EE2111A Activity Sheet - Week 4, Studio 2

Start	Duration	Activity
0:10	30 mins	Briefing
0:40	100 mins	Activity #1:
		Phase-shift between voltage and current in
		(a) series R-R circuit
		(b) series L-R circuit
		(c) series C-R circuit
		Activity #2:
		Frequency dependence of AC circuit
2:20	15 mins	Debriefing

Group size: Individual activity

Learning Objectives

To be able

- to measure phase shift using oscilloscope,
- to explain the concept of lead and lag, and
- to explain frequency dependence of the response in ac circuits.

Equipment and components

1. Oscilloscope
2. Signal generator
3. Breadboard
4. Components: 120 Ω and 100 Ω resistor, 1 mH inductor, and 0.1 μF capacitor.

Internal connection of oscilloscope channel grounds

Read this section carefully before doing the activities.

The ground wires (black probes) of CH1 and CH2 are internally connected. So, if these are connected to two different points of a circuit, those points get shorted. Because of this, we cannot observe in CH2 the voltage

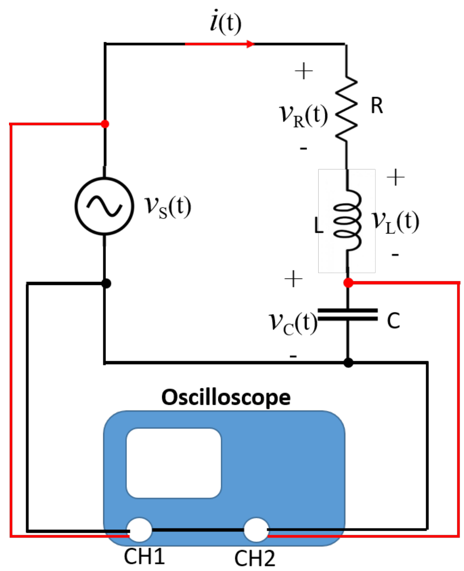


Figure 1: Ground wires (black) of CH1 and CH2 two of an oscilloscope are connected internally. User must be mindful of this fact while using both channels simultaneously.

across any component that is not connected to the node where we connect the GND of CH1. For the circuit shown above, one can observe $v_S(t)$ and $v_c(t)$ on two channels. However, it is not possible to see v_R or v_L using CH2 if $v_S(t)$ is connected to CH1. To observe the voltages across the inductor or the resistor, its position must be swapped with the capacitor's position.

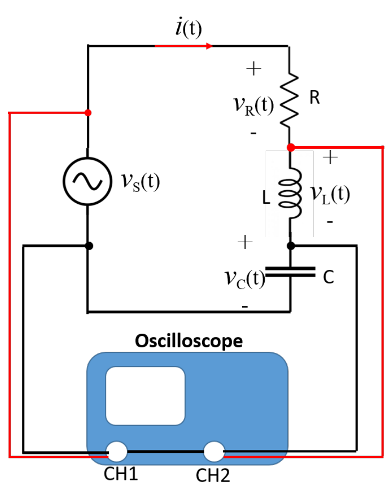
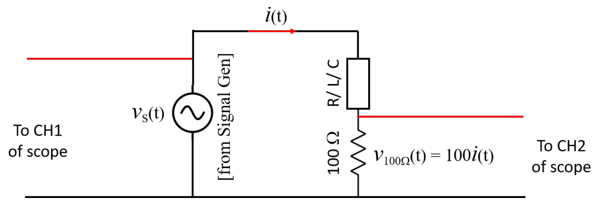


Figure 2: In this case, the inductor voltage of an RL circuit (not RLC) is displayed in CH2. The capacitor is shorted.

Activity #1: Phase shift between voltage and current



- Build the circuit shown above on the breadboard with 120 Ω resistor in place of the rectangular box.
- The 100 Ω resistor is used to observe the current waveform indirectly.

$$i(t) = \frac{v_{100\Omega}(t)}{100\ \Omega}.$$

Oscilloscope displays voltage signal as a function of time. One cannot observe current waveform directly using the scope probe. However, the current through a resistor is in-phase with the voltage across it, and its amplitude is equal to the amplitude of voltage divided by the resistance value. So, the observed voltage across a resistor is an amplitude-scaled version of the resistor current.

- Apply 10 kHz sinusoidal waveform (generated by the signal generator) to the circuit.
- Observe the input voltage and the voltage across the 100 Ω resistor in two channels of the oscilloscope.
- Measurements:

  i Measure the amplitude of the input voltage,

  ii Measure the amplitude of the voltage across the 100 Ω resistor & then calculate the amplitude of the current waveform, and

  iii Measure the phase-shift of $v_{100\ \Omega}$ with respect to the input voltage. This is effectively the phase-shift of current with respect to the input voltage.

- Repeat these measurements for

  a 1 mH inductor, and

  b 0.1 μF capacitor

  in place of the rectangular box in the schematic.

E-logbook:

At the least the following must be included in the eLogbook.

- Images of the oscilloscope screen with display of both channels ON for all three cases, and
- Measurement results in the form shown in Table 1.

	R-R circuit	C-R circuit	C-R circuit
Amplitude of V_S			
Amplitude of $V_{100\Omega}$			
Amplitude of $i(t)$			
Phase of i w.r.t. v_S			
Current leads or lags?			

Table 1: Results of the hands-on activity

Activity #2: Frequency dependence of AC circuit

The response of an AC circuit to the applied voltage depends on the frequency of the source voltage. The same circuit will draw different magnitude of current if the source frequency is changed though the source amplitude is kept fixed. You will verify that using a series RLC driven by a sinusoidal voltage source by measuring the amplitude of the current at different frequencies of the source voltage while keeping the amplitude of the source voltage unchanged, *i. e.*,

$$v_S(t) = A\sin(\omega_m t), \quad m = 1, 2, 3, \cdots$$

Resonance in series RLC

Let the current in a series RLC be

$$i(t) = I_m \sin(\omega t).$$

Then the voltage across the inductor (L) and the capacitor (C), respectively, are

$$v_L(t) = \omega L I_m \sin(\omega t + \frac{\pi}{2})$$

and

$$v_C(t) = \frac{I_m}{\omega C}\sin(\omega t - \frac{\pi}{2}).$$

- v_C and v_L are π radian (180°) out of phase.
- At a particular frequency (ω_r), the amplitudes of v_C and v_L are equal:

  $$\omega_r L I_m = \frac{I_m}{\omega_r C}.$$

  The series RLC is said to be in *resonance* at this frequency

  $$\omega_r = \frac{1}{\sqrt{LC}} \quad rad/s.$$

- At resonance, the amplitude of v_C is equal to the amplitude of v_L, and they are π rad out of phase. So, $v_C(t) + v_L(t) = 0$ and the voltage across the resistor is

  $$v_R(t) = v_S(t) - (v_C(t) + v_L(t)) = v_S(t).$$

  So, for a given amplitude of the source voltage, the amplitude of the current is maximum at the resonant frequency.

Things to do:

1. Patch up a series RLC circuit on the breadboard using $R = 100\ \Omega$, $L = 1$ mH, and $C = 0.1\ \mu$F.
2. Calculate the resonant frequency ω_r.
3. Use the signal generator to apply a sinusoidal signal across the series RLC.
4. Keeping the amplitude of the signal unchanged, vary its frequency and measure the amplitude of the current at each frequency. Take measurements at ω_r, few frequencies lower than ω_r, and a few frequencies higher than ω_r.
5. Plot using Excel or any other software a graph of the amplitude of the current as a function of frequency.

E-Logbook:

The e-Logbook must include at the least the following.

- Calculated value of ω_r
- Table showing the measurement data
- Graph of the amplitude of current versus frequency
- The value of ω_r obtained from the graph
- If the experimentally obtained value of ω_r differs from the theoretical value, state the reason(s) for the discrepancy.