Exercise 28

APPLICATIONS OF OPERATIONAL AMPLIFIERS

1. Purpose of the exercise

The purpose of this exercise is to present some selected applications of operational amplifiers commonly used in modern electronic analog systems.

Operational amplifiers (op-amp) are now used in all modern electronic systems. The rapid increase of the interest of operational amplifiers has occurred after the introduction in the 1970s to mass production, monolithic integrated circuits with very good properties and low price.

The variety of functions implemented using modern operational amplifiers is, practically speaking, unlimited. In addition to the typical functions for the operation of the operational amplifier in analog computers (basic arithmetic operations and logarithm, integrating and differentiating), are other uses of this system should be mentioned, e.g.:

- voltage limiters,
- comparator systems,
- linear rectifiers
- analog to digital and digital to analog converters,
- generators of rectangular, triangular and sinusoidal waveforms,
- active filters.

2. Introduction to operational amplifiers

2.1 Basic information

The operational amplifier is characterized by high-gain and generally is designed to operate in a system with an external negative feedback circuit. The properties of this circuit determine mainly the characteristics of the entire system.

Most operational amplifiers have **symmetrical (differential) inputs and unbalanced output**. Figure 2.1 shows a commonly used symbol of such amplifier.

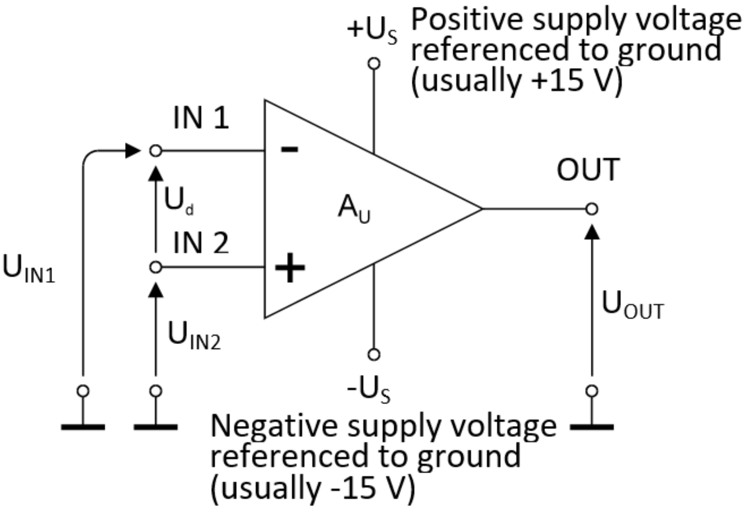

Figure 2.1. Symbol of operational amplifier

Terminal IN1	labeled "-" is **inverting input**, because the output signal is reversed in phase by 180° relative to the applied signal.
Terminal IN2	labeled "+" is **noninverting input**, because the output signal is in phase with the applied input signal.

The operational amplifier may operate in **unbalanced input** system if the input signal is supplied to one of the two inputs IN1 or IN2 (the signal is connected between the input terminal and the ground at the second terminal is attached to ground). In the system with symmetrical input, the input signal is supplied between inputs IN1 and IN2 of the amplifier. This signal is called a **differential signal**. The output voltage is proportional to the value of the differential signal, which is the equal to the difference of input voltages according to the dependence:

$$U_{OUT} = A_U(U_{IN1} - U_{IN2}) = A_U \cdot U_d$$

Where:

U_{IN1}, u_{IN2} - input voltages,
U_{OUT} - output voltage,
U_D - differential input voltage,
A_U - voltage gain of the amplifier with open feedback loop (**differential gain**).

Important feature of the operational amplifier (op-amp) is that **the output signal should be equal to zero when both inputs have identical signals relative to the ground**. The same signal given on both inputs is called a **common** signal. Op-amps suppresses the common signal.

2.2. Transformation characteristics

In Fig. 2.2 **the characteristics of transformation** with the open feedback loop and the basic system for measuring this characteristics are shown.

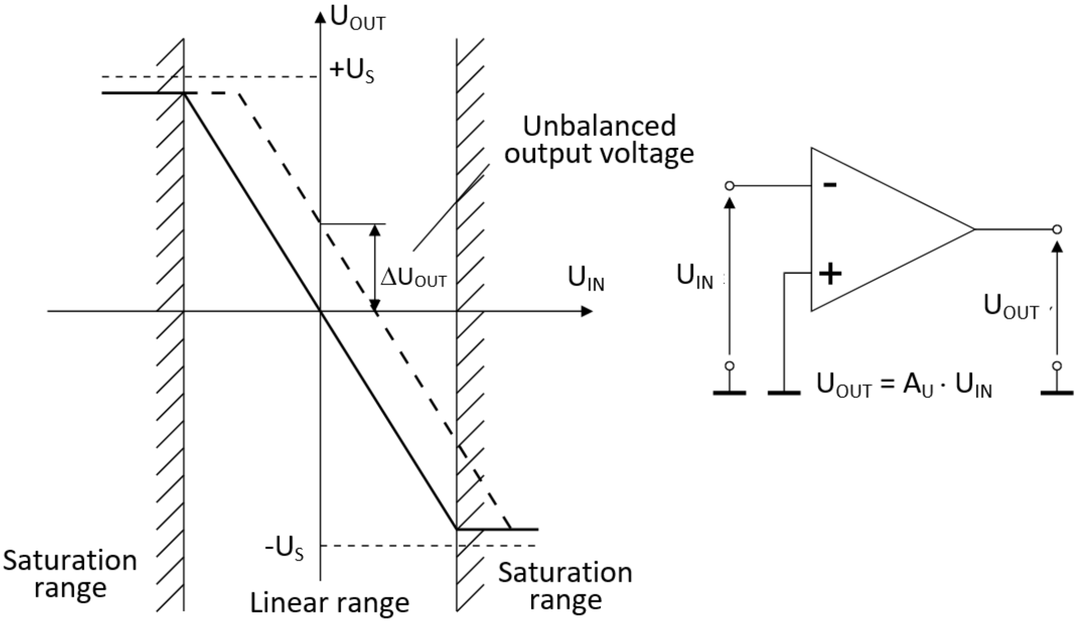

Figure 2.2. Operational amplifier transformation characteristics

In this characteristic three ranges of op-amp operation may be identified: linear operation range and two saturation ranges. For linear operation, the output voltage is defined by the formula:

$$U_{OUT} = A_U \cdot U_{IN}$$

In range of saturation, the output voltage has a positive or negative saturation voltage value, which is usually less by 1 to 2 V from the supply voltage. The linearity range of the op-amp without the feedback is very small. For example, when the op-amp has a saturation voltage of ±10 V and gain A_U is 100000 V/V, the linearity of the input voltage is in the range ±0, 1 mV.
When the linearity range is exceeded, the op-amp enters the saturation state. The output voltage of the op-amp should be zero at difference of the input voltage equal zero (U_{IN}= 0).
In practice, there is a certain voltage in this situation, called an **unbalanced output voltage**.
In Fig. 2.2. a dashed line corresponds to the transformation characteristic for the case when the unbalanced output voltage is greater than zero (ΔU_{IN}> 0). Modern op-amp have the possibility of simple compensation of the unbalance of the output voltage. In practice, this compensation is carried out using the P potentiometer attached to the specially derived amplifier terminals, as shown in figure. 2.3.

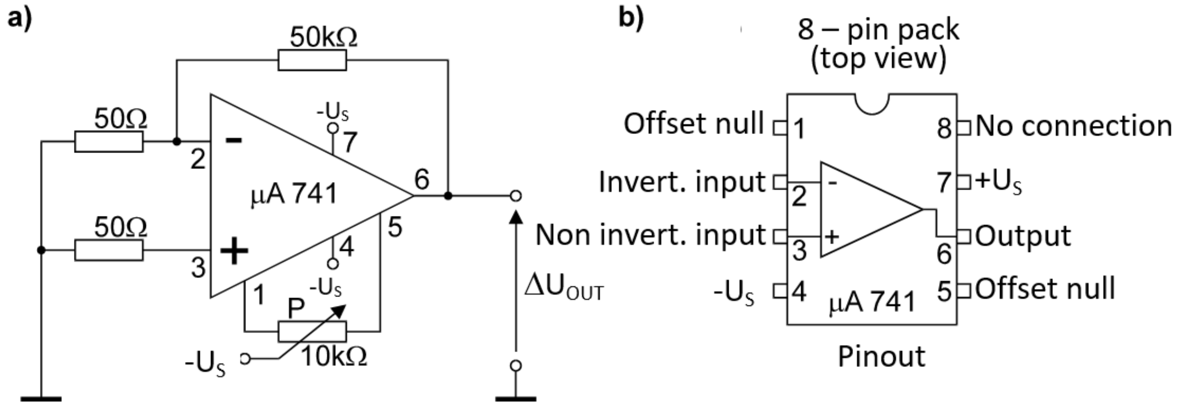

Figure. 2.3. Compensation (balancing, resetting) of the imbalance voltage of the op-amp µA 741 (a) and the arrangement of its terminals (b)

2.3 Ideal operational amplifier

In the analysis of operation of the op-amp with different types of feedbacks an idealized model which is **ideal op-amp** is often used**.**

Table 2.1. shows the basic parameters of ideal op-amps, mass-produced and most commonly used µA 741 produced by Fairchild (equivalent to polish ULY 7741N) and typical parameters of presently used op-amp.

Tab. 2.1.

		Ideal amplifier	µA 741	Other op-amp
Differential gain A_U	V/V	→ ∞	10^5	10^4... 10^7
Differential input resistance R_{ID}	MΩ	→ ∞	1	0.05... 10^4
Output resistance R_O	Ω	→ 0	75	50... 200
Limiting frequency f_T	MHz	→ ∞	1	1... 100

where:

DIFFERENTIAL VOLTAGE GAIN. A_U -	ratio of the output voltage to the differential input voltage at the open loop,
INPUT DIFFERENTIAL RESISTANCE R_{ID} -	resistance between the input terminals,
OUTPUT RESISTANCE R_O -	resistance between the output terminal and the ground in a balanced amplifier with an open loop,
LIMIT FREQUENCY f_T - (UNIT AMPLIFICATION BAND)	the highest frequency at which the differential gain equals to the maximum gain for DC.

From the data presented in the Tab. 2.1 it follows that the ideal parameters of the op-amp are a certain theoretical limit to which the parameters of the commonly constructed op-amp are approaching.

3. Basic circuits of operational amplifiers

3.1. Introduction

The op-amp can operate in the many numbers of different configurations. The simplest option is to use a layout with an open loop. In this case, the op-amp works as a voltage comparator, small differential values of the input voltage, depending on the sign of this voltage, cause one of the two saturation states. It operation is very unstable in this system.

The op-amps are primarily used in systems with external negative close loop. This loop improves the properties of amplifier – decrease nonlinearity of the characteristics and unbalance, extends the frequency band, enhances the steadiness of the parameters and allows to select the gain. Below some basic circuits with op-amp are presented, assuming that its properties are **ideal.**

3.2. Inverting amplifier

The inverting amplifier is such a system in which the input signal is connected in to the inverting input - Fig. 3.1.

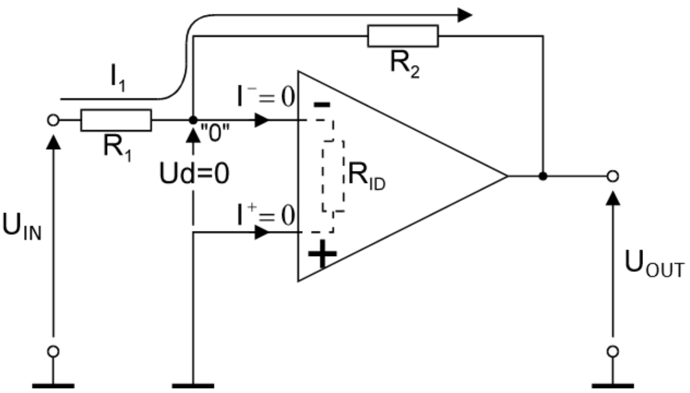

Figure 3.1 Inverting amplifier

If $A_U \to \infty$ than:

$$U_d = \frac{U_{OUT}}{A_U} \to 0$$

The potential of point "0" is equal to the potential of the noninverting input, so it is close to the potential of ground. For this reason, "0" is called the **"apparent ground"**.
If $R_{ID} \to \infty$ and $I^-= 0$, $I^+= 0$ than:

$$\frac{U_{IN}}{R_1} = -\frac{U_{OUT}}{R_2}$$

Therefore, gain of the **inverting amplifier**:

$$A_{uf} = \frac{U_{OUT}}{U_{IN}} = -\frac{R_2}{R_1}$$

By selecting the resistance R_2 (usually R_1= const) you can obtain the required gain.
In the case of $R_1 = R_2$, an inverter with a gain of 1 is obtained .
Inverting amplifier input resistance:

$$R_I = \frac{U_{IN}}{I_1} = R_1$$

Because the resistance R_1 has low value the resistance $R_\mathbf{I}$ has also low value.
In practice, **additional resistor** with a value equal to the resistance of parallel connection of R_1 and R_2 is often connected to the input "+" to achieve best compensation of error caused by unbalance voltage.

3.3. Noninverting amplifier

In the noninverting amplifier system, the input signal is applied to the noninverting input - Fig. 3.2.

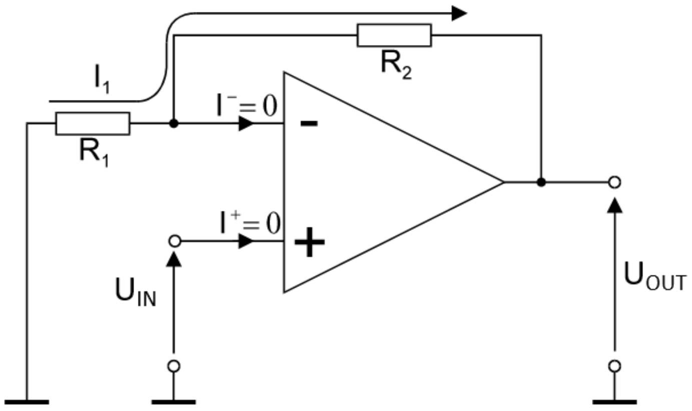

Figure 3.2. Non inverting amplifier

If the op-amp is ideal:

$$-\frac{U_{IN}}{R_1} = -\frac{U_{OUT} - U_{IN}}{R_2}$$

and hence the voltage gain of the system:

$$A_{uf} = \frac{U_{IN}}{U_{OUT}} = 1 + \frac{R_2}{R_1}$$

It is not possible to obtain a gain of ≤1.
Input resistance of the noninverting amplifier:

$$R_I = \frac{U_{IN}}{I^+}$$

Because $I^+ \rightarrow 0$ is $R_I \rightarrow \infty$, in practice resistance value R_I is very high.
For the same reasons as described in p.3.2, in the practical circuit to the input "+" resistor is connected with value equal to the resistance of parallel connection of R_1 and R_2.

3.4 Voltage follower

If in the noninverting amplifier from the Fig. 3.2 the value of resistor R_1 is infinitely high, the system with 100 percent negative feedback is obtained. This system is called a voltage follower (Fig. 3.3).

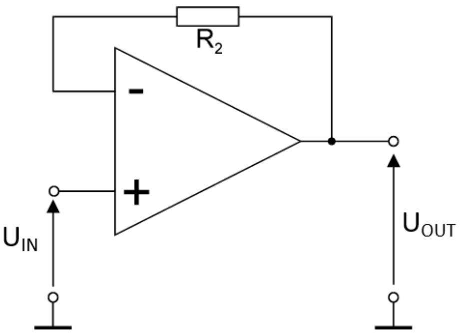

Figure 3.3. Voltage follower

By adopting in the formula for gain of the noninverting amplifier $R_1=\infty$ we receive:

$$A_{uf} = \frac{U_{IN}}{U_{OUT}} = 1$$

The voltage follower has a gain equal to 1 and is characterized by very high input resistance and low output resistance. For this reason, it is ideal for use as a buffer separating electronic circuits (e.g. in a memory-sampling system).
In practice, the resistance value R_2 must be equal to the resistance of the internal input source.

3.5 Differential amplifier

In Fig. 3.4 the differential amplifier diagram is shown.

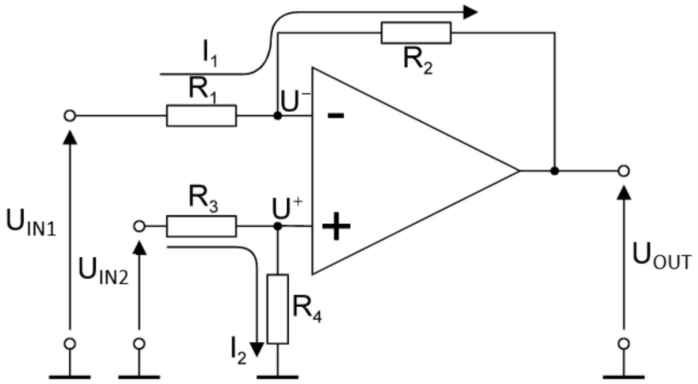

Figure 3.4 Differential amplifier

If the op-amp is ideal (U^+ and U^- voltage at the inputs of op-amp in relation to the ground):

$$\frac{U_{IN2} - U^+}{R_3} = \frac{U^+}{R_4}; \frac{U_{IN1} - U^-}{R_1} = \frac{U^- - U_{OUT}}{R_2}$$

By transforming the above equations and substituting:

$$U^- = U^+$$

The output voltage value is obtained:

$$U_{OUT} = \left(\frac{R_1 + R_2}{R_3 + R_4}\right)\frac{R_4}{R_1} \cdot U_{IN2} - \frac{R_2}{R_1}U_{IN1}$$

In most cases:

$$\frac{R_2}{R_1} = \frac{R_4}{R_3}$$

then the output voltage:

$$U_{OUT} = \frac{R_2}{R_1} = (U_{IN2} - U_{IN1})$$

In addition, if $\frac{R_2}{R_1} = 1$, then $U_{OUT} = U_{IN2} - U_{IN1}$.

3.6. Summing amplifier

Using the op-amp the summation of voltages may be realized using the circuit shown in Fig. 3.5.

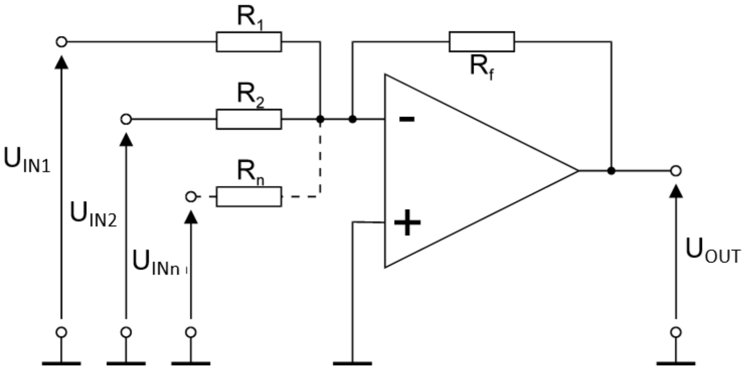

Figure. 3.5. Summing amplifier

$$U_{OUT} = -R_f\left(\frac{U_{IN1}}{R_1} + \frac{U_{IN2}}{R_2} + \ldots + \frac{U_{INn}}{R_n}\right)$$

Using different values of resistors R_1, R_2... R_N is obtained different signal amplification for individual inputs, additionally, performs the function of multiplying the input signals by the corresponding constants. If $R_1=R_2=\ldots=R_N=T_F$ is:

$$U_{OUT} = -(U_{IN1} + U_{IN2} + \ldots + U_{INn})$$

In practice, between the input terminal "+" and the ground a resistor is connected with a value equal to the resistance of parallel connection of resistors R_1, R_2,..., r_n, R_f.

3.7. Integrating amplifier (integrator)

The circuit enabling the integration function using op-amp is shown in Fig. 3.6.

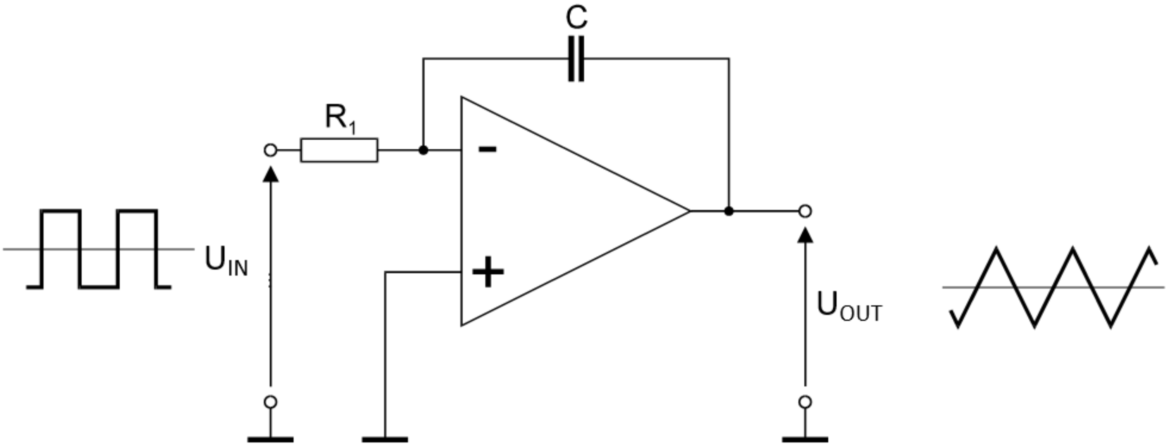

Fig. 3.6. Integrating amplifier

$$U_{OUT} = -\frac{1}{R_1 C}\int_0^T U_{IN} \cdot dt$$

where $R_1 \cdot C = \tau$ is the time constant of integration.

It should be noted that the integrating circuits are working property when the output signal is at a frequency less than $1/\tau$. In Fig. 3.6 A triangular waveform of the output signal is shown, which is the integral of the rectangular waveform input. The practical system of integrator is usually much more complex, because it contain additional elements that set the initial working conditions (containing capacitor C) and compensate errors.

3.8. Differentiator amplifier

If in inverting amplifier circuit, the input resistor is replaced by a capacitor C, the differentiator system is obtained (fig. 3.7).

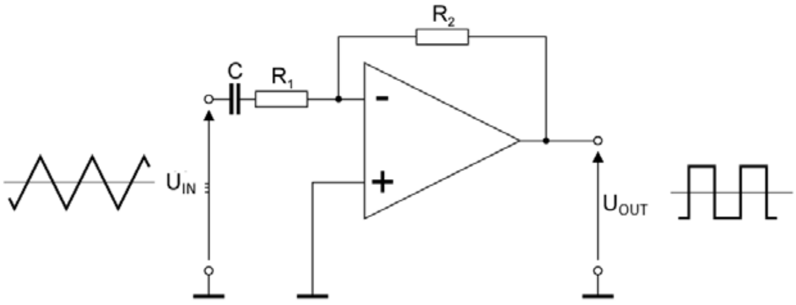

Figure. 3.7. Differentiator amplifier

$$U_{OUT} = -R_2 \cdot \frac{dU_{IN}}{dt}$$

where $R_2C = \tau$ is the time constant of the differentiating.

In Fig. 3.7 a rectangular waveform of the signal is shown, which is derived from the input triangle waveform. A properly selected R_1 resistor switch on to the circuit improves the stability of the amplifier. For the same reason, there is also necessity to include an additional capacitor in the loop circuit (parallel to the R_2 resistor).

4. Other applications of operational amplifiers

4.1 Linear rectifier

The usage of semiconductor diodes in conventional rectifier systems in the field of small signals is limited. This is due to the very high non-linearity of these elements at very small voltages. For example, for silicon diodes at voltages smaller than about 0,7V the conduction of current is practically impossible. The high linearity of the processing AC voltage to DC voltage is achieved by placing the diodes in the loop circuit, which causes the diodes to be conductive even at very low input voltage. The one-half linear rectifier is shown in Fig. 4.1.

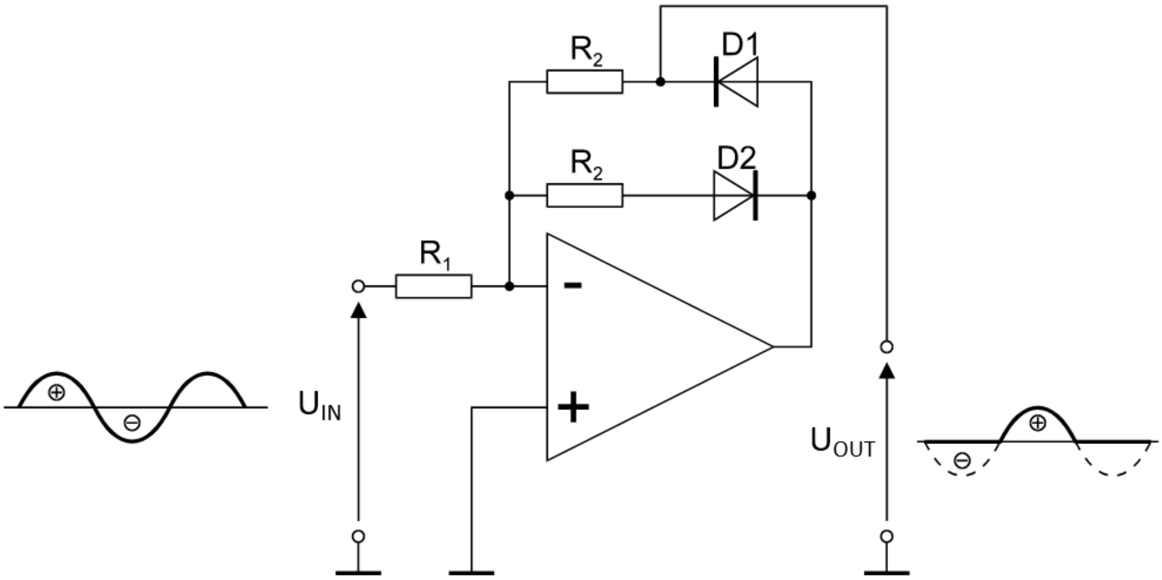

Figure 4.1. Single-half linear rectifier

D1 and D2 diodes are cut off if the output voltage of the op-amp is < |0, 7 V|, the gain of the system is determined by the differential gain of op-amp (open loop).
Closing the loop occurs when the output voltage of op-amp> |0, 7 V|.
The cut-off zone of the diodes D1 and D2 corresponds to a very low range of the input voltage (with op-amp for which A_U= 100 000 V/V the range of non rectified input voltages at which the diodes are cut off is ±0,7 V: 100 000 V/V = ±6 μV). This small range of non rectified input voltages practically has no effect on the accuracy of AC voltage processing in to DC voltage. For positive input voltages > + 6 μV diode D2 leads, so the D1 diode is cut off. The voltage U_{OUT} is equal to zero. The D2 diode is used to protect the op-amp before it enters saturation.
When the negative voltages are input <-6 μV, the D1 diode leads and the D2 diode is cut off. The output voltage of the system is equal:

$$U_{OUT} = -\frac{R_2}{R_1} U_{IN}$$

In case $R_1 = R_2$, the gain of the system equals - 1 and the negative half of the input voltage is repeated at the output as positive.

4.2 Voltage limiter

A voltage limiter is a system that contains negative loops of non-linear elements (rectifier diodes or Zener diodes).
The task of voltage limiters is to shape the input waveform consisting of an asymmetric or symmetrical limit of course - from top or bottom or on both sides. In the op-amp, the limitation may prevent the amplifier from entering the saturation that causes time delays. Necessity of reduction voltage value also arises when working with amplifiers with digital circuits. The voltage limiter with the Zener diodes in the loop shown in Fig. 4.2.

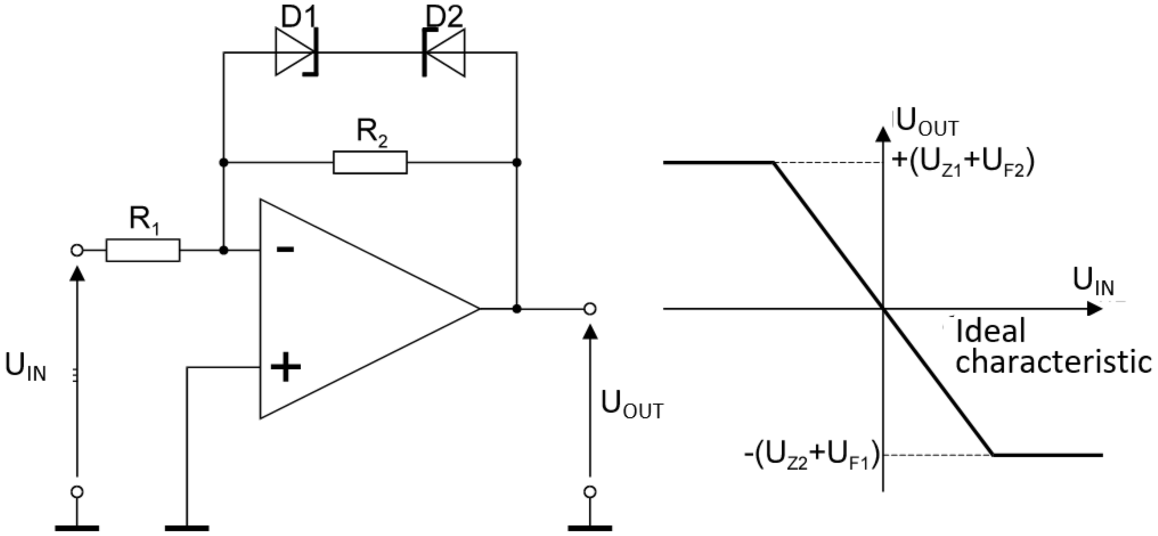

Figure. 4.2 Voltage Limiter

The system occurs the bilateral limit of the input waveform to the value $(U_z + U_F)$,with the Zener voltage of the D1 or D2 diodes, and U_F -their voltage in the direction of conduction. In the range of voltages in which the D1 and D2 diodes do not lead and none of them work in the Zener area, the system acts as a reinverting amplifier:

$$A_{uf} = -\frac{R_2}{R_1}$$

4.3. Comparator

The function of the comparator system is to comparing the analog input of the U_{IN} with the reference signal U_o. On the output of the system, a comparison is obtained in the form of a two-state logical signal indicating the difference between the input signal and the transmission signal. The comparator system is therefore an elementary single bit **- analog-to-digital converter** and is the intermediate link between analog and digital circuits.
Comparators distinguish between **threshold discriminators** (Reference voltage $U_0 \neq 0$) or with **Zero-pass detectors** ($U_0 = 0$). In Fig. 4.3 a differential threshold discriminator system is presented.

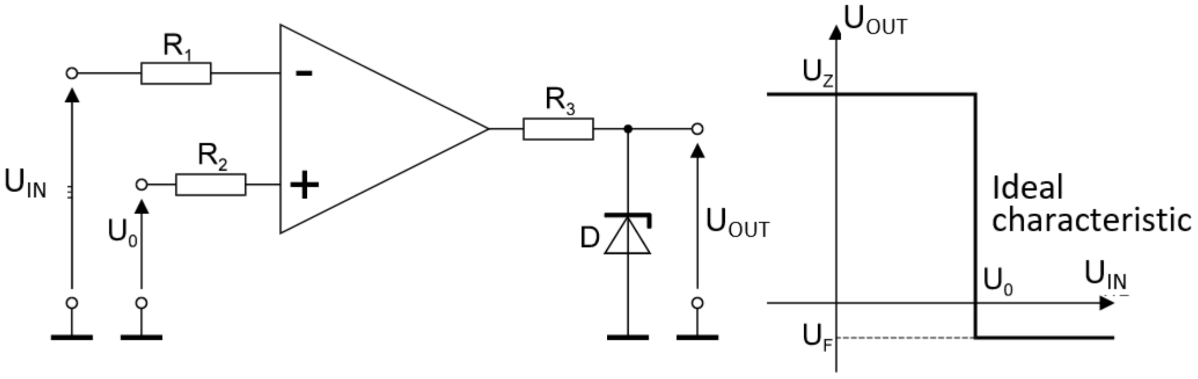

Figure 4.3. Comparator (threshold discriminator)

The output voltage in this system is equal to the Zener voltage U_Z if $U_{IN} < U_o$ or voltage U_F Zener diode polarized in the direction of conduction (about -0,7 V) if the $U_{IN} > U_0$.
To reduce the error caused by unbalance voltage, select $R_1 = R_2$.
Resistor R_3 is used to limit the current of Zener diodes D. By selecting the Zener diode, the output voltage levels appropriate for the cooperation with the logic gates of different types are determined.
A fairly high voltage can occur between the op-amp inputs due to the difference in input and reference voltages. This fact must be taken into account for the type of amplifier with an appropriately high permissible input differential voltage.
Given in Fig. 4.3 the threshold discriminator system can also operate as a **Zero pass detector** if the R_2 resistor is attached to the ground ($U_0 = 0$).
The input signal changes state each time the value of the analog inputs exceeds the zero level.
The zero-pass detectors are widely used in various systems for testing and processing analog signals.

4.4. Rectangular waveform generator

Previously discussed usege of the op-amps included negative loop circuits. An important field of use of amplifiers is also the waveform generators, which are circuits with **positive loop**. An example of a simple solution of a rectangular pulse generator using a single op-amp is given in Fig. 4.4.

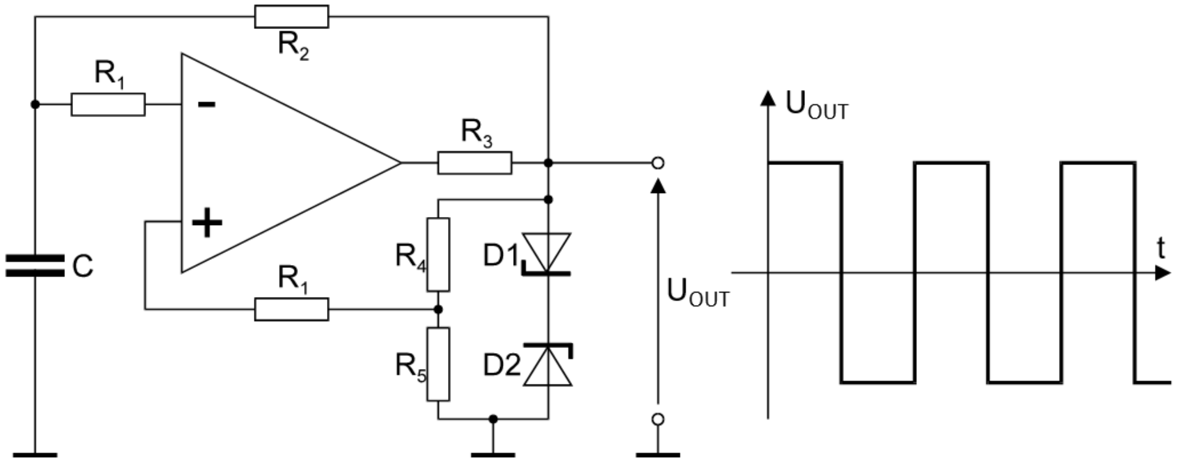

Figure 4.4. Rectangular waveform generator

The voltage obtained at the output is limited by Zener diodes D1 and D2. The Elements R_2 and C form an integral system that determines the frequency of the generator. The frequency adjustment is best done by changing the value of resistor R_2.

4.5. Sinusoidal waveform generator

Diagram of the simplest and most commonly used sinusoidal generators with a fixed frequency is shown in Fig. 4.5.

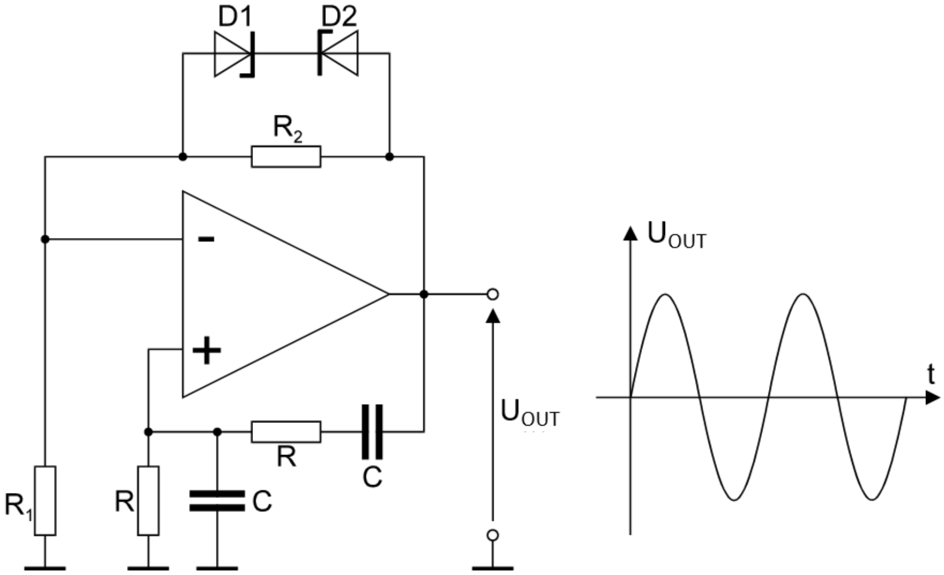

Figure 4.5. Sinusoidal waveform generator

The Zener D1 and D2 diodes limit and stabilize the amplitude of oscillation. The RC elements of the Wiena bridge are placed in the positive loop. These elements determine the frequency of the generator.

4.6 Active RC Filters

4.6.1. Introduction

Filters built with the use of the op-amps are called **active filters.**

The active filter is a group of **passive RC components and active** elements, most often operational amplifiers. The properties of amplifiers, including filters, describe frequency characteristics. The primary is the amplitude characteristic, which determines the dependence of the amplification module on the frequency. The two frequency values at which the gain decreases to the specified value are called boundary frequencies: lower f_L and upper f_H , and they denote the frequency response . In amplifiers as typical assumed a reduction in the gain to the value $\frac{1}{\sqrt{2}} \approx 0{,}707$ of what the logarithmic scale corresponds to 3dB.

The task of **passband filters** is to transform signals of frequencies lying in the **transformation band**, and suppress signals with frequency lying outside in this band.

Band-stop filters fulfill the inverse function, suppress the signals of the frequencies lying in the **band-stop**, and transmit all other signals with frequencies lying out of the band-stop.

Active filters, compared with the passive filters RLC have many advantages, eg. high stability of operation, accuracy, ease of frequency tunability, lack of attenuation of the signal and even the possibility of its amplification, elimination of inductance elements (L) costly and uncomfortable due to large dimensions. RC active filters can operate in a wide range of frequencies - from the thousandths of parts hertz to tens, and even to several hundred kilohertz. The upper frequency of the filter operation is the deliberately and the transmission of the op-amp band.

4.6.2. Band-stop filter

Band-stop filters are used to suppress interfering signals with frequencies lying in the usable bands. They can be used e.g. to eliminate the undesirable frequency in the grid.

One of the many possible execution of a band-stop filter shows the figure. 4.6.

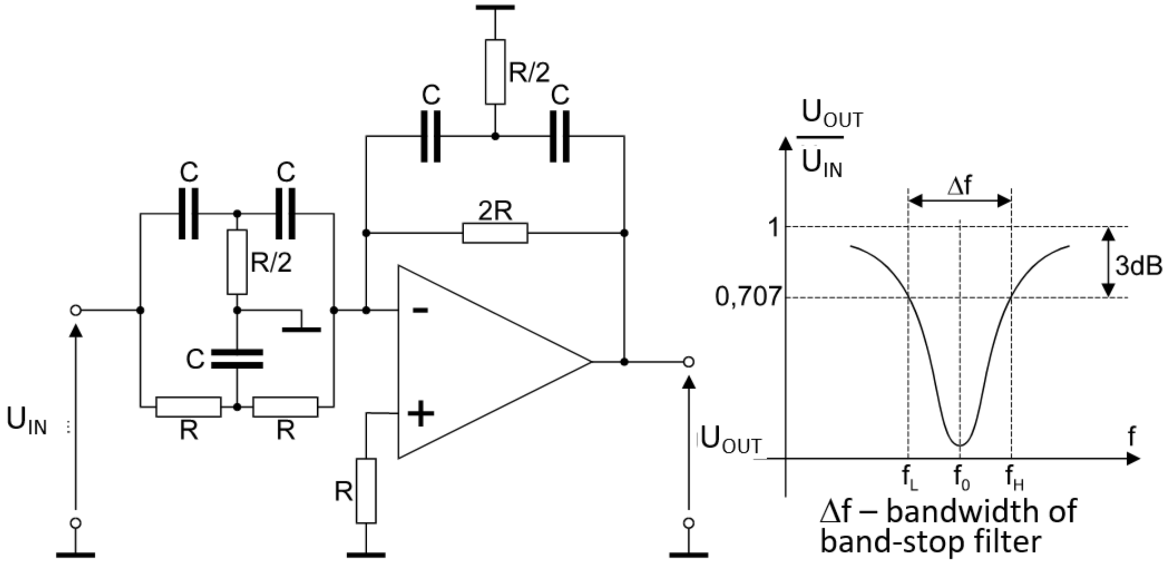

Figure 4.6 Band-stop filter

The frequency at which maximum signal attenuation occurs is the **central (or zero) frequency of f_0**. For the filter presented in Fig. 4.6:

$$f_0 = \frac{1}{2\pi RC};\ A_{uf} = -1$$

where A_{uf} is the **gain of the system in the pass-through band**.

4.6.3. Low-pass filter

An example of a low-pass multi loop filter is shown on Fig. 4.7.

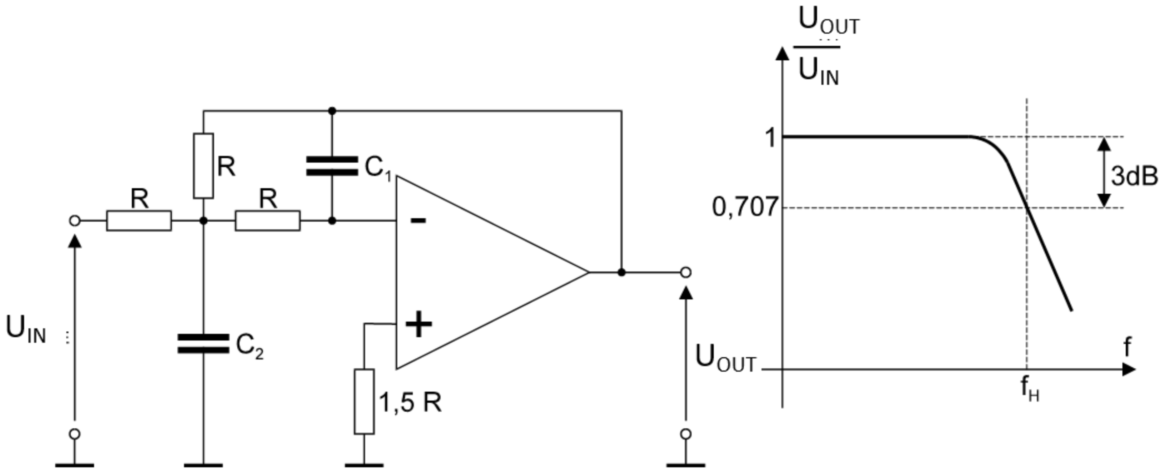

Figure. 4.7. Low-pass filter

In this filter:

$$f_L = \frac{1}{2\pi R\sqrt{C_1 C_2}};\ A_{uf} = -1$$

4.6.4. High-pass filter

The filter diagram is shown in Fig. 4.8.

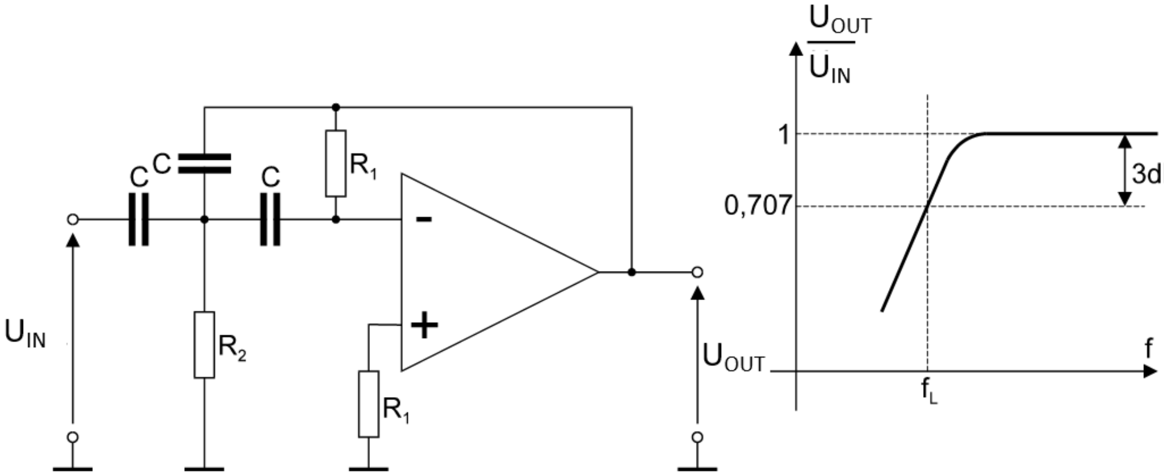

Figure. 4.8 High-pass filter

In this filter:

$$f_H = \frac{1}{2\pi C\sqrt{R_1 R_2}};\ A_{uf} = -1$$

4.6.5. Bandpass filter

The pass (central-pass) filters are mainly used in cases where one frequency signal or a narrow frequency band should be removed, the accompanying noise or interference with frequencies that are similar to the frequency of the signal.

The bandpass filter is shown in Fig. 4.9.

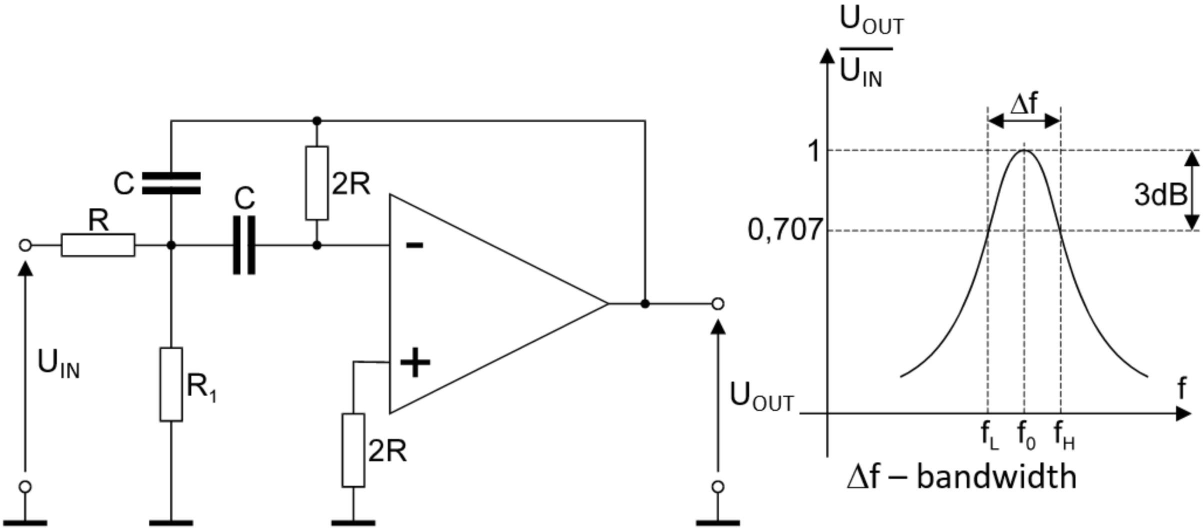

Figure 4.9. Bandpass filter

In this filter:

$$f_H = \frac{1}{2\pi RC\sqrt{\frac{2R_1}{R+R_1}}};\ A_{uf} = -1$$

5. Laboratory studies

All circuits from the op-amp are prepared in the form of a combined device. All attachments, adjustments and measurements are made using the buttons, knobs and voltmeters mounted on the front of the device. The only elements attached to the outside are oscilloscopes and a generator.

5.1 Balancing the amplifier

System tested was presented in Fig. 2.3.

Attach the voltmeter to the terminals of the op-amp and by adjusting the potentiometer P bring the voltmeter display to zero. During an exercise it is **not necessary** to reposition the potentiometer P, as the zeroed op-amp is switched on to all other systems.

After balancing the op-amp, disconnect the compensating system with the corresponding button.

5.2. Inverting amplifier

System tested is presented in Fig. 3.1.

A. Attach voltage U_{IN} with " +" or "-" polarization. Attach the voltmeter to the outputs terminals and supply U_{IN} measure the U_{OUT} value for individual amplifier gains. Note the results in the table. Based on the results of the measurements, determine the actual gain of A_{ufr} amplifier (as the average of the measurements).

A_{uf}= 10		A_{uf}= 20		A_{uf}= 100	
U_{IN}	U_{OUT}	U_{IN}	U_{OUT}	U_{IN}	U_{OUT}
V	V	V	V	V	V
0.5 1.0		0.25 0.40		0.05 0.10	
A_{ufr}=....		A_{ufr}=....		A_{ufr}=....	

$$A_{ufr} = \frac{U_{IN}}{U_{OUT}}$$

B. For gain A_{uf}= 10 specify characteristics of U_{OUT}= f (U_{IN}) over the entire range of the amplifier. Note the measurement results in the table.

A_{uf}= 10	U_{IN}	V	-1.5	-1.4	-1.2	-1.0	-0.6	-0.2	+ 0.2	+ 0.6	+ 1.0	+ 1.2	+ 1.4	+ 1.5
	U_{OUT}	V												

Based on the characteristics, determine the voltage of the U_{OUT} at which the amplifier reach the saturation

+ U_{OUTsat}=.....

- U_{OUTsat}=.....

5.3. Noninverting amplifier

System tested is presented in Fig. 3.2.

As in p. 5.2. (measure the U_{OUT} voltage and determine the actual gain and A_{ufr} (as the mean value of the measurements). Note the results in the table.

A_{uf}= 10		A_{uf}= 20		A_{uf}= 100	
U_{IN}	U_{OUT}	U_{IN}	U_{OUT}	U_{IN}	U_{OUT}
V	V	V	V	V	V
0.5 1.0		0.25 0.40		0.05 0.10	
A_{ufr}=....		A_{ufr}=....		A_{ufr}=....	

5.4 Voltage follower

System tested is presented in Fig. 3.3.

Attach the U_{IN} voltage of the polarization "+" or "-". Attach the voltmeter to the terminals of the OUT. Check the operation of the auxiliary unit by dealing the voltage U_{IN} and measuring U_{OUT}. Note the results in the table.

U_{IN}	V	2	4	6	8	10
U_{OUT}	V					

5.5 Differential amplifier

System tested is presented in Fig 3.4.
Check the operation of the amplifier by dealing different voltage values U_{IN1} and U_{IN2} and measuring U_{OUT}. Compare one of the results obtained with the value obtained as a result of the calculation according to the theoretical relationship describing the amplifier. Specify A_{uf} layout. Results note in the table.

U_{IN1}	V	+5	+5	-5	+5
U_{IN2}	V	+ 2	-2	+ 2	+5
U_{OUT}	V				

A_{uf} =..... $U_{OUT} = A_{uf}(U_{IN2} - U_{IN1})$ =...

5.6. Summing amplifier

System tested is presented in Fig 3.5.
Check the performance of the amplifier by dealing different voltage values U_{IN1} and U_{IN2} and measuring U_{OUT}. Note the results in the table.

U_{IN1}	V	+5	+5	-5	+5
U_{IN2}	V	+ 2	-2	+ 2	+5
U_{OUT}	V				

5.7. Integrating amplifier

System tested is presented in Fig 3.6.
At the input of the system, conect the generator and set the rectangular waveform at the amplitude U_{INemax}= 1 V and frequency 50 Hz. Check the performance of the system by observing the output. Determine the amplitude of the output signal U_{OUTmax}. Observations and measurements made by using an oscilloscope. Specify the $|A_{uf}|$ of the system.

$U_{OUTmax} =$ $|A_{uf}| =$

5.8. Differentiator amplifier

System tested is presented in Fig 3.7.
For the input of the system, connect the generator and set the triangular waveform with amplitude U_{INmax}= 1 V and frequency 50 Hz. Check the performance of the system by observing the output waveform. Determine the amplitude of the output signal U_{OUTmax}. Observations and measurements made using an oscilloscope. Specify the $|A_{uf}|$ system.

$U_{OUTmax} =$ $|A_{uf}| =$

5.9 Linear rectifier

System tested is presented in Fig 4.1.
For the input of the system, connect generator and set the sine waveform with frequency 50 Hz by adjusting the amplitude of the voltage U_{INmax}. Check the performance of the system by observing the output. Determine the amplitude of the output signal U_{OUTmax}. Observations and measurements made using an oscilloscope. Specify the $|A_{uf}|$ system. Note the results in the table.

U_{Wemax}	mV	50	100	200
U_{Wymax}	mV			

$|A_{uf}|$ =..............

5.10 Voltage limiter

System tested is presented in Fig 4.2.
Attach voltage U_{IN}. Attach the voltmeter to the terminals of the OUT. When adjusting the U_{IN} of the two polarizations "+" and "-", measure the characteristics of $U_{OUT}= f (U_{IN})$ of the system. Specify A_{uf} of the system. Note the results in the table.

U_{IN}	V	-2.0	-1.0	-0.5	-0.3	-0.2	-0.1	+ 0.1	+ 0.2	+ 0.3	+ 0.5	+ 1.0	+ 2.0
U_{OUT}	V												

A_{uf} =....

On the basis of the characteristics determine the values of Zener voltages U_{Z1}, U_{Z2} diodes D1 and D2. Assume that the voltage drop on the conductive diode is $U_{F1}= U_{F2}=$ 0,7 V.

U_{Z1}=....

U_{Z2}=....

5.11. Comparator

System tested is presented in Fig 4.3.
Attach voltage U_{IN}. Attach the reference voltage U_0. Attach the voltmeter to the terminals of the OUT. Set the reference voltage value (e.g. U_o= + 2v). Adjust U_{IN} voltage in the range: $U_{IN}< U_0$... $U_{IN}= U_0$... $U_{IN}> U_0$ by measuring the U_{OUT} voltage.
Measure the voltage in U_{IN} at which the state of the output is changed -thus defining the characteristics of the $U_{OUT}= f (U_{IN})$ of the system. On the basis of the characteristics determine the value of the Zener U_Z diode D and its voltage in the direction of conduction U_F.

U_0= + 2v

U_{IN}	V	-1.0	0	+ 1.0	+ 1.9	+ 2.0	+ 2.1	+ 3.0	+ 4.0
U_{OUT}	V								

U_Z=....

U_F=....

5.12. Rectangular waveform generator

System tested is presented in Fig. 4.4.
Attach the oscilloscope to the terminals of the OUT. Determine the frequency and amplitude of the output signal.

U_{OUTmax} =....

f =....

5.13. Sinusoidal waveform generator

System tested is presented in Fig 4.5.
Attach the oscilloscope to the terminals of the OUT. Determine the frequency and amplitude of the output signal.

U_{OUTmax} =....

f =....

5.14 Band-stop filter

System tested is presented in Fig 4.6.
Attach the generator to the IN terminals. Set the sine waveform witch the amplitude U_{INmax}= 1 V. Adjust the input voltage frequency. Measure the amplitude of the output voltage U_{OUTmax}. The measurements are performed using an oscilloscope - thus determining the frequency characteristics of the transformation of the filter - $\frac{U_{OUTmax}}{U_{INmax}} = F(f)$. Note the results in the table.

U_{INmax}= 1 V

f	kHz	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
U_{OUTmax}	V											
$\frac{U_{OUTmax}}{U_{INmax}}$	-											

On the basis of the characteristics specify $|A_{uf}|$ of the system, the central frequency f_0, the lower frequency f_L, the upper frequency f_H , and the bandwidth Δf.

$|A_{uf}|$ = ...

f_0 =....

f_L =....

f_H =....

Δf =....

5.15. Low-pass filter

System tested is presented in Fig 4.7.
Perform analogous steps as in p.5.14.
Designate the filter transformation characteristics -$\frac{U_{OUTmax}}{U_{INmax}} = F(f)$. Note the measurement results in the table.

U_{INmax}= 1 V

f	kHz	1	2	3	4	5	6	7	8	9	10	11
U_{OUTmax}	V											
$\frac{U_{OUTmax}}{U_{INmax}}$	-											

On the basis of the characteristics specify $|A_{uf}|$ The system and the upper frequency f_H.

$|A_{uf}|$ = ...

f_H =....

5.16 High-pass filter

System tested is presented in Fig 4.8.

Perform steps as in P. 5.14. Designate the filter transformation characteristics -$\frac{U_{OUTmax}}{U_{INmax}} = F(f)$. The results of the measurements are in the table.

U_{INmax}= 1 V

f	kHz	1	2	3	4	5	6	7	8	9	10	11
U_{OUTmax}	V											
$\frac{U_{OUTmax}}{U_{INmax}}$	-											

On the basis of the characteristics specify $|A_{uf}|$ The system and the lower frequency f_L.

$|A_{uf}|$ = ...

F_L =....

5.17. Pass band filter

System tested is presented in Fig 4.9.

Perform steps as in p.5.14. Designate the filter transformation characteristics-$\frac{U_{OUTmax}}{U_{INmax}} = F(f)$.. Note the measurement results in the table.

U_{INmax}= 1 V

f	kHz	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
U_{OUTmax}	V											
$\frac{U_{OUTmax}}{U_{INmax}}$	-											

On the basis of the characteristics specify $|A_{uf}|$ The system, the centre frequency f_0, the lower frequency f_L, the upper frequency f_H and the Δf bandwidth.

$|A_{uf}|$ =. ...

f_0 =....

f_L =....

f_H =....

Δf =....

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