

Application of PTC «Graphics –TR» for Teaching University Students on the Course «Computer Simulation of Circuits and Devices» *

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Abstract. This paper describes the capabilities of the Graphics-TR programmatically technical complex (PTC) as a tool for teaching university students the general principles of computer-aided design of schematic documentation using the Graphics-TP programmatically technical complex. A brief history of the development of CAD, CAM and PDM systems in our country and abroad is presented. The main disadvantages of using foreign CAD in Russia are given. Attention is focused on electronic design automation (EDA) systems for circuit engineering tasks, which is a subspecies of CAD systems. The article provides a justification for the development of domestic software at the scientific Institute (Computer Graphics Laboratory, part of the division of the V. A. Trapeznikov Institute of management problems of the Russian Academy of Sciences) for solving problems in the field of EDA design. With the help of "Graphics –TR", we consider computer modeling of circuits by automating design work on the example of a practical solution to the problem in the field of circuit engineering and development of printed circuit boards. There are also examples of practical classes on the study of circuitry by students of MTUCI on the course of lectures "Computer modeling of circuits and devices".

Keywords: Computer-Aided Design (CAD) Systems, EDA Systems, The Graphics-TR Programmatically Technical Complex, Circuit Diagrams, Wiring Diagrams, Printed Circuit Boards, Graphic Designation, Connection Tracing, Software, Element Placement.

1 Introduction

One of the goals of the modern educational space is its informatization. The main goal of introducing information technology into the educational process is to increase its

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quality and effectiveness. To a large extent, informatization can be realized through the introduction of information technologies in the educational process [1].

In the conditions of the modern dynamic development of society and the complexity of its technical and social infrastructure, information becomes the most important strategic resource. Along with traditional - material and energy resources - modern information technologies that allow you to create, store, process and provide effective ways of presenting information to the consumer, have become not only an important factor in the life of society, but also a means of improving the management of all areas of public activity. The level of informatization, in addition, is becoming one of the essential factors for successful economic development and competitiveness of the region both in the domestic and foreign markets. However, the informatization of modern educational space is unthinkable without automation.

We note that automation based on the use of computers and computer networks penetrates today into all spheres of life in modern society related to the use and processing of information, starting from the manufacturing sector, where automated systems for designing, managing production, technological processes, etc. have already appeared. The aging of the subject matter of disciplines in connection with new discoveries of science and technology, the preparation of school graduates in the field of using new ways to search for knowledge and methods of access to data banks containing relevant scientific and educational information is of particular importance.

In this article, we will consider a computer-aided design (CAD) system used in teaching students of a higher educational institution (university) in the field of circuitry and computer graphics.

A little definition and history. *Computer-aided manufacturing* system is an automated system that implements information technology for performing design functions, is an organizational and technical system designed to automate the design process, consisting of personnel and a set of technical, software and other means of automating its activities. To designate such systems, the abbreviation CAD was introduced [2].

Computer-aided design (CAD) and *computer-aided manufacturing* (CAM) began to be developed and implemented worldwide in all spheres of economic activity since the beginning of the 70s of the last century. However, in the USA, CAD systems began to be developed after the end of World War II by the forces of research organizations for use in the complex of command and control of forces and means of continental air defense in 1947 [3].

The first computer-aided design system in the USSR was developed in the late 1980s. working group of the Chelyabinsk Polytechnic Institute, under the guidance of Professor A. A. Koshin [4].

Then, computer-aided engineering (CAE) systems, product data management (PDM) and enterprise resource planning (ERP) systems were created, systems were integrated, and from the mid-90s there was a transition to paperless electronic documentation and Continuous Acquisition and Life cycle Support (CALC - technology). Huge amounts of money are currently being invested in the development and marketing of CAD / CAM / PDM systems (software) by both government agencies and private industrial corporations. The advantage of the software is that it does not need to

be transported across the border, but can be downloaded via the Internet. CAD / CAM / PDM software is a strategic commodity. CAD is an important link in industrial design, widely used in many industries, including in the automotive, shipbuilding and aerospace industries, industrial and architectural design, prosthetics and many others. Because of its economic importance, CAD has become the main driving force behind research in computational geometry, computer graphics, etc [5].

Computing and radio electronics are inconceivable without the use of printed circuit boards, the development of which requires the designer to know and take into account many diverse requirements. The increasing complexity of electronic devices has required the creation of complex multilayer printed circuit boards, which cannot be developed without the use of automation. The use of CAD in the design of electronic systems is known as automation of electronic design (EDA) [6].

Electronic device design systems or, in other words, EDA systems are software for designing electronic devices, creating microchips and printed circuit boards. EDA-systems allow you to create circuit diagrams of the designed devices using a graphical interface, create and modify the base of electronic components, check the integrity of the signals on the circuits. The created circuit directly or through an intermediate link file can be converting into a blank of the designed printed circuit board. Modern EDA systems allow for automatic arrangement of elements and automatic wiring of tracks on the drawing of a multilayer printed circuit board, thereby connecting the outputs of the electronic components in accordance with the circuit diagram [7].

Automation of the design of electronic devices helps to simulate the device being developed and to study its operation before it is implemented in the equipment.

For design in circuitry, such systems as AutoCAD, P-CAD, Caddy, OrCAD, SPECCTRA, AUTOSAR, PSpice, Cadence Allegro, Accel EDA, Express PCB, Pad2Pad, DesignSpark PCB, etc. are used.

These systems differ in the amount for occupied memory, functionality, algorithms for generating databases of typical elements, placing elements on the plane of the circuit, and tracing connections between elements. Such systems use various principles for the formation of specification tables and connections. However, the cost of these systems is high.

At the Department of Engineering and Computer Graphics, Moscow Technical University of Communications and Informatics (MTUCI), a course of lectures "Computer Modeling of Circuits and Devices" was delivered.

Based on the educational version of the complex, MTUCI conducted practical exercises on the course "Computer Modeling of Circuits and Devices", providing support for the educational process as a computer- training tool. The purpose of the practical classes at the course was to master the stages of the technical design of REA by students using the "Graphics - TR" tool complex, which is designed to automatically create REA schematic documentation [8].

The instrumental software complex "Graphics-TR" was developed at the V. A. Trapeznikov Institute of Control Sciences of Russian Academy of Sciences by the team of the Laboratory of Computer Graphics (lab. No. 18). The main objective of the complex was the design of elements in the field of computer graphics and circuitry. "Graphics-TR" is a domestic EDA-system with an attempt to bring this software clos-

er to the functionality of foreign systems. It must be added that the theoretical and practical activities of the laboratory are associated with the development of methods for designing interactive systems (IP) implemented in the form of hardware and software.

The program complex organically fit into a number of systems belonging to computer training systems (CTT), which have tremendously developed as applied tools for the education of university students. "Graphics-TR" has an intuitive interface, in addition to methodological recommendations in the form of a brochure on the system, there is an electronic manual. Students relatively easily learn the general principles of computer-aided design of schematic documentation based on this programmatically technical complex.

It should be noted that computer training tools (CTT) include text and graphic editors, compilers, programming systems and, of course, computer-aided design (CAD) systems, in other words, all computer tools considered as an object of study or acting as a tool for solving educational tasks [9].

Undoubtedly, CTT in the current conditions are becoming one of the main links in the educational system.

The special course "Computer simulation of circuits and devices" reveals the general principles of computer-aided design of circuit documentation.

The educational process using the applied systems of the instrumental complex has a number of advantages compared with the study of other commercial design systems:

1. The minimum cost of organizing the educational process and the minimum requirements for the computing resources of the computers used.
2. The basic algorithms for computer-aided design of schematic documentation are concentrated in one system.
3. To study the design processes of the entire spectrum of schematic documentation, the use of several systems is not required.
4. We study the basic methods of computer-aided design of schematic documentation, and not a specific system.

In addition, with a certain improvement of the Graphics-TR software complex, it is possible to integrate it into components supporting the activities of teachers during training sessions.

2 Training in the general principles of computer-aided design of schematic documentation using the «Graphics – TR» programmatically technical complex

Currently, computer-based training systems (CBS) are ideal for studying at a university, as one of the main tools in organized education and self-education. Organized education is understood as the educational process in educational institutions of different educational levels, etc.

The programmatically technical complex “Graphics-TR” undoubtedly enters the field of computer-based training systems, which has been proven in practice in the educational process.

We define the basic conditions in which it is advisable to set the task of using the “Graphics – TR” programmatically technical complex (PTC).

Firstly, to cover local sections of the courses. Locality means that the section material is characterized by significant semantic interconnectedness, but weakly correlates with the content of other sections of the course that are not covered by the computer-learning system. In addition, a specific methodology for studying a course in computer graphics and circuit modeling implies the advisability of using this particular software.

Secondly, CBS includes educational material that is less stable than the contents of the textbook (textbook) and updating the programmatically technical complex is simpler than processing large-scale educational material.

In the framework of organized education in the university, we distinguish the following categories of users:

- trainees - students, as well as professional development specialists;
- teachers who conduct training sessions using CBS, as well as coordinating the learning process in which these tools are used.

Teachers carry out:

- initial testing of trainees, assessment of their initial preparedness and the formation of individual tasks, which determine the composition and volume of the training material provided for them, as well as indicators reflecting the requirements for the generated knowledge;
- configuring CBS (the “Graphics – TR” programmatically technical complex) in accordance with the prepared tasks, as well as the functioning of the system itself, taking into account the settings;
- preparation of planned schedules for students to complete tasks;
- organizational and methodological support of events, as part of the application of the programmatically technical complex;
- monitoring the work of students, as well as analyzing and evaluating its results, and adjusting, based on these assessments, individual tasks and schedules for their implementation.

We proceed directly to the training module. Let us explain that the circuit documentation includes algorithms, structural, functional, circuit and wiring diagrams.

A diagram is a design document on which the component parts of a product or installation are depicted in the form of conventional graphic symbols (UGO) and the relationships between them are shown [10].

Schemes by type can be divided into structural, functional, principal and connections (mounting).

At the initial stage of technical design, all available information about the device is contained in a circuit diagram - it can be said, a model that displays the structure of

the device. Another model of the designed device is its wiring diagram. This model determines the position of the components (elements) in the installation space and the specific way to implement the connections. A large number of wiring diagrams can be building on the basis for a circuit diagram, some of which can correspond to some implementation of the device, others cannot be implemented.

The main objective of the technical design stage of the device is the construction of an implemented wiring diagram. A necessary condition for the implementation of the scheme is its satisfaction of a number of restrictions, which can be divided into two types:

1. Metric: fixed component size, width of conductors, minimum allowable distance between various structural elements, contact pad size, distance between conductors.
2. Topological: prohibition of the location of tracks in specified areas of the installation space, prohibition of the intersection of various connections, the requirement for the electrical connection of certain contacts, a fixed order of contacts, the indivisibility of the component into separate sections, the type of contact area, the restriction on the installation method [11].

From the foregoing, we can conclude that when developing design algorithms for wiring diagrams, it is necessary to take into account not only metric and topological restrictions, but also the specifics of the technological process for the production of printed circuit boards. These features were taken into account when developing the "Graphics - TR" tool complex, which, in particular, is intended to automate the process of designing circuit diagrams, wiring diagrams, and creating printed circuit boards.

Note that the circuit diagrams determine the full composition of the elements and the relationships between them and provide a detailed description of the principles of operation of the product or installation (they serve to develop other design documents). Connection diagrams (mounting) show the conjugation of the component parts of the product and determine the wires, bundles, cables or pipelines that carry out this interaction, as well as their connection and input points.

By a model of circuits we mean not only their only image with specific current values of the coordinates of elements and links, but also some mathematical description of its graph - a circuit whose vertices are individual functional parts of the equipment, and arcs - the connections between them [12].

Such models are easily converted to electronic documents and models that are used in subsequent stages. The connections between the contacts of the individual elements of the circuit (the main functional parts of the product) are created using special software tools used in computer-aided design systems. The model of the electrical circuit diagram (MSEP) is easily modified at the design stage of the electrical mounting circuit (SEM):

1. The image of each element is replaced by the image of its seat on the printed circuit board.

2. The location of each element is changed and obeys the laws of designing wiring diagrams with constant connectivity between them at these stages.

Below we consider the development of the circuit diagram and wiring diagrams in the “Graphics – TR” programmatically technical complex as applied to the educational process (laboratory lesson).

In the "2D-drawing" mode, the student is given the opportunity to create vector geometric models, edit models at the level of individual primitives (point, polyline, circle, circular arc, ellipse, ellipse arc, spline, symbol ...), composite nodes, create and maintain geometric libraries models. The accuracy of constructing primitives is achieved by the binding mode to the nodes of the dimensional grid and the scale of visualization.

In addition, editing is implemented: offset, scaling, rotation, mirroring, copying (including with mirroring), changing the characteristics of the line (type, color and thickness), shifting the end of the segment and converting it to a polyline, as well as deleting and cancel the current operation.

The process of designing basic electrical and wiring diagrams, as well as the development of printed circuit boards, includes the manual placement of elements, the tracing of connections between elements in the diagrams and the positioning of the element designations in the diagram in accordance with the requirements of GOST 2.710-81.

In addition, it contains interactive input of element characteristics and automatic creation of tables containing a list of elements.

The preparation of initial data for the formation of geometric models of schemes is also carried out in the "2D-drawing" mode. The initial data include a description of typical graphic images of elements of electronic equipment and the creation of a library of these descriptions. The library of elements contains two levels of description: conditional graphic designations of elements on a circuit diagram and graphic images of elements on a wiring diagram.

The “Graphics – TP” system allows you to save images on the screen in raster form (*.bmp files). In the future, viewing them inside the system, you can relatively quickly select the desired conditional graphic designation of the element. However, there is one limitation: there must necessarily exist a vector graphic symbol, previously stored in the system library. Consider below the development of the wiring diagram. In Fig. 1 shows the process of creating a geometric model of the concept. Graphic images of elements were selected from a previously created library and connections between elements were drawn [13].

Then, after all the data has been processed by the automatic tracing module, the circuit diagram shown in Fig. 2.

Automatic connection tracing implements the algorithm for determining the shortest path on a graph with and without intersections of compounds. By setting various trace parameters, you can change the distance between the tracks, the number of bends of the tracks, give preference to vertical or horizontal tracks.

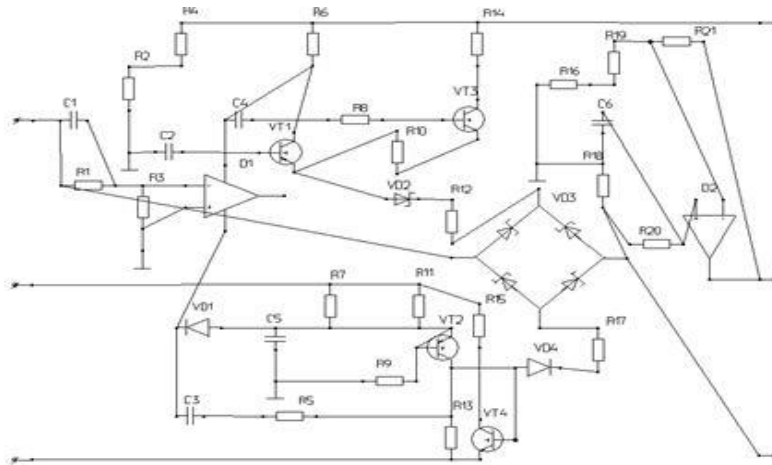


Fig. 1. Geometric concept model

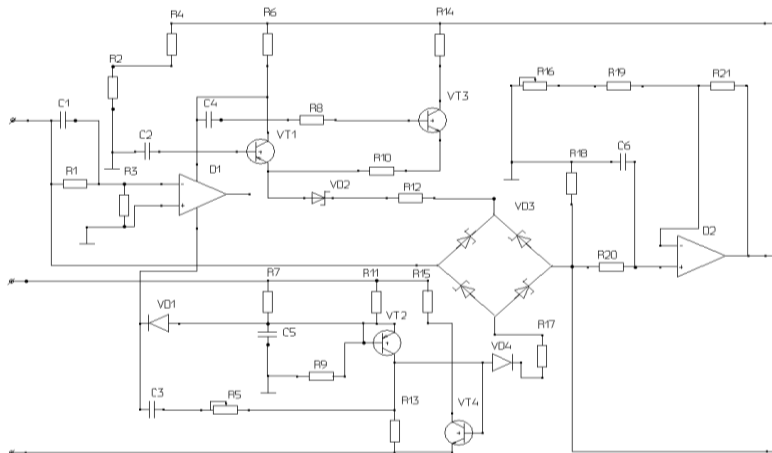


Fig. 2. Schematic diagram.

In the "Graphics-TR" system, there is a command by which the function of the number of intersections between the bonds in the projection on the OX and OY axis of the diagram drawing is built. The results obtained make it possible to evaluate the quality of placement of circuit elements. Setting trace parameters, modes of automatic sorting of chains, and placing elements on a diagram provide the ability to get the maximum number of traces.

Based on the model of a circuit diagram, it is automatically possible to obtain a model of a printed circuit board - a graphic image of the elements and lines of connections between them (Fig. 3), and vice versa.

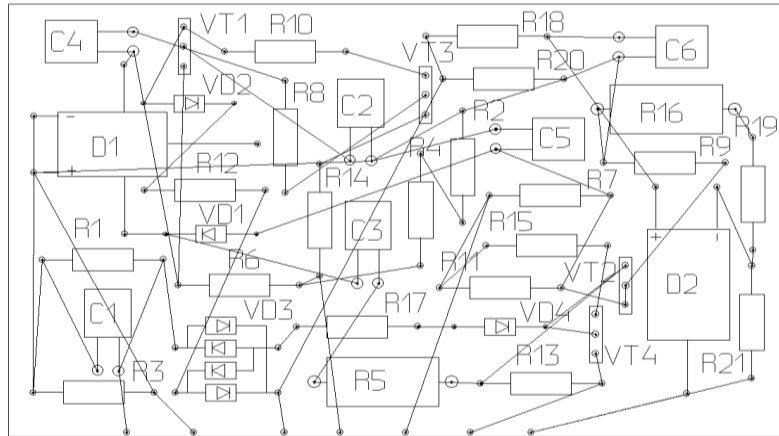


Fig. 3. Graphic representation of elements and lines of connections between them.

In the "2D-drawing" mode, the necessary layout of the elements of all layers of the printed circuit board is made as a whole and the trace command is applied to the model of the printed circuit board. The result will be a wiring diagram (Fig. 4).

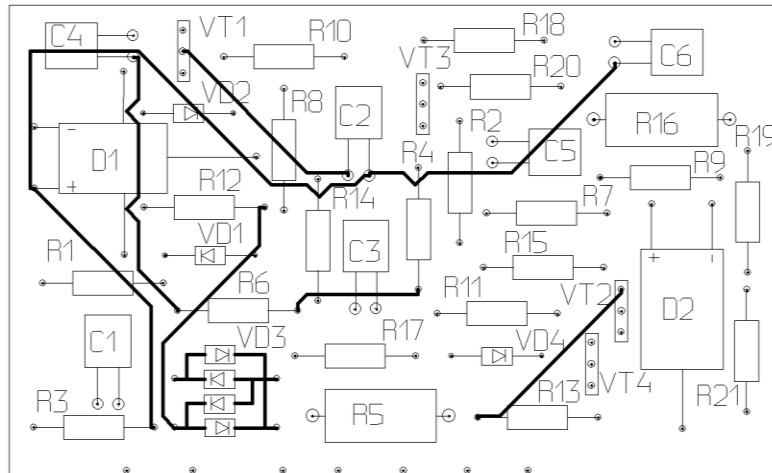


Fig. 4. Wiring diagram (1 layer).

At each design stage, the system provides the ability to edit the results: add, delete or change the position of the element. It should be noted that in this case, the lines of connections between the elements will automatically be modified.

Likewise, it is possible to edit communication lines in order to add or remove an element's contact from a connection. When designing, various geometric primitives can be included in the circuit model, directly creating them at the time of work or adding them from a previously saved file, for example, a frame with a stamp.

Parts list	
Name	Capacitors
Denotation	C4 - C6
Parameters	10 μF
Note	

Previous Record OK Cancel

Fig. 5. Preparation of the list of elements

The system also has a tool for creating and making changes to the list of elements (Fig. 5). The items listed will be parsed in the next chapter.

After automatic processing of the data of the list of circuit elements at the request of the user, the table of the list of elements made in accordance with GOST will be displayed on the screen [14]. The number of elements with the same parameters is calculated automatically.

All graphic information displayed on the monitor screen can be displayed on any printing medium at any time, and interaction with other graphic systems is carried out through files such as *.hpg, *.dxf, *.gbr, *.bmp, etc.

3 Practical exercises using the “Graphics-TR” programmatically technical complex

Let's figure out what the purpose of practical classes in the study of circuitry (the location of electrical circuits on analog and digital elements) is. Of course, this is an acquaintance with analog and digital circuits of various equipment with the necessary in this case study of graphic symbols of the most common elements. In addition, it is necessary to study the general requirements for the implementation of electrical circuit diagrams as a kind of design documentation. And at the end of the analysis of the purpose of practical classes, I would like to note that students acquire skills in the image and designation of elements of electrical circuits, the topology of the printed circuit board and the placement of elements on it.

The content of the practical work that students perform in the lessons on circuit design includes: drawing an electrical circuit diagram in A3 format for an individual task, putting down alphanumeric designations of elements of an electrical circuit diagram, compiling a list of elements and designing the main inscription. In other words, on the basis of an individual variant of the electrical circuit diagram (ECD), using the "Graphics-TR" system, students create a computer model of the electrical circuit diagram (MECD). In addition, on the basis of the MECD, it is necessary to obtain and issue an electronic drawing of the ECD and an electronic list of elements.

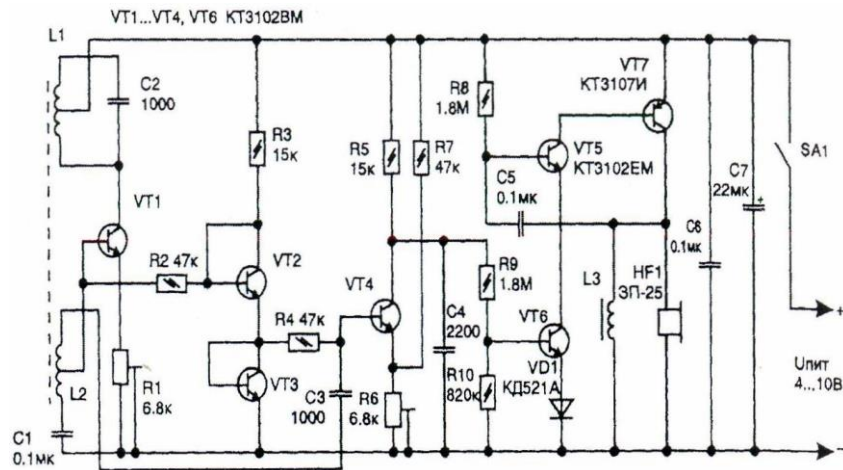


Fig. 6. Metal detector (electrical schematic for laboratory work).

Options for assignments (Fig. 6) are assigned by the teacher, providing students with mock-ups of electrical circuit diagrams. Students should return the lab work with the printed circuit board topology (Fig. 7) and the placement of elements on it.

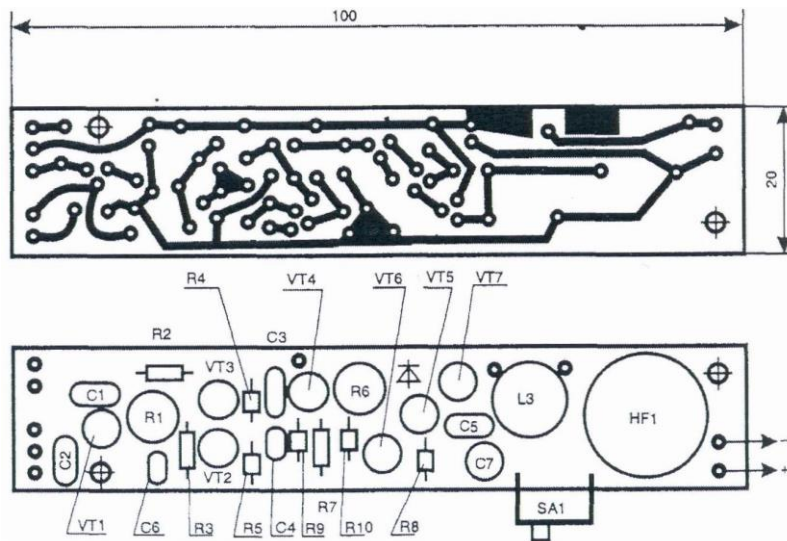


Fig. 7. The topology of the printed circuit board and the placement of elements on it (completed laboratory work).



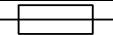
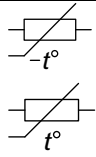


Designations of conventional graphic elements (Table 1), which will be required to perform laboratory work, are presented in the guidelines [15].

When passing the laboratory work, students must comply with the basic requirements for the design of schematic documentation. The graphic designations of the

elements and the communication lines connecting them should be placed on the diagram in such a way as to provide the best understanding of the structure of the product and the interaction of its components. All elements must be uniquely identified in the diagram. Full data on the elements is recorded in the list of elements.

Moreover, the correspondence of the list of elements to their conventional graphic images is carried out through reference designations. The list of elements is placed on the first sheet of the scheme or performed as an independent document. The list of elements is made out in the form of a table and placed above the main inscription of the drawing. The distance between the title block and the list of elements must be at least 12 mm. If necessary, the continuation of the list is placed to the left of the main inscription, repeating the names of the columns of the table. In the case when there is not enough space on the drawing for the list of elements, it is performed on A4 format as an independent document in accordance with GOST 2.104-68.

Table 1. Graphical symbols in diagrams (excerpts from standards)

№ π/ π	Name	Designation on a schematic diagram	Letter designation	Designation in the database of the Graphics-01-TR system
Designations for general use. STST 2.721-74				
1.	Grounding			Z_1
2.	Housing			Z_0
Dischargers, fuses. STST 2.727-68				
3.	Fuse		F	F_ppedpe
Resistors, capacitors. STST 2.728-74				
4.	Direct heating thermistor		R	
5.	Constant resistor 0.05 watts		R	
6.	Constant resistor 0.125 watts		R	R_mlt0125

In the columns of the list indicate the following data:

1. in the column "Positional designation": positional designation of an element, device or functional group (it is permissible to indicate several positional designations of the same type elements in one line);

2. in the column "Name": the name of the element in accordance with the document on the basis of which this element is used, and the designation of the document itself (GOST);
3. in the column "Quantity": the number of elements of the same type of the same name;
4. in the column "Note": the necessary additional information about the elements of the scheme.

Elements in the list are written in groups in alphabetical order of alphanumeric designations. If the designation uses positional signs made up of letters of the Latin and Russian alphabets, then the list first contains elements with positional signs made up of letters of the Latin alphabet, and then - from the Russian alphabet. It is allowed to leave several lines between separate groups of elements, and sometimes between elements.

Communication lines should consist of horizontal and vertical segments and have the smallest number of kinks and mutual intersections. The distance between adjacent parallel lines must be at least 3 mm.

4 Conclusion

Based on the above, I would like to note that when introducing the “Graphics-TR” programmatically technical complex as a computer training system in the practical classes of MTUCI students, a more in-depth study of the general principles of computer-aided design of schematic documentation is carried out by creating new opportunities in the educational system for all its participants and their interactions. Such new features are defined as follows [16]:

- minimum costs for the organization of the educational process and minimum requirements for the computing resources of the computers used;
- reduction of time for searching and access to the necessary educational and scientific information by teachers and students;
- acceleration of updating the content of education by reducing the time for teachers to develop new educational and methodological literature;
- freeing up additional time for students for individual independent work, and for teachers to improve and develop the educational process;
- acceleration in achievement by students of the established requirements (norms, standards) to the quality of education, etc.
- providing a wide field for active independent activity of students;
- high visualization of the presentation of educational material and, as a rule, ensuring the possibility of deep penetration into the essence of the studied processes and phenomena;
- multiple acceleration of the study of design processes of the entire spectrum of schematic documentation and reduction of the mass of routine operations.

Also note that the introduction of information technology in the educational process affects the quality of education. Students relatively easily learn the general principles of computer-aided design of schematic documentation based on this programmatically technical complex.

At the end of the article, I would like to say once again that computer-based training systems (CBTS) in education are among the most important components of modern educational systems and the educational processes implemented in them.

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