# Physics 334, Winter Quarter 2012, Examination #1

Name SOLUTIONS V1.0

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|---|---|
| 1 | /25 |
| 2 | /25 |
| 3 | /25 |
| 4 | /25 |
| TOTAL | /100 |

Exam notes: The exam is closed-book. You may use a calculator, but not smart phones, iPads or laptops. You may not use your own equation sheet. Check that you have a total of 5 pages, including this page. You can make reasonable assumptions based on standard component tolerances of 5%, which may save you some time. You may use scratch paper or the back of the exam, but that won't be graded. Sloppy or disorganized work may be downgraded. Answers without showing work may be downgraded.

Possibly useful information and equations:

Ohm's Law: $V = IR$  Generalized Ohm's Law: $V = IZ$

Thévenin-equivalent circuits, conceptually (voltage-source and series resistor):
Vth = Vout (open-circuit) and Rth = Vth/Isc(current through short-circuit)

Norton-equivalent circuits, conceptually (current source and parallel resistor):
In = Iout (short circuit) and Rn = Voc(voltage open-circuit)/In

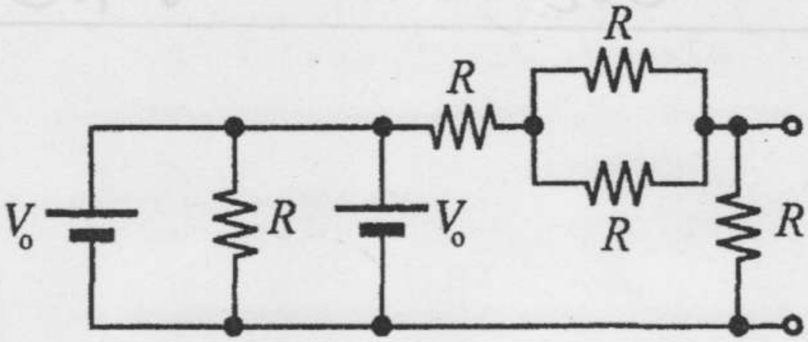
Impedance/reactance equations:
Resistor: $Z=R$  Capacitor: $Z = -i/(\omega C)$  Inductor: $Z = i\omega L$

Other equations: $\omega = 2\pi f$  $e^{ia} = \cos a + i \sin a$  Power(t) = V(t) I(t)

For sine & cosine: $V_{rms} = V_{peak}/\sqrt{2}$  $\omega$(3db) = is ½ power angular frequency (or $1/\sqrt{2}$ voltage)

Capacitors: $Q = C V$  $I = C\,(dV/dt)$

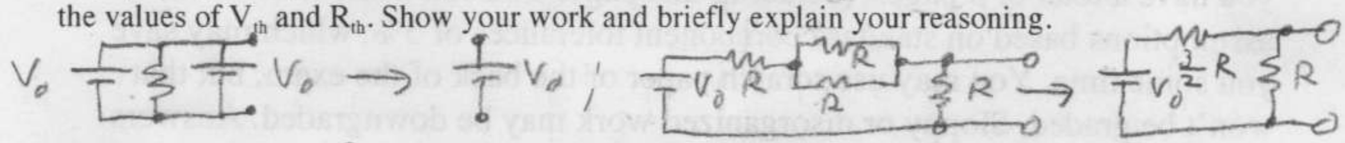
1. (25 points total) Thévenin and Norton equivalent circuits.
Consider the circuit shown below, consisting of two identical and ideal voltage sources and five identical resistors.




a. (4 points) In 10 words or less, what is meant by "ideal" in "ideal voltage sources"?

THE VOLTAGE ACROSS THE DEVICE IS CONSTANT REGARDLESS OF CURRENT.

b. (7 points) Neatly and clearly sketch below the Thévenin equivalent circuit and determine the values of $V_{th}$ and $R_{th}$. Show your work and briefly explain your reasoning.

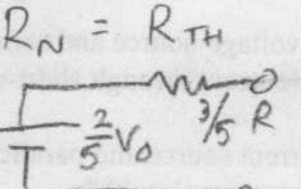


$$V_{OC} = V_{TH} = \frac{R}{\left(\frac{3R}{2} + R\right)} V_0 = \frac{2}{5} V_0, \quad I_{SC} = \frac{V_{TH}}{R_{TH}} = \frac{2V_0}{3R} \Rightarrow R_{TH} = \frac{3}{5} R$$

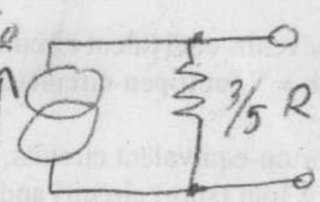
c. (7 points) Neatly and clearly sketch below the Norton equivalent circuit and determine the values of ~~V~~ $I_N$ and $R_n$. Show your work and briefly explain your reasoning.

$$I_{SC} = I_N \, ; \quad R_N = R_{TH}$$

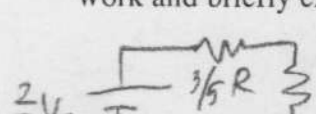
THÉVENIN: SKETCH



NORTON SKETCH



d. (7 points) An unknown resistor load is connected across the output and a voltage $V_{th}/4$ is measured across the load. What is the load resistance expressed in terms of R? Show your work and briefly explain your reasoning. USING THÉVENIN:

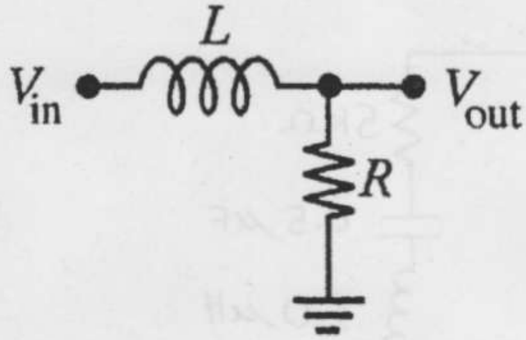


THIS IS A VOLTAGE DIVIDER WITH

$$\frac{V_{TH}}{4} = \frac{R_L}{R_L + R_{TH}} V_{TH} \Rightarrow \frac{1}{4} = \frac{R_L}{R_L + \frac{3}{5} R}$$

$$R_L = \frac{1}{5} R$$

2. (25 points total) Filters. Consider the circuit shown below. Assume L = 15 mH and R = 120 Ω. Also assume the circuit is driven by an AC voltage source with RMS voltage $V_{in,RMS} = 10$ V.




a. (4 points) Does this circuit behave like a high-pass, low-pass, band-pass or notch filter? Briefly explain your reasoning.

AS $\omega \to 0$, $Z_L = i\omega L \to 0$ AND ALL $V_{IN}$ IS ACROSS R; $V_{OUT} \approx V_{IN}$
AS $\omega \to \infty$, $Z_L \to \infty$ AND NO $V_{IN}$ ACROSS R; $V_{OUT} \to 0$

b. (7 points) Write an expression (or expressions) in terms of the given variables for the "3dB" angular frequency $\omega_{3dB}$. If there's more than one value of $\omega_{3dB}$, identify all such values. Show your work and briefly explain.

$Z = i\omega L + R$; $I = V_{IN}/Z$

$V_{OUT} = IR = RV_{IN}/Z \quad |V_{OUT}|^2/|V_{IN}|^2 = R^2/|Z|^2 = \frac{R^2}{R^2+\omega^2L^2}$

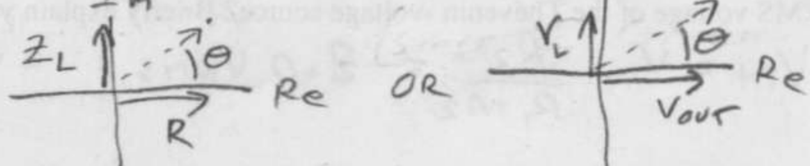
FOR $\frac{|V_{OUT}|^2}{|V_{IN}|^2} = \frac{1}{2}$, $\frac{R^2}{R^2+\omega_{3dB}^2L^2} = \frac{1}{2} \quad \omega_{3dB} = \frac{R}{L}$

c. (7 points) Calculate the value(s) of $f_{3dB}$ for this particular circuit. Show your work.

$$f_{3dB} = \frac{\omega_{3dB}}{2\pi} = \frac{R}{2\pi L} = \frac{120\,\Omega}{2\pi\ 15\times10^{-3}\,H} = 1.3\ KHz$$

d. (7 points) Suppose the input frequency is 950 Hz. Determine the phase difference in degrees between $V_{out}$ and $V_{in}$. If the two quantities are not in phase, be sure to state clearly whether $V_{out}$ lags or leads $V_{in}$. Show your work and briefly explain your reasoning.

RECALL THE COMPLEX IMPEDANCE

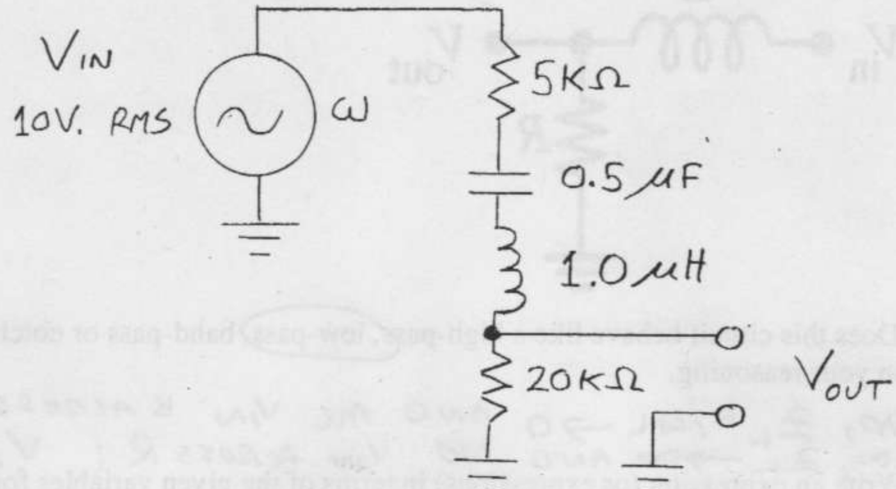



$$\cos\theta = \frac{|V_{OUT}|}{|V_{IN}|} = \frac{|Z_{OUT}|}{|Z_{IN}|} = \frac{R}{\sqrt{R^2+\omega^2L^2}}$$

$$= \frac{120\,\Omega}{\sqrt{(120\,\Omega)^2+(2\pi\cdot 950\,Hz)^2(15\,mH)^2}} = 0.80$$

$\theta \approx 40.^\circ$ AND $V_{OUT}$ LAGS $V_{IN}$

3. (25 points) Thévenin-equivalent circuit and resonance.
Consider the circuit shown below. Notice this circuit is driven by an AC voltage source with RMS voltage $V_{in}$ (RMS) = 10 V at angular frequency ω.




a. (4 points) At what source-frequency $f_0$ is the RMS current supplied by the voltage source at a maximum? Briefly explain your reasoning. $f_0 = \frac{1}{2\pi\sqrt{LC}} \approx 230KHz$.
AT THE RESONANT FREQUENCY THE SERIES C & L HAVE THEIR LOWEST IMPEDANCE AND HENCE HIGHEST CURRENT.

b. (7 points) What's the value of the RMS current supplied by the voltage-source at frequency $f_0$? Briefly explain your reasoning. AT $f_0$ $Z = 5K\Omega + 20K\Omega$; AT RESONANCE THE SERIES L & C CONTRIBUTE NO IMPEDANCE.
$I = 25K\Omega / 10V = 0.40mA$ RMS

c. (7 points) What's the RMS output voltage at frequency $f_0$? Briefly explain your reasoning.
OUTPUT IS VOLTAGE ACROSS 20KΩ RESISTOR
$V_{OUT} = 20K\Omega \cdot 0.40mA = 8.0V_{RMS}$

d. (7 points) Suppose you replace this circuit, operating at frequency $f_0$, by a Thévenin-equivalent circuit consisting of a single AC ideal voltage source in series with a single impedance. Hint: the circuit can be considerably simplified at the frequency $f_0$.

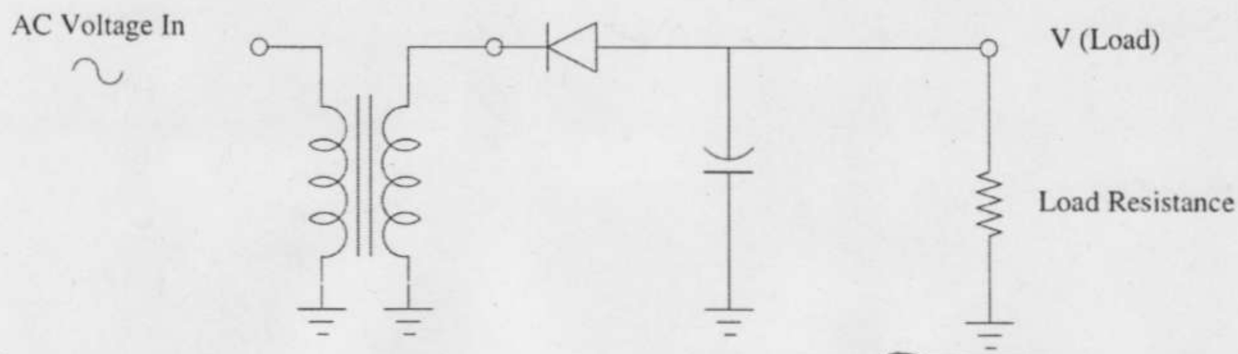
i. What's the RMS voltage of the Thévenin -voltage source? Briefly explain your reasoning.

$$V_{TH} = V_{IN} \frac{R_2}{R_1 + R_2} = 8.0 V_{RMS}$$

ii. What's the value of the Thévenin-equivalent series impedance? Briefly explain your reasoning.

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2} = \frac{5K\Omega \cdot 20K\Omega}{5K\Omega + 20K\Omega} = 4K\Omega$$

4. (25 points) Diodes and power supplies.
Consider the power-supply circuit shown below. The output is taken at the point labeled V(Load). Assume for now the Load Resistance is very very large.




a. (4 points) With the assumptions above, is this design an AC- or DC-voltage supply?

IT'S A CLASSIC DC SUPPLY AS SEEN IN LAB.

b. (6 points) If it's an AC supply, carefully and neatly sketch the output waveform. If it's a DC supply, is this a positive, negative, or 0 volt (ground) supply?

NEGATIVE: THE DIODE IS REVERSED FROM WHAT YOU SAW IN LAB.

c. (7 points) Assume the AC Voltage In applied to the transformer primary is 120 V AC(RMS), the standard US line voltage. Assuming further that the transformer turns-ratio is 12:1 (meaning the transformer's secondary voltage is ×12 smaller than the primary input voltage). What V(Load) output do you expect for very large load resistance: either carefully and neatly sketch the output waveform or otherwise explain as appropriate.

$V_{TRANS} = 10\,V\,(RMS)$; $V_{TRANS}\,(PEAK) = \sqrt{2}\,10\,V$
ACCOUNTING FOR THE DIODE DROP (SAY, 0.6 V);
$V(LOAD) \approx -\sqrt{2}\,10\,V + 0.6\,V \approx -13.4\,V$

d. (8 points) Now assume a finite load resistance of 10 kΩ. What value of capacitance should you chose so that the output voltage droops less than 1 V from the maximum value? You can assume the frequency of the AC Voltage In is 60 Hz.

$$C = \frac{I_{PEAK}}{\Delta V}\Delta t = \frac{1.3\,mA}{1\,V}(16\,ms) \approx 21\,\mu F \text{ MINIMUM}$$

$$\Delta t = \frac{1}{60\,Hz} \left(\tfrac{1}{2} \text{ WAVE RECTIFIER}\right) \approx 16\,ms$$

$$I_{PEAK} = \frac{13.4\,V}{10K} \approx 1.3\,mA$$