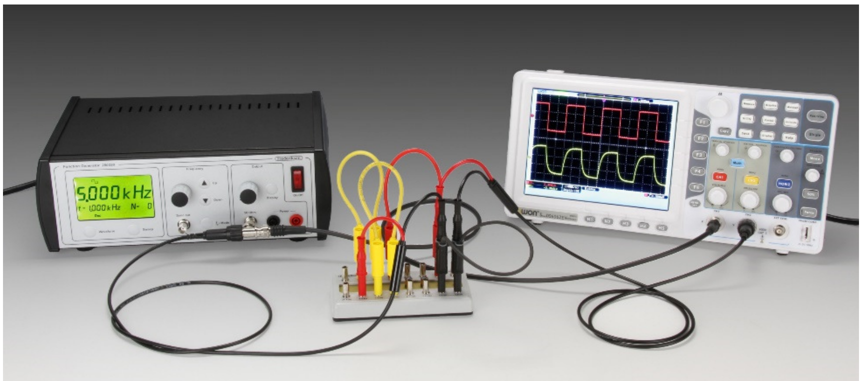
Frederiksen®
Passion for science

LCR band-pass and band-stop filters

Number	136340-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 LCR band-pass and band-stop filters are studied by measuring of frequency response.

Principle

The centre frequency (or phase resonance frequency) is determined by using the oscilloscope in XY mode.

Frequency response: The amplitude of a sine wave signal is measured before and after passing the filter. The ratio of the signal amplitudes are plotted in a logarithmic coordinate system.

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 ac-commodates (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 stack-able, these cables must be connected last to the circuit.

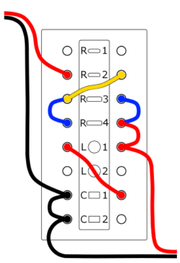
Now and then, you may need an extra socket for a ground lead – this can be fixed with an extra 25 cm safety cable, eventually placed in a socket to an unused component as shown below. (A component with only one leg connected isn't part of the circuit.)

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.

In

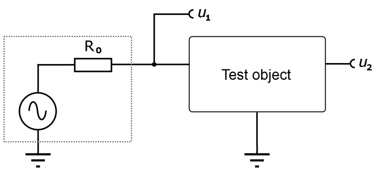


Out

Frederiksen Scientific A/S Tel. +45 7524 4966 info@frederiksen.eu
Viaduktvej 35 · DK-6870 Ølgod Fax +45 7524 6282 www.frederiksen.eu

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 *band-pass filter* is a circuit that allows signals to pass if they have a frequency lying in an interval around a given *centre frequency* – while other signals are damped.

The *bandwidth* of the filter is the length of the frequency interval, measured between the frequencies where the amplitude is reduced a factor of $1/\sqrt{2}$ i.e. to 70.7 % of the maximum.

A *band-stop* 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.

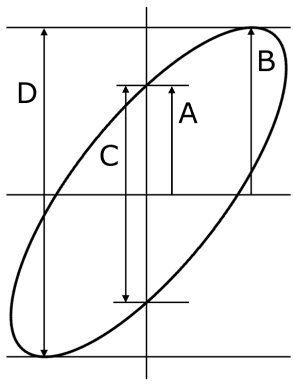
Measuring resonance frequency

We will define the *resonant frequency* f_0 for the LCR resonant circuit (or filter) as the frequency at which the input voltage and input current are in phase. (More accurately this frequency is called the *phase resonance frequency*.)

In the circuits shown on the following page, u_1 and u_2 will have 0° phase difference at the frequency f_0.

(At f_0, the current is in phase with voltage u_1, and the voltage difference $u_1 - u_2$ is proportional with the current – hence, u_2 must be in phase with u_1.)

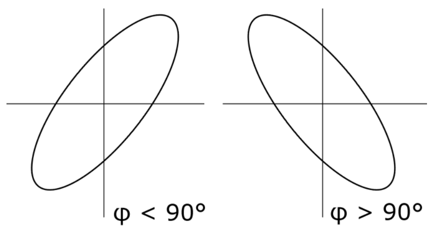
When the oscilloscope is in XY mode, and sinusoidal signals of the same frequency are applied to the inputs, the screen will show an ellipse – or possibly, as a special case, a line or a circle.
The phase difference φ between the two signals is determined by reading the distances C and D (or A and B) of the screen - see the figure below.
(Measuring A and B requires you to be careful to zero-adjust the y-signal.)



The following applies:

$$\sin(\varphi) = \frac{A}{B} = \frac{C}{D}$$

If the phase difference is larger than 90° the major axis of the ellipse will move from quadrant I and IV to quadrant II and III – see figure below.



A phase difference of 0 or 180° will produce a straight line, sloping upwards, resp. downwards. (For larger phase differences than 180° you will see an ellipse again, and if you keep your head the value can still be found. We will not see phase differences that large.)

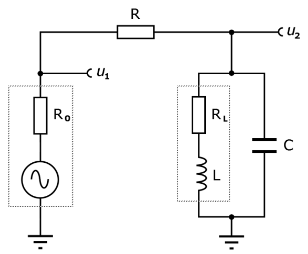
As phase can be perceived as an angle you may hear the term “phase angle” for φ.

Both signals are sine waves so on the 250350 function generator we will use the 50 Ω output.

1) Band pass filters – measuring frequency response

A resonant circuit, consisting of an inductor L (with a series resistance R_L) and a capacitor C, is fed from a function generator through a resistor R as shown. As we measure the actual size of the sine wave voltage u_1, we will not consider R_0 as part of the filter circuit.

The 50 Ω output on the function generator is used.



The parallel resonant circuit has an impedance maximum at its resonance frequency; a signal with a frequency further away will be damped.
The circuit constitutes a simple band-pass filter.

Use R =3.3 kΩ, L = 4.7 mH ($R_L \approx 9$ Ω) and C = 2.2 nF. Figure (a).

Complete the following measurement program:

Determine f_0 where the phase difference is 0°.

Use the oscilloscope to measure the input voltage u_1 and the output voltage u_2 at f_0 as well as at the following frequencies: 5, 20, 30, 40, 45, 50, 55, 60, 75, 100, 110, 130, 150, 200, 300 kHz

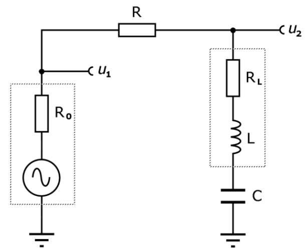
Plot u_2/u_1 as a function of frequency. Use a logarithmic frequency axis. Comment the appearance.

Repeat the measurements with L = 1.8 mH ($R_L \approx 3$ Ω) and C = 1.0 nF. Figure (b).

(Should you have time to spare: Try to repeat with R = 24.9 kΩ.)

2) Band-stop filters – measuring frequency response

The series resonant circuit has an impedance minimum at the resonance frequency – the circuit will dampen signals whose frequency is close to the resonance frequency. This setup is called a band-stop filter.

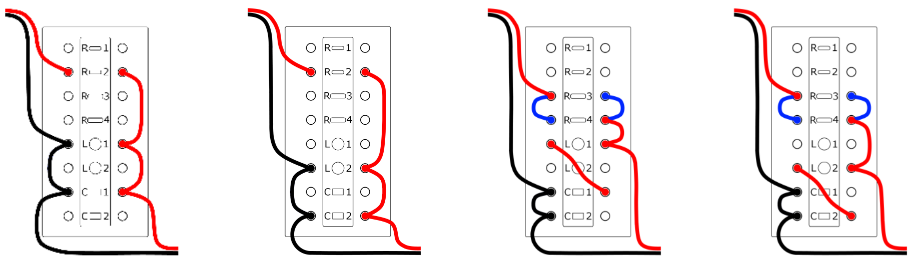


Use R = 500 Ω (achieved by coupling two 1 kΩ in parallel) – se figure (c)

Complete the same measurement program as with the band-pass filters.

Use first L = 4.7 mH ($R_L \approx 9$ Ω) and C = 2.2 nF. Figure (c).

Repeat with L = 1.8 mH ($R_L \approx 3$ Ω) and C = 1.0 nF. Figure (d).



(a) (b) (c) (d)

Theory

The centre frequency – the (phase) resonance frequency – is by a very good approximation given by:

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

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

Specify the centre frequency and bandwidth for the filters. Try to describe the behaviour of the filters in words.

Teacher's notes

Concepts used

- Frequency response
- Centre frequency
- Bandwidth
- parallel connection
- Serial connection

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

Please be aware that many high school math text-books will define a separate concept called "phase shift" which **differs** from its normal use in university mathematics and in physics. It may be a good idea to have a look in your students' math books to avoid any confusion.
It should be safe to talk about "phase difference" or "phase angle" for the quantity φ used in the present text.

Decibel are not used (but can of course be introduced, if you want to). The same applies to the Q factor.

The two filter configurations used are very simple and should in no way be construed as covering this comprehensive subject!

This experiment can with advantage be combined with experiment 136330-EN Resonant circuits.

If you continue to 136350-EN LCR low-pass filters, please notice the two **different** values for the phase difference (measured with the oscilloscope) that indicates the resonance: In the present text, the voltage u_2 is measured across the complete resonant circuit – in 136350-EN it is measured across a capacitor.

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 (2 ea.)
105713	Safety test lead 25cm, blue (2 ea.)