Name: ______________________________ (please print)

Signature: ___________________________

ECE 2300 – Final Exam
July 22, 2015

Keep this exam closed and face up until you are told to begin.

1. This exam is closed book, closed notes. You may use one 8.5” x 11” crib sheet, or its equivalent.
2. Show all work on these pages. Show all work necessary to complete the problem. A solution without the appropriate work shown will receive no credit. A solution which is not given in a reasonable order will lose credit.
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5. Do not use red ink. Do not use red pencil.
6. You will have 170 minutes to work on this exam.

1. ________________/50

2. ________________/40

3. ________________/30

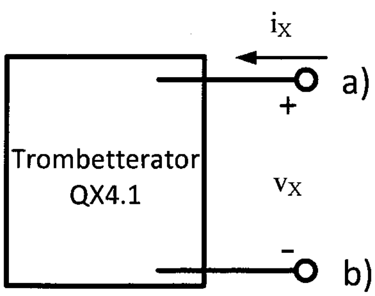
4. ________________/40

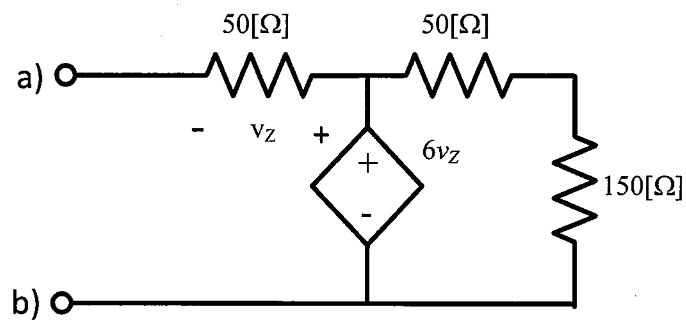
5. ________________/40

Room for extra work

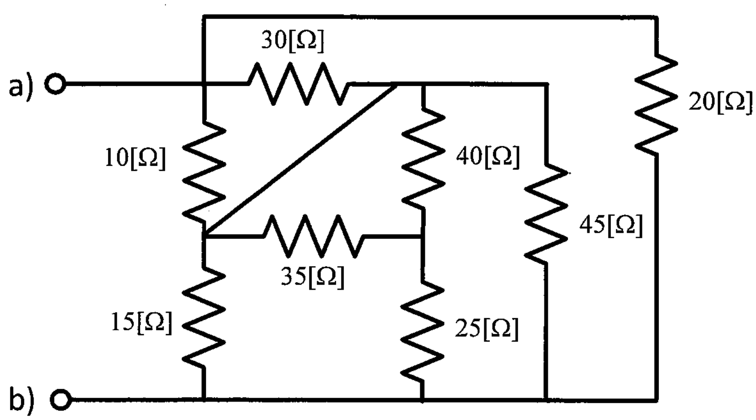
1. (50 points) Extensive research has shown that the Trombetterator QX4.1 can be modeled as a current source i_N in parallel with a resistance R_N. When the Trombetterator is connected to Circuit 1 at terminals a) and b), it is found that the voltage $v_X = 69.89$ [mV]. When Circuit 2 is connected at terminals a) and b), it is found that the current $i_X = 32.56$ [mA].

Draw the model for the Trombetterator, labeling the terminals a), b) and the values of the model parameters i_N and R_N.





Circuit 1

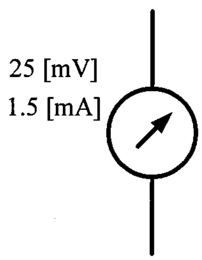


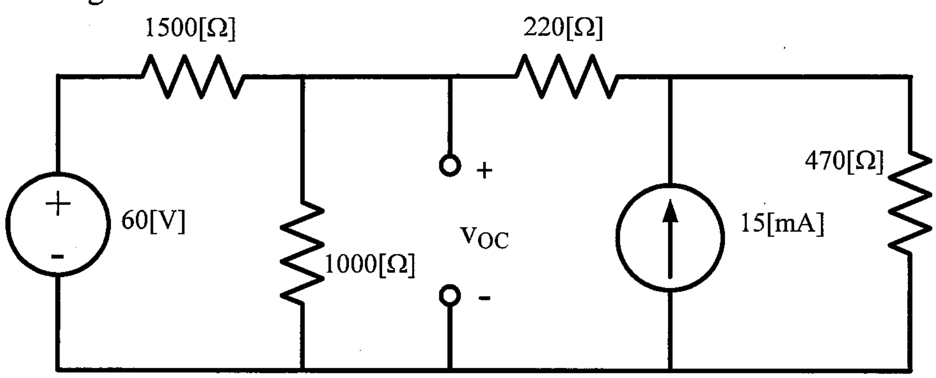
Circuit 2

Room for Extra Work

2. (40 points) A d'Arsonval based voltmeter is to be inserted into the circuit below to measure the voltage v_{OC}. The meter is constructed using the d'Arsonval meter movement shown below. The voltmeter has a range of full-scale voltages and can be set at a full-scale voltage of 0.1[V], 0.2[V], 0.5[V], 1[V], 2[V], 5[V], 10[V], 20[V], 50[V], 100[V], 200[V], 500[V], and 1000[V].

Find the smallest full-scale voltage range that can be set such that the magnitude of the error in the voltage reading is no larger than 0.5%.

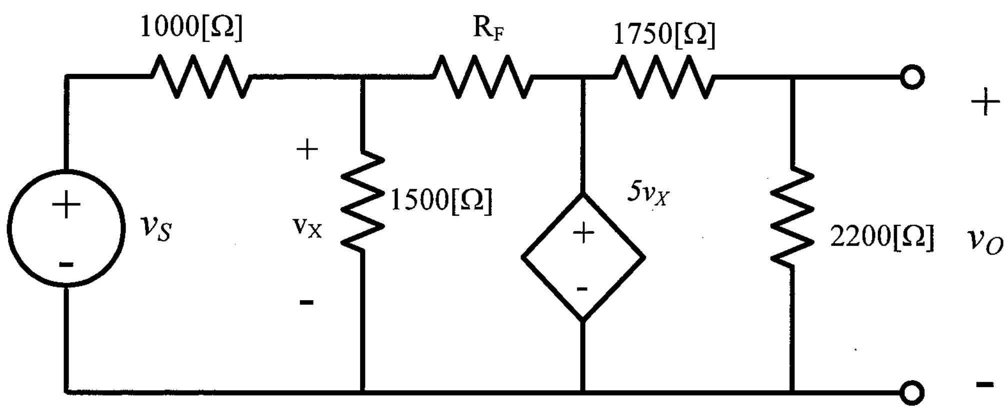




Room for extra work

3. (30 points) The circuit below is a model of a voltage amplifier.

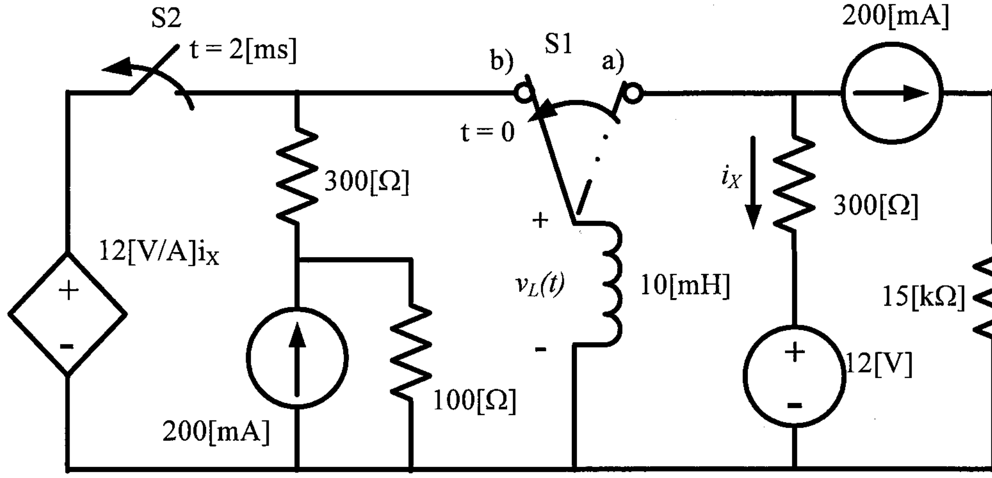
i) Find the Thevenin equivalent resistance seen by the source v_S when $R_F = 1[k\Omega]$.
ii) Find the value of R_F such that the Thevenin equivalent resistance seen by the source v_S is infinite.



Room for extra work

4. (40 points) For a long time switch S1 was in position a) and switch S2 was closed. S1 moved to position b) at t = 0. At t = 2[ms] switch S2 opened.

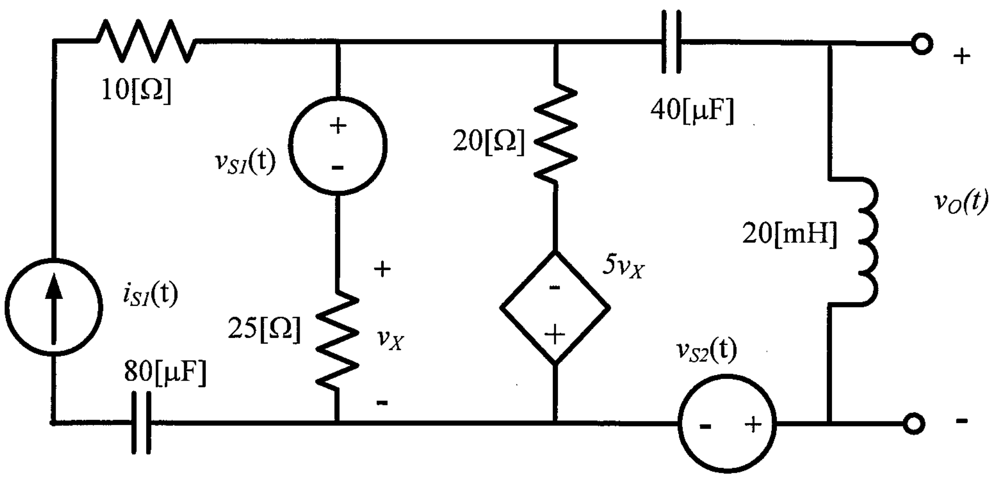
Find expressions for $v_L(t)$ for $t > 0$.



Room for extra work

5. (40 points) For the circuit below, find the steady state expression for $v_O(t)$.

$$v_{S1}(t) = 250[\text{mV}] \cos(800[\text{rad/s}]\, t + 20^\circ)$$
$$v_{S2}(t) = 150[\text{mV}] \sin(800[\text{rad/s}]\, t - 25^\circ)$$
$$i_{S1}(t) = 35[\text{mA}] \cos(1000[\text{rad/s}]\, t)$$



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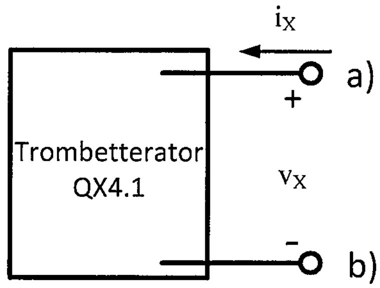
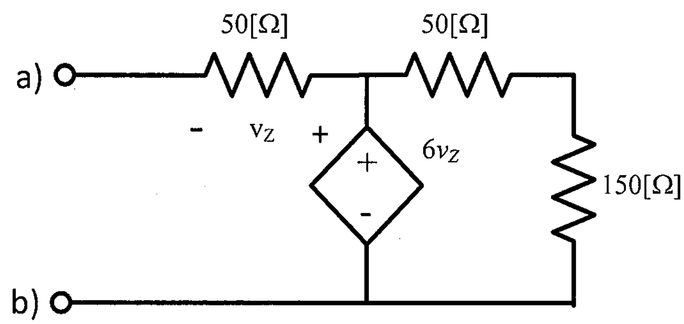
Room for extra work

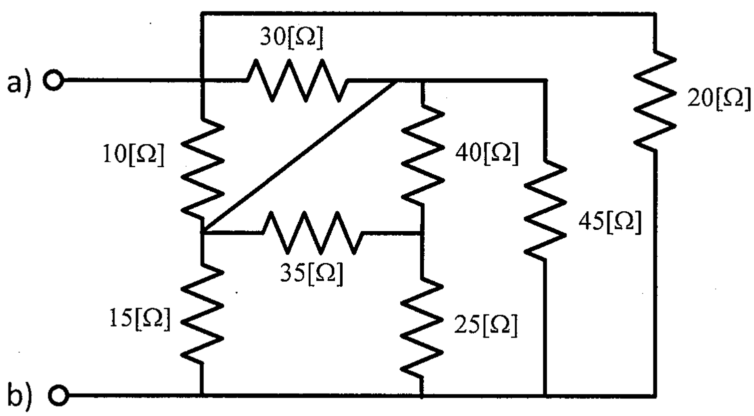
1. (50 points) Extensive research has shown that the Trombetterator QX4.1 can be modeled as a current source i_N in parallel with a resistance R_N. When the Trombetterator is connected to Circuit 1 at terminals a) and b), it is found that the voltage $v_X = 69.89$ [mV]. When Circuit 2 is connected at terminals a) and b), it is found that the current $i_X = 32.56$ [mA].

Draw the model for the Trombetterator, labeling the terminals a), b) and the values of the model parameters i_N and R_N.





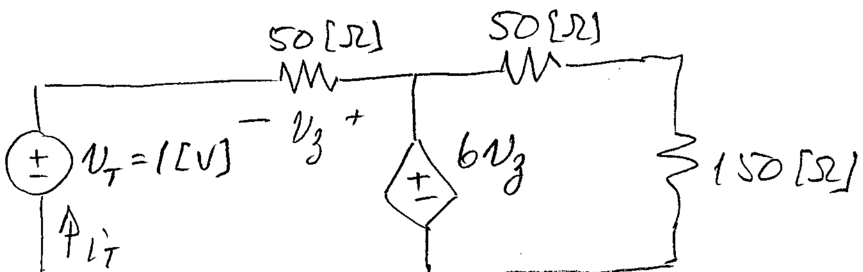
Circuit 1



Circuit 2

We will find the equivalent resistance at a), b) for circuits 1 and 2, and then connect to the QX4.1 :

1:

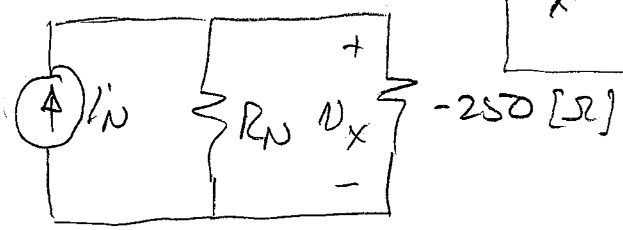


$i_T = \frac{1-6v_3}{50}$ $v_3 = -50\, i_T$

$i_T = \frac{1+300\, i_T}{50}$ $\Rightarrow i_T = -4[mA] \Rightarrow R_{TH} = -250[\Omega]$

(1)

Room for Extra Work



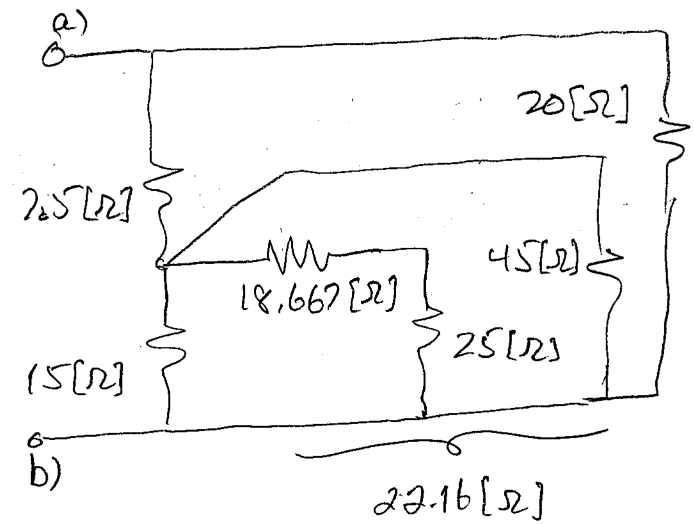
$$v_x = -250 \cdot i_N \frac{R_N}{R_N - 250} = 0.06989 \text{ [V]}$$

2:

$30[\Omega] \,//\, 10[\Omega] = 7.5[\Omega]$ $\quad$ $40[\Omega] \,//\, 35[\Omega] = 18.667[\Omega]$

$45[\Omega] \,//\, (25[\Omega] + 18.67[\Omega]) = 22.16[\Omega]$

$15[\Omega] \,//\, 22.16[\Omega] = 8.945[\Omega]$



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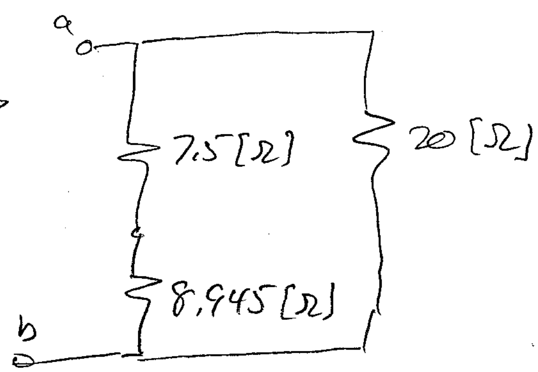
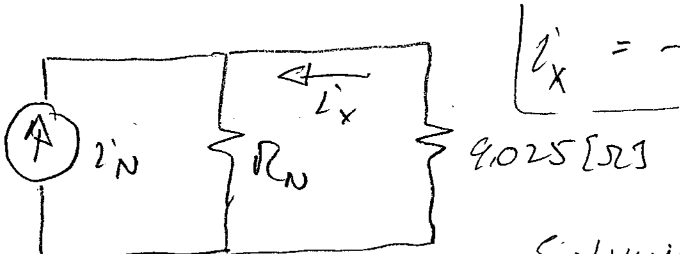


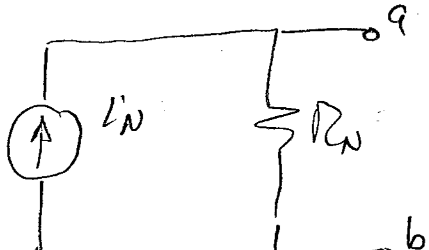
$$R_{TH} = (7.5[\Omega] + 8.945[\Omega]) \,//\, 20[\Omega]$$
$$= 9.025[\Omega]$$

(2)



$$i_x = -i_N \cdot \frac{R_N}{R_N + 9.025} = 0.03256 \text{ [A]}$$

Solving (1) & (2) gives

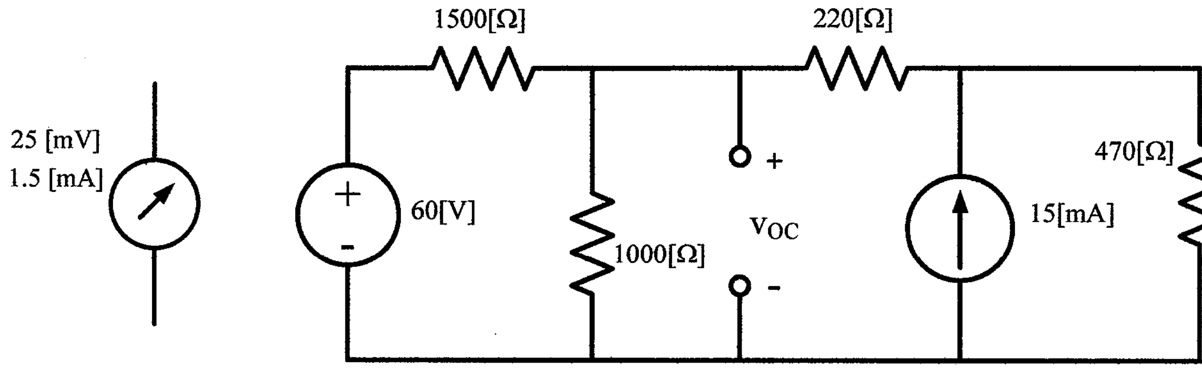


$i_N = -6.4819 \text{ [mA]}$

$R_N = -11.268 [\Omega]$

2. (40 points) A d'Arsonval based voltmeter is to be inserted into the circuit below to measure the voltage v_{OC}. The meter is constructed using the d'Arsonval meter movement shown below. The voltmeter has a range of full-scale voltages and can be set at a full-scale voltage of 0.1[V], 0.2[V], 0.5[V], 1[V], 2[V], 5[V], 10[V], 20[V], 50[V], 100[V], 200[V], 500[V], and 1000[V].

Find the smallest full-scale voltage range that can be set such that the magnitude of the error in the voltage reading is no larger than 0.5%.

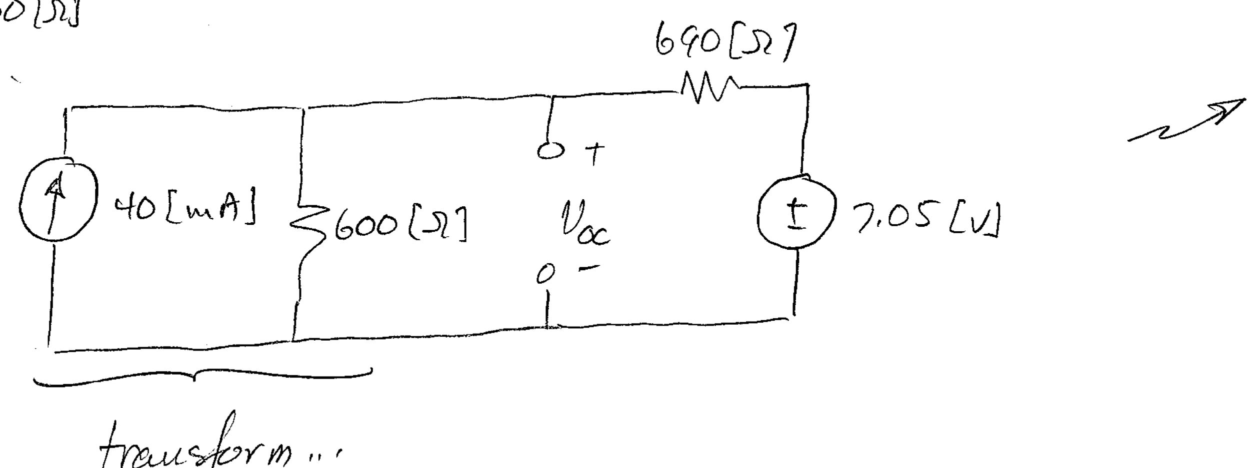


We need to find V_{oc} without the meter, and then find R_{mv} that gives −0.05% error. Note that error must be negative since the voltmeter measures a value smaller than the "true" value.

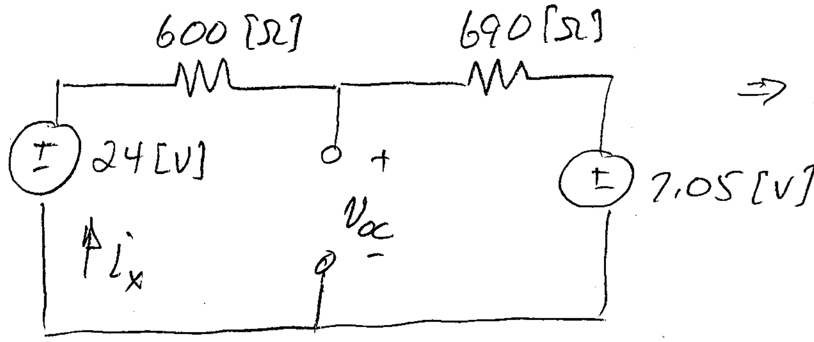
Source transformations:

$1500[\Omega] \,//\, 1000[\Omega] = 600[\Omega]$ $\qquad$ $15[mA] \cdot 470[\Omega] = 7.05[V]$

$\frac{60[V]}{1500[\Omega]} = 40[mA]$ $\qquad$ $470[\Omega] + 220[\Omega] = 690[\Omega]$



Room for extra work



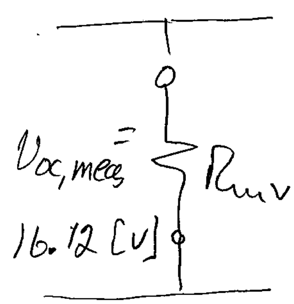
$$i_x = \frac{24 - 7.05}{600 + 690} = 13.14\,[mA]$$

$$\Rightarrow V_{oc,true} = 24 - 600\,i_x = 16.12\,[V]$$

Now −0.5% error means $-0.005 = \dfrac{V_{oc,meas} - V_{oc,true}}{V_{oc,true}}$

$$\Rightarrow V_{oc,meas} = 16.039\,[V]$$

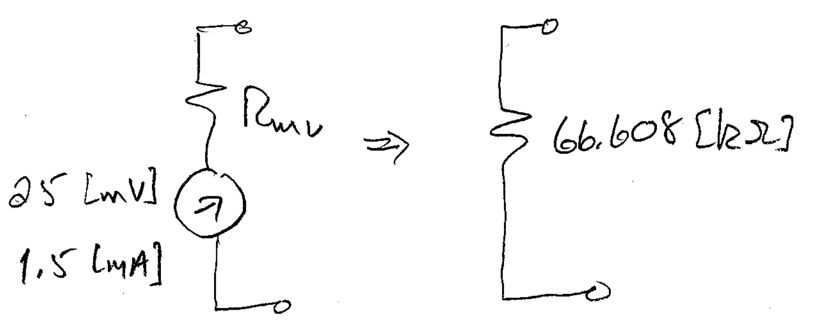
So this is the voltage with the meter (R_{mv}) in place:



$$\therefore \frac{16.039}{R_{mv}} + \frac{16.039 - 24}{600} + \frac{16.039 - 7.05}{690} = 0$$

$$\Rightarrow R_{mv} = 66.608\,[k\Omega]$$

So our voltmeter looks like this:



... and V_{fs} is

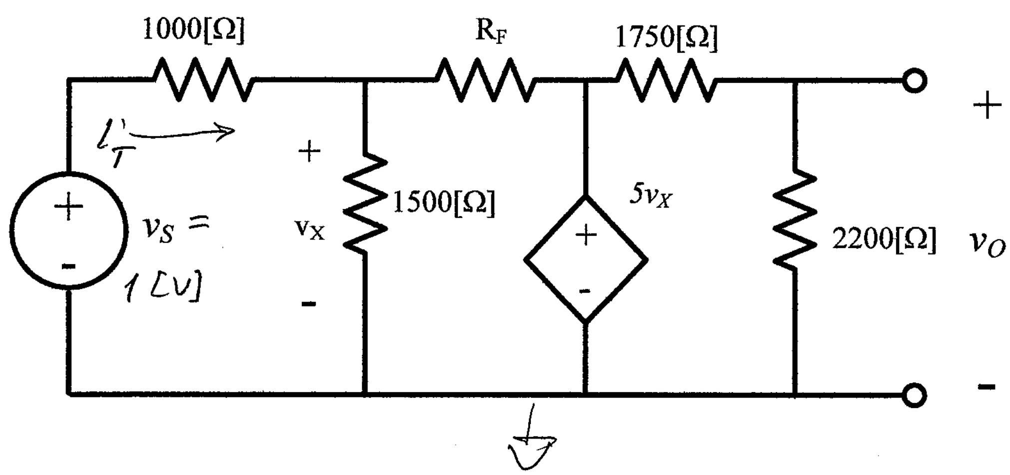
$i_{d'A,fs}$

$$V_{fs} = 66.608\,[k\Omega] \times 1.5\,[mA] = 99.9\,[V]$$

Therefore we need to set our voltmeter to 100 [V].

3. (30 points) The circuit below is a model of a voltage amplifier.

i) Find the Thevenin equivalent resistance seen by the source v_S when $R_F = 1[k\Omega]$.
ii) Find the value of R_F such that the Thevenin equivalent resistance seen by the source v_S is infinite.



i) $R_F = 1000\ [\Omega] \Rightarrow$

$$\frac{V_X}{1500} + \frac{V_X - 1\,[V]}{1000} + \frac{V_X - 5V_X}{1000} = 0 \quad \Rightarrow V_X = -0.42857\ [V]$$

$$i_T = \frac{1\,[V] - V_X}{1000} \quad \Rightarrow \quad i_T = 1.4286\ [mA]$$

$$\therefore\ R_{TH} = \frac{1}{i_T} = 700\ [\Omega]$$

ii) The input resistance will be infinite when $i_T = 0$. This requires that $V_X = V_S$. If we assume a 1 [V] test source, then we need $V_X = 1\,[V]$.

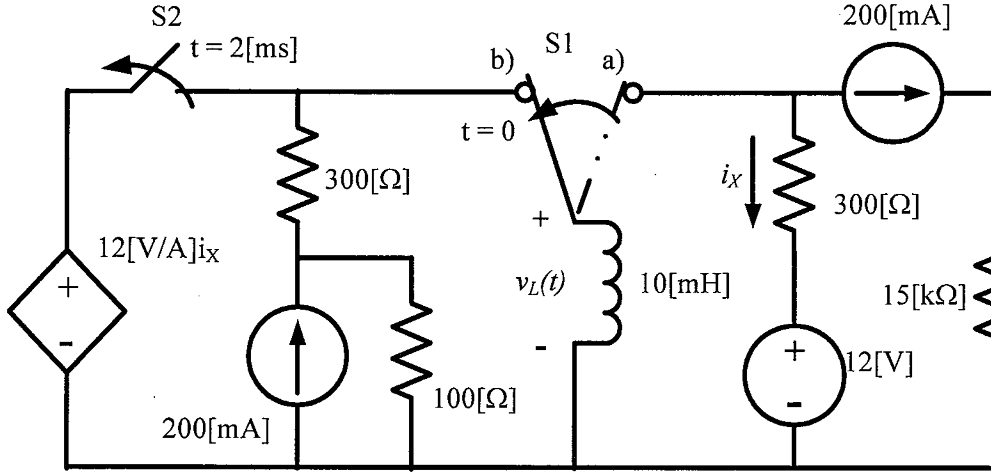
Then:
$$\frac{1}{1500} + \frac{1-1}{1000} + \frac{1-5}{R_F} = 0$$

$$\frac{1}{1500} = \frac{4}{R_F} \Rightarrow R_F = 6\,[k\Omega]$$

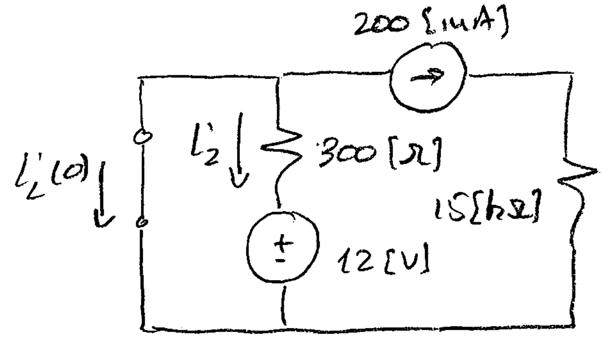
Room for extra work

4. (40 points) For a long time switch S1 was in position a) and switch S2 was closed. S1 moved to position b) at t = 0. At t = 2[ms] switch S2 opened.

Find expressions for $v_L(t)$ for $t > 0$.



Re-draw for $t < 0$ to find initial condition:



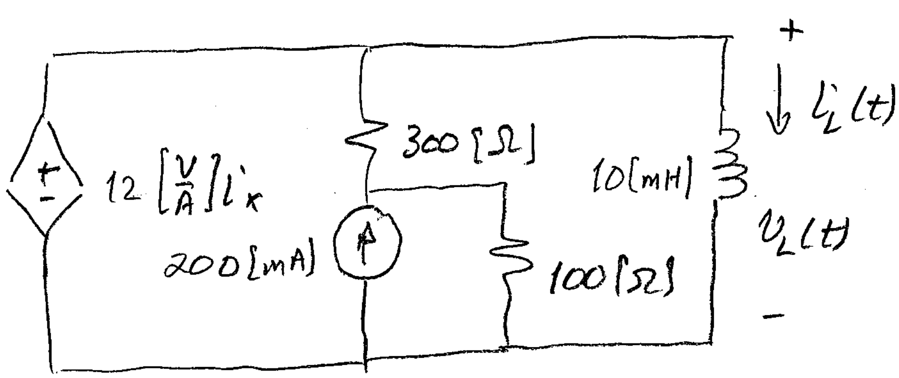
$$i_L'(0^-) = i_L'(0^+) \equiv i_L'(0)$$

$$= -i_2' - 0.2$$

$$300 i_2' + 12 = 0 \Rightarrow i_2' = -0.04 [A]$$

$$\Rightarrow \quad i_L'(0) = 0.04 - 0.2 = -0.16 [A]$$

$0 < t < 2[ms]$:



$$i_x' = -0.2 [A]$$

Room for extra work

we have a voltage source in parallel with L, so...

$$i_L(t) = i_L(0) + \frac{1}{L}\int_0^t 12\left[\frac{V}{A}\right] i_x \, dt \qquad i_x = -0.2\,[A]$$

$$i_L(t) = -0.16\,[A] + \frac{1}{0.01}\int_0^t (-2.4)\,dt = -0.16 - 240t\,[A]$$

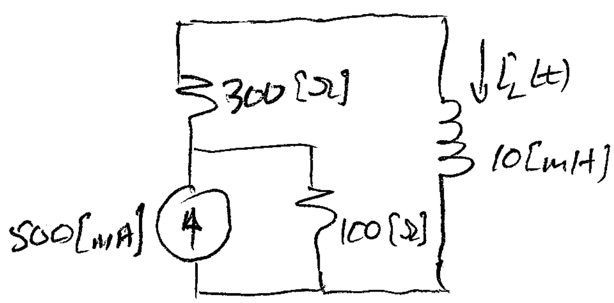
$$0 \le t \le 2\,[ms]$$

$$v_L(t) = -2.4\,[V] \qquad 0 < t < 2\times10^{-3}\,[s]$$

For the next time interval we need $i_L(2\,[ms])$:

$$i_L(2\,[ms]) = -0.16 - 240(2\times10^{-3}) = -0.64\,[A]$$

Re-draw for $t > 2\,[ms]$:



$$R_{TH} = 400\,[\Omega] \Rightarrow \tau = 25\times10^{-6}\,[s]$$

$$i_L(2\,[ms]) = -0.64\,[A]$$

$$i_{L,f} = i_L(t\to\infty) = 0.5\,\frac{100}{100+300} = 0.125\,[A]$$

$t \geq 2\,[ms]$:

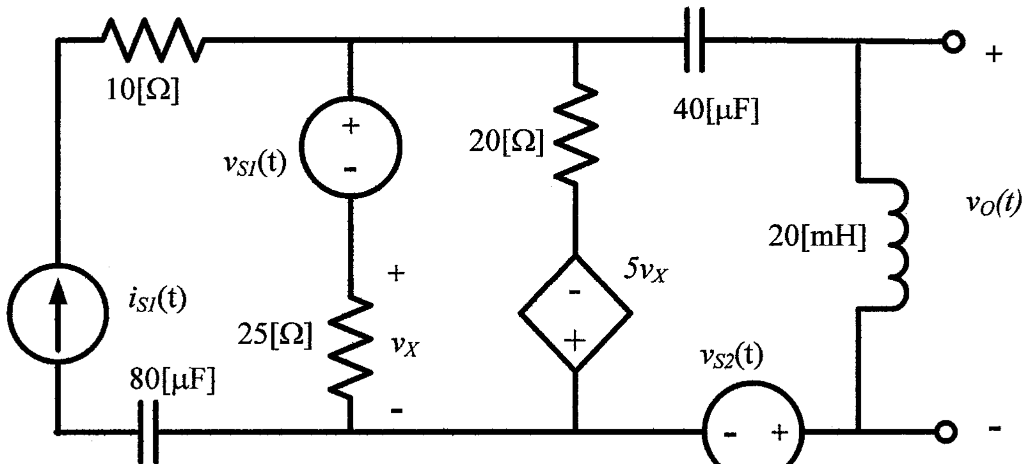
$$i_L(t) = 0.125 + (-0.64 - 0.125)\,e^{-(t-2\times10^{-3}[s])/25\times10^{-6}[s]}\ [A]$$

$$v_L(t) = L\frac{di_L(t)}{dt} = 0.01(-0.765)\left(\frac{-1}{25\times10^{-6}}\right)e^{-(t-2\times10^{-3}[s])/25\times10^{-6}[s]}\ [V]$$

$$v_L(t) = 306.0\,e^{-(t-2\times10^{-3}[s])/25\times10^{-6}[s]}\ [V] \quad t > 2\times10^{-3}\,[s]$$

5. (40 points) For the circuit below, find the steady state expression for $v_O(t)$.

$v_{S1}(t) = 250[\text{mV}] \cos(800[\text{rad/s}]\, t + 20^\circ)$
$v_{S2}(t) = 150[\text{mV}] \sin(800[\text{rad/s}]\, t - 25^\circ)$
$i_{S1}(t) = 35[\text{mA}] \cos(1000[\text{rad/s}]\, t)$

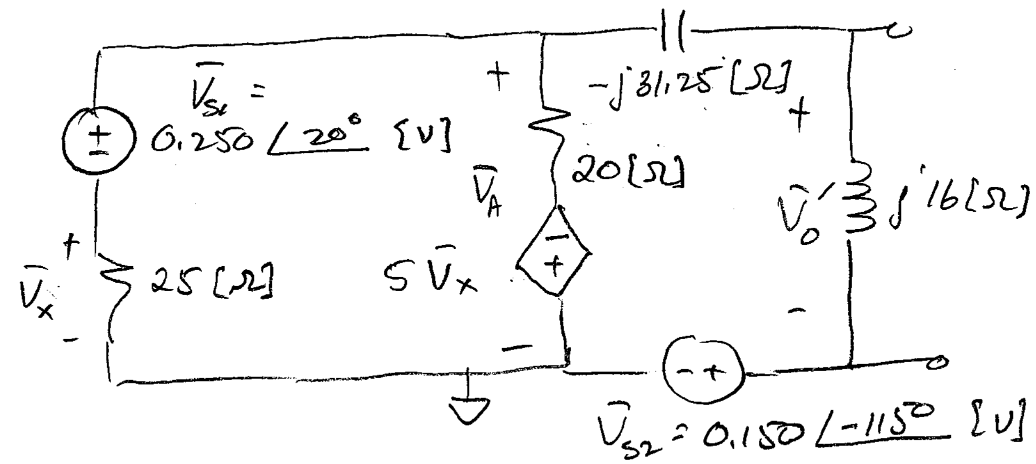


We need superposition: for $\omega = 800$ [rad/s] and $\omega = 1000$ [rad/s]

800 [rad/s]: $\bar{V}_{S1} = 0.250 \angle 20^\circ$ [V] sin → cos

$\bar{V}_{S2} = 0.150 \angle -25^\circ - 90^\circ$ [V] = $0.150 \angle -115^\circ$ [V]

Re-draw in phasor domain & de-activate $i_{S1}(t)$:



$$\frac{\bar{V}_A + 5\bar{V}_x}{20} + \frac{\bar{V}_A - 0.150\angle{-115^\circ}}{-j31.25 + j16} + \frac{\bar{V}_A - 0.250\angle{20^\circ}}{25} = 0$$

$$\bar{V}_A - \bar{V}_x - 0.250\angle{20^\circ} = 0$$

$\bar{V}_A = 0.1032\angle{115.6^\circ}$ [V]
$(-0.04456 + j0.09307$ [V]$)$

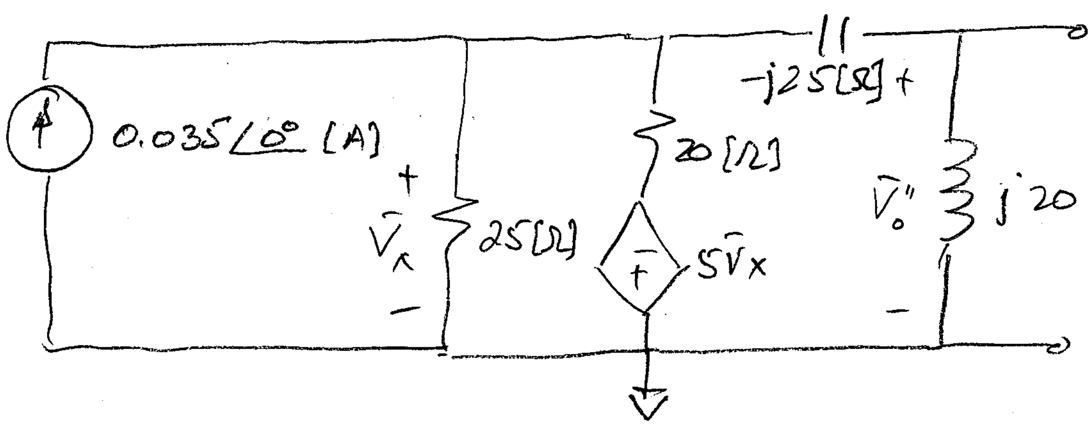
$\bar{V}_x = 0.2796\angle{178.4^\circ}$ [V]
$(-0.2795 + j0.00756$ [V]$)$

$$\bar{V}_o' = \bar{V}_A \cdot \frac{j16}{-j31.25 + j16}$$

$= 0.1083\angle{-64.4^\circ}$ [V]
$(0.04678 - j0.09765)$ [V]

$v_o'(t) = 108.3$ [mV] $\cos(800$ [rad/s]$t - 64.4^\circ)$

1000 [rad/s]: deactivate $v_{s1}(t)$, $v_{s2}(t)$



$$\frac{\bar{V}_x}{25} - 0.035 + \frac{\bar{V}_x + 5\bar{V}_x}{20} + \frac{\bar{V}_x}{-j25 + j20} = 0 \Rightarrow \bar{V}_x = 0.0873\angle{-30.46^\circ} \text{ [V]}$$

$(0.0765 - j0.0450)$ [V]

$$\bar{V}_o'' = \bar{V}_x \cdot \frac{j20}{-j25 + j20} = 0.349\angle{149.5^\circ} \text{ [V]}$$

$(-0.301 - j0.177)$ [V]

$v_o''(t) = 349$ [mV] $\cos(1000$ [rad/s]$t + 149.5^\circ)$

$v_o(t) = v_o'(t) + v_o''(t)$

$v_o(t) = 108.3$ [mV] $\cos(800$ [rad/s]$t - 64.4^\circ) + 349$ [mV] $\cos(1000$ [rad/s]$t + 149.5^\circ)$