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NAU + CQUPT: Fall 2021

EE 188L Lab 7

AC Measurements of a Series Resistor & Capacitor Voltage Output, and of a Series Resistor & Inductor Voltage Output, at Several Frequencies with the Dual-Channel Oscilloscope

Summary

The purpose of this lab is first to demonstrate AC Measurements using the Dual-Trace Oscilloscope. The impedance & output voltage of a reactive element depends on the frequency, and this is seen by measuring the output voltage across the capacitor or the inductor. The capacitor and inductor are each connected in series with a resistor to form two separate simple circuits.

Secondly, the idea of a 'phase shift' will also be noted on the oscilloscope.

The figure below shows the impedance relationships for the 3 passive circuit elements (R, L and C). Note that the impedances are dependent on frequency (ω)!

$$\mathbf{V} = R\mathbf{I}, \qquad \mathbf{V} = j\omega L\mathbf{I}, \qquad \mathbf{V} = \frac{\mathbf{I}}{j\omega C}$$

$$\frac{\mathbf{V}}{\mathbf{I}} = R, \qquad \frac{\mathbf{V}}{\mathbf{I}} = j\omega L, \qquad \frac{\mathbf{V}}{\mathbf{I}} = \frac{1}{j\omega C}$$

$$\boxed{\mathbf{Z} = \frac{\mathbf{V}}{\mathbf{I}} \quad \text{or} \quad \mathbf{V} = \mathbf{Z}\mathbf{I}}$$

Element	Impedance
R	$\mathbf{Z} = R$
L	$\mathbf{Z} = j\omega L$
C	$\mathbf{Z} = \frac{1}{j\omega C}$

The **impedance** **Z** of a circuit is the ratio of the phasor voltage **V** to the phasor current **I**, measured in ohms (Ω).

The impedance of the reactive element will be calculated at different frequencies, and the output voltage will be calculated using voltage divider formula (with complex impedances).

So, $\mathbf{V_{out}} = \mathbf{V_s}\angle\_ * [\mathbf{Z_{out}} / \mathbf{Z_{Total}}]$

These will be used to predict the phasor voltages (magnitude and phase) of the output waveforms. The actual output phasor voltages will be measured by the Oscilloscope, by measuring magnitude and phase-shift of the output waveforms relative to the reference input waveform.

These measured values will be compared to predicted values. Total complex impedances will be plotted on the complex plane of numbers for each case → one for the RC circuit and one for the RL circuit.

I. Test bench equipment and parts

Function Generator:
The Function Generator (FG) is an AC Waveform Voltage Signal source. It is capable of producing Sinusoidal waveforms, Square waves, and Ramp waves, in frequency ranges of 1 Hertz (Hz) to Mhz (10^6 HZ). For this lab we shall look at a sinusoidal voltage wave at frequencies ranging from 100Hz to 100 kHz.

The Dual-Trace Oscilloscope (Osc): The Osc is capable of displaying two AC voltage waveforms at the same time. One trace display is designated as the reference voltage waveform (usually the FG source waveform), and the other trace display is the measured waveform.

→This means that its phase-shift is with respect to the reference waveform.

Components: Two 4.7 mH inductors(L), a .01µF capacitor (C) and 2 circuit resistors: 5.1kohm.

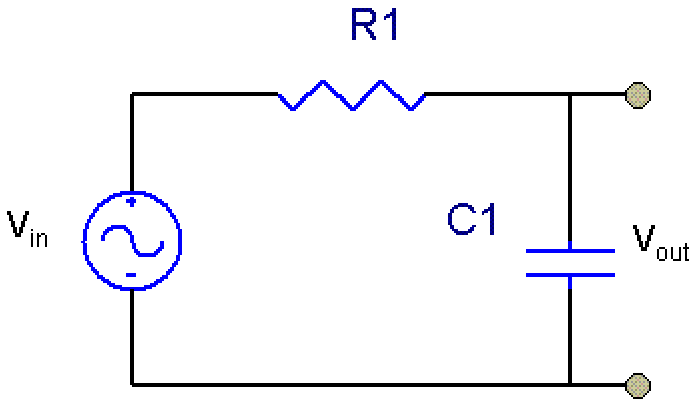
II. Measuring Resistance of Resistors
Locate the resistors with the values given below, and measure the actual resistance with the DMM in Resistance mode. Record the actual values to 2 decimal places (for example if R_1 measures=> 5.326kΩ, use 5.33kΩ).
Use these measured values in all calculations.

R_1 = 5.1 kΩ => ____5.14 kΩ ____________(measured)
R_2 = 5.1 kΩ => ____5.07 kΩ ____________(measured)

III. Frequency-Dependent Circuits and Voltage Division

A. RC circuit

On the BB put resistor R_1 in series with the capacitor C and the FG voltage source as shown in the schematic below.



Put the Channel 1 probe of the Oscilloscope on the output of the FG (red one), with the Osc ground tied to the FG ground (black one).

Adjust the peak-to-peak voltage $v_s(t)$ of the FG to $V_{in(P\text{-}P)}$ = 2 Volts, so $V_{in(Peak)}$ = 1 Volts, and frequency f = 1kHz. (So, period T_p = 1/f = 1.0msec). Move it on the Osc to have it be a sinewave. Put it into the circuit as shown above.
Note: All AC voltages are with respect to the Osc & FG ground!

Use Channel 2 of the Osc to display and measure peak voltages at the top of the capacitor. The Osc can also display both peak voltage values and RMS voltage values. **For this lab, use peak voltages.**

For the frequencies listed in the first table below, calculate the capacitor impedance, total impedance, and output voltage phasor (magnitude and phase). Also measure, as shown.

$$\omega = 2\pi f$$

$$\mathbf{Z_C = 1/j\omega C = -j/\omega C}$$

$$\mathbf{Z_{Total}} = R - j/\omega C = \mathbf{Z_T \underline{/\Phi_1}}$$

$$\mathbf{V_{OutPeak)} = V_{in} * [Z_C/Z_{Total}] = V_{Out} \underline{/-\Phi_1}}$$

Note: To find angle $\underline{/-\Phi_1}$, measure each time shift t_x, and T_p

Then, calculate$|\underline{/\Phi_1}| = (t_x/T_p) \times 360^0$

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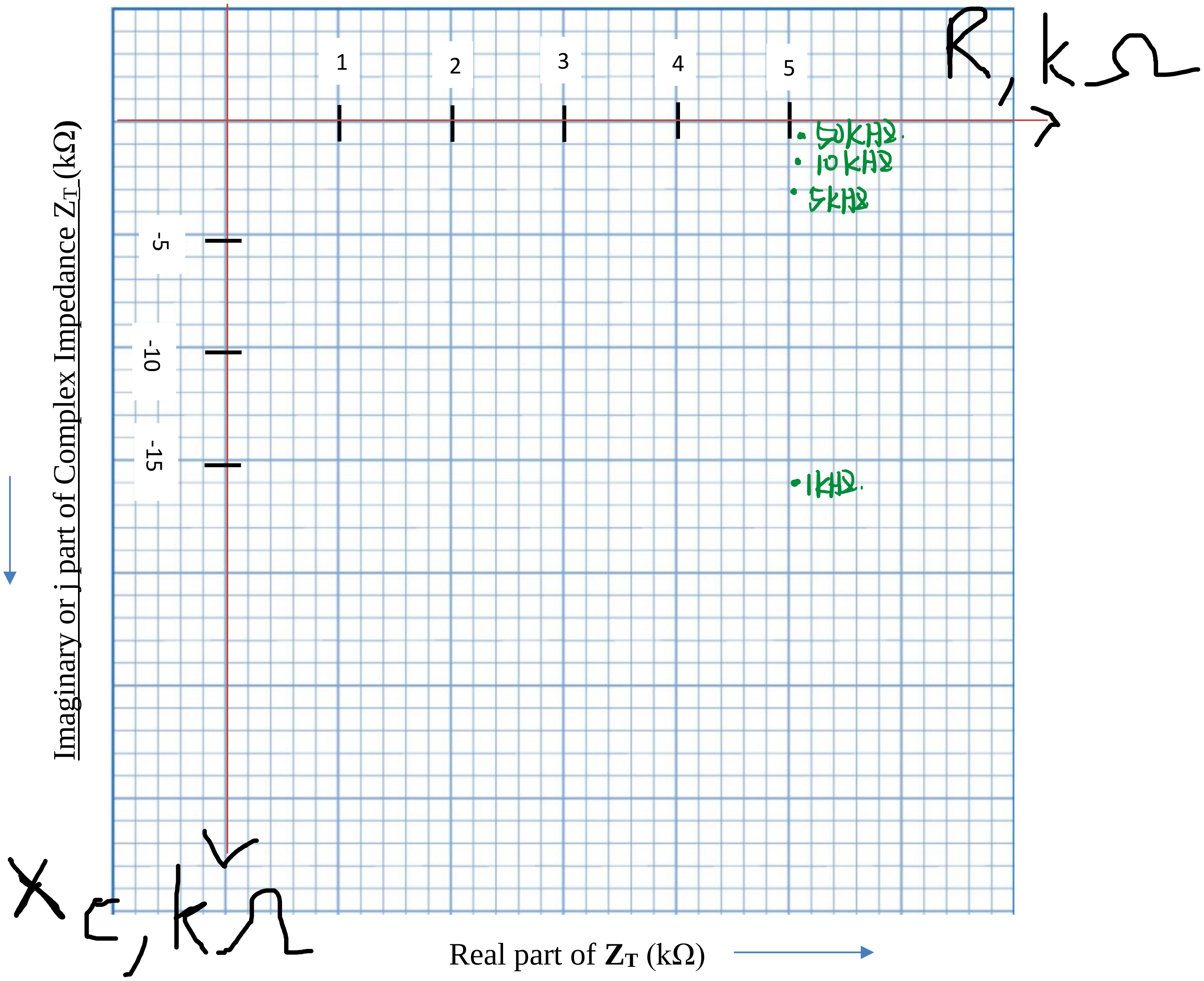
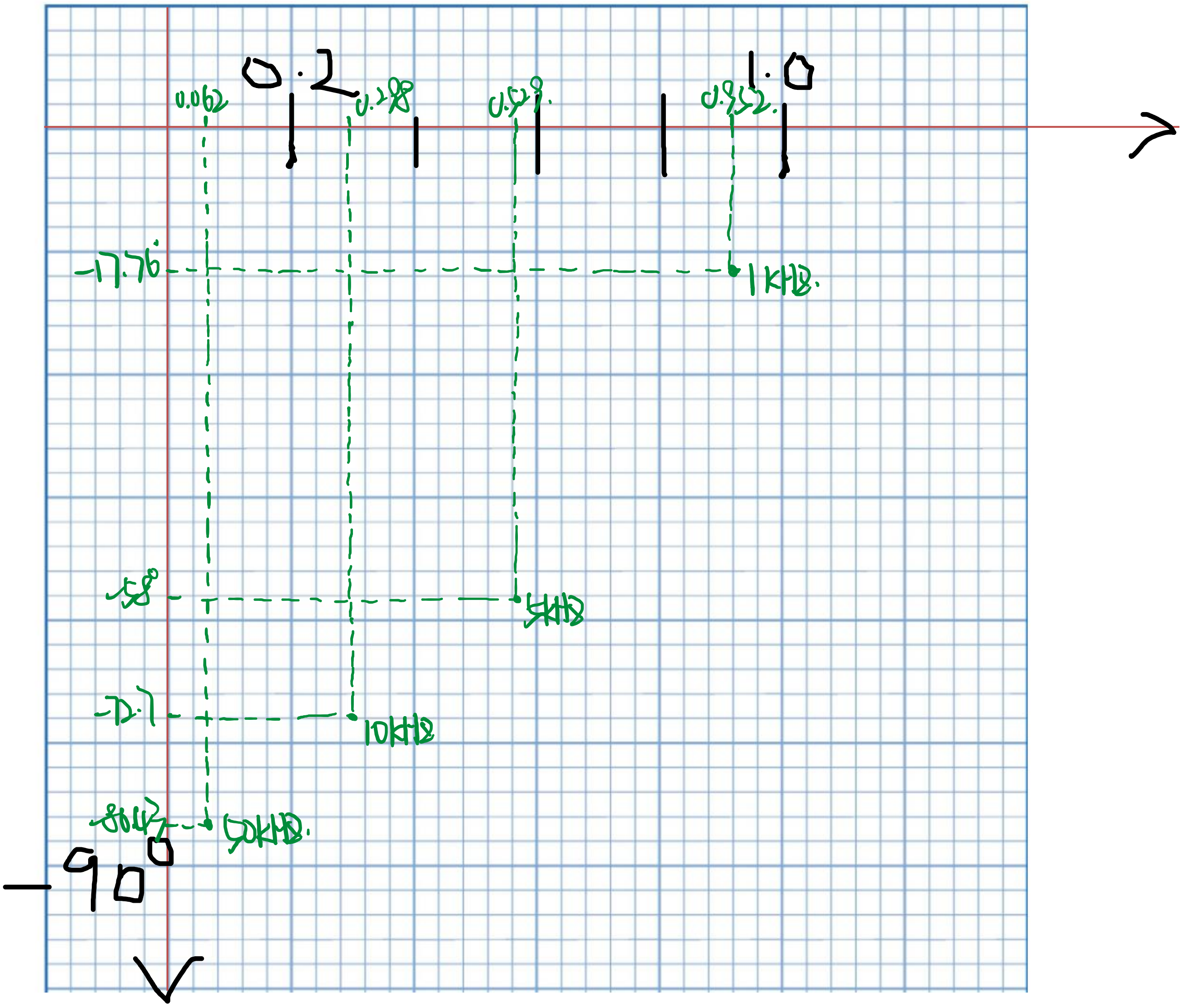
Frequency	1 kHz	5 kHz	10 kHz	50 kHz
$\mathbf{Z_C}$	-15915.49jΩ	-3183.1jΩ	-1591.54jΩ	-318.31jΩ
$\mathbf{Z_{Total}}$	16712.6∠-72.2°Ω	6011.8∠-32°Ω	5342.56∠-17.3°Ω	5109.9∠-3.57°Ω
$\mathbf{Z_C}$ **/** $\mathbf{Z_{Total}}$	0.952∠-17.76°	0.529∠-58°	0.298∠-72.7°	0.062∠-86.43°
$\mathbf{V_{Load}}$ **(calculated)**	0.952∠-17.76°V	0.529∠-58°V	0.298∠-72.7°V	0.062∠-86.43°V
$T_p = 1/f$	1ms	0.2ms	0.1ms	20us
t_x (measured)	58us	34us	19.8us	4.68us
$\underline{/\Phi}_1$	20.88°	61.2°	71.28°	84.24°
$\mathbf{V_{Load}}$ **(measured)**	0.96V	520mV	300mV	63mV

On the Complex Plane of Numbers below, plot the real versus imaginary parts of the total impedances ($Z_T = R - j/\omega C$) for each frequency. Pick an appropriate scale. Note that the real part does not change with frequency, only the imaginary part does. (Note: All units are in kΩ!)



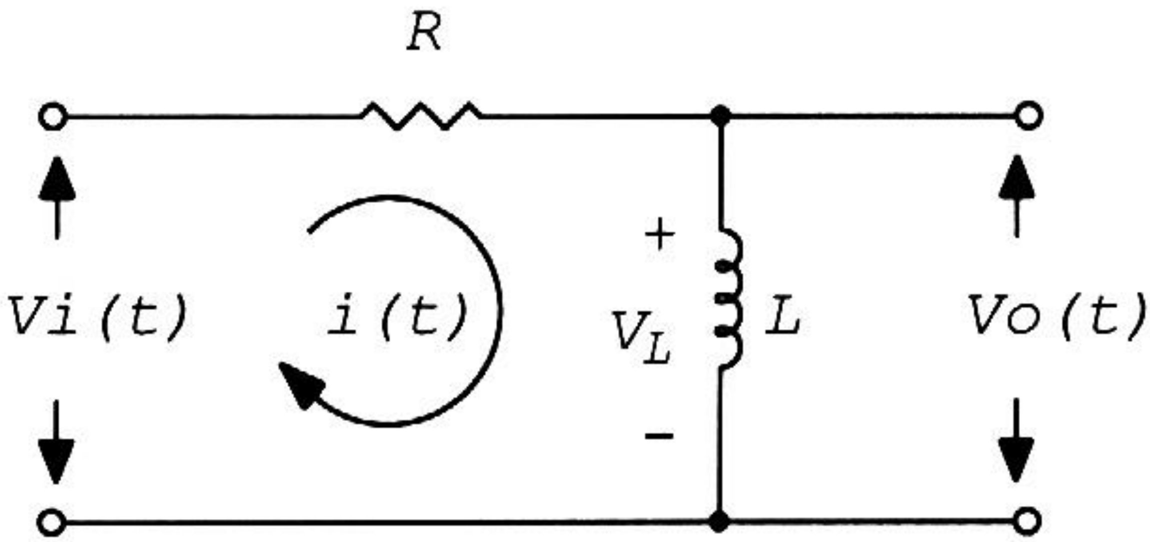
On the Complex Plane of Numbers below, show the output Voltages for each frequency in Polar form (V /_θ_). Note: All units are in Volts!



Polar form of $\mathbf{V_{out}}$(Volts)

B. RL circuit

On the BB put resistor R_2 in series with the **two 4.7 mH inductors in** series to form L = 9.4 mH and apply the FG voltage source, $V_i(t)$, at the input at the in the schematic below.



Put the Channel 1 probe of the Oscilloscope on the output of the FG (red one), with the Osc ground tied to the FG ground (black one).

Adjust the peak-to-peak voltage $v_i(t)$ of the FG to $V_{i(p\text{-}p)}$ = 2 Volts, so $V_{in(Peak)}$ = 1 Volts. and frequency f = 10kHz. (So, T_p = 1/f = 0.1 msec = 100 µsec). Move it on the Osc to have it be a sinewave. Put it into the circuit as shown above.

<u>Note</u>: All AC voltages are <u>with respect to the Osc & FG ground</u>!

Use Channel 2 of the Osc to display and measure <u>peak voltages</u> at the top of the inductor. The Osc can also display both peak voltage values and RMS voltage values. **For this experiment just work with peak voltages.**

For the frequencies listed in the first table below, calculate the inductor impedance, total impedance, and output voltage phasor (magnitude and phase). Also measure, as shown.

$$\omega = 2\pi f$$

$$T_p = 1/f$$

$$\mathbf{Z_L = j\omega L}$$

$$\mathbf{Z_{Total}} = R + \mathbf{j\omega L = Z_T \underline{/\Phi_2}}$$

$$\mathbf{V_{out(Peak)} = V_{in} * [Z_L/Z_{Total}] = V_{out(Peak)}\ \underline{/+\Phi_2}}$$

<u>Note</u>: To find angle $\underline{/-\Phi}_2$ measure each <u>time shift:</u> t_y and T_p ;

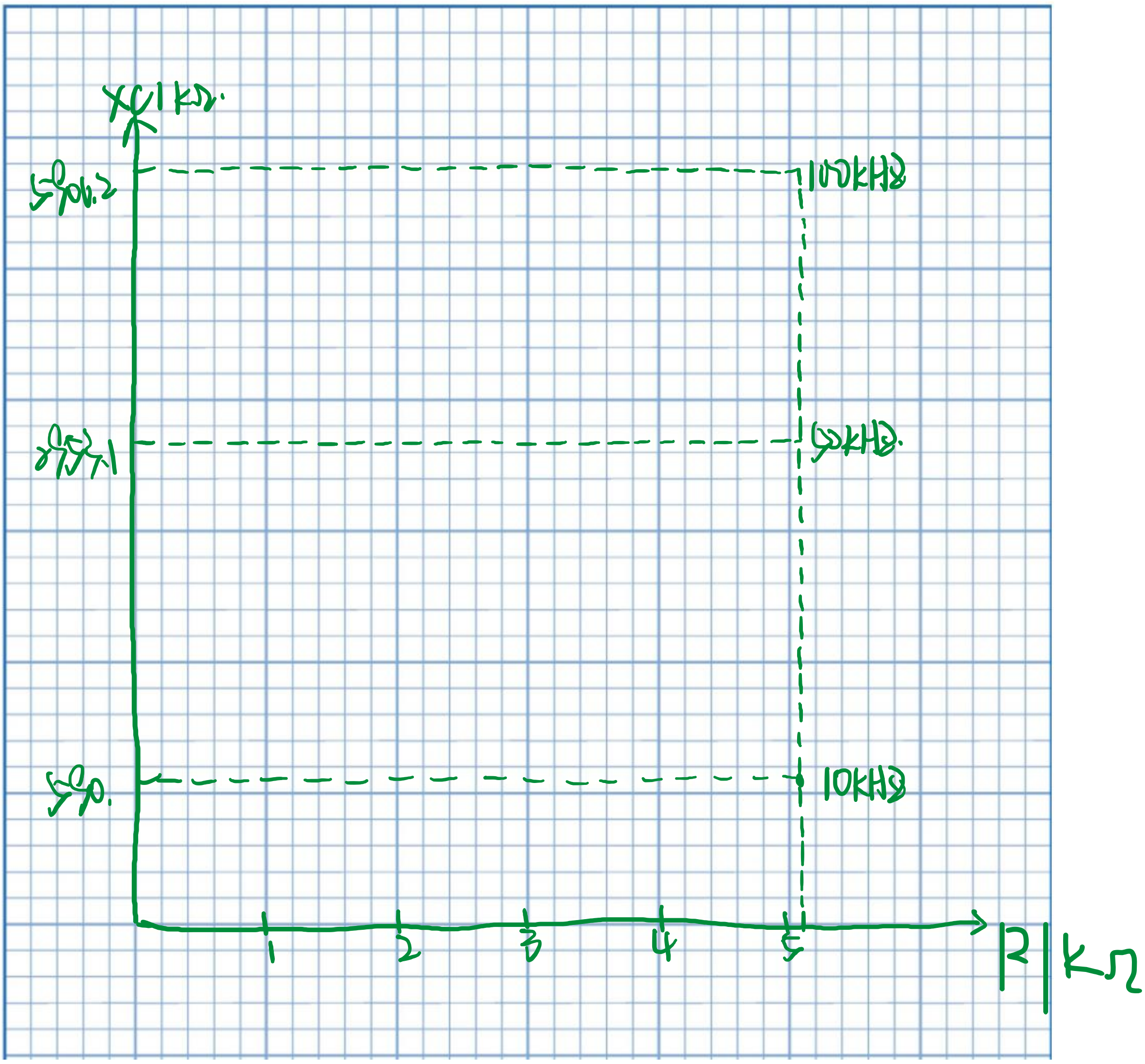
then calculate $\underline{/\Phi}_2 = (t_y/T_p) \times 360^0$

Frequency	10 kHz	50 kHz	100 kHz
Z_L	590.619j Ω	2953.1j Ω	5906.2j Ω
Z_{Total}	5134.1∠6.6°Ω	5893.28∠30.1°Ω	7803.409∠49.19°Ω
Z_L / Z_{Total}	0.115∠83.39°	0.5∠59.93°	0.757∠40.81°
V_{out} (calculated)	0.115∠83.39°V	0.5∠59.93°V	0.757∠40.81°V
T_p	0.1ms	20us	10us
t_y (measured)	19.7us	3.12us	940ns
$\underline{/\Phi}_2$	-70.92°	-56.16°	-33.84°
V_{out} (measured)	104mV	456mV	800mV

On the Complex Plane of Numbers below, plot the real versus imaginary parts of the total impedances ($Z_T = R + j\omega L$) for each frequency. Pick an appropriate scale. Note that the real part does not change with frequency, only the imaginary part does.

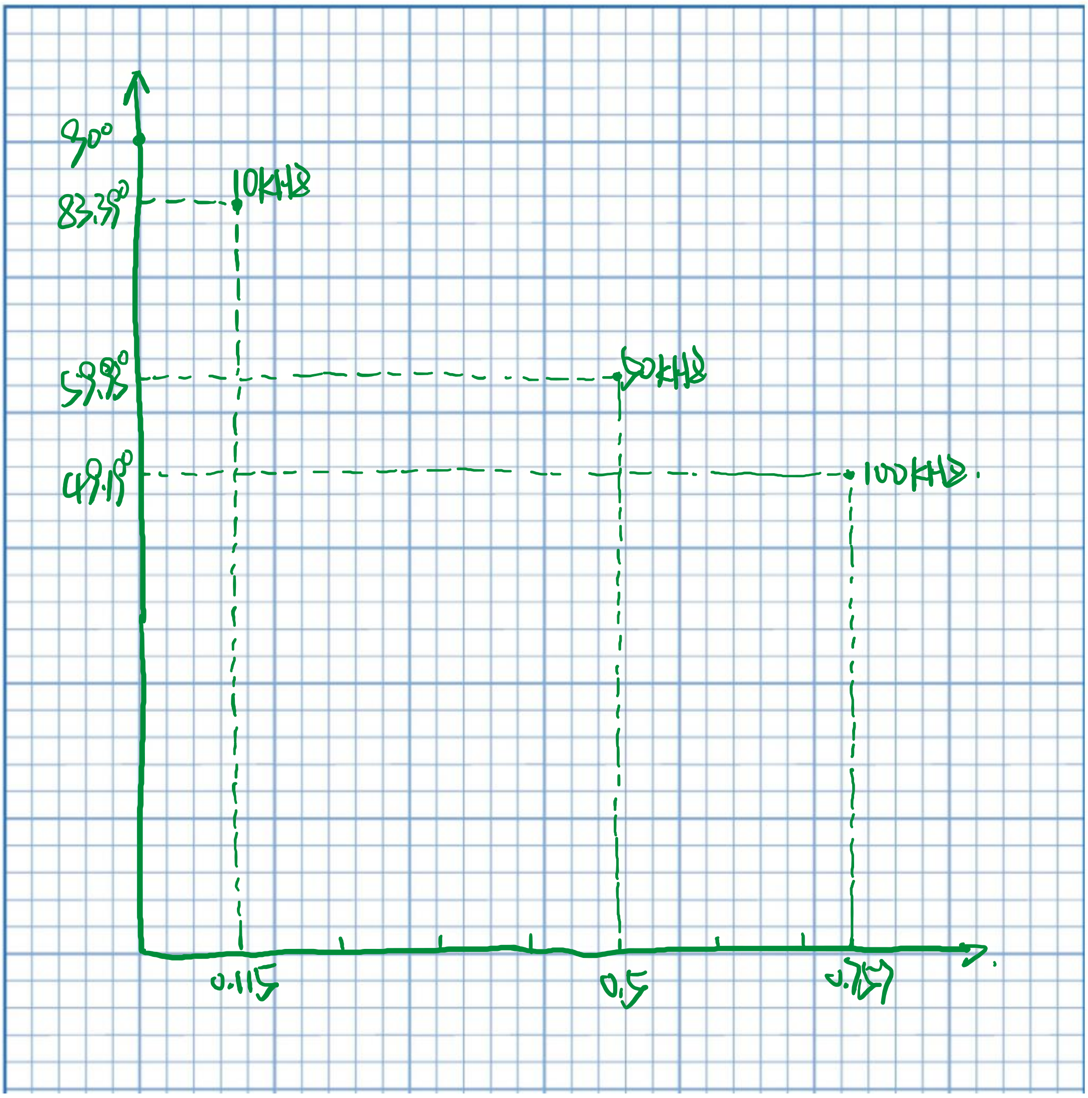
Note: All units are in kΩ!

Imaginary or j part of Complex Impedance Z_T (kΩ)



Real part of $\mathbf{Z_T}$ (kΩ)

On the Complex Plane of Numbers below, show the output Voltages for each frequency in Polar form. Pick an appropriate scale. Note: All units are in Volts!



Polar form of $\mathbf{V_{out}}$ (Volts)

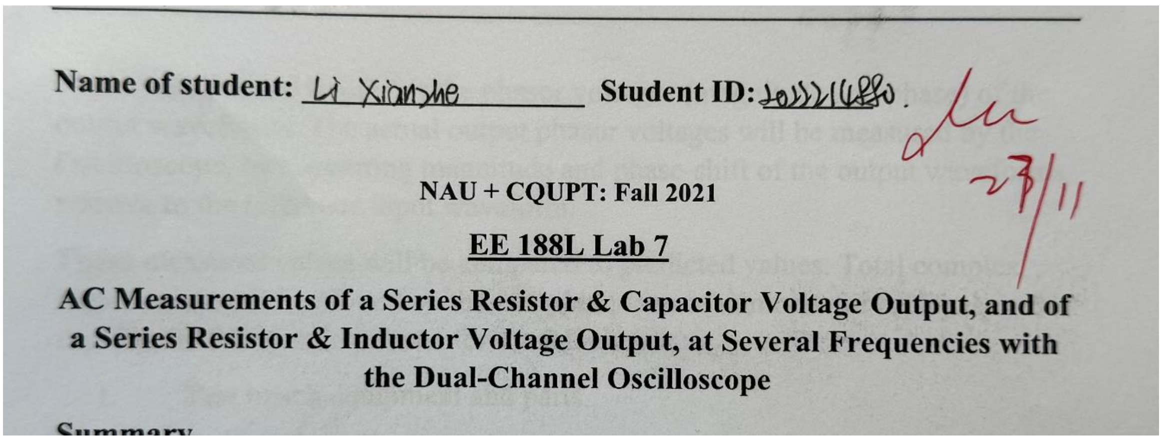
IV. Questions

A. We have been using Ohm's Law for resistors, V = IR. Now that we are including the concept of complex impedance, $\mathbf{Z}\underline{/\varphi_z}$, state Ohm's Law in terms of Phasor Voltages, $\mathbf{V}\underline{/\varphi_v}$, Phasor Current, $\mathbf{I}\underline{/\varphi_i}$ and Complex Impedance, $\mathbf{Z}\underline{/\varphi_z}$.

$$\mathbf{Z}\underline{/\varphi_z} = \mathbf{V}\underline{/\varphi_v} \;/\; \mathbf{I}\underline{/\varphi_i}$$

B. How are the magnitudes of the three related mathematically? How are the phases of the three related mathematically? Explain clearly in your own words.

Z is the ratio of V. For phase, the phase of Z is the phase of V minus the phase of I.



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