

# Electronic Instrumentation

## Quiz 1

Spring 2018

1.	/20
2.	/20
3.	/20
4.	/20
5.	/20
6. Online Quiz	/20
Total	/120

Name \_\_\_\_\_

Please write your name at the top of every page (following this page)!

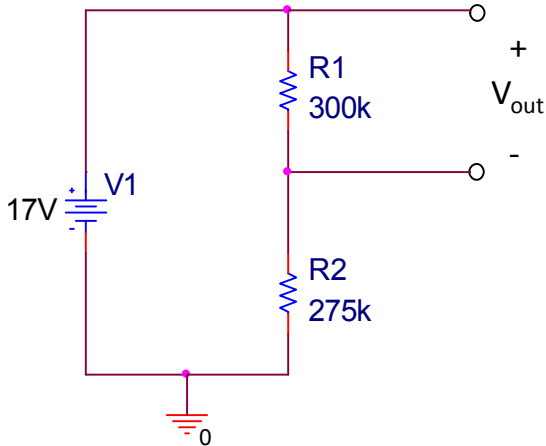
Notes:

**SHOW ALL WORK. BEGIN WITH FORMULAS, THEN SUBSTITUTE VALUES AND UNITS.** No credit will be given for numbers that appear without justification. Read the entire quiz before answering any questions. Also it may be easier to answer parts of questions out of order. Round answers to 3 significant digits.

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**Problem 1: Voltage and Current Dividers (20 pts).** As stated on the cover page: Round answers to 3 significant digits. Show formulas first and show your work. No credit will be given for numbers that appear without justification.

1.1: (4 pts) Find the voltage  $V_{out}$  in the circuit below.



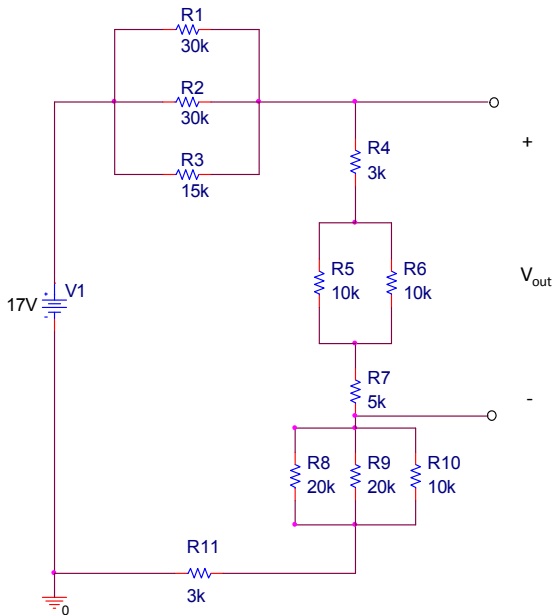
$$R_{11} := 300k\Omega \quad R_{21} := 275k\Omega$$

$$V_{11} := 17V$$

$$V_{out11} := V_{11} \cdot \frac{R_{11}}{R_{11} + R_{21}}$$

$$V_{out11} = 8.87 V$$

1.2: (4 pts) Reduce the circuit to 3 resistors (in a way to make it easy to find  $V_{out}$ ). Redraw the circuit and label the circuit with the appropriate component values. Find the voltage  $V_{out}$  in the circuit below.



$$R_{12} := 30k\Omega \quad R_{22} := 30k\Omega$$

$$R_{32} := 15k\Omega \quad R_{42} := 3k\Omega$$

$$R_{52} := 10k\Omega \quad R_{62} := 10k\Omega$$

$$R_{72} := 5k\Omega \quad R_{82} := 20k\Omega$$

$$R_{92} := 20k\Omega \quad R_{102} := 10k\Omega$$

$$R_{112} := 3k\Omega \quad V_{12} := 17V$$

$$R_{123} := \left( \frac{1}{R_{12}} + \frac{1}{R_{22}} + \frac{1}{R_{32}} \right)^{-1}$$

$$R_{123} = 7.5 \times 10^3 \Omega$$

$$R_{4567} := R_{42} + \left( \frac{1}{R_{52}} + \frac{1}{R_{62}} \right)^{-1} + R_{72}$$

$$R_{4567} = 1.3 \times 10^4 \Omega$$

$$R_{891011} := R_{112} + \left( \frac{1}{R_{82}} + \frac{1}{R_{92}} + \frac{1}{R_{102}} \right)^{-1}$$

$$R_{891011} = 8 \times 10^3 \Omega$$

$$V_{outp12} := V_{12} \cdot \frac{R_{4567}}{R_{123} + R_{4567} + R_{891011}}$$

$$V_{outp12} = 7.754 V$$

$$V_{out} = 7.75$$

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1.3: (4 pts) Using the circuit shown in part 1.2, find the total current from the 17V source (total source current).

$$R_{eq3} := R_{123} + R_{4567} + R_{891011}$$

$$R_{eq3} = 2.85 \times 10^4 \Omega$$

$$I_{V12} := \frac{V_{12}}{R_{eq3}} = 5.965 \times 10^{-4} \text{ A}$$

$$I_{V12} = 5.97 \cdot 10^{-4} \text{ A}$$

1.4: (4 pts) Using the circuit shown in part 1.2, find the current through R4.

It must be the same as the source current.

$$I_{R4} := I_{V12} = 5.965 \times 10^{-4} \text{ A}$$

$$I_{R4} = 5.97 \cdot 10^{-4} \text{ A}$$

1.5: (4 pts) Using the circuit shown in 1.2, find the current through R10.

You must use a current divider with the same current as the source

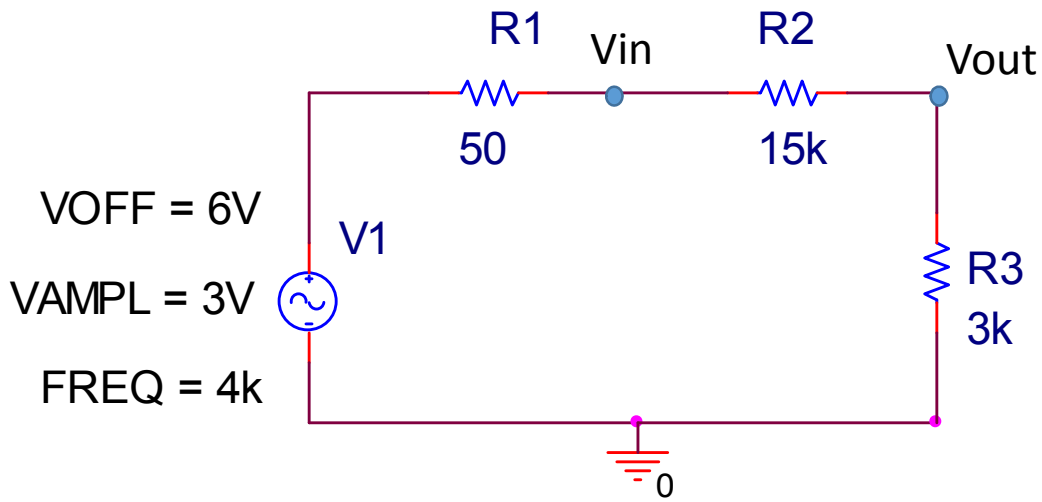
$$I_{R10} := I_{R4}$$

$$I_{R10} := I_{R4} \cdot \frac{\left(\frac{1}{R_{82}} + \frac{1}{R_{92}}\right)^{-1}}{\left(\frac{1}{R_{82}} + \frac{1}{R_{92}}\right)^{-1} + R_{102}} = 2.982 \times 10^{-4} \text{ A}$$

$$I_{R10} = 2.98 \cdot 10^{-4} \text{ A}$$

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**Problem 2: Filters and Transfer Functions (20 pts)**



2.1: (2 pt) What does the 50 ohm resistor (R1) represent in most commercial function generators?

*Internal resistance.*

2.2: (3 pts) Find the transfer function  $V_{out}/V_{in}$  for the resistive circuit shown above. Note that the output is measured across R3. *Hint: You may not need to include all components in the transfer function.*

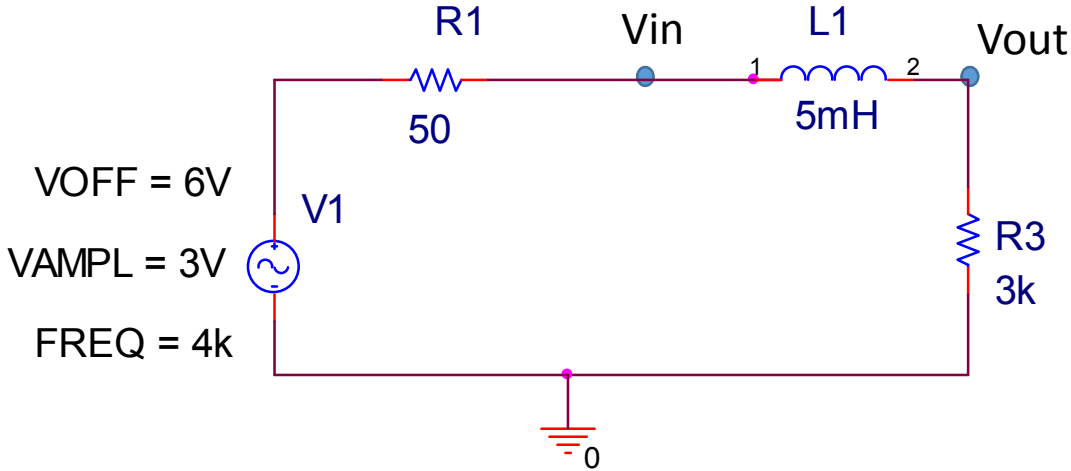
$$R_{2p2} := 15k\Omega \quad R_{3p2} := 3k\Omega$$

$$\frac{V_{out}}{V_{in}} = \frac{R_3}{R_2 + R_3} \quad H_s := \frac{R_{3p2}}{R_{2p2} + R_{3p2}}$$

$$H_s = 0.167$$

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2.4: (4 pts) The previous circuit is modified by replacing the second resistor with an inductor as shown in the circuit below. Find the transfer function  $V_{out}/V_{in}$  for the new circuit. Write it first in general form (symbolically, where  $H(j\omega)$  includes terms like  $\omega$ ,  $R_3$ ,  $L_1$  etc. and then plug in numerical values.



$$f_2 := 4\text{kHz}$$

$$V_{out} = \frac{Z_{R3}}{Z_{L1} + Z_{R3}} \cdot V_{in}$$

$$L_1 := 5\text{mH}$$

$$\omega_{23} := 2 \cdot \pi f_2 = 2.513 \times 10^4 \frac{1}{s}$$

$$Z_{L1} := L_1 \cdot \omega_{23} = 125.664 \Omega$$

$$\frac{V_{out}}{V_{in}} = \frac{R_3}{j\omega L_1 + R_3}$$

$$H_2 = \frac{3k}{125.7j + 3k}$$

2.5: (4 pts) Simplify the transfer function for low frequencies and high frequencies.

$$H_{low}(j\omega) = 1$$

$$H_2 = \frac{5k}{0j + 5k} = 1$$

$$H_{High}(j\omega) = \frac{5k}{j\omega L_1}$$

$$H_2 = \frac{5k}{j\omega L_1} \quad \text{also } \sim 0$$

2.6: (1 pt) What kind of filter response would best represent this circuit (from diagram under 2.4)? Circle one.

**Low Pass**

Low pass

Band Pass

High Pass

Notch (Band Reject)

2.7: (1 pt) What kind of filter would best represent the circuit if the position of  $L_1$  and  $R_3$  were interchanged? Circle one.

**High Pass**

Low pass

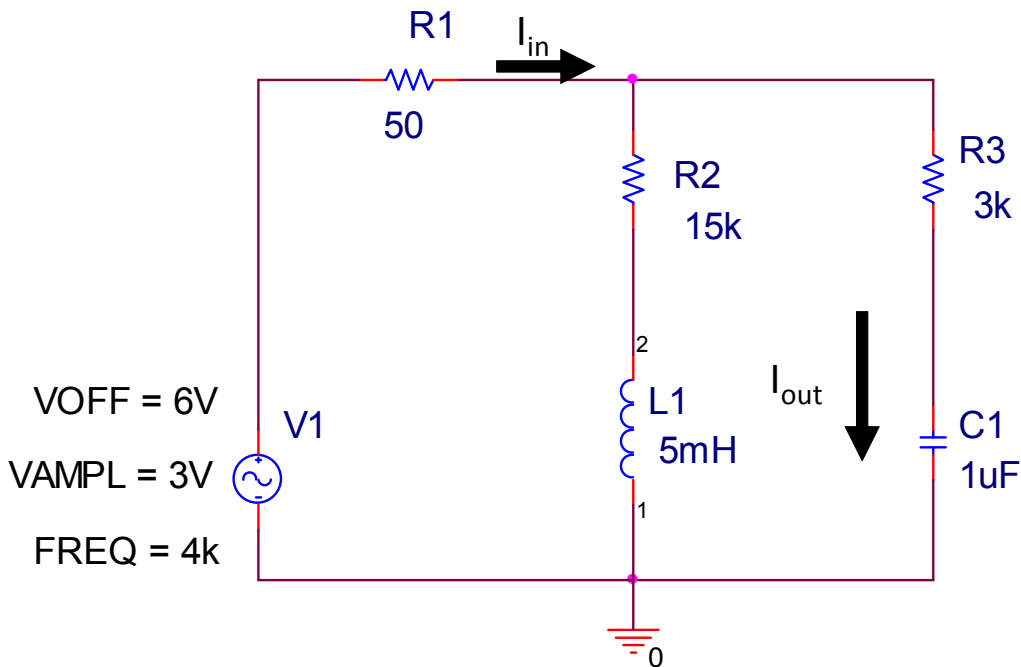
Band Pass

High Pass

Notch (Band Reject)

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2.8: (4 pts) Find the transfer function  $I_{out}/I_{in}$  for the RLC circuit below. Note:  $I_{out}$  is the current through C1. Write it first in general form (symbolically), where  $H(j\omega)$  includes terms like  $\omega$ , R3, C1, L1 etc. and **then plug in numerical values**.



$$H_s = \frac{I_{C1}}{I_{in}} = \frac{R_2 + sL_1}{R_3 + \frac{1}{sC_1} + R_2 + sL_1} = \frac{R_2 \cdot s \cdot C_1 + s^2 \cdot L_1 \cdot C_1}{R_3 \cdot s \cdot C_1 + 1 + R_2 \cdot s \cdot C_1 + s^2 \cdot C_1 \cdot L_1}$$

*students do not have to simplify*

$$\frac{R_2 \cdot s \cdot C_1 + s^2 \cdot L_1 \cdot C_1}{s^2 \cdot C_1 \cdot L_1 + s \cdot C_1 \cdot (R_2 + R_3) + 1} = \frac{s^2 + s \cdot \frac{R_2}{L_1}}{s^2 + \frac{R_2 + R_3}{L_1} s + \frac{1}{L_1 \cdot C_1}}$$

where  $s=j\omega$

2.9: (1 pt) What kind of filter response would best represent this circuit (from diagram under 2.8)? Circle one.

Highpass

Low pass

Band Pass

High Pass

Notch (Band Reject)

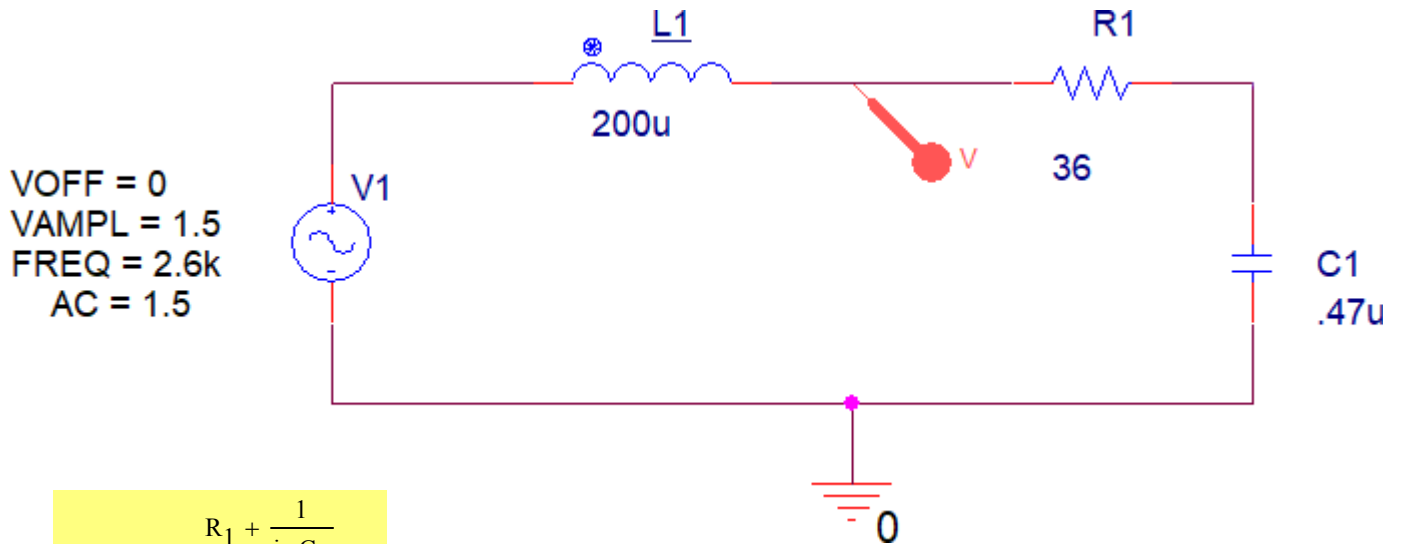
$$H_{High} = \frac{s^2}{s^2} = 1$$

$$H_{Low} = \frac{\frac{R_1}{s \cdot L_1}}{\frac{1}{L_1 \cdot C_1}} = \dots \sim 0$$

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**Problem 3: More Transfer Functions and Phasors (20 pts)**

3.1: (4 pts) Find the symbolic transfer function of the circuit below. The output voltage is marked with the red voltage probe



$$H(j\omega) = \frac{R_1 + \frac{1}{j\omega C_1}}{j\omega L_1 + R_1 + \frac{1}{j\omega C_1}} \quad \text{also} \quad \frac{36 - j130}{36 - j127}$$

3.2: (10 pts) What is the magnitude and phase (in degrees) of the transfer function above using the component values from the schematic at:

a) (2 pts) Low Frequencies?

$$H(j\omega) = \frac{1}{\frac{1}{j\omega C_1}} = j\omega C_1$$

$$|H(j\omega)| = 1$$

$$\angle H(j\omega) = 0^\circ$$

b) (4 pts) High Frequencies?

$$H(j\omega) = \frac{R_1}{j\omega L_1}$$

$$|H(j\omega)| = \frac{36}{200 \cdot 10^{-6} \omega} = \frac{180000}{\omega}$$

$$\angle H(j\omega) = -90^\circ (270^\circ)$$

c) (4 pts) Ideal Resonance?

$$L_{1c} := 200\mu\text{H} \quad C_{1c} := 0.47\mu\text{F}$$

$$\omega_{0c} := \frac{1}{\sqrt{L_{1c} \cdot C_{1c}}} = 1.031 \times 10^5 \frac{1}{\text{s}}$$

$$f_{0c} := \frac{\omega_{0c}}{2 \cdot \pi} = 16.416 \cdot \text{kHz}$$

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$$H_{j\omega} := \frac{36 + \frac{1}{(j \cdot 1.031 \cdot 10^5 \cdot 0.47 \cdot 10^{-6})}}{(j \cdot 1.031 \cdot 10^5 \cdot 200 \cdot 10^{-6}) + 36 + \frac{1}{(j \cdot 1.031 \cdot 10^5 \cdot 0.47 \cdot 10^{-6})}} = 1 - 0.573j$$

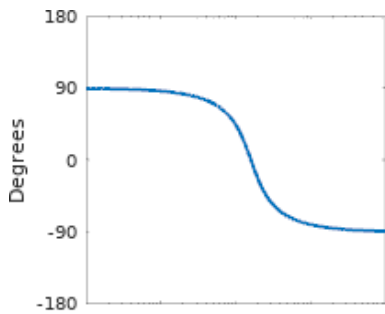
$$|H(j\omega)| = |1 - 0.573j|$$

$$\sqrt{1^2 + (-0.573)^2} = 1.153$$

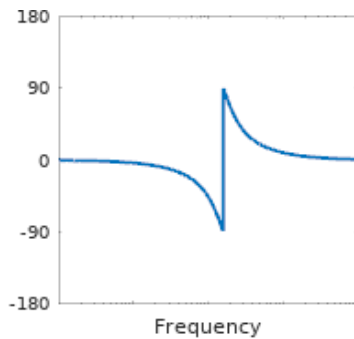
$$\text{angle}H_{j\omega} := \text{atan}\left(\frac{-0.573}{1}\right) = -29.813 \cdot \text{deg}$$

$$\angle H(j\omega) = -29.8^\circ (330.2^\circ)$$

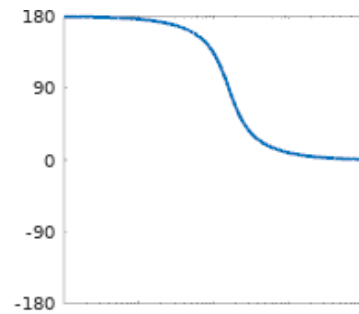
3.3: (6 pts) Given the three transfer function phase plots below, pick the corresponding transfer function from the provided. Write the letter of the transfer function below the phase plot.



**c**



**e**



**b**

a)  $H(j\omega) = \frac{1}{\frac{1}{j\omega C} + R + j\omega L}$

d)  $H(j\omega) = \frac{\frac{1}{j\omega C} + R}{\frac{1}{j\omega C} + R + j\omega L}$

b)  $H(j\omega) = \frac{j\omega L}{\frac{1}{j\omega C} + R + j\omega L}$

e)  $H(j\omega) = \frac{\frac{1}{j\omega C} + j\omega L}{\frac{1}{j\omega C} + R + j\omega L}$

c)  $H(j\omega) = \frac{R}{\frac{1}{j\omega C} + R + j\omega L}$

f)  $H(j\omega) = \frac{R + j\omega L}{\frac{1}{j\omega C} + R + j\omega L}$



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**Problem 4: Signals, Transformers, and Inductors (20 pts)**

4.1: (2 pts) Given the measurements of an RLC circuit of unknown arrangement below, what is the resonant frequency of the circuit?

f (kHz)	H(j $\omega$ )	f (kHz)	H(j $\omega$ )
10	0.394 + j0.546	60	1.076 + j0.169
20	0.793 + j0.529	70	1.077 + j0.129
30	0.978 + j0.404	80	1.072 + j0.101
40	1.039 + j0.300	90	1.067 + j0.079
50	1.067 + j0.224	100	1.061 + j0.063

*Maximum magnitude - 50 kHz*

4.2: (4 pts) The inductor of the above circuit was measure to be 26  $\mu$ H. What is the value of the capacitor?

$$L_2 := 26\mu\text{H} \quad f := 50\text{kHz}$$

$$f = \frac{1}{2\pi\sqrt{LC}} \quad C_2 := \frac{1}{L_2 \cdot (2\pi f)^2} = 389.697 \cdot \text{nF} \quad \text{390nF}$$

4.3: (2 pts) After measuring the value of the capacitor and comparing to the above calculated value (assuming correct), a non-negligible error between the two values in present. Why?

*The resonance equation doesn't account for the frequency shift due to the resistor.*

4.4: (4 pts) An inductor is built which is 2.5 cm long built with 28 AWG wire (0.32 mm diameter) around a ferrite core (permeability of 975  $\mu$ H/m) with a diameter of 4 mm. The coils of the inductor are tightly spaced. What is the inductance of this inductor?

*Number of turns calculated by wire diameter and lengths:*

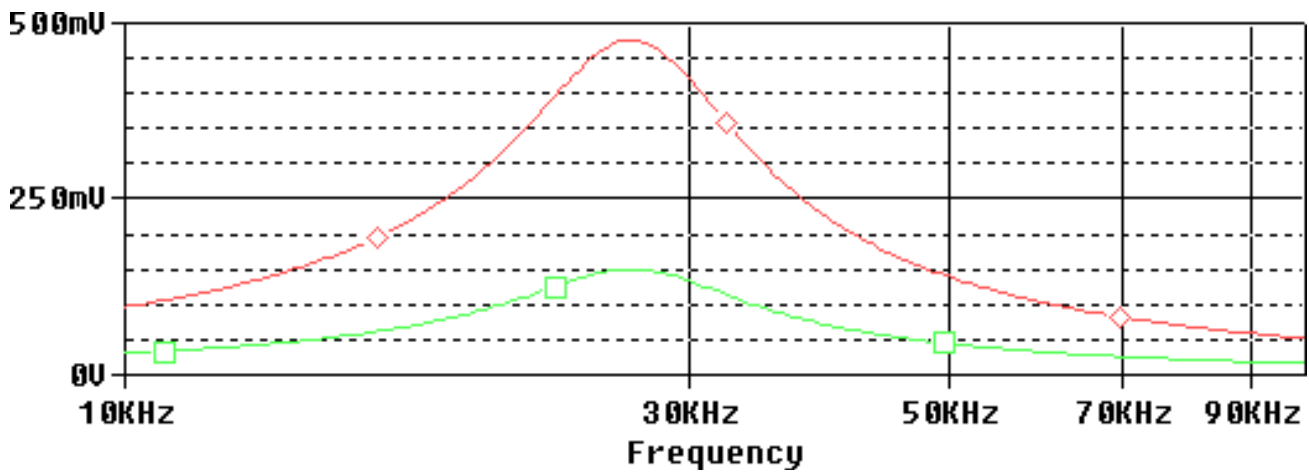
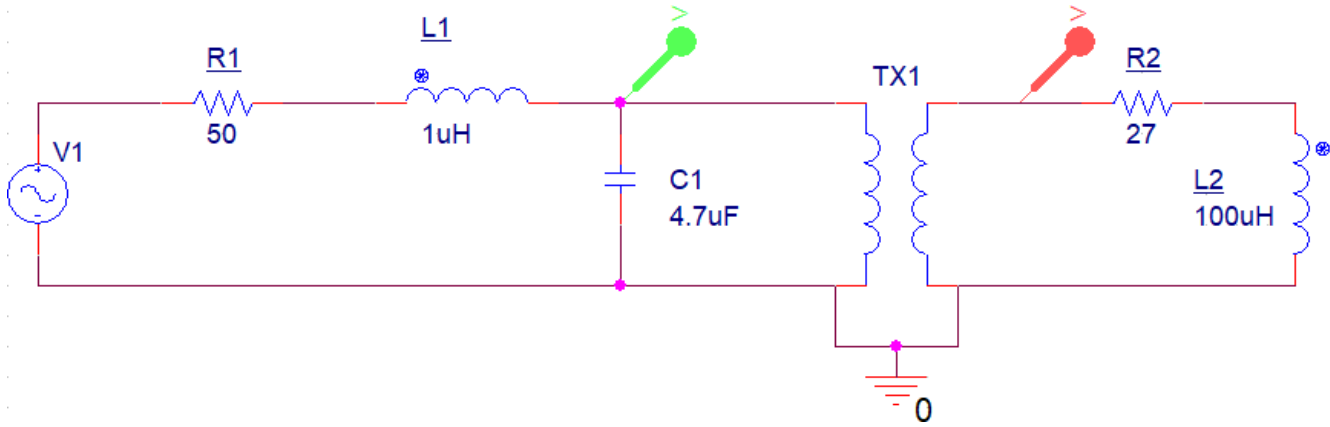
$$N_{\text{turns}} := \frac{2.5\text{cm}}{0.32\text{mm}} = 78.125$$

$$\mu_{\text{perm}} := 975 \frac{\mu\text{H}}{\text{m}} \quad d := 4\text{mm} \quad l_{\text{ind}} := 2.5\text{cm}$$

$$L_3 := \frac{\mu_{\text{perm}} \cdot N_{\text{turns}}^2 \cdot \pi \cdot \left(\frac{d}{2}\right)^2}{l_{\text{ind}}} = 2.991 \times 10^{-3} \text{ H}$$

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4.5: (4 pts) What is the equivalent impedance presented to the circuit by the primary coil of the transformer, given the measurements of  $V_{\text{Green}}$  and  $V_{\text{red}}$ ? Assume the transformer operates ideally.



$$V_2 := 475\text{mV}$$

$$V_1 := 150\text{mV}$$

$$a := \frac{V_2}{V_1} = 3.167$$

$$Z_{\text{eq}} = \frac{Z}{a^2} = \frac{27 + j\omega 100 \cdot 10^{-6}}{3.167^2} \quad 3.167^2 = 10.03$$

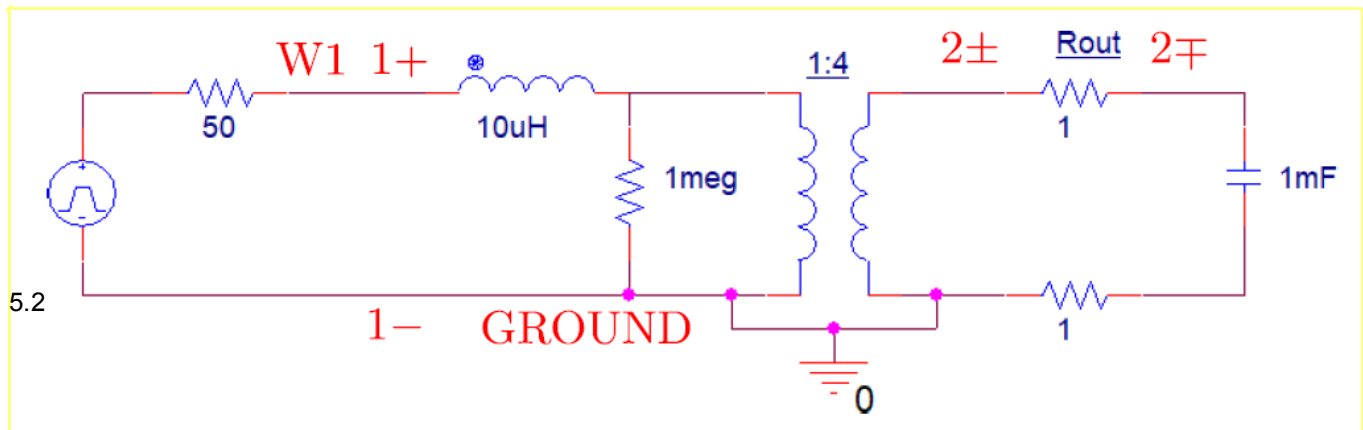
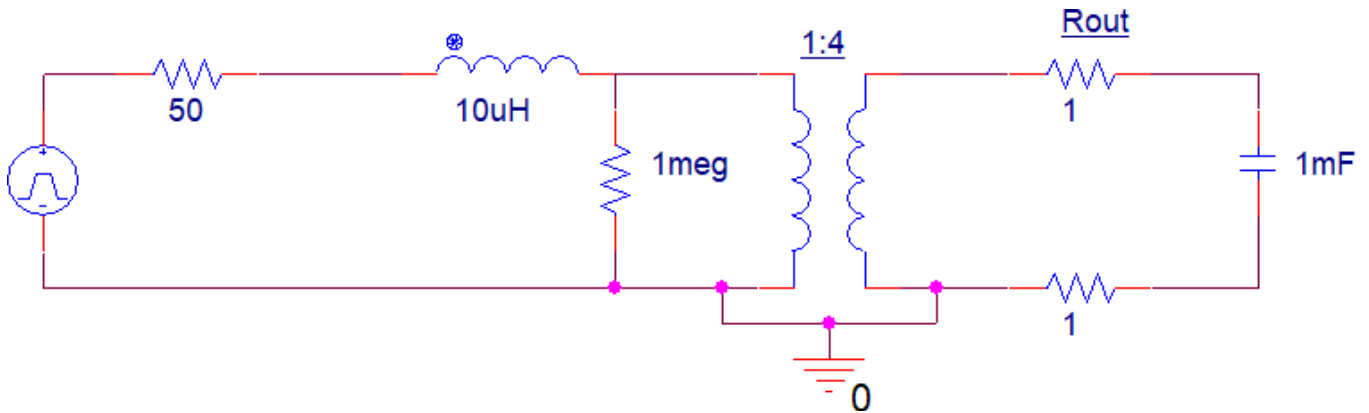
$$Z_{\text{eq}} = 2.7 + j\omega 10 \cdot 10^{-6}$$

4.6: (4 pts) Draw a 2-component replacement with values for the transformer and attached circuitry (TX1, R2, L2) that will cause the circuit to behave exactly the same in the transformer's ideal region.

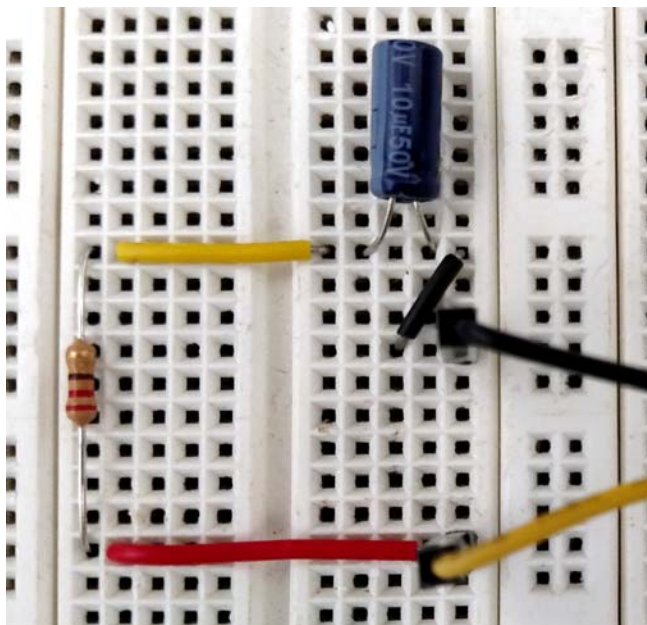
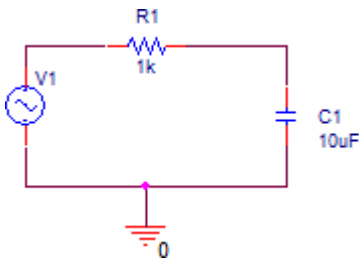


**Problem 5: Miscellaneous (20 pts)**

5.1: (4 pts) Add annotations to the schematic below that describes how you would hook up the Analog Discovery to power and test the circuit. The input voltage should be measured relative to ground. The output voltage should be measured differentially across  $R_{out}$ . Note: The source impedance is included in the schematic.



5.2: (4 pts) What is wrong with the circuit assembled below, considering the provided schematic? **Note: There may be multiple problems.**



**Two problems:**

1. Capacitor is shorting itself
2. Resistor value is incorrect.

5.3: (2 pts) Why do we care about the oscilloscope probe impedances when measuring voltages in a circuit with large resistances. Be specific.

*Some version of this answer is sufficient:*

*If testing across resistors with similar magnitudes or greater, the probe will pull a non-negligible amount of current from the circuit changing the measured behavior of the circuit.*

*Answer must mention current draw of the probe (or at least imply it clearly).*

5.4: (2 pts) When testing a circuit with a fresh 9V battery, the voltage being fed to the circuit is observed to be only 8V. Why?

*The internal resistance of the battery is causing a voltage drop seen at the terminals of the battery due to a high current draw.*

5.5: (6 pts) True or False Questions (circuit T or F):

T	F	Connection of the Discovery signal generator requires 2 wires	T
T	F	Connection of the Discovery probe only requires 1 wire	F
T	F	The black line on the diodes used in the lab point in the direction of current flow	T
T	F	Transformers work best with DC voltages	F
T	F	The component described in 4.4 is an ideal inductor	F
T	F	An RC low pass filter will have a transfer function magnitude of 1 at low frequencies and 0 at high frequencies	T

5.6: (2 pt) What is the best way to ask a question about the experiment in Electronic Instrumentation when it is the middle of the night?

Use Piazza