1.

(a) $t = RC = 88.0 \text{ ms}$

$$v(t) = 5e^{-t/88ms} \text{ V}$$

(b)

$$v(0) = 5e^{0} = 5 \text{ V}$$

$$v(50ms) = 5e^{-50/88} = 2.8328 \text{ V}$$

$$v(500ms) = 5e^{-500/88} = 0.0170 \text{ V}$$

(c)

$$w = \frac{1}{2}Cv^2$$

$$w(0) = (0.5)(22 \times 10^{-6})(5)^2 = 275 \text{ mJ}$$

$$w(50ms) = (0.5)(22 \times 10^{-6})(2.8328)^2 = 88.27 \text{ mJ}$$

$$w(500ms) = (0.5)(22 \times 10^{-6})(0.0170)^2 = 3.179 \text{ nJ}$$

2.

(a)

$$v\left(250\times 10^{-6}\right)=12e^{-250\times 10^{-6}/\tau}=5.215\text{ V}$$

$$\tau=300\,\mu s=RC=(100)(C)$$

$$\boxed{C=3\,\mu F}$$

(b)

$$v(0)=12e^{0}=12\text{ V}$$

$$v(250\,\mu s)=12e^{-250/300}=5.2152\text{ V}$$

$$v(500\,\mu s)=12e^{-500/300}=2.2665\text{ V}$$

$$v(1ms)=12e^{-1000/300}=0.4281\text{ V}$$

$$w=\frac{1}{2}Cv^{2}$$

$$w(0)=(0.5)\left(3\times 10^{-6}\right)(12)^{2}=\boxed{216\ \mu J}$$

$$w(250\,\mu s)=(0.5)\left(3\times 10^{-6}\right)(5.2152)^{2}=\boxed{40.80\ \mu J}$$

$$w(500\,\mu s)=(0.5)\left(3\times 10^{-6}\right)(2.2665)^{2}=\boxed{7.706\ \mu J}$$

$$w(1ms)=(0.5)\left(3\times 10^{-6}\right)(0.4281)^{2}=\boxed{274.9\text{ nJ}}$$

3.

a)

$$w = \frac{1}{2}Cv^2$$

$$v(0) = \sqrt{\frac{2w}{C}} = \sqrt{\frac{2(0.2)}{(3.1\times 10^{-9})}} = 11.359 \text{ kV}$$

$$\tau = RC = 0.1705\ s$$

$$v(t) = 11.359e^{-t/0.1705} \text{ kV}$$

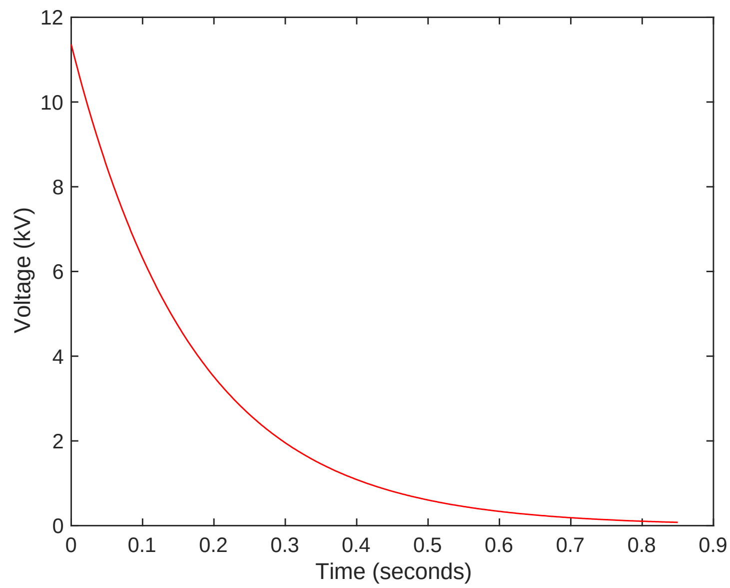
b)

$$v(0.17) = 11.359e^{-0.17/0.1705} = 4.191 \text{ kV}$$

$$w = \frac{1}{2}(3.1\times 10^{-9})(4.191\times 10^{3})^2$$

$$w(0.17) = 27.2 \text{ mJ}$$

c)



$$2\tau = 0.341 \text{ s}$$

$$v(0.341) = 1.537 \text{ kV}$$

4.

(a)

$$w = \frac{1}{2}Cv^2$$

$$v(0) = \sqrt{\frac{2w}{C}} = \sqrt{\frac{2(0.891)}{(0.022)}} = 9 \text{ V}$$

$$\tau = RC = 0.022\ s = 22 \text{ ms}$$

$$\boxed{v(t) = 9e^{-t/22ms} \text{ V}}$$

b)

t=11 ms:

$$v(11ms) = 9e^{-11/22} = 5.4588 \text{ V}$$

$$w = \frac{1}{2}(0.022)(5.4588)^2$$

$$\boxed{w(11ms) = 327.8 \text{ mJ}}$$

t=33 ms:

$$v(33ms) = 9e^{-33/22} = 2.0082 \text{ V}$$

$$w = \frac{1}{2}(0.022)(2.0082)^2$$

$$\boxed{w(33ms) = 44.4 \text{ mJ}}$$

c) The capacitor dielectric resistance is still very high relative to the 1 ohm resistor, and will not noticeably change the circuit response. The results will therefore be the same as for (a) and (b).

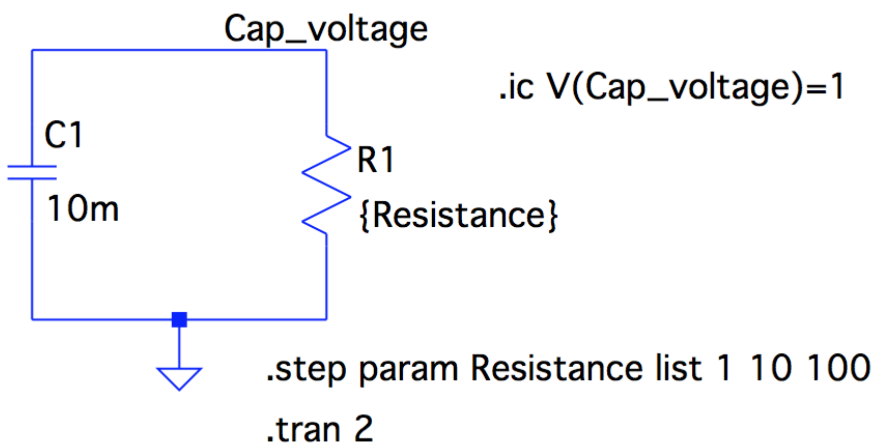
5.

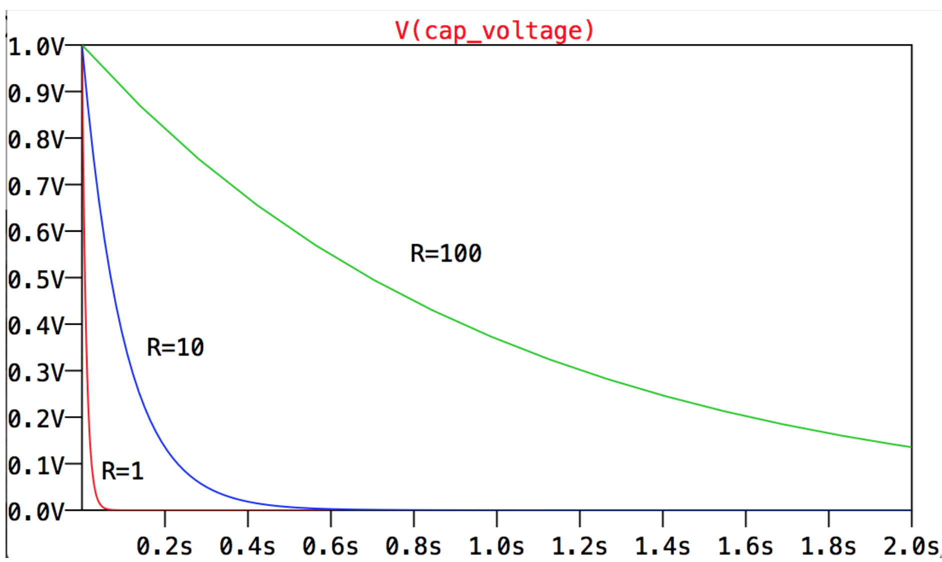
(a) $t = RC = (1)(0.01) = \boxed{10\text{ ms}}$

(b) $t = RC = (10)(0.01) = \boxed{100\text{ ms}}$

(c) $t = RC = (100)(0.01) = \boxed{1\text{ s}}$

(d)





6.

(a) For t>0, there is a series connection between the capacitor and all three resistors

$$\tau = RC = (100 + 200 + 150)(2 \times 10^{-9}) = \boxed{900\ n\text{s}}$$

(b) At t=0, capacitor charged to 4 V.

$$v(t) = 4e^{-t/\tau} = 4e^{-t/900ns}$$

$$\boxed{\begin{aligned} v(\tau) &= 4e^{-1} = 1.4715\ \text{V} \\ v(2\tau) &= 4e^{-2} = 0.5413\ \text{V} \\ v(5\tau) &= 4e^{-5} = 0.0270\ \text{V} \end{aligned}}$$

7.

(a) For t>0, there is a series connection between the capacitor and two resistors

$$t = RC = (12+9)(0.05) = \boxed{1.05\text{ s}}$$

(b) $i_1(t) = v(t)/R = v(t)/21$

At t=0, capacitor charged to 8 V.

$$v(t) = 8e^{-t/t} = 8e^{-t/1.05s}$$

$$i_1(t) = \boxed{380.95e^{-t/1.05s}\text{ mA}}$$

(c) Power dissiptated by 12 ohm resistor given by $p=i^2R$

$$p = \left(0.38095e^{-0.5/1.05}\right)^2(12)$$

$$p = \boxed{671.9\text{ mW}}$$

8.

(a) The equivalent resistance is given by

$$R_{eq} = 20k + 3k + \left(\frac{1}{5k} + \frac{1}{1k}\right)^{-1} + 10k$$

$$R_{eq} = 33.833 \text{ k}\Omega$$

$$\tau = R_{eq}C = \left(33.833\times 10^{3}\right)\left(5\times 10^{-6}\right)$$

$$\tau = \boxed{169.17 \text{ ms}}$$

(b) At t=0, capacitor charged to 12 V

$$v(t) = 12e^{-t/\tau} = \boxed{12e^{-t/0.16917s} \text{ V}}$$

(c) $v(0.170) = 12e^{-0.170/0.16917} = 4.393 \text{ V}$

$$w = \frac{1}{2}\left(5\times 10^{-6}\right)\left(4.393\right)^{2}$$

$$w(170ms) = \boxed{48.25 \ \mu J}$$

9.

(a) Initial voltage at t=0 is 20 V

$$\tau = RC = \left(82 \times 10^{3}\right)\left(12 \times 10^{-3}\right)$$

$$\tau = 984 \text{ s}$$

$$v(t) = 20e^{-t/984s} \text{ V}$$

$$v(0) = 20e^{-0/984} = \boxed{20 \text{ V}}$$

$$v(984s) = 20e^{-984/984} = \boxed{7.3576 \text{ V}}$$

$$v(1236s) = 20e^{-1236/984} = \boxed{5.6953 \text{ V}}$$

(b)

$$v(100s) = 20e^{-100/984} = 18.0673 \text{ V}$$

$$w = \frac{1}{2}(0.012)(18.0673)^2$$

$$w(100s) = \boxed{1.9586 \text{ J}}$$

10.

Analyzing the circuit at steady state before the switch is flipped, v(0) = 15 V

(a) For t>0, we have the capacitor in series with the 100 and 300 ohm resistors

$$\tau = R_{eq}C = (400)(6\times 10^{-6})$$

$$\tau = 2.4 \text{ ms}$$

$$\boxed{v(t) = 15e^{-t/2.4ms} \text{ V}}$$

The current is given by v/R_{eq}

$$\boxed{i(t) = 37.5e^{-t/2.4ms} \text{ mA}}$$

(b) Evaluating at t = 1ms

$$v(1ms) = 15e^{-1/2.4} = \boxed{9.8886 \text{ V}}$$

$$i(1ms) = 37.5e^{-1/2.4} = \boxed{24.7215 \text{ mA}}$$

11.

(a) Analyzing the circuit at steady state before the switch is flipped, v(0) = 15 V

$$w = \frac{1}{2}Cv^2 = 0.5\left(6 \times 10^{-6}\right)\left(15\right)^2$$

$$w = \boxed{675\ mJ}$$

(b) For t>0, we have the capacitor in series with the 100 and 300 ohm resistors

$$t = R_{eq}C = \left(400\right)\left(6 \times 10^{-6}\right)$$

$$t = 2.4 \text{ ms}$$

$$v\left(t\right) = 15e^{-t/2.4ms} \text{ V}$$

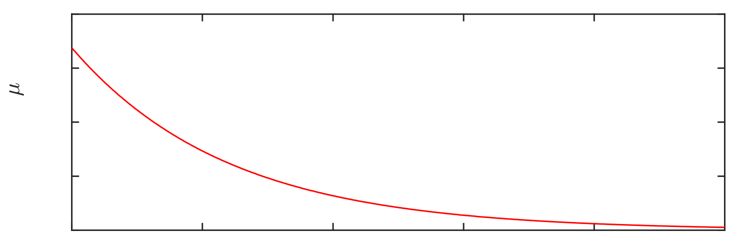
The current is given by v/R_{eq}

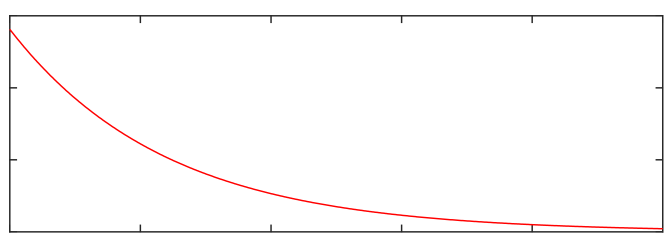
$$i\left(t\right) = 37.5e^{-t/2.4ms} \text{ mA}$$

$$w = \frac{1}{2}Cv^2 = \boxed{675e^{-t/1.2ms}\ mJ}$$

$$p = vi = \boxed{562.5e^{-t/1.2ms} \text{ mW}}$$

(c)





12.

<Design> One possible solution

Choose a series resistor network with a 9V voltage source, with a switch that opens at t=0. The voltage decay requirement will determine the time constant.

$$v(2ms) = 9e^{-2ms/\tau} = 1.2\text{ V}$$
$$\tau = 992.6\ \mu s$$

The maximum current requirements will determine the resistor values

$$i(t) = \frac{v(t)}{R} = \frac{9}{R}e^{-t/\tau}$$

For the maximum 1mA requirement for t>0,

$$i(0) < 1\text{ mA}$$
$$R > 9\text{ k}\Omega$$

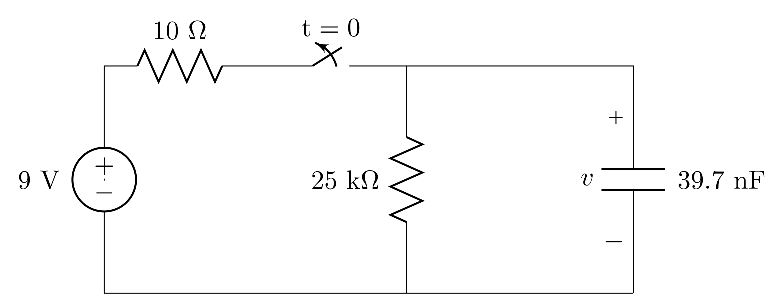
For the maximum 0.4mA requirement for t>100ns,

$$i(100ns) < 0.4\text{ mA}$$
$$R > 22.5\text{ k}\Omega$$

Choosing R=25kΩ, meeting both requirements, determine capacitance from time constant.

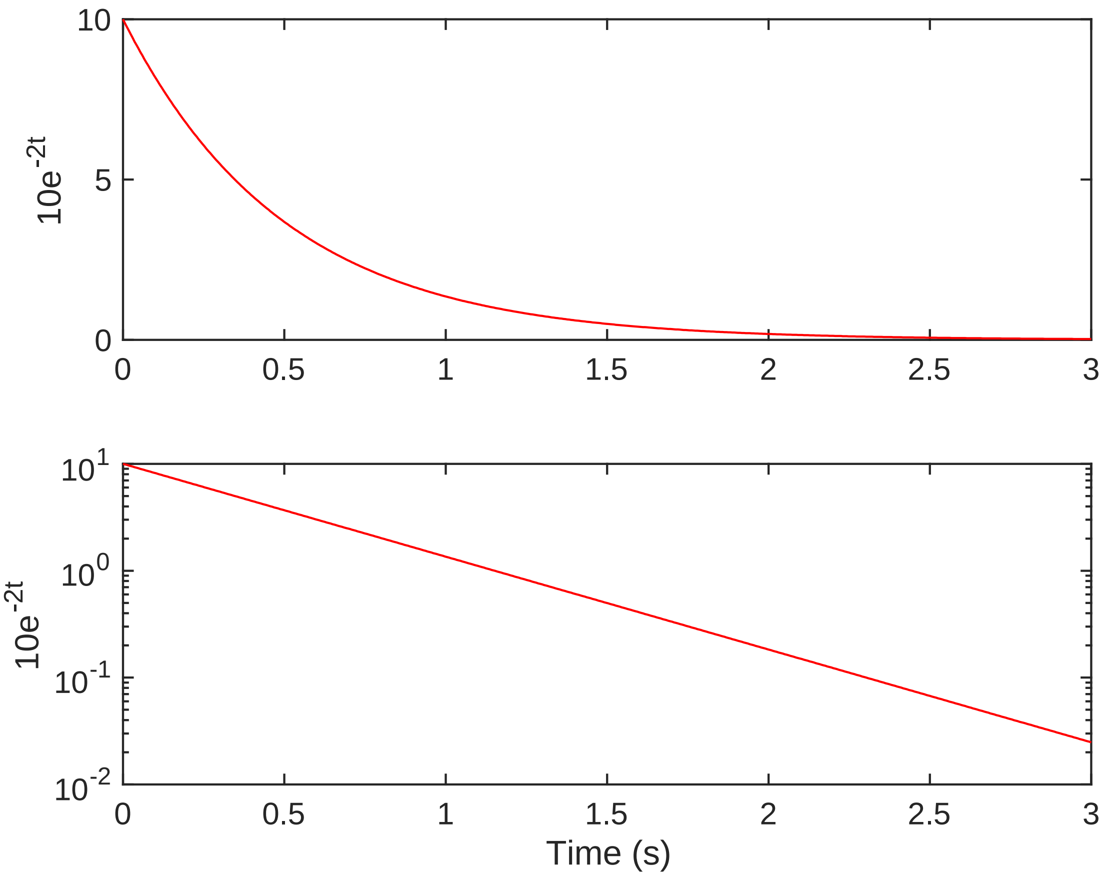
$$C = \frac{\tau}{R} = 39.7\ nF$$

The resulting circuit:



13.

(a) and (b)



(c) t is a unit of time in seconds, so the "2" is in units of inverse time or s^{-1}

(d) f = 9 at 52.68 ms
f = 8 at 111.6 ms
f = 1 at 1.151 s

14.

(a) $v = iR = \left(5e^{-10t} \text{ mA}\right)\left(1000\Omega\right) = 5e^{-10t} \text{ V}$

$$t = -\frac{1}{10}\ln\left(\frac{v}{5V}\right)$$

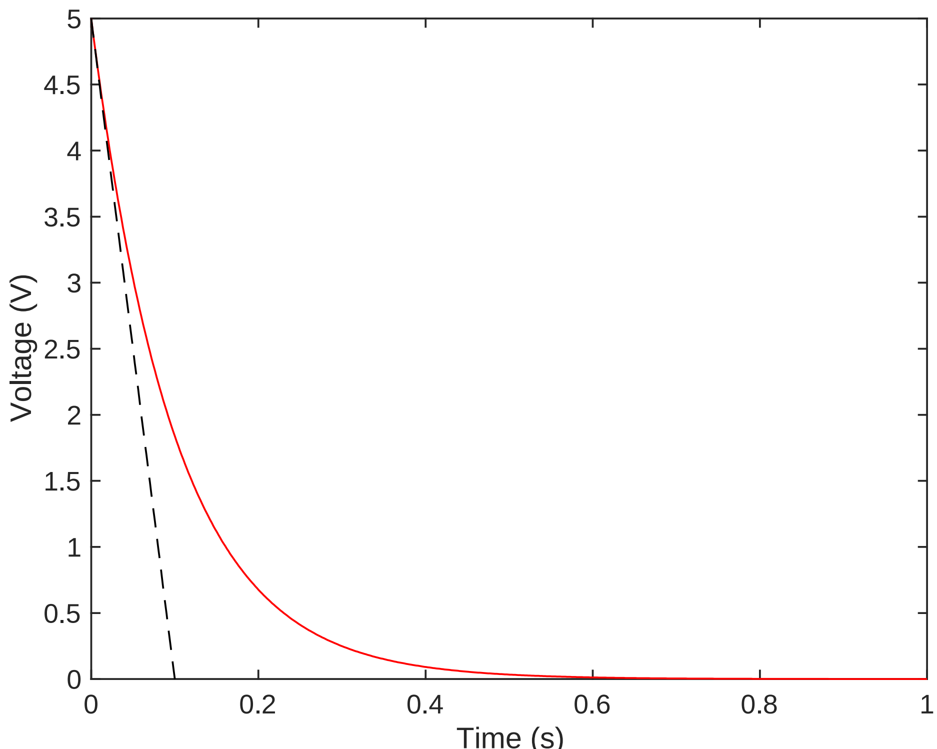
$v = 5$ V at 0 s

$v = 2.5$ V at 69.31 ms

$v = 0.5$ V at 230.3 ms

$v = 5$ mV at 690.8 ms

(b) and (c)



Tangent intersects at $t = 100$ ms, as expected for the function to decrease by a factor of 1/e

15.

(a)

$$-\lambda t = \ln\left(\frac{N}{N_0}\right)$$

$$\lambda = -\frac{1}{t}\ln\left(\frac{N}{N_0}\right) = -\frac{1}{5700}\ln\left(\frac{1}{2}\right) = \boxed{121.6\times10^{-6}\text{ years}^{-1}}$$

λ is in units of inverse time, or years^{-1}

(b)

$$-\lambda t = \ln\left(\frac{N}{N_0}\right)$$

$$t = -\frac{1}{\lambda}\ln\left(\frac{N}{N_0}\right) = -\frac{1}{121.6\times10^{-6}}\ln\left(\frac{16}{42}\right) = \boxed{7{,}936\text{ years}}$$

16.

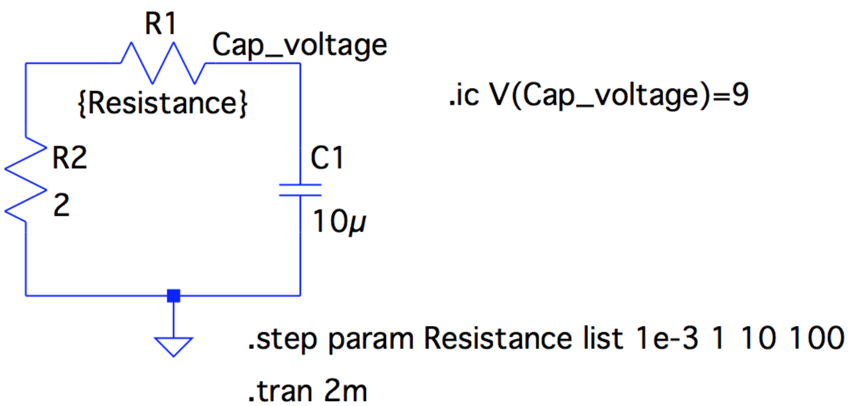
(a) $t = RC = (2)(10 \times 10^{-6}) = \boxed{20\ \mu s}$

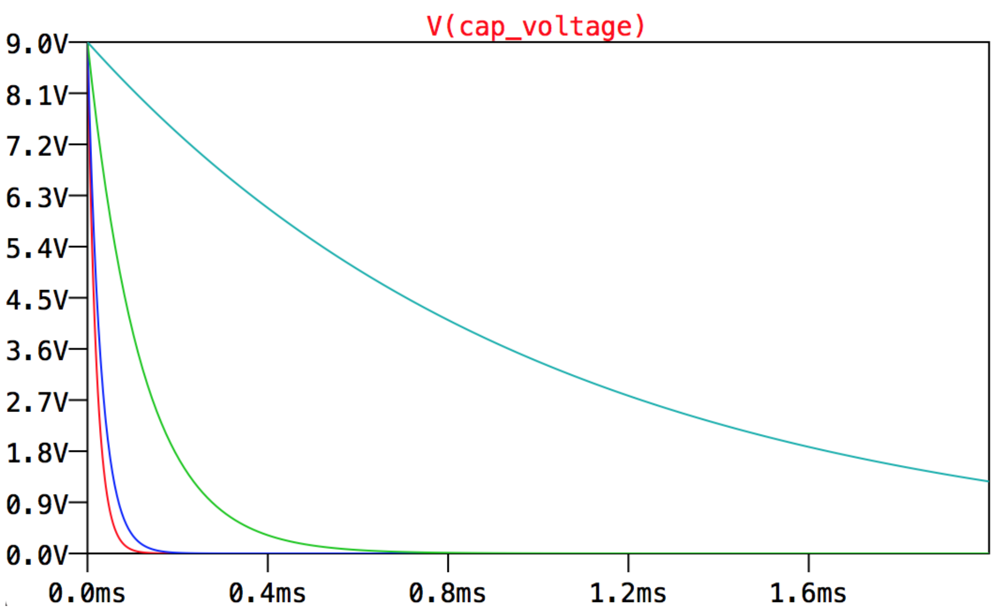
(b) $t = RC = (1+2)(10 \times 10^{-6}) = \boxed{30\ \mu s}$

(c) $t = RC = (5+5+2)(10 \times 10^{-6}) = \boxed{120\ \mu s}$

(d) $t = RC = (100+2)(10 \times 10^{-6}) = \boxed{1.02\ ms}$

(e)





17.

<Design> One possible solution

Choose a basic RC circuit, where choice of variables are R, C, and initial capacitor voltage.

$$v(t) = V_0 e^{-t/\tau}$$

$$i(t) = \frac{v(t)}{R} = \frac{V_0}{R} e^{-t/\tau}$$

$$i(0) = 1mA = \frac{V_0}{R}$$

choosing $V_0 = 5$ V,

R = 5 kΩ

$$i(5) = 1e^{-5/\tau} = 0.368$$

$$\tau = 5s$$

C = 1 mF

18.

(a)

$$i(t) = i(0)e^{-Rt/L}$$

$$\boxed{i(t) = -3e^{-t/1ps} \text{ mA}}$$

(b)

$$i(0) = -3 \text{ mA}$$
$$\text{i}(1\ ps) = -1.104 \text{ mA}$$
$$\text{i}(2\ ps) = -406.0\ \mu\text{A}$$
$$\text{i}(5\ ps) = -20.21\ \mu\text{A}$$

(c)

$$w = \frac{1}{2}Li^2$$

$$w(0) = \frac{1}{2}(10^{-9})(3 \times 10^{-3})^2 = \boxed{4.5 \text{ fJ}}$$

$$w(1 \text{ ps}) = \frac{1}{2}(10^{-9})(1.104 \times 10^{-3})^2 = \boxed{609.4 \text{ aJ}}$$

$$w(5 \text{ ps}) = \frac{1}{2}(10^{-9})(1.104 \times 10^{-3})^2 = \boxed{204.2 \text{ zJ}}$$

19.

(a)

$$i(t) = i(0)e^{-Rt/L}$$

$$L = -\frac{Rt}{\ln\left(\frac{i(t)}{i(0)}\right)} = -\frac{(100)(0.05)}{\ln\left(\frac{0.368}{1}\right)} = \boxed{5\ H}$$

(b)

$$w = \frac{1}{2}Li^2$$

$$w(0) = \frac{1}{2}(5)(1)^2 = \boxed{2.5\text{ J}}$$

$$w(50\text{ ms}) = \frac{1}{2}(5)\left(1e^{-0.05/0.05}\right)^2 = \boxed{338.3\text{ mJ}}$$

$$w(100\text{ ms}) = \frac{1}{2}(5)\left(1e^{-0.1/0.05}\right)^2 = \boxed{45.79\text{ mJ}}$$

$$w(150\text{ ms}) = \frac{1}{2}(5)\left(1e^{-0.15/0.05}\right)^2 = \boxed{6.197\text{ mJ}}$$

20.

$$i(t) = i(0)e^{-Rt/L}$$
$$v_R(t) = -i(t)R$$

$$R = -\frac{v_R(0)}{i(0)} = -\frac{10}{-5}$$

$$R = 2\ \Omega$$
$$L = 2\ \text{H}$$

(a)

$$v_R(t) = 10e^{-t}$$
$$v_R(0) = 10e^{0} = 10\ \text{V}$$
$$v_R(1) = 10e^{-1} = 3.679\ \text{V}$$
$$v_R(2) = 10e^{-2} = 1.353\ \text{V}$$
$$v_R(3) = 10e^{-3} = 497.9\ \text{mV}$$
$$v_R(4) = 10e^{-4} = 183.2\ \text{mV}$$
$$v_R(5) = 10e^{-5} = 67.38\ \text{mV}$$

(b)

$$p = v^2 / R$$
$$p(0) = 50\ \text{W}$$
$$p(1) = 10e^{-1} = 6.768\ \text{W}$$
$$p(5) = 10e^{-5} = 2.270\ \text{mW}$$

(c)

$$w = \frac{1}{2}Li^2$$

$$\frac{w(5)}{w(0)} = \frac{i(5)^2}{i(0)^2} = \frac{\left(e^{-5}\right)^2}{\left(e^{0}\right)^2} = 45.40 \times 10^{-6} \text{ or } 0.00454\%$$

21.

$$i(t) = i(0)e^{-Rt/L}$$

$$\frac{R}{L} = -\frac{1}{0.001}\ln\left(\frac{2.207}{6}\right) = \boxed{1,000}$$

22.

(a) Before the switch opens, all current from the source will be flowing through the inductor

$$i_L(0^-) = \boxed{4 \text{ mA}}$$

(b) Just after the switch opens, the current through the inductor will be the same, since it cannot change instantaneously
Before the switch opens, all current from the source will be flowing through the inductor

$$i_L(0^+) = \boxed{4 \text{ mA}}$$

(c) The current for t>0 will be given by

$$i(t) = 4e^{-220t/0.002} = 4e^{-t/9.0909\,\mu s} \text{ mA}$$

$$i(15.8) = 4\times 10^{-3} e^{-15.8/9.0909} = \boxed{703.5 \ \mu\text{A}}$$

(d)

$$i(31.5) = 4\times 10^{-3} e^{-31.5/9.0909} = \boxed{125.1 \ \mu\text{A}}$$

(e)

$$i(78.8) = 4\times 10^{-3} e^{-78.8/9.0909} = \boxed{688.0 \text{ nA}}$$

23.

(a) Before the switch opens, all current from the source will be flowing through the inductor

$v(0^-) = \boxed{0}$

$i_L(0^-) = 4 \text{ mA}$

$w = \frac{1}{2}Li^2 = \boxed{16 \text{ nJ}}$

(b) Just after the switch opens, the current through the inductor will be the same, since it cannot change instantaneously. All of the current from the source will now flow through the resistor.

$v(0^+) = \boxed{1.2 \text{ V}}$

$i_L(0^+) = 4 \text{ mA}$

$w = \frac{1}{2}Li^2 = \boxed{16 \text{ nJ}}$

(c) The current through the inductor for t>0 will be given by

$i(t) = 4e^{-220t/0.002} = 4e^{-t/9.0909\,ms} \text{ mA}$

$i(8) = 4 \times 10^{-3} e^{-8/9.0909} = 1.6591\ mA$

$w = \frac{1}{2}Li^2 = \boxed{2.7527 \text{ nJ}}$

And the voltage across the 300 ohm resistor is unchanged, $v = \boxed{1.2 \text{ V}}$

(d)

$i(80) = 4 \times 10^{-3} e^{-80/9.0909} = 602.9 \text{ nA}$

$w = \frac{1}{2}Li^2 = \boxed{363.5 \text{ aJ}}$

And the voltage across the 300 ohm resistor is unchanged, $v = \boxed{1.2 \text{ V}}$

24.

(a) For t>0, the inductor is in series with three resistors.

$$i_L(t) = i_L(0)e^{-R_{eq}t/L}$$

The initial current is determined before the switch is opened, where the inductor is a short circuit.

$$i_L(0) = 10/50 = 0.2 \text{ A}$$

$$\boxed{i_L(t) = 200e^{-2125t} \text{ mA}}$$ where time t is given in seconds

The voltage across the resistor is given by Ohm's Law

$$v = -i_L(25\Omega)$$

$$\boxed{v(t) = -5e^{-2125t} \text{ V}}$$ where time t is given in seconds

(b)

$$i_L(0^-) = \boxed{200 \text{ mA}}$$

$$v(0^-) = \boxed{7.1429 \text{ V}}$$ (voltage divider)

$$i_L(0^+) = \boxed{200 \text{ mA}}$$

$$v(0^+) = \boxed{-5 \text{ V}}$$

$$i_L(470\mu s) = \boxed{73.67 \text{ mA}}$$

$$v(470\mu s) = \boxed{-1.8417 \text{ V}}$$

25.

(a)

Prior to the switch closing, the current i_L = (1.5)/(5k + 10k) = 0.1 mA = 100 μA

After the switch closes, $i_w = -i_L$

$$i_W(t) = i_W(0)e^{-Rt/L}$$

$$\boxed{i_W(t) = -100e^{-t/2ns}\ \mu A}$$

(b)

$$i_W(0) = \boxed{-100\ \mu A}$$

$$i_W(t) = -100e^{-1.3/2} = \boxed{-52.20\ \mu A}$$

26.

(a)

From KCL, $\frac{v}{R_4} + \frac{v}{R_3} = i_L$

$$v = \frac{R_3 R_4}{R_3 + R_4} i_L$$

$$i_L = i_L(0) e^{-t/\tau}$$

$$\tau = L / R_{eq}$$

$$R_{eq} = R_1 + R_2 + \frac{R_3 R_4}{R_3 + R_4}$$

$$v = \frac{R_3 R_4}{R_3 + R_4} i_L(0) e^{-R_{eq} t/L}$$

(b)

$$R_{eq} = 1.2k + 600 + \frac{(400)(300)}{400 + 300} = 1{,}971\ \Omega$$

$$v(500\ ns) = \frac{(400)(300)}{400 + 300}(0.003) e^{-(1971)(500 \times 10^{-9})/(0.001)}$$

$$v(500\ ns) = 192.0\ \text{mV}$$

27.

(a) At t=0⁻, the inductor is a short circuit, and we have a resistor network
The voltage at the top center node (defining reference potential at the bottom):

$$\frac{v-4}{10}+\frac{v}{3}+\frac{v}{5}=0$$

$$v=0.6316\ \text{V}$$

$$i_x=-\frac{v}{3}=-210.5\ \text{mA}$$

$$i_L=\frac{v}{5}=126.3\ \text{mA}$$

$$v_L=0$$

(b) At t=0⁺, the inductor current remains the same, but the voltage can change

$$i_x=i_L=126.3\ \text{mA}$$

$$v_L=-i_L(3+5)=-1.0104\ \text{V}$$

28.

(a) At t=0⁻, the inductor is a short circuit, and we have a resistor network
The voltage at the top center node (defining reference potential at the bottom):

$$\frac{v-1.2}{1000}+\frac{v}{1000}+\frac{v}{2000}=0$$

$$v=0.48\text{ V}$$

$$i_L=\frac{v}{2000}=240\ \mu\text{A}$$
$$v_L=0$$
$$v_R=v=0.48\text{ V}$$

(b) At t=0⁺, the inductor current remains the same, but the voltage can change

$$i_L=240\ \mu\text{A}$$
$$v_L=-i_L\left(1000+2000\right)=-0.72\text{ V}$$
$$v_R=i_L\left(2000\right)=0.48\text{ V}$$

(c) For t>0

$$i_L\left(t\right)=i_L\left(0\right)e^{-R_{eq}t/L}=240e^{-t/10\mu s}\ \mu\text{A}$$

$$i_L\left(1\mu s\right)=240e^{-1/10}=217.16\ \mu\text{A}$$
$$v_L=-0.6515\text{ V}$$
$$v_R=0.4343\text{ V}$$

(d)

$$i_L\left(10\mu s\right)=240e^{-10/10}=88.29\ \mu\text{A}$$
$$v_L=-0.2649\text{ V}$$
$$v_R=i_L\left(2000\right)=0.1766\text{ V}$$

29.

The circuit may be simplified using an equivalent circuit using series/parallel inductor and resistor combinations.

The 1 H and 2 H inductors in parallel: Leq = 2/3 H
This is in series with the 3 H inductor: Leq = 11/3 H

Examine at t=0$^-$ to find the initial condition
The node voltage at the top center of the circuit

$$5 = \frac{v}{8} + \frac{v}{3} + \frac{v}{2}$$

$$v = 5.2174 \text{ V}$$

$$i_L = \frac{v}{2} = 2.6087 \text{ A}$$

For t>0, the inductors is in series with the 2 ohm and 3 ohm resistors

$$t = \frac{L}{R} = \frac{11}{15} \text{ s}$$

$$i_L(t) = 2.6087e^{-15t/11} \text{ A}$$

$$i_1(t) = -i_L(t) = -2.6087e^{-15t/11} \text{ A}$$

30.

Assume that the constant in the exponential is given in inverse seconds (90 s^{-1})

The voltage will reach half when $e^{-90t} = 0.5$

$$t = \frac{\ln(0.5)}{-90} = \boxed{7.702 \text{ ms}}$$

The current will reach 10% when $e^{-90t} = 0.1$

$$t = \frac{\ln(0.1)}{-90} = \boxed{25.58 \text{ ms}}$$

31.

Examine initial conditions for the inductor, before the switch is flipped
Analyzing the circuit using nodal analysis or source transformation,

$$i_L(0) = \frac{9}{5} \text{ mA}$$

After the switch is flipped, the current source and 1 ohm resistor are shorted.
As a result, there will essentially be two independent circuits: 1) current source flowing through the short, and 2) RL circuit consisting of the 4 ohm resistor and the inductor.

$$i_1(t) = 0 \text{ (no current through shorted resistor)}$$

$$i_2(t) = 9\ mA - i_L$$

$$i_L(t) = \frac{9}{5}e^{-800t} \text{ mA}$$

(a)

$$\boxed{i_1(1ms) = 0}$$

$$i_L(1ms) = 9 - \frac{9}{5}e^{-0.8} = \boxed{8.1912 \text{ mA}}$$

(b)

$$\boxed{i_1(3ms) = 0}$$

$$i_L(3ms) = 9 - \frac{9}{5}e^{-2.4} = \boxed{8.8367 \text{ mA}}$$

32.

Begin by finding the inductor current before the switch is flipped
The inductor is a short, which also shorts the 1 ohm resistor
The resulting series circuit has a current

$$i_L(0) = \frac{2V}{5W + 3W} = 0.25A$$

When the switch is flipped, There are essentially two independent circuits: 1) voltage source in series with 5 ohm resistor; 2) inductor in parallel with 1 ohm resistor in parallel with 3 ohm resistor. From KCL,

$$\frac{-v_x}{3} + i_L + \frac{-v_x}{1} = 0$$

$$v_x = \frac{3}{4} i_L$$

The equivalent resistance is given by the parallel connection of the 1 ohm and 3 ohm resistors, defining the time constant L/R.

$$t = \frac{L}{R} = \frac{0.01}{3/4} = \frac{1}{75}$$

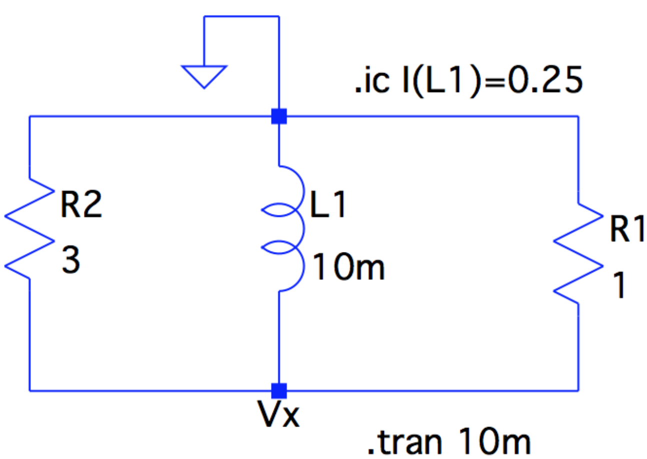
$$v_x = \frac{3}{4} i_L(0) e^{-Rt/L}$$

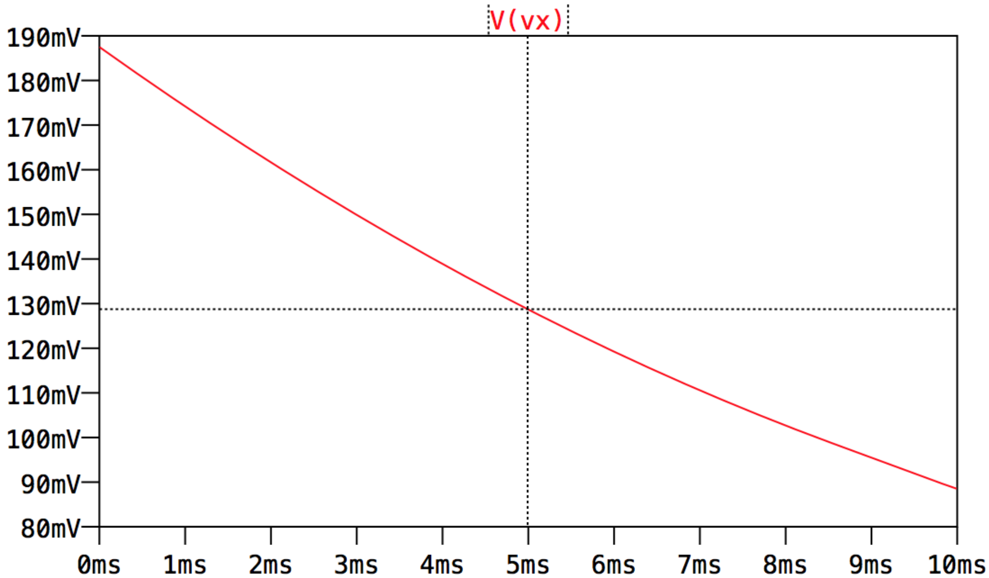
$$\boxed{v_x = \frac{3}{16} e^{-75t} \text{ V}}$$

(b)

$$v_x = \frac{3}{4} i_L(0) \quad v_x(5ms) = \boxed{128.9 \text{ mV}}$$

(c)




V(vx)
190mV
180mV
170mV
160mV
150mV
140mV
130mV
120mV
110mV
100mV
90mV
80mV
0ms
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10ms

33.

<Design> One possible solution

Setup the voltage supply to provide the initial value of 5 V
The voltage decay to 2 V at 1 s will determine the required time constant

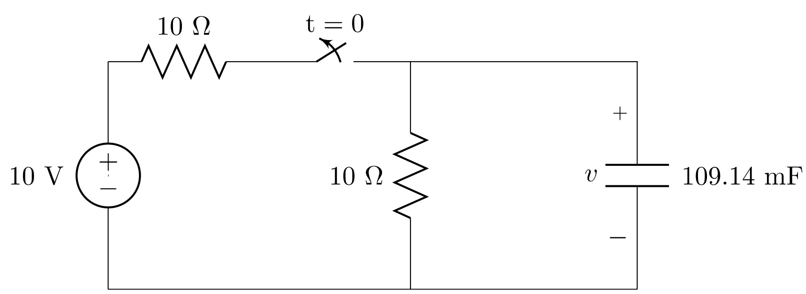
$2 = 5e^{-t/t}$

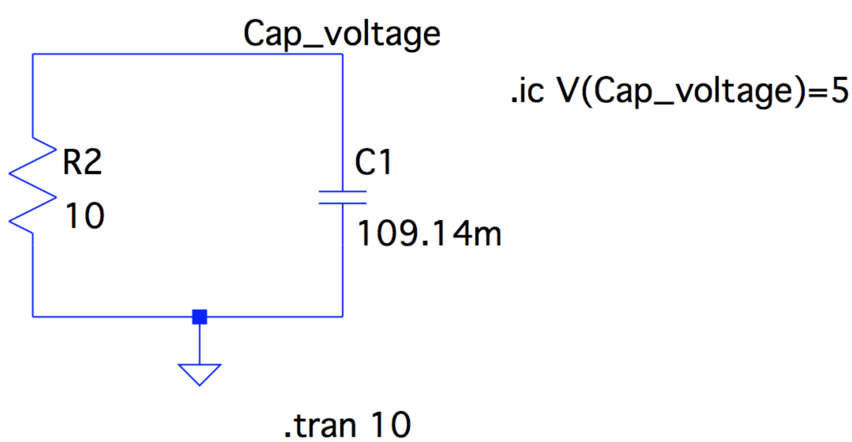
$t = 1.0914$ s

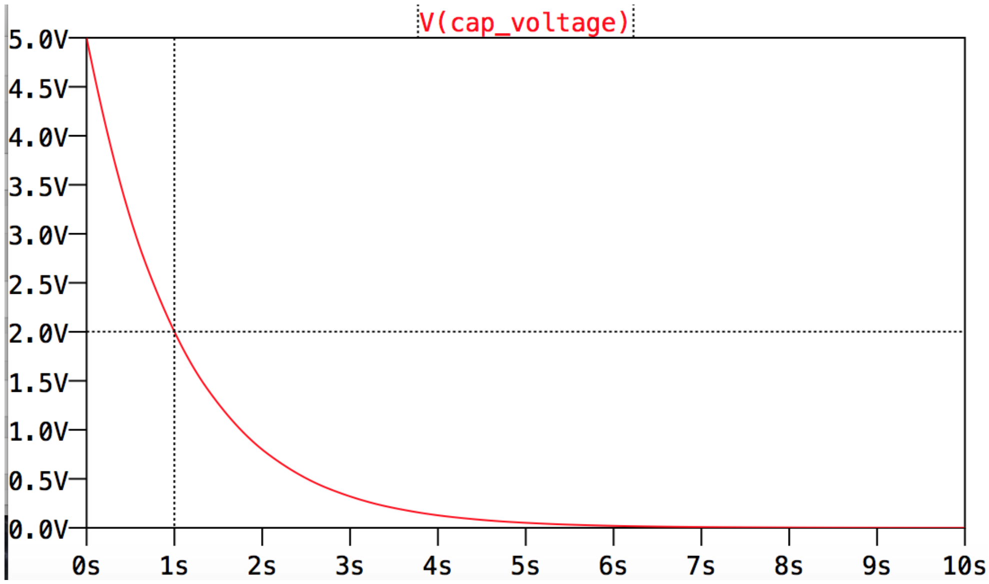
Verify that this will meet the specification of less than 60 mV at t=5 s.

$v = 5e^{-5/1.0914} = 51.2$ mV

Choose resistor values of 10 ohms, resulting a capacitor value of 109.14 mF to provide the desired time constant. Note that a 10 V supply is used, where an initial value on the capacitor of 5 V is obtained through voltage division across the two resistors. The final design and SPICE simulation are below.






V(cap_voltage)
5.0V
4.5V
4.0V
3.5V
3.0V
2.5V
2.0V
1.5V
1.0V
0.5V
0.0V
0s
1s
2s
3s
4s
5s
6s
7s
8s
9s
10s

34.

Beginning with the initial value,

$$v_C(0) = 12.5\left(\frac{R_1}{R_1 + 10}\right)$$

The expression for t=0.65

$$v_C(0.65s) = 5.22 = 12.5\left(\frac{R_1}{R_1 + 10}\right)\exp\left(-\frac{0.65}{(60 + R_1)(0.01)}\right)$$

Solving using Matlab or other software,

$$\boxed{R_1 = 40\ \text{W}}$$

At t=2 s,

$$v_C(2s) = 12.5\left(\frac{40}{40 + 10}\right)\exp\left(-\frac{2}{(60 + 40)(0.01)}\right) = 1.3534\ \text{V}$$

We can find the time constant required for t=2.21 s

v $v_c(2.21) = 1 = 1.3534e^{-0.21/t}$

$t = 0.6939$ s

When the switch is flipped at t=2, the new equivalent resistance becomes

$$R_{eq} = 40 + \frac{60R_0}{60 + R_0} = \frac{t}{C} = 69.394\ \text{W}$$

Solving,

$$\boxed{R_0 = 57.62\ \text{W}}$$

35.

(a) The voltage across the capacitor will be continuous

$$v_c\left(0^+\right) = 2.5 \text{ V}$$

Using KCL to relate v to v_C

$$\frac{v}{10} + \frac{v - v_c}{8} + \frac{v}{20} = 0$$

$$v = \frac{v_c}{8} \Big/ \left(\frac{1}{10} + \frac{1}{8} + \frac{1}{20}\right)$$

$$v = \frac{5}{11} v_c$$

$$i_1 = \frac{v}{10}$$

at $t=0^+$,

$v_C = 2.5$ V
$v = 1.1364$ V
$i_1 = 113.64$ mA

(b) The equivalent resistance observed by the capacitor is 8 ohms in series with the parallel connection of the 10 ohm and 20 ohm resistor

$$R_{eq} = 8 + \frac{(10)(20)}{10 + 20} = 14.67 \text{ W}$$

$$C = \frac{t}{R_{eq}} = \frac{14}{14.67} = \frac{21}{22} = 954.5 \text{ mF}$$

36.

(a) For t=0$^-$, the capacitor is an open circuit
We can simplify the resistor network, noting the series connection of 2k + 4k = 6k, in parallel with the capacitor and 6k resistor. The capacitor is therefore in parallel with a 3k resistance.

$$v_C = 1\frac{3k}{3k+1k} = \boxed{0.75 \text{ V}}$$

The current in the branch on the right is given by

$$i = \frac{1}{5k+2k} = \frac{1}{7} \text{ mA}$$

$$v_0 = \left(\frac{1}{7}m\right)(2k) = \frac{2}{7} = \boxed{0.28571 \text{ V}}$$

(b) For t=0$^+$, v_C stays the same

$$v_C = 1\frac{3k}{3k+1k} = \boxed{0.75 \text{ V}}$$

And from voltage division,

$$v_0 = \frac{2k}{1k+5k+2k}v_C = \frac{3}{16} = \boxed{0.1875 \text{ V}}$$

(c) The equivalent resistance observed by the capacitor is the 3k in parallel with (1k +5k + 2k), or R_{eq} = 24/11 kohms

$$\tau = R_{eq}C = \left(\frac{24}{11}k\right)(1m) = 2.1818 \text{ ms}$$

$$v_C(t) = v_C(0)e^{-t/2.1818ms}$$

$$v_C(10ms) = v_C(0)e^{-t/2.1818ms} = \boxed{7.6653 \text{ mV}}$$

$$v_0(10ms) = \boxed{1.9163 \text{ mV}}$$

(d)

$$v_C(12ms) = v_C(0)e^{-12/2.1818} = \boxed{3.0649 \text{ mV}}$$

$$v_0(12ms) = \boxed{766.2 \ \mu\text{V}}$$

37.

(a) For t=0$^-$, applying KCL to node v_C

$$i_1 + 1.5 i_1 + \frac{v_C - 10}{6k} = 0$$

$$i_1 = \frac{v_C}{8k}$$

$$v_C = \boxed{3.4783 \text{ V}}$$

(b) Remains unchanged at t=0+

$$v_C = \boxed{3.4783 \text{ V}}$$

(c) Need to find the equivalent resistance as observed by the capacitor. Applying a test current of 1 A in place of the capacitor

$$1 = i_1 + 1.5 i_1 = 2.5 \frac{v}{8k}$$

$$v = 3200$$

$$R_{eq} = v / 1 = 3.2 \text{ kW}$$

$$t = R_{eq} C = \boxed{3.2 \text{ ms}}$$

(d)

$$v_C(3ms) = 3.4783 e^{-3/3.2} = \boxed{1.3621 \text{ V}}$$

38.

(a)

$v_1(0^-) = 100$ V
$v_2(0^-) = 0$
$v_R(0^-) = 0$

(b) The capacitor voltages will remain, though v_R will change according to the values fixed by the capacitors

$v_1(0^-) = 100$ V
$v_2(0^-) = 0$
$v_R(0^-) = 100$ V

(c) The two capacitors are connected in series

$$C_{eq} = \frac{5 ´\ 20}{5+20} = 4\ mF$$

$$t = RC_{eq} = (20k)(4m) = 80 \text{ ms}$$

(d) v_R will be the same as the voltage across the equivalent capacitance

$$v_R = 100e^{-t/80ms} \text{ V}$$

(e)

$$i = \frac{100}{20k}e^{-t/80ms} = 5e^{-t/80ms} \text{ mA}$$

(f)

$$v_1 = \frac{1}{C_1}\int idt + v_1(0)$$

$$v_1 = -\frac{1}{20m}(5m)(80m)\left[1 - e^{-t/80ms}\right] + 100$$

$$v_1 = 100 - 20\left[1 - e^{-t/80ms}\right] \text{ V}$$

$$v_2 = \frac{1}{C_2}\int idt + v_2(0)$$

$$v_2 = \frac{1}{5m}(5m)(80m)\left[1 - e^{-t/80ms}\right]$$

$$v_2 = 80\left[1 - e^{-t/80ms}\right] \text{ V}$$

(g)

Total stored at t=0 is $w = \frac{1}{2}Cv^2 = \frac{1}{2}(20m)(100)^2 = \boxed{100\ mJ}$

Total stored at t=∞ is $w = \frac{1}{2}Cv^2 = \frac{1}{2}(20m + 5m)(80)^2 = \boxed{80\ mJ}$

Total absorbed by resistor $w = \int i^2 R\, dt = (20k)\int (5m)^2 e^{-2t/80ms}\, dt = \boxed{20\ mJ}$

39.

(a) The same energy will remain at t=0+, 54 nJ

(b) Find the initial condition based on energy storage

$$w = \frac{1}{2}Li^2$$

$$i(0) = \sqrt{\frac{(2)(54\times 10^{-9})}{48\times 10^{-3}}} = 1.5 \text{ mA}$$

Analyzing circuit to find Req as observed by inductor

$$R_{eq} = 42\ \Omega$$

$$\tau = \text{L/R}_{eq} = 1.1429\ ms$$

$$1/\tau = 875\ \text{s}^{-1}$$

$$i = 1.5e^{-875t}\ \text{mA}$$

$$w = \frac{1}{2}(48\times 10^{-3})(1.5\times 10^{-3}e^{-(0.001)(875)})^2$$

$$w = 9.3838\ \text{nJ}$$

(c)

$$w = \frac{1}{2}(48\times 10^{-3})(1.5\times 10^{-3}e^{-(0.005)(875)})^2$$

$$w = 8.5569\ \text{pJ}$$

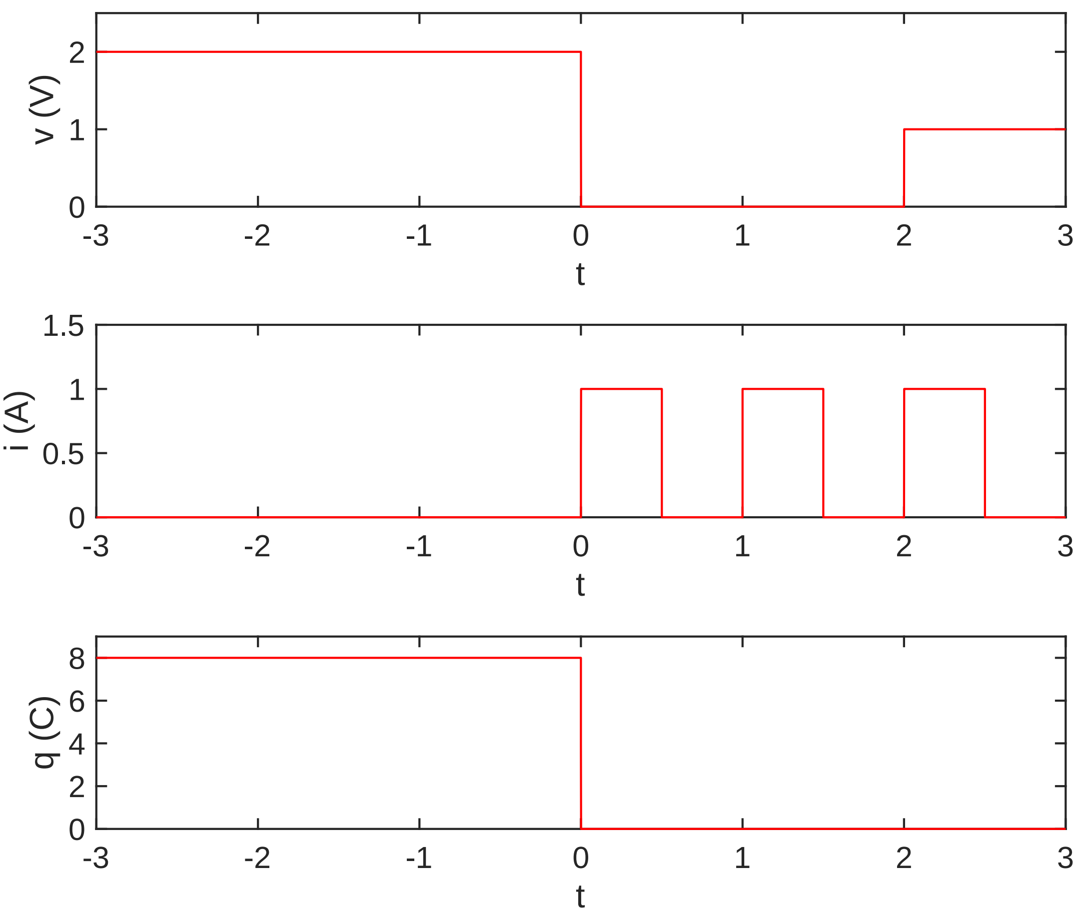
40.

	$t = -2$	$t = 0^+$	$t = +2$
(a)	0	3	3
(b)	8	8	3
(c)	0	0	0
(d)	11	11	4

41.

	$t = -1$	$t = 0$	$t = +3$
(a)	−1	0	0
(b)	10	10	8
(c)	2	2	1
(d)	2	2	3

42.



43.

$$\boxed{f(t) = u(1-t) + u(t-1) - u(t-2)}$$

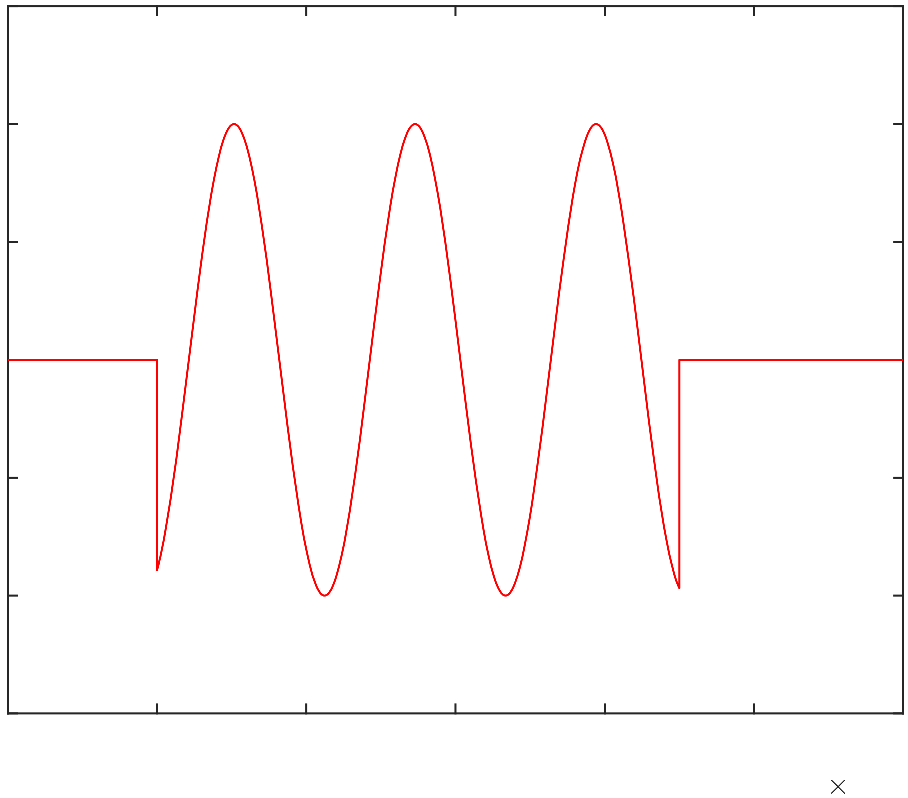
(other answers may be possible)

44.

$$v(t) = -2u(1-t) - 2u(t-1) + 7u(t-2) - 5u(t-3) + 2u(t-5)$$

(other answers may be possible)

45.



```
t0=2e-8;
syms t
figure(1)
fplot((heaviside(t-t0)-heaviside(t-t0-7e-8))*sin(259e6*t), [0, 12e-8],'r','LineWidth',1.0)
```

46.

(a) Capacitor is initially uncharged, $v(0^-) = 0$

(b) Capacitor voltage will not change instantaneously, $v(0^+) = 0$

(c) Determine the time dependence and evaluate at t = 2 ms.

The final voltage will be given by voltage division for the two resistors

$$v(¥) = 6\frac{2k}{500 + 2k} = 4.8 \text{ V}$$

The equivalent resistance seen by the capacitors are the two resistors in parallel

$$R_{eq} = \frac{(500)(2000)}{(500 + 2000)} = 400 \text{ W}$$

$$t = R_{eq}C = 1.6 \text{ ms}$$

$$v(t) = v(\infty) + [v(0) - v(\infty)]e^{-t/t}$$

$$v(t) = 4.8 + [0 - 4.8]e^{-t/1.6ms} \text{ V}$$

$$v(t) = 4.8[1 - e^{-t/1.6ms}] \text{ V}$$

$$v(2ms) = 4.8[1 - e^{-2/1.6}] = 3.4248 \text{ V}$$

(d)

$$v(5ms) = 4.8[1 - e^{-5/1.6}] = 4.5891 \text{ V}$$

47.

(a) For t<0, capacitor open circuit, voltage source zero.

The 5 mA current source will be evenly divided among the two 2 kΩ resistors

$$v_c(0^-) = (2.5m)(2k) = \boxed{5\text{ V}}$$

Capacitor voltage will not change instantaneously,

$$v_c(0^+) = \boxed{5\text{ V}}$$

$$i_c(0^-) = \boxed{0}$$

Find $i_C(0^+)$ from KCL

$$5m = \frac{v_c - 12}{2k} + \frac{v_c}{2k} + i_c$$

$$i_c(0^+) = \boxed{6\text{ mA}}$$

(b) From source transformation, an equivalent circuit is a series connection of an 11 V source, 1 kΩ resistor, and capacitor

$$v_c(t) = v_c(\infty) + [v_c(0) - v_c(\infty)]e^{-t/\tau}$$

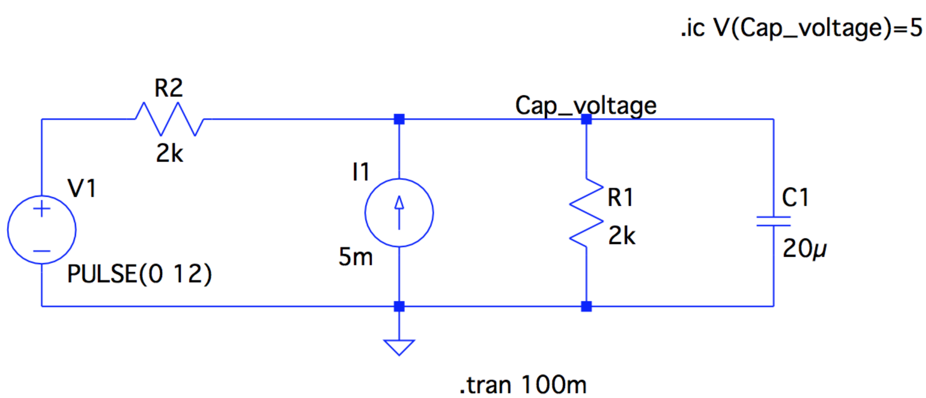
$$v_c(¥) = 11\text{ V}$$

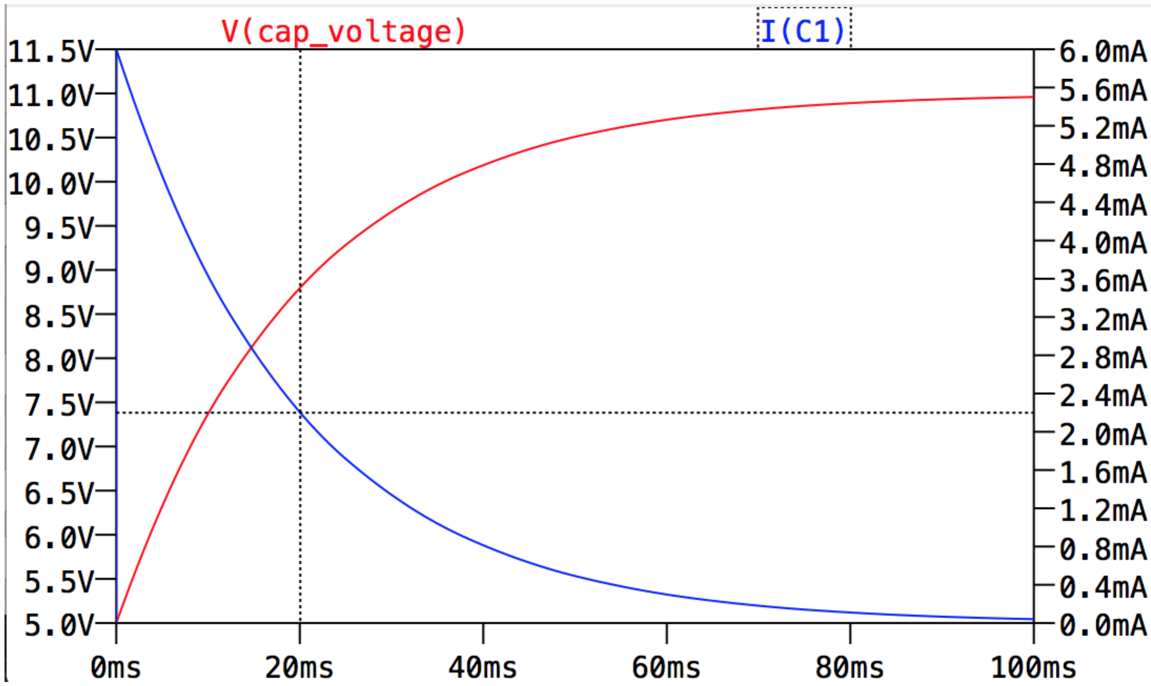
$$v_c(t) = 11 + [5 - 11]e^{-t/(1k)(20m)} = 11 - 6e^{-t/20ms}\text{ V}$$

$$v_c(20ms) = 11 - 6e^{-20/20} = \boxed{8.7927\text{ V}}$$

$$i_c(20ms) = \frac{11 - 8.7927}{1k} = \boxed{2.2073\text{ mA}}$$

(c)




V(cap_voltage)
I(C1)
11.5V
11.0V
10.5V
10.0V
9.5V
9.0V
8.5V
8.0V
7.5V
7.0V
6.5V
6.0V
5.5V
5.0V
6.0mA
5.6mA
5.2mA
4.8mA
4.4mA
4.0mA
3.6mA
3.2mA
2.8mA
2.4mA
2.0mA
1.6mA
1.2mA
0.8mA
0.4mA
0.0mA
0ms
20ms
40ms
60ms
80ms
100ms

48.

(a) The capacitor is initially uncharged, and will not change instantaneously at t=0, $v_c(0) = 0$.

The final voltage will be given by voltage division for the two resistors

$$v(¥) = 3\frac{1k}{1k+2k} = 1\text{ V}$$

The equivalent resistance seen by the capacitors are the two resistors in parallel

$$R_{eq} = \frac{(1k)(2k)}{(1k+2k)} = 666.7\text{ W}$$

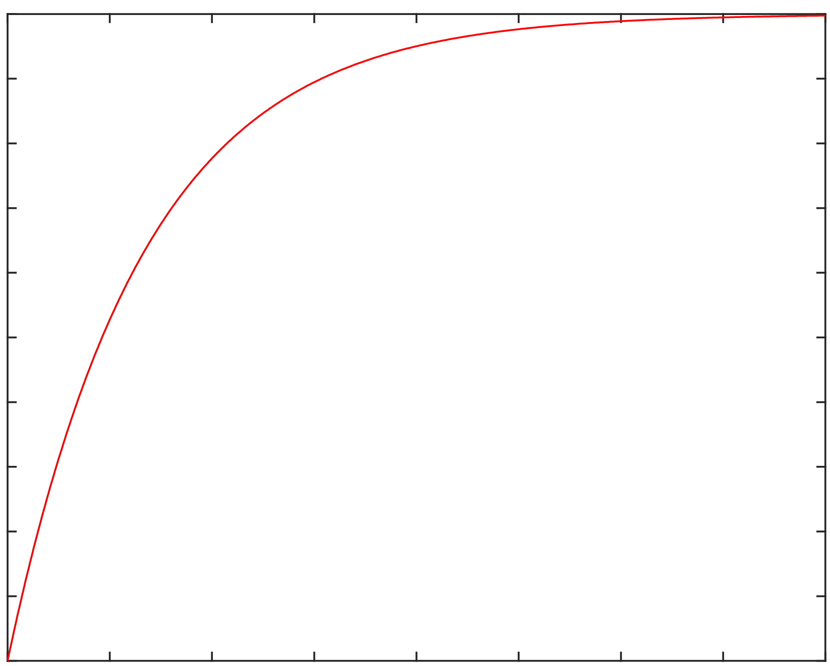
$$t = R_{eq}C = 666.7\text{ ns}$$

$$v(t) = v(\infty) + [v(0) - v(\infty)]e^{-t/t}$$

$$v(t) = 1 + [0 - 1]e^{-t/666.7ns}\text{ V}$$

$$\boxed{v(t) = 1 - e^{-t/666.7ns}\text{ V}}$$

(b)



μ

49.

The capacitor is initially uncharged, and will not change instantaneously at t=0, $v(0) = 0$.

The capacitor will also be an open circuit, so $i_A = 0$.

The capacitor will charge to the source voltage of 10 V

$$v(\infty) = 10\text{ V}$$

The equivalent resistance seen by the capacitors are the two resistors in series

$$R_{eq} = 4\text{ k}\Omega$$

$$\tau = R_{eq}C = 1.2\text{ ms}$$

$$v(t) = v(\infty) + [v(0) - v(\infty)]e^{-t/\tau}$$

$$v(t) = 10 + [0 - 10]e^{-t/1.2ms}\text{ V}$$

$$v(t) = 10[1 - e^{-t/1.2ms}]\text{ V}$$

The current is related to the capacitor voltage by

$$i_A(t) = \frac{10 - v}{4k} = 2.5e^{-t/1.2ms}\text{ mA}$$

$$i_A(t) = \begin{cases} 0 & t < 0 \\ 2.5e^{-t/1.2ms}\text{ mA} & t > 0 \end{cases}$$

50.

(a)

$$w = \frac{1}{2}Cv^2 = \frac{1}{2}(50)(3)^2$$

$$\boxed{w = 225 \text{ J}}$$

(b)

$$v(t) = v(\infty) + [v(0) - v(\infty)]e^{-t/t}$$

$$v(t) = 3\left[1 - e^{-t/500s}\right] \text{ V}$$

$$\frac{w}{w_{\max}} = 0.95 = \frac{v^2}{v_{\max}{}^2}$$

$$v = 2.924 \text{ V}$$

$$\boxed{t = 1{,}838 \text{ s}}$$

51.

When the switch is closed for t<0, the capacitor is shorted out, v=0.
When the switch is opened, the capacitor will charge.

The circuit can be revised to a Thevenin equivalent using source transformation or other techniques with V_{TH} = 90/11 mV and R_{eq} = 370/11 Ω

The final voltage is 90/11 mV
Time constant is $\tau = (370/11)(0.002) = 67.27$ ms

$$i_x(t) = i_x(\infty) + [i_x(0) - i_x(\infty)]e^{-t/\tau}$$

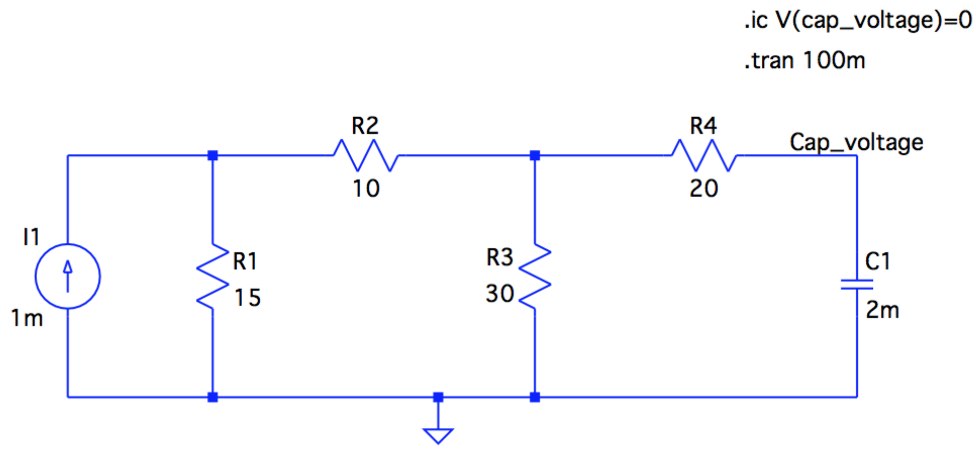
$i_x(0) = [V_{TH} - v(0)]/R_{eq} =$ 243.24 μA

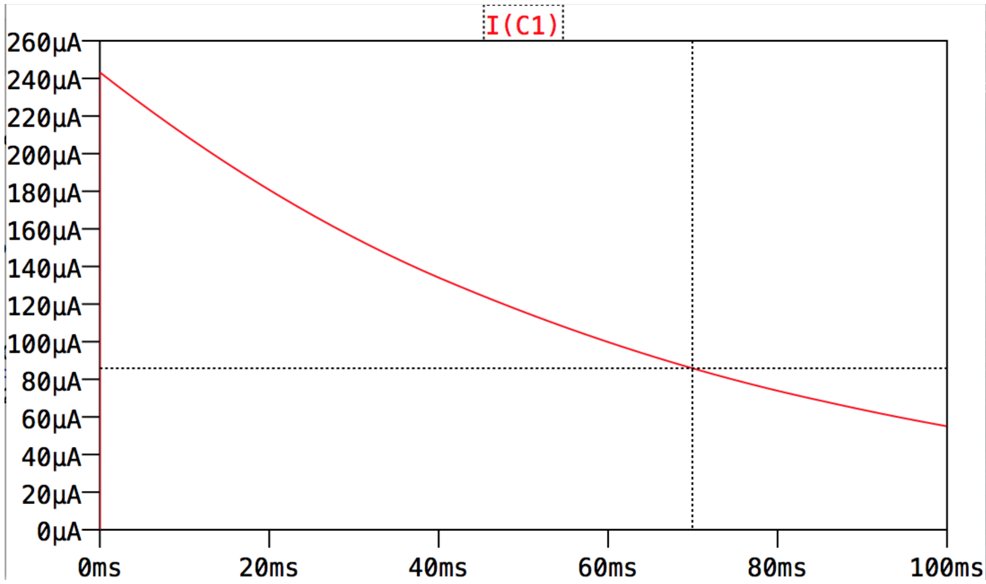
$i_x(\infty) = 0$

$i_x(t) = 243.24e^{-t/67.27}$ μA

$i_x(70\text{ ms}) = 243.24e^{-70/67.27} =$ **85.93 μA**

(b)




I(C1)
260µA
240µA
220µA
200µA
180µA
160µA
140µA
120µA
100µA
80µA
60µA
40µA
20µA
0µA
0ms
20ms
40ms
60ms
80ms
100ms

52.

When the switch is open for t<0, the capacitor is charged.
The circuit can be revised to a Thevenin equivalent using source transformation or other techniques with V_{TH} = 90/11 mV and R_{eq} = 370/11 Ω
The final voltage is 90/11 mV

For t>0, the short circuit of the switch will alter the circuit to two independent circuits. The i_x branch is part of a series RC circuit on the right side, where the capacitor will discharge.

Time constant is $\tau = (20)(0.002) = 40$ ms

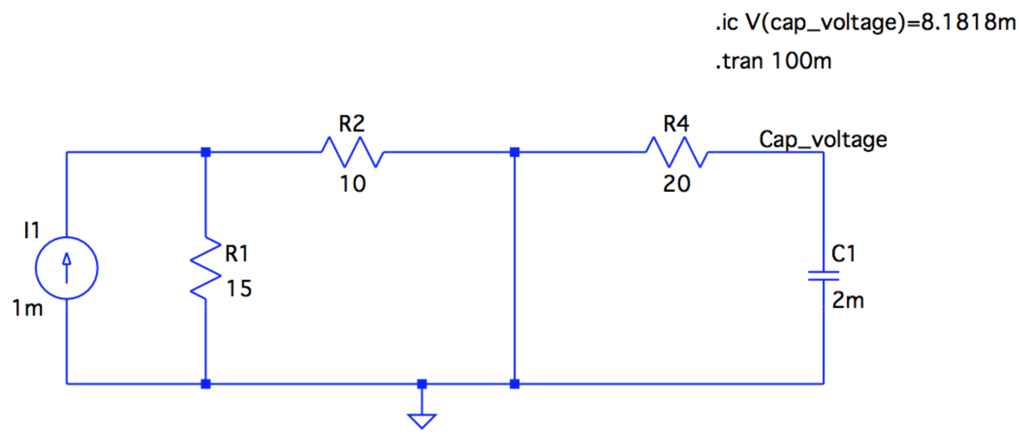
$$i_x(t) = i_x(\infty) + [i_x(0) - i_x(\infty)]e^{-t/\tau}$$

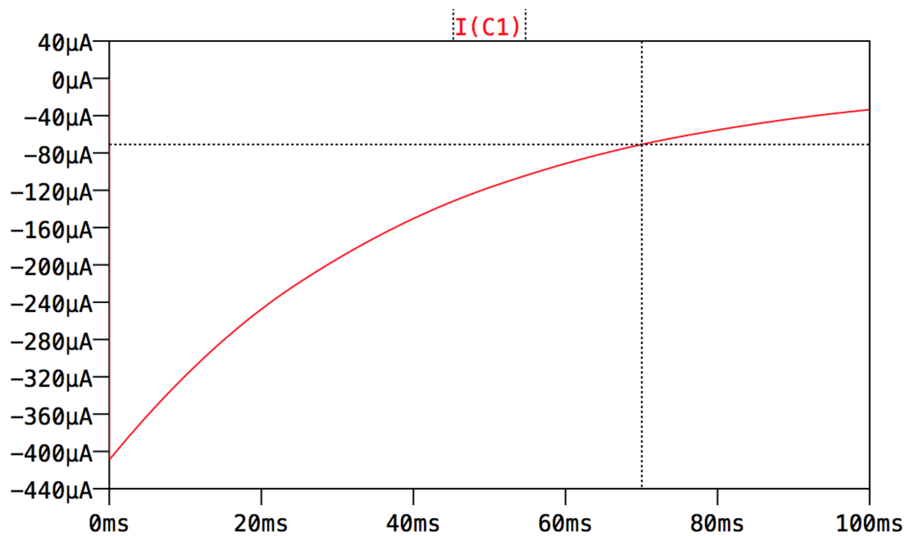
$i_x(0)$ = (−90/11mV)/(20)=-409.09 μA

$i_x(\infty) = 0$

$$i_x(t) = -409.09e^{-t/40ms}\ \mu A$$

$$i_x(70ms) = -409.09e^{-70/40} = -71.09\ \mu A$$





53.

(a) For t<0, capacitor is charged by the 10 V source.
The source voltage is divided among the 5k and 20k resistors

$$v_C(0) = 10\frac{20k}{20k + 5k} = 8 \text{ V}$$

When the switch is flipped, we have a Thevenin equivalent circuit with
I=0.6A, R=10
I=0.6A, R=25/3
R=8.3299 ohm
Vth=4.9979 V

$$v_{TH} = 4.9979 \text{ V} \approx 5 \text{ V}$$

$$R_{eq} = 8.3299 \ \Omega$$

$$\tau = R_{eq}C = 16.66 \ \mu s$$

$$v_c(t) = v_c(\infty) + [v_c(0) - v_c(\infty)]e^{-t/\tau}$$

$$v_c(t) = 5 + [8 - 5]e^{-t/16.66\mu s} \text{ V}$$

$$\boxed{v_c(t) = 5 + 3e^{-t/16.66\mu s} \text{ V}}$$

$$\boxed{i(t) = \frac{v_c}{50} = 100 + 60e^{-t/16.66\mu s} \text{ mA}}$$

(b)

$$w = \frac{1}{2}Cv^2 = \frac{1}{2}(2 \times 10^{-6})(5.4139)^2$$

$$\boxed{w = 29.31 \ \mu J}$$

54.

(a) For t<0, source transformation can be used to determine a Thevenin equivalent circuit with

$v_{TH} = 1.4206 \text{ V}$

$R_{eq} = 0.8824 \text{ W}$

$v_c(0) = 1.4206 \text{ V}$

The power dissipated by the 5 ohm resistor is

$$p = \frac{v_c(0)^2}{5} = \frac{(1.4206)^2}{5} = \boxed{403.62 \text{ mW}}$$

(b) For t>0, a similar Thevenin equivalent can be determined, without the 10 mA source and 5 ohm resistor, and with the switch shorting out the top 1 ohm resistor.

$v_{TH} = 24/11 \text{ V}$

$R_{eq} = 6/11 \text{ W}$

$$v_c(t) = v_c(\infty) + [v_c(0) - v_c(\infty)]e^{-t/t}$$

$$v_c(t) = 2.1818 + [1.4206 - 2.1818]e^{-t/545.5 m} \text{ V}$$

$$v_c(t) = 2.1818 - 0.7612e^{-t/545.5 m} \text{ V}$$

The power dissipated in the 3 ohm resistor is given by

$$p = \frac{v_c^2}{3} = \frac{(2.1623)^2}{3}$$

$$p = \boxed{1.5586 \text{ W}}$$

55.

(a) The circuit on the left may be represented by a Thevenin equivalent circuit with

$v_{TH} = 2.25 \text{ V}$

$R_{eq} = 1.25\ \Omega$

$\tau = R_{eq}C = (1.25)(20\mu) = 25\ \mu s$

The capacitor is initially uncharged, v=0

$v_c(t) = v_c(\infty) + [v_c(0) - v_c(\infty)]e^{-t/\tau}$

$v_c(t) = 2.25 + [0 - 2.25]e^{-t/25\mu s} \text{ V}$

$$v_c(t) = 2.25\left[1 - e^{-t/25\mu s}\right] \text{ V}$$

(b)

$$w = \frac{1}{2}Cv^2$$

$$w(0) = \frac{1}{2}(20\mu)(0)^2 = 0$$

$$w(25\mu s) = \frac{1}{2}(20\mu)(1.4223)^2 = 20.229\ \mu J$$

$$w(150\mu s) = \frac{1}{2}(20\mu)(2.2444)^2 = 50.374\ \mu J$$

56.

The circuit on the left may be represented by a Thevenin equivalent circuit with

$v_{TH} = 6 \text{ V}$

$R_{eq} = 1\ \Omega$

$\tau = R_{eq}C = (1)(20\mu) = 20\ \mu s$

The capacitor is initially uncharged, v=0

$v_c(t) = v_c(\infty) + [v_c(0) - v_c(\infty)]e^{-t/\tau}$

$v_c(t) = 6 + [0 - 6]e^{-t/20\mu s} \text{ V}$

$v_c(t) = 6\left[1 - e^{-t/20\mu s}\right] \text{ V}$

The circuit will fail when the 5 ohm resistor power is 2 W

$p = 2 = \dfrac{v_c^{\ 2}}{5}$

$v_c = \sqrt{10}$

$\sqrt{10} = 6\left[1 - e^{-t/20\mu s}\right] \text{ V}$

$\boxed{t = 14.975\ \mu s}$

57.

The 1 ohm resistance in parallel will not impact the resistance and voltage observed by the capacitor, where a Thevenin equivalent circuit can be drawn with

$v_{TH} = 12e^{-2t}u(t)$ V

$R_{eq} = 1$ W

$t = R_{eq}C = (1)(1) = 1\ s$

The capacitor is initially uncharged, v=0

Since we no longer have a step response, we need to evaluate the forced solution from the differential equation

$$\frac{dv_c}{dt} + \frac{v_c}{RC} = 12e^{-2t}$$

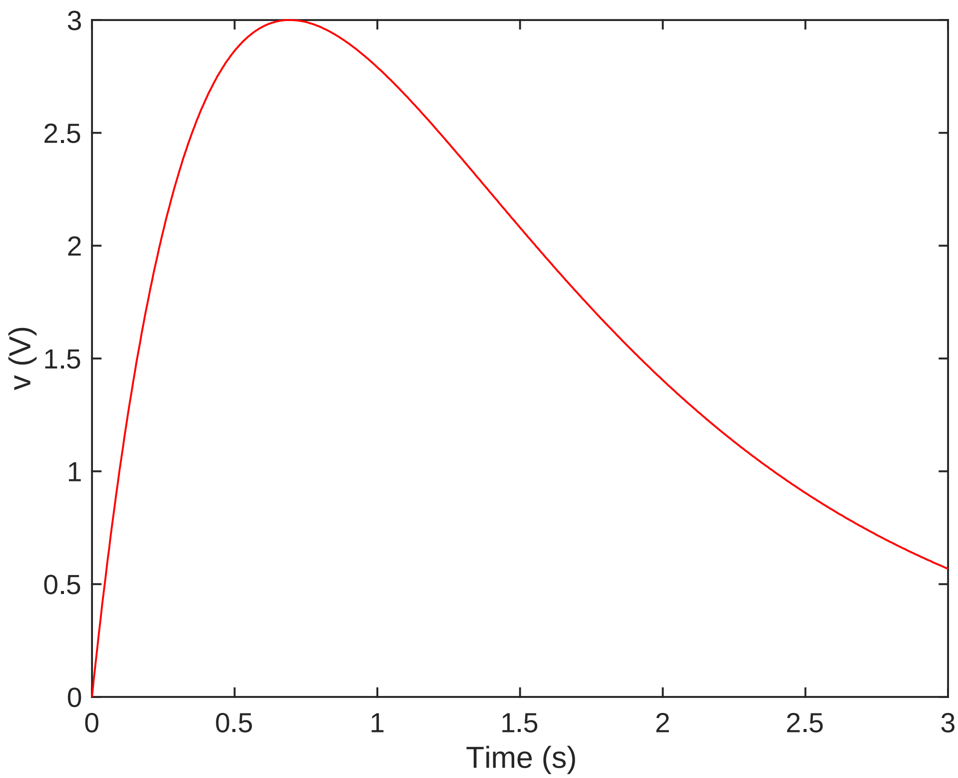
$$v_f(t) = -12e^{-2t}$$

$$v_n(t) = Ke^{-t}$$

$$v(t) = Ke^{-t} - 12e^{-2t}$$

Evaluating at t=0 to find K: $K = 12$

$$\boxed{v(t) = 12\left(e^{-t} - e^{-2t}\right)\ \text{V}}$$



58.

There is no current flowing into the op amp terminals. Therefore, the output of the op amp will be the same as the 9u(t) source. The capacitor will be have similar to a series RC circuit, with the capacitor initially uncharged.

$$v_c(t) = 9 + [0 - 9]e^{-t/16ms}$$

$$v_c(t) = 9\left[1 - e^{-t/16ms}\right] \text{ V}$$

The voltage across the resistor will be $9 - v_c$

$$\boxed{v_x(t) = 9e^{-t/16ms} \text{ V for } t > 0}$$

59.

The response of the series RL circuit is time-shifted, where the voltage source turns on at t = 1.

$$i(t) = i(\infty) + [i(1) - i(\infty)]e^{-(t-1)/t}$$

$$t = \frac{L}{R} = \frac{1}{3}\ ms$$

$$i(\text{¥}) = \frac{9}{3k} = 3\text{ mA}$$

$$i(t\,\text{£}\,1) = 0$$

$$i(t) = 3\left(1 - e^{-(t-1)/t}\right)\text{ mA for t > 1}$$

(a) $i(0^-) = 0$

(b) $i(0^+) = 0$

(c) $i(1^-) = 0$

(d) $i(1^+) = 0$

(e) $i(2ms) = 3\left(1 - e^{-1/(1/3)}\right) = 2.8506\text{ mA}$

60.

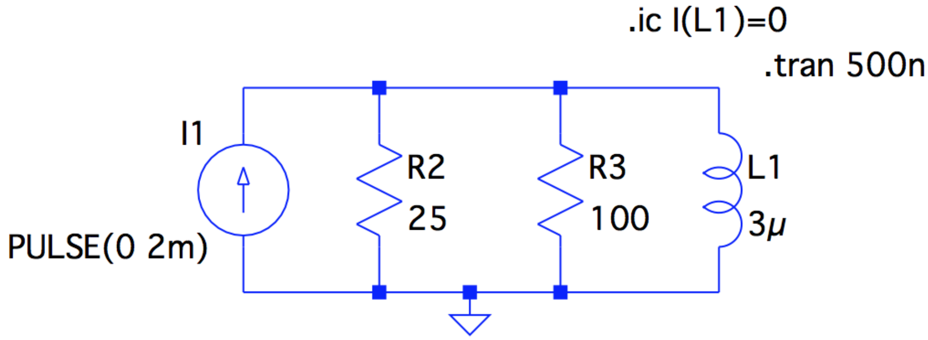
(a) The inductor has no energy storage for $t < 0$, and hence no current flow. When the source turns on, current will begin flowing through the resistors, current increasing through the inductor as time progresses.

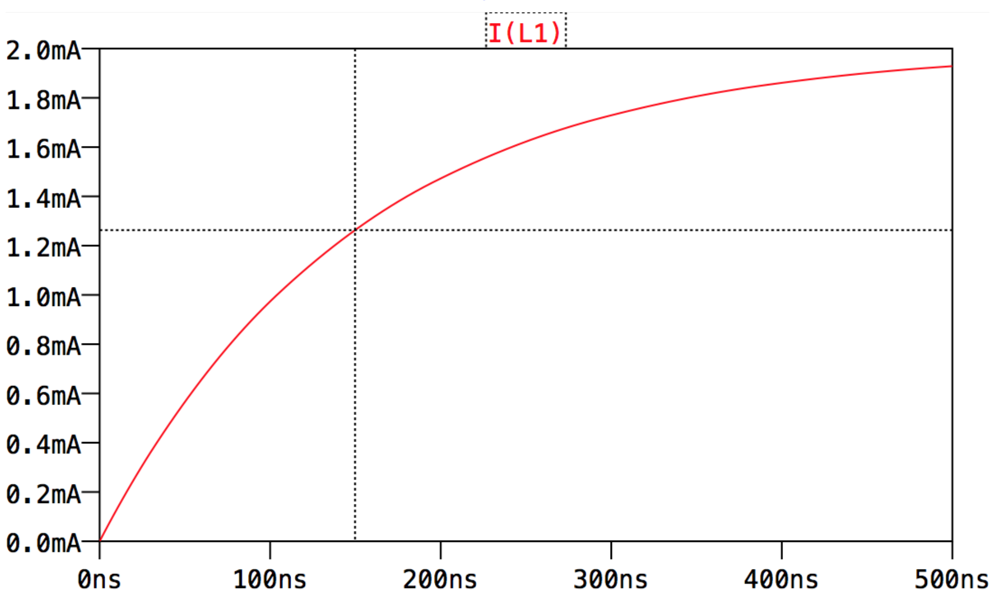
$$i(0^-) = i(0^+) = 0$$
$$v(0^-) = 0$$
$$v(0^+) = (2mA)(25 // 100\Omega) = 40\ mV$$

(b)

$$i(t) = i(\infty) + [i(0) - i(\infty)]e^{-t/\tau}$$
$$i(t) = 2 + [0 - 2]e^{-20t/3m}\ \text{mA}$$
$$i(t) = 2(1 - e^{-t/150ns})\ \text{mA}$$
$$i(150ns) = 2(1 - e^{-150/150})\ \text{mA}$$
$$i(150ns) = 1.2642\ \text{mA}$$

(c)





61.

(a)

$$i(t) = i(\infty) + \left[i(0) - i(\infty)\right]e^{-t/\tau}$$

$$i(0) = 400\ \mu\text{A}$$

$$i(\infty) = 33.733\ \text{mA}$$

$$R_{eq} = (2k + 1k)\,||\,1k = 750\ \Omega$$

$$\tau = \frac{L}{R_{eq}} = \frac{10m}{750} = 13.33\ \mu\text{s}$$

$$i(t) = 33.733 + \left[0.4 - 33.733\right]e^{-t/13.33\mu\text{s}}\ \text{mA}$$

$$\boxed{i(t) = 33.733 - 33.333e^{-t/13.33\mu\text{s}}\ \text{mA}}$$

(b)

$$i(10\,\mu\text{s}) = 17.99\ \text{mA}$$

$$i(20\,\mu\text{s}) = 26.30\ \text{mA}$$

$$i(50\,\mu\text{s}) = 32.95\ \text{mA}$$

62.

(a) $i(t) = i(\infty) + [i(0) - i(\infty)]e^{-t/\tau}$

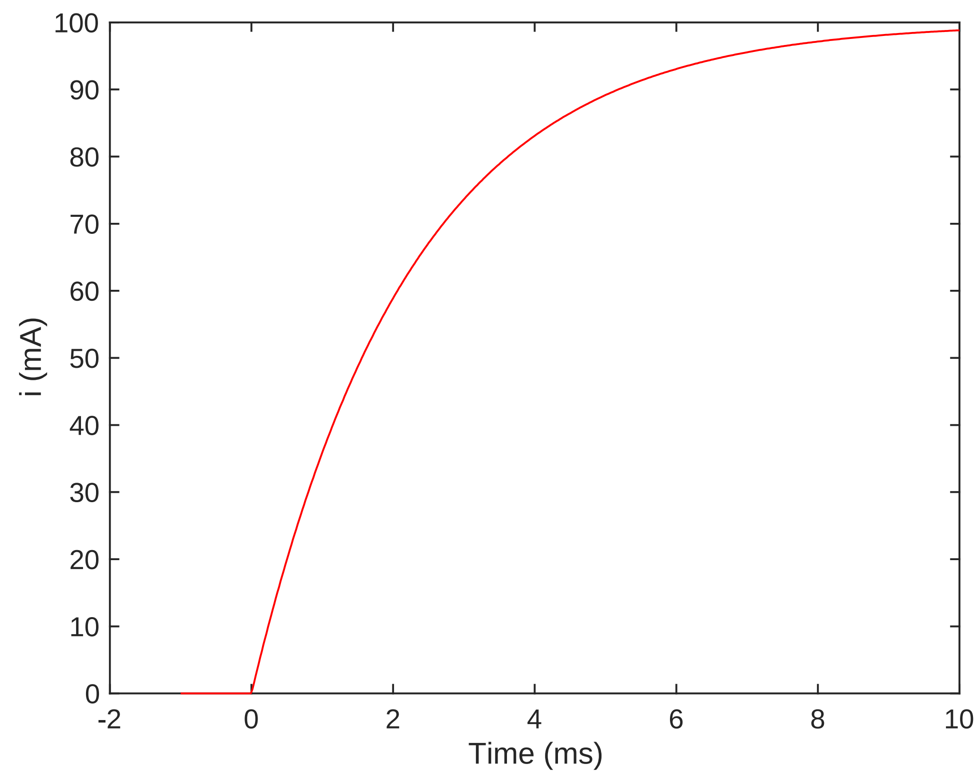
$$\tau = \frac{L}{R} = \frac{0.045}{20} = 2.25\ ms$$

$$i(\infty) = \frac{2}{20} = 0.1\ \text{A}$$

$$i(t \le 0) = 0$$

$$\boxed{i(t) = 0.1\left(1 - e^{-t/2.25ms}\right)\ \text{A}}$$

(b)



63.

(a) $i(t) = i(\infty) + [i(0) - i(\infty)]e^{-t/t}$

$R_{eq} = 30 \,||\, 5 = \frac{30}{7}\ \Omega$

$t = \frac{L}{R} = \frac{5}{30/7} = \frac{7}{6}\ s$

$i(¥) = \frac{12}{30} = 0.4\ \text{A}$

$i(t\,£\,0) = 0$

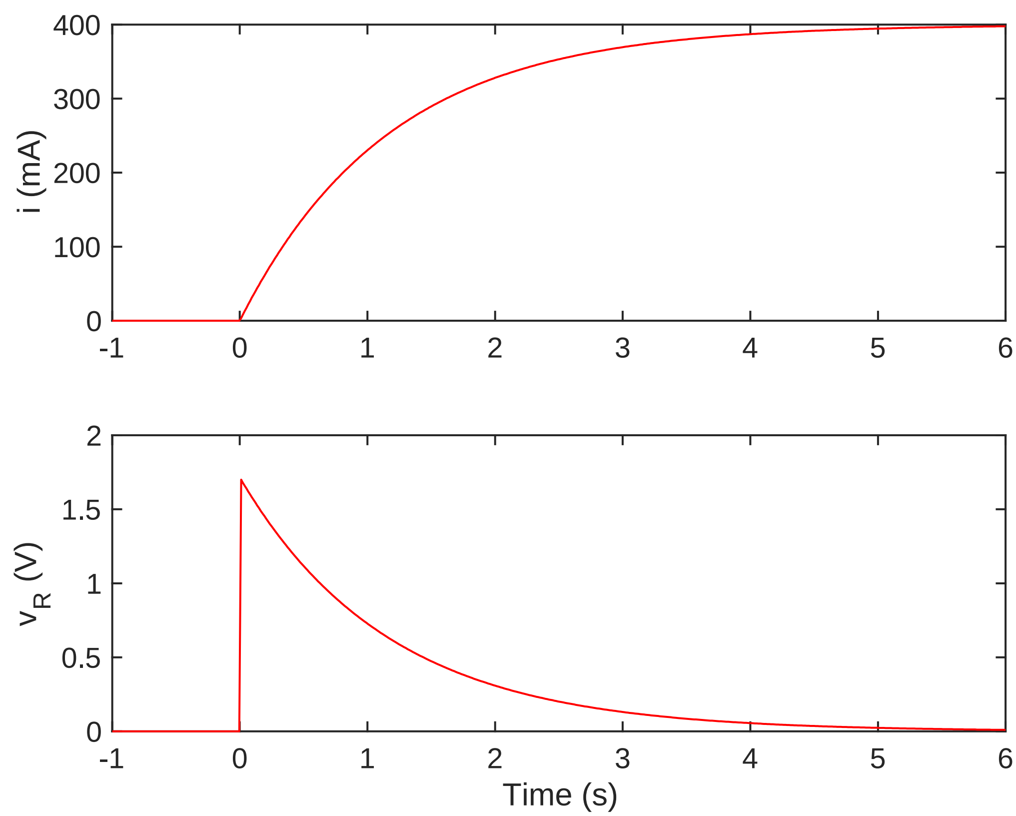
$$i(t) = 0.4\left(1 - e^{-6t/7}\right)\ \text{A}$$

(b)

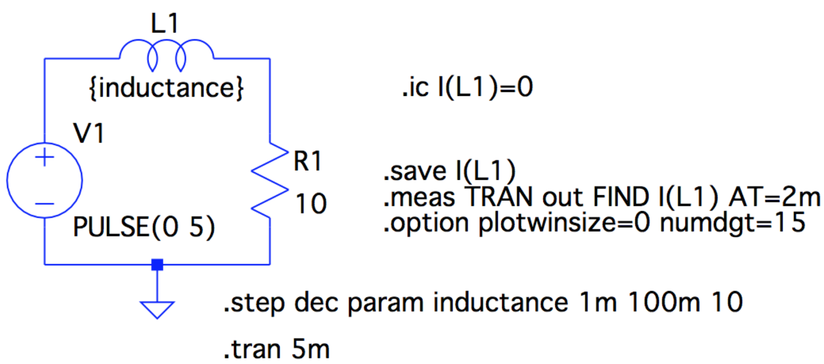
$v_R = v_L = L\frac{di}{dt}$

$$v_R = \frac{12}{7}e^{-6t/7} = 1.7143e^{-6t/7}\ \text{V}$$

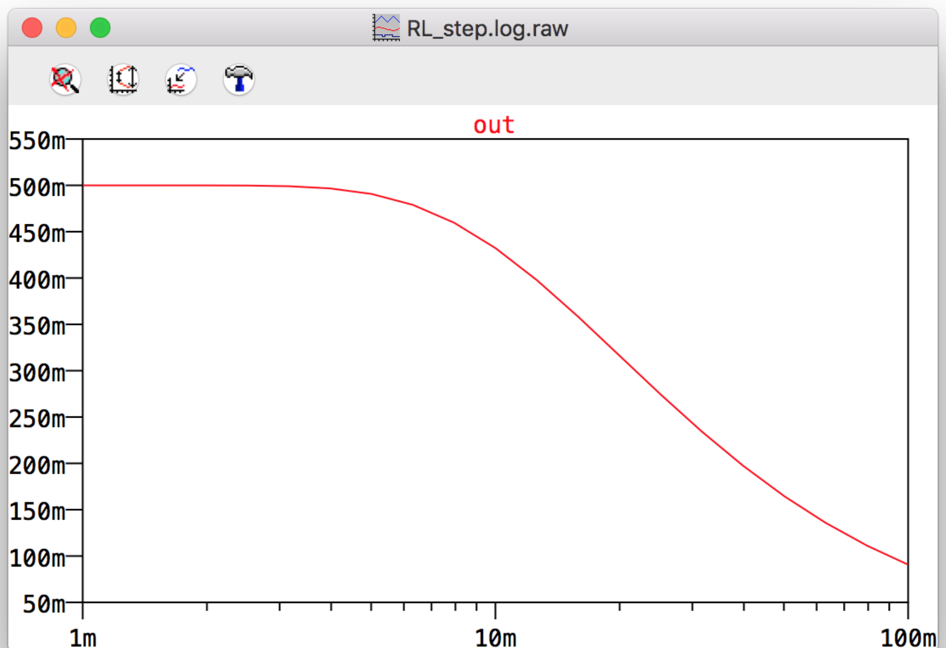
(c)



64.



The plot below shows output, with current at 2ms as y-axis and inductance as x-axis.



65.

(a) For t < 0, voltage supply is 5 V, all current flows through 100 ohm resistor and inductor; inductor shorts the 400 ohm source. For t > 0, source switches to a total of 11 V. Equivalent resistance observed by inductor is parallel combination of 100 and 400 ohm resistors.

$$i(t) = i(\infty) + [i(0) - i(\infty)]e^{-t/t}$$

$$R_{eq} = 100 \,||\, 400 = 80\ \Omega$$

$$t = \frac{L}{R} = \frac{5}{80} = 62.5\ \text{m}s$$

$$i(\text{¥}) = \frac{11}{100} = 110\ \text{mA}$$

$$i(t\ \text{£}\ 0) = \frac{5}{100} = 50\ \text{mA}$$

$$\boxed{i(t) = 110 - 60e^{-t/62.5ms}\ \text{mA}}$$

(b) $w = \frac{1}{2}Li^2$

$$\frac{w}{w_{\max}} = 0.9 = \frac{i^2}{i_{\max}^2}$$

$$i = \sqrt{0.9}\,i_{\max} = 104.35\ \text{mA}$$

$$\boxed{t = 147.7\ \text{ms}}$$

66.

(a) For t < 0, the switch shorts the 4.5 V source and 60 ohm resistor. When the switch opens, the source and resistor are added in series.

$$i(t) = i(\infty) + [i(0) - i(\infty)]e^{-t/\tau}$$

$$R_{eq} = 60 + 20 = 80\ \Omega$$

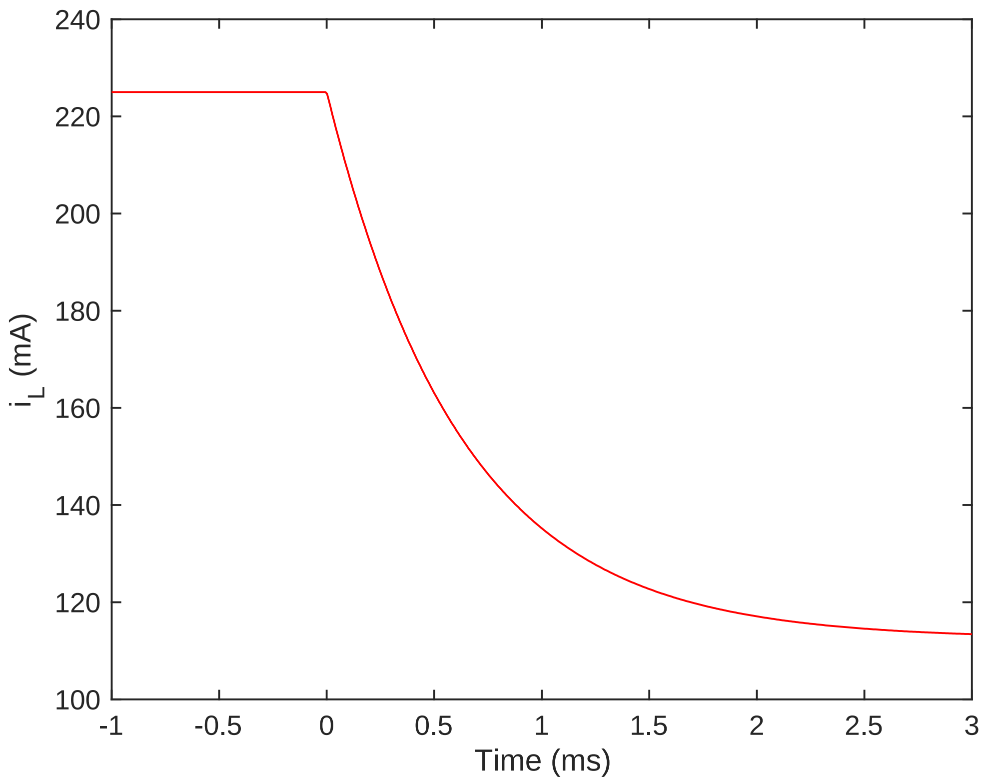
$$\tau = \frac{L}{R} = \frac{0.05}{80} = 625\ \mu s$$

$$i(\infty) = \frac{9}{80} = 112.5\text{ mA}$$

$$i(t \le 0) = \frac{4.5}{20} = 225\text{ mA}$$

$$i_L(t) = \begin{cases} 225\text{ mA} & t < 0 \\ 112.5 + 112.5e^{-t/625\,\mu s}\text{ mA} & t \geq 0 \end{cases}$$

(b)



67.

For t < 0, the isolates the 100 mA source and 30 ohm resistor. When the switch closes, the source and resistor are added in parallel.

$$i(t) = i(\infty) + \left[i(0) - i(\infty)\right]e^{-t/t}$$

$$R_{eq} = 30 \,||\, 40 = \frac{120}{7}\ \Omega$$

$$t = \frac{L}{R} = \frac{0.03}{120/7} = 1.75\ \text{m}s$$

$$i_L(¥) = 300\ \text{mA}$$

$$i_L(t\, £\, 0) = 200\ \text{mA}$$

However, we are asked to find the current through the 40 ohm resistor

$$i(¥) = 0$$

Voltage at the node at time = 0^+

$$\frac{v}{30} + \frac{v}{40} + 200m = 100m + 200m$$

$$v = 1.7143\ \text{V}$$

$$i(t = 0^+) = \frac{v}{40} = 42.857\ \text{mA}$$

$$i(t) = \begin{cases} 0 & t < 0 \\ 42.857e^{-t/1.75ms}\ \text{mA} & t \geq 0 \end{cases}$$

$$i(\ )$$

$$p = i^2 R = \left(0.042857e^{-2.5/1.75}\right)^2 (40)$$

$$p = 4.2195\ \text{mW}$$

68.

For t < 0, there is no energy stored in the inductor. For t > 0, source turns on and current begins flowing through inductor. Find initial and final values, time constant of circuit.

$$i_1(t) = i_1(\infty) + \left[i_1(0) - i_1(\infty)\right]e^{-t/t}$$

Need to negate independent sources and apply a test source to find Req

$$R_{eq} = \frac{25}{13}\ \text{W}$$

$$t = \frac{L}{R} = \frac{50n}{25/13} = 26\ \text{n}s$$

$$i_1(0^+) = \frac{2}{13} = 153.85\ \text{mA}$$

$$i_1(¥) = 400\ \text{mA}$$

$$i_1(t) = 400 - 246.15e^{-t/26ns}\ \text{mA}$$

$$i_1(t) = \begin{cases} 0 & t < 0 \\ 400 - 246.15e^{-t/26ns}\ \text{mA} & t \geq 0 \end{cases}$$

69.

For t < 0, the sources are off, no energy storage.
At t = 0, the 9 V source turns on, inductor charges
At t = 1, -9 V source turns on, canceling the 9 V source, inductor discharges

$$i(t) = i(\infty) + \left[i(0) - i(\infty)\right]e^{-t/t}$$

For 0 < t < 1

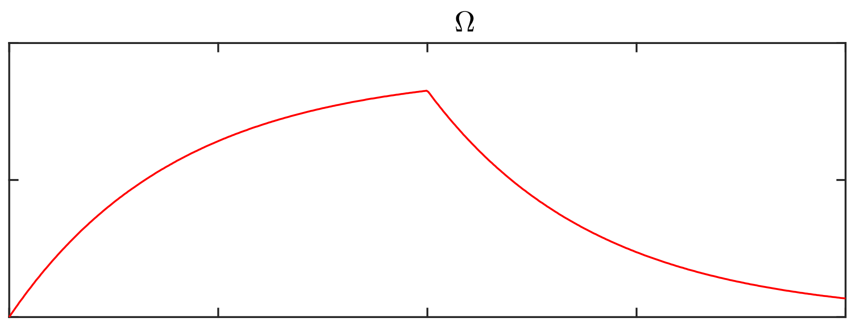
$$i(t) = \frac{9}{R}\left(1 - e^{-Rt/4}\right)$$

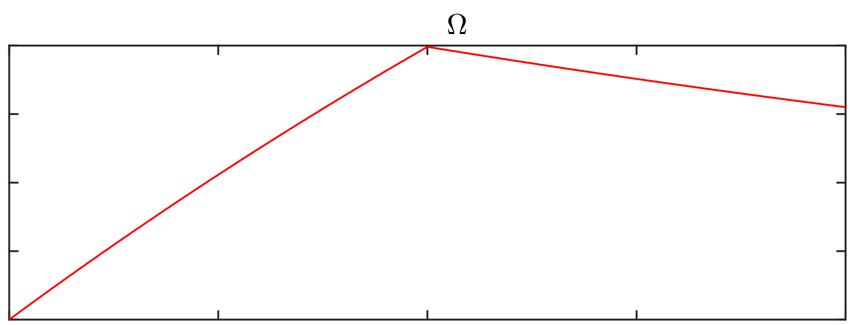
At t = 1,

$$i(1) = \frac{9}{R}\left(1 - e^{-R/4}\right)$$

For t > 1

$$i(t) = i(1)e^{-R(t-1)/4} = \frac{9}{R}\left(1 - e^{-R/4}\right)e^{-R(t-1)/4}$$





The circuit with R = 1 ohm reaches a higher current, and will therefore lead to larger energy storage in the inductor.

70.

$$i(t) = i(\infty) + [i(0) - i(\infty)]e^{-t/t}$$

$$t = \frac{L}{R} = \frac{0.02}{10} = 2 \text{ m}s$$

$$i(0^+) = \frac{2.5}{10} = 250 \text{ mA}$$

$$i(¥) = \frac{5}{10} = 500 \text{ mA}$$

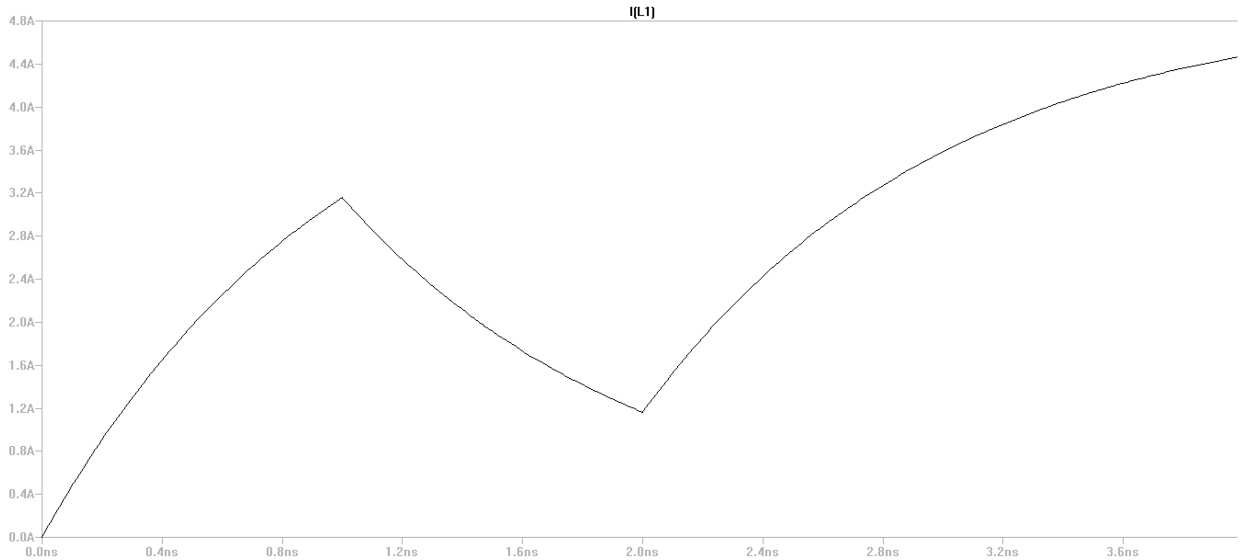
$$i(t) = 500 - 250e^{-t/2ms} \text{ mA}$$

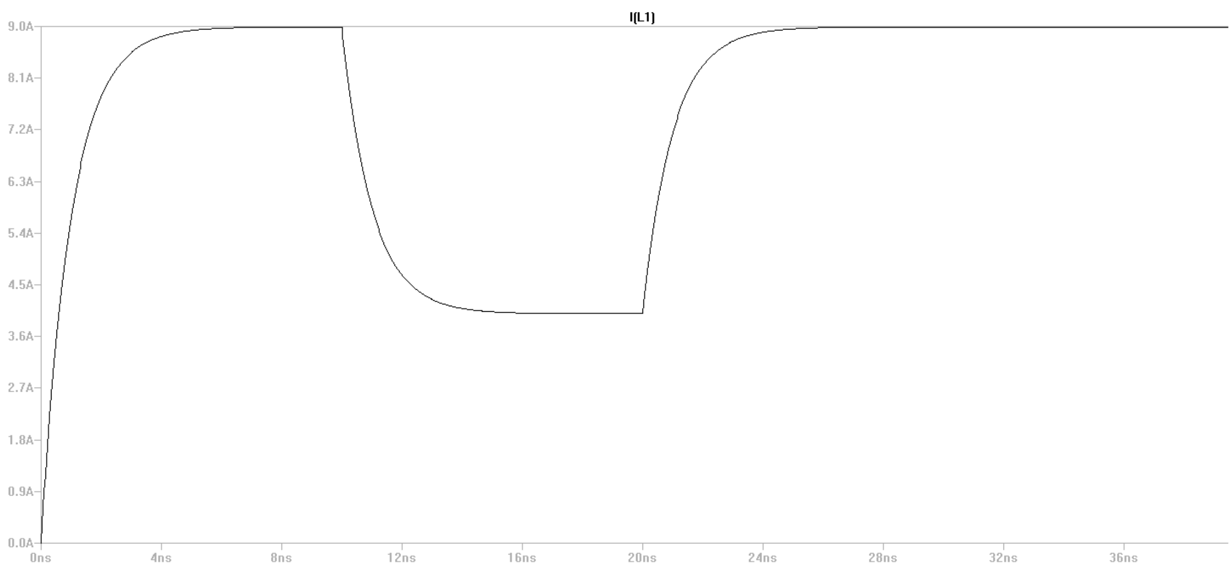
95% of full speed when current is 475 mA

$$\boxed{t = 4.6052 \text{ ms}}$$

71.

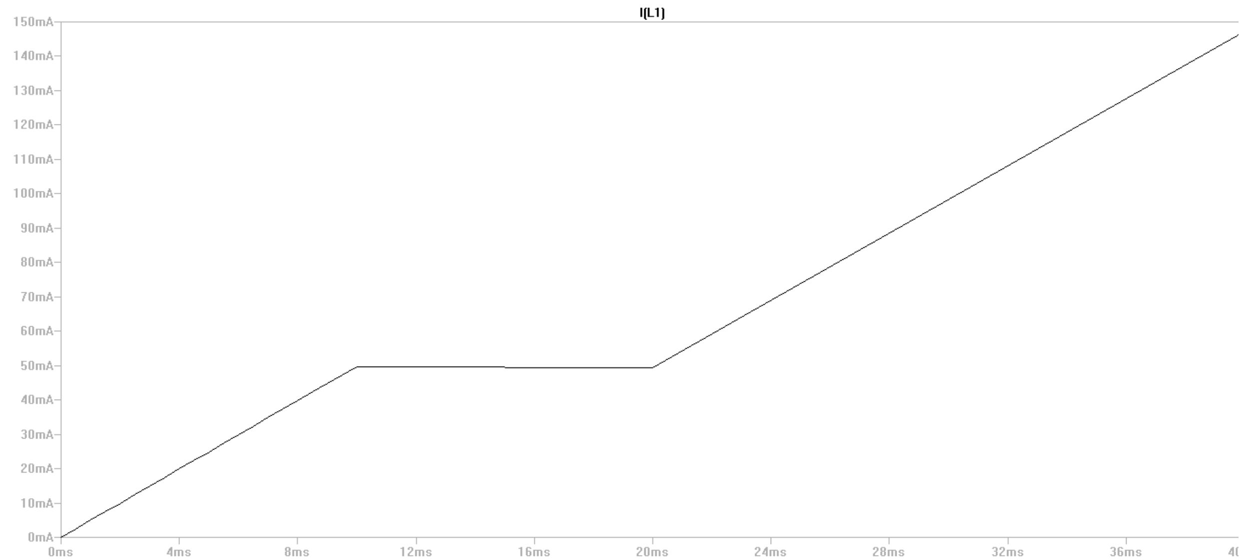
The new time constant for the circuit is 1 ns.

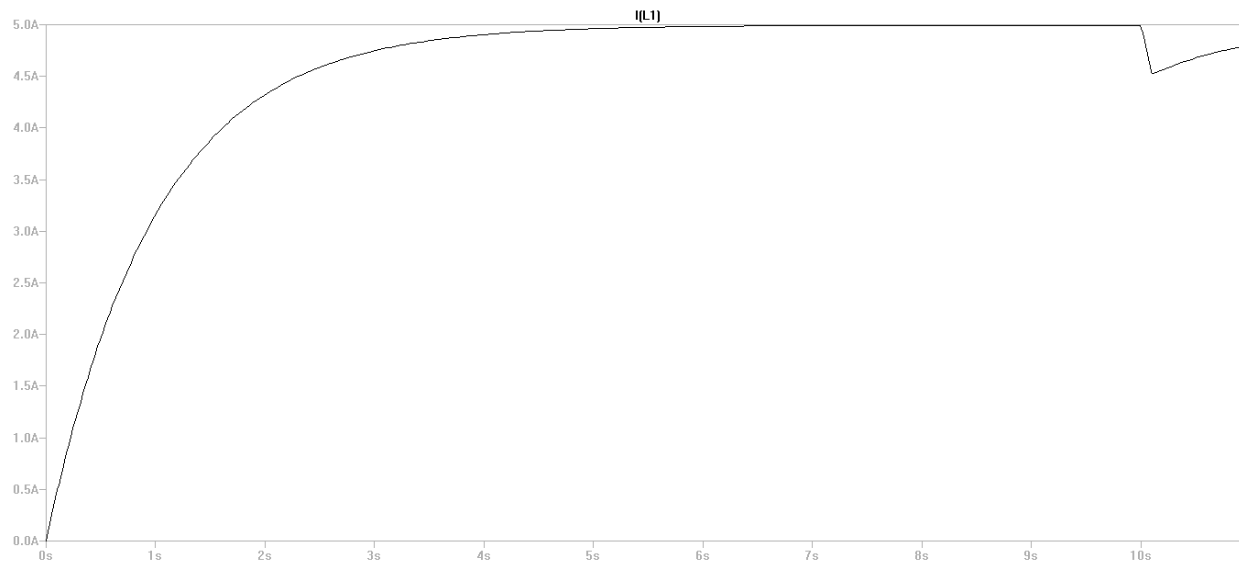




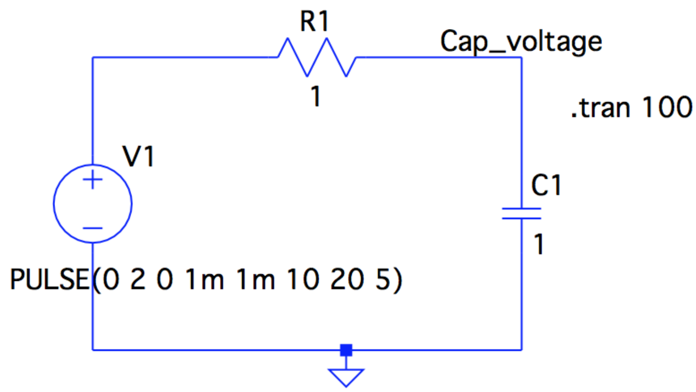
72.

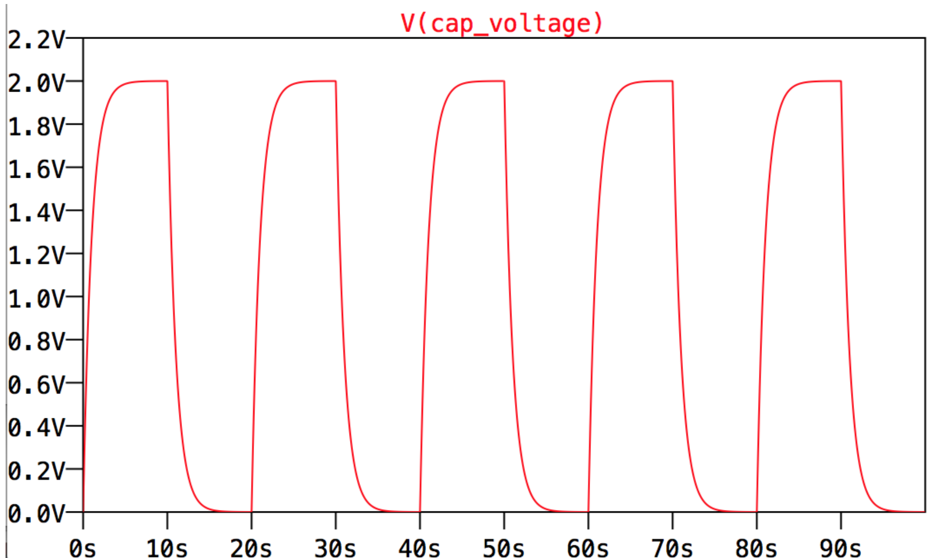
The new time constant for the circuit is now 1 s.

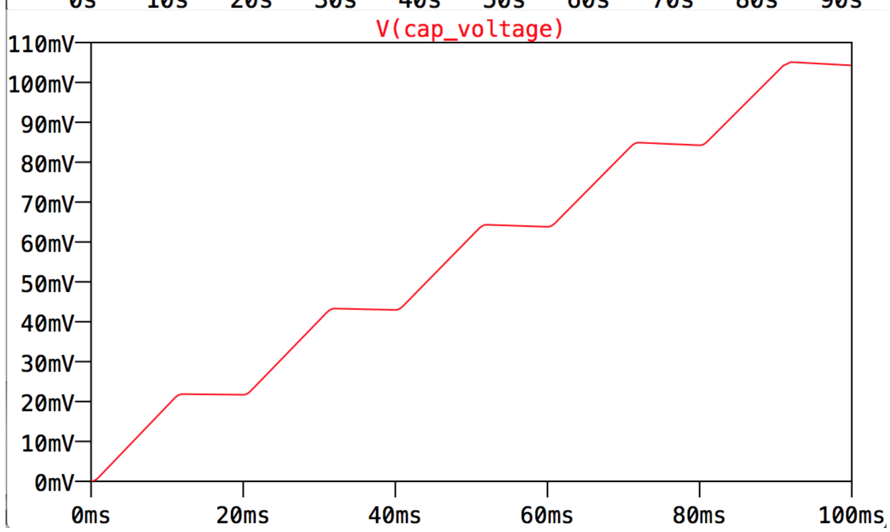




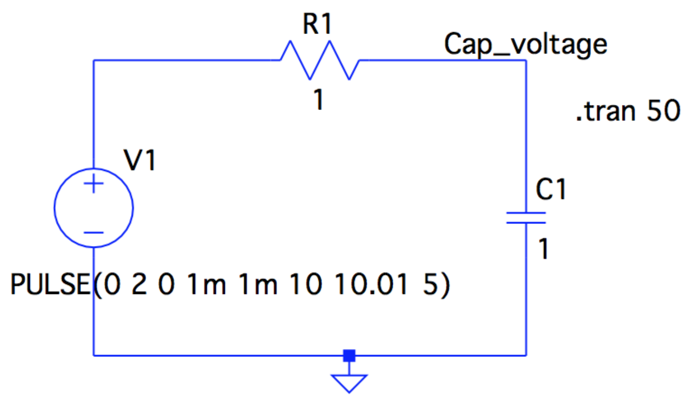
73.

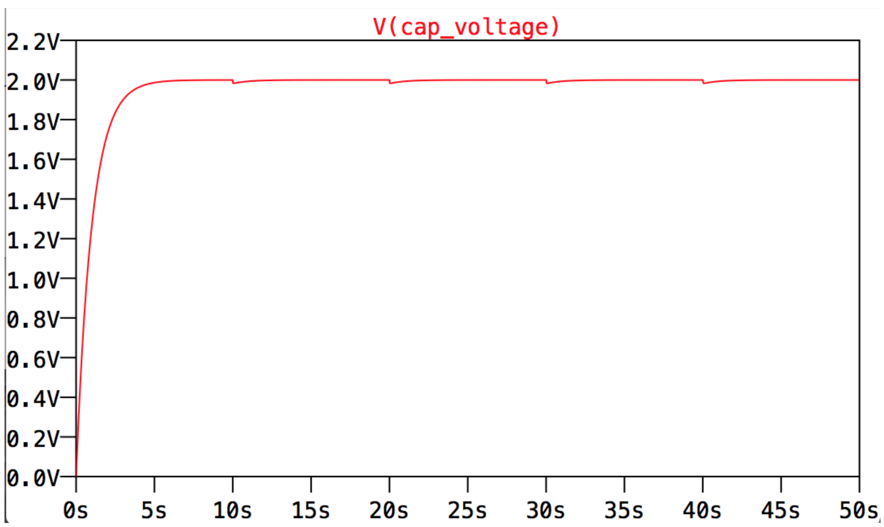

R1
1
Cap_voltage
.tran 100
V1
C1
1
PULSE(0 2 0 1m 1m 10 20 5)

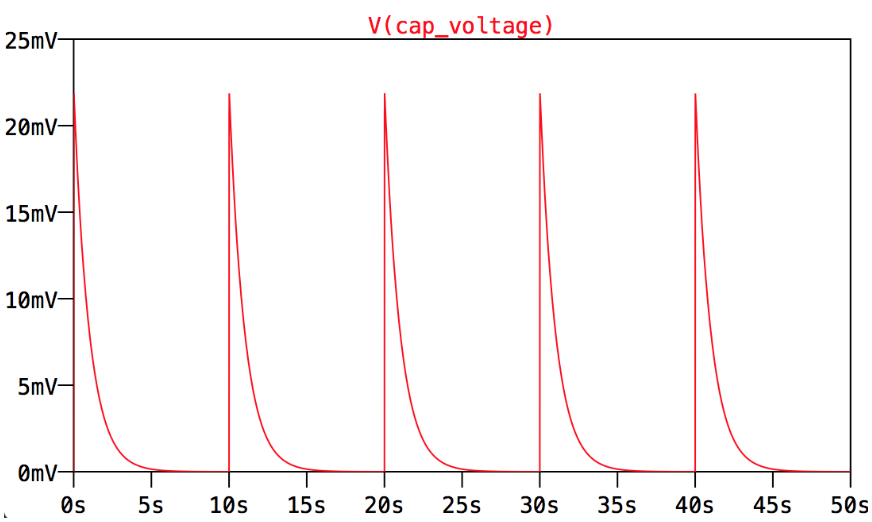

V(cap_voltage)
2.2V
2.0V
1.8V
1.6V
1.4V
1.2V
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
0s
10s
20s
30s
40s
50s
60s
70s
80s
90s


V(cap_voltage)
110mV
100mV
90mV
80mV
70mV
60mV
50mV
40mV
30mV
20mV
10mV
0mV
0ms
20ms
40ms
60ms
80ms
100ms

74.

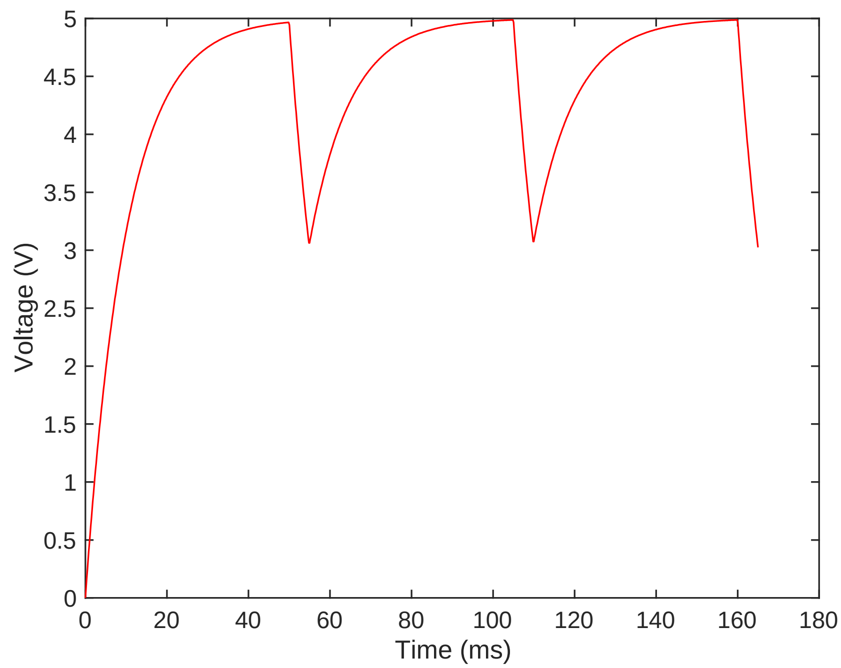

R1
1
Cap_voltage
.tran 50
V1
C1
1
PULSE(0 2 0 1m 1m 10 10.01 5)


V(cap_voltage)
2.2V
2.0V
1.8V
1.6V
1.4V
1.2V
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
0s 5s 10s 15s 20s 25s 30s 35s 40s 45s 50s


V(cap_voltage)
25mV
20mV
15mV
10mV
5mV
0mV
0s 5s 10s 15s 20s 25s 30s 35s 40s 45s 50s

75.

Time constant is 10 ms. Evaluate RC response piecewise, evaluating initial conditions for each step of the input pulse.




```
Vin=5;
R=200;
C=50e-6;

tau=R*C*1000;

tpts=1000;
t1=50;
t2=55;
t3=105;
t4=110;
t5=160;
t6=165;

t=linspace(0,t6,tpts);

for i=1:tpts;
    if t(i)<t1;
        vc(i)=Vin*(1-exp(-(t(i)-0)/tau));
        c1=i; % counter
    end
    if t(i)>=t1 & t(i)<t2;
        vcinit=vc(c1);
        vc(i)=vcinit*exp(-(t(i)-t1)/tau);
        c2=i;
```

```
        end
        if t(i)>=t2 & t(i)<t3;
            vcinit=vc(c2);
            vc(i)=(vcinit-Vin)*exp(-(t(i)-t2)/tau)+Vin;
            c3=i;
        end
        if t(i)>=t3 & t(i)<t4;
            vcinit=vc(c3);
            vc(i)=vcinit*exp(-(t(i)-t3)/tau);
            c4=i;
        end
        if t(i)>=t4 & t(i)<t5;
            vcinit=vc(c4);
            vc(i)=(vcinit-Vin)*exp(-(t(i)-t4)/tau)+Vin;
            c5=i;
        end
        if t(i)>=t5 & t(i)<=t6;
            vcinit=vc(c5);
            vc(i)=vcinit*exp(-(t(i)-t5)/tau);
            c6=i;
        end
    end

    figure(1)
    plot(t,vc,'r','LineWidth',1.0)
    xlabel('Time (ms)','FontSize',14)
    ylabel('Voltage (V)','FontSize',14)
    set(gca,'Fontsize',14,'LineWidth',1.0)
```

76.

(a) Canceling current source and analyzing to find Req:

$R_{eq} = 13.6\ \Omega$

$\tau = L / R_{eq} = 220.6\ \mu s$

(b) For t > 0, one method is to develop a Thevenin equivalent circuit

We already have R_{eq} above

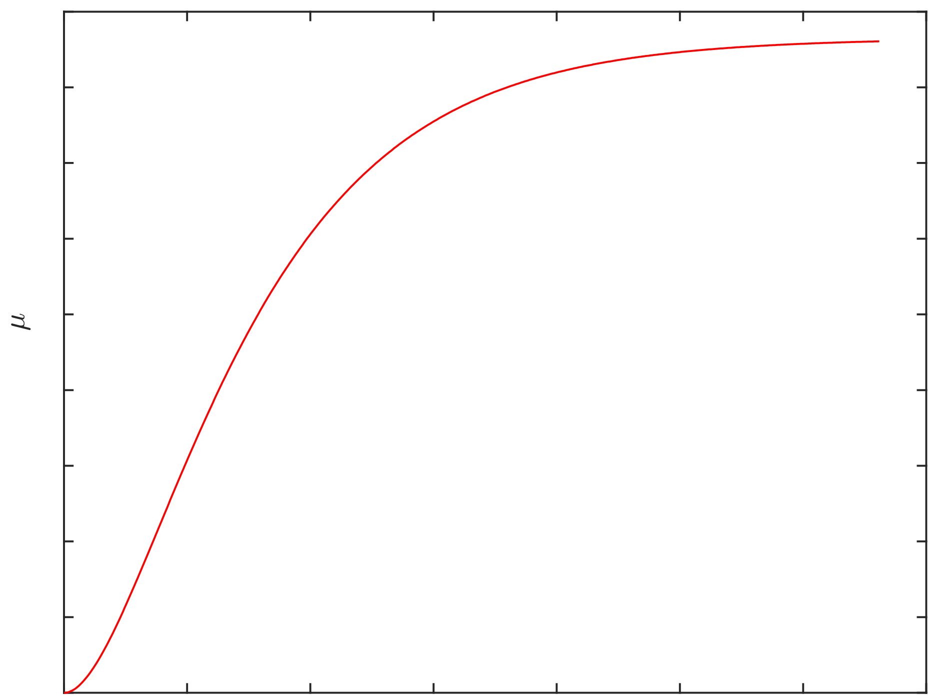
The open circuit voltage at the inductor is (2m)(10) = 20 mV

$$i(t) = \frac{20m}{13.6}\left(1 - e^{-t/220.6\mu s}\right) = 1.4706\left(1 - e^{-t/220.6\mu s}\right)\ \text{mA}$$

$$v_x = 4i(t) = 5.8824\left(1 - e^{-t/220.6\mu s}\right)\ \text{mV}$$

(c)

$p = i^2 R$



(d)

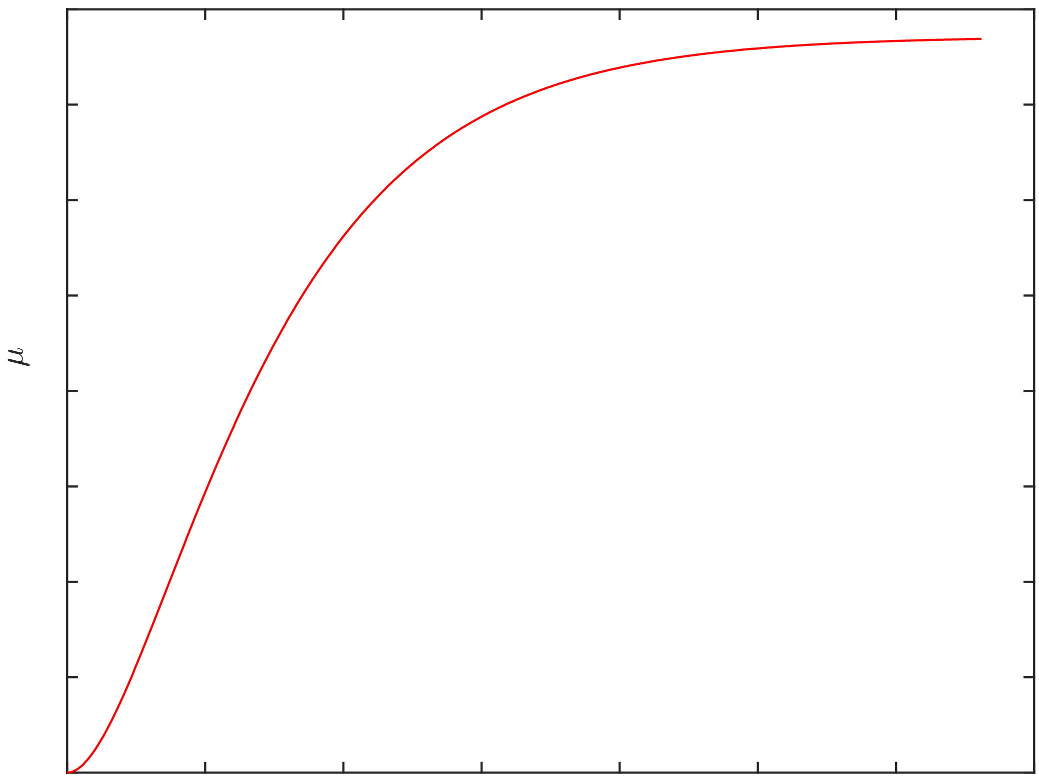
Changing the dependent source results in a change in Req. V_{TH} remains the same.

$$R_{eq} = 14.4\ \mathrm{W}$$

$$t = L / R_{eq} = 208.3\ ms$$

$$i(t) = \frac{20m}{14.4}\left(1 - e^{-t/208.3ms}\right) = 1.3889\left(1 - e^{-t/208.3ms}\right)\ \mathrm{mA}$$

$$v_x = 4i(t) = 5.5556\left(1 - e^{-t/208.3ms}\right)\ \mathrm{mV}$$



(e) Both circuit configurations are “stable”, they both approach a constant value for final voltage, only differing in equivalent resistance (time constant) and final value.

77.

(a) Canceling current source and analyzing to find Req:

$R_{eq} = 13.6\ \text{W}$

$t = R_{eq}C = 40.8\ ms$

For the case of the 10k resistor, equivalent resistance and time constant change to

$R_{eq} = 13.5815\ \text{W}$

$t = R_{eq}C = 40.7446\ ms$

Not much difference in time constant, changes by about 0.14%

(b) Find the time response of the circuit, using Thevenin equivalent, and then relate to variable v_x

Without the 10k resistor,

$$i(t) = \frac{20m}{13.6}\left(1 - e^{-t/40.8ms}\right) = 1.4706\left(1 - e^{-t/40.8ms}\right)\ \text{mA}$$

$$v_x = 4i(t) = 5.8824\left(1 - e^{-t/40.8ms}\right)\ \text{mA}$$

$$v_x(200ms) = 5.8387\ \text{mV}$$

With the 10k resistor,

$$i(t) = \frac{19.973m}{13.518}\left(1 - e^{-t/40.7446ms}\right) = 1.4775\left(1 - e^{-t/40.7446ms}\right)\ \text{mA}$$

$$v_x = 4i(t) = 5.9100\left(1 - e^{-t/40.7446ms}\right)\ \text{mA}$$

$$v_x(200ms) = 5.8664\ \text{mV}$$

Not much error, approximately 0.47%

78.

Writing KCL at the inverting terminal of the op amp

$$\frac{v_s}{10} = i_c = C\frac{dv_c}{dt}$$

$$v_c = 333.3k \int v_s \, dt$$

We have an *integrator*, where the output is related to the integral of the input. We can relate the capacitor voltage to the desired output

$$v_0 = -v_c - 15i_c = -v_c - 15\left(\frac{v_s}{10}\right)$$

(a)

$$v_c = 1.333t \text{ MV}$$

$$\boxed{v_0 = -1.333 \times 10^6 t - 6 \text{ V}}$$

(b)

$$v_c = \frac{333.3k \times 4}{-130,000}\left(e^{-130,000t} - 1\right) = 10.2554\left(1 - e^{-130,000t}\right) \text{ V}$$

$$\boxed{v_0 = -10.2554\left(1 - e^{-130,000t}\right) - 6e^{-130,000t} \text{ V}}$$

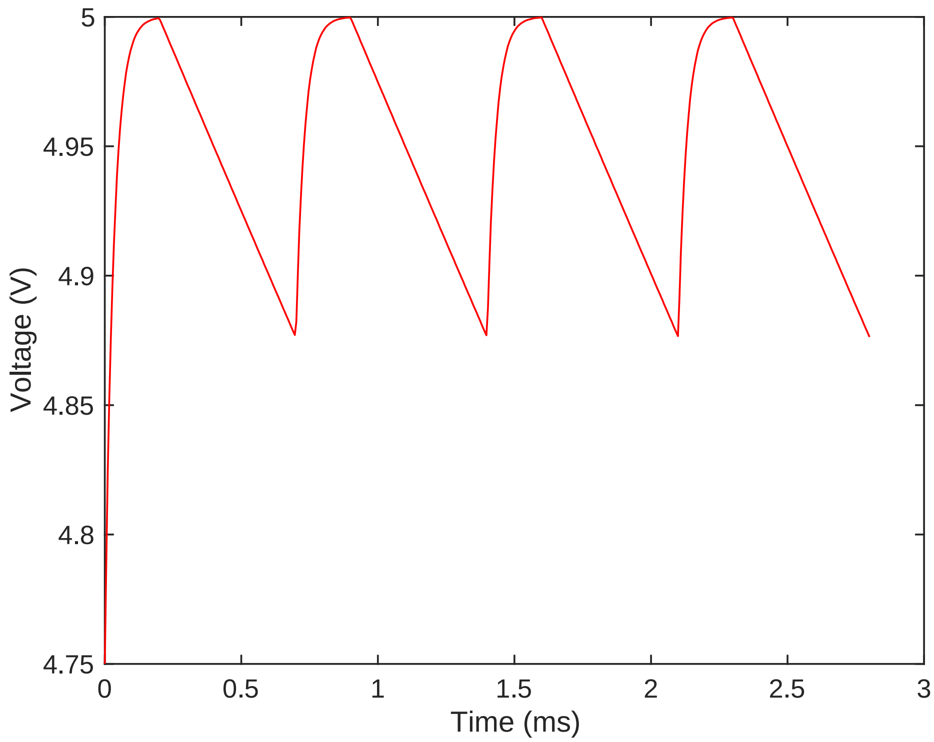
79.

<Design> One possible solution
Choose time constants to be within desired parameters
Choose reasonable values for Rs and RL.

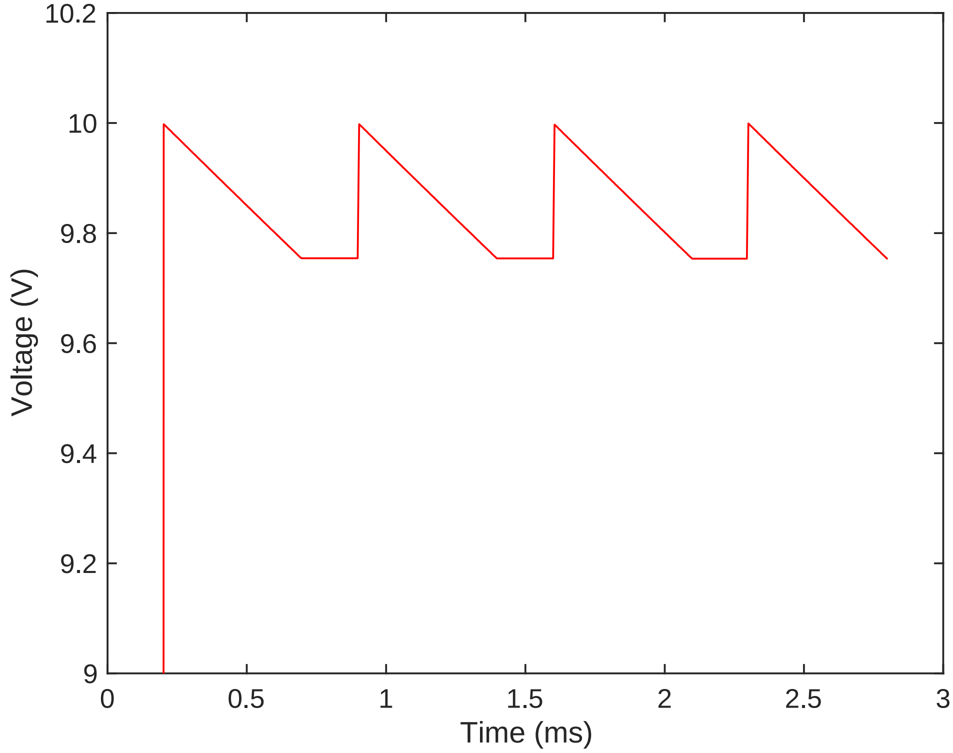
Below is the simulated response for the voltage at C_1 and at the output.

Circuit values:
V_{in} = 5 V
C_1= 8 μF
C_2 = 8 μF
R_s = 2 Ω
R_L = 5000 Ω

Voltage at C1



Voltage output




```
C1=8e-6;
C2=8e-6;
Rs=2;
Rl=5000;

Ceqp=C1+C2;
Ceqs=C1*C2/(C1+C2);

taup=Rs*Ceqp;
taus=Rl*Ceqs;

Vin=5;

tpts=500;
tspace1=2e-4;
tspace2=5e-4;
t1=tspace1;
t2=tspace1+tspace2;
t3=t2+tspace1;
t4=2*t2;
t5=2*t2+tspace1;
t6=3*t2;
t7=3*t2+tspace1;
t8=4*t2;

t=linspace(0,t8,tpts);
```

```
for i=1:tpts;
    if t(i)<t1;
        vc1(i)=(4.75-Vin)*exp(-(t(i)-0)/taup)+Vin;
        Vo(i)=0;
        c1=i; % counter
    end
    if t(i)>=t1 & t(i)<t2;
        vc1init=vc1(c1);
        vc1(i)=vc1init*exp(-(t(i)-t1)/taus);
        Vo(i)=2*vc1(i);
        c2=i;
    end
    if t(i)>=t2 & t(i)<t3;
        vc1init=vc1(c2);
        vc1(i)=(vc1init-Vin)*exp(-(t(i)-t2)/taup)+Vin;
        Vo(i)=2*vc1init;
        c3=i;
    end
    if t(i)>=t3 & t(i)<t4;
        vc1init=vc1(c3);
        vc1(i)=vc1init*exp(-(t(i)-t3)/taus);
        Vo(i)=2*vc1(i);
        c4=i;
    end
    if t(i)>=t4 & t(i)<t5;
        vc1init=vc1(c4);
        vc1(i)=(vc1init-Vin)*exp(-(t(i)-t4)/taup)+Vin;
        Vo(i)=2*vc1init;
        c5=i;
    end
    if t(i)>=t5 & t(i)<t6;
        vc1init=vc1(c5);
        vc1(i)=vc1init*exp(-(t(i)-t5)/taus);
        Vo(i)=2*vc1(i);
        c6=i;
    end
     if t(i)>=t6 & t(i)<t7;
        vc1init=vc1(c6);
        vc1(i)=(vc1init-Vin)*exp(-(t(i)-t6)/taup)+Vin;
        Vo(i)=2*vc1init;
        c7=i;
    end
    if t(i)>=t7 & t(i)<=t8;
        vc1init=vc1(c7);
        vc1(i)=vc1init*exp(-(t(i)-t7)/taus);
        Vo(i)=2*vc1(i);
    end
end

figure(1)
plot(t*1000,vc1,'r','LineWidth',1.0)
xlabel('Time (ms)','FontSize',14)
ylabel('Voltage (V)','FontSize',14)
set(gca,'Fontsize',14,'LineWidth',1.0)
```

```
figure(2)
plot(t*1000,Vo,'r','LineWidth',1.0)
xlabel('Time (ms)','FontSize',14)
ylabel('Voltage (V)','FontSize',14)
set(gca,'Fontsize',14,'LineWidth',1.0)
axis([0 3 9 10.2])
```