

## LC Resonant Circuits

### INVESTIGATE THE RESONANCE RESPONSE OF A SERIES LC RESONANT CIRCUIT

- Record an amplitude resonance curve for a series LC resonant circuit with various degrees of damping.
- Determine the resonant frequency of the series LC resonant circuit.

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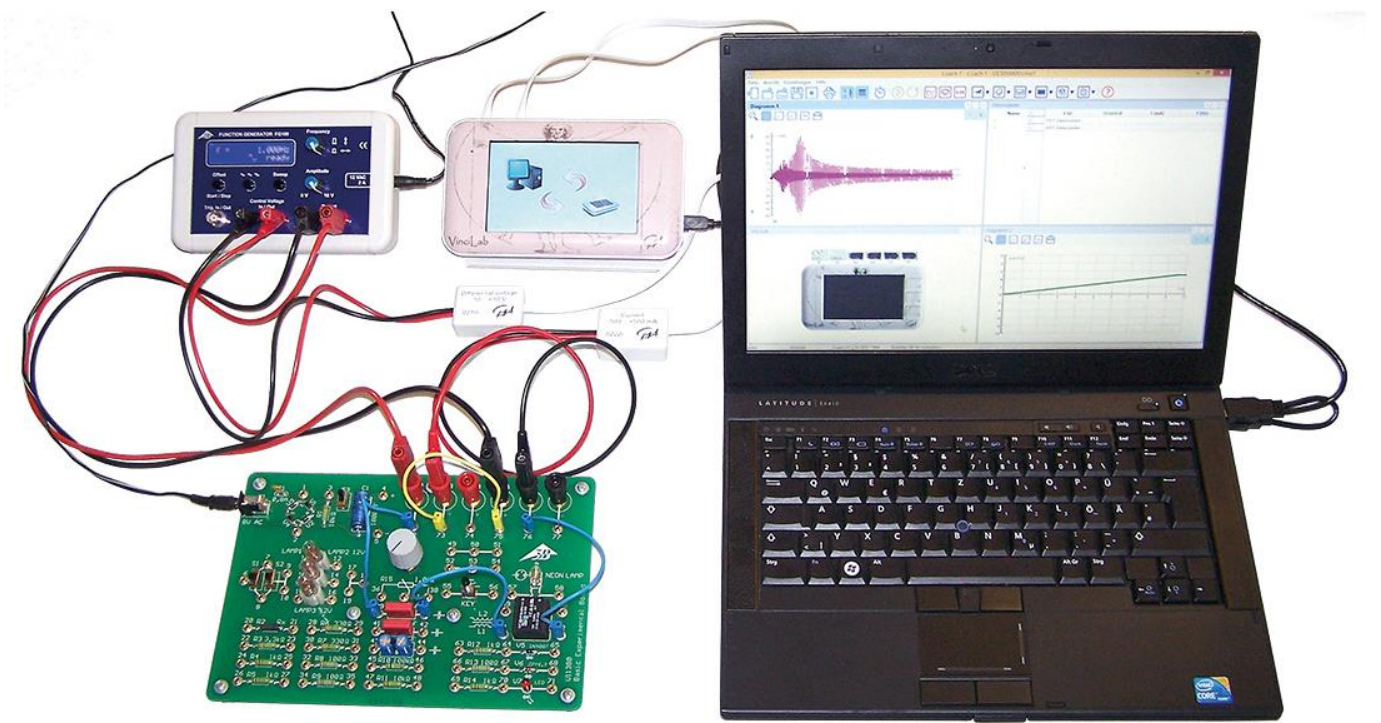


Fig. 1: Experiment set-up

### GENERAL PRINCIPLES

An electric resonant circuit is a circuit consisting of an inductor with inductance  $L$  and a capacitor with capacitance  $C$ . The periodic transfer of energy between the magnetic field of the coil and the electric field of the capacitor results in oscillation of the electric circuit. This transfer results in alternating instances where there is maximum current through the coil or maximum voltage across the capacitor.

If the resonant circuit is not oscillating freely, but is excited by an external sine-wave signal, it oscillates at the same frequency as the excitation signal and the amplitude of the current and voltage across the individual components are dependent

on the frequency. The current  $I$  can be deduced from Ohm's law as follows:

$$(1) \quad I = \frac{U}{Z} = \frac{U_0 \cdot e^{i\omega t}}{Z}$$

$U$ : sinusoidal input voltage

$U_0$ : amplitude,  $\omega$ : angular frequency

$Z$ : total impedance

In a series circuit, the total impedance is made up of the sum of the impedances of the individual components. In addition there is an ohmic resistance  $R$ , which covers the losses which inevitably occur in a real resonant circuit and which may also have any external resistance  $R_{ext}$  added to it. The following expression therefore arises:

$$(2) \quad Z = R + i\omega L + \frac{1}{i\omega C}$$

From equation (1) and (2) the current is given by

$$(3) \quad I(\omega) = \frac{U_0 \cdot e^{i\omega t}}{R + i\left(\omega L - \frac{1}{\omega C}\right)}$$

The magnitude of the current corresponds to its amplitude, which is frequency-dependent:

$$(4) \quad I_0(\omega) = \frac{U_0}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

This reaches its maximum value at the resonant frequency

$$(5) \quad f_r = \frac{\omega_r}{2\pi} = \frac{1}{2\pi \cdot \sqrt{L \cdot C}}$$

At that point, its magnitude is

$$(6) \quad I_0(\omega_r) = \frac{U_0}{R}$$

Therefore, in the case of resonance, the resonant circuit behaves as if it consisted solely of an ohmic resistance. In particular, an inductor and capacitor and capacitor connected in series act as if they were a short circuit when resonance is occurring.

This experiment involves an AC voltage generated by a function generator being used to excite the tuned circuit. The current  $I$  is measured as a function of the frequency  $f$  while the amplitude of the voltage remains constant. The current is measured using a measuring interface and recorded by means of measurement and evaluation software which allows it to be displayed graphically. The amplitude resonance curve of the current, i.e. the way the amplitude of the current depends on the frequency, is recorded automatically.

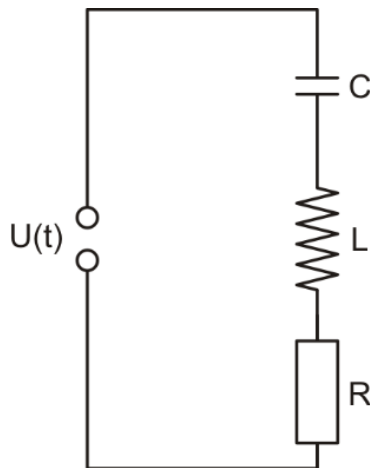


Fig. 2: Circuit diagram sketch for series LC resonant circuit.

## LIST OF EQUIPMENT

1	Basic Experiment Board @230V	1000573 (U11380-230)
or	@115V	1000572 (U11380-115)
1	Function Generator FG 100 @230V	1009957 (U8533600-230)
or	@115V	1009956 (U8533600-115)
1	Set of 15 Experiment Leads 1 mm <sup>2</sup> , 75 cm	1002840 (U13800)
1	VinciLab	1021477 (UCMA-001)
1	Coach 7, School Site License 5 Years	1021522 (UCMA-18500)
or	Coach 7, University License 5 Years	1021524 (UCMA-185U)
2	Voltage Sensor 10 V, Differential	1021680 (UCMA-0210i)
1	Current Sensor 500 mA	1021679 (UCMA-0222i)

## SET-UP AND CONFIGURATION

### Wiring

- Connect the following terminals together:
  - FG 100 Control Voltage OUT → Voltage sensor → VinciLab A1
  - FG 100 Output → Board X2, X5
  - Board X3, X6 → Current sensor → VinciLab A2
  - Board 72 ↔ 39
  - Board 40 ↔ 61
  - Board 62 ↔ 76
  - Board 75 ↔ 73



### Function generator FG 100

- Select a sinusoidal signal form (Sine).
  - Turn the amplitude knob clockwise as far as it will go, i.e.  $U_0 = 10 \text{ V}$ .
  - Press the "Sweep" button and configure the function generator as follows:
    - Start: 1 Hz
    - Stop: 1000 Hz
    - Mode: int. single
    - Time: 10.00 sec
- "ready" will be shown on the display.


The FG 100 function generator is now fully configured for the measurement.

### VinciLab and Coach 7

- Install Coach 7 software on the computer you will be using for the measurement.
- Connect the VinciLab module to the computer with the help of the USB cable.

- Start VinciLab and Coach 7. Press the  button in Coach 7 and select the "User level: Author" from the drop-down menu in the "Log-in" window which opens. Enter the password for " Author key " and confirm it with OK.
- Click the  button. The "Activity Options" window will open. Confirm the pre-selected settings, "Activity type: Measurement" and "Interface: VinciLab" by clicking OK.

The software will establish a connection to VinciLab. A graphic representing the VinciLab module with pictograms of the connected sensors will appear in the bottom left of the four windows.

- Click the  button, enter the following parameters and then confirm with OK:

**Method**

Type: Time-based  
 Measuring time: 10 seconds  
 Frequency: 200 per second  
 Number of samples: 2000

**Triggering**

Trigger channel: A2: Current sensor  
 Trigger level: 0.4 mA  
 Direction: up  
 Pre-trigger time: 0 seconds


- Click the  button.

The data table will appear in the top right window. It will have columns for time *t*, voltage *U* and current *I*, all initially empty.

- Click the spanner in the title bar of the window with the data table. Select "Add a New Variable", "into Data Series" and "Formula" from the menu which opens. In the window which opens then, enter the following parameters under "Variables Properties":  
 Label: f  
 Unit: Hz  
 Formula: V/0.005

When the control voltage is switched through as the output ("Out") the function generator generates a ramped voltage of 0 – 5 V, corresponding to a voltage of 0.005 V/Hz for the selected frequency range, 1 – 1000 Hz.

Another, fourth column appears in the data table for the frequency *f*.

- Click the  button. In the menu which opens select "Add new ...", then move the mouse cursor to the top left window and click on it.


The window will then display a graph (initially blank)

- Click the voltage symbol "V(mV)" in the header for the second column of the data table and, keeping the mouse button held down, drag it to the active axis region for the left of the plot, then click on the border when it lights up blue. Click the frequency symbol in the header for the fourth column of the data table and, again keeping the mouse button down, drag it to the active axis region for the bottom of the plot, then click on the border when it lights up blue.

This assigns the x-axis of the trace to be the axis for frequency and the y-axis to be the axis for current.

VinciLab and Coach 7 are now fully configured for the measurement.

**EXPERIMENT PROCEDURE**


- Start the measurement in Coach 7 by clicking the  button. A "Waiting for trigger event" window opens.
- Press the "Start" button for the FG 100. As soon as the trigger threshold is passed, the frequency scan starts automatically. The recorded measurements are shown on the trace plot in Coach 7.

Since we are measuring direct current, the values for both polarities are shown. The resonance curve corresponds to the envelope for the values in the positive quadrant.

- Carry out the same measurement but using coil L2 (terminals 59 and 60 instead of 61 and 62 on the basic experiment board).

**SAMPLE MEASUREMENT AND EVALUATION**

Fig. 3 shows the resonance amplitude curves of the current through coils L1 and L2 on the basic experiment board and  $R_{ext} = 0$ . As expected, the resonant frequency  $f_r$  coincides with the maximum amplitude of the current  $I_0$ .

- Click the  button in Coach 7 and open "Select/Remove Data" from the menu which opens. In the window which opens then select "Selection method: Point by point". Red cross hairs will then appear.
- Move the cross hairs to the maximum and make a note of the resonant frequency and corresponding current:

$$(7) \quad \begin{aligned} f_r &= \begin{cases} 178 \text{ Hz} & (\text{Coil L1}) \\ 88 \text{ Hz} & (\text{Coil L2}) \end{cases} \\ I_0(f_r) &= \begin{cases} 59 \text{ mA} & (\text{Coil L1}) \\ 24 \text{ mA} & (\text{Coil L2}) \end{cases} \end{aligned}$$

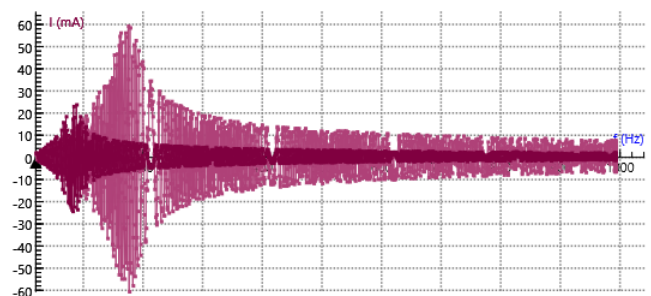


Fig. 3: Resonance amplitude curve for current through coils L1 and L2 and  $R_{ext} = 0$ . Screenshot from Coach 7.

Calculate the unknown inductance values *L* from the known capacitance  $C = 2.2 \mu\text{F}$  using equation (5):

$$(8) \quad L = \frac{1}{4\pi^2 \cdot f_r^2 \cdot C} = \begin{cases} 363 \text{ mH} & (\text{Coil L1}) \\ 1487 \text{ mH} & (\text{Coil L2}) \end{cases}$$

Calculate the ohmic resistance values *R* from the maximum amplitudes of the resonance curve using equation (6) ( $U_0 = 10 \text{ V}$ ):

$$(9) \quad R = \frac{U_0}{I_0(f_r)} = \begin{cases} 169 \Omega & (\text{Coil L1}) \\ 417 \Omega & (\text{Coil L2}) \end{cases}$$

Since no external resistance  $R_{ext}$  is in the circuit, *R* corresponds to ohmic resistance losses which arise in a real resonant circuit.