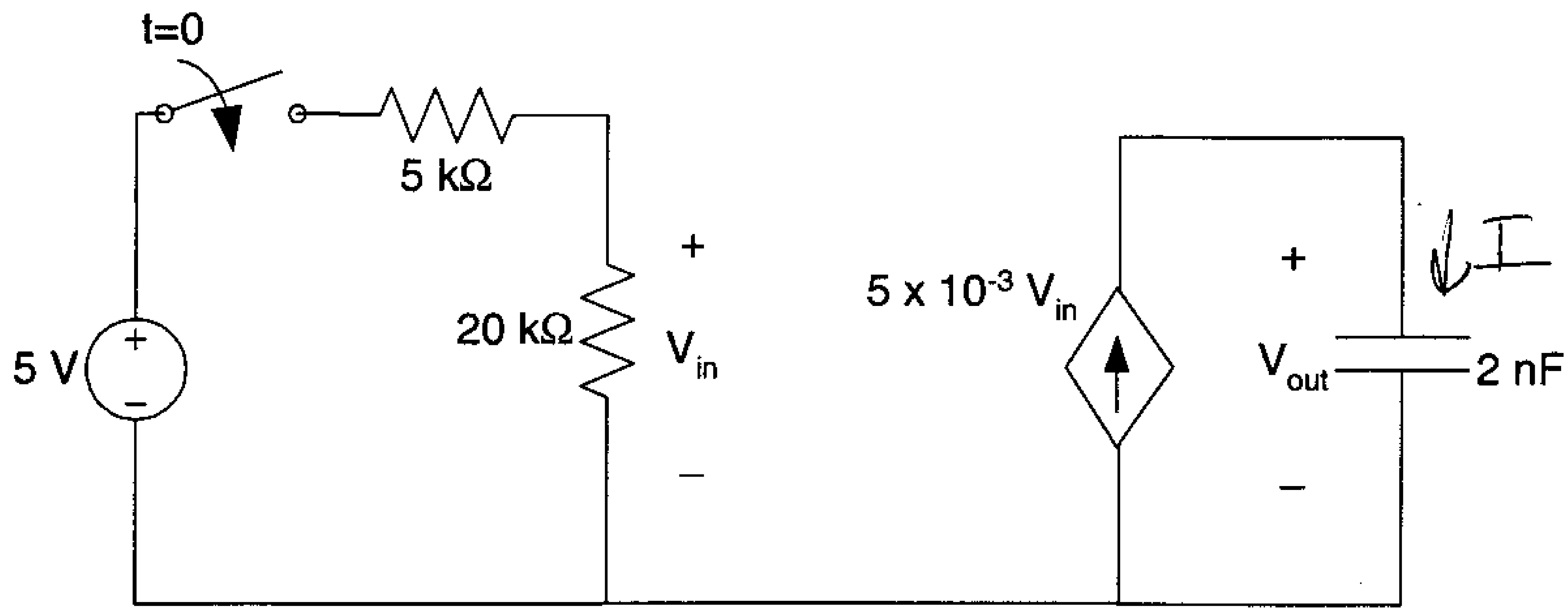
Problem 7: 10 Points Possible



Suppose that $V_{out}(0) = 1$ V.

Find $V_{out}(t)$ for $t \geq 0$.

for $t \geq 0$,

$$I = C \frac{dV_{OUT}}{dt} \qquad 5 \times 10^{-3} V_{IN} = 2 \times 10^{-9} F \frac{dV_{OUT}}{dt}$$

$V_{IN} = 4V$ for $t \geq 0$ by voltage division

$$\frac{dV_{OUT}}{dt} = \frac{5 \times 10^{-3} \cdot 4}{2 \cdot 10^{-9}} V/s = 10 \cdot 10^{6} V/s$$

$$V_{out}(t) = \int_0^t \frac{dV_{out}}{dt'} dt' + V_{OUT}(0)$$

$$= \int_0^t 10^7 dt' + 1V$$

$$= 10^7 t + 1$$