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# RC Low-pass filters

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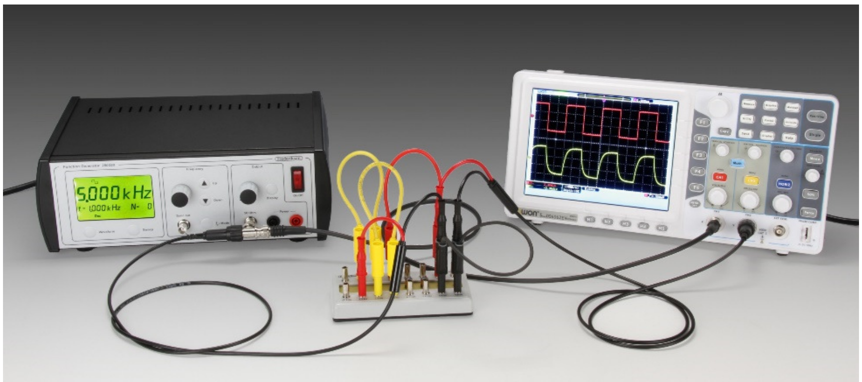
|---|---|---|---|---|---|---|---|
| *Number* | 136310-EN | *Topic* | Alternating current / electronics | | | | |
| *Version* | 2017-01-18 / HS | *Type* | Student exercise | *Suggested for* | grade 12+ | *p.* | 1/4 |



420600

## Objective

The behaviour of simple RC low-pass filters is investigated by measuring of frequency response and step response.

## Principle

Frequency response: The amplitude of a sine wave signal is measured before and after passage of the filter. The ratio between the two amplitudes is plotted with a logarithmic frequency axis.

Step response: A square wave signal is used as input and the output is studied on an oscilloscope.

## Equipment

LCR circuit 420600 includes the following components:

- Resistors:
  24.9 kΩ – 3.3 kΩ – 1.0 kΩ – 1.0 kΩ (1 %)
- Inductors:
  4.7 mH – 1.8 mH (5 %)
- Capacitors:
  2.2 nF – 1.0 nF (1 %)

The components are mounted with sockets that accommodates (shrouded and standard) banana plugs.

The resistors and the capacitors all tolerate more than 24 V DC or AC. The inductors tolerate up to 200 mA. None of these limits are exceeded in the circuits described in this manual.

Connections to function generator and oscilloscope are best made with two shielded cables (item no. 110002, BNC to safety plugs) – while the connection between function generator and oscilloscope is made with a BNC "T" and a standard BNC cable (110025).

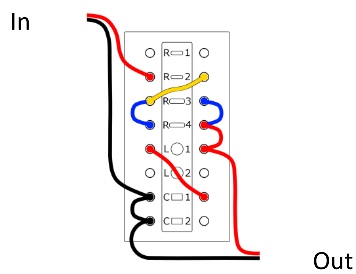
As the shrouded plugs on cable 110002 aren't stackable, these cables must be connected last to the circuit.

Now and then, you may need an extra socket for a ground lead – this can be fixed with an extra 25 cm safety cable, eventually placed in a socket to an unused component as shown below. (A component with only one leg connected isn't part of the circuit.)

The sketches in the manuals 136310 to 136350 all use the following colours:

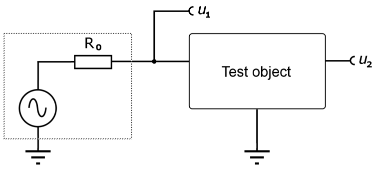
| | |
|---|---|
| Red: | Signal path |
| Black: | Ground |
| Blue: | Parallel connection of components |
| Yellow: | Serial connection of components |

Input to the circuit is in all cases drawn to the left, the output is to the right.



## Frequency response

The setup below shows the function generator hooked up to a test object, e.g. a filter.




The signals at the input and the output of the filter are designated $u_1$ resp. $u_2$.
The signal from the generator must be a sine wave.
The drawing shows explicitly that the generator has an output impedance, here $R_0$ = 50 Ω as we are using the normal output.

The two voltages are monitored by an oscilloscope. With a modern digital oscilloscope, you can directly measure the size of the voltages. If this is not possible you must measure the peak-to-peak voltage on the screen. (There is no need for converting this into an RMS value – as long as you stick to the same type of voltage for all measurements.)

When both voltages $u_1$ and $u_2$ are measured as a function of the frequency *f*, the frequency response of the test object can be determined as

$$A(f) = \frac{u_2}{u_1}$$

It is important to notice that by considering the *ratio* between the voltages, any (frequency dependent) voltage drop over $R_0$ is irrelevant.

*A* is normally plotted in a double-logarithmic coordinate system (a log-log plot).

A *low-pass filter* is a circuit that allows signals with a frequency lower than a certain limit to pass, while more high frequency signals are damped.

A *high-pass filter* works exactly opposite.

Any real filter has a more or less soft transition; there cannot be a sharp cut off at a certain frequency.

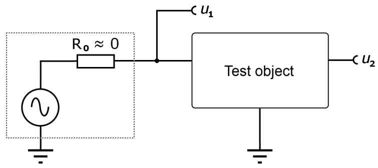
The simplest filters consist of just a resistor (R) and a capacitor (C). These are so-called *1st order filters*.

The components available on the 420600 board can be combined in many different ways: All in all, 260 different 1st order low-pass filters can be made.

## Step response

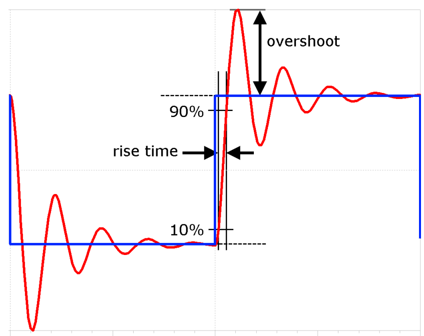
For this measurement, the power output on the function generator is used. Select square waves.

With the component values used here, a frequency of around 5 kHz is suitable. Hence we can profit of the negligible output impedance of the power output.




If you can make screen dumps from the oscilloscope, these can directly be used as measurement results – if not, you can take a photo or simply draw the image on checkered paper.

On the drawing below, the blue curve represents the input signal while the red curve represents a possible output.




We will concentrate on the two parameters rise time and overshoot:

*Rise time* is the time it takes the signal to rise from 10 % to 90 % of the final step value.

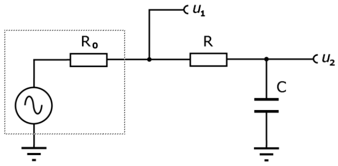
*Overshoot* is the size of the eventual voltage peak above the final step value.

Sometimes a damped oscillation follows the voltage step. This is called *ringing*.

Be warned that while digital oscilloscopes often can measure rise time, the reading can be invalid in the case of ringing – check with the axis units and common sense.

## 1) RC low-pass filter – measuring frequency response

Use the normal (50 Ω) output on the function generator.




The cut-off frequency $f_0$ of the filter is defined as the frequency where the signal is damped a factor of $1/\sqrt{2}$ (i.e. about 71 % of the input voltage). It is given by

$$f_0 = \frac{1}{2\pi \cdot R \cdot C}$$

Out of the many possible combinations that can be made with this equipment, we select the following which gives a good distribution of cut off frequencies:

| | |
|---|---|
| 3.3 kΩ and 1.0 nF | (a) |
| 5.3 kΩ and 2.2 nF | (b) |
| 24.9kΩ and 2.2 nF | (c) |

5.3 kΩ is the serial connection (1+1+3.3) kΩ

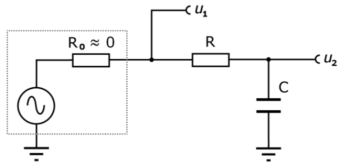
Measure, for each filter, the frequency response:

Use the oscilloscope to measure input and output voltages ($u_1$ and $u_2$) at $f_0$ – as well as at the following frequencies: 100 Hz; 500 Hz; 1,5 kHz; 5 kHz; 10 kHz; 25 kHz; 75 kHz; 150 kHz; 300 kHz.

Plot $u_2/u_1$ as a function of frequency. Use logarithmic axes. comment on the appearance.

## 2) RC low-pass filter – measuring step response

The setup is almost the same as before, but this time we use the power output on the function generator. We can therefore forget about $R_0$. The signal from the generator is fed to the input of the filter. Select square waves and a frequency of 5 kHz.

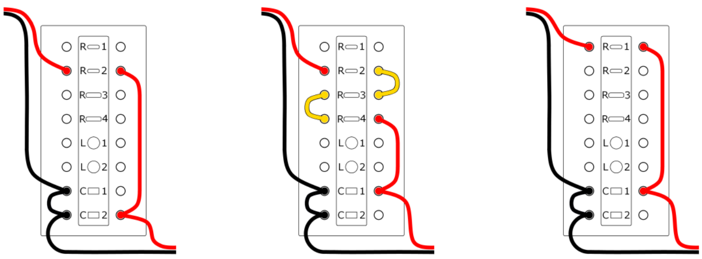



Use the same component values as in the previous experiment.

Adjust the oscilloscope to make both the input signal $u_1$ and the output signal $u_2$ visible on the screen.

For each filter, the oscilloscope screen is copied, photographed or drawn.
In all three cases, measure rise time and determine whether there is an overshoot.

Comment the results – possibly in the context of the results of the first experiment.



(a) (b) (c)

## Theory

The cut-off frequency is given by:

$$f_0 = \frac{1}{2\pi \cdot R \cdot C}$$

The frequency response for an RC low-pass filter:

$$A_{lowpass}(f) = \frac{1}{\sqrt{1 + \left(\frac{f}{f_0}\right)^2}}$$

## Presentation

Both the measured and the theoretical frequency response are most conveniently plotted using a spreadsheet.

Make both axes logarithmic. This will emphasize some points about the behaviour of the filters.

It is suggested to use the same coordinate system for all of the frequency response graphs.

## Discussion and evaluation

Try to describe the behaviour of the filters in words. What is the significance of the cut-off frequency?

Compare the theoretical and the measured frequency responses. Are there deviations? Can these simply be due to the tolerance (1%) of the components?

## Teacher's notes

### Concepts used

Frequency response
Cut-off frequency
Serial connection

Step response
Rise Time
Overshoot

### Mathematical skills

Logarithmic coordinate system
(Using a spreadsheet)

### About the equipment

The 1 kΩ resistors tolerate 1 W.
The other resistors: 0.6 W.
(These power limits will not be exceeded by using normal 0-24 V power supplies or our function generators.)

The capacitors tolerates at least 250 V.

The inductors (coils) has maximum RMS currents of 240 mA (4.7 mH) resp. 210mA (1.8 mH).
As the coils are wound on ferrite cores, a saturation phenomenon will be observed: The inductance drops when the current increases. To minimise this effect, keep signal levels low – never use peak currents larger than 200 mA.

## Didactical considerations

Decibel are not used (but can of course be introduced, if you want to).

This is the reason that we don't mention explicitly the 6 dB / octave slope of 1$^{st}$ order RC filters.

Based on both the theoretical and the measured frequency responses, students should never the less be able to discover the existence of a fixed roll-off slope.

It is recommended to combine this experiment with experiment 136320-EN RC High-pass filters.

It seems obvious to extend this experiment by inclu-ding inductors. These are used in the experiments 136330-EN, 136340-EN, 136350-EN of which especially the latter correspond with the content of this exercise.

## Detailed equipment list

### Specifically for this experiment

420600 LCR-circuit

### Larger equipment

250350 (or 250250) Function generator

400150 Oscilloscope, digital 60 MHz
or
400100 Oscilloscope 60 MHz PC-USB

### Standard lab equipment

| | |
|---|---|
| 110002 | Cable, BNC to two safety plugs (2 ea.) |
| 111100 | BNC T adapter |
| 110025 | Coaxial cable w. BNC connectors, 50 Ohm |
| 105710 | Safety test lead 25cm, black |
| 105711 | Safety test lead 25cm, red |
| 105712 | Safety test lead 25cm, yellow (2 ea.) |