Electrical engineering lab

Master in Energy Science and Technology

Master 1st semester

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(Document original source from Roberto Zoia/EPFL)

LABORATORY

CAPACITOR AND INDUCTOR IN SINUSOIDAL MODE

A. OBJECTIVES

- Study of capacitor and inductor in sinusoidal mode
- Demonstration of the influence of frequency

B. LAB

An electrical circuit is said to be in sinusoidal mode when the external excitations (currents or voltages) are sinusoidal functions.

The sinusoidal function plays a role of primary importance in electricity.

This predominance is linked to the fact that the production of electrical energy generally results from the use of electrical generators whose output voltages are sinusoidal.

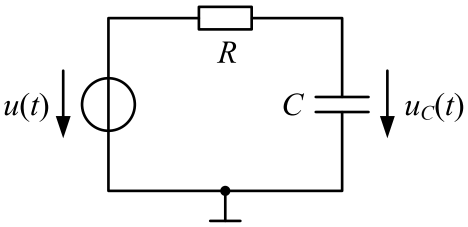
The analysis of the sinusoidal mode is simplified by the use of complex calculation which makes it possible to replace integro-differential relations by algebraic operations.

For the preparation of the session, consult the document

"TP d'électrotechnique – Laboratoire sans fautes"

1. <u>Capacitor in sinusoidal mode</u>

Circuit diagram :



$u(t) = \hat{U}\sin(2\pi f t)$ (HMF2525)

$R = 10\ \mathrm{k\Omega}$

$C = 10\ \mathrm{nF}$

The voltage $u(t)$ provided by the function generator **HMF2525** is a sinusoidal signal of frequency $f = 1\ \mathrm{kHz}$ and amplitude $\hat{U} = 10\ \mathrm{V}$.

Indicate which configuration should be chosen for the function generator:

Function	 ☐ ☐ ☐ ☐ ☐
Frequency	
Amplitude	
Offset	

Which button should be activated to correctly deliver the signal ?

- ☐ **OFFSET**
- ☐ **INVERT**
- ☐ **OUTPUT**

1.1. Observation of voltages $u(t)$ and $u_C(t)$

Visualize the voltages $u(t)$ and $u_C(t)$ on the oscilloscope.

Use the following configuration :

Canal 1 (CH1)	$u(t)$		
Canal 2 (CH2)	$u_C(t)$		
Time Base	$200\ \mu\mathrm{s}$		
Trigger	SOURCE : $u(t)$ (Canal 1)	LEVEL : $0\ \mathrm{V}$	SLOPE : Rising Edge

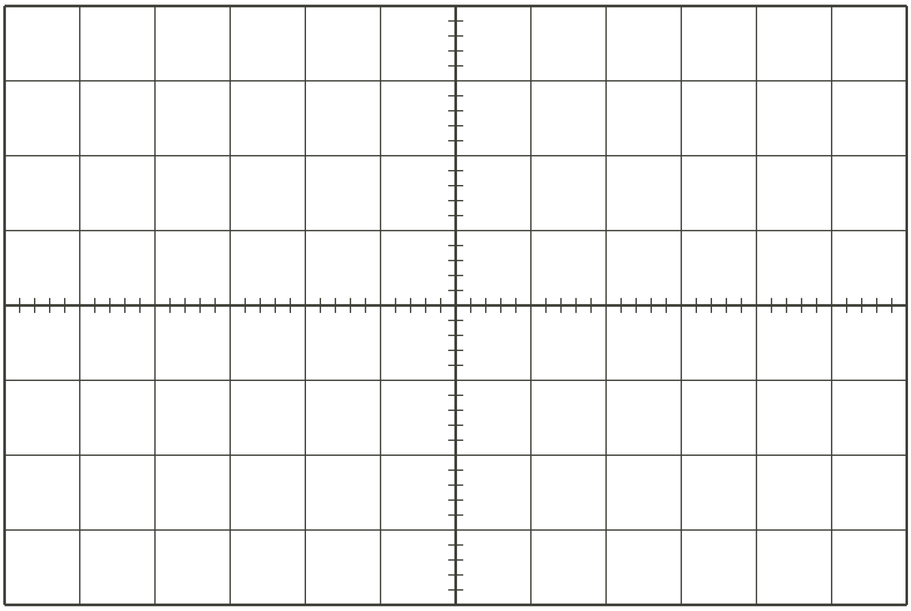
Which coupling should be used for the **two** channels in order to visualize the two curves correctly ?

- ☐ AC
- ☐ DC
- ☐ AC ou DC

Superpose the **GND** of the two curves.

⚠	Choose the position of the two curves and their voltage ranges in order to make maximum use of the size of the oscilloscope screen and increase the precision of the calculations.

Reproduce the signals observed on the graph below.



The voltage $u_C(t)$ is

- ☐ ahead of the voltage $u(t)$
- ☐ lagging behind the voltage $u(t)$

1.2. Frequency behavior

The relationship that expresses the peak value $\hat{U}_C$ of the voltage $u_C(t)$ with respect to the pulse ω is given by (see Annex A.1)

$$\hat{U}_C = \frac{1}{\sqrt{1+(\omega RC)^2}}\hat{U} \quad (1)$$

With

$$\omega = 2\pi f \quad (2)$$

How does the peak value vary $\hat{U}_C$ with respect to the frequency f ?

- ☐ If the frequency f increases, the peak value $\hat{U}_C$ diminishes
- ☐ The frequency f has no influence on the peak value $\hat{U}_C$
- ☐ If the frequency f increases, the peak value $\hat{U}_C$ increases

In which case, does the capacitor behave like :

- A short-circuit ?
  - ☐ $f \to 0$
  - ☐ $f \to \infty$
- An open circuit ?
  - ☐ $f \to 0$
  - ☐ $f \to \infty$

Work to be done :

Vary the frequency f and study the evolution of the peak value $\hat{U}_C$ and the voltage $u_C(t)$ using the menu **AUTO MEASURE** of the oscilloscope.

Note the chosen configuration in the following table :

MEASURE PLACE	
MEASURE 1	
TYPE	
SOURCE	

Use the sequence :

100 Hz	500 Hz	1 kHz	2 kHz	5 kHz	10 kHz	50 kHz	100 kHz

For each frequency :

1. Calculate the peak value $\hat{U}_C$ using the relationship (1).
2. Choose the position of the two curves and their voltage ranges in order to make maximum use of the size of the oscilloscope screen and increase the precision of the calculations.
3. Measure peak value $\hat{U}_C$.

Report the values in the table below.

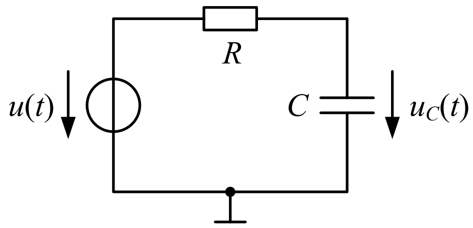
f [Hz]	$\hat{U}_C$ computed [V]	$\hat{U}_C$ measured [V]
100		
500		
1 k		
2 k		
5 k		
10 k		
50 k		
100 k		

The peak value $\hat{U}_C$ of the voltage $u_C(t)$ shows attenuation from peak value $\hat{U}$ of the voltage $u(t)$ with respect to the frequency f.

This property is used to make electrical filters.

1.3. Cancellation of the alternating component of a voltage $u(t) = U_0 + \hat{U}\sin(\omega t)$

Circuit diagram :



$u(t) = U_0 + \hat{U}\sin(2\pi f t)$ (HMF2525)

$R = 10\ \mathrm{k\Omega}$

$C = 10\ \mathrm{nF}$

The voltage $u(t)$ given by the function generator **HMF2525** is a sinusoidal signal of frequency $f = 50\ \mathrm{kHz}$, of amplitude $\hat{U} = 1\ \mathrm{V}$ and continuous component $U_0 = 5\ \mathrm{V}$.

Indicate which configuration should be chosen for the function generator:

Function	 ☐ ☐ ☐ ☐ ☐
Frequency	
Amplitude	
Offset	

Which buttons must be activated to deliver the signal correctly (several answers possible)?

- ☐ **OFFSET**
- ☐ **INVERT**
- ☐ **OUTPUT**
- ☐ **Aucune**

Visualize the voltages $u(t)$ and $u_C(t)$ on the oscilloscope.

Use the following configuration for the oscilloscope :

Canal 1 (CH1)	$u(t)$		
Canal 2 (CH2)	$u_C(t)$		
Time Base	$10\ \mu\mathrm{s}$		
Trigger	SOURCE : $u(t)$ (Canal 1)	LEVEL : $5\ \mathrm{V}$	SLOPE : Rising Edge

Which coupling should be used for the **two** channels in order to visualize the two curves correctly ?

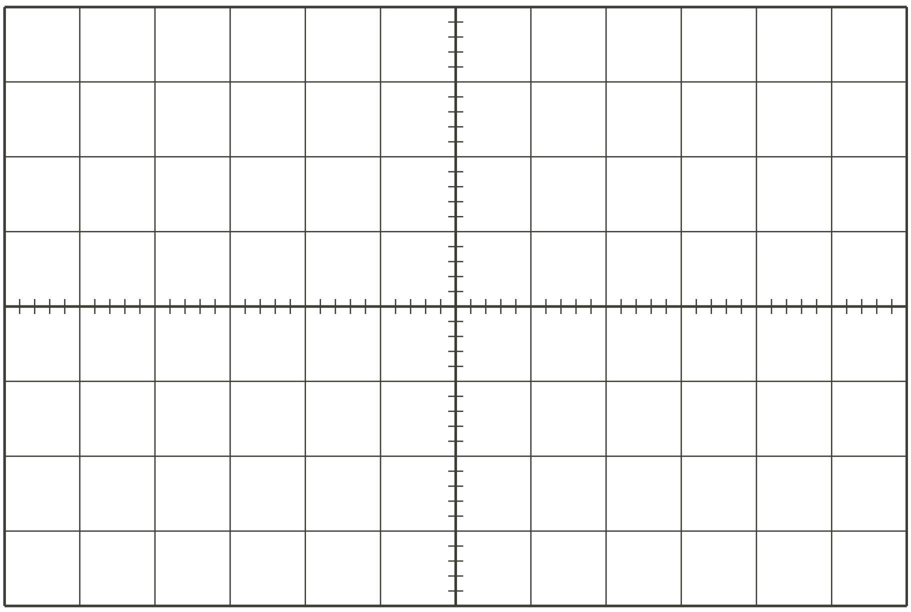
- ☐ AC
- ☐ DC
- ☐ AC ou DC

Superpose the **GND** of the two curves.

⚠	Choose the position of the two curves and their voltage ranges in order to make maximum use of the size of the oscilloscope screen and increase the precision of the calculations.

Choose the **same ranges in voltage** for voltages $u(t)$ and $u_C(t)$.

Reproduce the signals observed on the graph below.



The voltage $u_C(t)$ is

- ☐ same as voltage $u(t)$
- ☐ a continuous signal of $5\ \mathrm{V}$ with low ripple
- ☐ a continuous signal of $0\ \mathrm{V}$ with low ripple
- ☐ a sinusoidal signal with an amplitude of 1 V and no continuous component

Voltage ripple measurement $u_C(t)$

To correctly measure voltage ripple $u_C(t)$, we would like to be able to choose a voltage range which makes it possible to use the size of the oscilloscope screen to the maximum and increase the precision of the calculations.

Which configuration should be chosen for **Canal 2 (CH2) –** $u_C(t)$?

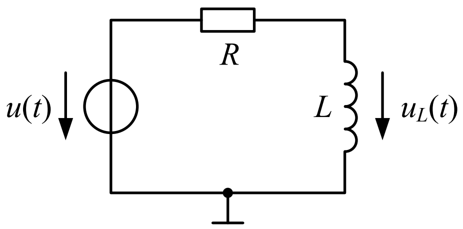
- ☐ Coupling AC **&** GND of canal 2 in the middle of the oscilloscope screen
- ☐ Coupling DC **&** GND of canal 2 at the bottom of the oscilloscope screen

Measure voltage ripple $u_C(t)$ using the menu **AUTO MEASURE** of the oscilloscope and **simultaneously** display the 3 values below :

CH2	Peak +	
CH2	Peak –	
CH2	Mean Value	

2. Inductor in sinusoidal mode

Circuit diagram :



$u(t) = \hat{U}\sin(2\pi f t)$ (HMF2525)

$R = 1\,\mathrm{k}\Omega$

$L = 10\,\mathrm{mH}$

The voltage $u(t)$ given by the function generator **HMF2525** is a sinusoidal signal of frequency $f = 10\,\mathrm{kHz}$ and amplitude $\hat{U} = 10\,\mathrm{V}$.

Indicate which configuration should be chosen for the function generator:

Function	 ☐ ☐ ☐ ☐ ☐
Frequency	
Amplitude	
Offset	

2.1. Observation of voltages $u(t)$ and $u_L(t)$

Visualize the voltages $u(t)$ and $u_L(t)$ on the oscilloscope.

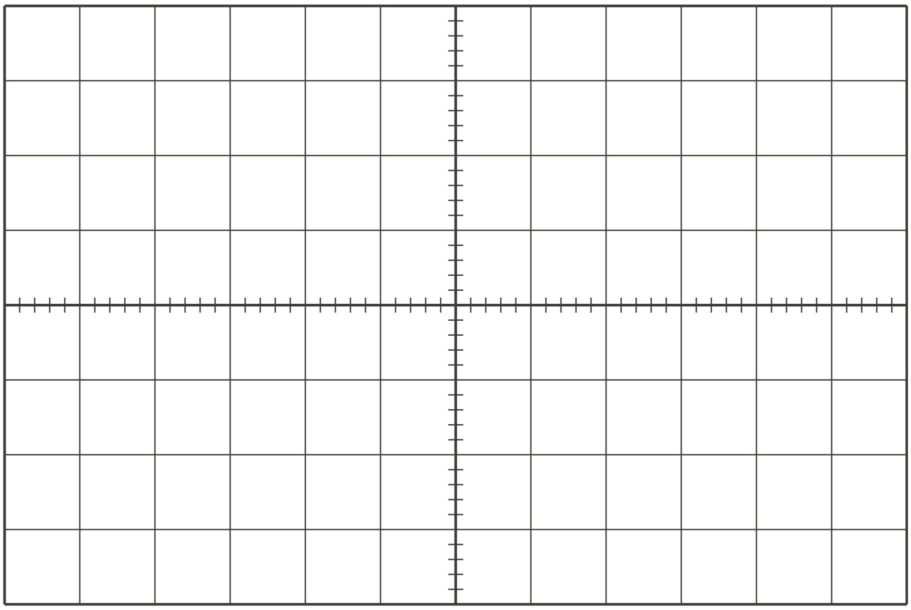
Use the following configuration :

Canal 1 (CH1)	$u(t)$	Coupling : AC ou DC	
Canal 2 (CH2)	$u_L(t)$	Coupling : AC ou DC	
Time Base	$20\,\mu\mathrm{s}$		
Trigger	SOURCE : $u(t)$ (Canal 1)	LEVEL : $0\,\mathrm{V}$	SLOPE : Rising Edge

Superpose the **GND** of the two curves.

⚠	Choose the position of the two curves and their voltage ranges in order to make maximum use of the size of the oscilloscope screen and increase the precision of the calculations.

Reproduce the signals observed on the graph below.



The voltage $u_L(t)$ is

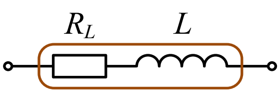
☐ ahead of the voltage $u(t)$

☐ lagging behind the voltage $u(t)$

2.2. Frequency behavior

The inductor has an **internal resistance** in series which influences the calculations in particular for **frequencies which tend towards 0**.

Its equivalent scheme is given by



The impedance $\underline{Z}_L$ of the inductor is then given by

$$\underline{Z}_L = R_L + \mathrm{j}\omega L \tag{3}$$

Measure the internal resistance R_L of the inductor using the multimeter **HMC8012**.

To make a correct measurement, you must **disconnect** the inductor from the rest of the circuit and then **connect** it only to the multimeter.

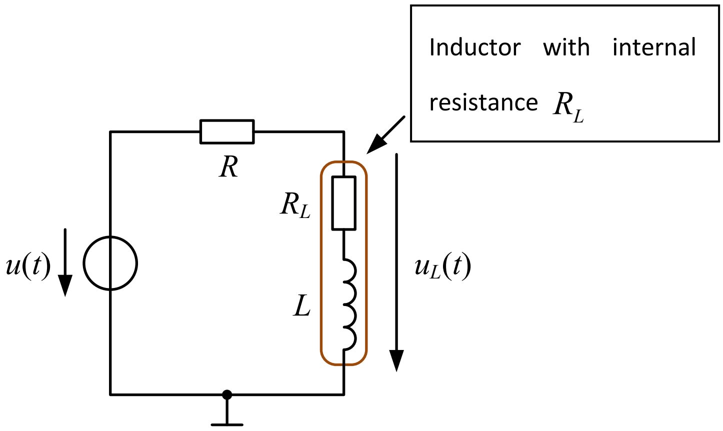
Which key is used to select the measurement of a resistance?

- ☐ **DC I**
- ☐ **Ω**
- ☐ **AC V**

Note the measured value

$R_L =$ ....

The circuit diagram becomes



The relationship that expresses the peak value $\hat{U}_L$ of the voltage $u_L(t)$ with respect to the pulse ω is given by (see Annex A.2)

$$\hat{U}_L = \frac{\sqrt{R_L^2 + (\omega L)^2}}{\sqrt{(R+R_L)^2 + (\omega L)^2}} \hat{U} \tag{4}$$

With

$$\omega = 2\pi f \tag{5}$$

How does the peak value $\hat{U}_L$ vary with respect to the frequency f ?

- ☐ If the frequency f increases, the peak value $\hat{U}_L$ diminishes
- ☐ The frequency f has no influence on the peak value $\hat{U}_L$

☐ If the frequency f increases, the peak value $\hat{U}_L$ increases

In which case, the ideal inductance ($R_L = 0$) behaves like :

- A short-circuit ?

  ☐ $f \to 0$

  ☐ $f \to \infty$

- An open-circuit ?

  ☐ $f \to 0$

  ☐ $f \to \infty$

<u>Work to be done:</u>

Vary the frequency f and study the evolution of the peak value $\hat{U}_L$ and the voltage $u_L(t)$ using the menu **AUTO MEASURE** on the oscilloscope.

Note the chosen configuration in the following table :

MEASURE PLACE	
MEASURE 1	
TYPE	
SOURCE	

Use the sequence :

100 Hz	1 kHz	2 kHz	5 kHz	10 kHz	20 kHz	50 kHz	100 kHz

For each frequency :

1. Calculate the peak value $\hat{U}_L$ using the relationship (4).
2. Choose the time base range and the voltage range $u_L(t)$ in order to make maximum use of the size of the oscilloscope screen and increase the precision of the calculations.
3. Measure the peak value $\hat{U}_L$.

Report the values in the table below.

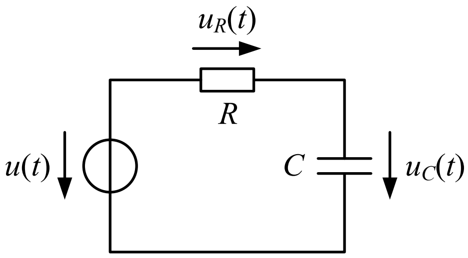
f [Hz]	$\hat{U}_L$ calculated [V]	$\hat{U}_L$ measured [V]
100		
1 k		
2 k		
5 k		
10 k		
20 k		
50 k		
100 k		

The peak value $\hat{U}_L$ of the voltage $u_L(t)$ shows attenuation from the peak value $\hat{U}$ of the voltage $u(t)$ with respect to the frequency f.

This property is exploited to make electrical filters.

APPENDIX

A.1 Peak value $\hat{U}_C$ calculation



$u(t) = \hat{U}\sin(2\pi f t)$

The calculation of $\hat{U}_C$ with respect to the frequency f is based on the complex calculation.

Impedances :

$$\underline{Z}_R = R$$
$$\underline{Z}_C = \frac{1}{\mathrm{j}\omega C} \tag{6}$$

Voltage divider :

$$\underline{U}_C = \frac{\underline{Z}_C}{\underline{Z}_R + \underline{Z}_C}\underline{U} \tag{7}$$

To simplify the calculations, we assume that $\underline{U}$ is real, hence $\underline{U} = U$.

The relation (7) becomes

$$\underline{U}_C = \frac{\frac{1}{\mathrm{j}\omega C}}{R + \frac{1}{\mathrm{j}\omega C}}U = \frac{1}{1 + \mathrm{j}\omega RC}U \tag{8}$$

The following relation is used to calculate the modulus of a complex number $\underline{z}$

$$\underline{z} = \frac{a + \mathrm{j}b}{c + \mathrm{j}d} \quad \Rightarrow \quad z = \frac{\sqrt{a^2 + b^2}}{\sqrt{c^2 + d^2}} \tag{9}$$

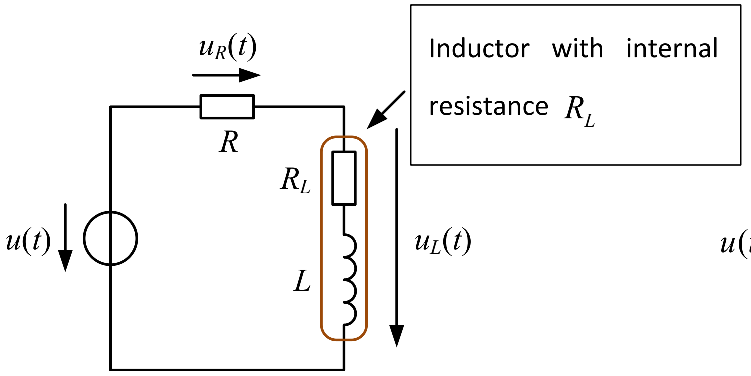
Using the relations (8) and (9), we obtain for the modulus of $\underline{U}_C$

$$U_C = \frac{1}{\sqrt{1 + (\omega RC)^2}}U \tag{10}$$

The relation to calculate $\hat{U}_C$ is finally given by

$$\hat{U}_C = \frac{1}{\sqrt{1 + (\omega RC)^2}}\hat{U} \tag{11}$$

A.2 Peak value $\hat{U}_L$ calculation



$u(t) = \hat{U}\sin(2\pi f t)$

The calculation of $\hat{U}_L$ with respect to the frequency f is based on the complex calculation.

Impedances :

$$\underline{Z}_R = R$$
$$\underline{Z}_L = R_L + \mathrm{j}\omega L \tag{12}$$

Voltage divider :

$$\underline{U}_L = \frac{\underline{Z}_L}{\underline{Z}_R + \underline{Z}_L}\underline{U} \tag{13}$$

To simplify the calculations, we assume that $\underline{U}$ is real, hence $\underline{U} = U$.

The relation (13) becomes

$$\underline{U}_L = \frac{R_L + \mathrm{j}\omega L}{R + R_L + \mathrm{j}\omega L}U \tag{14}$$

The following relation is used to calculate the modulus of a complex number $\underline{z}$

$$\underline{z} = \frac{a + \mathrm{j}b}{c + \mathrm{j}d} \quad \Rightarrow \quad z = \frac{\sqrt{a^2 + b^2}}{\sqrt{c^2 + d^2}} \tag{15}$$

Using the relations (14) and (15), we obtain for the modulus of $\underline{U}_L$

$$U_L = \frac{\sqrt{R_L^2 + (\omega L)^2}}{\sqrt{(R + R_L)^2 + (\omega L)^2}}U \tag{16}$$

The relation to calculate $\hat{U}_L$ is finally given by

$$\hat{U}_L = \frac{\sqrt{R_L^2 + (\omega L)^2}}{\sqrt{(R + R_L)^2 + (\omega L)^2}}\hat{U} \tag{17}$$