Operating amplifier – inverting and non-inverting amp

1 Objectives

The purpose of this lab exercise is to learn the properties of operational amplifiers and their basic applications. The scope of the exercise includes the design and measurement of analogue circuits with operational amplifiers.

2 Components and instrumentation.

Fig. 1a shows a schematic diagram of a system in which it is possible to perform basic operational amplifiers (amplifier: reversing, non-reversing, differential, integrating, differential). Fig.1b shows a printed circuit board view according to the scheme of Fig. 1a.

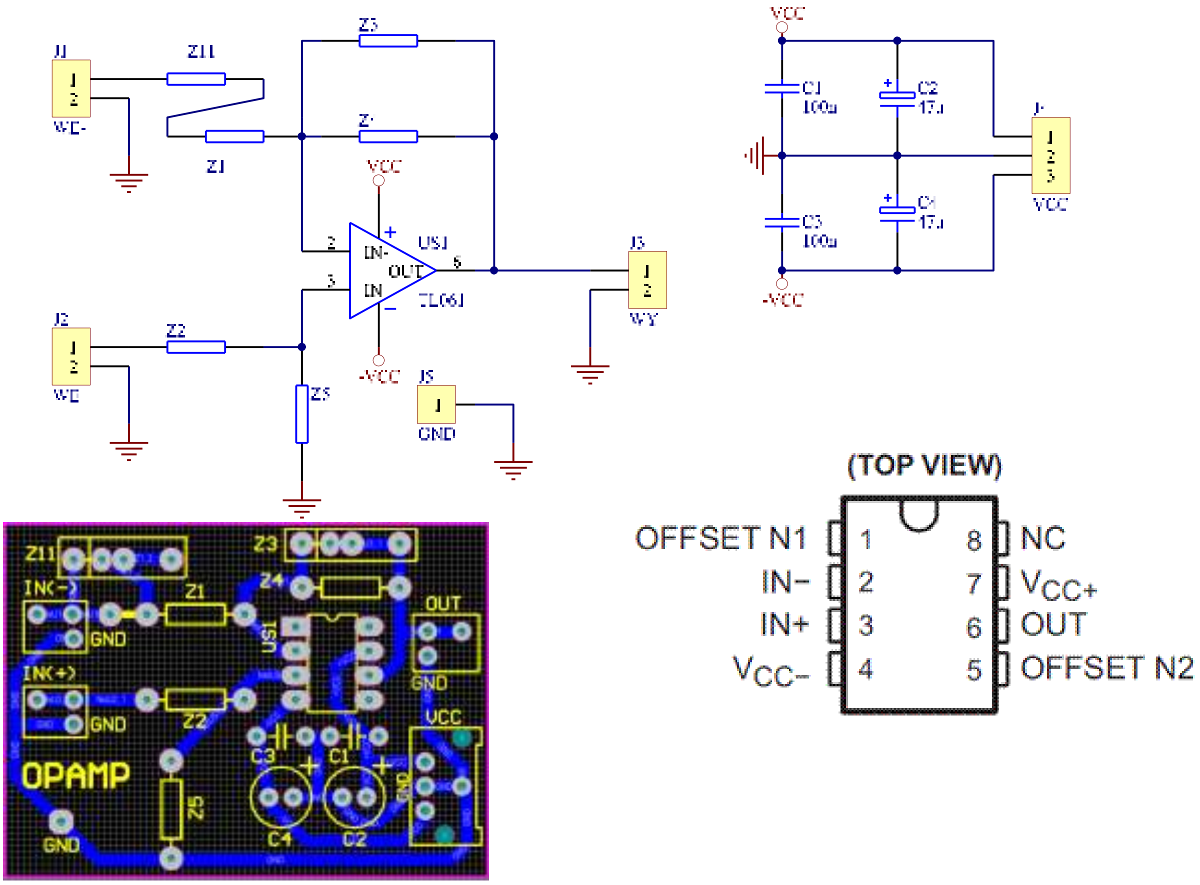


Fig.1. Basic Operational Amplifier schematic diagram, C1-C4 capacitors are used for power decoupling; PCB of the circuit; operational amplifier TL061 – pinout;.

Tab.1. Basic parameters of TL 061 IC

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 Inverting amplifier

Fig. 2 shows an inverting amplifier circuit implemented in the structure of the circuit from fig

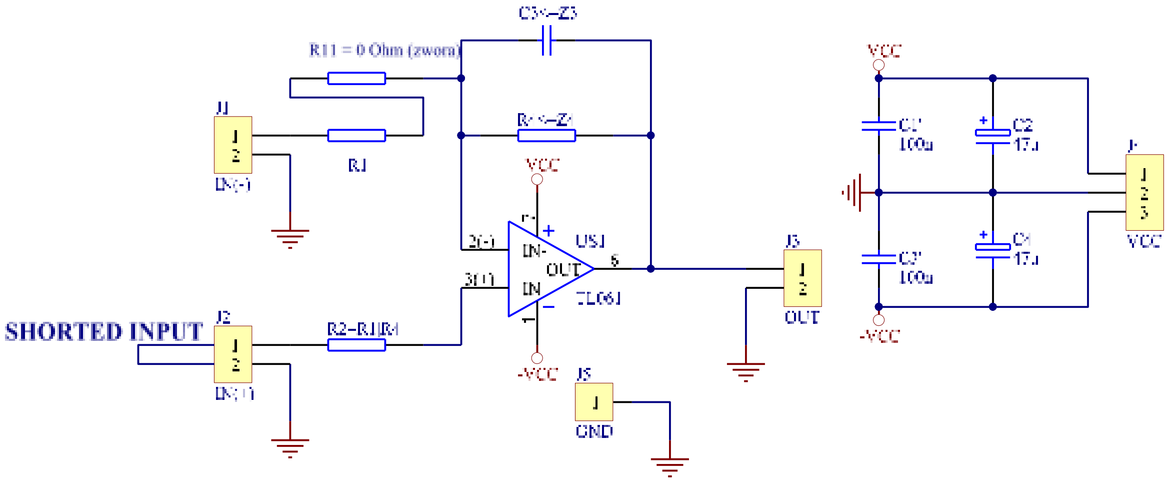


Fig. 2 Inverting amp schematic diagram.

Assuming that in the $A_{vol} \to \infty$, the voltage gain of the inverting amplifier circuit can be expressed as:

$$A_v = -\frac{R_4}{R_1} \quad , \qquad (1)$$

The input resistance of the amp is:

$$R_{IN} = \frac{U_{IN}}{I_{IN}} \approx R_1 \quad , \qquad (2)$$

and output resistance is equal:

$$R_{OUT} \approx R_O \left| \frac{A_V}{A_{VOL}} \right| \quad , \tag{3}$$

since the R_O has small values (tens of ohms) and very large A_{VOL} (=10^5), the inverting amplifier output resistance is negligible and the circuit behaves approximately as the ideal controlled voltage source.
The upper limit frequency of the inverting amplifier system can be estimated by the relation:

$$f_2 \approx \frac{f_T}{A_V} \tag{4}$$

where:
f_T – gain bandwidth
Appling a capacitor in parallel to the resistor R4, the upper limit value of the inverting amplifier can be changed. Then the upper limit frequency of the circuit is approximately equal:

$$f_2' \approx \frac{1}{2\pi R_4 C_3} \quad . \tag{5}$$

2.2 ***Non-inverting amplifier***

Fig. 3 shows the non-inverting amplifier circuit implemented in the structure of the circuit from Fig.1

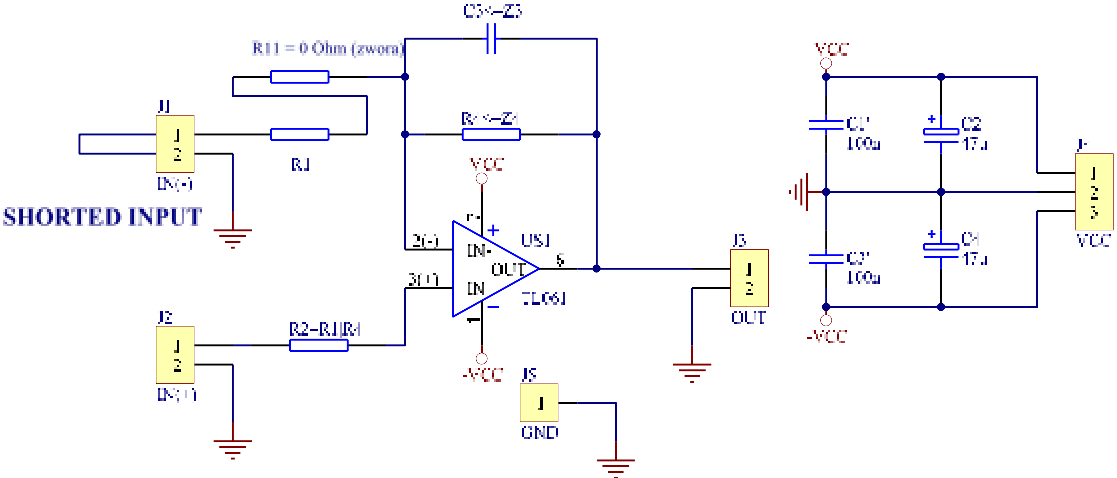


Fig.3,.Non-inverting amp.

Assuming that in the op-amp $A_{VOL} \to \infty$, the voltage gain of the non-inverting amplifier circuit is expressed as:

$$A_V = 1 + \frac{R_4}{R_1} \quad , \tag{6}$$

Input resistivity is then as high as input resistance of amplifier.
The output resistivity is equal:

$$R_{OUT} \approx \frac{R_O}{A_{VOL}} \quad . \tag{8}$$

The upper limit frequency of the non-inverting amplifier system can be approximated according to (4). An additional capacitor connected in parallel with R_2 can shape the value of this frequency according to (5).

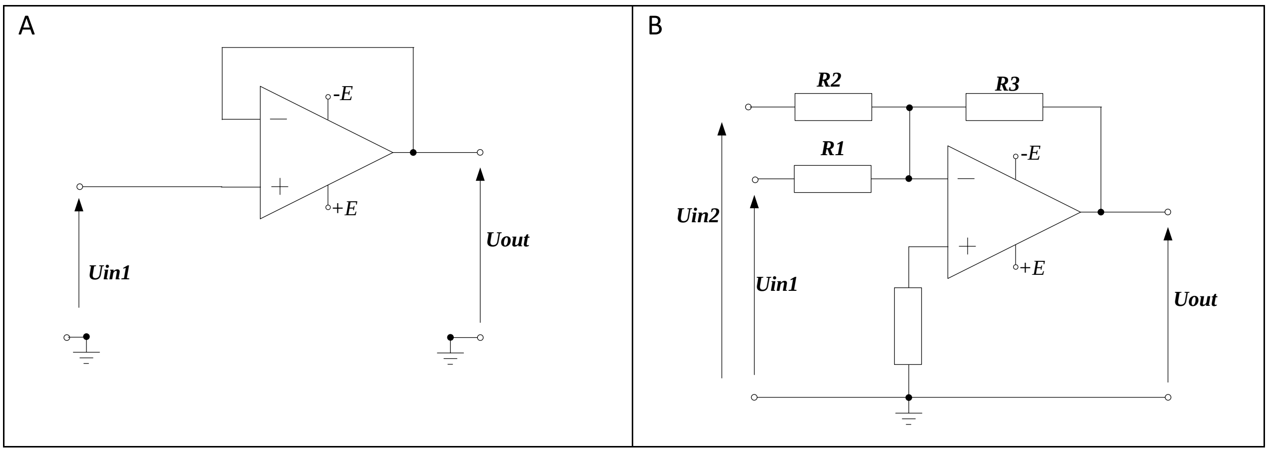
3 Preparation.

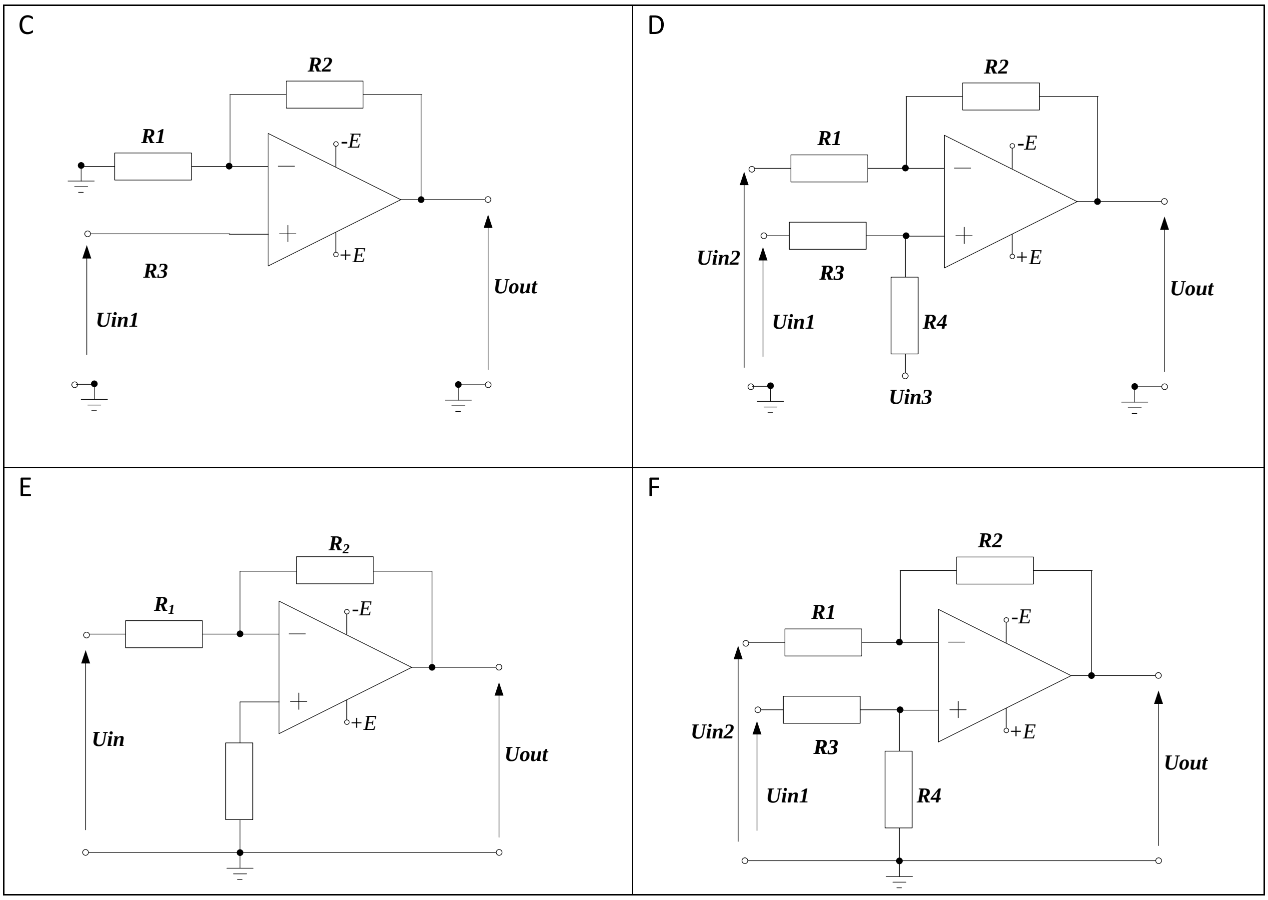
3.1 Readings

[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) Describe perfect operation amplifier parameters
2) Explain „the notion of virtual ground"
3) How symmetric supply of an op-amp can be realized?
4) Draw the schematic diagram and describe the operation principle of an inverting amplifier (derive the equation for gain).
5) Draw the schematic diagram and describe the operation principle of an non-inverting amplifier (derive the equation for gain).
6) Describe the linear range of operation of an amplifier?
7) When there is possible to achieve the gain of 1 in non-inverting amplifier ?
8) What kind of feedback is used in inverting and non-inverting amps with op-amps ?
9) In circuits below derive the output voltage when resistors and input voltages are given.





3.3 Detailed preparation

Calculate the resistors for inverting and non-inverting amplifier according to data given by tutor. Analyze both of circuits using SPICE type of computer program(e.g. LTspice) – calculate the transmittance (gain in dB and phase in *deg*; use logarithmic scale of frequency)

4 Measurements - contest of the report

4.1. Inverting amplifier

For given gain of the amplifier one should:

1. Assemble the circuit according to Fig. 2.
2. Apply supply voltage ± 12 V.
3. As an input signal use sine wave and observe output on scope.
4. Estimate linear range of operation and gain U_{out} = f(U_{in}) by changing the amplitude of input signal and observing picture on the scope in XY and YT regimes.
5. For small input signal $U_{IN(RMS)}$ <100mV, changing the frequency establish the 3dB upper limit frequency (optionally draw the frequency transfer function – both the phase and gain – in dB and logarithmic scale of frequency)
   NOTICE: In case measurements taken by scop one should use mode CycRMS measurement and averaging (Acquire -> Average-> 16)
6. For high (8-10V) amplitude on the output, increasing the frequency and observe the phenomena of slew rate (SR) when output signal have shape close to triangle. Estimate the SR parameter.

7. Apply in parallel to R_4 (Z_3 on PCB - Fig.1b) capacitor (e.g.. 1nF) and repeat measurements from point 5.

4.2. Non-inverting amplifier

For given gain of the amplifier one should:

8. Assemble the circuit according to Fig..3.
9. Apply supply voltage ± 12 V.
10. As an input signal use sine wave and observe output on scope.
11. Estimate linear range of operation and gain U_{out} = f(U_{in}) by changing the amplitude of input signal and observing picture on the scope in XY and YT regimes.
12. For small input signal $U_{IN(RMS)}$ <100mV, changing the frequency establish the 3dB upper limit frequency (optionally draw the frequency transfer function – both the phase and gain – in dB and logarithmic scale of frequency)
    NOTICE: In case measurements taken by scope one should use mode CycRMS measurement and averaging (Acquire -> Average-> 16)
13. For high (8-10V) amplitude on the output, increasing the frequency and observe the phenomena of slew rate (SR) when output signal have shape close to triangle. Estimate the SR parameter.
14. Apply in parallel to R_4 (Z_3 on PCB - Fig.1b) capacitor (e.g.. 1nF) and repeat measurements from point 12.

4.3. Conclusions.

1. Establish range of linear operation of the amplifier. Describe the influence of Av to the range.
2. Compare the measured gain and upper limit frequency with that calculated from equations.
3. Compare observed SR with that from data sheet.
4. Evaluate the impact of a additional capacitor applied in parallel with R_4.

5. 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

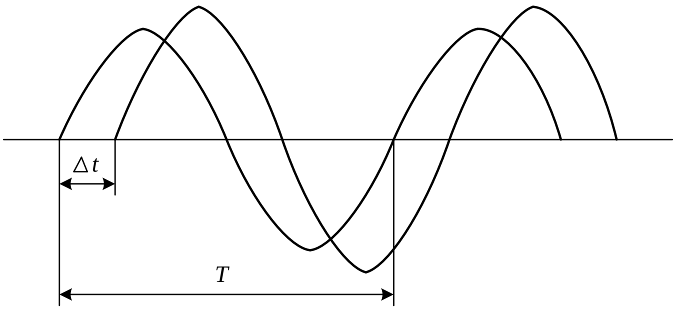


Fig.A.1. Idea phase shift measurement.

The pahse 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:

$$\varphi = \arcsin\frac{a}{b} \quad , \qquad \text{(A.2)}$$

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

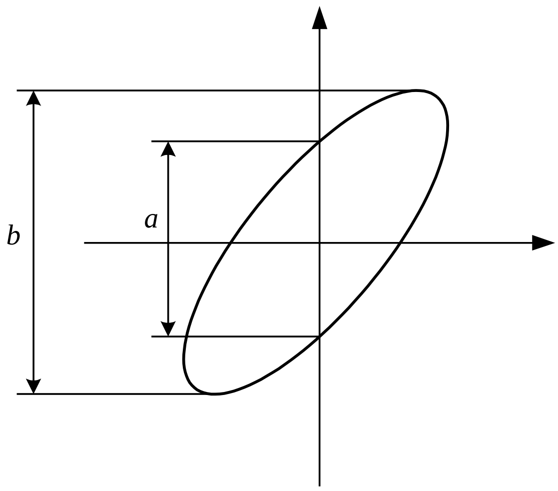


Fig.A.2. Idea phase shift measurement in XY regime of the scope