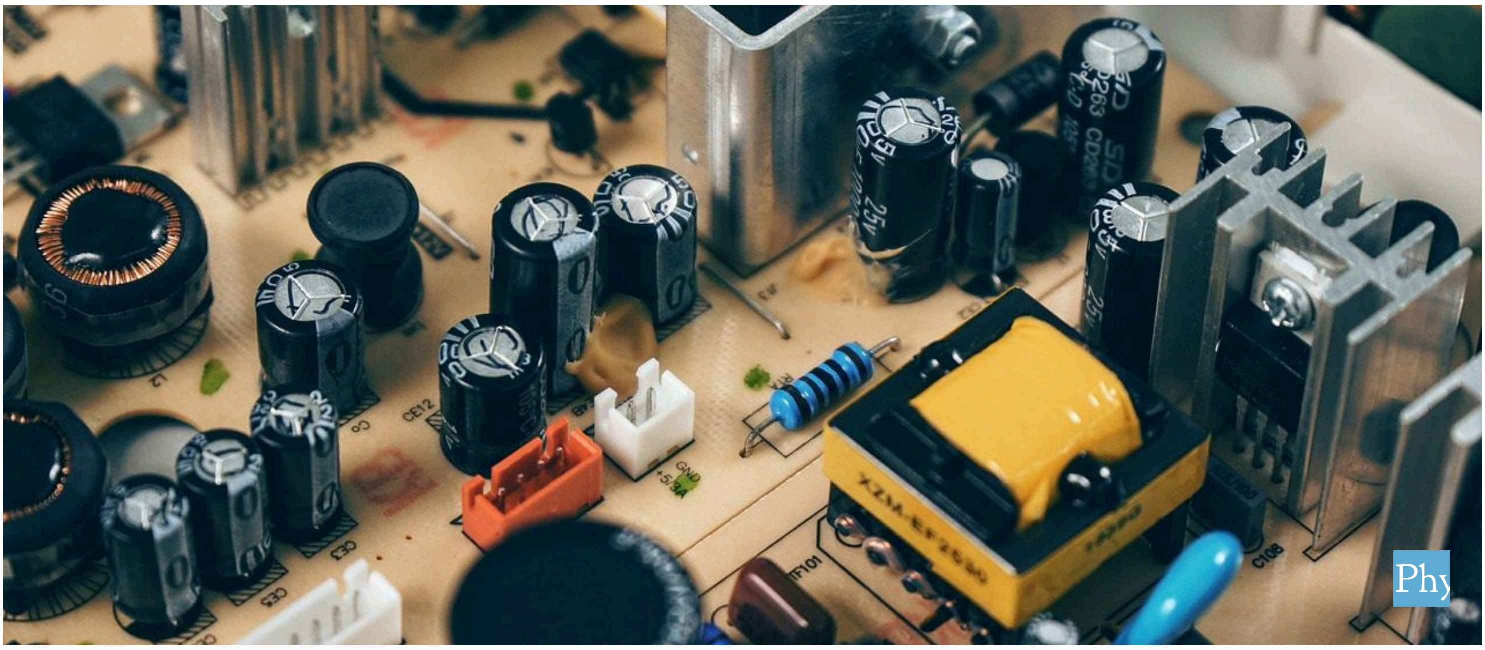
Capacitor in the AC circuit with Cobra4 Xpert-Link

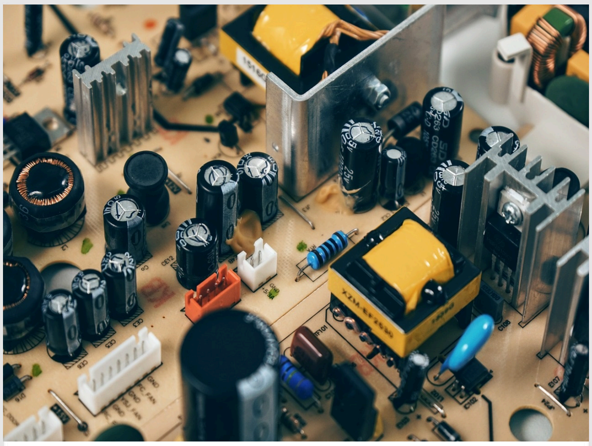


Physics > Electricity & Magnetism > Electromagnetic oscillations & waves

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

General information

Application



capacitators on computer platine

Alternating current refers to electrical current that changes its direction (polarity) in regular repetition and in which positive and negative instantaneous values sum up, so that the net current is zero on average over time.

Alternating current always has a real and an imaginary component. There is single-phase or multi-phase alternating current, which can be differentiated depending on the phase shift φ. Since a capacitors's properties are dependend on the applied voltage, while blocking DC currents and storing charges, a change in voltage is only achieved after a charging or discharging process (flowing currents) due to the inserted capacitor. This property makes a capacitor in a AC circuit a commonly used frequency filter component.

Other information (1/2)

Prior knowledge

Basic knowledge of physical quantities such as current, voltage, resistance, capacity and electric charge should be available. Ideally, the charging and discharging behaviour of a capacitor should be known.

Scientific principle

A capacitor is connected in a circuit with a voltage source of variable frequency. Due to the properties of the capacitor, a phase shift of the current occurs. The impedance and phase displacement are determined as a function of frequency and of capacitance. Parallel and series impedances are measured in comparison.

Other information (2/2)

Learning objective

After the successful completion of this experiment you will be able to theoretically describe the phenomenon of capacity with respect to alternating currents. You will also be able to experimentally determine the frequency dependend impedances and the caused phase shifts.

Tasks

Determination of the:

1. impedance of a capacitor as a function of frequency.
2. total impedance of capacitors connected in series and in parallel.
3. phase displacement between current and voltage over a RC network as a function of frequency.

Safety instructions

The general instructions for safe experimentation in science lessons apply to this experiment.

Theory (1/3)

The total capacitance C_{tot} for two capacitors C_1 and C_2 connected in series is

$$\frac{1}{C_{tot}} = \frac{1}{C_1} + \frac{1}{C_2}$$

For a parallel connection both capacitors add to the total capacitance

$$C_{tot} = C_1 + C_2$$

The voltage U_C on a capacitor is dependend on its capacitance C and the stored charge Q

$$Q(t) = \int_{t_1}^{t_2} I(t)\mathrm{d}t \;\;\Rightarrow\;\; U_C(t) = \frac{Q(t)}{C}$$

Theory (2/3)

The voltage on a resistance R, through which a current $I(t) = \mathrm{d}Q/\mathrm{d}t$ flows, is

$$U_R(t) = R \cdot I(t) = R \cdot \frac{\mathrm{d}Q}{\mathrm{d}t}$$

For a series connection of a capacitor and resistance with an AC voltage source the voltage is

$$U(t) = U_c(t) + U_R(t) = \frac{Q(t)}{C} + R\frac{\mathrm{d}Q}{\mathrm{d}t} = U_0 \cdot \cos(\omega t)$$

Differentiating this equation yields

$$\tfrac{I}{C} + R\tfrac{\mathrm{d}I}{\mathrm{d}t} = -\omega \cdot U_0 \cdot \sin(\omega t) \quad \Rightarrow$$

This differential equation is solved by

$$I(t) = I_0 \cdot \sin(\omega t + \phi) \quad \text{with:} \quad \tan(\phi) = \tfrac{1}{\omega RC} > 0$$

Theory (3/3)

This means the current is ahead of the voltage. The current amplitude I_0 is thus given by

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

The impedance Z is defined as

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

As can be seen, the capacitor contributes to the impedance $(R = 0)$ with

$$Z_c = \frac{1}{\omega C} = \frac{1}{2\pi f \cdot C} = \hat{R}_c$$

If one plots the impedance vs. the inverse frequency, the slope m is given by

$$m = \frac{1}{2\pi C} \quad \Rightarrow \quad C = \frac{1}{2\pi m}$$

Equipment

Position	Material	Item No.	Quantity
1	Cobra4 Xpert-Link	12625-99	1
2	Cobra4 Xpert-Link set of cables	12625-10	1
3	PHYWE Digital Function Generator, USB	13654-99	1
4	Connection box	06000-00	1
5	Capacitor 1 microF/ 100V, G2	39113-01	1
6	Capacitor 2,2microF/ 100V, G2	39113-02	1
7	Capacitor 4,7microF/ 100V, G2	39113-03	1
8	Resistor 47 Ohm, 1W, G1	39104-62	1
9	Resistor 100 Ohm, 1W, G1	39104-63	1
10	Resistor 220 Ohm, 1W, G1	39104-64	1

PHYWE
excellence in science

Setup and procedure

Setup (1/3)

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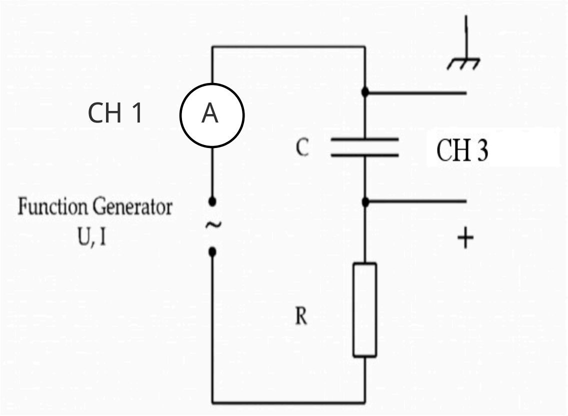
Experimental setup

- Build the electrical circuit according to the figure: The Capacitor is connected in series to the resistor.
- Connect both, Xpert-Link and digital function generator via USB with your computer.
- The sync-output of the function generator is connected to the T1 input of the Xpert-Link with a BNC cable and an adapter. Channel 3 (CH 3) of the Xpert-Link is connected with the connection box, so that it measures the voltage drop over the capacitor.

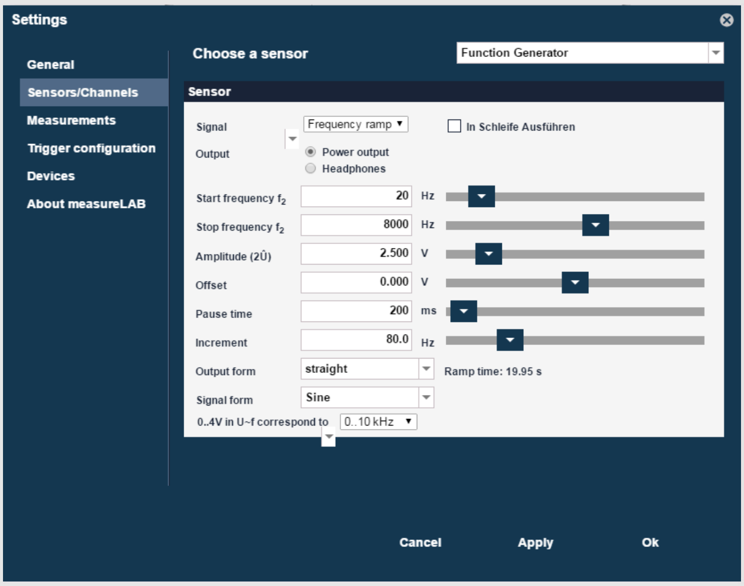
Setup (2/3)



Connection diagram for impedance measurement.

- The according connection diagram for the first measurement is shown in the figure.
- As output of the Function Generator the white and yellow jacks are used. Channel 1 (current) is connected in series to the output of the digital function generator.
- Open measureLAB and load the settings for the experiment.

Setup (3/3)



Choose a sensor: Function Generator

Sensor

Signal: Frequency ramp ☐ In Schleife Ausführen

Output: ● Power output ○ Headphones

Start frequency f_2: 20 Hz

Stop frequency f_2: 8000 Hz

Amplitude (2Û): 2.500 V

Offset: 0.000 V

Pause time: 200 ms

Increment: 80.0 Hz

Output form: straight Ramp time: 19.95 s

Signal form: Sine

0..4V in U~f correspond to 0..10 kHz

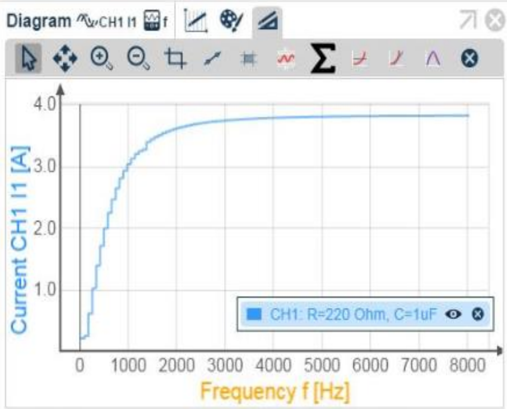
Impedance measurement

- Open the Function Generator's settings and set them according to the figure on the left.
- Then check if the settings of the Xpert-Link channels one and three (CH1 and CH3) are set to the parameters according to the figures below:

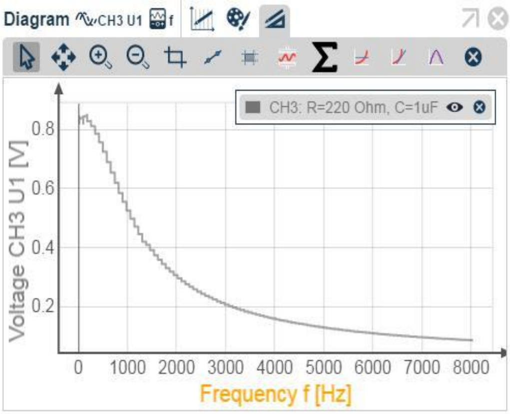
Prodedure (1/5)

Task 1:

Set up two diagrams, which plot voltage and current against frequency, which should result in curves as shown. Record curves and datasets for different combinations of resistors and capacitors.

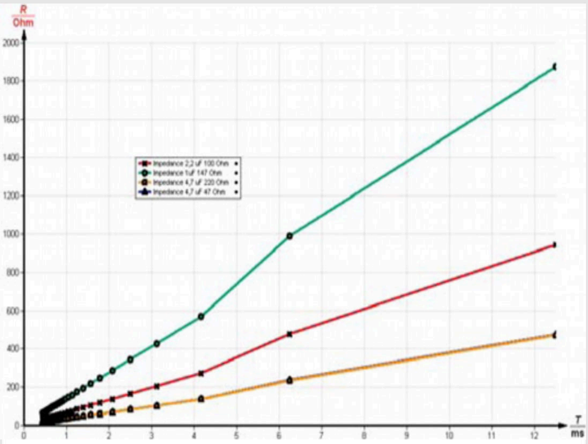


Current plotted against frequency of the function generator



Voltage over the capacitor plotted against frequency of the function generator.

Prodedure (2/5)

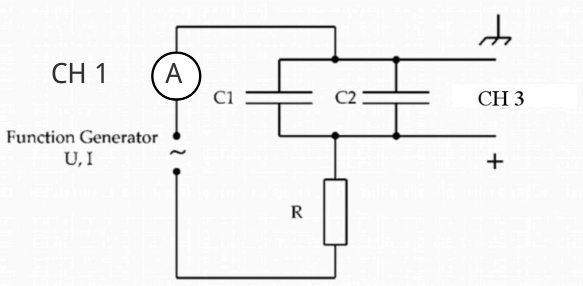


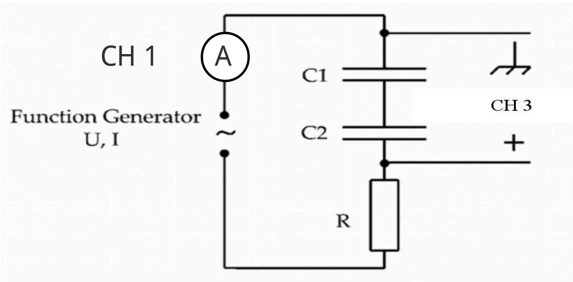
Period time dependency of impedance for different sets of capacitor and resistance

Impedance measurement

- Plot the impedance $Z = U/I$ in dependence of the reciprocal frequency $1/f$. To calculate these within measureLAB, select the symbol $\sqrt{\alpha}$ (top right). Drag and drop your data set of the respective data sets and enter the respective equation. Proceed accordingly for all different measured combinations of resistors and capacitors.
- You will receive data with a linear relationship as exemplary shown in the figure.
- Apply linear regressions to each data set and note the resulting slope in the table in the evaluation section.

Prodedure (3/5)

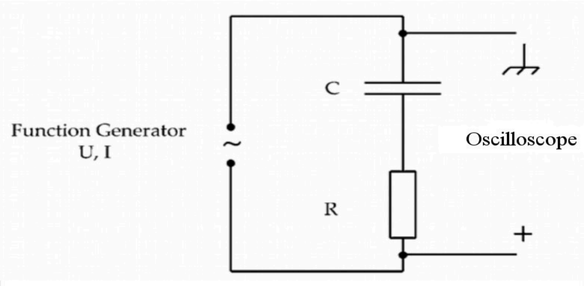


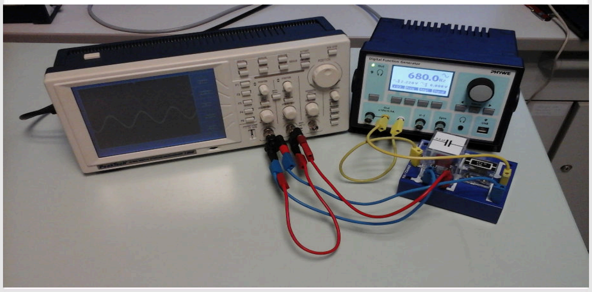


Task 2: Impedance of parallel and series connection

- To investigate the influence of parallel and series connection of capacitors measure the impedance for configurations shown in the figures.
- Use different combinations of capacitors and resistance. Perform the measurements the same way as in task 1.
- The total capacitance of two connected capacitors is given in the theory chapter.

Prodedure (4/5)



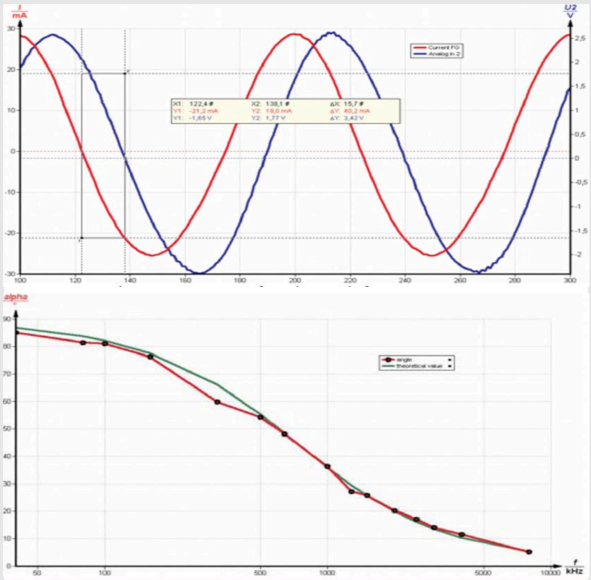


Task 3: Phase-shift measurement

Connect the capacitor $(C = 2.2\,\mu F)$ and the resistor $(R = 220\,\Omega)$ in series. You can also directly measure the current and the total voltage with measureLAB, But you will have to set the frequency manually and measure the temporal displacement for each frequency.

Note: To investigate the phaseshift $\Delta\phi$ between current and voltage, cost commonly an oscilloscope is used. The total voltage is measured with one channel of the oscilloscope according to the figures shown. Instead of the current signal, the voltage drop over the resistor R is usually measured, which is proportional to the current.

Prodedure (5/5)



Phase-shift measurement

- Out of both signals the temporal difference Δt between to maxima can be read off. Following the phase shift $\Delta\phi$ can be calculated with the used frequency f.
- Repeat this for 10 different frequencies by changing the frequency at the function generator in the range of $20 Hz$ to $8 kHz$.
- Note the values in the evaluation section. Finally, plot the values of $\Delta\phi$ against the frequency f. A graph like the one shown in the figure below should be obtained. This process can also be repeated for different combinations of capacitors and resistors.

Evaluation (1/4) - Task 1

Note the resulting slopes m of the linear regressions from the impedances Z_C plotted against the reciprocal frequency $1/f$ and calculate the respective experimental capacities C_{exp}.

	$R_1 = 47\,\Omega$		$R_2 = 100\,\Omega$		$R_2 = 220\,\Omega$	
$C\,[\mu F]$	$m\,[\Omega\,ms]$	$C_{exp}\,[\mu F]$	$m\,[\Omega\,ms]$	$C_{exp}\,[\mu F]$	$m\,[\Omega\,ms]$	$C_{exp}\,[\mu F]$
1.0						
2.2						
4.7						

Evaluation (2/4) - Task 2 (Series)

Note the resulting slopes m of the linear regressions from the impedances Z_C plotted against the reciprocal frequency $1/f$ and calculate the respective experimental capacities C_{exp}.

	$R_1 = 47\,\Omega$		$R_2 = 100\,\Omega$		$R_2 = 220\,\Omega$	
$C\,[\mu F]$	$m\,[\Omega\,ms]$	$C_{exp}\,[\mu F]$	$m\,[\Omega\,ms]$	$C_{exp}\,[\mu F]$	$m\,[\Omega\,ms]$	$C_{exp}\,[\mu F]$
1.0 - 2.2						
2.2 - 4.7						
4.7 - 1.0						

Evaluation (3/4) - Task 2 (Parallel)

Note the resulting slopes m of the linear regressions from the impedances Z_C plotted against the reciprocal frequency $1/f$ and calculate the respective experimental capacities C_{exp}.

	$R_1 = 47\,\Omega$		$R_2 = 100\,\Omega$		$R_2 = 220\,\Omega$	
$C\,[\mu F]$	$m\,[\Omega\,ms]$	$C_{exp}\,[\mu F]$	$m\,[\Omega\,ms]$	$C_{exp}\,[\mu F]$	$m\,[\Omega\,ms]$	$C_{exp}\,[\mu F]$
1.0 - 2.2						
2.2 - 4.7						
4.7 - 1.0						

Evaluation (4/4) - Task 3

Fill the table with the measured temporal displacements $\mathrm{d}t$ and calculate the resulting phase displacements $\Delta\phi$ and their tangent.

$f\,[kHz]$	$\mathrm{dt}\,[\mu s]$	$\Delta\phi\,[^\circ]$	$\tan\Delta\phi\,[1]$

$f\,[kHz]$	$\mathrm{dt}\,[\mu s]$	$\Delta\phi\,[^\circ]$	$\tan\Delta\phi\,[1]$

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