Proctor Copy

Midterm 2
EE40
Fall 2014

NAME:_____

Instructions

Read all of the instructions and all of the questions before beginning the exam.

There are 4 problems in this exam. The total score is 100 points. Points are given next to each problem to help you allocate time. Do not spend all your time on one problem.

Unless otherwise noted on a particular problem, you must show your work in the space provided, on the back of the exam pages or in the extra pages provided at the back of the exam.

Draw a BOX or a CIRCLE around your answers to each problem.

Be sure to provide units where necessary.

GOOD LUCK!

PROBLEM	POINTS	MAX
1		25
2		25
3		25
4		25

"Beyond the Wild Wood comes the Wide World," said the Rat. "And that's something that doesn't matter, either to you or me. I've never been there, and I'm never going, nor you either, if you've got any sense at all. Don't ever refer to it again, please."
— *The Wind in the Willows*, *Kenneth Grahame*

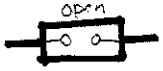
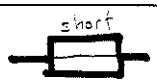
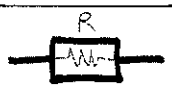
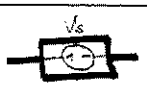
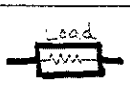
Problem 1 *(25 points)*

Consider the circuits below. Several components have been left "blank" for you to fill in.

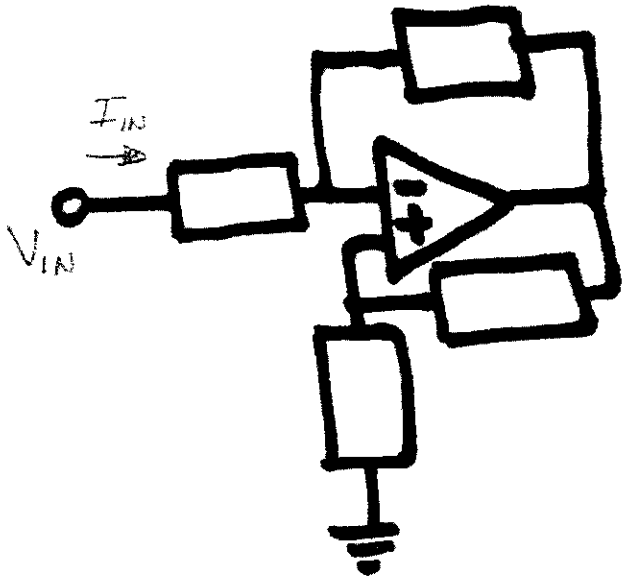
- The op amp is ideal in each case.
- In all cases, the opamp is connected to an ideal voltage source of value V_{IN} where shown.
- All sources are DC.
- The value of the load is unknown so your design should be able to satisfy the question regardless of the load value
- Voltages are in [V] and currents are in [A]; constants are in the appropriate units.

IMPORTANT: Partial credit will only be given if you show your work and solution (we can't give you partial points for blank circuits!).

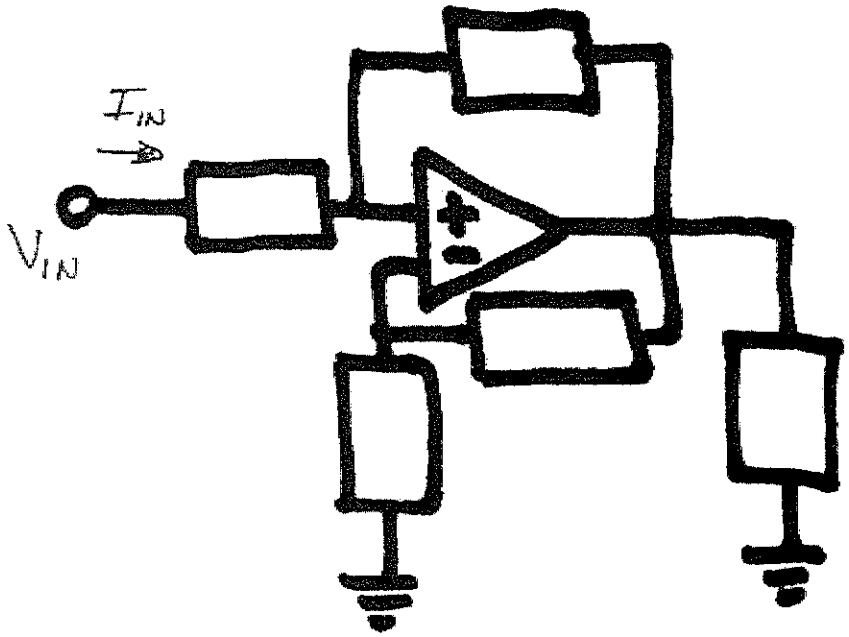
You have at your disposal ONLY ONE OF EACH of the following components:

an open circuit	
a short circuit	
a resistor (you choose the value)	
a capacitor	
an inductor	
a DC voltage source (you choose *a fixed value*)	
a load (whose value is unknown but high enough that the amp can drive it)	

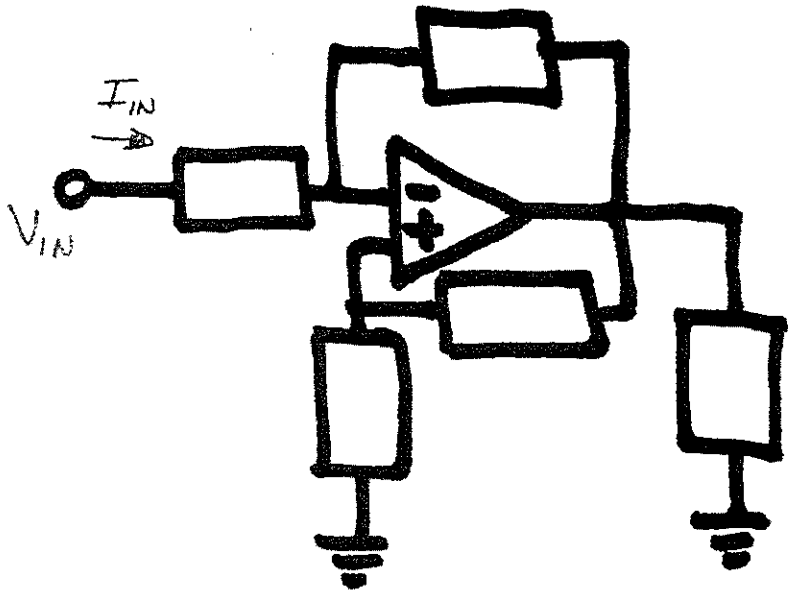
a) Draw components in all boxes below so that *the current through* ***the load*** *is exactly* $I_L = V_{IN} / 5$ *[A]*. You can place the load in any box. Remember you only have one of each component. *(10 points)*



b) Draw in components in all boxes below so that the voltage across **the load** is exactly $\mathbf{V_L = 11V_{IN}}$ [V]. You can place the load in any box. In addition to the ONE load, you may use TWO resistors and ONE of everything else. *(7.5 points)*



c) Draw in components in all boxes below so that the voltage across **the load** is exactly $\mathbf{V_L = -10I_{IN}}$ [V]. You can place the load in any box. In addition to the ONE load, you may use TWO resistors and ONE of everything else. *(7.5 points)*



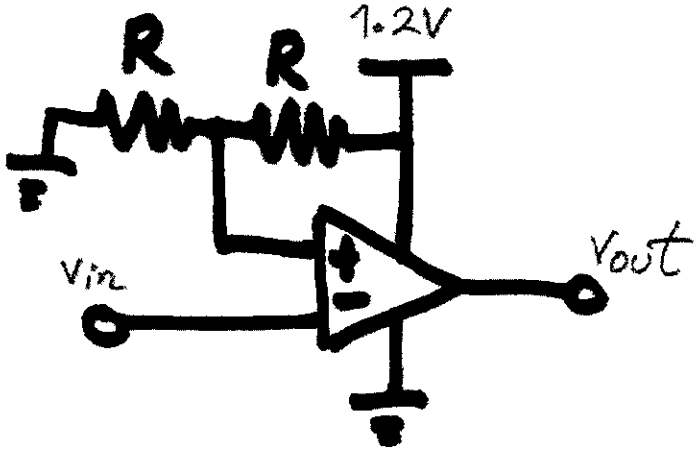
Extra Space

"When you are a Bear of Very Little Brain, and you Think of Things, you find sometimes that a Thing which seemed very Thingish inside you is quite different when it gets out into the open and has other people looking at it."
— *Winnie-the-Pooh*, A.A. Milne

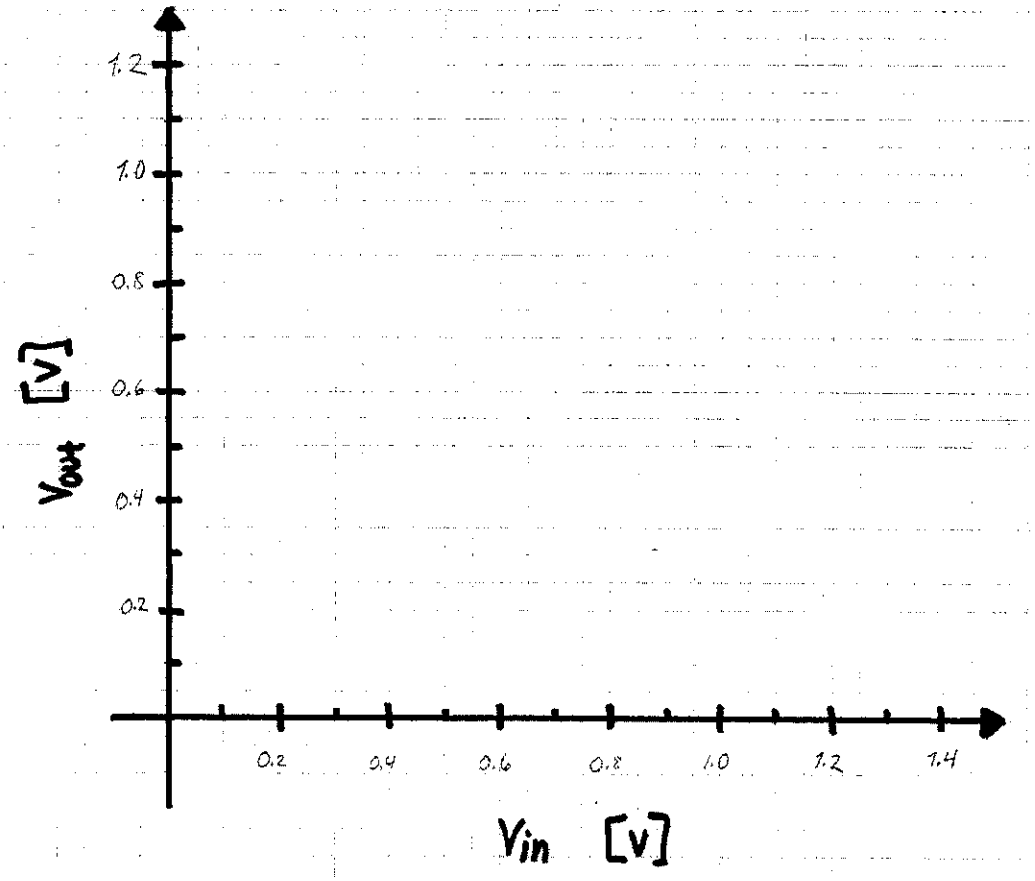
Problem 2 *(25 points)*

Consider the circuit below.

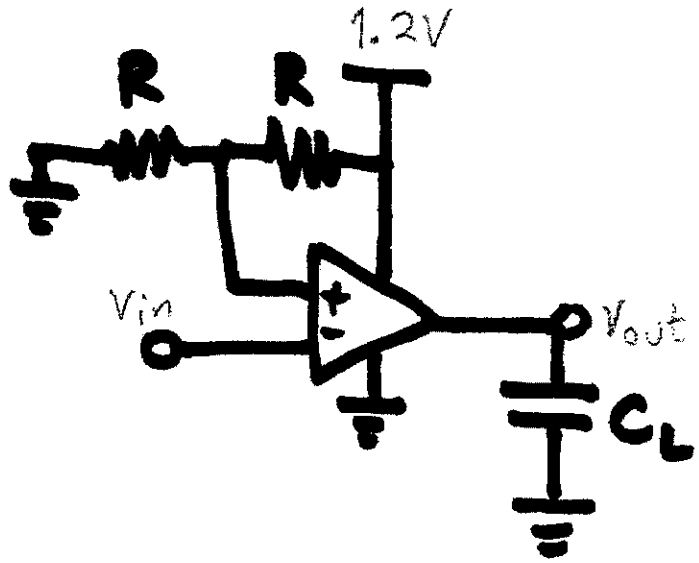
- Note that the upper (1.2 V) and lower (0 V) rails are specified for the amplifier.
- R = 1kΩ
- For the amplifier shown, the open loop gain, A = 10; $R_{in} = 10^9\ \Omega$ and $R_o = 10\ \Omega$.



a) Plot v_{out} as a function of v_{in} for v_{in} from 0 to 1.2 V in the graph below. *(10 points)*



b) Now consider the same circuit but with a capacitance at the output, as shown below. *(10 points)*



- For this part, $v_{in} = 0$ for $t < 0$ and jumps instantly to 1.2 V for $t \geq 0$.
- Provide a symbolic expression for $v_{out}(t)$ for $t \geq 0$.

Solution:

at what time t is vout halfway between is initial and final value?

c) If $C_L = 10\ \mu F$, ~~how long does it take for v_{out} to reach 50% of its final value~~? If pressed for time, provide a symbolic answer, then come back and fill in the numbers. *(5 points)*

Solution:

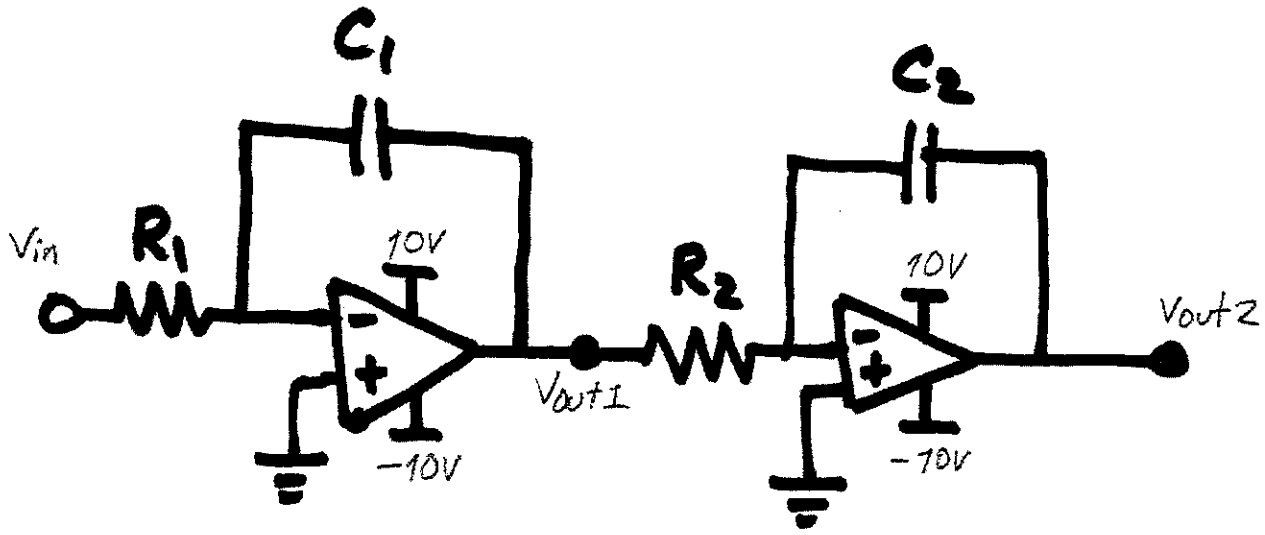
Extra Space

"God does not play dice with the universe; He plays an ineffable game of His own devising, which might be compared, from the perspective of any of the other players [i.e. everybody], to being involved in an obscure and complex variant of poker in a pitch-dark room, with blank cards, for infinite stakes, with a Dealer who won't tell you the rules, and who smiles all the time."

— *Terry Pratchett, Good Omens: The Nice and Accurate Prophecies of Agnes Nutter, Witch*

Problem 3 *(25 points)*

Consider the two stage op amp below.



- The op amps are ideal.
- It is driven by an input step voltage, $v_{in}(t)$
- The value of $v_{in}(t) = 0$ for $t < 0$ and 10 mV for $t \geq 0$.
- Neither capacitor is charged prior to $t = 0$
- $R_1 = 5\ k\Omega$, $R_2 = 4\ M\Omega$, $C_1 = 4\ \mu F$, $C_2 = 5\ \mu F$.

a) Provide an expression for $v_{out1}(t)$ for $t \geq 0$. *(10 points)*

Solution:

b) Provide an expression for $v_{out2}(t)$ for $t \geq 0$. (10 points)

Solution:

c) Does the output of the first amplifier ever saturate? If so, at what time, t, does this happen? *(5 points)*

Solution:

"Beyond the Wild Wood comes the Wide World," said the Rat. "And that's something that doesn't matter, either to you or me. I've never been there, and I'm never going, nor you either, if you've got any sense at all. Don't ever refer to it again, please."
— *The Wind in the Willows*, Kenneth Grahame

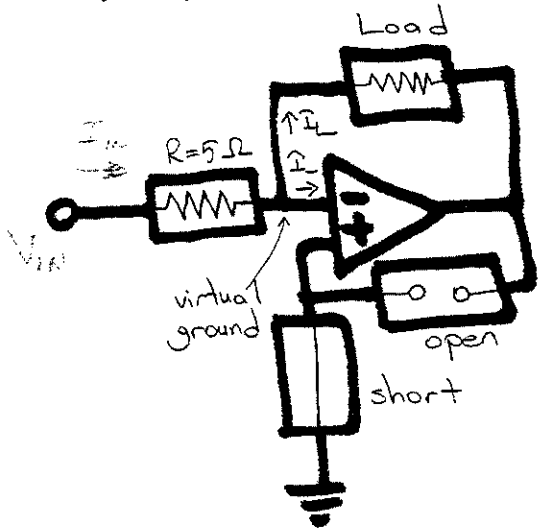
Problem 1 *(25 points)*

Consider the circuits below. The op amp is ideal in each case. In all cases, the opamp is connected to an ideal voltage source of value V_{IN} where shown. Several components have been left "blank" for you to fill in.

You have at your disposal ONLY ONE OF EACH of the following components:

an open circuit	
a short circuit	
a resistor (you choose the value)	
a capacitor	
an inductor	
a voltage source	
a load (whose value is unknown but high enough that the amp can drive it)	

a) Draw components in all boxes below so that *the current through* ***the load*** *is exactly* $V_{IN}/5$ ***[A]***. You can place the load in any box. Remember you only have one of each component. *(10 points)*

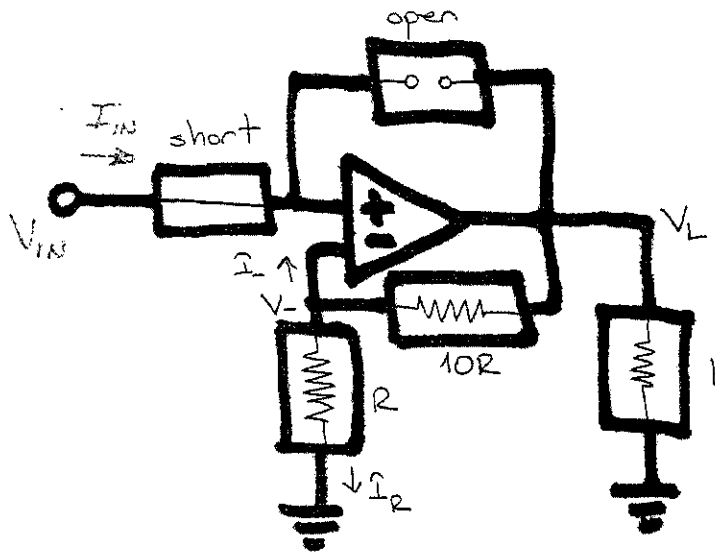


$I_{IN} = V_{IN}/(5\Omega)$ $\quad I_- = 0$ since the opamp is ideal

$I_L = I_{IN} - I_-$

$\boxed{I_L = V_{IN}/5\ [A]}$

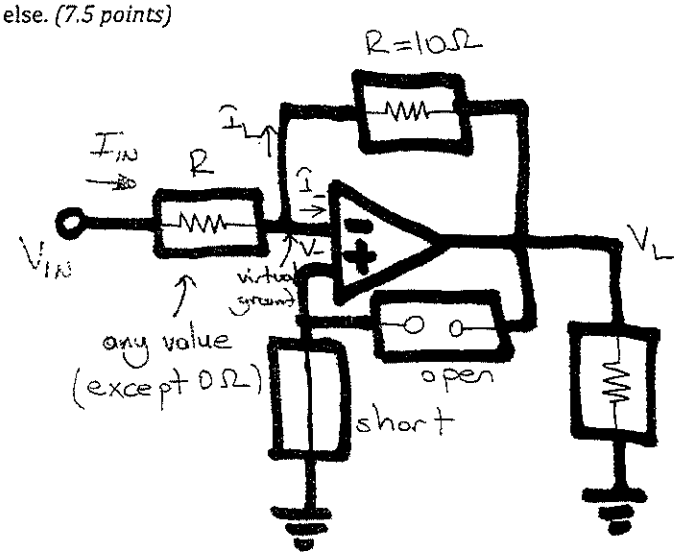
b) Draw in components in all boxes below so that the voltage across **the load** is exactly **$11V_{IN}$ [V]**. You can place the load in any box. In addition to the ONE load, you may use TWO resistors and ONE of everything else. *(7.5 points)*



The opamp is ideal:
$V_{IN} = V_-$ and $I_- = 0$
$I_R = V_{IN}/R$ ---(1)
$V_L = I_R(R) + I_R(10R)$
$= 11 I_R(R)$ ---(2)
Substitute (1) in (2)

$V_L = 11 V_{IN}$ [V]

c) Draw in components in all boxes below so that the voltage across **the load** is exactly **$-10I_{IN}$ [V]**. You can place the load in any box. In addition to the ONE load, you may use TWO resistors and ONE of everything else. *(7.5 points)*



The opamp is ideal:
$I_- = 0$ --(1). $V_- = 0$ --(2) virtual ground

KCL:
$I_{IN} = I_L + I_-$ ---(3)
Substitute (1) in (3)
$I_{IN} = I_L$ ---(4)

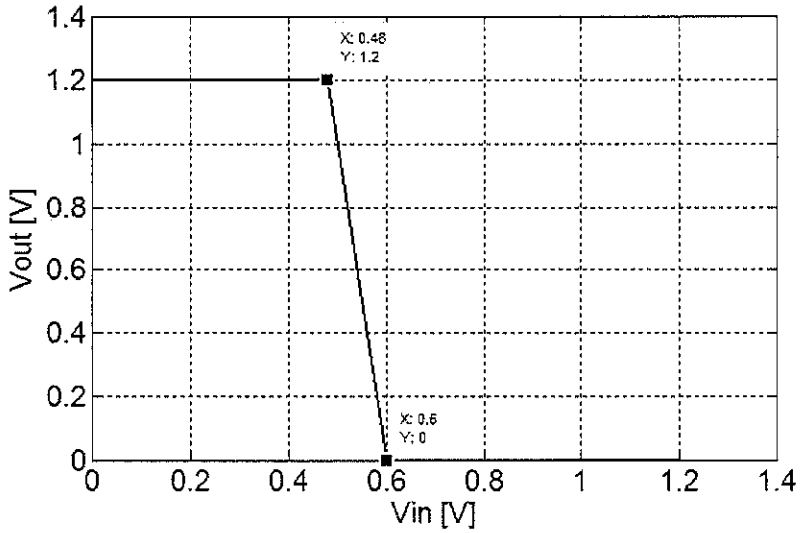
KVL:
$V_L = V_- - I_L(10\Omega)$ ----(5)
Substitute (2) in (5)
$V_L = -I_L(10\Omega)$ ---(6)
Substitute (4) in (6)

$V_L = -10 I_{IN}$ [V]

Problem2

a)

$V_{out} = (0.6 - V_{in}) \times 10$, but it saturates when larger than 1.2V or smaller than 0V.



b)

initial condition=1.2V

final condition= 0V

time constant = $R_o C_L$

$V_{out}(t) = 1.2 \cdot e^{\frac{-t}{R_o C_L}}$[V]

c)

$V_{out}(t_{50\%}) = 1.2 \cdot e^{\frac{-t_{50\%}}{R_o C_L}} = 0.6$

$t_{50\%} = (ln2) \cdot R_o C_L$

ee40
m+2 q3. (a) $\frac{V_{out1}}{V_{in}} = -\frac{1}{sR_1C_1}$

$$V_{out1} = \int_0^t -\frac{1}{R_1C_1} V_{in}\, dt + V_{in}(0)$$

$$= \int_0^t -\frac{1}{R_1C_1} 10m\, dt + V_{in}(0)$$

$$= -\frac{10m}{5k \cdot 4u} \int_0^t dt + 0$$

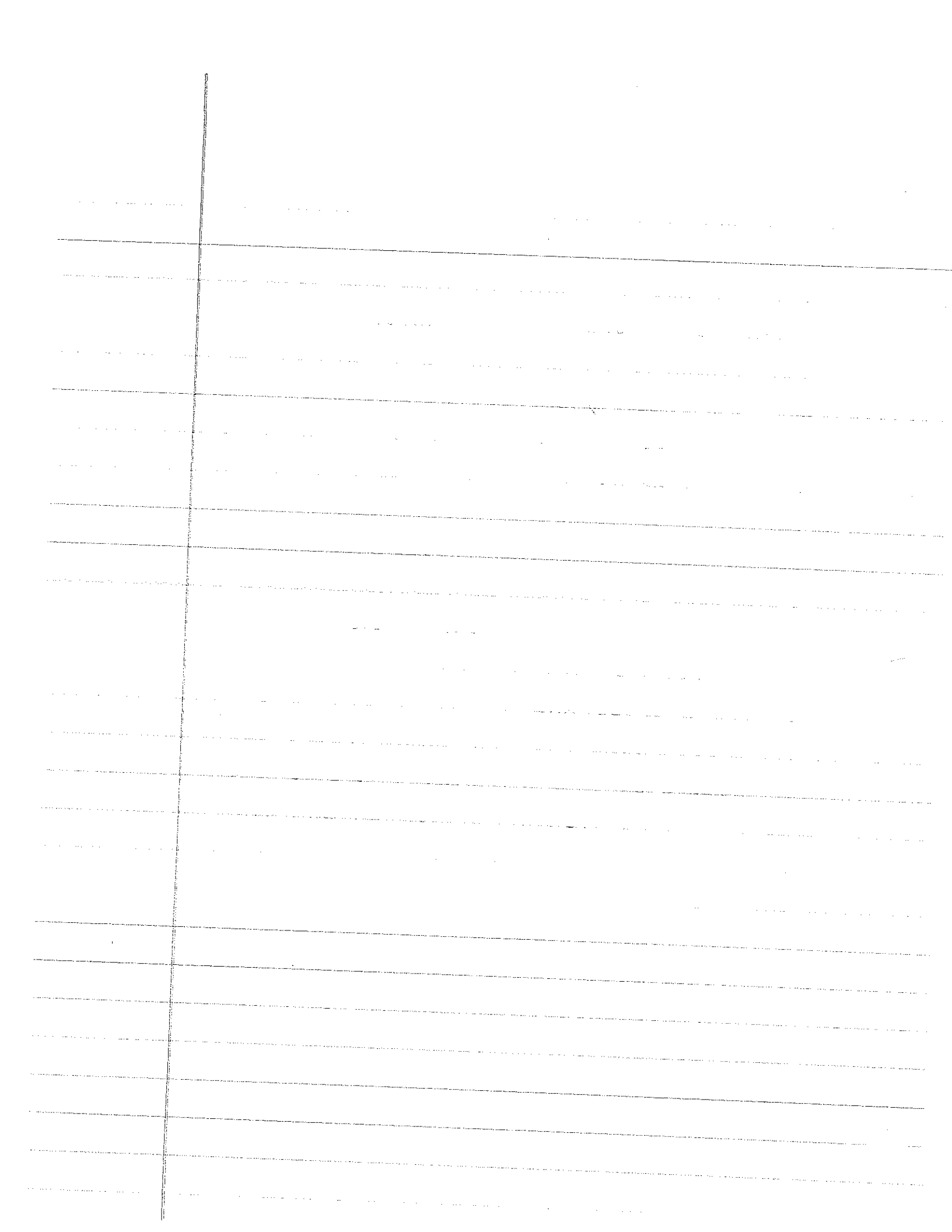
$$= -\frac{1}{2} t \qquad t \geq 0$$

when V_{out1} becomes saturated,

$V_{out1} = -10V = -\frac{1}{2}t$,

$\Rightarrow t = 20$ sec.

$$\therefore V_{out1} = \begin{cases} -\frac{1}{2}t & \text{for } 0 \leq t \leq 20 \text{ sec} \\ -10V & \text{for } t > 20 \text{ sec} \end{cases}$$



q3 (b) $\frac{V_{out2}}{V_{out1}} = -\frac{1}{sR_2C_2}$

$$V_{out2} = \int_0^t -\frac{1}{R_2C_2} V_{out1}\, dt + V_{out2}(0)$$

$$= \int_0^t \left(-\frac{1}{4M \cdot 5u}\right)\left(-\frac{1}{2}t\right) dt + 0$$

$$= \frac{1}{40}\int_0^t t\, dt$$

$$= \frac{1}{80} t^2 \qquad 0 \le t \le 20 \text{ sec}$$

$$V_{out2} = \int_{20}^t -\frac{1}{R_2C_2} V_{out1}\, dt + V_{out2}(20)$$

$$= \int_{20}^t \left(-\frac{1}{4M \cdot 5u}\right) \cdot (-10)\, dt + \frac{1}{80}(20)^2$$

$$= \frac{1}{2}(t-20) + 5$$

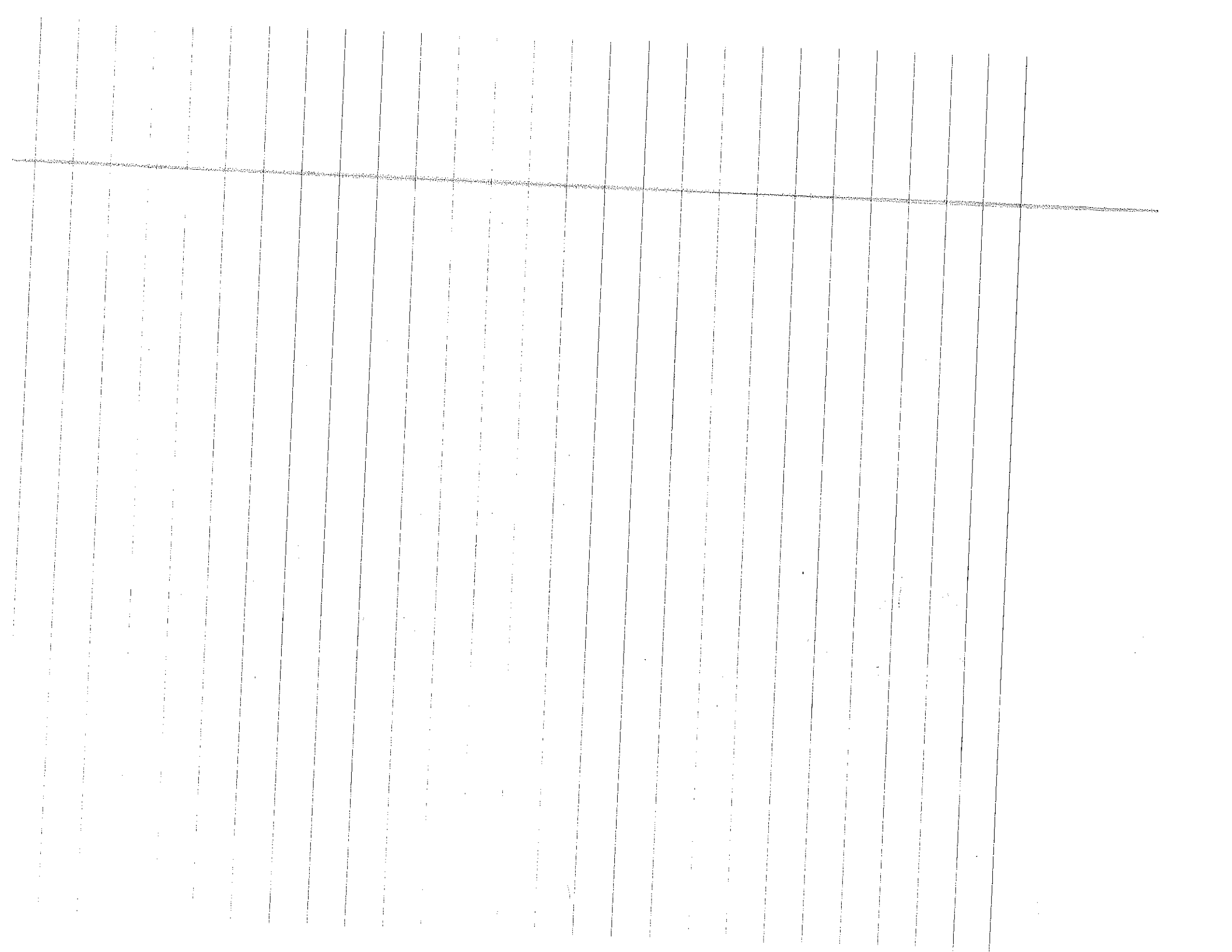
$$= \frac{1}{2}t - 5 \qquad t > 20 \text{ sec}$$

When V_{out2} saturates, $V_{out2} = 10V = \frac{1}{2}t - 5$

$\Rightarrow t = 30$ sec

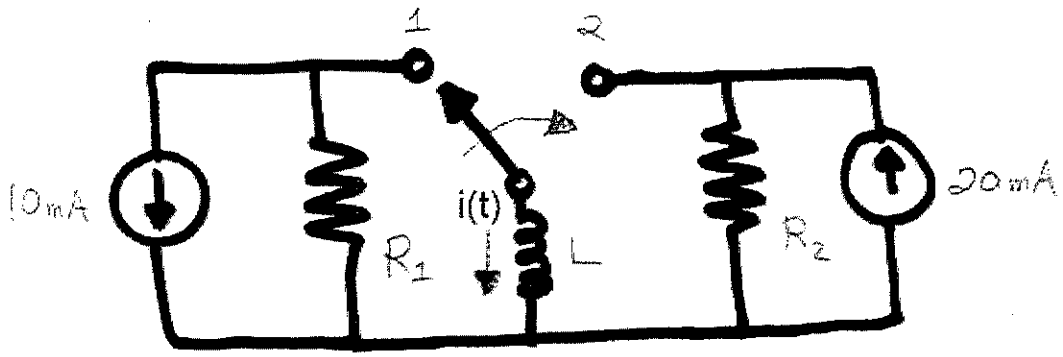
$$\therefore V_{out2} = \begin{cases} \frac{1}{80}t^2 & 0 \le t \le 20 \text{ sec} \\ \frac{1}{2}t - 5 & 20 < t \le 30 \text{ sec} \\ 10V & t > 30 \text{ sec} \end{cases}$$

q3 (c) $t = 20$ sec.



I have something to say! It's better to burn out than to fade away!
- *the Kurgan, Highlander*

Problem 4 *(25 points)*



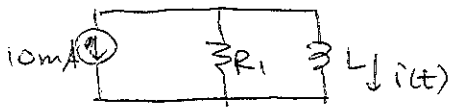
The switch in the circuit below was moved from position 1 to position 2 at t = 0. Prior to t = 0, it was at position 1. L = 80 mH. R_1 = 20 Ω, R_2 = 40 Ω

a) Provide an expression for i(t) for $t \geq 0$. *(10 points)*

Solution:

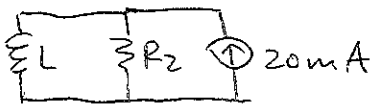
$i(t) = 20m - 30m\, e^{-t/(2m)}$, $t \geq 0$

① $t < 0$



$i(0) = -10mA$ —— 2

② $t > 0$



$i(\infty) = 20mA$ —— 2

$\tau = \frac{L}{R_2} = \frac{80m}{40} = 2m\ sec.$ —— 3

$i(t) = i(\infty) + [i(0) - i(\infty)]\, e^{-t/\tau}$ —— 1'

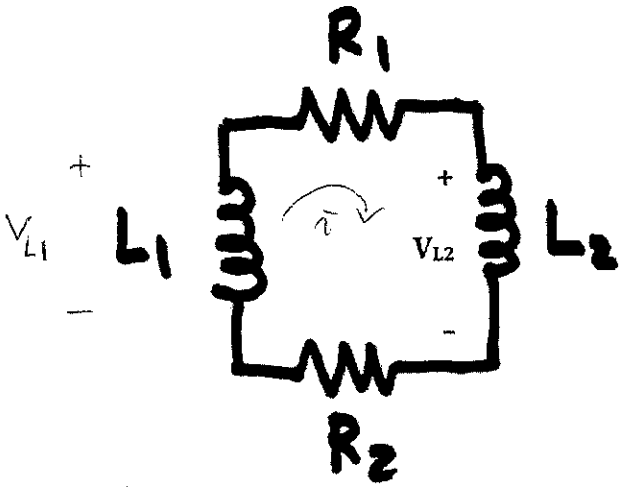
$= 20m + [-10m - 20m]\, e^{-t/2m}$ —— 1'

$= 20m - 30m \cdot e^{-t/(2m)}$, $t \geq 0$ —— 1'

no unit = −1

Extra Space

b) Now consider the different inductor circuit below. Provide a SINGLE differential equation that, if solved, would provide an expression for $v_{L2}(t)$ for $t \geq 0$. *DO NOT SOLVE THE EQUATION. (15 points)*



OR: $\frac{R_1+R_2}{L_1+L_2} V_{L2} + \frac{dV_{L2}}{dt} = 0$

Equation:

$$\frac{R_1+R_2}{L_2} V_{L2} + \left(1+\frac{L_1}{L_2}\right) \frac{dV_{L2}}{dt} = 0$$

$V_{L2} = L_2 \frac{di}{dt} \Rightarrow \frac{di}{dt} = \frac{V_{L2}}{L_2}$

$V_{L1} = -L_1 \frac{di}{dt}$

KVL: $V_{L2} = -i(R_1+R_2) + V_{L1} = -i(R_1+R_2) - L_1 \frac{di}{dt}$

$= -(R_1+R_2)\left[\int_0^t \frac{V_{L2}}{L_2} dt + i(0)\right] - L_1 \frac{V_{L2}}{L_2}$

$= -\frac{R_1+R_2}{L_2}\left[\int_0^t V_{L2}\, dt + i(0) L_2\right] - \frac{L_1}{L_2} V_{L2}$

$\left(1+\frac{L_1}{L_2}\right) V_{L2} = -\frac{R_1+R_2}{L_2}\left[\int_0^t V_{L2}\, dt + i(0) L_2\right]$

$\frac{d\left[\left(1+\frac{L_1}{L_2}\right) V_{L2}\right]}{dt} = -\frac{R_1+R_2}{L_2} V_{L2}$

$\frac{R_1+R_2}{L_2} V_{L2} + \left(1+\frac{L_1}{L_2}\right) \frac{dV_{L2}}{dt} = 0$

Extra Space