Determining the capacitive reactance of a capacitor in an AC circuit

Objects of the experiments

- Investigating the voltage and the current at a capacitor in an AC circuit.
- Observing the phase shift between the current and the voltage.
- Determining the capacitive reactance $X_C = \frac{1}{2\pi C f}$.

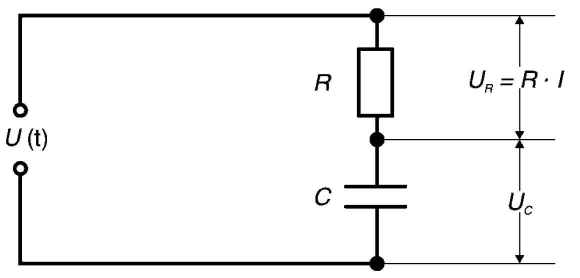
Principles

In a DC circuit, a capacitor represents an infinite resistance. Only during circuit closing and opening, respectively, a current flows.

However, a current flows in an AC circuit with a capacitor. The current I flowing in an AC circuit is determined by the capacitive reactance (impedance X_C of the capacitor) and the voltage U:

$$I = \frac{U}{X_C} \text{ or } X_C = \frac{U}{I}.$$

In the case of a sinusoidal voltage, a phase difference arises between the voltage and the current. The voltage takes its maximum when the current is zero, and the voltage is zero at maximum current, i.e. the current is in advance of the voltage by 90° ($\pi / 2$). Due to the power factor cos φ, no power ($P = U I \cos\varphi$) is lost in the capacitor, that is no energy is converted. Therefore the capacitive reactance is also called reactive impedance in contrast to the (ohmic) active resistance.



In the experiment, the current I is determined via the voltage drop U_R at the resistor R, and the voltage U_C at the capacitor C is measured directly. For this purpose the peak voltages are determined by means of an oscilloscope. The current then is:

$$I = \frac{U_R}{R}.$$

This is used to calculate the capacitive reactance

$$X_C = \frac{U_C}{I}.$$

In order to establish the equation

$$X_C = \frac{1}{2\pi C f},$$

first the dependence of the capacitive reactance on the capacitance $X_C \propto \frac{1}{C}$ and then on the frequency $X_C \propto \frac{1}{f}$ is investigated.

Apparatus

1 plug-in board A4 .... 576 74
1 resistor 1 Ohm STE2/19 .... 577 19
1 resistor 10 Ohm STE2/19 .... 577 20
3 capacitors 1 µF STE2/19 .... 578 15
1 function generator S12 .... 522 621
1 two-channel oscilloscope 303 .... 575 211
2 screened cables BNC/4 mm 575 24
1 pair of cables, 100 cm, blue and red 501 46

Kem 1105

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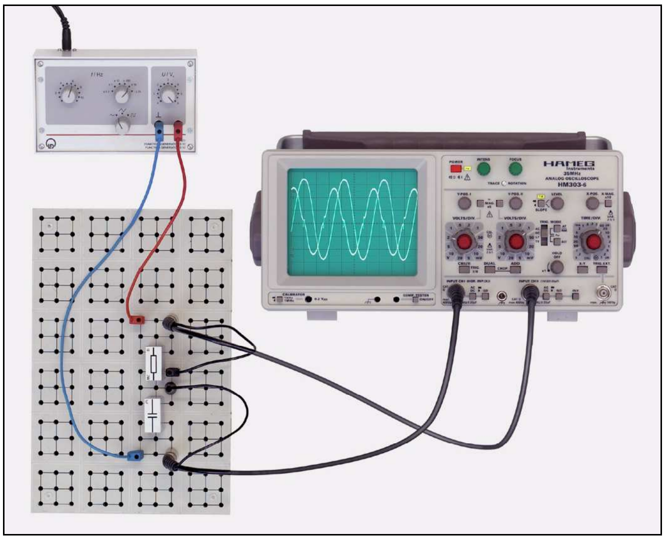
Setup



Setup according to Figure 1.

- Measure the voltage drop at the resistance with channel I and the voltage drop at the capacitor with channel II.
- Display both curves on the oscilloscope at the same time (DUAL). Set the coupling and the trigger to AC. For correct reading of the voltages and times (frequency) use the calibrated mode (CAL.) for the deflections. Invert (INV.) one channel for a correct in-phase representation of the two curves.

Carrying out the experiments

a) Observing the phase shift

- Adjust a sinusoidal voltage with a frequency $f \approx 5$ kHz and a voltage $U_S \approx 6$ V at the function generator.
- Select suitable Y-deflections and time bases at the oscilloscope to observe deflections as large as possible and several oscillations.
- Compare the positions of the maxima and minima, respectively, of the voltage at the capacitor with the position of the zero passages of the voltage at the resistor.

b) Dependence of the capacitive reactance on the capacitance

- Adjust the frequency f = 5000 Hz of the function generator precisely, by reading the period (T = 200 ms) on the oscilloscope.
- Implement various capacitances C through parallel and series connection of the capacitors.
- In each case determine the voltage drops (peak voltages) at the resistor U_R and the capacitor U_C using the oscilloscope.

c) Dependence of the capacitive reactance on the frequency

- Set up the experiment with the capacitance C = 1 µF.
- Adjust various frequencies f at the function generator precisely by reading the period on the oscilloscope.
- In each case determine the voltage drops (peak voltages) at the resistor U_R and the capacitor U_C using the oscilloscope.

Measuring example

a) Observing the phase shift

The maxima (and minima, respectively) of the voltage at the capacitor are located at the same position as the zero passages (+ to – and – to +, respectively) of the current, which is represented by the voltage at the resistor.

b) Dependence of the capacitive reactance on the capacitance

Table 1: R = 1 Ω, f = 5000 Hz

$\frac{C}{\mu F}$	$\frac{U_R}{mV}$	$\frac{U_C}{V}$	$\frac{I = \frac{U_R}{R}}{mA}$	$\frac{X_C = \frac{U_C}{I}}{\Omega}$
0.5	100	5.8	100	58
0.7	120	5.8	120	48
1.0	195	5.8	195	30
2.0	380	5.8	380	15

c) Dependence of the capacitive reactance on the frequency

Table 2: R = 10 Ω, C = 1µF

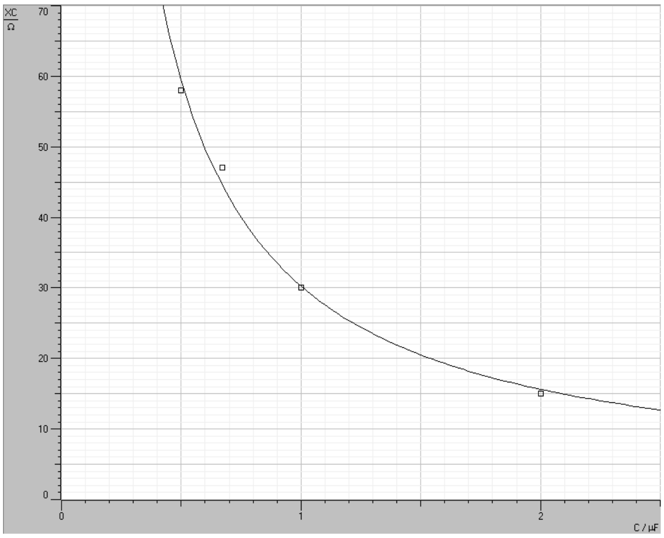
$\frac{f}{Hz}$	$\frac{U_R}{mV}$	$\frac{U_C}{V}$	$\frac{I = \frac{U_R}{R}}{mA}$	$\frac{X_C = \frac{U_C}{I}}{\Omega}$
400	150	5.8	15	387
500	195	5.8	20	290
1000	380	5.8	38	153
2000	760	5.8	76	76
4000	1500	5.8	150	39
5000	1800	5.8	180	32

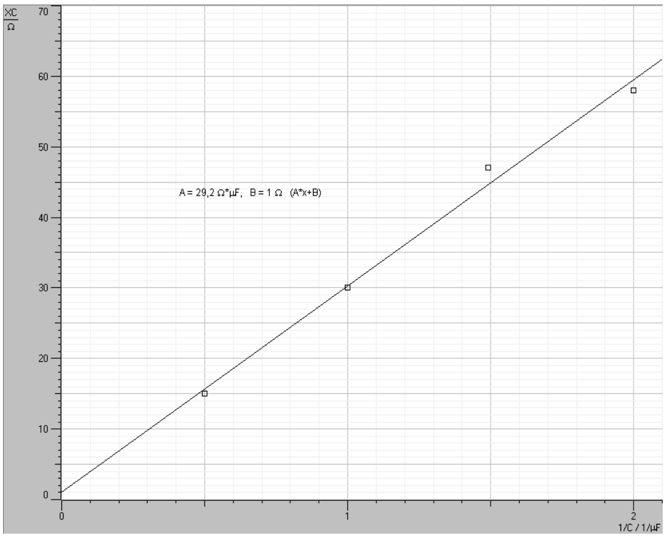
Evaluation and results

a) Observing the phase shift

In an AC circuit with a sinusoidal voltage, the current is in advance of the voltage by 90° (π/2).

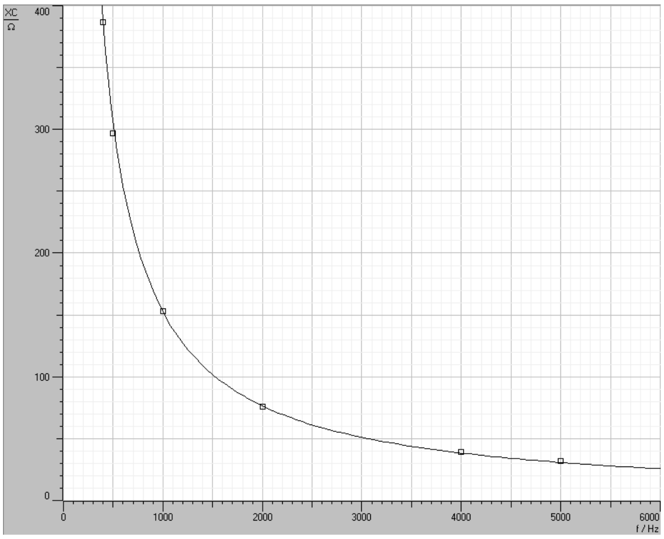
b) Dependence of the capacitive reactance on the capacitance

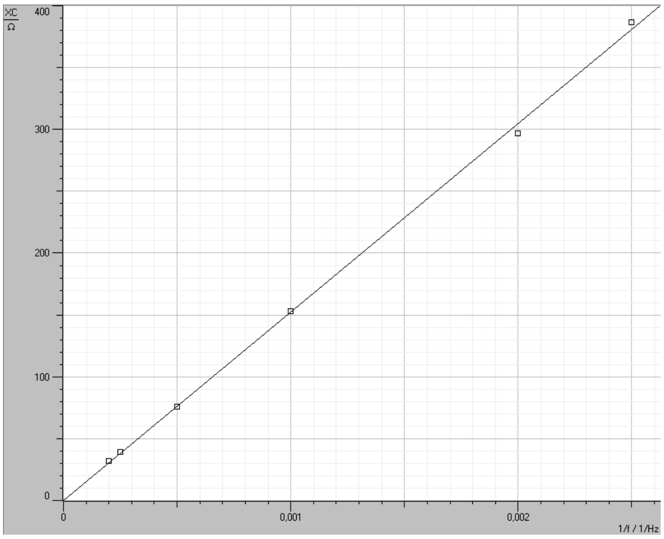




The following proportionality is established: $X_C \propto \frac{1}{C}$ (I)

c) Dependence of the capacitive reactance on the frequency



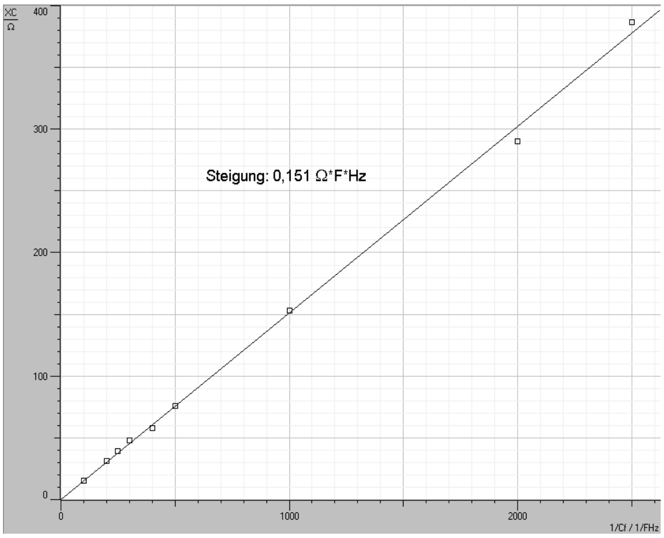


The following proportionality is established: $X_C \propto \frac{1}{f}$ (II)

d) Determining the constant of proportionality

From (I) and (II) we obtain: $X_C \propto \frac{1}{C\,f}$ (III)

$\frac{\frac{1}{C\,f}}{\frac{1}{\mathrm{F\,Hz}}}$	$\frac{X_C}{\Omega}$
2500	387
2000	290
1000	153
500	76
400	58
300	48
250	39
200	30 / 32
100	15



With a constant of proportionality K, it follows from (III) that:

$$X_C = K \frac{1}{C\,f}$$

From the diagram K = 0.151 is obtained.

Comparison with the theoretical value: $\frac{1}{2\,\pi} \approx 0{,}159$

Apart from the tolerances of the resistors and capacitors, the deviation (5 % in this case) can be explained particularly by the inaccurate reading from the oscilloscope.