Riga Technical University

ELECTRICAL ENGINEERING AND ELECTRONICS:
Tasks and
Methodical Guidelines

This collection contains the tasks, which are a part of the electrical engineering and electronics study programme, methodical guidelines, and tests. It has been developed for regular, external, and part-time students of electrical and non-electrical Bachelor's and Master's programmes.

The collection can also be used for studying electrical engineering and electronics-related topics in qualification raising courses.

The collection includes tasks developed by the Electrical Engineering and Electronics Department. Some tasks and variants thereof are reworked tasks from other collections.

Contents

Theoretical Basis of Electrical Engineering

Task No. 1   Linear direct current circuits

1. Draw up a system of Kirchhoff's equations for the given circuit.
2. Draw up a nodal matrix [A] and loop matrix [B] for the circuit and write the system of Kirchhoff's equations in a matrix.
3. Find all the currents, using the loop current method.
4. Find all the currents, using the node potential method.
5. Compare the currents found using both methods in a table.
6. Calculate the power balance for the given circuit.
7. Draw a potential diagram for any closed loop with minimum two EMFs.
8. Applying the active one-port rule, determine and show graphically $P_k(R_k)$ — dependency of the active power P_k of element R_k on the resistance value, if the resistance R_k ranges from zero to infinity ($0 \leq R_k \leq \infty$). The index k of element R_k is given in the table of given quantities (Table 1.1).

Methodical guidelines for the task

- When drawing up a system of Kirchhoff's equations for a circuit, one must consider that independent equations $k_1 = m - 1$ can be produced according to the Kirchhoff's first law, m being the number of nodes in the circuit; according to the Kirchhoff's second law, the number of independent equations equals the number of independent loops in circuit $k_2 = z - k_1$, i.e. z or the number of branches of a circuit graph.
- When writing equations, one must pay attention to the signs of equation members. In both Kirchhoff's equations, signs of the members depend on the directions of currents, EMF and going around loops; in addition, the directions of currents and loops are chosen arbitrarily.
- It shall be noted in equations produced for loop currents that a branch with an ideal current source does not form an independent loop. The current of a current source shall be considered as a given loop contour, and the branches through which it closes shall be selected arbitrarily. The voltage drops caused by this current are included in the equations of those loops that contain the arbitrarily chosen branches through which the current of the current source closes. The current of the current source shall also be observed when determining the actual currents of the respective branches.
- When drawing up equations using the node potential method, attention shall be paid to determining conductance of those branches with two or more resistances in a series. The conductance of such branch is inverse of the total resistance of that branch.
- When preparing the power balance, one shall remember that EMF and current sources may act as generator or load, i.e. the multiplications in EI and JU balance may be either positive or negative (may take plus or minus sign) depending on the positive directions of $E, I, J,$ and U.
- When drawing up a potential diagram, calculations of the separate point potentials must be included.
- The results of previous calculation may not be used for establishing the active one-port parameters (U_t, R_{ie}). This task is to be considered as independent.
- When drawing the curve $P_k(R_k)$, the following power values shall be indicated when $c = 0; 0.5R_k; R_k; 2R_k; 3R_k; 4R_k; 5R_k$. Assuming that R_k tends towards infinity, assess the nature of the curve $P_k(R_k)$ starting from $c = 5R_k$.

<div align="center">

Table 1.1

Given quantities

</div>

Variant	Circuit No.	E_1, V	E_2, V	E_3, V	J, A	R_1, Ω	R_2, Ω
1	1.1	5.0	10.0	3.0	0.50	12.0	20.0
2	1.2	8.0	10.0	20.0	3.00	8.0	13.0
3	1.3	5.0	10.0	20.0	2.50	5.0	8.0
4	1.4	35.0	30.0	9.0	3.00	20.0	10.0
5	1.5	40.0	16.0	15.0	1.45	30.0	25.0
6	1.6	8.0	10.0	5.0	4.25	10.0	20.0
7	1.7	5.0	14.0	11.0	0.80	15.0	30.0
8	1.8	12.0	10.0	30.0	0.40	20.0	50.0
9	1.9	5.0	14.0	10.0	2.35	20.0	5.0
10	1.10	10.0	8.0	5.0	1.50	23.0	27.0
11	1.11	4.0	2.0	6.0	3.00	14.0	8.0
12	1.12	12.0	16.0	9.0	1.75	19.0	40.0
13	1.13	8.0	10.0	5.0	1.40	7.0	4.0
14	1.14	12.0	14.0	4.0	0.85	50.0	20.0
15	1.15	6.3	7.0	10.0	3.35	15.0	40.0
16	1.16	12.0	4.0	2.0	1.50	7.0	8.0
17	1.17	25.0	9.0	36.0	3.00	13.0	19.0
18	1.18	6.0	8.0	5.0	0.50	35.0	15.0
19	1.19	2.0	4.0	10.0	1.00	40.0	15.0
20	1.20	6.0	4.0	10.0	1.75	5.0	28.0
21	1.21	5.0	3.0	6.0	2.40	30.0	50.0
22	1.22	10.0	8.0	16.0	1.50	15.0	25.0
23	1.23	8.0	12.0	11.0	2.40	20.0	30.0
24	1.24	12.0	16.0	20.0	0.25	26.0	60.0
25	1.25	10.0	12.0	10.0	3.25	16.0	14.5
26	1.26	15.0	10.0	24.0	1.00	30.0	50.0
27	1.27	6.0	6.0	10.0	2.00	40.0	8.0
28	1.28	10.0	20.0	5.0	1.25	5.0	11.0
29	1.29	8.0	2.0	5.0	4.50	12.0	3.0
30	1.30	4.0	10.0	8.0	4.00	18.0	4.0
31	1.1	10.0	20.0	6.0	0.50	24.0	40.0
32	1.6	16.0	20.0	10.0	4.25	20.0	40.0
33	1.11	8.0	4.0	12.0	3.00	28.0	16.0
34	1.16	24.0	8.0	4.0	1.50	14.0	16.0
35	1.21	10.0	6.0	12.0	2.40	60.0	100.0
36	1.26	30.0	20.0	48.0	1.00	60.0	100.0
37	1.2	4.0	5.0	10.0	3.00	4.0	6.5

Table 1.1 continued

R_3, Ω	R_4, Ω	R_5, Ω	R_6, Ω	R_7, Ω	R_8, Ω	R_9, Ω	k	Variant
15.0	5.0	10.0	20.0	10.0	4.0	–	1	1
16.0	2.0	15.0	14.0	7.0	12.0	–	3	2
5.0	15.0	20.0	28.0	20.0	5.0	15.0	7	3
15.0	25.0	40.0	18.0	20.0	15.0	–	1	4
7.5	44.0	18.0	60.0	24.0	26.0	–	3	5
15.0	8.0	30.0	4.0	10.0	18.0	–	5	6
25.0	70.0	25.0	15.0	25.0	12.0	–	1	7
18.0	45.0	15.0	6.0	5.0	20.0	–	3	8
15.0	20.0	30.0	13.0	16.0	–	–	5	9
50.0	30.0	40.0	20.0	25.0	4.0	–	1	10
20.0	8.0	4.0	2.0	12.0	10.0	–	3	11
80.0	16.0	21.0	32.0	26.0	16.0	–	5	12
35.0	5.0	12.0	35.0	4.0	5.0	–	1	13
7.0	19.0	23.0	9.0	9.0	20.0	4.5	7	14
20.0	6.0	14.0	60.0	5.0	11.0	–	5	15
15.0	22.0	10.0	24.0	14.0	8.0	10.0	1	16
27.0	14.0	12.0	6.0	30.0	2.5	12.0	3	17
32.0	30.0	8.5	7.0	8.0	8.0	–	5	18
18.0	15.0	40.0	27.0	6.0	16.0	–	1	19
20.0	20.0	30.0	35.0	19.0	7.0	–	3	20
22.0	53.0	28.0	7.0	11.0	5.0	4.0	5	21
30.0	24.0	18.0	5.0	30.0	15.0	–	7	22
12.0	13.0	18.0	10.0	23.0	27.0	–	3	23
20.0	60.0	30.0	17.0	15.0	9.0	–	5	24
6.0	18.0	9.0	7.0	15.0	28.0	–	1	25
7.0	9.0	50.0	15.0	20.0	16.0	–	3	26
52.0	10.0	14.0	40.0	60.0	35.0	35.0	5	27
8.0	50.0	45.0	22.0	18.5	30.0	–	1	28
16.0	28.0	25.0	18.0	5.0	6.0	–	3	29
20.0	4.0	5.0	28.0	42.0	6.5	–	3	30
30.0	10.0	20.0	40.0	20.0	8.0	–	3	31
30.0	16.0	60.0	8.0	20.0	36.0	–	3	32
40.0	16.0	8.0	4.0	24.0	20.0	–	5	33
30.0	44.0	20.0	48.0	28.0	16.0	20.0	3	34
44.0	106.0	56.0	14.0	22.0	10.0	8.0	1	35
14.0	18.0	100.0	30.0	40.0	32.0	–	7	36
8.0	1.0	7.5	7.0	3.5	6.0	–	5	37

Table 1.1 continued

Variant	Circuit No.	E_1, V	E_2, V	E_3, V	J, A	R_1, Ω	R_2, Ω
38	1.7	2.5	7.0	5.5	0.80	7.5	15.0
39	1.12	6.0	8.0	4.5	1.75	9.5	20.0
40	1.17	12.5	4.5	18.0	3.00	6.5	9.5
41	1.22	5.0	4.0	8.0	1.50	7.5	12.5
42	1.27	3.0	3.0	5.0	2.00	20.0	4.0
43	1.3	10.0	20.0	40.0	2.50	10.0	16.0
44	1.8	24.0	20.0	60.0	0.40	40.0	100.0
45	1.13	16.0	20.0	10.0	1.40	14.0	8.0
46	1.18	12.0	16.0	10.0	0.50	70.0	30.0
47	1.23	16.0	24.0	22.0	2.40	40.0	60.0
48	1.28	20.0	40.0	10.0	1.25	10.0	22.0
49	1.4	17.5	15.0	4.5	3.00	10.0	5.0
50	1.9	2.5	7.0	5.0	2.35	10.0	2.5

		E_1, V	E_2, V	E_3, V	J, A	R_1, Ω	R_2, Ω

Table 1.1 continued

| R_3, Ω	R_4, Ω	R_5, Ω	R_6, Ω	R_7, Ω	R_8, Ω	R_9, Ω	k	Variant
12.5	35.0	12.5	7.5	12.5	6.0	–	3	38
40.0	8.0	10.5	16.0	13.0	8.0	–	1	39
13.5	7.0	6.0	3.0	15.0	1.3	6.0	7	40
15.0	12.0	9.0	2.5	15.0	7.5	–	7	41
26.0	5.0	7.0	20.0	30.0	17.5	17.5	1	42
10.0	30.0	40.0	56.0	40.0	10.0	30.0	1	43
36.0	90.0	30.0	12.0	10.0	40.0	–	5	44
70.0	10.0	24.0	70.0	8.0	10.0	–	3	45
64.0	60.0	17.0	14.0	16.0	16.0	–	1	46
24.0	26.0	36.0	20.0	46.0	54.0	–	5	47
16.0	100.0	90.0	44.0	37.0	60.0	–	3	48
7.5	12.5	20.0	9.0	10.0	7.5	–	3	49
7.5	10.0	15.0	6.5	8.0	–	–	1	50
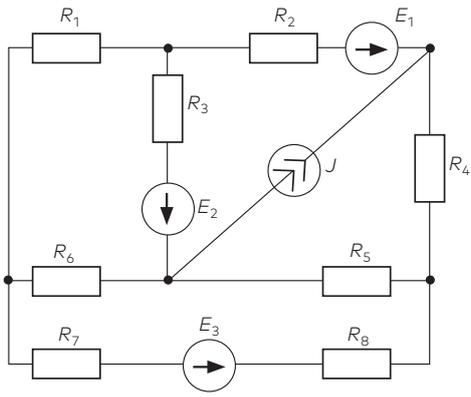
Circuit diagram **1.1**
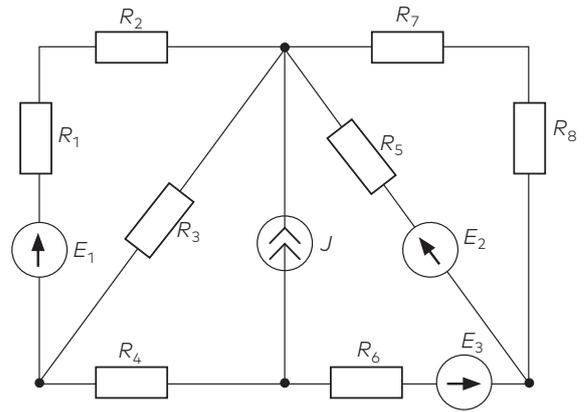
Circuit diagram 1.2
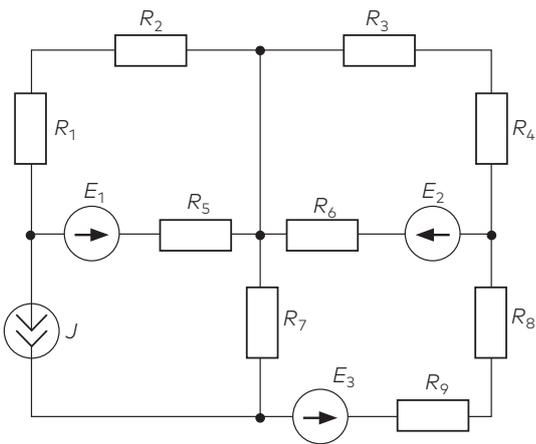
Circuit diagram **1.3**
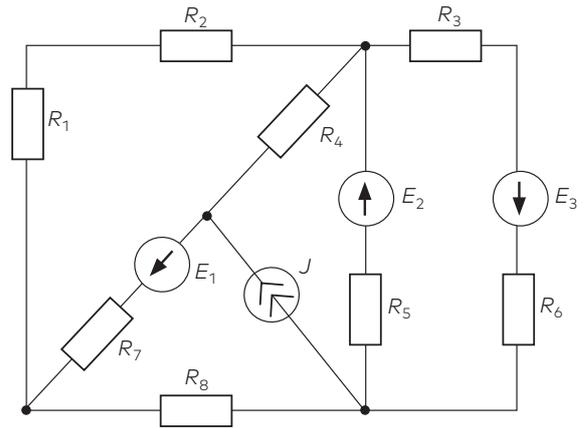
Circuit diagram **1.4**
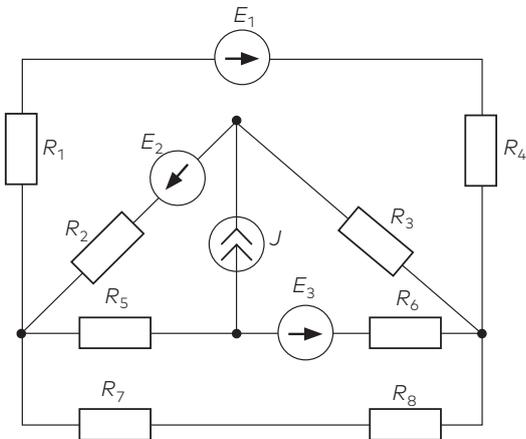
Circuit diagram **1.5**
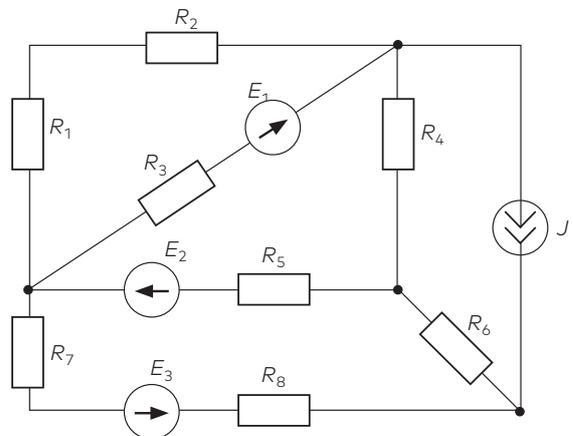
Circuit diagram **1.6**
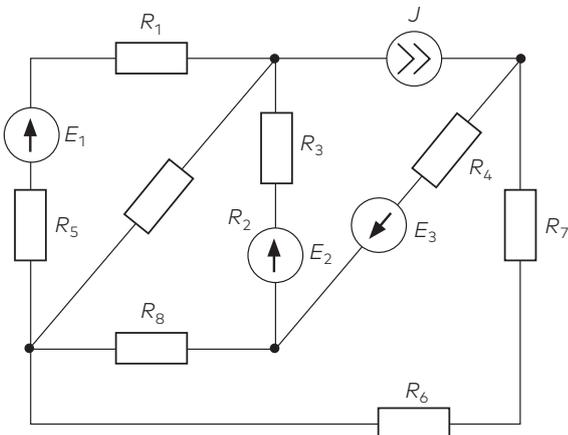
Circuit diagram **1.7**
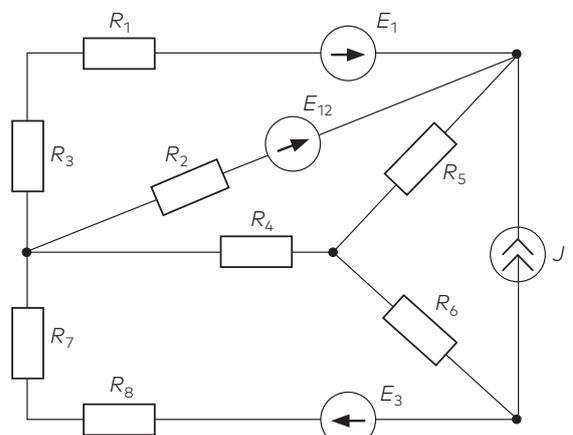
Circuit diagram **1.8**
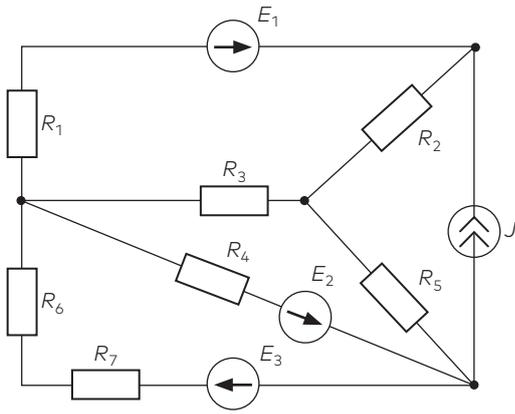
Circuit diagram **1.9**
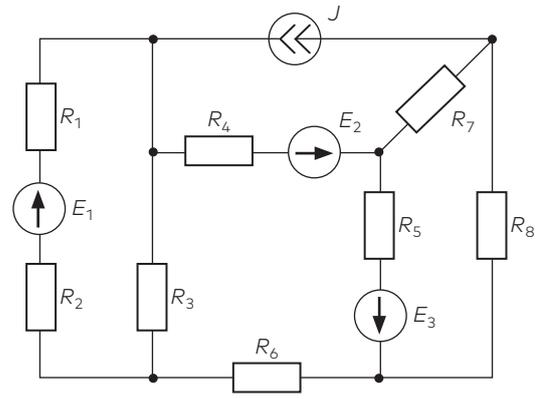
Circuit diagram **1.10**
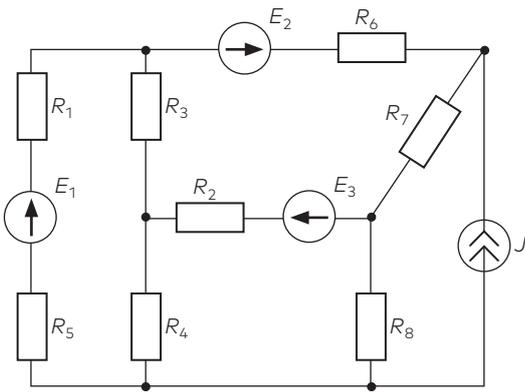
Circuit diagram **1.11**
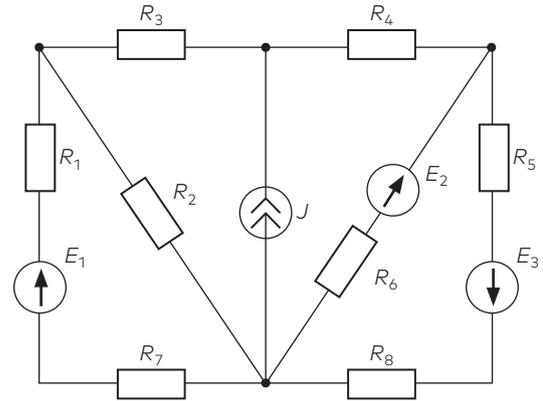
Circuit diagram **1.12**
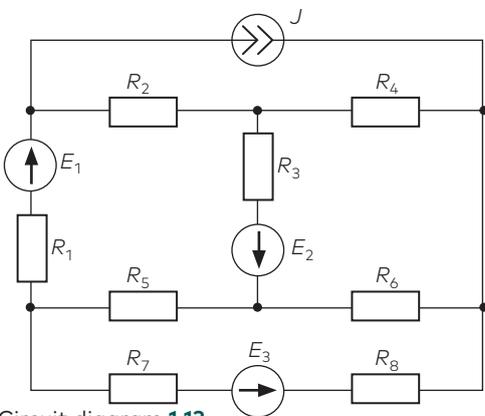
Circuit diagram **1.13**
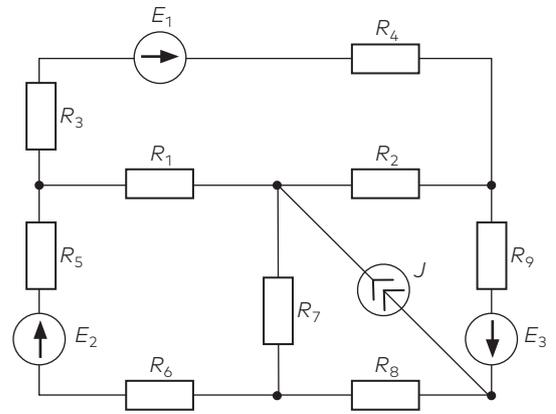
Circuit diagram **1.14**
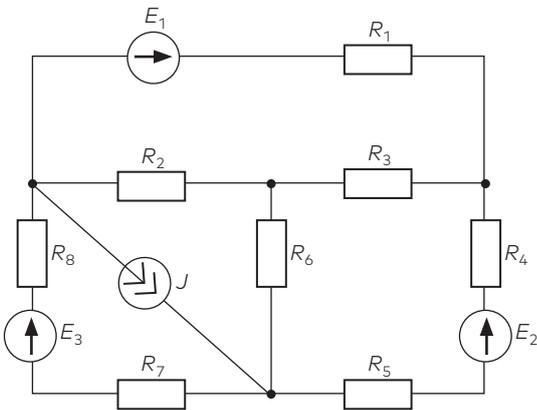
Circuit diagram **1.15**
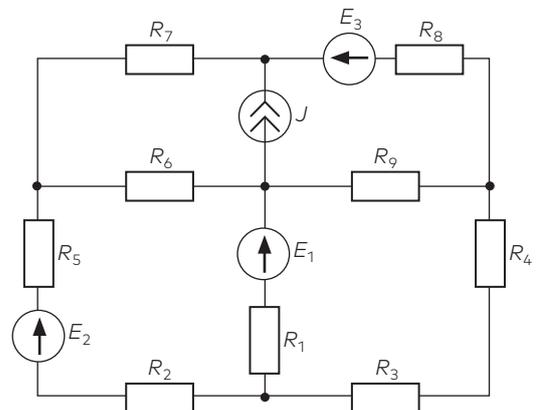
Circuit diagram **1.16**
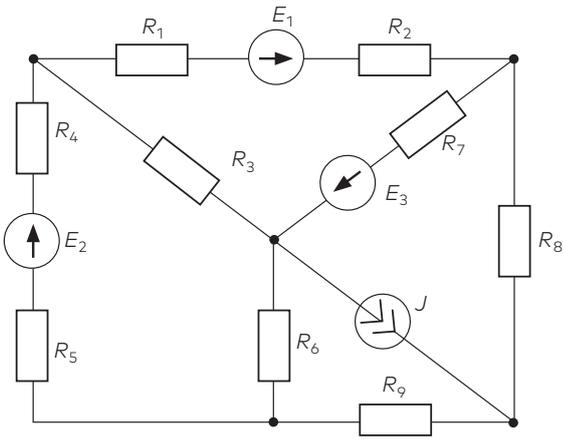
Circuit diagram **1.17**
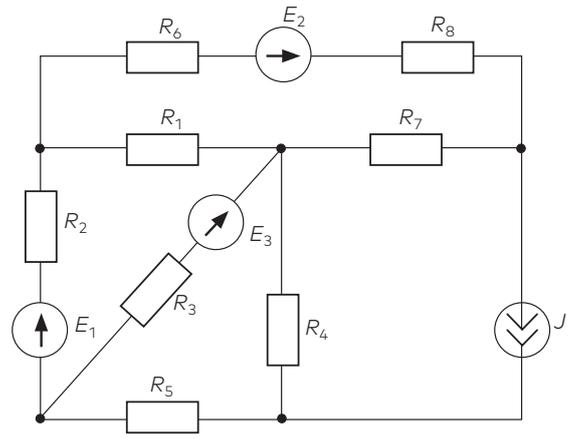
Circuit diagram **1.18**
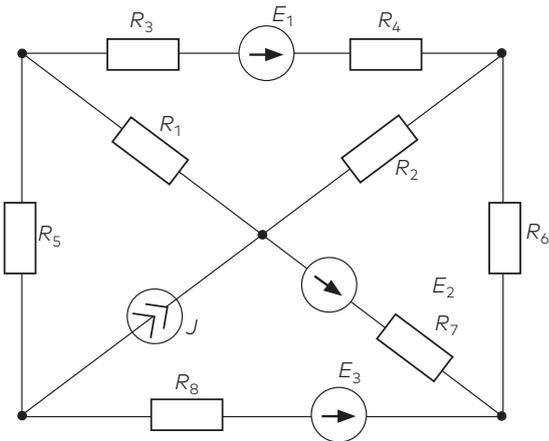
Circuit diagram **1.19**
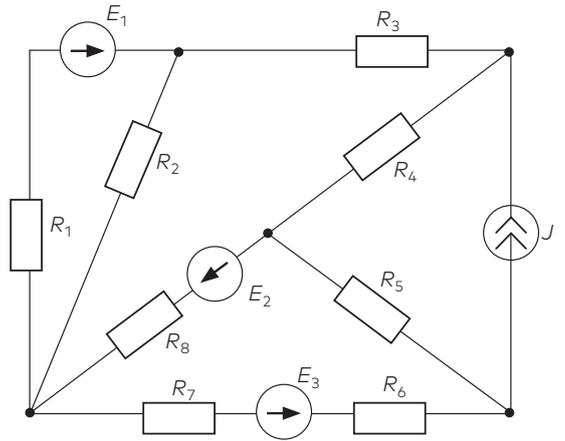
Circuit diagram **1.20**
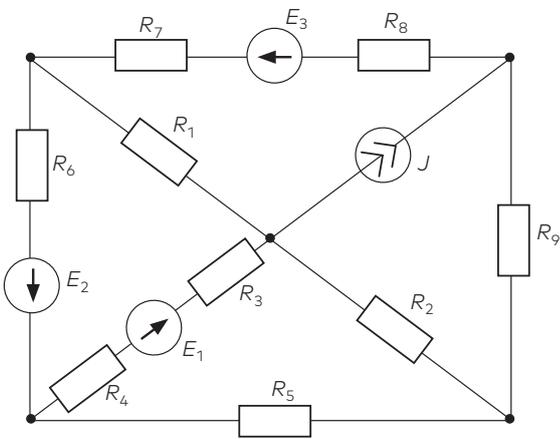
Circuit diagram **1.21**
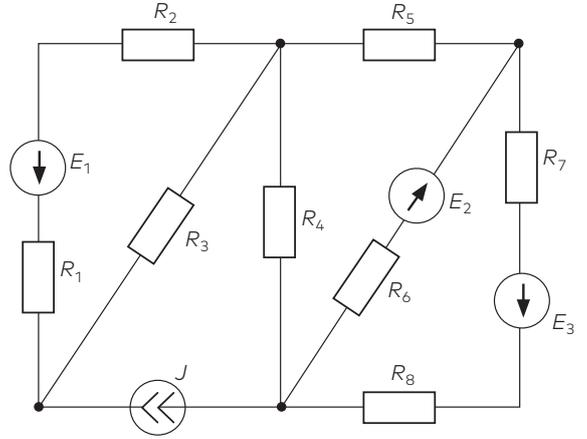
Circuit diagram **1.22**
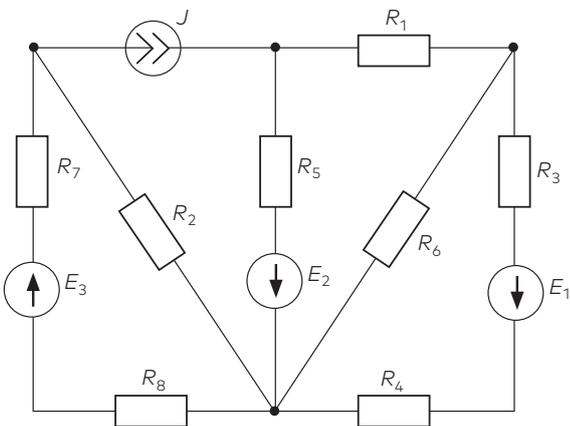
Circuit diagram **1.23**
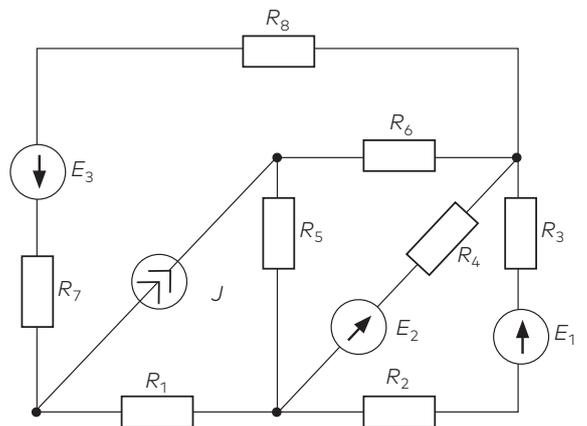
Circuit diagram **1.24**
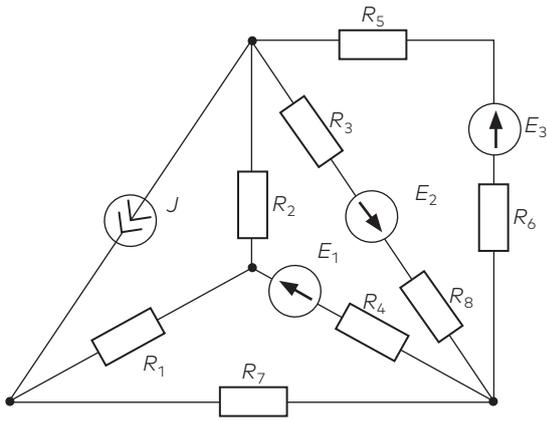
Circuit diagram **1.25**
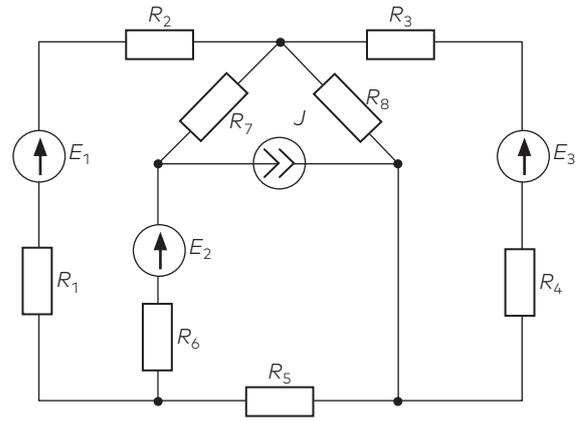
Circuit diagram **1.26**
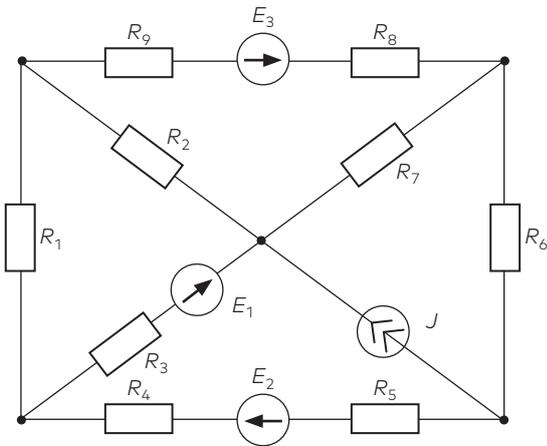
Circuit diagram **1.27**
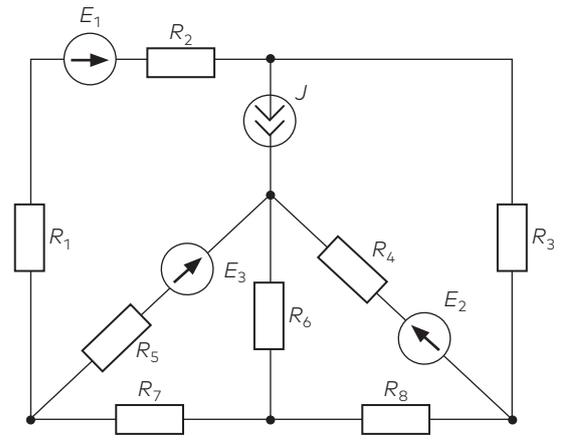
Circuit diagram **1.28**
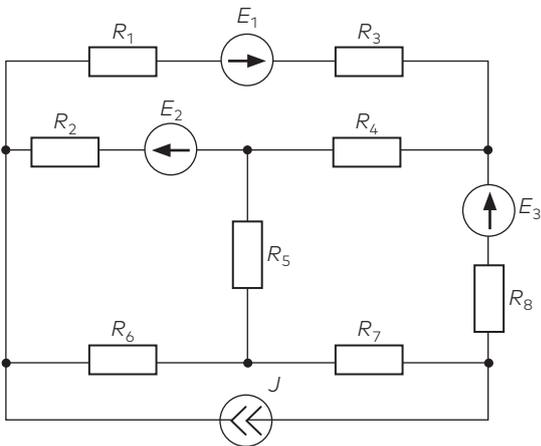

Circuit diagram **1.29**
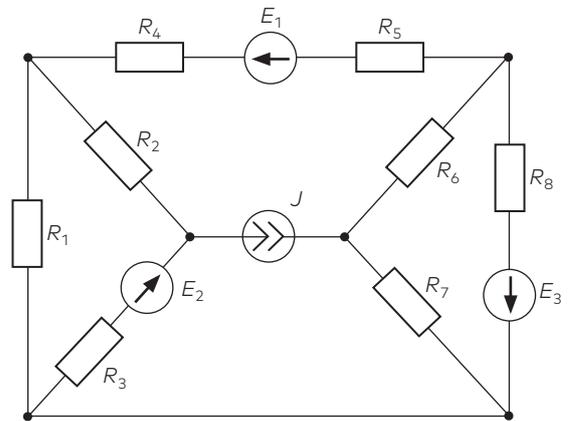
Circuit diagram **1.30**

Task No. 2   Linear Sinusoidal Current Circuits

1. Draw up a system of Kirchhoff's equations for the given circuit (Circuit diagram 2.1):
   a) for instantaneous values of currents;
   b) for complex values of currents.
2. Determine the RMS value of all currents, using any calculation method.
3. Draw up the real and reactive power balance.
4. Write down the expressions of instantaneous values of all currents and draw the instantaneous value graphs.
5. Construct the topographical diagram of potentials and phasor diagram in one graph.
6. Determine the readings on measuring instruments. Connect the wattmeter in line with the circuit. Connect the ammeter in a branch with variable resistance (resistance is shown in Table 2.1). Connect the voltmeter between points (indicated in Table 2.1).
7. Applying the active one-port rule, determine current in the branch with the variable element $\underline{Z}_k$. Show graphically $I_k(\underline{Z}_k)$ — dependence of the current module on the variable resistance module, if resistance $\underline{Z}_k$ changes from zero to infinity ($0 \leq \underline{Z}_k \leq \infty$). The index k of element $\underline{Z}_k$ is given in the table of given quantities (Table 2.1).
8. Assuming that coils in two branches of the given circuit are inductively coupled (if there are no coils, they shall be added in the drawing), draw up a system of Kirchhoff's equations in the complex form. Choose the similarly named ends of coils arbitrarily.

Note.

The general circuit includes 6 resistance sources and 6 EMF sources. The total number of circuit elements in each separate variant is 8. When solving the task, *it is not necessary to draw* the missing elements in the circuit. Each resistance shall be marked as inductive reactance, capacitive reactance, or resistance accordingly.

Do not change the item numeration!

Methodical guidelines for the task

1. Before solving the task, the assumed directions of currents shall be chosen arbitrarily and shown in the circuit.
2. It is advised to calculate the currents (Paragraph 2 of the task) using the RMS value and the correct representation of complex values. It is suggested to do the calculation using the node potential or loop contour method.
3. When drawing up the active and reactive power balance, one shall take into account that the apparent power of source is $\tilde{S} = P + jQ = \dot{E}\dot{I}^*$ if EMF and the direction of current flow in the source match, or $\tilde{S} = -\dot{E}\dot{I}^*$ if they are opposite. When writing down the power of reactive elements, one shall remember that they are opposite for elements L and C.
4. Before drawing a potential diagram, it must be verified if the solution satisfies Kirchhoff's second law, i.e. if $\sum \dot{U} = \sum \dot{E}$ for a closed loop.
5. When constructing the topographical diagram of potentials and phasor diagram, indicate the direction of the real and imaginary axes of the complex plane, as well as current and voltage scale. It is more convenient to draw the graphs using the algebraic representation of complex values.
6. The results of previous calculation may not be used for establishing the active one-port parameters ($\dot{U}_t$, $\underline{Z}_{ie}$). This task is to be considered as independent.
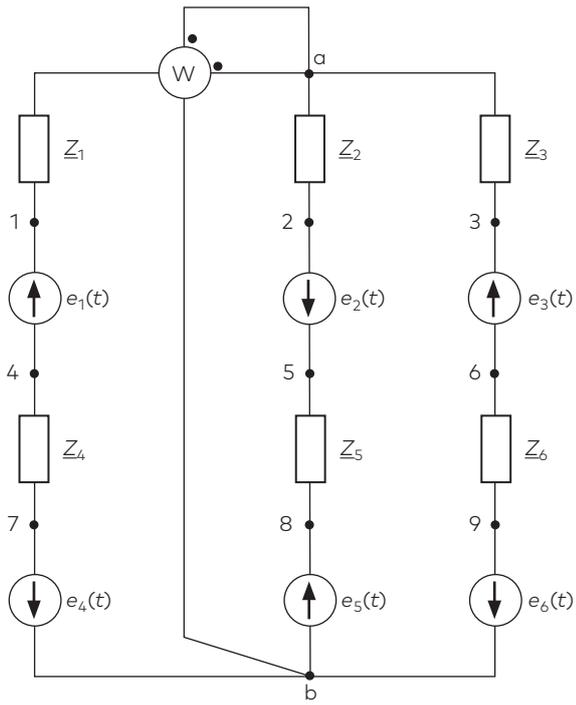
Circuit diagram **2.1**

Table 2.1
Given quantities

Variable resistance	Instantaneous values of source EMF, V		Voltmeter between points	Variant
$\underline{Z}_4$	$e_1=28.2\sin(\omega t+50°)$	$e_2=100.0\sin\omega t$	4, 8	1
	$e_3=141.0\sin(\omega t-30°)$			
$\underline{Z}_6$	$e_4=70.7\sin(\omega t+36°)$	$e_5=56.6\sin(\omega t-90°)$	7, 9	2
	$e_6=70.7\sin(\omega t-114°)$			
$\underline{Z}_2$	$e_1=113.0\sin(\omega t+150°)$	$e_3=63.6\sin(\omega t-50°)$	3, 7	3
	$e_4=56.6\sin(\omega t-165°)$			
$\underline{Z}_3$	$e_1=98.8\sin(\omega t+24°)$	$e_2=28.3\sin(\omega t-36°)$	2, b	4
	$e_5=127.0\sin(\omega t+60°)$			
$\underline{Z}_6$	$e_1=106.0\sin(\omega t+150°)$	$e_2=56.6\sin(\omega t+45°)$	8, 1	5
$\underline{Z}_4$	$e_1=42.4\sin(\omega t+135°)$	$e_3=84.7\sin(\omega t-15°)$	9, 1	6
$\underline{Z}_4$	$e_1=70.7\sin(\omega t+204°)$	$e_3=56.6\sin\omega t$	1, 6	7
	$e_5=98.8\sin(\omega t+45°)$			
$\underline{Z}_1$	$e_1=56.6\sin(\omega t-36°)$	$e_2=56.6\sin(\omega t-90°)$	3, 4	8
	$e_3=42.4\sin(\omega t+60°)$			
$\underline{Z}_3$	$e_2=84.7\sin(\omega t+90°)$	$e_3=28.3\sin(\omega t+120°)$	9, 4	9
	$e_5=70.7\sin(\omega t+50°)$			
$\underline{Z}_3$	$e_2=42.4\sin(\omega t+45°)$	$e_3=56.6\sin(\omega t+90°)$	2, 9	10
	$e_4=106.0\sin(\omega t+210°)$			
$\underline{Z}_6$	$e_4=70.7\sin(\omega t+180°)$	$e_5=70.7\sin(\omega t-45°)$	4, 3	11
	$e_6=42.4\sin(\omega t+60°)$			
$\underline{Z}_2$	$e_1=84.7\sin(\omega t-15°)$	$e_2=56.6\sin(\omega t-135°)$	3, 1	12
	$e_6=113.0\sin(\omega t-30°)$			
$\underline{Z}_1$	$e_1=106.0\sin(\omega t+135°)$	$e_2=141.0\sin\omega t$	a, 8	13
	$e_5=98.8\sin(\omega t+24°)$			
$\underline{Z}_2$	$e_1=106.0\sin(\omega t+135°)$	$e_3=42.4\sin(\omega t-90°)$	8, a	14
$\underline{Z}_1$	$e_1=35.3\sin(\omega t+50°)$	$e_5=84.7\sin(\omega t-36°)$	9, a	15
	$e_6=42.4\sin(\omega t-90°)$			
$\underline{Z}_5$	$e_1=70.7\sin(\omega t+50°)$	$e_3=84.7\sin(\omega t+105°)$	4, 6	16
$\underline{Z}_1$	$e_1=35.3\sin(\omega t-105°)$	$e_3=42.4\sin(\omega t-90°)$	9, 4	17
	$e_6=56.6\sin(\omega t+36°)$			
$\underline{Z}_1$	$e_1=28.2\sin(\omega t-24°)$	$e_2=42.4\sin(\omega t+45°)$	4, a	18
	$e_3=35.3\sin(\omega t+60°)$			
$\underline{Z}_6$	$e_2=56.6\sin\omega t$	$e_4=42.4\sin(\omega t+240°)$	b, 3	19
	$e_6=70.7\sin(\omega t+135°)$			
$\underline{Z}_6$	$e_1=106.0\sin(\omega t+210°)$	$e_2=42.4\sin(\omega t+90°)$	2, b	20

Table 2.1 continued

Variant	$\underline{Z}_1$, Ω	$\underline{Z}_2$, Ω	$\underline{Z}_3$, Ω	$\underline{Z}_4$, Ω	$\underline{Z}_5$, Ω	$\underline{Z}_6$, Ω
1	10	–j20	–j30	j10	j30	–
2	15	–j30	–	–j10	15	j20
3	20	j30	15	–	30	–j15
4	25	–	j10	–j20	40	15
5	30	–j20	10	j20	j30	–j20
6	5	j30	–j10	–j15	20	10
7	12	10	–	j12	–j20	j15
8	16	24	–j15	j30	–j20	–
9	18	20	j30	–j18	–	15
10	40	–	–j5	j20	–j10	10
11	–j10	–	20	j20	j20	–j30
12	j15	–j10	j20	15	–	30
13	j20	15	–	–j10	j10	10
14	j25	15	–j15	15	–j10	20
15	j30	20	–	j10	–j20	30
16	–j10	20	j15	20	j10	15
17	–j15	j15	–j20	j30	5	–
18	–j20	10	16	20	j15	–
19	–j25	30	–	–j15	j10	35
20	–j30	j20	–	15	–	25

Table 2.1 continued

Variable resistance	Instantaneous values of source EMF, V		Voltmeter between points	Variant
	$e_3=35.3\sin(\omega t+60°)$	$e_5=56.6\sin(\omega t+180°)$		
$\underline{Z}_6$	$e_1=42.4\sin(\omega t-24°)$	$e_2=56.6\sin(\omega t+45°)$	1, 5	21
	$e_5=98.9\sin(\omega t+90°)$			
$\underline{Z}_6$	$e_2=70.7\sin(\omega t+204°)$	$e_3=56.6\sin(\omega t+150°)$	5, 1	22
$\underline{Z}_1$	$e_1=141.0\sin(\omega t+105°)$	$e_3=56.6\sin(\omega t-150°)$	6, 4	23
$\underline{Z}_6$	$e_2=106.0\sin(\omega t+60°)$	$e_3=127.0\sin(\omega t+150°)$	2, 9	24
	$e_6=56.6\sin\omega t$			
$\underline{Z}_2$	$e_1=70.7\sin(\omega t-120°)$	$e_2=98.8\sin(\omega t+24°)$	a, 6	25
$\underline{Z}_6$	$e_1=28.2\sin\omega t$	$e_2=42.4\sin(\omega t+15°)$	1, 9	26
	$e_6=56.6\sin(\omega t-60°)$			
$\underline{Z}_4$	$e_4=35.3\sin(\omega t+50°)$	$e_5=28.2\sin(\omega t+90°)$	7, 6	27
	$e_6=42.4\sin(\omega t+24°)$			
$\underline{Z}_2$	$e_1=127.0\sin(\omega t-60°)$	$e_2=106.0\sin(\omega t+75°)$	7, 5	28
	$e_4=100.0\sin\omega t$	$e_5=84.7\sin(\omega t+180°)$		
$\underline{Z}_5$	$e_1=113.0\sin(\omega t+216°)$	$e_2=56.6\sin(\omega t-135°)$	5, 7	29
	$e_3=42.4\sin(\omega t+90°)$	$e_4=84.7\sin(\omega t+180°)$		
$\underline{Z}_4$	$e_2=70.7\sin(\omega t+60°)$	$e_4=84.7\sin(\omega t-90°)$	2, 7	30
	$e_6=42.4\sin(\omega t-105°)$			
$\underline{Z}_2$	$e_1=14.1\sin\omega t$	$e_2=42.4\sin(\omega t-30°)$	3, 7	31
	$e_3=42.4\sin(\omega t+30°)$	$e_4=56.6\sin(\omega t+45°)$		
$\underline{Z}_5$	$e_1=56.6\sin(\omega t+180°)$	$e_3=56.6\sin(\omega t+165°)$	1, 6	32
	$e_4=28.2\sin(\omega t-90°)$			
$\underline{Z}_3$	$e_1=84.7\sin(\omega t+165°)$	$e_5=42.4\sin(\omega t+24°)$	9, 1	33
	$e_6=42.4\sin(\omega t-24°)$			
$\underline{Z}_6$	$e_1=35.3\sin(\omega t+130°)$	$e_3=56.6\sin\omega t$	3, 7	34
	$e_4=106.0\sin(\omega t-135°)$			
$\underline{Z}_4$	$e_1=98.8\sin(\omega t-114°)$	$e_5=70.7\sin(\omega t+90°)$	2, 9	35
	$e_6=113.0\sin(\omega t-36°)$			
$\underline{Z}_2$	$e_2=100.0\sin\omega t$	$e_3=141.0\sin(\omega t-30°)$	6, 1	36
	$e_4=28.2\sin(\omega t-130°)$			
$\underline{Z}_2$	$e_1=84.7\sin(\omega t-90°)$	$e_2=70.7\sin(\omega t-120°)$	2, 4	37
	$e_3=42.4\sin(\omega t-105°)$			
$\underline{Z}_3$	$e_1=70.7\sin(\omega t-144°)$	$e_2=56.6\sin(\omega t+90°)$	3, 4	38
	$e_6=70.7\sin(\omega t-144°)$			
$\underline{Z}_2$	$e_1=56.6\sin(\omega t+216°)$	$e_4=42.3\sin(\omega t+180°)$	4, 9	39
	$e_5=28.3\sin(\omega t+45°)$	$e_6=21.2\sin(\omega t-90°)$		

Variable resistance	Instantaneous values of source EMF, V		Voltmeter between points	Variant

Table 2.1 continued

Variant	$\underline{Z}_1$, Ω	$\underline{Z}_2$, Ω	$\underline{Z}_3$, Ω	$\underline{Z}_4$, Ω	$\underline{Z}_5$, Ω	$\underline{Z}_6$, Ω
21	j12	20	10	j8	–	–j10
22	j16	–j10	5	16	5	15
23	j40	j10	10	–j20	20	j20
24	–j12	–	j15	24	16	5
25	–j16	30	j20	–j14	j30	10
26	–j40	–	10	j20	20	j10
27	j5	j10	–	15	10	–j25
28	–j5	j15	j20	10	–	–
29	–	8	–	j10	j8	16
30	–	12	16	–j20	j12	j8
31	–	j20	10	15	j5	–
32	5	10	–	15	j15	–j12
33	–	j10	–j12	j15	10	12
34	–	20	16	–j15	–j5	4
35	–	20	5	30	j20	–j10
36	j10	–j10	–	10	j20	–j30
37	–j20	j12	16	–	12	j8
38	15	–j30	j20	–j10	15	–
39	–	j8	16	j10	8	–
	$\underline{Z}_2$, Ω	$\underline{Z}_3$, Ω	$\underline{Z}_4$, Ω	$\underline{Z}_5$, Ω	$\underline{Z}_6$, Ω

Table 2.1 continued

Variable resistance	Instantaneous values of source EMF, V		Voltmeter between points	Variant
$\underline{Z}_3$	$e_1=113.0\sin(\omega t+150°)$	$e_3=63.3\sin(\omega t-50°)$	b, 3	40
	$e_4=56.6\sin(\omega t-165°)$			
$\underline{Z}_1$	$e_1=100.0\sin(\omega t+180°)$	$e_2=106.0\sin(\omega t+70°)$	1, b	41
	$e_4=127\sin(\omega t+120°)$	$e_5=84.7\sin(\omega t+180°)$		
$\underline{Z}_3$	$e_2=127.0\sin(\omega t-120°)$	$e_4=98.8\sin(\omega t-156°)$	7, a	42
	$e_5=28.3\sin(\omega t+144°)$			
$\underline{Z}_4$	$e_2=56.6\sin(\omega t-90°)$	$e_4=70.7\sin(\omega t+50°)$	2, 7	43
	$e_6=84.8\sin(\omega t+24°)$			
$\underline{Z}_6$	$e_2=56.6\sin(\omega t+45°)$	$e_4=106.0\sin(\omega t-30°)$	b, 1	44
$\underline{Z}_6$	$e_1=28.3\sin(\omega t+180°)$	$e_2=42.4\sin(\omega t-165°)$	9, 4	45
	$e_6=56.6\sin(\omega t+120°)$			
$\underline{Z}_4$	$e_3=84.7\sin(\omega t-15°)$	$e_4=42.4\sin(\omega t-45°)$	3, b	46
$\underline{Z}_6$	$e_4=70.7\sin(\omega t+60°)$	$e_5=98.8\sin(\omega t-156°)$	7, 3	47
$\underline{Z}_4$	$e_2=199.6\sin(\omega t-135°)$	$e_3=113.2\sin\omega t$	5, 3	48
	$e_4=141.0\sin(\omega t+204°)$			
$\underline{Z}_6$	$e_3=56.6\sin(\omega t+180°)$	$e_5=53.0\sin(\omega t-120°)$	2, 9	49
	$e_6=127.0\sin(\omega t-165°)$			
$\underline{Z}_4$	$e_2=56.6\sin(\omega t+90°)$	$e_4=56.6\sin(\omega t+144°)$	b, 2	50
	$e_6=42.4\sin(\omega t-120°)$			

Variant	$\underline{Z}_1$, Ω	$\underline{Z}_2$, Ω	$\underline{Z}_3$, Ω	$\underline{Z}_4$, Ω	$\underline{Z}_5$, Ω	$\underline{Z}_6$, Ω
40	–	30	–j15	20	j30	15
41	–j10	–	j40	20	j30	–
42	25	40	15	–j20	–	j10
43	30	j20	–j50	j10	20	–
44	15	–j10	5	j10	j15	–j10
45	j15	20	10	–j35	–	j10
46	10	j30	–j10	–j30	40	10
47	–j25	15	5	j10	j15	j10
48	j12	10	j15	12	–j20	–
49	24	16	j15	–j12	–	5
50	8	–j10	–j7,5	j15	12	–

Task No. 3   Three-Phase Sinusoidal Current Circuits

A symmetrical three-phase generator with sinusoidal phase voltage system is connected to an asymmetrical load.

1. Assuming that $R_0 = 0\ \Omega$, calculate the following for the given circuit (Circuit diagram 3.1):
   a) RMS value of all currents;
   b) voltage between the neutral points of generator and load;
   c) load phase and line voltage;
   d) voltage drops in line wires.
2. Calculate the quantities listed in Paragraph 1, assuming that $R_0 = \infty$.
3. Construct the topographical diagram of potentials and phasor diagram for both cases ($R_0 = 0\ \Omega$ and $R_0 = \infty$); remember that the potential of points A, B, C, a, b, and c must be established before.

Methodical guidelines for the task

1. When deriving phase voltages from the given line voltage, note that not only the numerical values of these quantities differ but also their phases.
2. Applying the basic formulas for asymmetrical three-phase circuit calculations, the common positive directions of currents shall be observed in line wires from the generator to the load and the opposite in the neutral wire.
3. When constructing the topographical diagram of potentials and phasor diagram, indicate the direction of the real and imaginary axes of the complex plane, as well as current and voltage scale. It is more convenient to draw the graphs using the algebraic representation of complex values.
4. Note the following when constructing the topographical diagram:
   a) the zero potential shall be the potential of generator's neutral point (point 0 in the circuit);
   b) mark the potential of points A, B, C, a, b, and c;
   c) mark the symmetrical voltages of generator's phases and lines;
   d) from the point 0, mark the voltage between the neutral points $\dot{U}_{0,0}$ of generator and load (if $R_0 = 0\ \Omega$, this voltage equals zero);
   e) from the point 0_1, mark the load's phase voltages, and then — load's line voltages;
   f) mark voltage drops in line wires.
5. Symbols of point potentials in the topographic diagram must conform to the point designations in the circuit diagram.
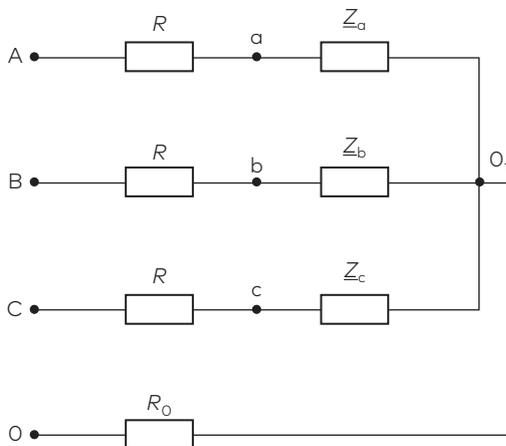
Circuit diagram **3.1**

Table 3.1
Given quantities

Variant	$\dot{U}_{AB}$, V	R, Ω	$\underline{Z}_a$, Ω	$\underline{Z}_b$, Ω	$\underline{Z}_c$, Ω
1	110.0 + j63.5	5	10	j5	−j5
2	155.8 − j155.8	3	2	−j3	j5
3	−63.5 + j110.0	5	j10	−j10	10
4	−75.2 − j206.5	3	2	−j3	j5
5	−119.3 − j43.5	5	j10	−j10	10
6	−206.5 + j75.2	5	10	j5	−j5
7	43.5 − j119.3	5	j10	−j10	10
8	110.0 + j190.5	5	10	j5	−j5
9	89.7 + j89.7	3	2	−j3	j5
10	190.5 − j110.0	5	10	j5	−j5
11	−110.0 + j63.5	3	2	−j3	j5
12	−155.8 − j155.8	5	j10	−j10	10
13	−63.5 − j110.0	3	2	−j3	j5
14	−75.2 + j206.5	5	j10	−j10	10
15	119.3 − j43.5	5	10	j5	−j5
16	206.5 + j75.2	5	j10	−j10	10
17	43.5 + j119.3	5	10	j5	−j5
18	110.0 − j190.5	3	2	−j3	j5
19	−89.7 + j89.7	5	10	j5	−j5
20	−190.5 − j110.0	3	2	−j3	j5
21	−110.0 − j63.5	5	j10	−j10	10
22	−155.8 + j155.8	3	2	−j3	j5
23	63.5 − j110.0	5	j10	−j10	10
24	75.2 + j206.5	5	10	j5	−j5
25	119.3 + j43.5	5	j10	−j10	10
26	206.5 − j75.2	5	10	j5	−j5
27	−43.5 + j119.3	3	2	−j3	j5
28	−110.0 − j190.5	5	10	j5	−j5
29	−89.7 − j89.7	3	2	−j3	j5
30	−190.5 + j110.0	5	j10	−j10	10
31	110.0 − j63.5	3	2	−j3	j5
32	155.8 + j155.8	5	j10	−j10	10
33	63.5 + j110.0	5	10	j5	−j5
34	75.2 − j206.5	5	j10	−j10	10
35	−119.3 + j43.5	5	10	j5	−j5
36	−206.5 − j75.2	3	2	−j3	j5
37	−43.5 − j119.3	5	10	j5	−j5
38	−110.0 + j190.5	3	2	−j3	j5
39	89.7 − j89.7	5	j10	−j10	10
40	190.5 + j110.0	3	2	−j3	j5

Variant	$\dot{U}_{AB}$, V	R, Ω	$\underline{Z}_a$, Ω	$\underline{Z}_b$, Ω	$\underline{Z}_c$, Ω
41	110.0 + j63.5	5	j10	−j10	10
42	155.8 − j155.8	5	10	j5	−j5
43	−63.5 + j110.0	3	2	−j3	j5
44	−75.2 − j206.5	5	10	j5	−j5
45	−119.3 − j43.5	3	2	−j3	j5
46	−206.5 + j75.2	5	j10	−j10	10
47	43.5 − j119.3	3	2	−j3	j5
48	110.0 + j190.5	5	j10	−j10	10
49	89.7 + j89.7	5	10	j5	−j5
50	190.5 − j110.0	5	j10	−j10	10

Test No. 1   Semi-conductor connection circuits

The test variant shall depend on the last three digits of your student's card marked *XYZ* respectively. The variant number is composed of a two-digit number *XZ*, if *XZ* ≤ 50, or (100 – *XZ*), if *XZ* > 50.

1.1   Semiconductor stabilitron

The circuit diagram of a voltage stabiliser is shown in Fig. 1.1. Values of stabilitron VD1 parameters – stabilisation voltage U_z, minimum stabilisation current I_{z_min}, maximum permitted stabilisation current I_{z_max}, as well as the values of other elements are given in Table 1.1.

1. Depending on your test variant, determine the maximum or minimum permitted resistance () of resistor R1, or the resistance of load resistor R2, or the input voltage U, so that the stabilitron worked in voltage reference mode (i.e. when the current $I_z = I_{z\_min}$ or $I_z = I_{z\_max}$).
2. Calculate the power generated in stabilitron and the coefficient of performance of the stabilitron in voltage reference mode.
3. Determine the outgoing voltage U_{iz} and the current I_z in two cases:
    a) if the parameter calculated in Paragraph 1 (R_1, R_2 or U) increases twice;
    b) if the parameter calculated in Paragraph 1 (R_1, R_2 or U) reduces twice. (If $I_z < I_{z\_min}$, then it is assumed that $I_z = 0$ A.)
4. Draw conclusions on the stabilitron capacity in the analysed conditions.
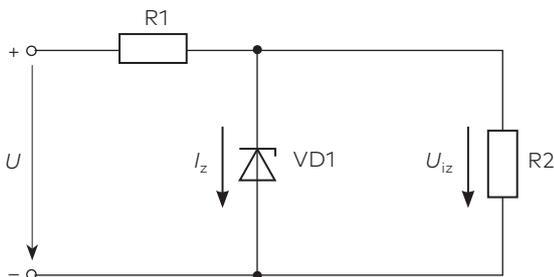
Fig. 1.1. Circuit diagram of voltage stabiliser for Task 1.1.

1.2   Bipolar transistor in common-emitter circuit

The transistor VT1 connection circuit is shown in Fig. 1.2. The transistor is regulated by input voltage signal with range *U*. Values of the variable parameters of circuit elements are given in Table 1.2.

1. Depending on your variant, ensure saturation mode for the transistor and determine the **minimum** permitted value of transmission coefficient β_{min} or the value of input voltage range U_{min} or the value of collector chain resistance R_{k_min}, or the **maximum** permitted value of power supply voltage E_{k_max} or the value of base chain resistance R_{B_max}.
2. Calculate the power amplification coefficient K_p in the given mode, assuming that voltage in working transistor $U_k = 0$ V.
3. Determine the voltage U_k and current I_k in transistor's collector in two cases:
    a) if the parameter calculated in Paragraph 1 (U, E_k, R_k, R_B, β) increases twice;
    b) if the parameter calculated in Paragraph 2 reduces twice. (Do not take into account the reverse current of collector's p-n junction, i.e. $I_{ko} = 0$ A.)

4. Draw conclusions on transistor's modes of operation in the analysed conditions.
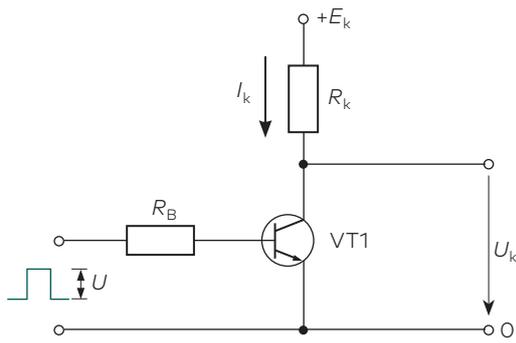
Fig. 1.2. Circuit diagram of transistor connection for Task 1.2.

<div align="right">

Table 1.1

Parameter values for Task 1.1

</div>

Variant	U_z, V	I_{z_min}, mA	I_{z_max}, mA	U, V	R_1, Ω	R_2, Ω	Determine
0	11.2	3	33	30	220	–	R_{2_max}
1	100.0	5	50	250	–	300	R_{1_max}
2	12.0	3	24	50	–	470	R_{1_max}
3	3.8	3	70		120	390	U_{max}
4	7.5	3	33	20	560	–	R_{2_min}
5	8.0	3	29	36	–	180	R_{1_max}
6	4.3	3	70	12	–	240	R_{1_min}
7	22.0	10	230		110	82	U_{min}
8	5.6	50	1400	15	–	110	R_{1_max}
9	10.3	3	33	24	330	–	R_{2_max}
10	47.0	10	110		180	130	U_{min}
11	3.0	3	81	20	–	430	R_{1_min}
12	7.5	3	33	15	–	110	R_{1_min}
13	4.0	3	70		240	560	U_{min}
14	6.8	50	1150	24	–	100	R_{1_min}
15	3.4	3	81	12	82	–	R_{2_max}
16	9.0	3	26		240	160	U_{max}
17	7.7	3	33	36	–	820	R_{1_max}
18	68.0	5	75	100	680	–	R_{2_min}
19	39.0	10	130		150	110	U_{max}
20	10.0	3	23	48	1300	–	R_{2_min}
21	4.1	3	58	14	120	–	R_{2_max}
22	8.2	50	950	–	110	75	U_{min}
23	8.0	3	33	30	680	–	R_{2_min}
24	9.4	3	33	–	560	910	U_{max}
25	56.0	5	90	180		560	R_{1_min}
26	4.2	3	58	–	390	270	U_{min}
27	11.5	3	20	36	1000	–	R_{2_max}
28	9.6	3	20	20	–	1300	R_{1_max}
29	82.0	5	60	250	–	910	R_{1_min}
30	7.2	3	33	20	750	–	R_{2_min}
31	10.0	25	800	36	20	–	R_{2_max}
32	4.5	3	58	–	220	120	U_{max}
33	27.0	10	180	90		270	R_{1_max}
34	13.5	3	20	24	390		R_{2_max}
35	3.7	3	81	12		180	R_{1_min}
36	12.0	25	650	–	200	270	U_{min}

Table 1.1 continued

Variant	U_z, V	I_{z_min}, mA	I_{z_max}, mA	U, V	R_1, Ω	R_2, Ω	Determine
37	5.0	3	58	–	510	910	U_{max}
38	7.8	3	40	21	430	–	R_{2_min}
39	3.6	3	81	–	390	270	U_{max}
40	6.8	3	45	–	100	1800	U_{min}
41	8.6	3	36	25	910	–	R_{2_min}
42	5.6	3	55	18	–	510	R_{1_max}
43	15.0	25	550	48	24	–	R_{2_max}
44	33.0	10	150	80	270	–	R_{2_min}
45	9.5	3	32	–	200	130	U_{max}
46	3.5	3	70	10	–	160	R_{1_min}
47	18.0	25	450	30	15	–	R_{2_max}
48	5.2	3	58	10		510	R_{1_max}
49	11.0	3	29	–	160	430	U_{min}
50	5.0	3	58	–	510	910	U_{max}

Table 1.2

Values of variable parameters for Task 1.2

Variant	β	E_k, V	U, V	R_k, Ω	R_B, kΩ	Determine
0	–	24	6	300	3.6	β_{min}
1	15	12	5	620	–	R_{B_max}
2	85	20	–	470	18.0	U_{min}
3	40	–	10	270	9.1	E_{k_max}
4	60	50	20	–	18.0	R_{k_min}
5	110	12	6	–	16.0	R_{k_min}
6	–	36	12	750	3.9	β_{min}
7	35	6	12	130	–	R_{B_max}
8	15	110	–	1800	4.7	U_{min}
9	90	–	20	510	18.0	E_{k_max}
10	65	–	12	120	9.1	E_{k_max}
11	70	24	12	–	8.2	R_{k_min}
12	–	12	6	240	2.4	β_{min}
13	50	9	5	160	–	R_{B_max}
14	25	15	–	910	9.1	U_{min}
15	130	24	–	1200	33.0	U_{min}
16	40	–	5	150	2.0	E_{k_max}
17	20	36	12	–	4.3	R_{k_min}

Table 1.2 continued

Variant	β	E_k, V	U, V	R_k, Ω	R_B, kΩ	Determine
18	–	12	3	300	1.8	β_{min}
19	60	80	15	680	–	R_{B_max}
20	80	24	10	560	–	R_{B_max}
21	95	12	–	820	75.0	U_{min}
22	35	–	4	270	1.8	E_{k_max}
23	10	90	25	–	3.6	R_{k_min}
24	–	12	3	360	3.6	β_{min}
25	90	36	12	–	24.0	R_{k_min}
26	115	–	5	1100	15.0	E_{k_max}
27	20	24	–	160	1.3	U_{min}
28	65	12	6	430	–	R_{B_max}
29	–	50	12	220	3.3	β_{min}
30	–	18	6	180	2.0	β_{min}
31	70	12	5	–	12.0	R_{k_min}
32	45	–	10	150	2.2	E_{k_max}
33	30	10	–	910	16.0	U_{min}
34	60	24	4	470	–	R_{B_max}
35	15	30	12	360	–	R_{B_max}
36	–	36	6	820	9.1	β_{min}
37	20	12	5	–	1.5	R_{k_min}
38	40	–	12	510	10.0	E_{k_max}
39	70	9	–	200	7.5	U_{min}
40	25	75	–	560	2.7	U_{min}
41	105	24	15	470	–	R_{B_max}
42	–	18	6	240	5.6	β_{min}
43	30	24	12	–	8.2	R_{k_min}
44	55	–	5	1000	15.0	E_{k_max}
45	20	–	5	1500	8.2	E_{k_max}
46	85	36	–	390	1.8	U_{min}
47	15	12	4	270	–	R_{B_max}
48	–	18	6	680	6.8	β_{min}
49	30	24	5	–	1.5	R_{k_min}
50	70	9	–	200	7.5	U_{min}

Test No. 2   Modes of operation of bipolar transistor

For Test No. 1, the variant number is composed of a two-digit number XZ (the last three digits of student's card being XYZ), if XZ ≤ 50, or (100 – XZ), if XZ > 50. For Test No. 2, the variant $N_{V2} = N_{V1}$, if $N_{V1} ≤ 35$, or $N_{V2} = N_{V1} – 35$, if $N_{V1} > 35$. N_{V2} — variant number of Test No 2; N_{V1} – variant number of Test No. 1.

NPN transistor connection circuit is shown in Fig. 2.1. Analyse operation of the circuit in four intervals (Fig. 2.2): $\Delta t_1, \Delta t_2, \Delta t_3,$ and Δt_4.
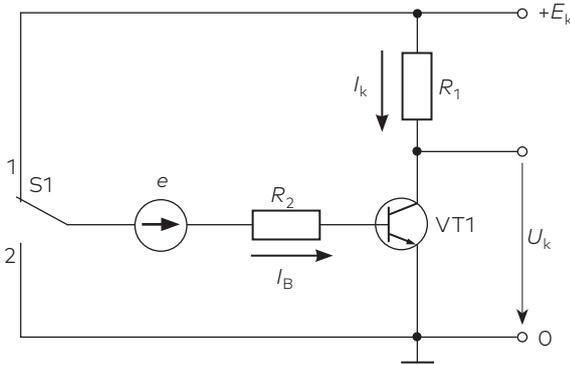

Fig 2.1. Transistor connection circuit.
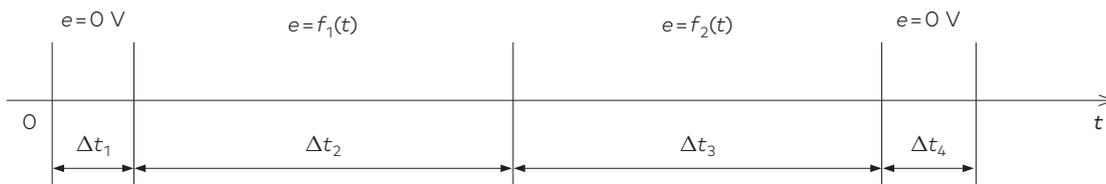
Fig. 2.2. Four intervals for analysis of the circuit.

Durations of intervals: $\Delta t_2 = \Delta t_3 = 8\Delta t_1 = 8\Delta t_4$. EMF of signal source in intervals Δt_1 and Δt_4 is $e = 0$ V, while in intervals Δt_2 and Δt_3 it changes according to the sine law. Both the interval Δt_2 and Δt_3 last two sinusoidal periods. At the beginning of interval Δt_2, the EMF initial phase equals zero.

The current transmission coefficient β (signal amplification coefficient) in transistor's base, E_K of power supply EMF, and resistances of resistors R1 and R2 for all variants are given in Table 2.1. The range of variable EDS e increases or decreases by 25 % in each half-interval in comparison to the previous one. Table 2.1 presents also the value of EMF range E_{m0} in the first half-interval; symbols ↑ or ↓ indicate whether the range E_m increases or decreases in the particular interval. Position of the switch S1 in each of the four intervals is also indicated in the table.

1. Make the necessary calculations on a graph paper sheet (A4), draw the following diagrams for all four intervals:
   - EMF $e = f(t)$;
   - transistor's base current $i_B(t)$;
   - collector current $i_k(t)$;
   - collector voltage $u_k(t)$.

   Choose appropriate scales for the currents, EMF, and voltage u_k, and mark interval Δt_1 as a 10 mm line segment on the time axis.
2. In calculations, assume that the internal resistance of EMF source, reverse current of the transistor's collector, and the collector voltage in saturation mode equals zero. Assume that the resistance of transistor's emitters lead is considerably lower than resistance R_2, and thus does not affect the value of the base current i_B.
3. When drawing sinusoids, calculate only their extreme (marginal) values.
4. Draw conclusions on transistor's operation modes in all intervals.

<div align="right">

Table 2.1
Given quantities

</div>

Variant	R_1, kΩ	R_2, kΩ	E_k, V	β	E_{m0}, V	Position of switch S1				Change of E_m	
						Δt_1	Δt_2	Δt_3	Δt_4	Δt_2	Δt_3
1	0.60	10.0	10	30	15.0	1	1	2	2	↓	↑
2	0.70	12.0	8	40	5.0	2	1	2	1	↑	↓
3	0.35	8.0	15	25	16.5	1	2	1	2	↑	↓
4	0.80	39.0	24	60	36.0	2	1	2	1	↓	↑
5	1.00	15.0	20	20	22.0	2	2	1	1	↑	↓
6	0.27	9.0	12	45	18.0	1	1	2	2	↓	↑
7	0.65	18.0	9	35	10.5	1	2	1	2	↓	↑
8	0.18	2.5	18	15	20.0	2	2	1	1	↑	↓
9	1.25	27.0	25	30	29.3	1	2	1	2	↓	↑
10	1.50	20.0	22	18	33.0	2	1	2	1	↓	↑
11	0.80	8.0	10	12	11.0	1	2	1	2	↑	↓
12	1.00	20.0	15	23	17.5	2	2	1	1	↓	↑
13	0.25	10.0	18	50	21.0	1	2	1	2	↓	↑
14	0.80	20.0	43	33	27.0	1	1	2	2	↑	↓
15	2.00	20.0	18	10	27.0	2	1	2	1	↓	↑
16	1.50	18.0	36	15	42.0	1	2	1	2	↓	↑
17	0.70	20.0	25	40	29.2	2	2	1	1	↓	↑
18	0.90	22.0	12	28	13.5	1	2	1	2	↑	↓
19	0.60	10.0	9	20	14.0	1	1	2	2	↓	↑
20	0.35	14.0	18	60	12.0	2	1	2	1	↑	↓
21	1.20	50.0	12	45	7.4	1	1	2	2	↑	↓
22	0.18	6.0	36	35	54.0	2	1	2	1	↓	↑
23	0.07	3.2	22	52	25.7	2	2	1	1	↓	↑
24	0.15	3.5	9	25	10.0	1	2	1	2	↑	↓
25	0.42	16.0	42	40	26.0	2	1	2	1	↑	↓
26	0.75	11.0	15	15	23.0	1	1	2	2	↓	↑
27	1.50	80.0	60	60	37.0	2	1	2	1	↑	↓
28	0.26	6.9	18	28	21.0	1	2	1	2	↓	↑
29	1.20	22.0	36	20	54.0	1	1	2	2	↓	↑
30	0.15	6.0	20	45	22.0	2	2	1	1	↑	↓
31	0.26	8.5	9	35	13.5	2	1	2	1	↓	↑
32	0.50	30.0	42	70	46.0	1	2	1	2	↑	↓
33	0.60	25.0	15	50	16.5	2	2	1	1	↑	↓
34	0.15	4.0	26	40	16.0	1	1	2	2	↑	↓
35	0.18	10.0	12	75	18.0	2	1	2	1	↓	↑

Test No. 3   Operational amplifier

For Test No. 1, the variant number is composed of a two-digit number XZ (the last three digits of student's card being XYZ), if XZ ≤ 50, or (100 – XZ), if XZ > 50. For Test No. 3, the variant $N_{V3} = N_{V1}$, if $N_{V1} \leq 35$, or $N_{V3} = N_{V1} - 35$, if $N_{V1} > 35$. N_{V3} — variant number of Test No 3; N_{V1} – variant number of Test No. 1.

The amplifier's circuit diagram is given in Table 3.1. Values and variants of the given parameters are shown in Table 3.1. There is a signal delivered to the amplifier's input, the time diagram is presented in Fig. 3.2. In moment t_S, switch S1 is switched from position 1 to position 2, or the other way round. **In moment $t = 0$ s, condenser C1 is discharged.**

1. Draw in scale time a diagram of the input signal $u_{ie}(t)$ and calculate and draw in scale a time diagram of the output signal $u_{iz}(t)$. Both diagrams shall be drawn one below the other in similar time scales. If the output signal is linear, it is enough if two points are calculated – at the beginning and end of the particular interval. In case of non-linear signal, calculate and mark in the diagram an additional point **in the middle of the interval**.
2. Analyse the characteristic modes of amplifier operation.
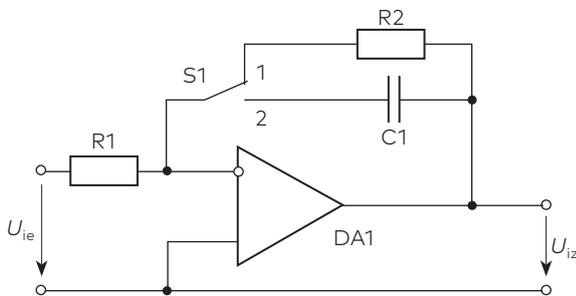

Fig. 3.1. Amplifier's circuit diagram.
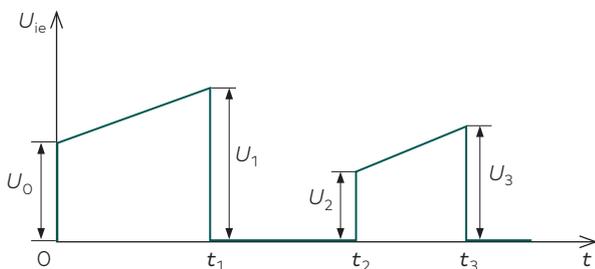
Fig. 3.2. Time diagram of the input signal.

Methodical guidelines

It is easy to calculate the output signal in case of inverting amplifier (switch S1 is located in position 1): $U_{iz} = KU_{ie}$. Note that the polarities of input and output signals are opposite.

In case of an inverting amplifier it is suggested to determine the time constant first: $\tau = RC$ (in milliseconds!). Then, integrate the input signal:

$$u_{iz} = -\frac{1}{\tau} \int_{t_a}^{t_b} u_{iz} dt + U_a.$$

In this formula, t_a and t_b are beginning and end of integration, U_a is voltage on the condenser (thus, the **output** voltage) at the beginning of the particular integration phase.

To simplify the calculation, one can use the integral geometric interpretation: integral of function u_{ie} equals the area of a figure composed by the function's graph, abscissa axis, and vertical lines with abscissa values t_a and t_b. In case of a trapezium, one will get

$$S = \frac{\left(u_{\text{ie\_a}} + u_{\text{ie\_b}}\right)\left(t_{\text{b}} - t_{\text{a}}\right)}{2}, \text{V} \cdot \text{ms}.$$

Then, the output voltage can be found:

$$u_{\text{iz}} = -\frac{S}{\tau} + U_{\text{a}}.$$

It is advised to use both the time values and the time constant in formulas in milliseconds.

If the input signal does not change during integration, the output voltage is linear function; it is enough, therefore, to calculate only one point at the end of the interval. If the input voltage changes linearly, integral of such function will be a curve (a section of parabola); therefore, it is required in this task to calculate also an additional point in the middle of the interval. If the input signal changes its sign (plus or minus) in integration interval, the extreme value of output signal will be at the moment when $u_{\text{ie}} = 0$ V. It is suggested to calculate this value and mark it in the graph.

Note that a condenser is connected to an **integrating** amplifier's output, thus the output signal may change only constantly, namely without jumps.

Table 3.1

Value of given parameters and quantities

Variant	R_1, kΩ	R_2, kΩ	C, mF	t_1, ms	t_2, ms	t_3, ms	t_S, ms	U_0, V	U_1, V	U_2, V	U_3, V	S1 commutation
1	43.0	51.0	0.47	30	75	126	101	1.5	1.5	0.0	3.5	1→2
2	16.0	36.0	1.00	18	38	47	41	−0.5	2.0	−0.5	−0.5	1→2
3	3.6	6.8	2.20	20	30	68	12	2.0	2.0	1.0	3.0	2→1
4	5.6	7.5	4.70	48	86	124	19	0.5	−2.0	−1.5	−1.5	2→1
5	2.0	2.0	10.00	25	33	63	54	−1.0	−1.0	−1.0	−4.0	2→1
6	13.0	27.0	0.68	10	20	26	23	1.5	4.5	3.0	3.0	1→2
7	7.5	12.0	1.50	24	34	58	7	0.5	0.5	−1.5	−5.0	1→2
8	2.7	1.6	3.30	13	22	40	8	0.0	−2.0	−2.5	−2.5	1→2
9	3.9	7.5	6.80	32	70	99	82	1.0	1.0	−0.5	3.0	2→1
10	11.0	12.0	0.47	14	25	46	40	1.0	3.5	2.5	2.5	2→1
11	30.0	8.2	1.00	50	120	155	25	−2.0	−2.0	0.5	2.5	2→1
12	5.6	12.0	2.20	17	27	54	5	−1.0	−3.5	1.5	1.5	1→2
13	3.9	6.8	4.70	19	44	78	64	−0.5	−0.5	1.5	−1.5	1→2
14	2.0	1.8	10.0	40	100	144	118	−1.5	1.5	2.0	2.0	1→2
15	12.0	18.0	0.68	12	25	49	8	−1.5	−1.5	0.0	−3.5	2→1
16	27.0	10.0	1.50	45	68	127	23	−0.5	−2.5	−1.0	−1.0	2→1
17	1.8	4.3	3.30	15	27	33	29	3.0	3.0	1.0	4.5	2→1
18	2.4	3.0	6.80	28	36	84	65	0.5	3.0	0.5	0.5	1→2
19	27.0	20.0	0.47	16	32	40	6	−2.5	−2.5	−1.0	1.0	1→2
20	30.0	62.0	1.00	30	42	99	21	1.5	−1.0	1.0	1.0	1→2
21	3.9	1.8	2.20	18	31	45	38	2.5	2.5	−1.5	−4.5	2→1
22	2.7	1.8	4.70	20	44	68	51	0.0	3.0	−2.0	−2.0	2→1
23	4.3	6.8	10.00	48	86	115	29	1.5	1.5	−0.5	−4.0	2→1
24	13.0	15.0	0.68	25	60	85	10	1.0	−1.0	−0.5	−0.5	1→2
25	3.9	9.1	1.50	10	16	30	26	2.0	2.0	0.5	4.0	1→2
26	5.6	10.0	3.30	24	55	77	66	−1.0	1.5	−1.5	−1.5	1→2
27	1.8	2.4	6.80	13	33	53	4	−1.0	−1.0	1.5	3.5	2→1
28	33.0	33.0	0.47	32	67	89	19	−1.5	−4.0	3.0	3.0	2→1
29	9.1	18.0	1.00	14	21	43	30	0.5	0.5	0.0	−3.0	2→1
30	20.0	30.0	2.20	50	90	180	153	−0.5	2.5	−2.5	−2.5	1→2
31	1.3	0.75	4.70	17	22	41	9	1.0	1.0	1.0	−2.5	1→2
32	1.1	2.2	10.00	19	38	76	6	0.5	−1.5	2.5	2.5	1→2
33	47.0	51.0	0.68	40	56	108	87	−2.0	−2.0	−1.0	2.5	2→1
34	7.5	2.2	1.50	12	20	25	22	1.5	4.0	1.5	1.5	2→1
35	11.0	12.0	0.47	14	25	46	40	1.0	3.5	2.5	2.5	2→1