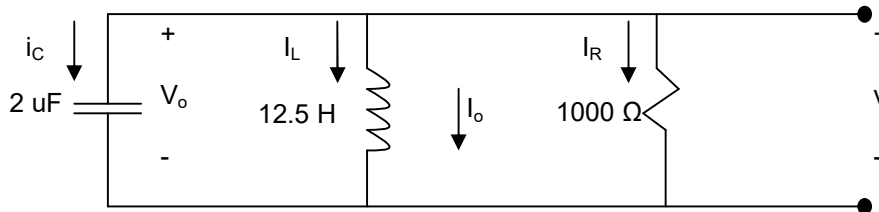


Fundamentals of Electrical Circuits - Chapter 8

- 1) The resistance, inductance, and capacitance in a parallel RLC circuit are 1000Ω , 12.5 H , and $2\text{ }\mu\text{F}$, respectively.
- Calculate the roots of the characteristic equation that describe the voltage response of the circuit.
 - Will the response be over-, under-, or critically damped?
 - What value of R will yield a damped frequency of 120 krad/s ?
 - What are the roots of the characteristic equation for the value of R found in (c)?
 - What value of R will result in a critically damped response?

Solution:



- a) Calculate the roots of the characteristic equation that describe the voltage response of the circuit.

$$\alpha = \frac{1}{2RC} = \frac{1}{2 * 1000 * 2 * 10^{-6}} = 250 \text{ rad/sec} \quad \text{Neper Frequency}$$

$$\omega_0 = \sqrt{\frac{1}{LC}} = \sqrt{\frac{1}{12.5 * 2 * 10^{-6}}} = 200 \text{ rad/sec} \quad \text{Resonant Radian Frequency}$$

$$s_1 = -\alpha + \sqrt{\alpha^2 - \omega_0^2} = -100 \text{ rad/sec} \quad \text{Characteristic Root or Complex Frequency 1}$$

$$s_2 = -\alpha - \sqrt{\alpha^2 - \omega_0^2} = -400 \text{ rad/sec} \quad \text{Characteristic Root or Complex Frequency 2}$$

- b) Will the response be over-, under-, or critically damped?
 $\omega_0^2 < \alpha^2 \rightarrow \text{Overdamped}$

- c) What value of R will yield a damped frequency of 120 krad/s ?

$$\omega_d = \sqrt{\omega_0^2 - \alpha^2} \text{ rad/sec} \quad \text{Damped Radian Frequency}$$

$$120 = \sqrt{(200)^2 - \left(\frac{1}{2R * 2 * 10^{-6}}\right)^2} \Rightarrow R = 1562.5\Omega$$

- d) What are the roots of characteristic equation for the value of R found in (c)?

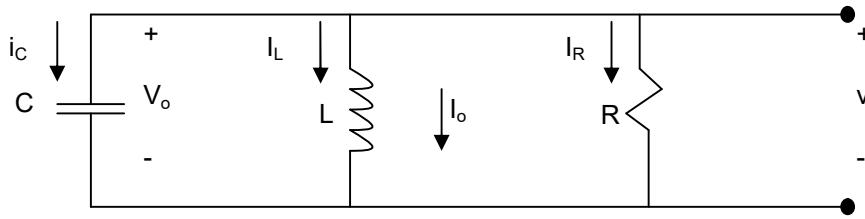
$$s_{1,2} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2} = -160 \pm j120 \text{ rad/sec} \quad \text{Characteristic Roots}$$

- e) What value of R will result in a critically damped response?

Critically damped response requires $\omega_0^2 = \alpha^2$

$$\left(\frac{1}{2RC}\right)^2 = \frac{1}{LC} \Rightarrow \left(\frac{1}{2 * R * 2 * 10^{-6}}\right)^2 = \frac{1}{12.5 * 2 * 10^{-6}} \Rightarrow R = 1250\Omega$$

- 2) The initial voltage on the $0.1\text{ }\mu\text{F}$ capacitor in the following circuit is 24 V . The initial current in the inductor is zero. The voltage response for $t \geq 0$ is $\{v(t) = -8 e^{-250t} + 32 e^{-1000t} \text{ V}\}$



- a) Determine the numerical values of R, L, α , ω_0 .
 b) Calculate $i_R(t)$, $i_L(t)$ and $i_C(t)$ for $t \geq 0^+$.

Solution:

- a) Determine the numerical values of R, L, α , ω_0 :
 This is RLC Natural Response " $v(t) = -8 e^{-250t} + 32 e^{-1000t} \text{ V}$ "

For RLC Natural Response can have any of the following three form

Overdamped ($\omega_0^2 < \alpha^2$) $\Rightarrow v(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t}$

Critically Damped ($\omega_0^2 = \alpha^2$) $\Rightarrow v(t) = D_1 t e^{-\alpha t} + D_2 e^{-\alpha t}$

Underdamped ($\omega_0^2 > \alpha^2$) $\Rightarrow v(t) = B_1 e^{-\alpha t} \cos \omega_d t + B_2 e^{-\alpha t} \sin \omega_d t$

From value $v(t)$ given then it is overdamped response \rightarrow

Overdamped ($\omega_0^2 < \alpha^2$) $\Rightarrow v(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t} = -8e^{-250t} + 32e^{-1000t}$

$s_1 = -250$; $s_2 = -1000$

$$\alpha = \frac{1}{2RC} = \frac{5 \cdot 10^6}{R} \text{ rad/sec}$$

$$\omega_0 = \sqrt{\frac{1}{LC}} = \sqrt{\frac{5 \cdot 10^6}{L}} \text{ rad/sec} \quad \rightarrow \alpha = -1250 \text{ rad/sec}; R = 8 \text{ k}\Omega; \omega_0 = 500 \text{ rad/sec}; L = 40 \text{ H}$$

$$s_1 = -\alpha + \sqrt{\alpha^2 - \omega_0^2} = -250 \text{ rad/sec}$$

$$s_2 = -\alpha - \sqrt{\alpha^2 - \omega_0^2} = -1000 \text{ rad/sec}$$

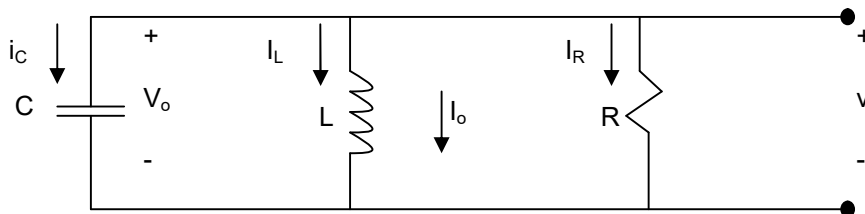
- b) Calculate $i_R(t)$, $i_L(t)$ and $i_C(t)$ for $t \geq 0^+$.

$$i_R = \frac{v(t)}{R} = -1e^{-250t} + 4e^{-1000t} \text{ mA} \quad t \geq 0^+$$

$$i_C = C \frac{dv(t)}{dt} = 0.2e^{-250t} - 3.2e^{-1000t} \text{ mA} \quad t \geq 0^+$$

$$i_L = -(i_R + i_C) = 0.8e^{-250t} - 0.8e^{-1000t} \text{ mA} \quad t \geq 0^+$$

- 3) The natural voltage response of the following circuit is $\{v(t) = 100e^{-20,000t} [\cos(15,000t - 2\sin(15,000t)) \text{ V for } t \geq 0\}$.



When the capacitor is 0.04 μF , Find:

- a) L b) R c) V_o d) I_o e) $i_L(t)$

Solution:

a) L

For RLC Natural Response can have any of the following three form

$$\text{Overdamped } (\omega_0^2 < \alpha^2) \Rightarrow v(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t}$$

$$\text{Critically Damped } ((\omega_0^2 = \alpha^2) \Rightarrow v(t) = D_1 t e^{-\alpha t} + D_2 e^{-\alpha t}$$

$$\text{Underdamped } (\omega_0^2 > \alpha^2) \Rightarrow v(t) = B_1 e^{-\alpha t} \cos \omega_d t + B_2 e^{-\alpha t} \sin \omega_d t$$

From value $v(t)$ given then it is underdamped response \rightarrow

$$v(t) = e^{-\alpha t} (B_1 \cos \omega_d t + B_2 \sin \omega_d t) = e^{-20,000t} (100 \cos 15,000t - 200 \sin 15,000t) \quad t \geq 0$$

$$\alpha = 20,000 \text{ rad/sec}; \quad \omega_d = 15,000 \text{ rad/sec}$$

$$\omega_d = \sqrt{\omega_0^2 - \alpha^2} \Rightarrow 15,000 = \sqrt{\omega_0^2 - 20,000^2} \Rightarrow \omega_0 = 625 \times 10^6$$

$$\omega_0 = \frac{1}{LC} = \frac{1}{L * 0.04 * 10^{-6}} = 625 \times 10^6 \Rightarrow L = 40 \text{ mH}$$

b) R

$$\alpha = \frac{1}{2RC} \Rightarrow 20,000 = \frac{1}{2R * 0.04 * 10^{-6}} \Rightarrow R = 625 \Omega$$

c) V_o

$$V_o = v(0) = 10 \text{ V}$$

d) I_o

$$I_o = i_L(0) = -i_R(0) - i_C(0)$$

$$i_R(0) = \frac{V_o}{R} = \frac{100}{625} = 160 \text{ mA}$$

$$\frac{dv(t)}{dt} = 100 \{ e^{-20,000t} [-15,000 \sin 15,000t - 30,000 \cos 15,000t] - 20,000 e^{-20,000t} [\cos 15,000t - 2 \sin 15,000t] \}$$

$$i_C(t) = C \frac{dv}{dt}(0) = (0.4 \times 10^{-6}) \{ 100 \{ 1(-30,000) - 20,000 \} \} = -200 \text{ mA}$$

$$I_o = i_L(0) = -i_R(0) - i_C(0) = 200 - 160 = 40 \text{ mA}$$

e) $i_L(t)$

$$i_L(t) = -i_R(t) - i_C(t)$$

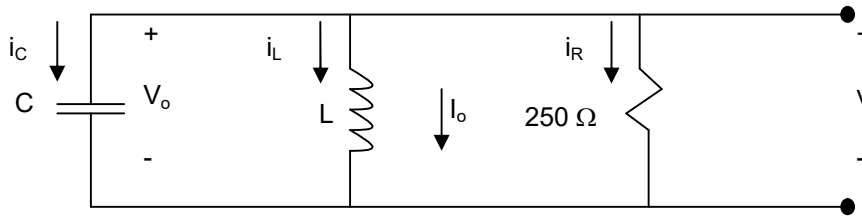
$$i_C(t) = C \frac{dv}{dt}(t) = 0.1 e^{-20,000t} [\sin 15,000t - 2 \cos 15,000t] \text{ A}$$

$$i_R(t) = \frac{v(t)}{R} = 0.16 e^{-20,000t} [\cos 15,000t - 2 \sin 15,000t] \text{ A}$$

$$i_L(t) = -i_R(t) - i_C(t) = e^{-20,000t} [40 \cos 15,000t - 220 \sin 15,000t] \text{ mA} \quad t \geq 0$$

4) The initial value of the voltage v in the following circuit is 15 V. and the initial value of the capacitor current, $i_C(0^+)$, is 45 mA. The expression for the capacitor current is known to be

$$i_C(t) = A_1 e^{-200t} + A_2 e^{-800t} \quad \text{for } t \geq 0^+$$



Find:

- The value of α , ω_0 , L , C , A_1 , and A_2 .
- The expression for $v(t)$, $t \geq 0$.
- The expression for $i_R(t)$, $t \geq 0$.
- The expression for $i_L(t)$, $t \geq 0$.

Solution:

- The value of α , ω_0 , L , C , A_1 , and A_2 .

The response given is for a RLC natural response $i_C(t) = A_1 e^{-200t} + A_2 e^{-800t}$ for $t \geq 0$ and by comparing to possible response types:

$$\text{Overdamped } (\omega_0^2 < \alpha^2) \Rightarrow i_C(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t}$$

$$\text{Critically Damped } ((\omega_0^2 = \alpha^2) \Rightarrow i_C(t) = D_1 t e^{-\alpha t} + D_2 e^{-\alpha t}$$

$$\text{Underdamped } (\omega_0^2 > \alpha^2) \Rightarrow i_C(t) = B_1 e^{-\alpha t} \cos \omega_d t + B_2 e^{-\alpha t} \sin \omega_d t$$

It can be concluded that it is overdamped response:

$$i_C(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t} = A_1 e^{-200t} + A_2 e^{-800t} \rightarrow s_1 = -200; s_2 = -800$$

Use the above information and definition of frequency and roots

$$\alpha = \frac{1}{2RC} = \frac{1}{500C} \text{ rad/sec}$$

$$\omega_0 = \sqrt{\frac{1}{LC}} \text{ rad/sec}$$

$$\rightarrow \alpha = 500 \text{ rad/sec}; \omega_0 = 400 \text{ rad/sec}; C = 4 \mu\text{F}; L = 1.56 \text{ H}$$

$$s_1 = -\alpha + \sqrt{\alpha^2 - \omega_0^2} = -200 \text{ rad/sec}$$

$$s_2 = -\alpha - \sqrt{\alpha^2 - \omega_0^2} = -800 \text{ rad/sec}$$

$$i_C(0^+) = A_1 + A_2 = 0.045 \text{ A}$$

KCL $\rightarrow i_C + i_L + i_R = 0$ take a derivative \rightarrow

$$\frac{di_C(0)}{dt} + \frac{di_L(0)}{dt} + \frac{di_R(0)}{dt} = 0$$

$$\frac{di_C(0)}{dt} = -\frac{di_L(0)}{dt} - \frac{di_R(0)}{dt} = \frac{v(0)}{L} - \frac{1}{R} \frac{i_C(0^+)}{C} \text{ "hint"}$$

$$\frac{di_C(0)}{dt} = \frac{15}{1.56} - \frac{1}{250} \frac{0.045}{4 \times 10^{-6}} = -54.6 \text{ A/s}$$

$$\frac{di_C(t=0)}{dt} = 200A_1 + 800A_2 = 54.6$$

$$A_1 + A_2 = 0.045$$

$$\text{Solve above two equations } \Rightarrow A_1 = -31 \text{ mA} \quad \& \quad A_2 = 76 \text{ mA} \Rightarrow$$

$$i_C(t) = -31 e^{-200t} + 76 e^{-800t} \text{ mA} \quad t \geq 0^+$$

b) The expression for $v(t)$, $t \geq 0$.

$$\text{Given that the form will be } \Rightarrow v_c(t) = A_3 e^{-200t} + A_4 e^{-800t} V \quad t \geq 0^+$$

$$v(0^+) = A_3 + A_4 = 15$$

$$i_c(t) = C \frac{dv_c(t)}{dt} \Rightarrow \frac{dv_c(0)}{dt} = \frac{i_c(0)}{C} = \frac{0.045}{4 \times 10^{-6}} = 11,250 \text{ V/s}$$

$$-200A_3 - 800A_4 = 11,250$$

$$v(0^+) = A_3 + A_4 = 15$$

$$\text{Solve } \Rightarrow A_3 = 38.75 \text{ V}; \quad A_4 = -23.75 \text{ V}$$

$$v_c(t) = 38.75 e^{-200t} - 23.75 e^{-800t} V \quad t \geq 0^+$$

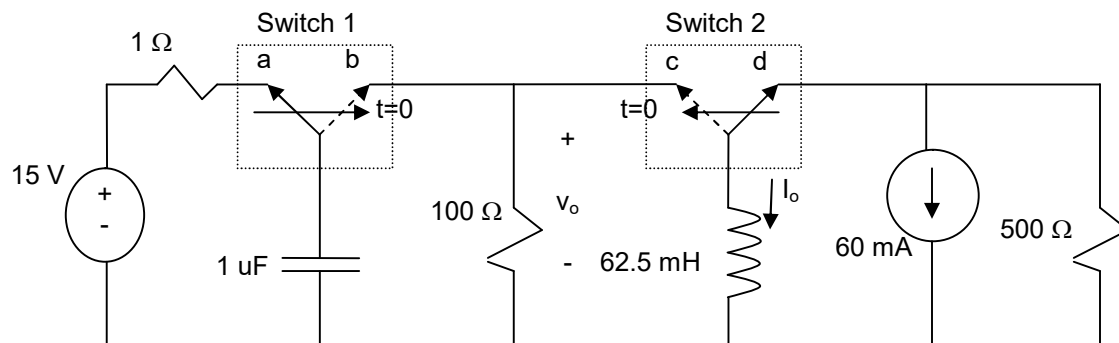
c) The expression for $i_R(t)$, $t \geq 0$.

$$i_R(t) = \frac{v_c(t)}{R} = 155 e^{-200t} - 95 e^{-800t} \text{ mA} \quad t \geq 0^+$$

d) The expression for $i_L(t)$, $t \geq 0$.

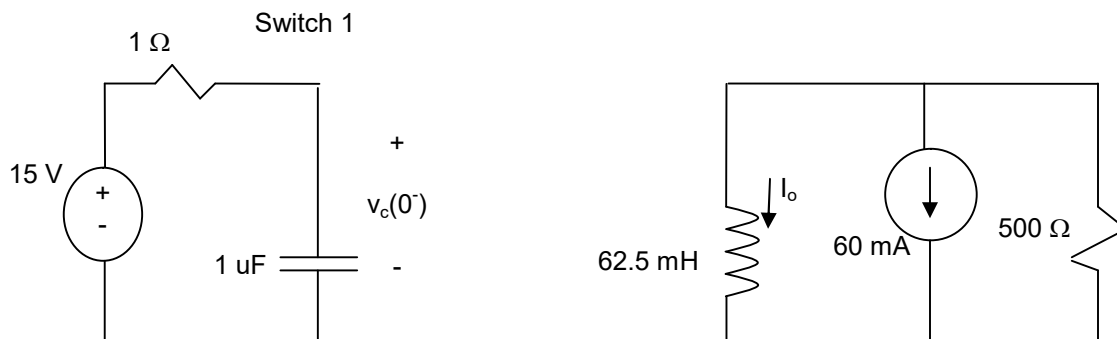
$$i_L(t) = -i_R(t) - i_C(t) = -124 e^{-200t} + 19 e^{-800t} \text{ mA} \quad t \geq 0^+$$

- 5) The two switches in the circuit seen below operate synchronously. When switch 1 is in position a, switch 2 is in position d. When switch 1 moves to position b, switch 2 moves to position c. Switch 1 had been in position a for a long time. At $t=0$, the switches move to their alternate positions. Find $v_o(t)$ for $t \geq 0$.



Solution:

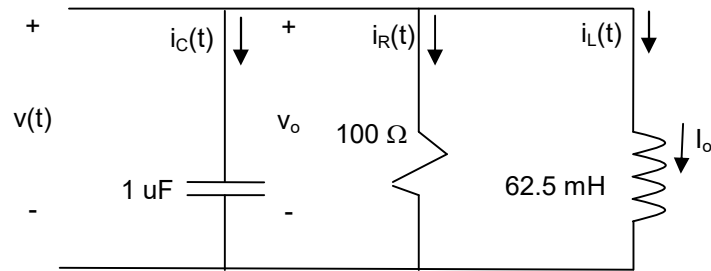
At $t=0^-$ (before switches change position), the circuit is as follows:



From RC and RL circuit analysis, it is understood that:

- * Capacitor appears as an open after a long time $\rightarrow v_c(0^-) = 15\text{V}$
- * Inductor appears as a short after a long time $\rightarrow i_o = -60 \text{ mA}$

At $t=0^+$ (after switches changes position), the circuit is as follows:



Find the natural response for a RLC parallel circuits.

$$\alpha = \frac{1}{2RC} = \frac{1}{2 * 100 * 1 * 10^{-6}} = 5000 \text{ rad/sec} \Rightarrow \alpha^2 = 25 * 10^6$$

$$\omega_0^2 = \frac{1}{LC} = \frac{1}{63.5 * 10^{-3} * 1 * 10^{-6}} = 16 * 10^6 \text{ rad/sec}$$

$$s_1, s_2 = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2} = -5000 \pm 3000 \text{ rad/sec} \Rightarrow s_1 = -2000 \text{ rad/sec}; s_2 = -8000 \text{ rad/sec}$$

The response is:

$$\text{Overdamped } (\omega_0^2 < \alpha^2) \Rightarrow v(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t} = A_1 e^{-2000t} + A_2 e^{-8000t}$$

Use the initial conditions to find A_1 and A_2 :

$$i_c(0) = -i_R(0) - i_L(0) = -\frac{v(0)}{R} - I_0 = -\frac{15}{100} - (-60) = -90 \text{ mA}$$

$$i_c(t) = C \frac{dv(t)}{dt} \Rightarrow \frac{dv(0)}{dt} = \frac{i_c(0)}{C} = \frac{-0.090}{10^{-6}} = -90,000$$

$$\frac{dv(t)}{dt} = -2000A_1 e^{-2000t} - 8000A_2 e^{-8000t}$$

$$-2000A_1 - 8000A_2 = -90,000$$

$$v(0) = A_1 + A_2 = 15$$

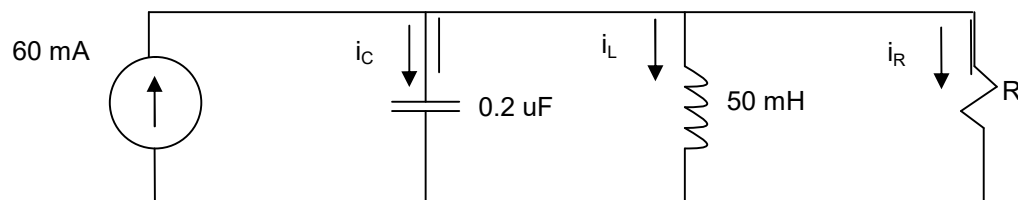
$$\text{Solve} \Rightarrow A_1 = 5V; \quad A_2 = 10V$$

$$v(t) = 5A_1 e^{-2000t} - 10A_2 e^{-8000t} \quad t \geq 0$$

6) Assume that at the instant the 60 mA dc current source is applied to the following circuit where:

* The initial current in the 50 mH inductor is -45 mA

* The initial voltage on the capacitor is 15 V (Positive at the upper terminal)



a) Find the expression for $i_L(t)$ for $t \geq 0$ if R is equal 200 Ω .

b) Find the expression for $i_L(t)$ for $t \geq 0$ if R is equal 312.5 Ω .

c) Find the expression for $i_L(t)$ for $t \geq 0$ if R is equal 250 Ω .

Solution:

a) Find the expression for $i_L(t)$ for $t \geq 0$ if R is equal 200 Ω .

$$\alpha^2 = \left(\frac{1}{2RC}\right)^2 = \left(\frac{1}{2 * 200 * 0.2 * 10^{-6}}\right)^2 = (12500)^2$$

$$w_0^2 = \frac{1}{LC} = \frac{1}{50 * 10^{-3} * 0.2 * 10^{-6}} = 10^8$$

$$s_1, s_2 = -\alpha \pm \sqrt{\alpha^2 - w_0^2} = -12500 \pm 7500 \text{ rad / sec} \Rightarrow s_1 = -5000 \text{ rad / sec}; s_2 = -20,000 \text{ rad / sec}$$

$$\text{Overdamped} (\omega_0^2 < \alpha^2) \Rightarrow i_L(t) = I_f + A_1 e^{s_1 t} + A_2 e^{s_2 t} = 0.06 + A_1 e^{-5000t} + A_2 e^{-20,000t}$$

Use initial condition to find A_1 and A_2

$$v(t) = L \frac{di_L(t)}{dt} \Rightarrow \frac{di_L(0)}{dt} = \frac{v(0)}{L} = \frac{15}{0.05} = 300$$

$$\frac{di_L(t)}{dt} = -5000A_1 e^{-5000t} - 20,000A_2 e^{-20,000t}$$

$$-5000A_1 - 20,000A_2 = 300$$

$$i_L(0) = 0.06 + A_1 + A_2 = -0.045$$

$$\text{Solve} \Rightarrow A_1 = -0.12A; \quad A_2 = 0.015A$$

$$i_L(t) = 0.06 - 0.12e^{-2000t} + 0.015A_2 e^{-8000t} A \quad t \geq 0$$

b) Find the expression for $i_L(t)$ for $t \geq 0$ if R is equal 312.5 Ω .

$$\alpha^2 = \left(\frac{1}{2RC}\right)^2 = \left(\frac{1}{2 * 312.5 * 0.2 * 10^{-6}}\right)^2 = (8000)^2$$

$$w_0^2 = \frac{1}{LC} = \frac{1}{50 * 10^{-3} * 0.2 * 10^{-6}} = 10^8$$

$$s_1, s_2 = -\alpha \pm \sqrt{\alpha^2 - w_0^2} = -8000 \pm j6000 \text{ rad / sec}$$

$$w_d = \sqrt{w_0^2 - \alpha^2} = 6000 \text{ rad / sec}$$

$$\text{underdamp} (\omega_0^2 > \alpha^2) \Rightarrow i_L(t) = I_f + B_1 e^{\alpha t} \cos w_d t + B_2 e^{\alpha t} \sin w_d t$$

$$i_L(t) = 0.06 + B_1 e^{-8000t} \cos 6000t + B_2 e^{-8000t} \sin 6000t$$

Use initial condition to find B_1 and B_2

$$v(t) = L \frac{di_L(t)}{dt} \Rightarrow \frac{di_L(0)}{dt} = \frac{v(0)}{L} = \frac{15}{0.05} = 300$$

$$\frac{di_L(t)}{dt} = -8000B_1 + 6,000B_2 = 300$$

$$i_L(0) = 0.06 + B_1 = -0.045$$

$$\text{Solve} \Rightarrow B_1 = -0.105A; \quad A_2 = -0.090A$$

$$i_L(t) = 0.06 - 0.105e^{-8000t} \cos 6000t - 0.090e^{-8000t} \sin 6000t A \quad t \geq 0$$

c) Find the expression for $i_L(t)$ for $t \geq 0$ if R is equal 250 Ω .

$$\alpha^2 = \left(\frac{1}{2RC}\right)^2 = \left(\frac{1}{2 * 250 * 0.2 * 10^{-6}}\right)^2 = (10^4)^2$$

$$w_0^2 = \frac{1}{LC} = \frac{1}{50 * 10^{-3} * 0.2 * 10^{-6}} = 10^8$$

Critically damped ($\omega_0^2 = \alpha^2$) $\Rightarrow i_L(t) = I_f + D_1te^{-\alpha t} + D_2e^{-\alpha t} = 0.06 + A_1e^{-10,000t} + A_2e^{-10,000t}$

Use initial condition to find A_1 and A_2

$$v(t) = L \frac{di_L(t)}{dt} \Rightarrow \frac{di_L(0)}{dt} = \frac{v(0)}{L} = \frac{15}{0.05} = 300$$

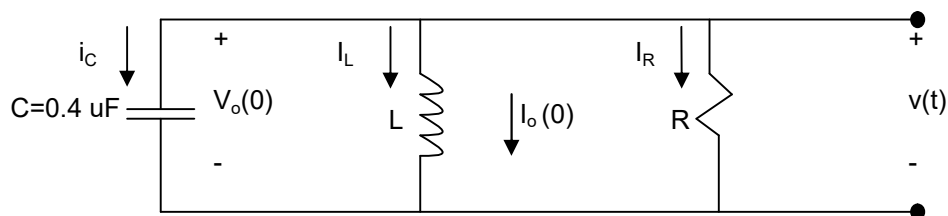
$$\frac{di_L(0)}{dt} = -10,000D_2 + D_1 = 300$$

$$i_L(0) = 0.06 + D_2 = -0.045$$

$$\text{Solve } \Rightarrow D_1 = -750 A; \quad D_2 = -0.105 A$$

$$v(t) = 0.06 - 750e^{-10,000t} - 0.105e^{-10,000t} A \quad t \geq 0$$

E1)



The natural voltage response for the above circuit: is:

$$v(t) = 100e^{-20,000t} [\cos(15,000t) - 2\sin(15,000t)] V \quad \text{for } t \geq 0.$$

Find L , R , $V_o(0)$, and $I_o(0)$

Solution

Find L)

From value $v(t)$ given then it is underdamped response \rightarrow

$$v(t) = e^{-\alpha t} (B_1 \cos \omega_d t + B_2 \sin \omega_d t) = e^{-20,000t} (100 \cos 15,000t - 200 \sin 15,000t) \quad t \geq 0$$

$$\alpha = 20,000 \text{ rad/sec}; \quad \omega_d = 15,000 \text{ rad/sec}$$

$$\omega_d = \sqrt{\omega_0^2 - \alpha^2} \Rightarrow 15,000 = \sqrt{\omega_0^2 - 20,000^2} \Rightarrow \omega_0^2 = 625 \times 10^6$$

$$\omega_0 = \frac{1}{LC} = \frac{1}{L * 0.4 * 10^{-6}} = 625 \times 10^6 \Rightarrow L = 4mH$$

Find R)

$$\alpha = \frac{1}{2RC} \Rightarrow 20,000 = \frac{1}{2R * 0.4 * 10^{-6}} \Rightarrow R = 62.5 \Omega$$

Find V_o)

$$V_o = v(0) = 100 \text{ V}$$

Find I_o)

$$I_o = i_L(0) = -i_R(0) - i_C(0)$$

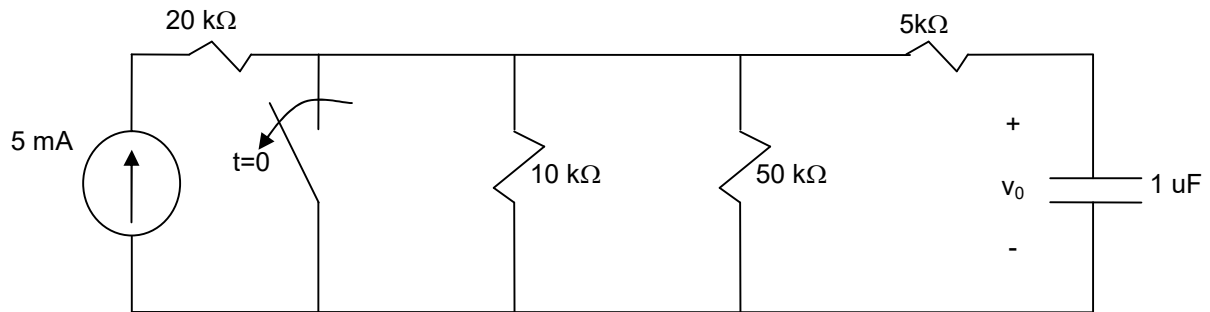
$$i_R(0) = \frac{V_o}{R} = \frac{100}{62.5} = 1.6 \text{ A}$$

$$\frac{dv(t)}{dt} = 100 \{ e^{-20,000t} [-15,000 \sin 15,000t - 30,000 \cos 15,000t] - 20,000 e^{-20,000t} [\cos 15,000t - 2 \sin 15,000t] \}$$

$$i_C(0) = C \frac{dv}{dt}(0) = (0.4 \times 10^{-6}) \{ 100 \{ 1(-30,000) - 20,000 \} \} = -2 \text{ A}$$

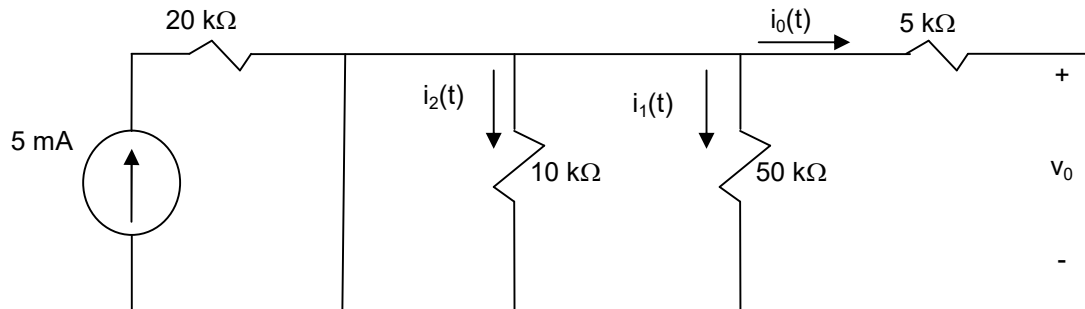
$$I_o = i_L(0) = -i_R(0) - i_C(0) = -1.6 - (-2) = 0.4 \text{ A}$$

7. The switch in the following circuit has been closed a long time before opening at $t = 0$. For $t \geq 0+$, find $v_o(t)$.



Solution:

After a long time at $t=0^-$, capacitor appears as open...

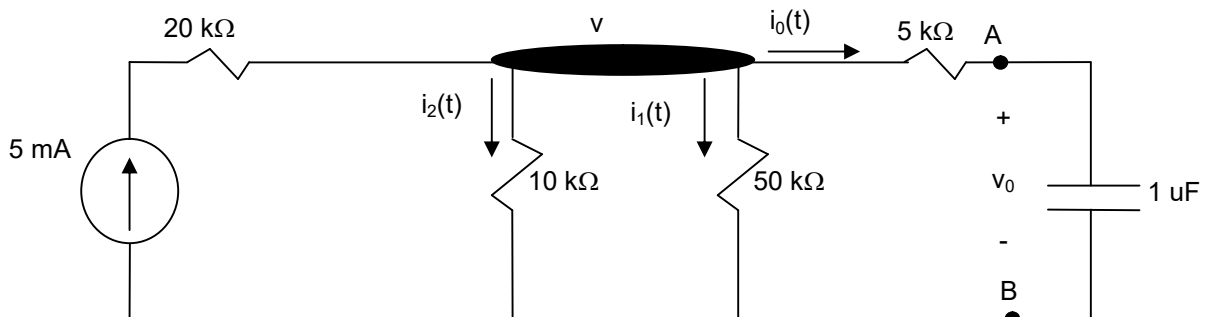


Short across the source then no power is delivered to the rest of the circuit \rightarrow

$$v_o(0^-) = 0 \text{ V}$$

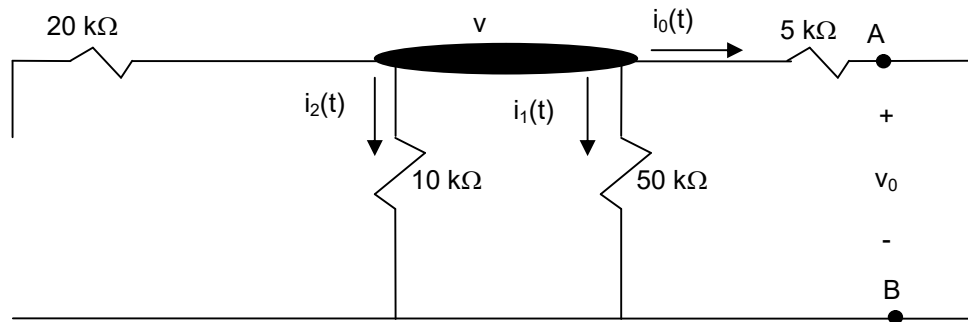
$$i_o(0^-) = i_1(0^-) = i_2(0^-) = 0 \text{ A}$$

After $t=0$ ($t>0$), circuit is redrawn as:

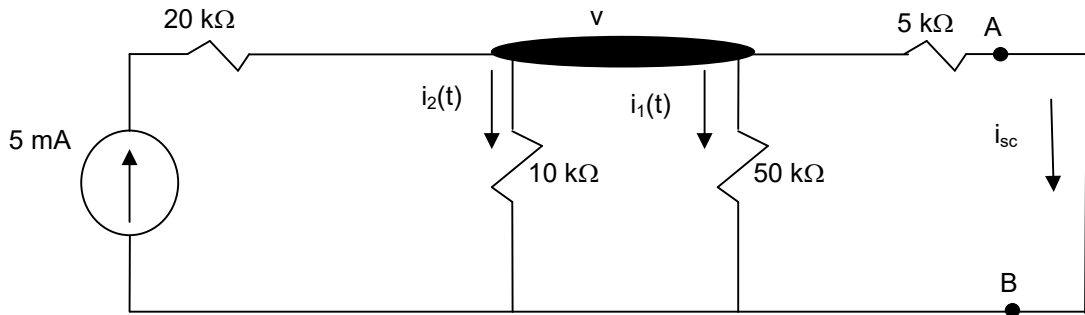


At $t=0^+$, Capacitor appears as a short $\rightarrow V_o(0^+)=0$ V.

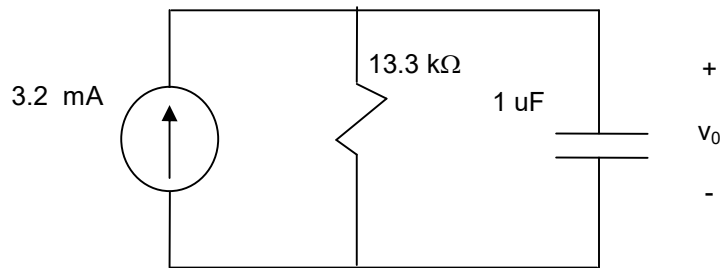
Find the Norton Equivalent at terminal AB \rightarrow
 Disable current source (open) to find R_{th} :



$R_{th} = (10 \parallel 50) + 5 = 13.3 \text{ k}\Omega$
 Find I_{sc} :



KCL $\rightarrow -5 + v/10 + v/50 + v/5 = 0 \rightarrow 16v = 250 \rightarrow v(0^+) = 15.6 \text{ V} \rightarrow i_{sc} = 3.12 \text{ mA}$



Apply the step response for RC circuit $C \frac{dv}{dt} + \frac{v}{R} = I_s$
 $v(t) = I_s R + (V_0 - I_s R) e^{-t/RC}$ for $t \geq 0$
 $v_0(t) = 0.0032 * 13,300 + (0 - 0.0032 * 13,300) e^{-t/(13,300 * 10^{-6})}$ for $t \geq 0$
 $v_0(t) = 42.6 - 42.6 e^{-75.2t} \text{ V}$ for $t \geq 0$