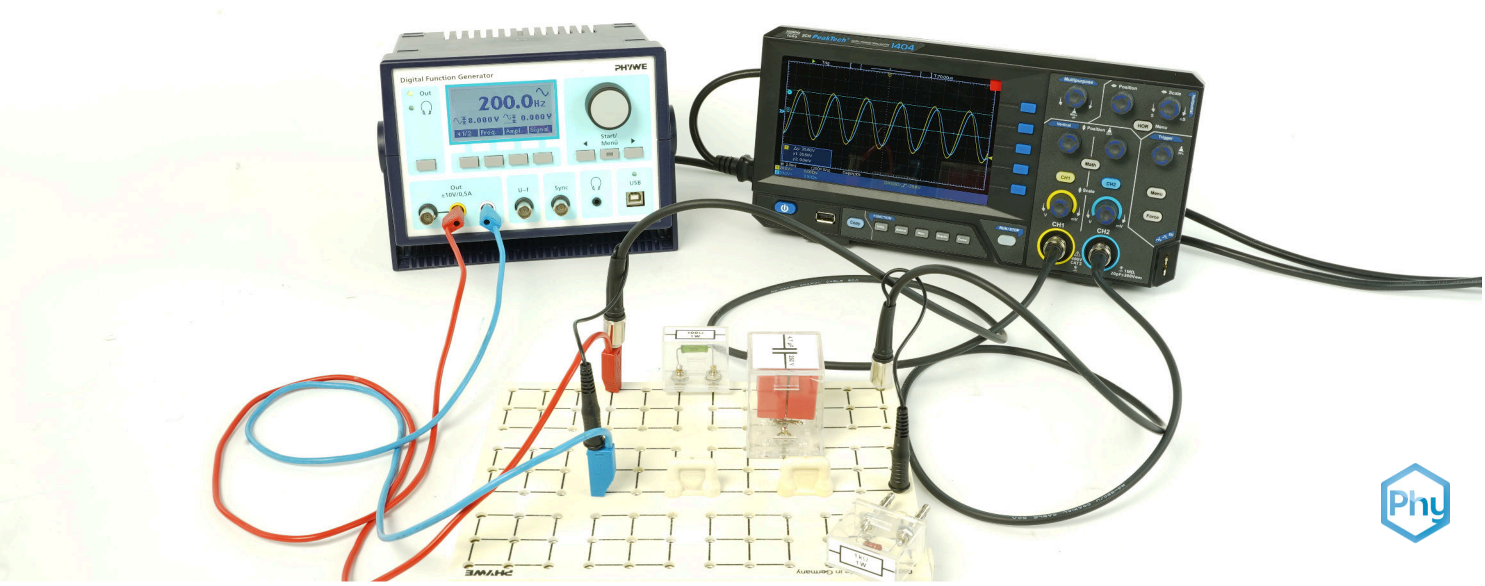
High-pass and low-pass filters



Physics | Electricity & Magnetism | Electronics

Difficulty level	Group size	Preparation time	Execution time
hard	-	10 minutes	20 minutes

This content can also be found online at:

http://localhost:1337/c/64b1040f83f79f0002efec15

General information

Application

A typical application is found in your car radio, which employs both a low-pass and a high-pass filter. The low-pass filter directs low-frequency sounds (like bass) to the subwoofer, while the high-pass filter channels high-frequency sounds (like vocals or instruments) to the speakers engineered for higher tones. Consequently, all aspects of the music can be heard clearly and distinctly.

Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Other information (1/2)

PHYWE

Prior knowledge

Basic knowledge is found in the theory section.

Scientific principle

A high-pass filter allows high frequencies through and blocks low ones, while a low-pass filter allows low frequencies through and blocks high ones.

Other information (2/2)

PHYWE

Learning objective

After the successful completion of this experiment you will be able to theoretically describe the functionof high- and lowpass filters.

Tasks

1. Make initial measurements on the low-pass filter and observe the phase response.
2. Investigate the amplitude response of a low-pass filter.
3. Make first measurements on a high pass and observe the phase response.
4. Investigate the amplitude response of a high-pass filter.
5. Observe the phase shift of the high pass.
6. Investigate the effects of a square wave voltage on the high and low pass.

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Safety instructions

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

Theory (1/6)

Passive RC- Component

The frequency response of signals can be altered using RC circuits. This can be observed in the context of two passive RC elements - a low-pass and a high-pass filter. Being labeled as 'passive' signifies the absence of any amplifying element within the circuit. 'Low-pass' and 'high-pass' designations indicate that the low frequencies are permitted in the low-pass filter and the high frequencies in the high-pass filter, whereas the respective other frequencies are blocked. To comprehend this behavior, one examines the resistances present in the circuit. Apart from the ohmic resistance R, there is also a capacitive resisitance X_C.

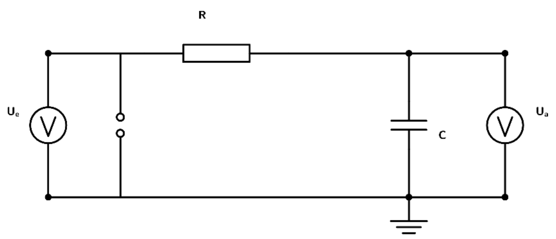


Fig. 1a: Lowpass

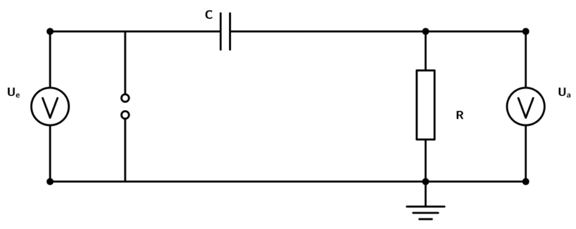


Fig. 1b: Highpass

Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Theory (2/6)

In an alternating current circuit, a capacitor behaves akin to a resistor (reactance).

The magnitude of this depends on the frequency f and the capacitance C. The relationship is expressed as follows in formulaic terms:

$$X_c = \frac{1}{2\pi f C} = \frac{1}{wC} \qquad (1)$$

That means:

1. As the applied frequency increases, the reciprocal decreases.

2. The larger the capacitor's capacitance, the smaller the reciprocal.

3. The smaller the reciprocal, the smaller the capacitor's reactance.

Theory (3/6)

An additional attribute of a capacitor is that its current is ahead of its voltage. This can be easily understood when starting with a completely discharged capacitor. When it's connected to a power source, a high charge current is initially present, which diminishes over time. As more charges are gathered on the capacitor plates, the movement of the charge decreases. As the charge flow occurs, a voltage develops across the plates.

In the ideal capacitor the phase shift is $\pi/2$ between current and voltage.

In general, the following applies to a capacitor with capacitance C:

$$I(t) = C\frac{dU}{dt} \qquad (2)$$

If a sinusoidal alternating voltage

$$U(t) = U_0 sin(\omega t) \qquad (3)$$

is applied to the capacitor, the current is calculated:

$$I(t) = CU\omega \cdot cos(wt) \qquad (4)$$

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Theory (4/6)

PHYWE

For the impedance Z of resistors R and X_c connected in series in an AC circuit, the following applies:

$$Z = \sqrt{R^2 + X_c^2}$$

$$= \sqrt{R^2 + \frac{1}{(\omega C)^2}} \qquad (5)$$

Theory (5/6)

PHYWE

Amplitude, phase response and cut-off frequency for a low pass

The following applies to the dependence of input and output voltage on frequency (amplitude response) for a low-pass filter:

$$G(f) = |\frac{U_a}{U_e}| = \frac{1}{\sqrt{1 + (\omega CR)^2}} \qquad (6)$$

If the voltage drop at R and X_c is equal, then the following applies to the amplitude response at this point

$$G(f) = |\frac{U_a}{U_e}| = \frac{1}{\sqrt{2}} \qquad (7)$$

The phase response is determined by

$$\phi = -arctan(\omega CR) \qquad (8)$$

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Theory (6/6)

Amplitude, phase response and cut-off frequency for a high pass

The following applies to the dependence of input and output voltage on frequency (amplitude response) for a high-pass filter:

$$G(f) = |\frac{U_a}{U_e}| = \frac{\omega CR}{\sqrt{1+(\omega CR)^2}} \qquad (9)$$

The phase response is determined by

$$\phi = -arctan(\frac{1}{\omega CR}) \qquad (10)$$

Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Equipment

Position	Material	Item No.	Quantity
1	Plug-in board, for 4 mm plugs	06033-00	1
2	Resistor 100 Ohm, 1W, G1	39104-63	1
3	Resistor 1 kOhm, 1W, G1	39104-19	1
4	Capacitor 4,7microF/ 100V, G2	39113-03	1
5	Digital storage oscilloscope with USB, 100 MHz / 2CH, 1GS/s	EAK-P-1404	1
6	Connecting cord, 32 A, 750 mm, blue	07362-04	2
7	Connecting cord, 32 A, 750 mm, red	07362-01	2
8	Measuring cable BNC to 4 mm banana plug, length 1 m	EAK-MKS-1	2
9	brigde plug	06027-07	4
10	PHYWE Digital Function Generator, USB	13654-99	1

Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

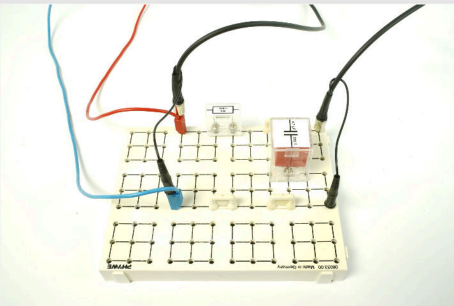
PHYWE

Setup and procedure

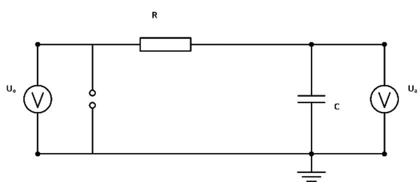
Setup (1/2)

PHYWE

- Set up the experiment of a low-pass filter according to the circuit diagram an the shown picture.
- The voltage curve of the input signal U_e is measured with $CH1$ and the voltage curve of the output signal U_a with $CH2$ of the oscilloscope.



Experimental setup lowpass



Circuit diagram

Use the autoscaling of the oscilloscope.

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Prodedure (1/3)

PHYWE

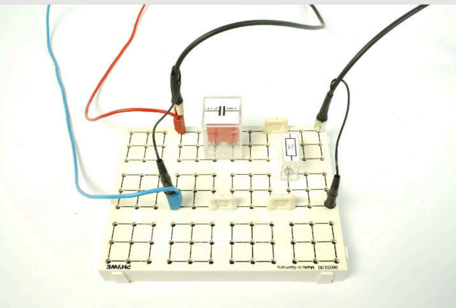
meausrements on a low-pass filter

- Observe the output voltage for different resistors and capacitors at a fixed input voltage of about $8V$ and frequencies of $1Hz, 50Hz, 100Hz, 500Hz$.
- Use the resistance $R = 100\Omega$.
- Note the results in a table.
- Measure Ue and Ua for the frequencies: $1Hz, 10Hz, 50Hz, 100Hz, 250Hz, 500Hz, 650Hz, 800Hz, 1000Hz, 1500Hz, 2000Hz$.
- Create a table and enter the measured values there.
- Save the recordings of the oscilloscope (instructions for this can be found in the operating manual of the oscilloscope).

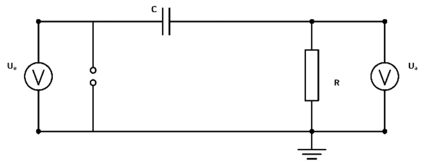
Setup (2/2)

PHYWE

- Set up the experiment of a high-pass filter according to the circuit diagram an the shown picture.
- The voltage curve of the input signal U_e is measured with $CH1$ and the voltage curve of the output signal U_a with $CH2$ of the oscilloscope.



Experimental setup highpass



Circuit diagram

Use the autoscaling of the oscilloscope.

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Prodedure (2/3)

PHYWE

meausrements on a high-pass filter

- Observe the output voltage for different resistors and capacitors at a fixed input voltage of about $8V$ and frequencies of $10Hz, 50Hz, 100Hz, 500Hz$.
- Use the resistance $R = 1000\Omega$
- Note the results in a table.
- Measure U_e and U_a for the frequencies: $10Hz - 2000Hz$
- Create a table and enter the measured values there.
- Save the recordings of the oscilloscope (instructions for this can be found in the operating manual of the oscilloscope).

Prodedure (3/3)

PHYWE

square wave voltage as input signal at, high and low pass filter

- Finally, select a square wave voltage signal as the input signal. Set the parameters:
  - Amplitude = $8V$ and
  - signal: square wave
    - low pass: frequency = $400Hz$
    - high pass: frequency = $20Hz$
- Observe the output signal and save the oscilloscope recording.

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

PHYWE

Results and evaluation

Results and evaluation (1/5)

PHYWE

Lowpass filter

The following behavior could be observed at the lowpass:

- $f = 10Hz$ U_e and U_a in phase, same amplitudes.
- $f = 50Hz$ U_e and U_a slight phase shift, same amplitudes.
- $f = 100Hz$ U_e and U_a slight phase shift, same amplitudes.
- $f = 500Hz$ U_e and U_a significant phase shift, different amplitudes.

Fig. 1: $U_e = 8V, f = 10Hz, R = 100\Omega, C = 4,7\mu F$

Fig. 2: $U_e = 8V, f = 50Hz, R = 100\Omega, C = 4,7\mu F$

Fig. 3: $U_e = 8V, f = 500Hz, R = 100\Omega, C = 4,7\mu F$

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Results and evaluation (2/5)

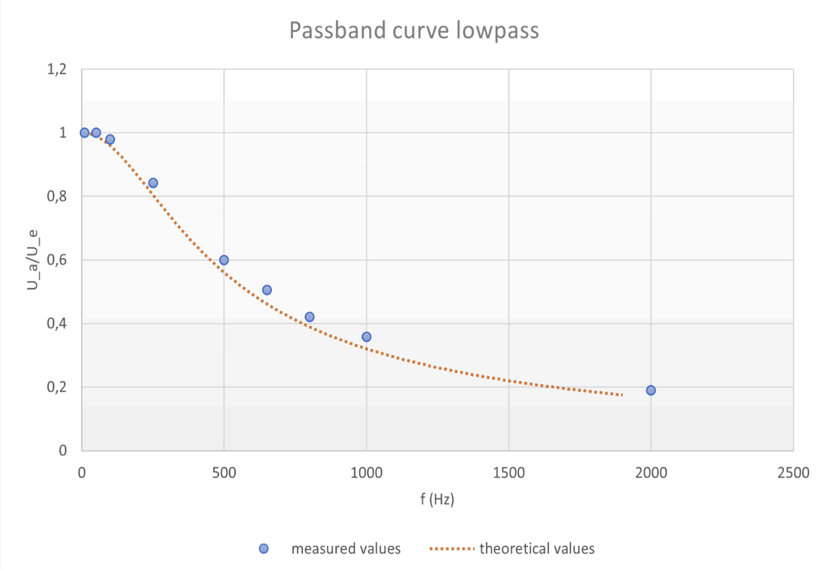
PHYWE

Amplitude response low pass

If the amplitude response is represented graphically, the diagram on the right is obtained.

For high frequencies the resistance of the capacitor becomes smaller and smaller, it becomes permeable and thus the output voltage goes more and more towards zero.

The calculated value for the cutoff frequency f_g is $338 Hz$, this value is well confirmed experimentally.



Results and evaluation (3/5)

PHYWE

Lowpass filter

The following behavior could be observed at the lowpass:

- $f = 500 Hz$ U_e and U_a in phase, same amplitudes.
- $f = 100 Hz$ U_e and U_a significant phase shift, different amplitudes.
- $f = 50 Hz$ U_e and U_a sphase shift of 0,2 π, different amplitudes.
- $f = 10 Hz$ U_e and U_a sphase shift of 0,4 π, significant different amplitudes.

Fig. 1: $U_e = 8V, f = 500Hz, R = 1000\Omega, C = 4,7\mu F$

Fig. 2: $U_e = 8V, f = 100Hz, R = 100\Omega, C = 4,7\mu F$

Fig. 3: $U_e = 8V, f = 10Hz, R = 100\Omega, C = 4,7\mu F$

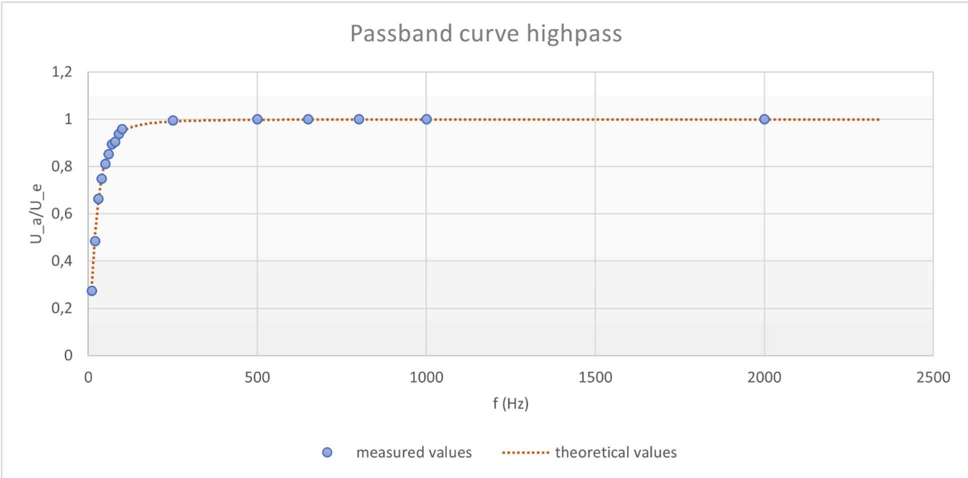
PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Evaluation (4/5)

PHYWE

Amplitude response high pass

For high frequencies, X_c becomes small compared to R; it follows that U_a tends towards U_e or, in other words, the two voltage values U_a and U_e equalize each other. This can be clearly seen in the graph, but can also be derived from equation (9).

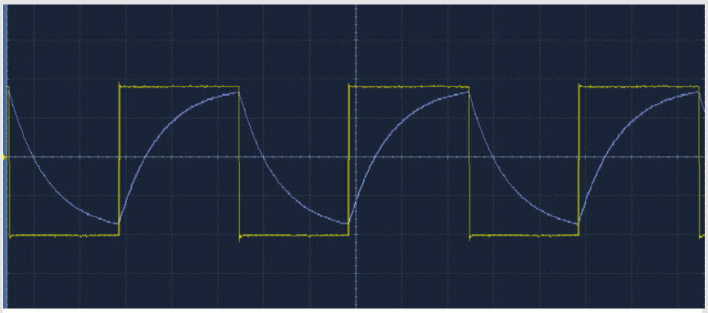


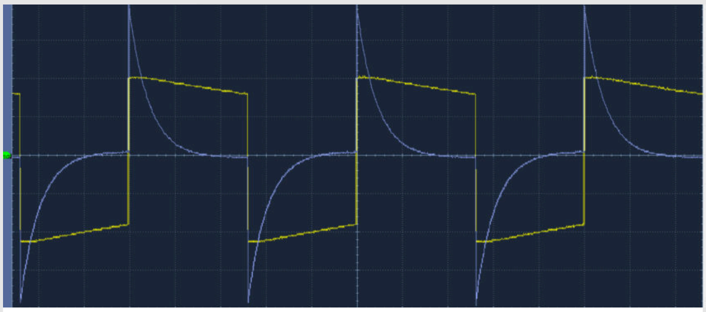
Evaluation (5/5)

PHYWE

Square wave voltage at high and low pass

The following two oscillograms show the voltage characteristics with an applied square wave voltage at the high and low pass. $U_e = yellow, U_a = blue$


lowpass


highpass

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de