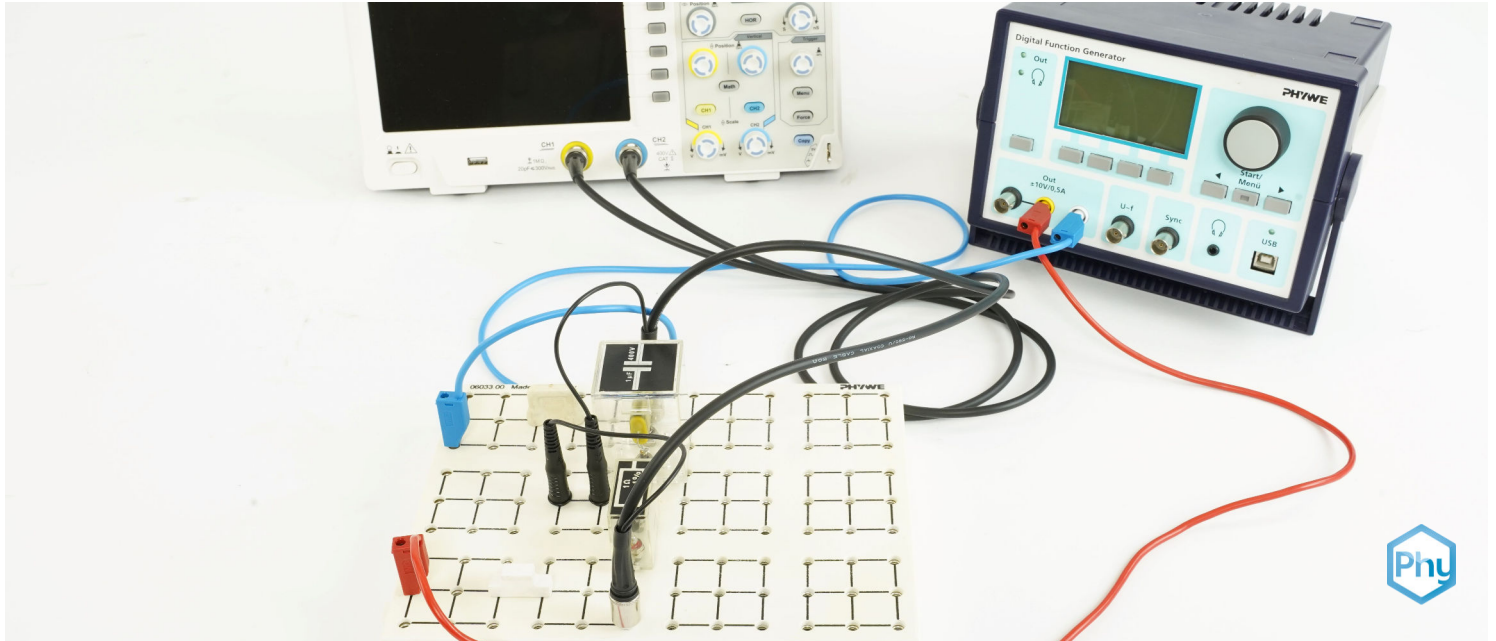


Capacitor in the AC circuit



Physics

Electricity & Magnetism

Electronics



Difficulty level

hard



Group size

-



Preparation time

45+ minutes



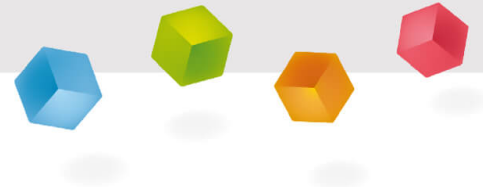
Execution time

45+ minutes

This content can also be found online at:

<http://localhost:1337/c/64ad3d35ee382f0002b6ee87>

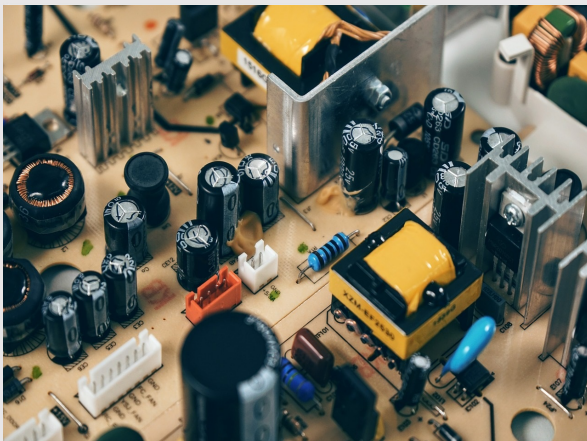
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General information

Application

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capacitors 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 depend 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)

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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



Every change in voltage across a capacitor induces a current through the capacitor. When alternating voltage is applied, alternating current flows with a phase shift relative to the voltage.

Other information (2/2)

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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 dependent impedances and the caused phase shifts.

Tasks



1. Determination of the amplitude and phase of the capacitive resistance as a function of the capacitance of the capacitor.
2. Determination of amplitude and phase of capacitive resistance as a function of frequency.

Safety instructions

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

Theory (1/2)

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

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

For a parallel connection both capacitors add to the total capacitance

$$C_{tot} = C_1 + C_2 \quad (2)$$

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

$$Q(t) = \int_{t_1}^{t_2} I(t) dt \Rightarrow U_C(t) = \frac{Q(t)}{C} \quad (3)$$

Theory (2/2)

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It follows directly from the capacitor equation:

$$I = C \cdot \frac{dU}{dt} \quad (4)$$

with I as current, U as voltage, C as capacitance.
The application of an alternating voltage

$$U = U_0 \cdot e^{i\omega t} \quad (5)$$

causes the following current:

$$I = i\omega C U_0 e^{i\omega t} \quad (6)$$

The capacitance has the complex resistance

$$X_c = \frac{U}{I} = \frac{1}{i\omega C} = \frac{1}{2\pi i f C} \quad (7)$$

The real part of the quantities is:

$$U = U_0 \cos(\omega t), I = I_0 \cos(\omega t + \frac{\pi}{2}) \quad (8)$$

$$X_C = \frac{U_0}{I_0} = \frac{1}{\omega C} = \frac{1}{2\pi f C} \quad (9)$$

Notes

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In the experiment, a function generator provides alternating voltages with frequencies up to $5kHz$. A dual-channel oscilloscope records both current and voltage, capturing the amplitude and phase of both quantities. The current through the capacitor corresponds to the voltage drop across a measurement resistor R , whose value is negligible compared to the capacitive resistance.



Equipment

Position	Material	Item No.	Quantity
1	Plug-in board, for 4 mm plugs	06033-00	1
2	Resistor 1 Ohm 2%, 2W, G1	06055-10	1
3	Resistor 10 Ohm 2%, 2W, G1	06056-10	1
4	Capacitor 1 microF/ 100V, G2	39113-01	1
5	Capacitor 100 nF/250V, G1	39105-18	3
6	PHYWE Digital Function Generator, USB	13654-99	1
7	Digital storage oscilloscope with USB, 100 MHz / 2CH, 1GS/s	EAK-P-1404	1
8	Connecting cord, 32 A, 500 mm, blue	07361-04	2
9	Connecting cord, 32 A, 500 mm, red	07361-01	2
10	bridge plug	06027-07	4
11	Measuring cable BNC to 4 mm banana plug, length 1 m	EAK-MKS-1	2

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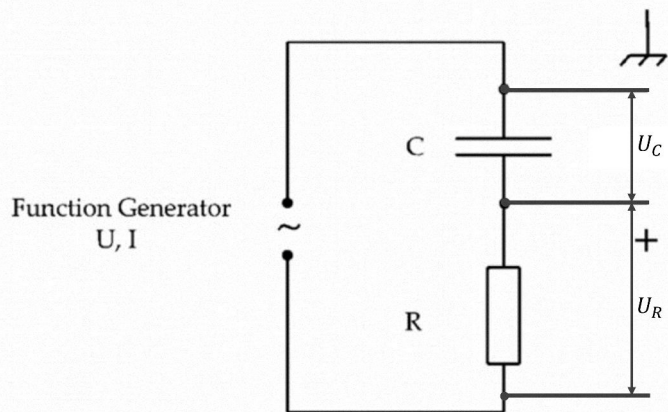


Setup and procedure

Setup

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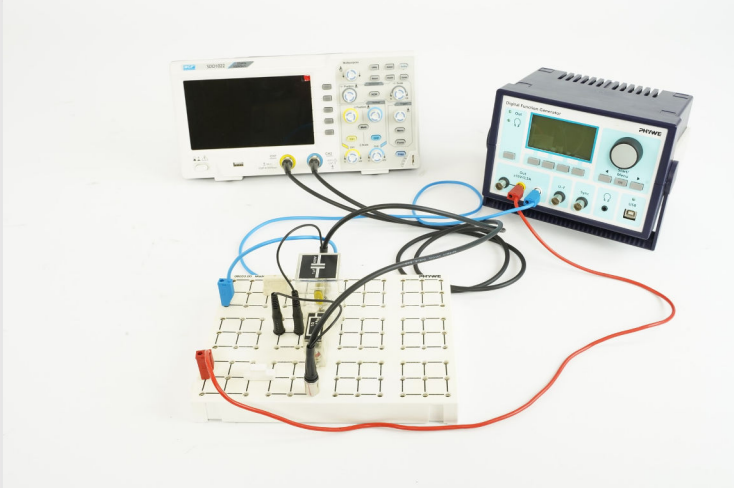
- Set up the experiment according to the circuit diagram with
 - the resistor ($R = 1\Omega$) and
 - the capacitor ($C = 1\mu F$).
- The voltage curve U_R of the measuring resistor is measured with *CH1* and the voltage curve of the capacitor U_C with *CH2* of the oscilloscope.
- Use the autoscaling of the oscilloscope.



Connection diagram

Prodedure (1/5)

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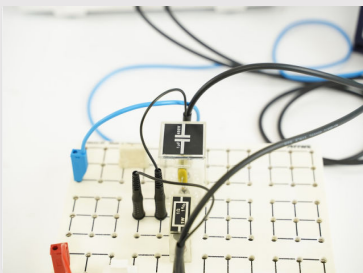


setup of a capacitor in an AC circuit

- Set a frequency of $f = 4000\text{ Hz}$ at the function generator.
- Select "Sine" as the waveform and set the amplitude of the input signal to $U_0 = 4\text{ V}$.
- Note: The value of the measuring resistor R is negligible compared to the capacitive resistance X_C at the frequencies considered. Thus in good approximation $U_{C0} \approx U_0 = 4\text{ V}$

Prodedure (2/5)

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1. Phase shift between current and voltage

- observe the relative position of the voltage waveforms $U_C(t)$ and $U_R(t)$ and note your observations.

2. Dependence of the capacitive resistance on the capacitance

- using the capacitor $0.1\mu\text{F}$ and series and parallel connection of the capacitors $1\mu\text{F}$, generate the following capacitances:
 $C = 0.10\mu\text{F}, 0.33\mu\text{F}, 0.50\mu\text{F}, 0.67\mu\text{F}, 1.00\mu\text{F}, 2.00\mu\text{F}$.
- Read the amplitudes U_{R0} on the oscilloscope and write them down in a table.

Prodedure (3/5)

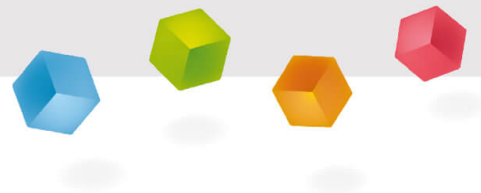
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3. Dependence of the capacitive resistance on the frequency

- use the condenser $C = 1\mu F$ and the resistor $R = 10\Omega$ as measuring resistance
- Set the frequencies $f = 200Hz, 300Hz, 500Hz, 1000Hz, 2000Hz, 3000Hz, 4000Hz, 5000Hz$ on the function generator one after the other.
- read the amplitudes U_{R0} on the oscilloscope and enter them in a table.

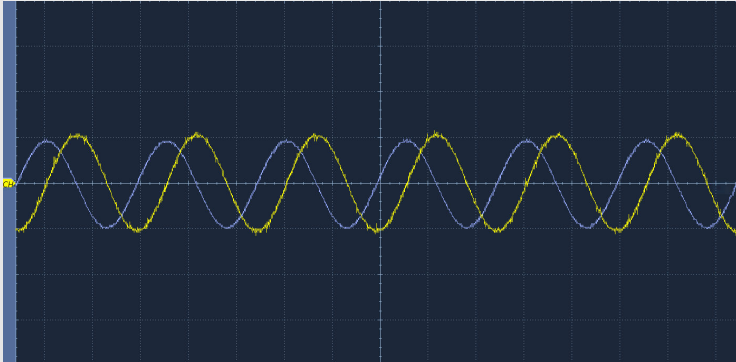
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Evaluation



Evaluation (1/5)

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Capacitor in the AC circuit (oscilloscope image)

voltage: yellow; current: blue

Phase shift between current and voltage

As can be clearly seen in the figure, the current signal is shifted by a quarter period to the right compared to the voltage signal.

The current through the capacitor is 90° ahead of the voltage across the capacitor in phase, since the charging current (positive sign) and the discharging current (negative sign) are at their maximum when the voltage reaches zero.

Evaluation (2/5)

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Dependence of the capacitive resistance on the capacitance

The values shown in the table could be recorded.

$$f = 4000 \text{ Hz}, R = \Omega, U_0 = 4 \text{ V}$$

$C(\mu\text{F})$	$U_{R0}(mV)$	$1/C(1/\mu\text{F})$	$I_0 = U_{R0}/R(mA)$	$X_C = U_0/I_0(\Omega)$
0,1	9,4	10	9,4	425,53
0,33	32,3	3,03	32,3	123,84
0,5	51,3	2	51,3	77,97
0,67	68	1,49	68	58,82
1	101,8	1	101,8	39,29
2	204,1	0,5	204,1	19,6

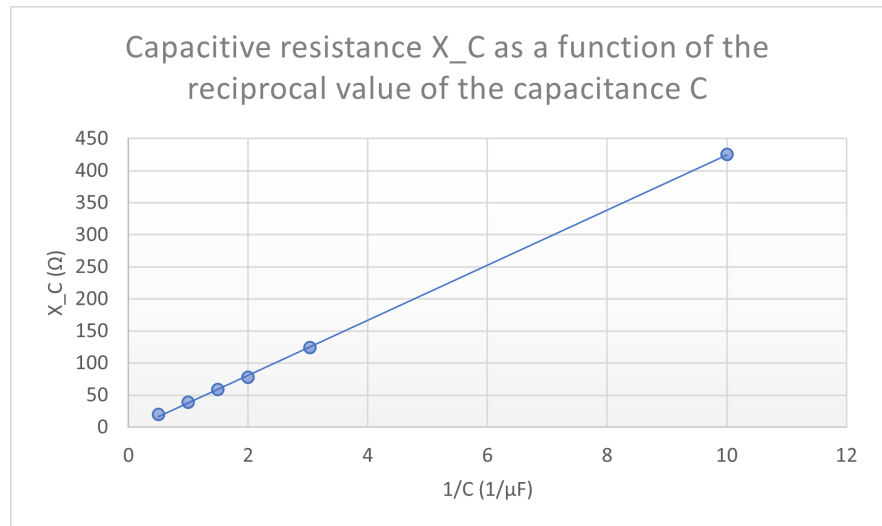
Evaluation (3/5)

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Dependence of the capacitive resistance on the capacitance

The capacitive resistances X_C are plotted against the reciprocal values of the capacitance.

It can be seen that the capacitive resistance X_C is proportional to the reciprocal value of the capacitance C . This observation is consistent with equation (7).



Evaluation (4/5)

PHYWE

Dependence of the capacitive resistance on the frequency

The values shown in the table could be recorded.

$$C = 1\mu\text{F}, R = 10\Omega, U_0 = 4\text{V}$$

$f(\text{Hz})$	$U_{R0}(\text{mV})$	$1/f(1/\text{kHz})$	$I_0 = U_{R0}/R(\text{mA})$	$X_C = U_0/I_0(\Omega)$
200	51	5	5,1	784,31
300	79	3,33	7,9	506,33
500	126	2	12,6	317,46
1000	254	1	25,4	157,48
2000	490	0,5	49	81,63
3000	735	0,33	73,5	54,42
4000	991	0,25	99,1	40,36
5000	1201	0,2	120,1	33,31

Evaluation (5/5)

PHYWE

Dependence of the capacitive resistance on the frequency

The capacitive resistances X_C are plotted against the reciprocal values of the frequency.

It can be seen that the capacitive resistance X_C is proportional to the reciprocal value of the frequency f . This observation is consistent with equation (7).

