Active filters – band-pass filter

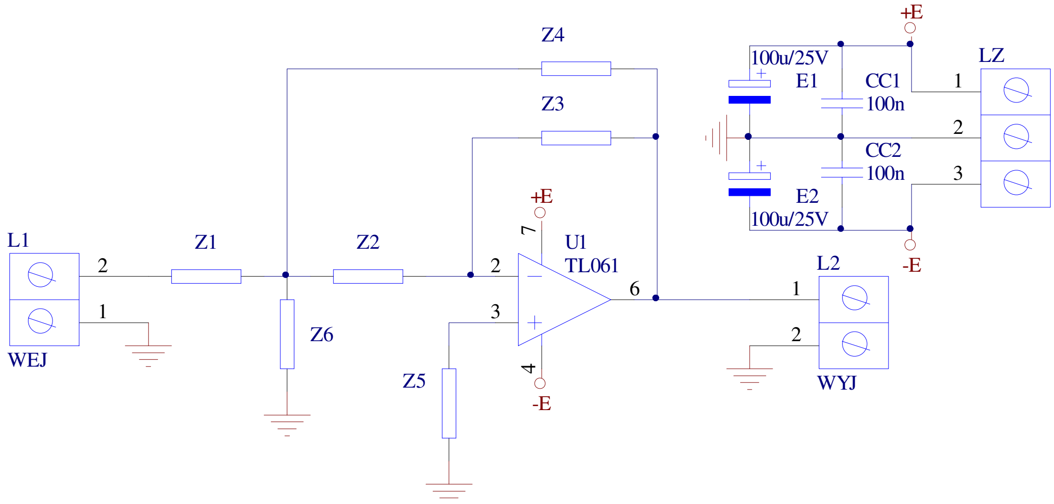
1. Objectives.

The aim of the exercise is to get to know the properties of active filters, their design methods and the measurement of basic filter parameters.

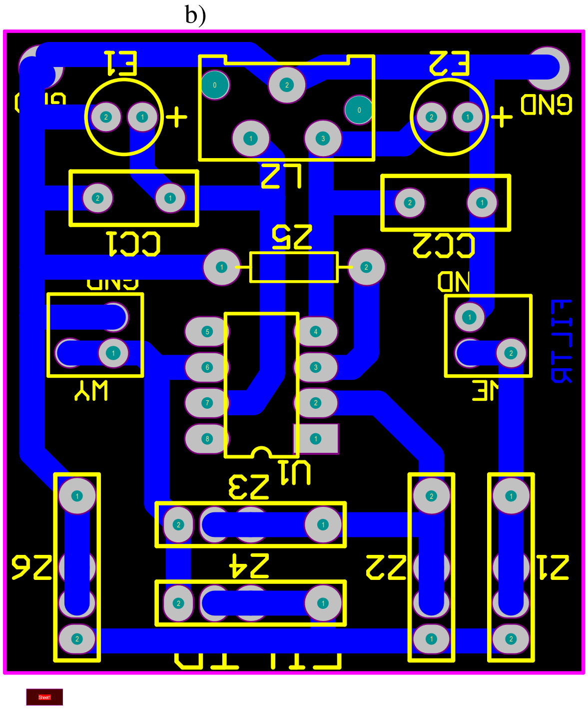
2. Components and instrumentation

Fig.1a presents a schematic diagram of a multiple loop feedback system in which an active low-, upper- or middle-pass filter can be implemented. Fig. 1b shows the view of the PCB according to the diagram in Fig.1a.

a)



b)



c)

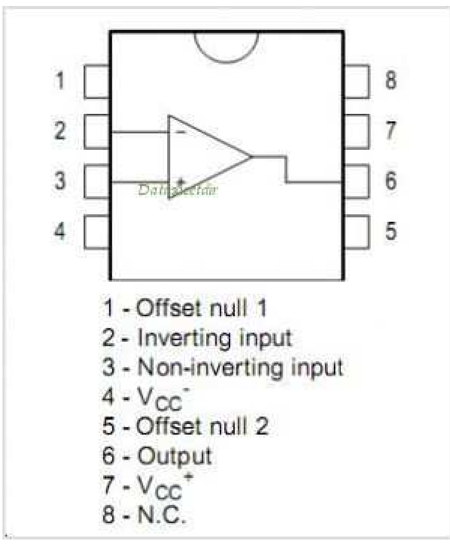


Fig.1. 2nd order active filter with multiple negative feedback loop: a) circuit diagram, b) view of the PCB with the arrangement of elements, c) operational amplifier TL061 - pinout.

Tab.1. Basic parameters of TL 061OPAMP.

Symbol	Parameter	Measurement conditions	Value			Unit.
			Min	Typ	Max	
V_{CC}	Supply voltage			±18		V
V_I	Maximum input voltage			±15		V
V_{IO}	Input offset voltage	$U_O = 0V$		3	15	mV
I_{IO}	Input current offset			5	100	pA
K_{UR}	Open loop gain	$R_L = 2k\Omega$, f = 10Hz		10^5		V/V
$GB=f_T$	gain bandwidth	$R_L = 10k\Omega$		1		MHz
R_I	Input resistance			10^{12}		Ω
R_O	Output resistence			60		Ω
CMRR	Common Mode Rejection Ratio		80	86		dB
SR	Slew Rate	$V_I = 10mV$, $R_L = 10k\Omega$, $K_u = 1$	1.5	3,5		V/µs

2.1. Bandpass filter

Fig. 2 presents the active bandpass filter system implemented in the system structure from Fig.1

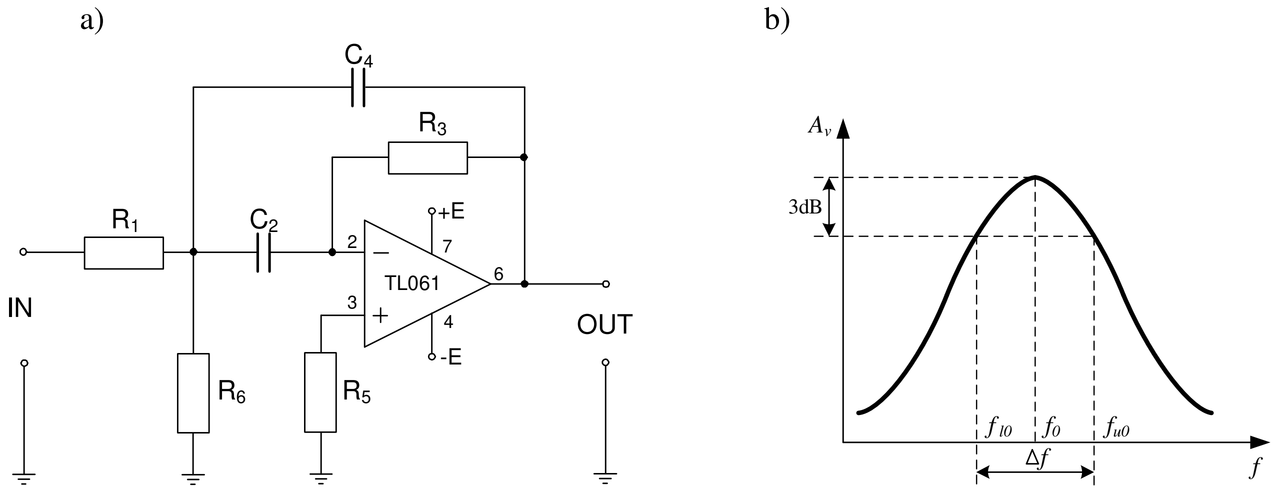


Fig.2. Active band-pass filter: a) implementation, b) transfer function.

Transfer function of the 2nd order band-pass filter from Fig. 2 takes the form of:

$$H_S = \frac{U_{wy}(s)}{U_{we}(s)} = \frac{-\frac{s}{R_1 C_4}}{s^2 + s\left(\frac{1}{R_3 C_4} + \frac{1}{R_3 C_2}\right) + \frac{\frac{1}{R_1} + \frac{1}{R_6}}{R_3 C_4 C_2}} \quad . \tag{1}$$

The values of the band-pass filter elements for given f_0, K_u, Q:

$$|A_v| = \frac{R_3}{2R_1} \quad , \tag{2}$$

$$C_2 = C_4 = C \quad , \tag{3}$$

$$C = \frac{Q}{2\pi f_0 R_1 |A_v|} \quad , \tag{4}$$

$$R_6 = \frac{Q}{2\pi f_0 C\left(2Q^2 - |A_v|\right)} \quad , \tag{5}$$

$$R_3 = \frac{Q}{\pi f_0 C} \quad , \tag{6}$$

$$Q = \frac{f_0}{\Delta f} = \frac{f_0}{f_{u0} - f_{d0}} \quad , \tag{7}$$

$$f_0 = \frac{1}{2\pi C}\sqrt{\frac{R_1 + R_6}{R_1 R_3 R_6}} \quad , \tag{8}$$

where: R_5 – resistor used to minimize the offset error ($R_5 \approx R_3$).

3. Preparation.

3.1. Readings

[1] Lab materials and lectures of the course.

[2] U. Tietze, Ch. Schenk, Electronic circuits. Handbook for Designers and Applications, Springer, 2008, p. 438-572, .

[3] P. Horowitz, W. Hill, The Art of Electronics, Cambridge Univ. Press, London, 2015, p.223-291

3.2. Problems

1. Basic differences between active and passive filters.
2. Classification of active filters.
3. Properties and basic parameters of operational amplifiers.
4. Discuss filters according to frequency response, phase shift and step response:
- Bessel,
- Butterworth,
- Chebyshev.

3.3. Detailed preparation

1. For the parameters of the bandpass filter given by the tutor
   - calculate and select filter elements (resistor values from the E24 series, capacitors from the values available in the laboratory: 1n, 1n5, 3n3, 4n7, 6n8, 10n, 15n, 22n, 100nF),
   - prepper a graph with the frequency response (module and phase) of the filter (e.g. LTspice).
     NOTE: The graph should be prepared on a scale that will allow the actual characteristics measured in the laboratory to be applied to the drawing as well.

*(Usually the characteristics in dB and the frequency on a linear scale and range f0 ± 0.3 * f0 is the right choice)*

- prepare a chart with step response (e.g. LTspice).

4. *Contest of the report - measurements*

1. Assemble the filter according to Fig.2.
2. Apply the symmetric supply ± 15 V.
3. Assemble the measurement setup as in Fig.3.

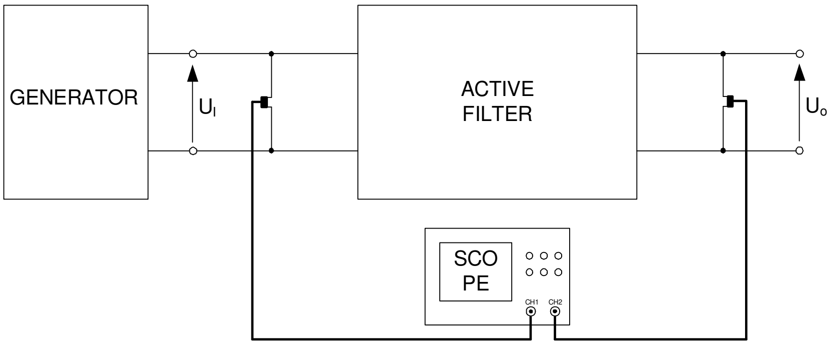


Fig.3. Active filter measurement setup.

1. Observe the ratio of the output and input voltages of the system and determine the limit lower and upper frequencies (3dB). Explain possible differences between measurements and design assumptions. If necessary, correct calculations of the filter.
2. Frequency response measurements:
   For constant input voltage (generator) chosen low enough to achieve undisturbed sine wave on the output for frequency f_0.
   - Read the ratio of the output to the input voltage (amplitude frequency response). The results of measurements should be applied to the prepared graph obtained in the simulation.
   - Read the phase shift between the input and output voltages (phase frequency response). Phase shift read directly from the scope or by applying the method described in Appendix A. The results of measurements should be applied to the prepared graph obtained in the simulation.
   - Estimate Q factor and f_0 frequency from the frequency response..
3. .Step response measurement:.
   - Apply on the input of the filter square wave of the frequency 10-20 times smaller then f0
   - Print the scope screen
   - Estimate Q factor and F0 frequency from the step response.
4. Compare the filter parameters obtained in measurements with that calculated and obtained in simulations (e.g. LTspice) - indicate and justify the differences between the theoretical and the actual results.

Appendix - Phase shift measurement in case the oscilloscope is deprived of this function

Measurement of the phase shift between the two sine signals is most easily done on the screen of the oscilloscope. When measuring, keep in mind that the zero axes of both waveforms must overlap as shown in Fig. A.1. Then the offset between waveforms can be calculated as:

$$\varphi = 360^0 \frac{\Delta t}{T} = 360^0 * \Delta t * f \quad , \qquad \text{(A.1)}$$

Where *Δt, T* – times read directly from scope Fig.A.1

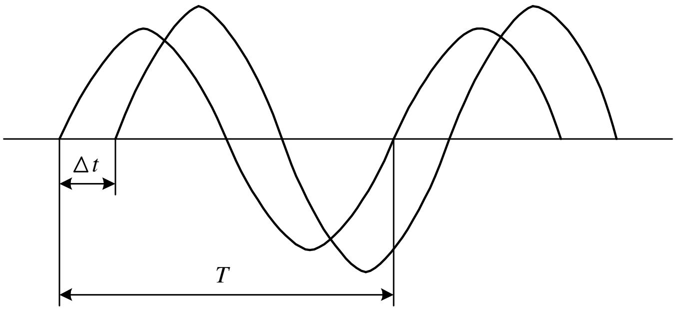


Fig.A.1. Idea phase shift measurement.

The phase shift can also be measured using the Lissajous curve obtained on an XY oscilloscope regime (Fig. A.2). The phase offset between waveforms is calculated from the relation:

$$\varphi = \arcsin \frac{a}{b}$$

where: a, b- reading from scope according to Fig.A.2

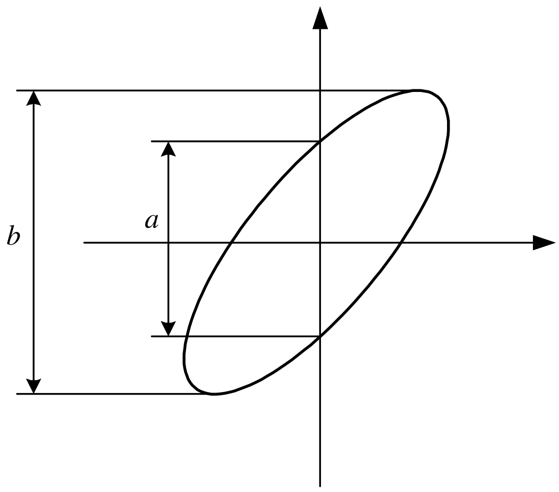


Fig.A.2. Idea phase shift measurement in XY regime of the scope