Experiment 12
Electrical Measurements: AC Power

Brandon Eidson
Revised by Elizabeth Devore
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Purpose
- Familiarize students with making AC electrical measurements using an oscilloscope
- Reinforce AC principles, such as inductor and capacitor effects on voltage/current angles
- Practice making AC power calculations

Introduction
This lab will require the students to breadboard a variety of AC circuits using the NI ELVIS board and the provided resistor, capacitor, and inductor; make a variety of measurements; and perform an array of calculations.

For each exercise, students will use
- R ≈ 330 Ω
- C ≈ 10 μF
- L ≈ 0.4 H

The provided resistor and capacitor can be directly breadboarded, but our inductor cannot. Use banana cables to connect the inductor to Banana A and Banana B ports as shown in Figure 1. Now the Banana A and Banana B breadboard ports can be used as the two inductor leads (you can refer to Lab 8 if you need additional help working with the banana ports).

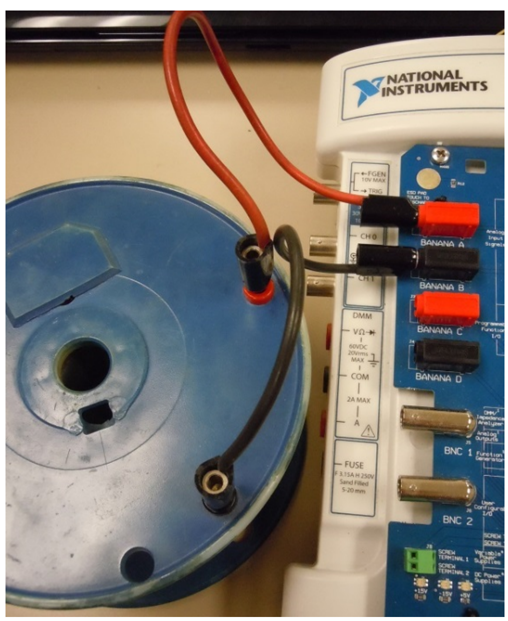

Figure 1: Connecting the Inductor using Banana Ports

NI ELVIS's function generator will serve as every exercise's source voltage, $v_s(t)$. Remember, you will control this through the desktop Instrument Launcher and the source voltage is accessed through the breadboard port pin "FGEN". NI ELVIS's oscilloscope will be the primary means for making measurements in this lab.

Open the o-scope front panel via the Instrument Launcher and make measurements by setting the Channel 0 and Channel 1 sources to two of the AI breadboard ports (AI1, AI2, etc.).

Keeping up with AC notation will be essential in this lab, so a brief review is in order. A steady-state, single frequency, time-domain signal, such as the source voltage for this lab, has the following form:

$$v_S(t) = V_S \cos(\,\omega t \pm \theta_S)$$

Where V_S is the peak value, ω is the frequency (in rad/s), and θ_S is the phase. A phasor version of this voltage can be written as

$$\bar{V}_S = V_S \angle \theta_S$$

IMPORTANT REMINDERS:

- θ_S is usually expressed in degrees due to most individuals' familiarity with the unit, even though ω*t is in radians.
- $\bar{V}_S$ is a vector; V_S is a scalar.
- VERY IMPORTANT: V_S is the notation for either a peak or RMS value. Make sure you are clear by using units of {V} for peak values and {V_{RMS}} for RMS values. For some purposes RMS values are needed (e.g., for calculating AC powers), and, for other purposes, peak values are needed (e.g., for writing time-domain expressions).
- For a single-frequency sinusoid, $V_{RMS} = V_{peak}/\sqrt{2}$
- Speaking of a single waveform's phase is arbitrary, and, therefore, scientifically meaningless. We measure and speak of a phase between two different waveforms. Because of this, we must pick a waveform to be the phase reference. In this lab, use $v_S(t)$'s phase as the reference (i.e., set $\theta_S = 0°$). Therefore, a v(t) or i(t), with reference to $v_S(t)$, will have θ = (±dT*360°)/T.

An impedance, $\bar{Z}$, can be calculated by

$$\bar{Z} = \frac{\bar{V}}{\bar{I}}$$

where the magnitude of V and I can be peak or RMS values. Impedance can be represented as

$$\begin{aligned} Z &= R \pm jX \\ &= Z\angle\theta_Z \end{aligned}$$

where R is resistance and X is reactance. The reactance of an inductor or capacitor can be calculated by

$$\mathrm{j}X_L = j\omega L$$

$$-\mathrm{j}X_C = \frac{-j}{\omega C}$$

respectively. Complex power, $\bar{S}$, can be calculated by

$$S = \bar{V}(\,\bar{\mathrm{I}}\,)^* = VI\angle(\theta v - \theta i)$$

where the magnitudes, V and I, must be RMS values. Complex power can be represented as

$$\begin{aligned} \bar{S} &= P \pm jQ \\ &= S\angle\theta_S \end{aligned}$$

Where P is real power {W}, Q is reactive power {Vars}, and S is apparent power {VA}. Recall that real power is only absorbed by resistance, and reactive power is only absorbed by reactance. Because of this relationship, the following equations can be developed:

$$P_R = I_R^2 R = \frac{V_R^2}{R}$$

$$Q_X = I_X^2 X = \frac{V_X^2}{X}$$

Power factor (expressed as a decimal or percent) is defined as the ratio of real power to apparent power:

$$pf = \frac{P}{S} = \cos(\theta_S) = \cos(\theta_v - \theta_i)$$

We refer to a *lagging* pf if $\theta_i < \theta_v$ and a *leading* pf if $\theta_i > \theta_v$. A pf of 1 (100%) is called *unity*.

Exercises

1) Use your DMM to measure the exact value of R. Record this value in your lab report and, unless otherwise noted, use it (not the theoretical values) for calculations. We do not have means to directly measure L, and, it should be noted, the given value is highly approximate. Unless otherwise specified, **do not** assume L = 0.4 H. Additionally, know that this inductor's resistance, r_L, is not trivial and will have effects on measurements. Some questions in this lab will relate to this fact. Also, unless otherwise specified, **do not** assume C = 10 µF.

2) Setup $v_S(t)$ using the function generator. Set its amplitude to max (10 Vpp). Set the frequency to 60 Hz. Measure $v_S(t)$ using the oscilloscope. Make sure the oscilloscope's Source is changed to the appropriate AI port. The Trigger Type setting will most likely need to be changed to "Edge". With the function generator running and the prototype board turned on, press "Autoscale". Record the oscilloscope's measured value of the frequency and calculate the corresponding period, T (1/f). Include a single screenshot showing both the function generator and oscilloscope front panels.

3) Breadboard the circuit with a series R-C load shown in Figure 2.

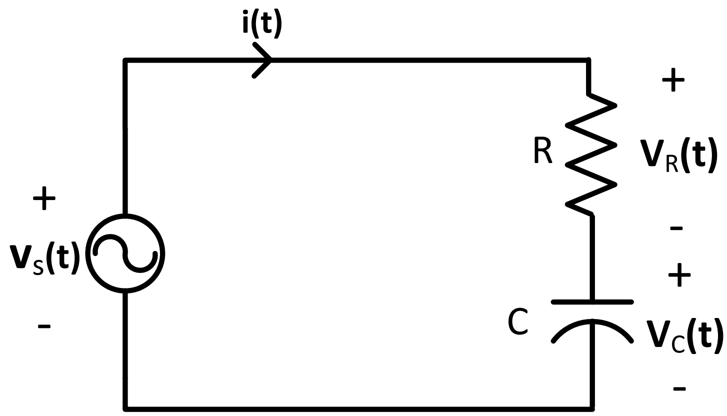

Figure 2: Load = series R-C

Use the oscilloscope to measure and record the following RMS voltages:

- V_S
- V_R
- V_C

You will notice that the peak-to-peak value for $v_S(t)$ is lower than the measurement in Exercise 2. This is expected due to the loading effect. Now use the oscilloscope's cursors to measure and record the time delay between $v_S(t)$ and $v_R(t)$ and the time delay between $v_S(t)$ and $v_C(t)$ (You will need to use both oscilloscope sources and two AI ports to do this). Remembering that the source voltage angle, θ_S is 0°, use these time delays and known period, T, to calculate the phase angles:

- θ_R
- θ_C

Hint: How many degrees are in one period? Be sure to keep up with whether the phase is positive or negative. Make a screenshots of your oscilloscope window with the time delay between $v_S(t)$ and $v_R(t)$ and $v_S(t)$ and $v_C(t)$ being measured. With your measured values, calculate the following:

- the phasor current, $\bar{I}$
- the phase difference between the capacitor voltage, $v_C(t)$, and the current, i(t) — is this value what you would expect? Why or why not?
- the complex power absorbed by the load, $\bar{S}_{Load}$
- the power factor of the load, pf_{Load}
- the series reactance of the load, X
- the value of C

4) Breadboard the circuit with a series R-L load shown in Figure 3.

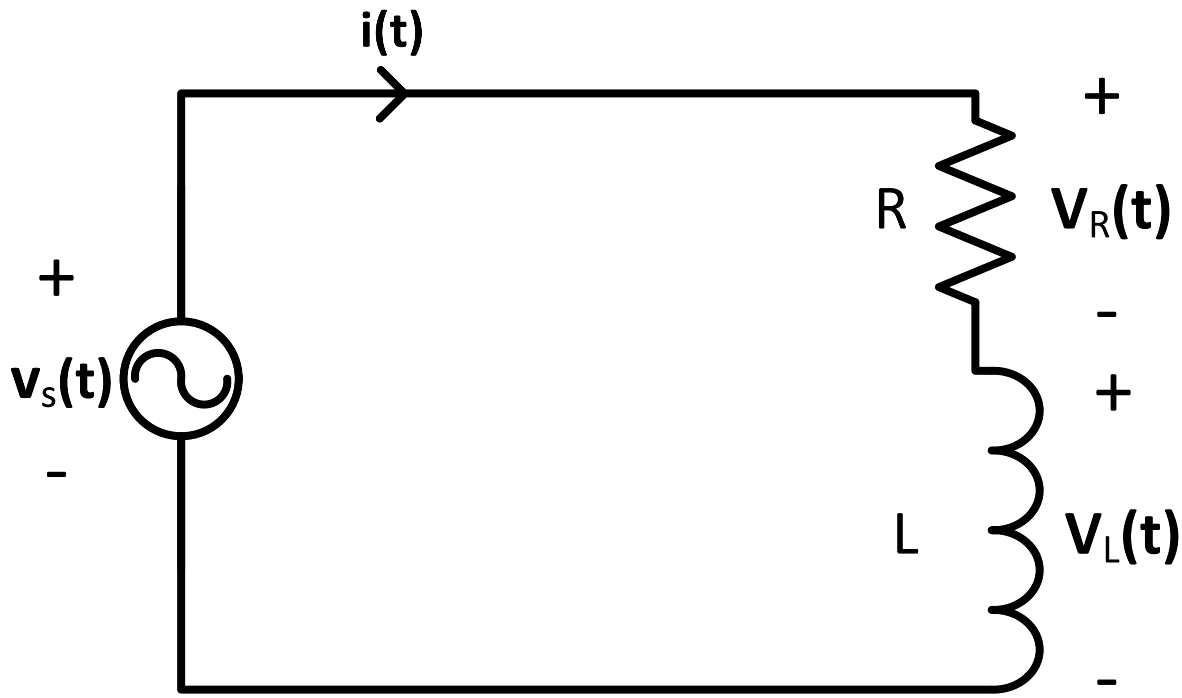

Figure 3: Load = series R-L

Use the oscilloscope to <u>measure and record</u> the following RMS voltages:

- V_S
- V_R
- V_L

<u>Measure and record</u> the time delay between $v_S(t)$ and $v_R(t)$ and the time delay between $v_S(t)$ and $v_L(t)$. Remembering that the source voltage angle, θ_S is 0°, use these time delays and known period, T, to <u>calculate</u> the phase angles:

- θ_R
- θ_L

Make <u>screenshots</u> of your oscilloscope window with the time delay between $v_S(t)$ and $v_R(t)$ and $v_S(t)$ and $v_L(t)$ being measured. With your measured values, <u>calculate</u> the following:

- the phasor current, $\bar{I}$
- the phase difference between the inductor voltage, $v_L(t)$, and the current, i(t) — is this value what you would expect? Why or why not?
- the complex power absorbed by the load, $\bar{S}_{Load}$
- the power factor of the load, pf_{Load}
- the series reactance of the load, X
- the value of L
- the real power absorbed by the resistor, R
- the value of the inductor's equivalent series resistance, r_L

5) Breadboard the circuit with a series R-L-C load shown in Figure 4.

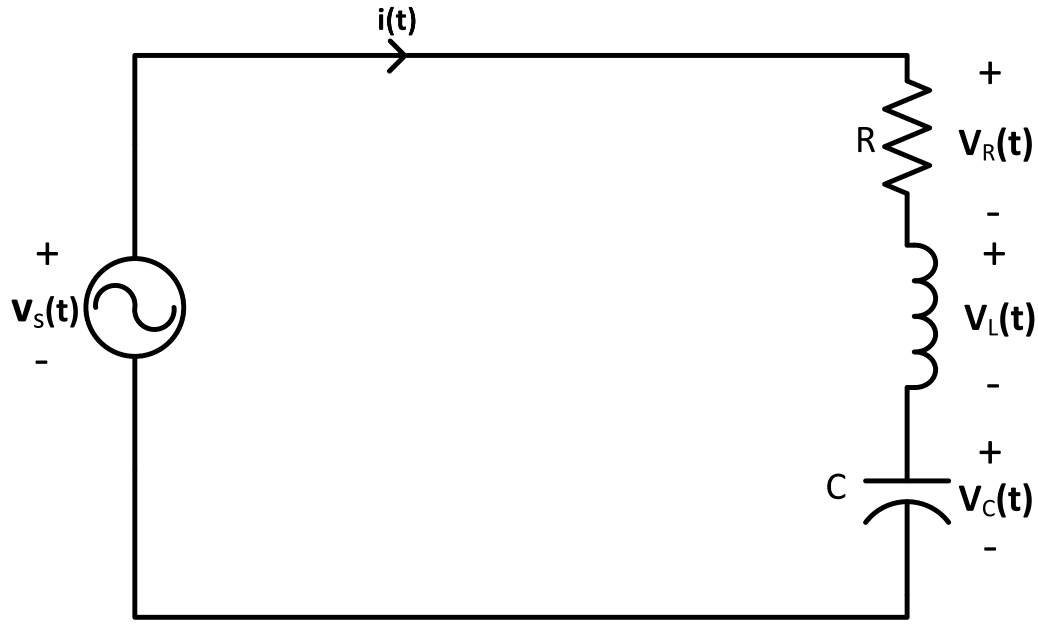

Figure 4: Load = series R-L-C

Use the oscilloscope to <u>measure and record</u> the following RMS voltages:

- V_S
- V_R
- V_L
- V_C

<u>Measure and record</u> the time delay between $v_S(t)$ and $v_R(t)$, the time delay between $v_S(t)$ and $v_L(t)$, and the time delay between $v_S(t)$ and $v_C(t)$. Remembering that the source voltage angle, θ_S is 0°, use these time delays and known period, T, to <u>calculate</u> the phase angles:

- θ_R
- θ_L
- θ_C

Make <u>screenshots</u> of your oscilloscope window with the time delay between $v_S(t)$ and $v_R(t)$, $v_S(t)$ and $v_L(t)$, and $v_S(t)$ and $v_C(t)$ being measured. With your measured values, <u>calculate</u> the following:

- the phasor current, $\bar{I}$
- the complex power absorbed by the load, $\bar{S}_{Load}$
- the power factor of the load, pf_{Load}
- the complex power absorbed individually by R, L, and C – confirm their real and reactive powers add to the total real and reactive load powers, $\bar{S}_{Load} = \bar{S}_R + \bar{S}_L + \bar{S}_C$ (Remember, your inductor and capacitor are non-ideal so they will have some real power absorbed, especially the inductor.)
- the equivalent series load impedance, $\bar{Z}$

<u>Write</u> the full expressions for

- $v_S(t)$
- $v_R(t)$
- $v_L(t)$
- $v_C(t)$
- i(t)

6) Breadboard the circuit with a series R-L with parallel C load shown in Figure 5.

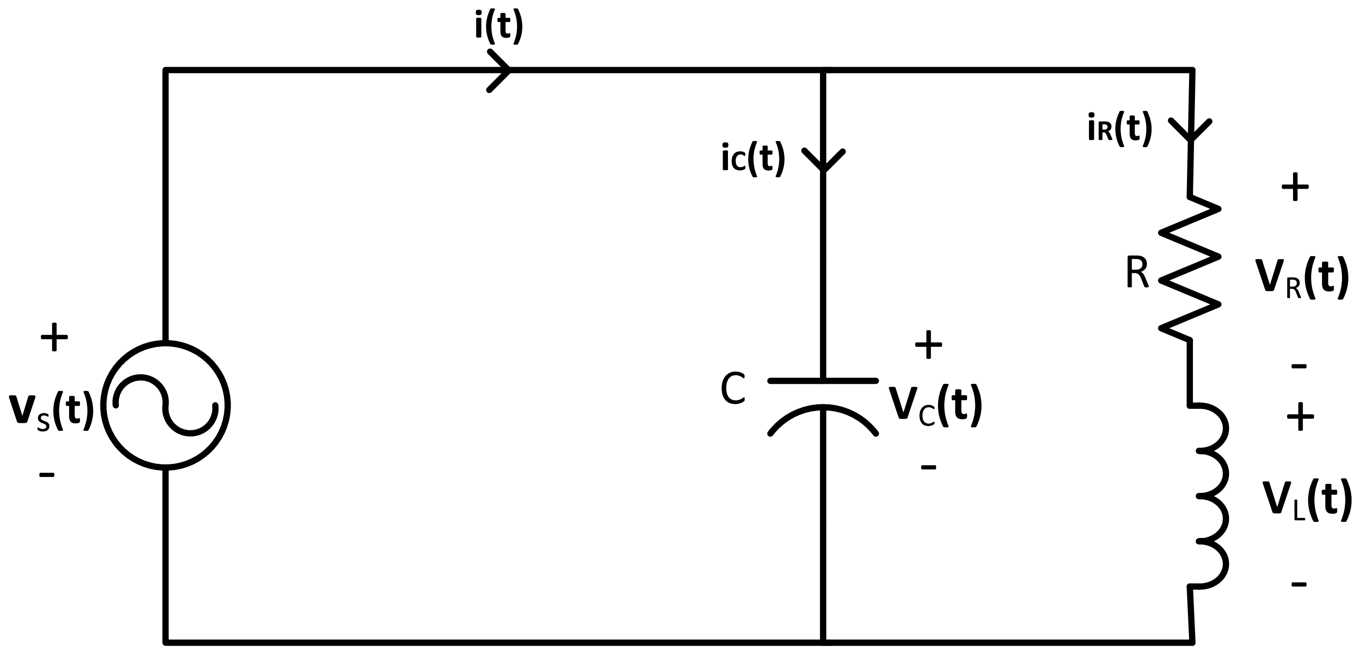

Figure 5: Load = series R-L in parallel with C

Use the oscilloscope to <u>measure and record</u> the following RMS voltages:

- V_S
- V_R
- V_L

<u>Measure and record</u> the time delay between $v_S(t)$ and $v_R(t)$, the time delay between $v_S(t)$ and $v_L(t)$, and the time delay between $v_S(t)$ and $v_C(t)$. Remembering that the source voltage angle, θ_S is 0°, use these time delays and known period, T, to <u>calculate</u> the phase angles:

- θ_R
- θ_L
- θ_C

Make <u>screenshots</u> of your oscilloscope window with the time delay between $v_S(t)$ and $v_R(t)$ and $v_S(t)$ and $v_L(t)$, being measured. With your measured values, <u>calculate</u> the following:

- the phasor currents, $\bar{I}_R$ and $\bar{I}_C$ (assume C = 10 μF)
- the complex power absorbed by the C branch, $\bar{S}_C$, and the R-L branch, $\bar{S}_{RL}$
- the phasor current, $\bar{I}$
- the total complex power absorbed by the load, $\bar{S}_{Load}$
- the power factor of the load, pf_{Load} – To obtain a unity power factor (pf_{Load} = 1), should the parallel capacitor be increased or decreased? How do you know? It might be helpful to compare this power factor to the power factor calculated in Exercise 4 (series R-L). Consider the Q "absorbed" by a capacitor.
- the equivalent <u>series</u> load impedance, $\bar{Z}$