

## ENGR-2300

## Electronic Instrumentation

## Quiz 1

Fall 2025

Print Name \_\_\_\_\_

RIN \_\_\_\_\_

Section \_\_\_\_\_

*Solution*

I have read, understood, and abided by the Collaboration and Academic Dishonesty statement in the course syllabus. The work presented here was solely performed by me.

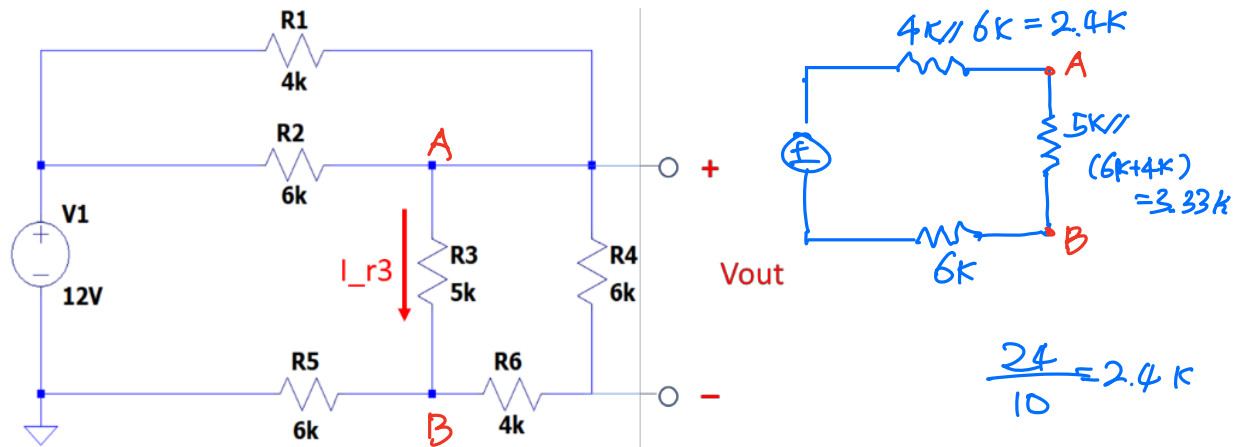
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On all questions: SHOW ALL WORK. BEGIN WITH FORMULAS, THEN SUBSTITUTE VALUES AND UNITS. No credit will be given for numbers that appear without justification. Unless otherwise stated in a problem, provide 3 significant digits in answers. Read the entire quiz before answering any questions. Also, it may be easier to answer parts of questions out of order.

### 1. Circuit Analysis: series and parallel connection [30 points]

A. We have a resistive network with DC voltage source of 12V.



1. Find the current through R3. Show your approach one by one by redrawing the circuit [5 pts]

$$V_{AB} = 12 \text{ V} \cdot \frac{3.33 \text{ k}}{2.4 \text{ k} + 3.33 \text{ k} + 6 \text{ k}}$$

$$= 12 \text{ V} \cdot \frac{3.33}{11.73} = 3.406 \text{ V}$$

$$I_{R3} = \frac{V_{AB}}{5 \text{ k}} = 0.681 \text{ mA}$$

2. Find the  $V_{out}$  (voltage across resistor R4). Show your reasoning in your calculation. [5 pts]

$$V_{out} = V_{AB} \cdot \frac{6 \text{ k}}{4 \text{ k} + 6 \text{ k}} = 3.406 \text{ V} \cdot \frac{6}{10}$$

$$= 2.044 \text{ V}$$

3. Find the power consumption through the resistor R4. [3 pts]

$$I_{R4} = \frac{V_{AB}}{4k + 6k} = \frac{3.406V}{10k} = 0.341 \text{ mA}$$

$$\begin{aligned} \text{Power}_{R4} &= I_{R4}^2 \cdot R4 = (0.341 \text{ mA})^2 \cdot 6k \\ &= 0.696 \text{ mW} \end{aligned}$$

4. If the voltage source V1 is replaced by AC voltage source: 4V peak-to-peak with frequency of 1k Hz.

Draw a plot of the transfer function ( $V_{out}/V_{in}$ ).  $V_{in}$  is given below.

- Sketch the shape of  $V_{out}$  response [3 pts]
- Give correct annotations for peak values and crossing points [2 pts]
- Is there phase change between  $V_{in}$  and  $V_{out}$ ? [2 pts]

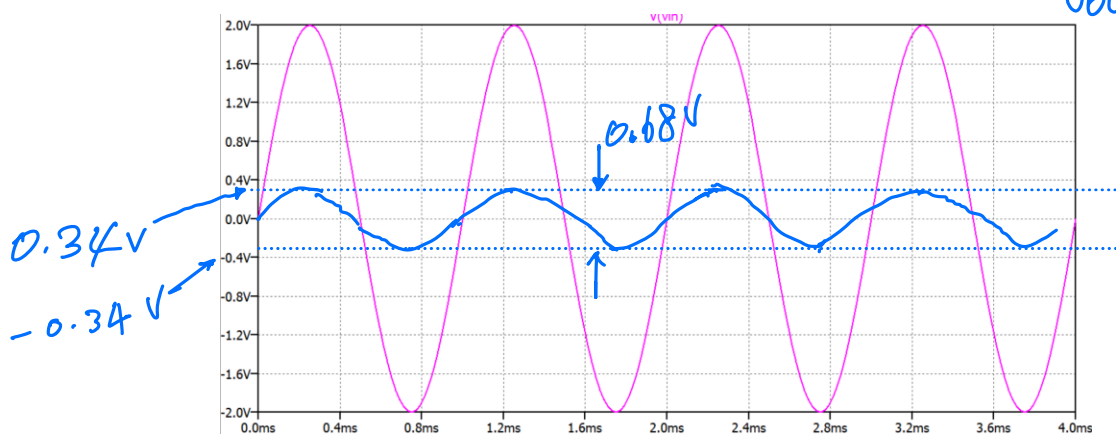
$$\begin{aligned} \frac{V_{out}}{V_{in}} &= \frac{2.044V}{12V} \\ &= 0.17 \end{aligned}$$

a. YES

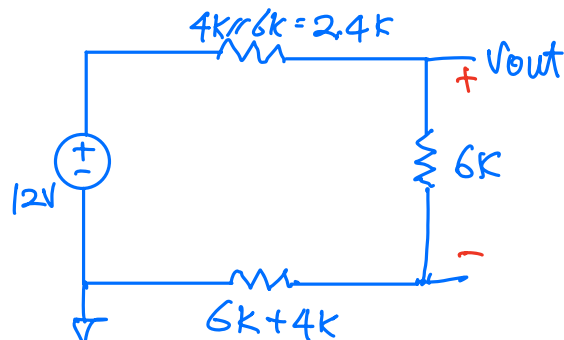
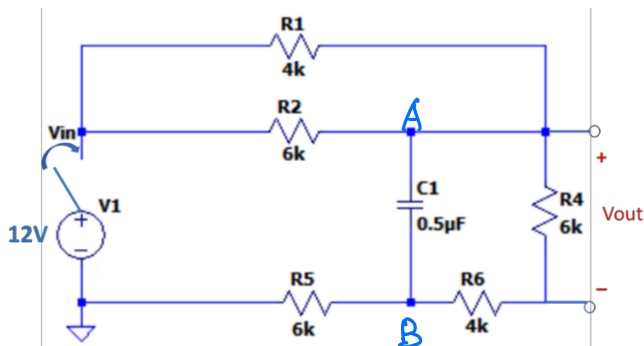
b. NO

$$V_{in} = 4V \text{ p-p}$$

$$\begin{aligned} V_{out} &= 4 \cdot (0.17) \text{ V} \\ &= 0.68 \text{ V p-p} \end{aligned}$$



5. Now back to 12V DC voltage source, the resistor R3 is replaced with a capacitor C1 (0.5uF) as shown below. The circuit is switched ON at time (t=0) and leave it ON for a long time (this means it reaches a steady state; fully settled down). What is the Vout [5pts]



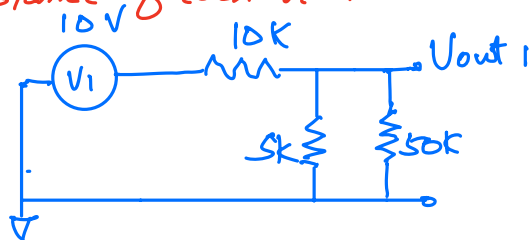
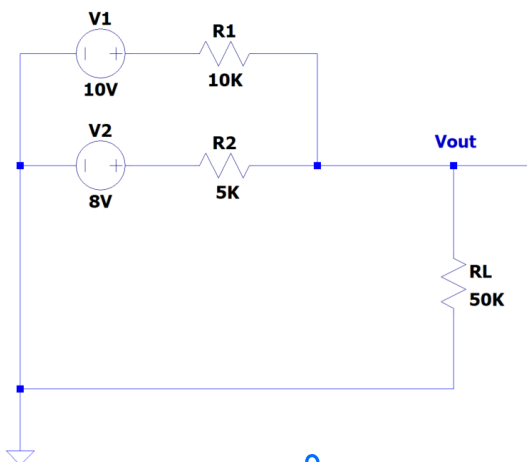
at steady state: C<sub>1</sub> fully charged  
just consider it as open circuit (V<sub>C</sub>=V<sub>AB</sub>)  
Voltage across C<sub>1</sub>.

$$V_{out} = 12V \cdot \frac{6K}{2.4K + 10K + 6K}$$

$$= 3.913V$$

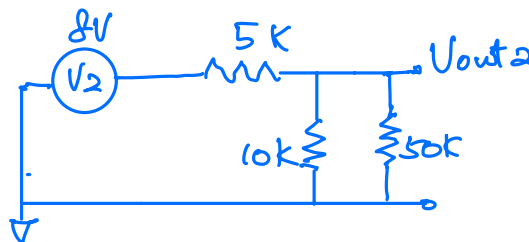
- B. This is a question on voltage divider with multiple input voltages (DC). Following circuit has two voltage sources: V1 and V2. Find the Vout across the load resistor RL=50Kohm. [ [5pts]

calculate for each V<sub>i</sub> and sum them up.  
Resistance of each V<sub>i</sub> is zero (more like ideal battery)



$$V_{out1} = 10 \cdot \frac{4.545}{10 + 4.545}$$

$$= 3.124V$$



$$V_{out2} = 8V \cdot \frac{8.333K}{5K + 8.333K}$$

$$= 5V$$

$$5K \parallel 50K = \frac{250K^2}{55K}$$

$$= 4.545K$$

$$10K \parallel 50K = \frac{500K^2}{60K}$$

$$= 8.333K$$

$$V_{out} = V_{out1} + V_{out2}$$

$$= 3.124V + 5V$$

$$= 8.124V$$

## 2. Impedance and Phasors [15 points]

A. At what frequency will the reactance (impedance) of 200mH inductor match the resistance level of a 5 k $\Omega$  resistor? [4 pts]

$$\omega L = 5 \text{ k}\Omega$$

$$2\pi \cdot f \cdot (200 \text{ mH}) = 5 \text{ k}\Omega$$

$$f = \frac{5 \text{ k}\Omega}{200 \text{ mH} \cdot 2\pi} = 3.98 \text{ kHz}$$

B. At what frequency will an inductor of 5 mH have the same impedance as a capacitor of 0.1  $\mu\text{F}$ ? [4 pts]

$$|j\omega L| = \left| \frac{1}{j\omega C} \right|, \quad \omega L = \frac{1}{\omega C}$$

$$\omega^2 = \frac{1}{LC} \quad \omega = \frac{1}{\sqrt{LC}}$$

$$2\pi f = \frac{1}{\sqrt{LC}} \quad f = \frac{1}{2\pi \sqrt{LC}}$$

$$= \frac{1}{2\pi \cdot \sqrt{5 \text{ mH} \cdot 0.1 \mu\text{F}}}$$

$$= 71.2 \text{ kHz}$$

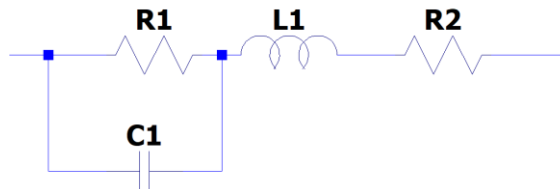
- C. Given the voltage phasor  $V = 1.8 - j1.02V$ , what is the voltage's magnitude and phase? [3 pts]

$$V = 1.8 - j1.02 V$$

$$\text{Mag. } |V| = \sqrt{1.8^2 + (-1.02)^2} = 2.0 V$$

$$\text{phase } \angle V = \tan^{-1}\left(\frac{-1.02}{1.8}\right) = -29.5 \text{ deg.}$$

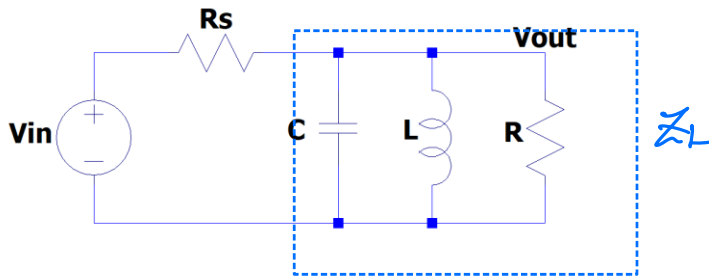
- D. Calculate the frequency-dependent equivalent impedance (total impedance) of the component network shown below. [4 pts]



$$\begin{aligned} Z_{\text{total}} &= R_1 \parallel Z_{C_1} + Z_{L_1} + R_2 \\ &= \frac{R_1}{1 + j\omega R_1 C_1} + j\omega L_1 + R_2 \end{aligned}$$

$$= \frac{R_1}{1 + j\omega R_1 C_1} + j\omega L_1 + R_2$$

3. Filters & Transfer function [45 points]



- A. For the circuit above, solve for the transfer function of the circuit in terms of  $R_s$ ,  $C$ ,  $L$  and  $R$ . [7pts]

$$\frac{1}{Z_L} = \frac{j\omega C}{1} + \frac{1}{j\omega L} + \frac{1}{R} = \frac{j\omega C \cdot j\omega R L + R + j\omega L}{j\omega R L}$$

$$Z_L = \frac{j\omega R L}{R - \omega^2 R L C + j\omega L}$$

$$H(\omega) = \frac{\frac{j\omega R L}{R - \omega^2 R L C + j\omega L}}{R_s + \frac{j\omega R L}{R - \omega^2 R L C + j\omega L}} = \frac{j\omega R L}{R_s(R - \omega^2 R L C + j\omega L) + j\omega R L}$$

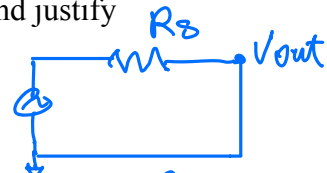
$$= \frac{j\omega R L}{R_s R - \omega^2 R_s R L C + j\omega(R_s + R)L}$$

- B. Using the high and low frequency limit approximation, predict what kind of filter the above circuit will perform. For each limit case, draw the simplified circuit and justify your answer. [4 pts]

Lower order winner

$\omega \rightarrow 0$

$$H(\omega) = \frac{j\omega R L}{R_s R} = \frac{j\omega L}{R_s} \Rightarrow 0$$



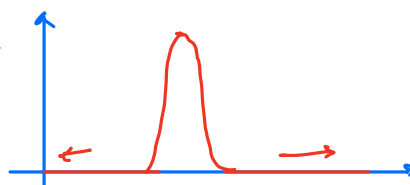
$\omega \rightarrow \infty$

Higher order winner

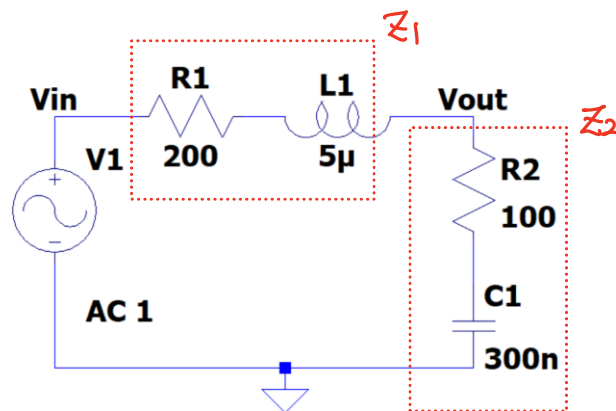
$$H(\omega) = \frac{j\omega R L}{-\omega^2 R_s R L C} = \frac{j}{-\omega R_s C} \Rightarrow 0$$



Band pass filter



C. Consider the circuit below. [4 pts]



$$H(\omega) = \frac{Z_2}{Z_1 + Z_2}$$

$$Z_1 = R_1 + j\omega L_1$$

$$Z_2 = R_2 + \frac{1}{j\omega C_1}$$

1. Write an expression for the transfer function of the circuit above in terms of  $R_1$ ,  $L_1$ ,  $R_2$  and  $C_1$ . [5 pts]

$$\begin{aligned} H(\omega) &= \frac{R_2 + \frac{1}{j\omega C_1}}{(R_1 + j\omega L_1) + (R_2 + \frac{1}{j\omega C_1})} = \frac{R_2 + \frac{1}{j\omega C_1}}{R_1 + R_2 + j\omega L_1 + \frac{1}{j\omega C_1}} \\ &= \frac{1 + j\omega R_2 C_1}{1 - \omega^2 L_1 C_1 + j\omega(R_1 + R_2)C_1} \\ &= \frac{1 + j\omega R_2 C_1}{(1 - \omega^2 L_1 C_1) + j\omega(R_1 + R_2)C_1} \end{aligned}$$

2. With given values of each component, determine the magnitude and phase of the transfer function at 1 MHz. [5 pts]

$$\begin{aligned} |H(\omega)| &= \left| \frac{1 + j(2\pi \cdot 10^6)(100) \cdot 300 \cdot 10^{-9}}{[1 - (2\pi \cdot 10^6)^2 \cdot 5 \cdot 10^{-6} \cdot 300 \cdot 10^{-9}] + j(2\pi \cdot 10^6)(300) \cdot 300 \cdot 10^{-9}} \right| \\ &= \frac{|1 + j188.5|}{|-58.22 + j565.5|} = \frac{\sqrt{1^2 + 188.5^2}}{\sqrt{(-58.22)^2 + 565.5^2}} = \frac{188.5}{568.5} \\ &= 0.332 \end{aligned}$$

$$\angle H(\omega) = \tan^{-1}(188.5) - \tan^{-1}\left(\frac{565.5}{-58.22}\right)$$

$$= 89.7^\circ - (-84.1^\circ) = 173.8^\circ$$

$$(6.067 \text{ rad})$$

**EI**

You must include units.

8

S. Han

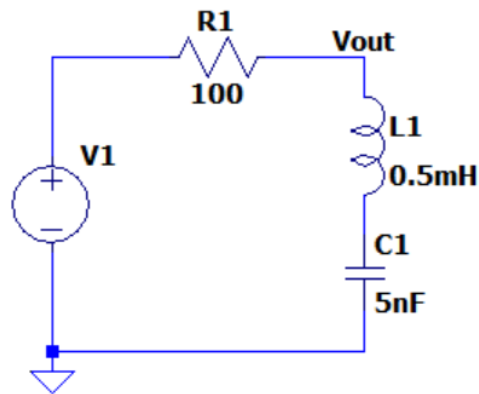
3. Does this circuit have a resonant frequency? If so, what is it? [3 pts]

$$f_{res} = \frac{1}{2\pi\sqrt{L_1 C_1}} = \frac{1}{2\pi\sqrt{(5 \cdot 10^{-6})(300 \cdot 10^{-9})}}$$

$$= 1.30 \times 10^5 \text{ Hz}$$

$$= \boxed{130 \text{ kHz}}$$

D. Consider the circuit below.



1. Find the transfer function  $H(\omega)$  in terms of  $R_1$ ,  $L_1$  and  $C_1$  from  $V_{out}$ . [5 pts]

$$H(\omega) = \frac{j\omega L_1 + \frac{1}{j\omega C_1}}{R_1 + j\omega L_1 + \frac{1}{j\omega C_1}} = \frac{1 - \omega^2 L_1 C_1}{1 - \omega^2 L_1 C_1 + j\omega R_1 C_1}$$

$$= \boxed{\frac{1 - \omega^2 L_1 C_1}{(1 - \omega^2 L_1 C_1) + j\omega R_1 C_1}}$$

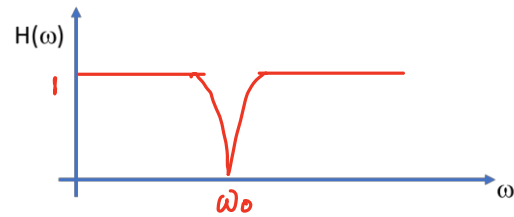
2. Find the magnitude of transfer functions for two extreme cases of frequency limit (Zero and infinite), and draw the transfer function and simplified circuits for each case. [4 pts]

when  $\omega \rightarrow 0$

$$H(\omega) = \frac{f}{1} = 1$$

when  $\omega \rightarrow \infty$

$$H(\omega) = \frac{-\omega^2 L_1 C_1}{-\omega^2 L_1 C_1} = 1$$



Band reject filter

3. What is the resonance frequency of this filter? [2pts]

$$f_{res} = \frac{1}{2\pi \sqrt{L_1 C_1}} = \frac{1}{2\pi \sqrt{0.5 \text{ mH} \cdot 5 \text{ nF}}}$$

$$= \frac{1}{2\pi \sqrt{0.5 \cdot 10^{-3} \cdot 5 \cdot 10^{-9}}} = 100.7 \text{ kHz}$$

4. What is the phase angle of  $H(\omega)$  at resonance. [3 pts]

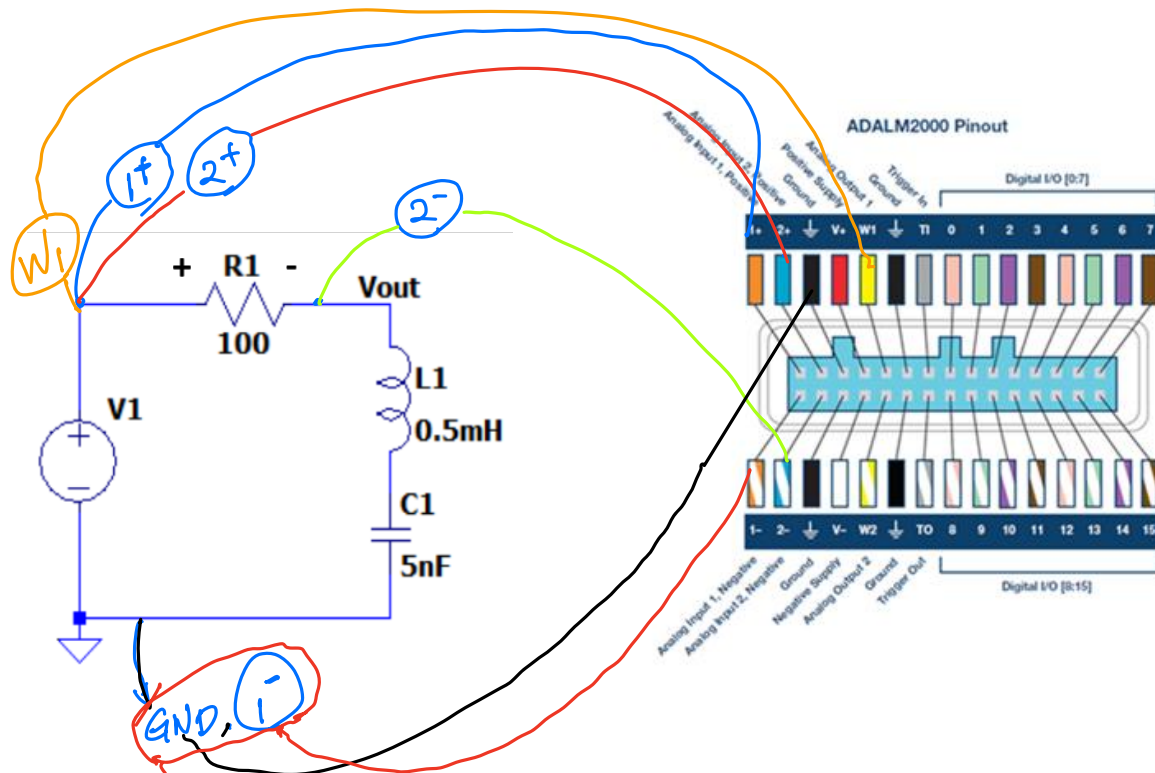
$H(\omega)$  @ resonance

$$H(\omega) = \frac{0}{j\omega R_1 C_1}$$

$$\frac{1 - \omega^2 L_1 C_1}{(1 - \omega^2 L_1 C_1) + j\omega R_1 C_1}$$

$$\angle H(\omega) = 0$$

5. With the same circuit configuration, we want to measure the frequency response of this filter across  $R_1$  ( $100\Omega$ ), NOT  $V_{out}$  with M2K by applying sinusoidal voltage signal using the signal generator of the M2K. Draw a hand drawn wiring diagram to measure  $V_1$  (voltage signal) and frequency response across the  $R_1$  using two channels of M2K. Clearly annotate all the points of wiring including ground. [5 pts]



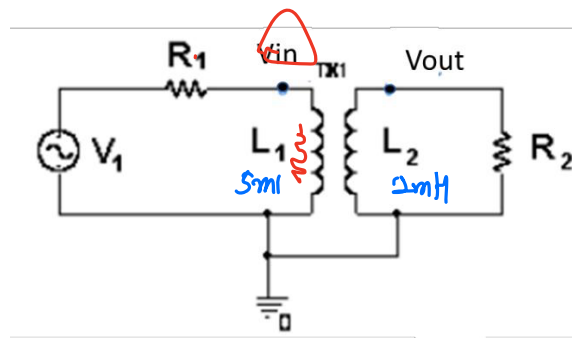
6. What type of filter do you expect from this measurement? [3 pts]

Low pass filter  
 High pass filter  
 Band pass filter  
 Band reject filter

*across  $R_1$ , NOT  $V_{out}$*

#### 4. Transformer circuits [10 points]

- A. Show all calculations. You are given the transformer pictured below. Values of each component are:  $L_1=5\text{mH}$ ,  $L_2=2\text{mH}$ ,  $R_1=100\Omega$ ,  $R_2=1\text{k}\Omega$ , and the source voltage,  $V_1$  is 20V.



$$\frac{V_{out}}{V_{in}} = \sqrt{\frac{L_2}{L_1}} = \frac{1}{a}$$

$$a = \sqrt{\frac{2\text{mH}}{5\text{mH}}} = 0.632$$

1. What is the voltage across the load resistor,  $R_2$ : i.e.  $V_{out}$ ? [6 pts]

$$Z_{in} = \frac{R_2}{a^2} = \frac{1\text{k}\Omega}{0.4} = 2.5\text{ k}\Omega$$

$$V_{in} = V_1 \cdot \frac{Z_{in}}{R_1 + Z_{in}} = 20 \cdot \frac{2500}{100 + 2500} = 19.23\text{ V}$$

$$V_{out} = a \cdot V_1 = 19.23\text{ V} \cdot (0.632) = 12.15\text{ V}$$

2. Is this transformer a step UP or a step DOWN. Circle the one you choose. [1 pts]

3. What are the currents through  $R_2$  and  $R_1$ ? [3 pts]

$$I_{R_1} = \frac{V_1 - V_{in}}{R_1} = \frac{20\text{ V} - 19.23\text{ V}}{100\ \Omega} = 7.7\text{ mA}$$

$$I_{R_2} = \frac{V_{out}}{R_2} = \frac{12.15\text{ V}}{1\text{ k}\Omega} = 12.15\text{ mA}$$