Name: ______________________________ (please print)

Signature: ___________________________

ECE 2300 – Final Exam
July 23, 2014

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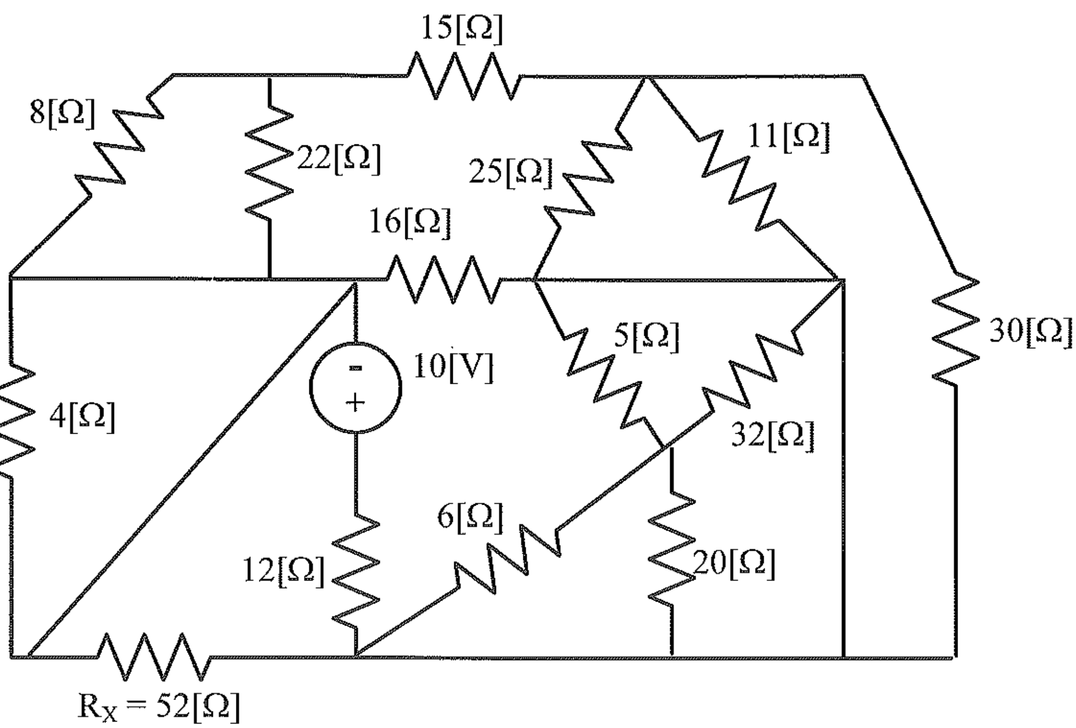
6. You will have 180 minutes to work on this exam.

1. ________________/20	2. ________________/35
3. ________________/35	4. ________________/40
5. ________________/35	6. ________________/35

Total________________/200

Room for extra work

1. (20 points) For the circuit below:
i) Find the power delivered by the voltage source.
ii) Find the power absorbed by resistor R_X.

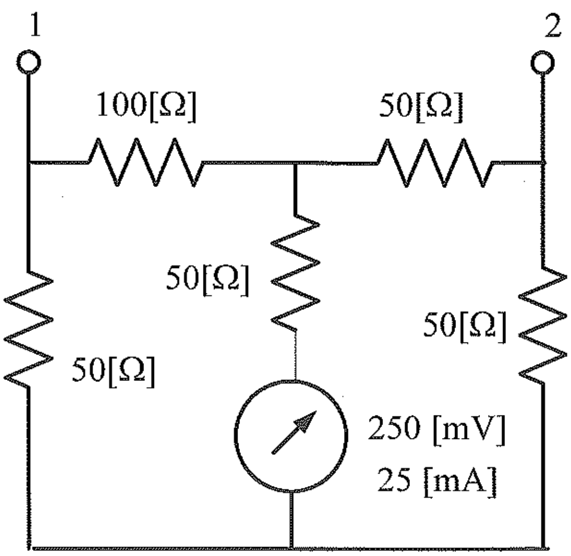


Room for extra work

2. (<u>35 points</u>) The circuit below shows an extended range voltmeter constructed using the d'Arsonval meter movement indicated in the figure. The meter measures voltages connected between terminals 1 and 2.

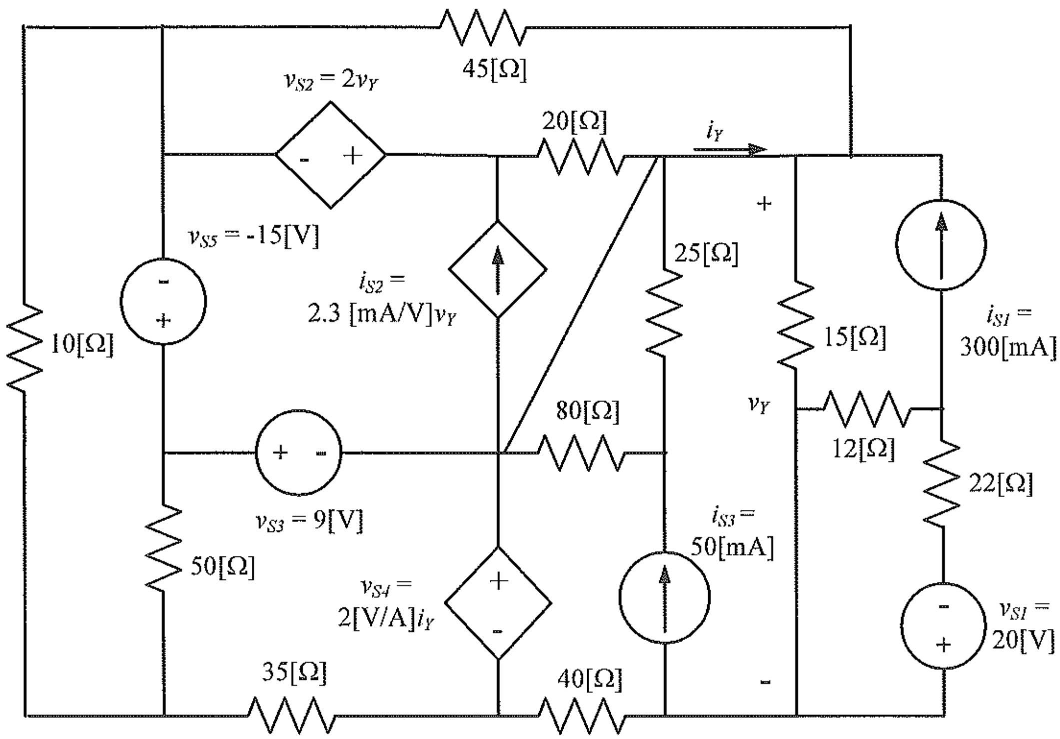
i) What is the full scale range of this meter?

ii) What is the equivalent resistance of this meter?



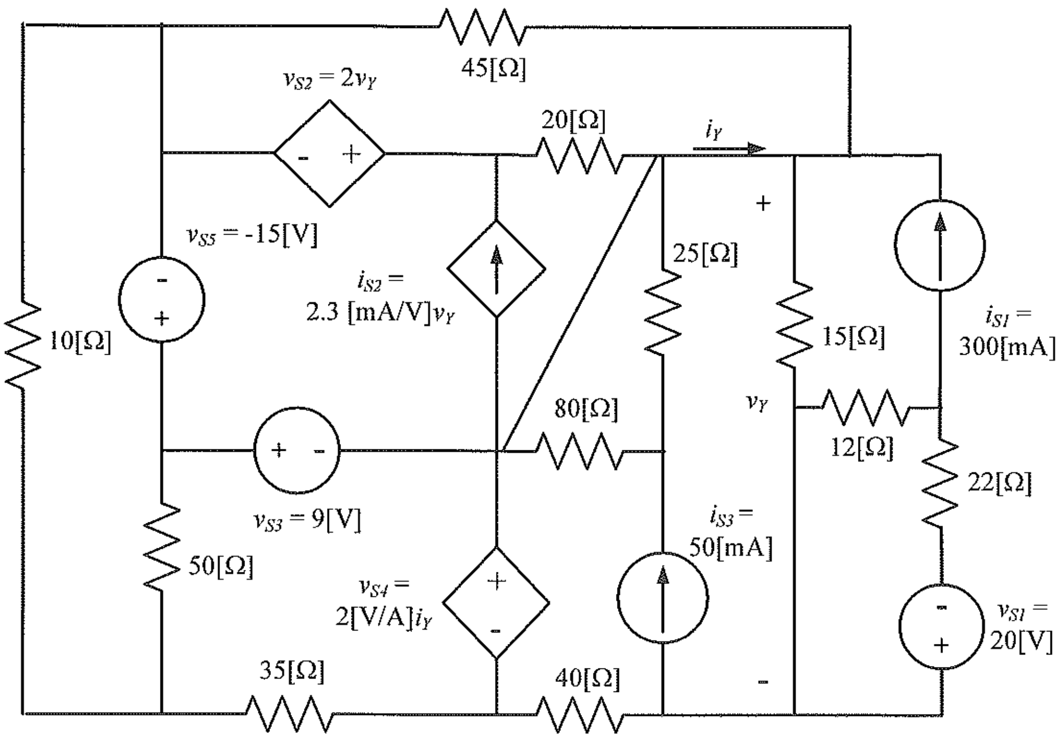
Room for extra work

3. (35 points) Use either the node voltage method or the mesh current method to write a complete set of equations that could be used to solve the circuit below. Do not simplify the circuit. Do not attempt to solve the equations.



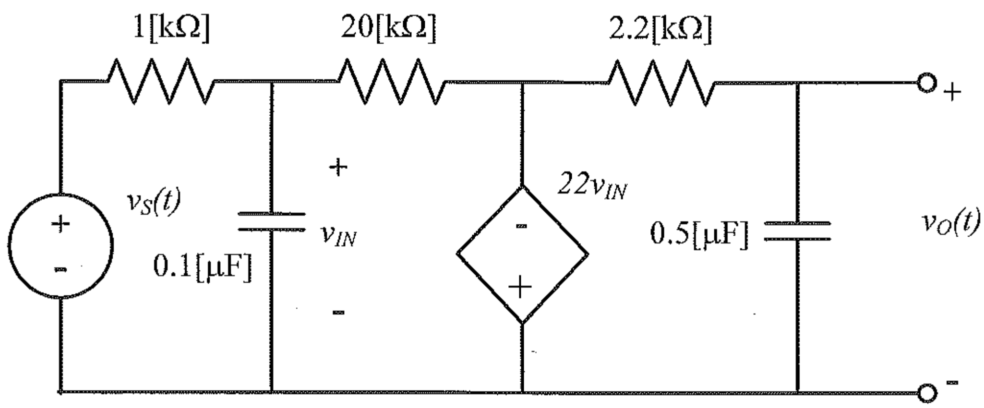
Room for extra work

4. (40 points) In the circuit shown, both switches were in position a) for a long time. At t = 0, switch S1 moved to position b). At t = 20 [ms], switch S2 opened. Find numerical expressions for $v_C(t)$ for all t > 0.



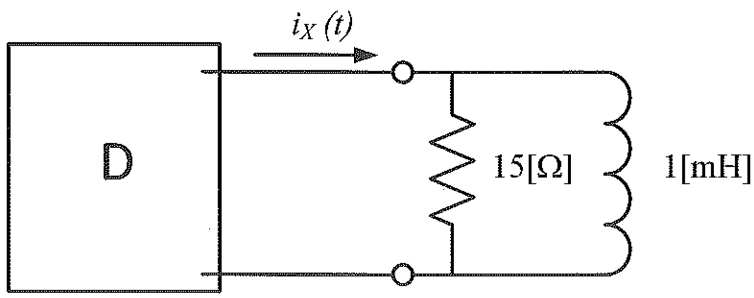
Room for extra work

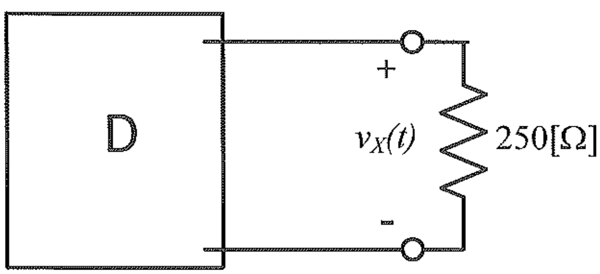
5. (35 points) For the circuit below, $v_S(t) = 1[V]\cos(10{,}000[rad/s]t)$.
i) Find $v_O(t)$ in steady state.
ii) Find the Thevenin Equivalent impedance Z_{TH} seen by the source $v_S(t)$.
iii) Find a circuit element that could be added in series with the 1 [kΩ] resistor to make Z_{TH} purely resistive. State the value of the circuit element.

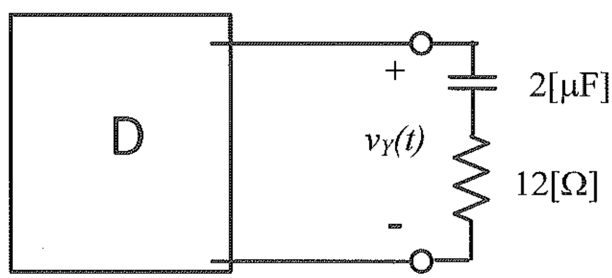


Room for extra work

6. (35 points) A device D was connected to a load consisting of a resistor in parallel with an inductor, as shown in the top figure below. As a result, the current was $i_X(t) = 192.9$ [mA] cos(20,000[rad/s] t + 54.65°) in steady-state. This load was then removed, and the device was connected to a different load consisting of a 250 [Ω] resistor, as shown in the figure on the bottom left, resulting in $v_X(t) =$ 5.436[V] cos(20,000[rad/s] t - 98.53°) in steady state. Find the steady state voltage $v_Y(t)$ that would result if the second load were removed and the device were connected to a 12[Ω] resistor in series with a 2[μF] capacitor, as shown in the figure on the bottom right.







Room for extra work

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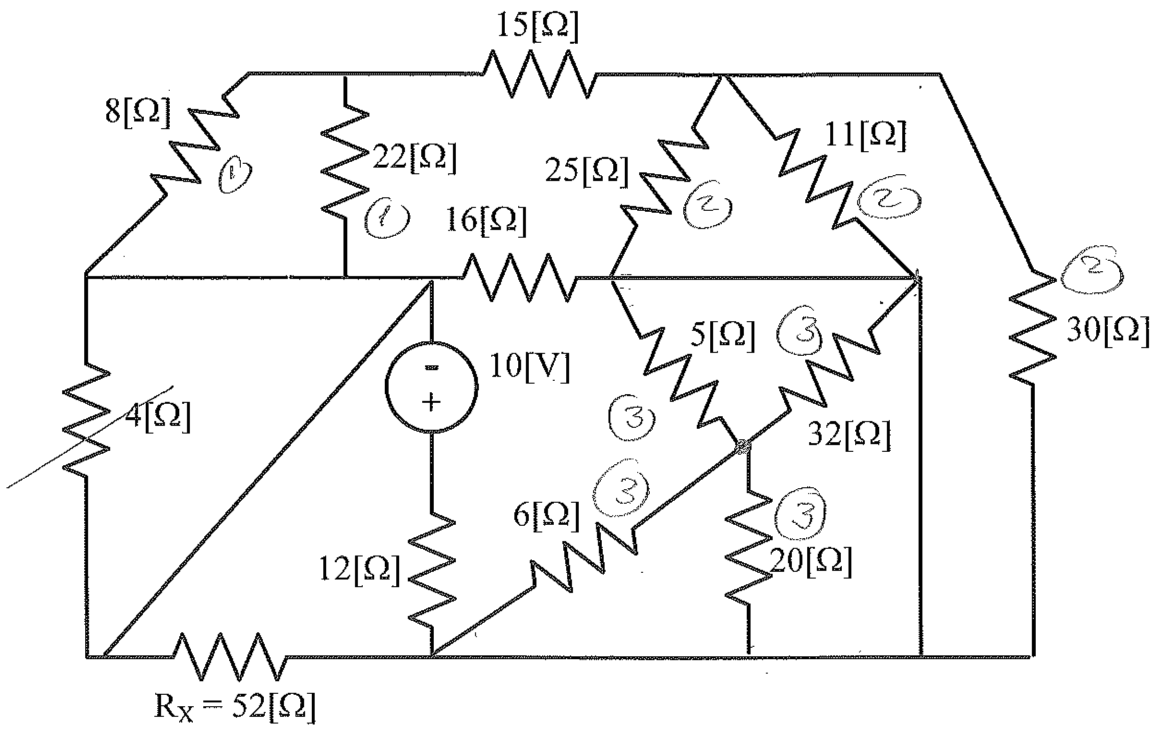
Total________________/200

1. (20 points) For the circuit below:

i) Find the power delivered by the voltage source.

ii) Find the power absorbed by resistor R_X.

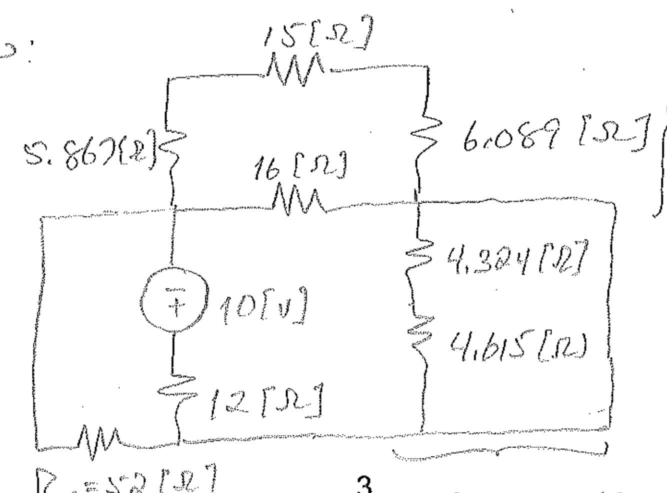


There are several groups of resistors in parallel - these have been numbered. Also we can ignore 4 [Ω].

① $8 \parallel 22 = 5.867\ [\Omega]$ ② $25 \parallel 11 \parallel 30 = 6.089\ [\Omega]$

③ $5 \parallel 32 = 4.324\ [\Omega]$ $20 \parallel 6 = 4.615\ [\Omega]$

We now redraw:

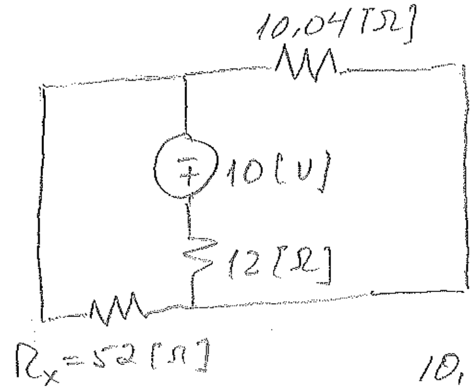


$(15 + 5.867 + 6.089) = 26.956\ [\Omega]$

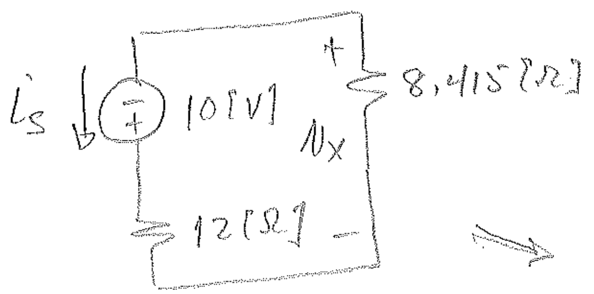
$26.956 \parallel 16 = 10.04\ [\Omega]$

so we can ignore these resistors

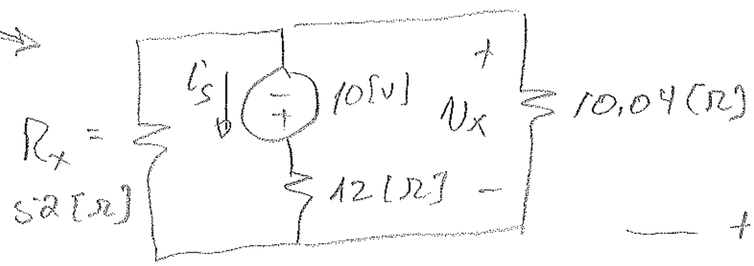
Room for extra work



$10{,}04 \,//\, 52 = 8{,}415$ [Ω]



$$v_x = -10 \frac{8{,}415}{8{,}415 + 12} = -4{,}122 \text{ [V]}$$



$$i_s' = \frac{10}{8{,}415 + 12}$$

$$= 0{,}4898 \text{ [A]}$$

— +8

i_s	P_{del}
+4	+2
v_x	P_{abs}
+4	+2

Now:

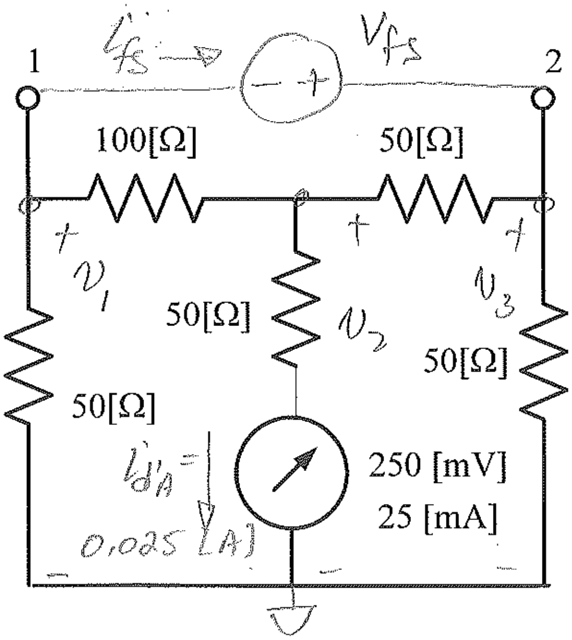
$$\boxed{P_{\text{del by } 10} = 10 \cdot i_s' = 4{,}90 \text{ [W]}}$$

$$\boxed{P_{\text{abs by } R_x} = v_x^2 / R_x = 0{,}327 \text{ [W]}}$$

2. (35 points) The circuit below shows an extended range voltmeter constructed using the d'Arsonval meter movement indicated in the figure. The meter measures voltages connected between terminals 1 and 2.

i) What is the full scale range of this meter?

ii) What is the equivalent resistance of this meter?



$R_{d'A} = 10$ [Ω]

At full-scale, $i_{d'A} = 25$ [mA], so we set this current and find V_{fs}. We have placed a source at the terminals since otherwise there is no way to drive the current $i_{d'A}$.

+10

NVM:

$$v_2 = 0.025\,(50+10) = 1.5\,[V]$$

$$\frac{v_1}{50} + \frac{v_1 - v_2}{100} + \frac{v_3 - v_2}{50} + \frac{v_3}{50} = 0$$

(Supernode)

$$\frac{v_2}{60} + \frac{v_2 - v_1}{100} + \frac{v_2 - v_3}{50} = 0$$

$$v_3 - v_1 = V_{fs}$$

Room for extra work

Solving... $v_1 = -9.5$ [V] $\quad v_3 = 8.25$ [V]

$$\boxed{V_{fs} = v_3 - v_1 = 17.75 \text{ [V]}}$$ +10

We can find the equivalent resistance at the meter terminals, but it's easier to find i_{fs} and take $R_{eq} = V_{fs}/i_{fs}$.

$$i_{fs} = \frac{v_3}{50} + \frac{v_3 - 1.5}{50} = 0.3 \text{ [A]}$$

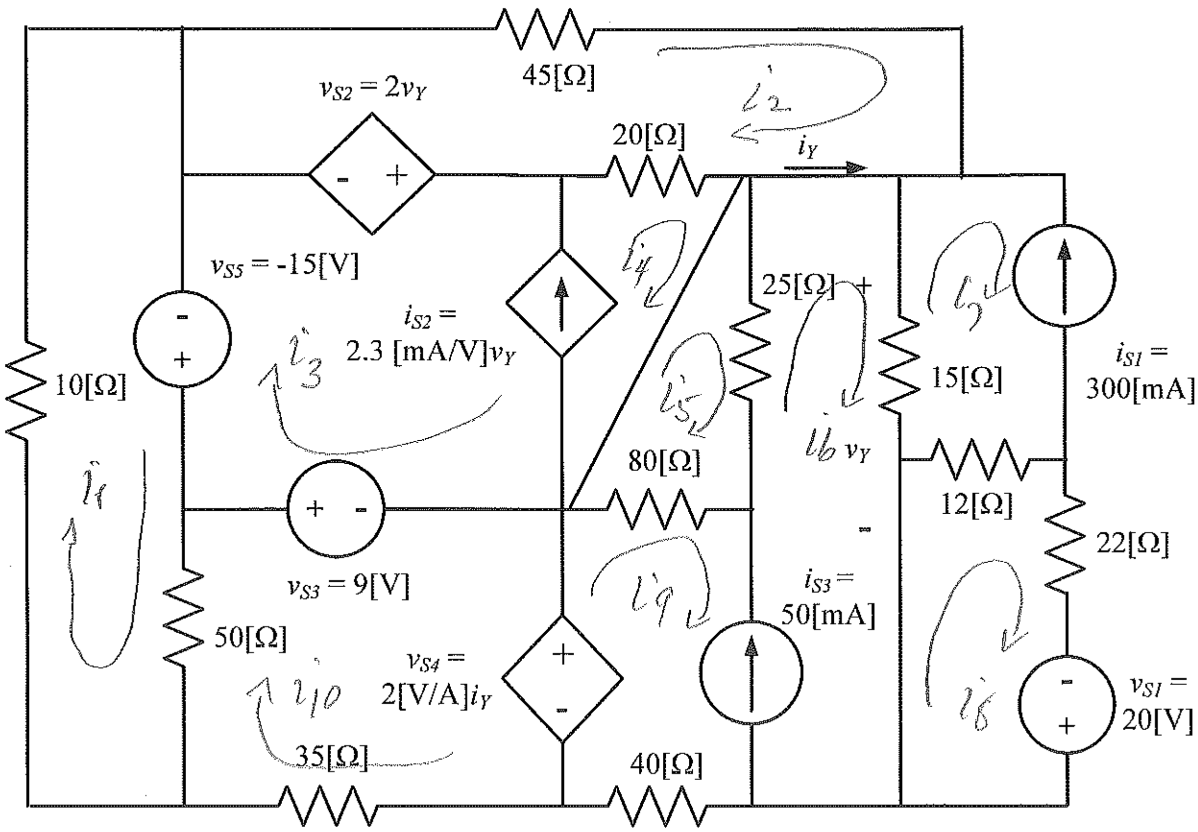
$$\boxed{R_{eq} = \frac{17.75}{0.3} = 59.17 \text{ [}\Omega\text{]}}$$ +15

What if we had put V_{fs} in place with the polarity reversed? We would have had

$$v_1 - v_3 = V_{fs} = -17.75 \text{ [V]}$$

Also, i_{fs} would need to be reversed, so $i_{fs} = -0.3$ [A]. This answer was also accepted. Note that R_{eq} is the same either way.

3. (35 points) Use either the node voltage method or the mesh current method to write a complete set of equations that could be used to solve the circuit below. Do not simplify the circuit. Do not attempt to solve the equations.



Mesh current method is here and on the next page.

We have 10 mesh current equations and two auxiliary equations for v_Y and i_Y.

Room for extra work

+3

(1) $10i_1' - (-15) + 50(i_1' - i_{10}) = 0$

+3

(2) $45 i_2 + 20(i_2' - i_4') + 2v_r = 0$

+5

(3)(4) $+(-15) - 2v_r + 20(i_4' - i_2') - 9 = 0$ } supermesh +2

$i_4' - i_3' = i_{s2} = 2.3 \left[\frac{mA}{V}\right] v_r$

+3

(5) $25(i_5' - i_6') + 80(i_5' - i_9') = 0$

(6)(9) $25(i_6' - i_5') + 15(i_6' - i_7') + 40 i_9' - 2 i_r' + 80(i_9' - i_5') = 0$ +6

$i_6' - i_9' = 0.05 \; [A]$ +2

(7) $i_7' = -0.3 \; [A]$ +1

(8) $12(i_8' - i_7') + 22 i_8' - 20 = 0$ +3

(10) $50(i_{10}' - i_1') + 9 + 2i_r' + 35 i_{10}' = 0$ +3

(v_r) $v_r = 15(i_6' - i_7')$

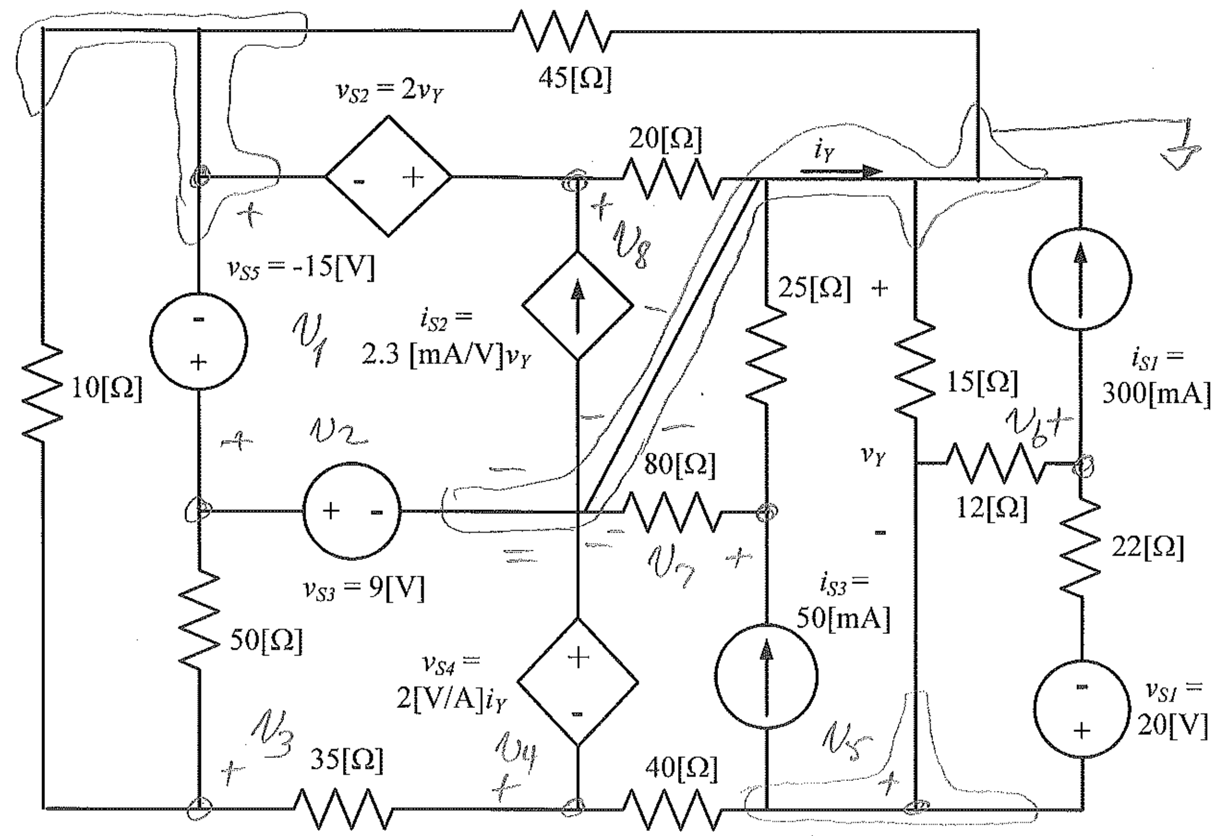
+2

(i_r') $i_r' = i_6' - i_2'$

+2

only one current for supermesh -6

3. (35 points) Use either the node voltage method or the mesh current method to write a complete set of equations that could be used to solve the circuit below. Do not simplify the circuit. Do not attempt to solve the equations.



We'll do node voltage method here and on the next page. Mesh current method follows after that.

We will need 8 node voltage equations and two auxiliary equations for v_Y and i_Y.

Room for extra work

(1) $v_1 = v_{s5} + v_{s3} = (+15 + 9)\ [V]$ +3

(2) $v_2 = v_{s3} = 9\ [V]$ +3

(3) $\frac{v_3 - v_4}{35} + \frac{v_3 - v_2}{50} + \frac{v_3 - v_1}{10} = 0$ +4

(4) $v_4 = v_{s4} = -2\,[\frac{V}{A}]\,i_Y$ +3

(5) $\frac{v_5 - v_4}{40} + 0.05 + \frac{v_5 - v_6 - 20}{22} + \frac{v_5 - v_6}{12} + \frac{v_5}{15} = 0$ +5

(6) $\frac{v_6 - v_5}{12} + \frac{v_6 - v_5 + 20}{22} + 0.3 = 0$ +4

(7) $\frac{v_7}{80} - 0.05 + \frac{v_7}{25} = 0$ +3

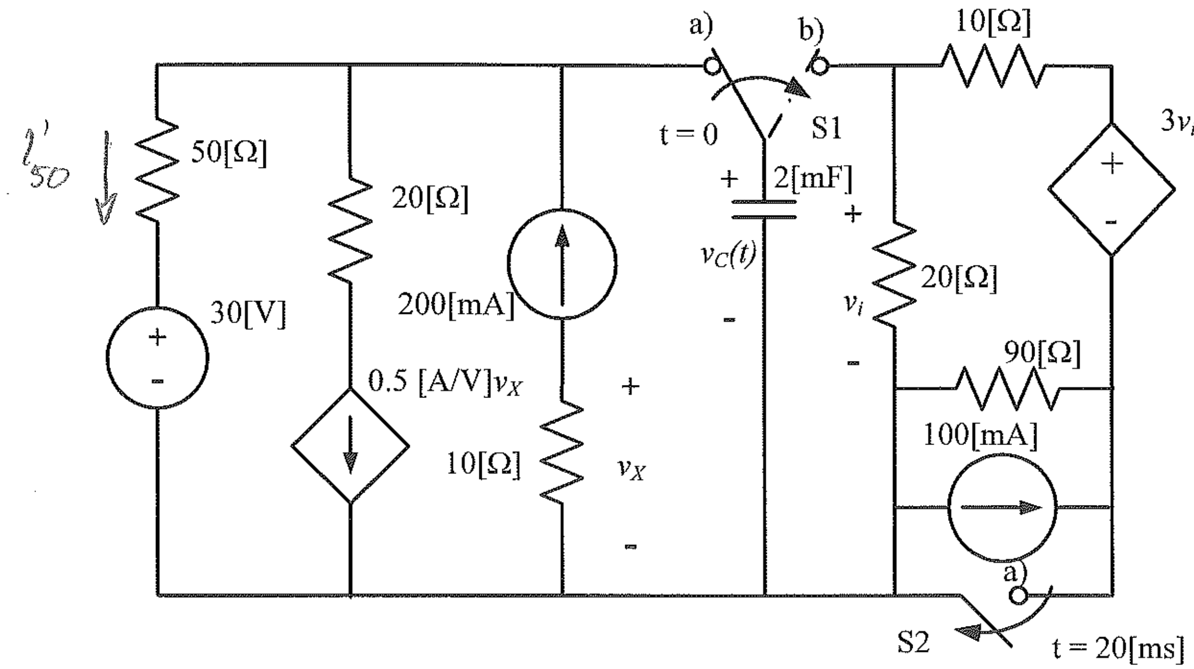
(8) $v_8 = v_{s2} - v_{s5} + v_{s3} = (2v_Y + 15 + 9)\ [V]$ +5

(v_Y) $v_Y = -v_5$ +2

(i_Y) $i_Y = \frac{-v_1}{45} - \frac{v_5}{15} - 0.3$ +3

extra node voltage variable −3
undefined sources −3
undefined variable −2
extra equation −4

4. (40 points) In the circuit shown, both switches were in position a) for a long time. At t = 0, switch S1 moved to position b). At t = 20 [ms], switch S2 opened. Find numerical expressions for $v_C(t)$ for all t > 0.



We start by looking at the circuit for t<0. From the original diagram above, we see that

$$V_{C,i} = V_C(t=0) = i'_{50}(50) + 30$$

$$i'_{50} = 0.2 - 0.5 V_X = 0.2 - 0.5(-0.2 \times 10) = 1.2 \, [A]$$

$$\therefore V_{C,i} = 60 + 30 = 90 \, [V]$$

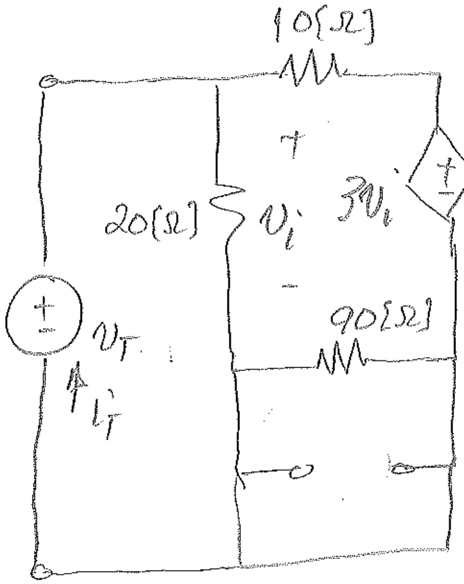
We now redraw for t>0

V_X sign -2

no $V_C(t)$ 0<t<20 [ms] -2
(implicit)

wrong i_T direction -3

Room for extra work



We have applied a test source to find R_{Th} and so we have de-activated the current source. The 90 [Ω] resistor is irrelevant.

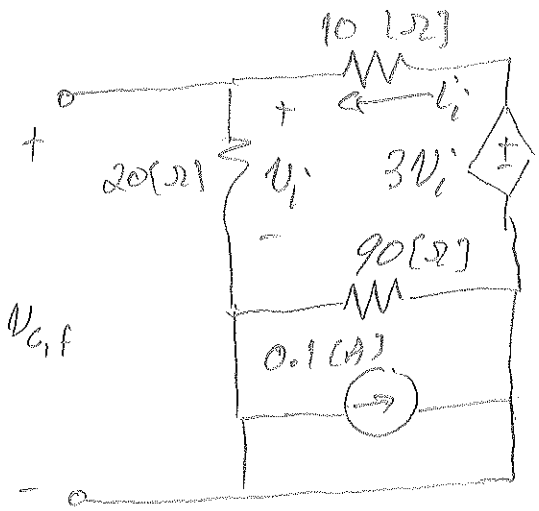
$$v_i = v_T$$

$$i_T = \frac{v_T}{20} + \frac{v_T - 3v_T}{10} = v_T\left(-\frac{3}{20}\right)$$

$$R_{TH} = \frac{v_T}{i_T} = -\frac{20}{3} = -6.667\,[\Omega]$$

$$\Rightarrow \tau_c = -0.0133\,[s]$$

We now find $v_{c,f} = v_c(t=\infty)$.



$$v_i - 3v_i + 10 i_i = 0$$

But $i_i = \frac{v_i}{20} \Rightarrow v_i = 0$

$$\Rightarrow v_{c,f} = v_i = 0$$

So the 90[Ω] resistor and the current source can both be ignored here.

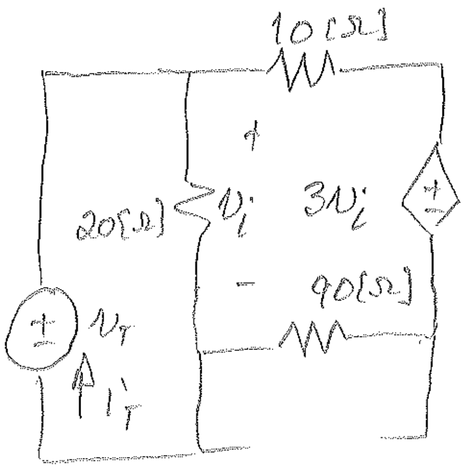
$0 < t < 0.02\,[s]$:

$$\boxed{v_c(t) = 90e^{+t/0.0133[s]}}\ [V]$$

to page 2

Room for extra work

Re draw for $t > 0.02$ [s]



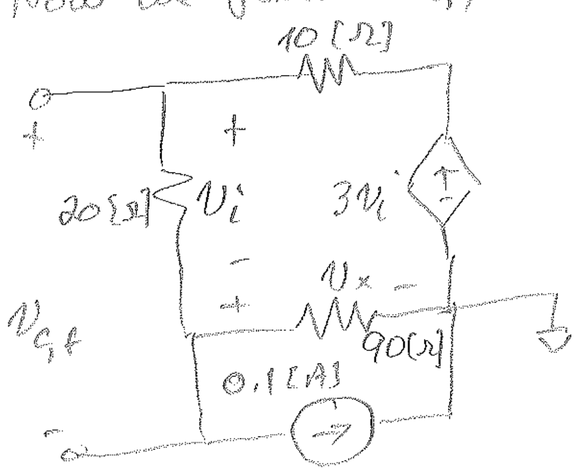
we have applied another test source and de-activated the current source.

$v_i = v_T$

$i_T = \frac{v_T}{20} + \frac{v_T - 3v_T}{100} = v_T\left(\frac{1}{20} + \frac{1}{100} - \frac{3}{100}\right)$

$R_{TH} = \frac{v_T}{i_T} = 33.33\,[\Omega] \Rightarrow \tau_c = 0.0667\,[s]$

Now we find $v_{c,f}$:



NVM: $\frac{v_x}{90} + 0.1 + \frac{v_x - 3v_i}{30} = 0$

$v_i = -\left(\frac{v_x - 3v_i}{30}\right) \times 20$

$\Rightarrow v_x = 4.5\,[V] \qquad v_i = 3\,[V]$

$v_{c,f} = v_i = 3\,[V]$

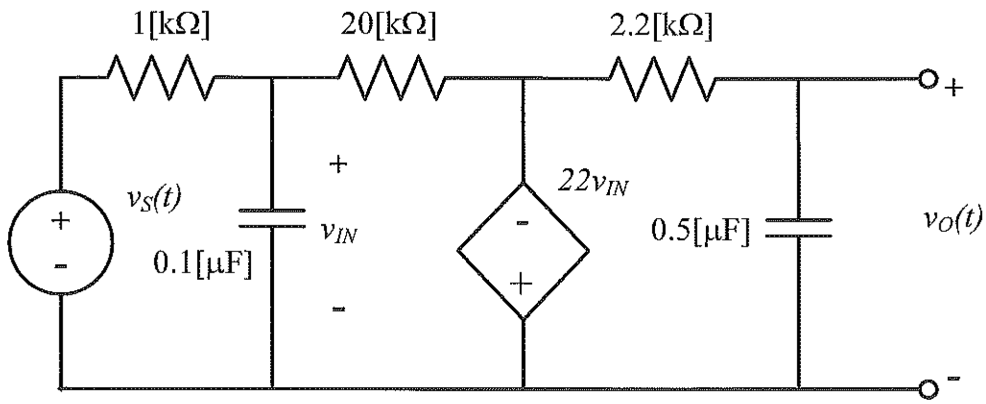
From our previous solution: $v_{c,i} = 90\, e^{0.02/0.0133} = 404.9\,[V]$

So...

$v_c(t) = 3 + (404.9 - 3)\, e^{-(t - 0.02[s])/0.0667[s]}$

$$\begin{cases} v_c(t) = 3 + 401.9\, e^{-(t-0.02[s])/0.0667[s]}\ [V] & t > 0.02\,[s] \\ v_c(t) = 90\, e^{+t/0.0133[s]}\ [V] & 0 < t < 0.02\,[s] \end{cases}$$

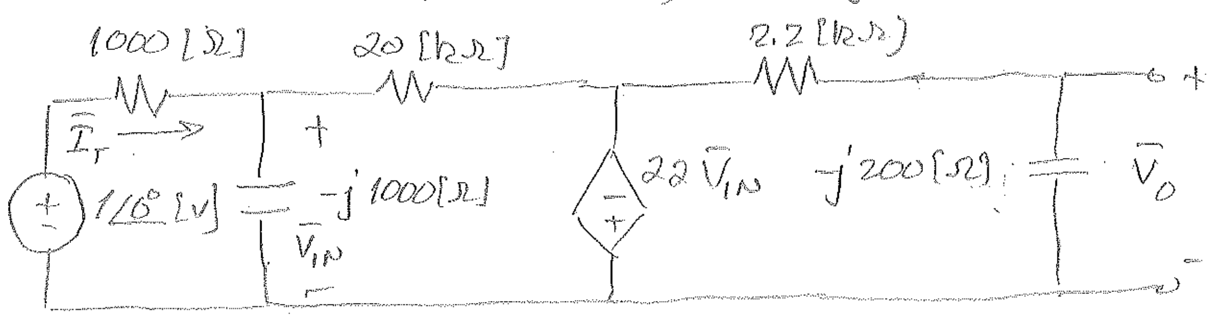
5. (35 points) For the circuit below, vS(t) = 1[V]cos(10,000[rad/s]t).
i) Find $v_O(t)$ in steady state.
ii) Find the Thevenin Equivalent impedance Z_{TH} seen by the source $v_S(t)$.
iii) Find a circuit element that could be added in series with the 1 [kΩ] resistor to make Z_{TH} purely resistive.



We transform to the phasor domain for $\omega = 10\,000 \left[\frac{rad}{s}\right]$.

$0.5[\mu F] \longrightarrow -j/(10^4 \cdot 5\times10^{-7}) = -j\,200\,[\Omega]$

$0.1[\mu F] \longrightarrow -j/(10^4 \cdot 1\times10^{-7}) = -j\,1000\,[\Omega]$



+4

$$\frac{\bar{V}_{IN}}{-j1000} + \frac{\bar{V}_{IN} - 1}{1000} + \frac{\bar{V}_{IN} - 22\bar{V}_{IN}}{20\,000} = 0 \Rightarrow \bar{V}_{IN} = \begin{cases} 0.3825 - j0.1775\,[V] \\ 0.4217 \angle -24.9^\circ\,[V] \end{cases}$$

+8

$$\bar{V}_o = -22\bar{V}_{IN}\,\frac{-j200}{2200 - j200} = \begin{cases} 0.840 \angle 70.25^\circ\,[V] \\ 0.2838 + j0.7906\,[V] \end{cases}$$

+5

i) $\therefore$ $\boxed{v_o(t) = 0.840\cos\left(10\,000\left[\frac{rad}{s}\right]t + 70.25^\circ\right)\,[V]}$

Room for extra work

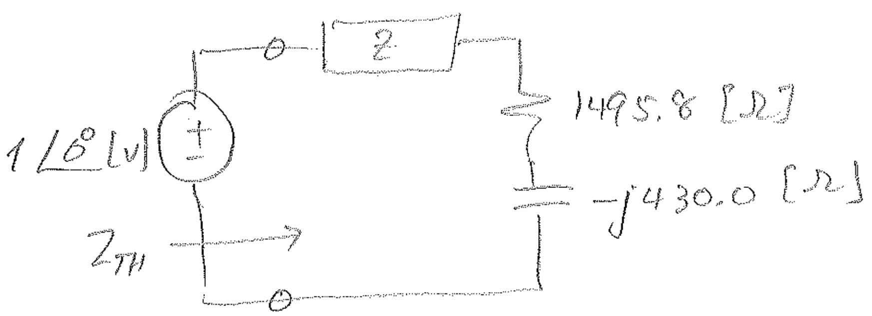
We can think of $\bar{V}_S$ as a test source and find $\bar{I}_T$.

$$\bar{I}_T = \frac{1-\bar{V}_{IN}}{1000} = (6.425 \times 10^{-4})\angle 16.04^\circ \ [A]$$

ii)

$$\therefore \boxed{Z_{TH} = \frac{1}{\bar{I}_T}} = \begin{cases} 1556.4\angle -16.04^\circ & [\Omega] \\ 1495.8 - j\,430.0 & [\Omega] \end{cases}$$ +12

We can model the impedance as follows:



So for Z_{TH} to be purely resistive we need

$$Z = j\,430.0 \ [\Omega]$$

This is an inductor of value +6

iii)

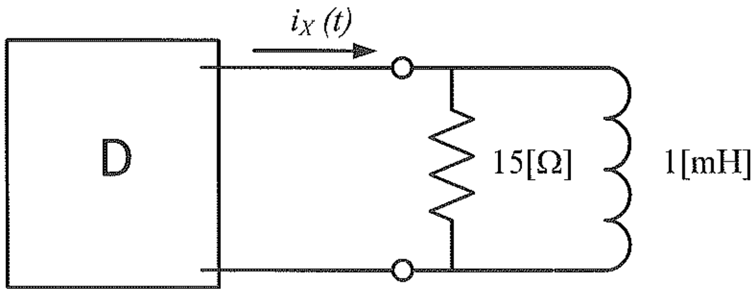
$$\boxed{L = \frac{430.0}{10^4}} = 0.0430 \ [H] = 43 \ [mH]$$

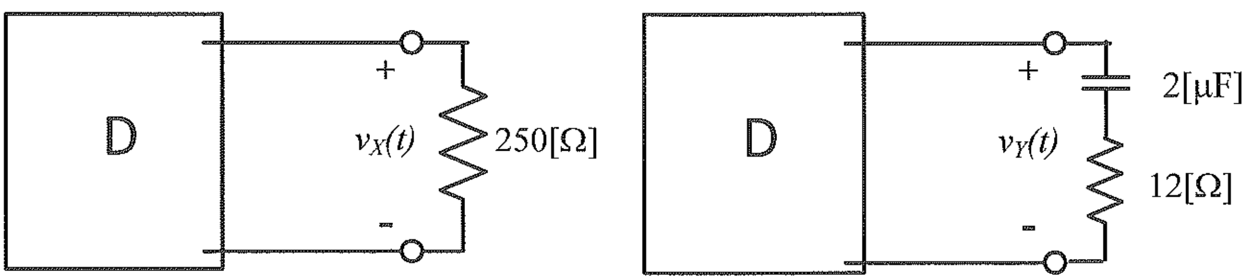
inconsistent phasor notation −3

no phasor notation −6

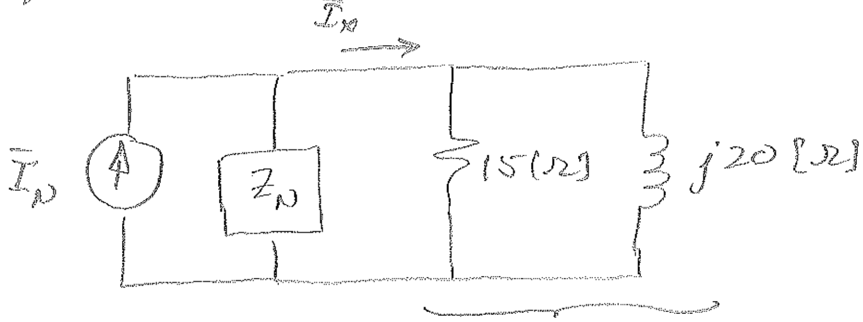
R as a complex number −1

6. (35 points) A device D was connected to a load consisting of a resistor in parallel with an inductor, as shown in the top figure below. As a result, the current was $i_X(t) = 192.9$ [mA] cos(20,000[rad/s] t + 54.65°) in steady-state. This load was then removed, and the device was connected to a different load consisting of a 250 [Ω] resistor, as shown in the figure on the bottom left, resulting in $v_X(t) =$ 5.436[V] cos(20,000[rad/s] t - 98.53°) in steady state. Find the steady state voltage $v_Y(t)$ that would result if the second load were removed and the device were connected to a 12[Ω] resistor in series with a 2[μF] capacitor, as shown in the figure on the bottom right.





We will model what's inside the box as a Norton Equivalent (although Thevenin would do just as well).



1 [mH] → j(20000)(0.001) = j 20 [Ω]

+1

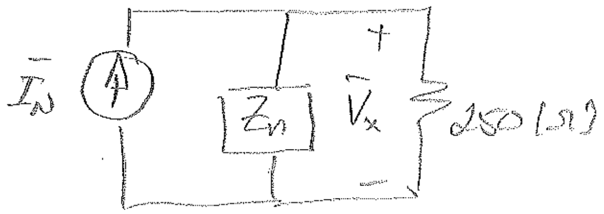
$$Z_{eq} = \begin{cases} 9.6 + j\,7.2\ [\Omega] \\ 12 \angle 36.87^\circ\ [\Omega] \end{cases}$$

x5

Room for extra work

$$\bar{I}_x = \bar{I}_N \cdot \frac{Z_N}{Z_N + 12\angle 36.87^\circ} = \underline{0.1929\angle 54.65^\circ}\ [A] \qquad +6$$

We need another equation... $\qquad +6$



$$\bar{V}_x = \bar{I}_N \cdot \frac{Z_N}{Z_N + 250} \times 250$$

$$= \underline{5.436\angle -98.53^\circ}\ (V)$$

Solving gives

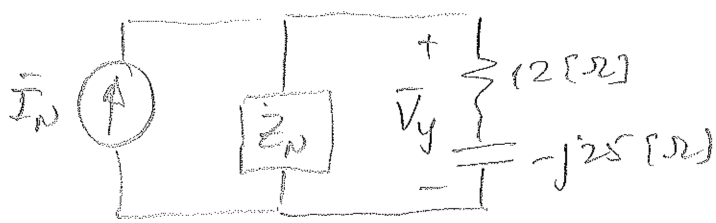
$$0.08395 + j0.01\ [A]$$

$$\bar{I}_N = \underline{0.1306\angle 50^\circ}\ [A] \qquad +6$$

$$Z_N = \underline{36.35\angle -152.8^\circ}\ [\Omega]$$

$$-32.33 - j16.62\ [\Omega]$$

So... $\qquad +1$



$2\ [\mu F] \longrightarrow$

$$-j/(20000)(2\times 10^{-6})$$

$$= -j25\ [\Omega]$$

$+5$

$$\bar{V}_y = \bar{I}_N \cdot \frac{Z_N}{Z_N + (12 - j25)} \cdot (12 - j25) = \underline{2.84\angle -51.1^\circ}\ [V]$$

$+5$

$$\Rightarrow \quad v_y(t) = 2.84\ [V] \cos(20000\,t - 51.1^\circ)$$