



**PLOVDIV UNIVERSITY
“PAISII HILENDARSKI”**



FACULTY OF PHYSICS AND TECHNOLOGY

**DEPARTMENT OF ELECTRONICS, COMMUNICATIONS AND INFORMATION
TECHNOLOGIES**

TSVETELINA LACHEZAROVA IVANOVA-VARADINOVA

**SYSTEM OF TECHNOLOGY-BASED DECISIONS IN ENGINEERING
EDUCATION**

AUTHOR`S SUMMARY

**of a dissertation for acquiring the educational and scientific
degree of “Doctor”**

Field of higher education: 5. Technical sciences

Professional area: 5.3. Communication and Computer engineering

**Doctoral program: Automatization of areas in the intangible sphere (medicine,
education, science, administrative work, etc.)**

ADVISER: ASSOC. PROF. NADEZHDA KAFADAROVA, PhD

Plovdiv, 2024

The dissertation has a volume of 146 pages, 118 figures, 36 tables, 4 chapters, conclusions of scientific and applied contributions, a list of abbreviations and a list of the author's publications. The literature cited in the dissertation includes 92 titles by Bulgarian and foreign authors. The numbers and titles of the figures and tables used in the author's summary correspond to those used in the dissertation.

The dissertation work was discussed and forwarded for a defense procedure at a meeting of the Department of ELECTRONICS, COMMUNICATIONS AND INFORMATION TECHNOLOGIES at PLOVDIV UNIVERSITY "PAISII HILENDARSKI" on 28.02.2024, Record № 61

The defense of the dissertation work will take place at a meeting of the scientific panel on 27.05.2024 at 11.00 o'clock in hall "EKИT", 21 Kostaki Peev Str., PLOVDIV UNIVERSITY "PAISII HILENDARSKI"

The materials related to the defence of the doctoral student are at the interested parties' disposal in the administrative office of the Faculty of Physics and Technology at PLOVDIV UNIVERSITY "PAISII HILENDARSKI", 21 Kostaki Peev Str., 4th floor, room 1

Scientific panel: Prof. Anna Vladova Stoyanova, PhD

Prof. Zhelyazka Dimitrova Raykova, PhD

Assoc. Prof. Diana Velkova Stoyanova, PhD

Assoc. Prof. Borislav Hristov Milenkov, PhD

Assoc. Prof. Nikolay Atanasov Shopov, PhD

Author: Tsvetelina Lachezarova Ivanova-Varadinova

Title: SYSTEM OF TECHNOLOGICAL-BASED DECISIONS IN ENGINEERING EDUCATION

Circulation: 30 copies

INTRODUCTION

The digitalization of learning poses new challenges to engineering education. The digital transformation of learning involves expanding the spaces and models of engineering learning to suit students' preferences and strengths in ways that are meaningful to them.

Engineering education is subject to digital transformation and requires a change in the organization of learning models motivated by digital innovation. The change in engineering education poses new questions and hypotheses for technology-based decisions in the context of its digital and social orientation. A synergy of digital technologies is needed; consideration of factors oriented to the personal characteristics of the trainees and organizational-administrative factors for engineering education.

In the focus of engineering education, the solution of the problems related to the provision of knowledge and the formation of skills without neglecting the traditional models of training, and with the inclusion of digital and the formation of digital competences is placed more strongly.

These new challenges can emerge in several spaces:

- development, updating and implementation of specifics of models of engineering education in face-to-face learning, in distance learning with simulations and in learning with remote access;
- bringing out a social orientation of engineering education with an emphasis on personal positioning through self-efficacy and with an emphasis on the introduction not only of rational but also of critical and creative cognitive models;
- Technology-based decision making in engineering education.

The relevance of the current dissertation is also determined by the current state and prospective modernization of engineering education at the university in accordance with the requirements of the labour market and business; and according to the need to form digital and soft competencies that will be able to be implemented in the learning process, everyday life and professional realization throughout the entire life cycle of each student.

The subject of the dissertation is interdisciplinary. The defined goals and tasks of scientific development include the application of knowledge, skills and competencies in the field of technical sciences 5.3 and pedagogical sciences 1.3. The development of exercises in the discipline "electronics" and the remote access system is directly related to the

development of a pedagogical methodology for the laboratory exercises themselves.

Aim of the present dissertation work and tasks for its achievement:

The aim of the dissertation is the development and research of a system of technology-based decisions in engineering education, with the main emphasis being the correct definition of the specifics of engineering education and the provision of opportunities for qualitative evaluation of the effectiveness of the developed system.

To achieve the goal of the dissertation, it is necessary to perform the following research tasks:

1. To explore the existing technology-based decisions implemented in education. To carry out a critical theoretical analysis of the literature in the field of scientific research;
2. To define the specifics of engineering education in terms of technology-based decision-making;
3. To develop a model of technology-based decisions in engineering education;
4. Within the framework of the model, to develop a system of laboratory exercises in engineering disciplines for the different learning methods defined in the model;
5. To create a methodology for conducting the laboratory exercises;
6. To build a remote access system for conducting laboratory exercises in real time;
7. To investigate the effectiveness of the developed model of technology-based decisions in engineering education by conducting pedagogical research and analysing the obtained results.

CHAPTER ONE

THEORETICAL ANALYSIS

1. TECHNOLOGY-BASED DECISIONS IN TRAINING

1.1. *Methods of education*

Learning methods are systematically organized procedures and approaches that are used to facilitate the learning process and the acquisition of new knowledge, skills and beliefs. They include a variety of strategies, techniques, and tools that are applied by educational institutions and educators in order to achieve certain educational goals and assist students and undergraduates in their educational progress. Teaching methods may vary depending on the learning context, the academic discipline, the students' and students' learning styles, and the preferences of the educational institution.

There is a wide range of learning methods used in education, science, technology and other fields.

Table 1. Comparative characteristics between different educational methods

Method	Advantages	Limits
Traditional education	<ul style="list-style-type: none">▪ Effective transfer of basic knowledge and information.▪ It can be easily mass-applied to large groups of students.	<ul style="list-style-type: none">▪ The potential for interaction and active participation of students is limited.▪ It can be monotonous and not engaging enough for some students.
Distance learning	<ul style="list-style-type: none">▪ Allows flexibility and access to distance learning.▪ Suitable for students who cannot attend physically.	<ul style="list-style-type: none">▪ It requires a strong Internet connection and appropriate technology infrastructure.▪ Not all textbooks can be successfully adapted to distance learning.
Problem-based learning	<ul style="list-style-type: none">▪ It encourages critical thinking and real-world problem solving.▪ It supports the application of knowledge in a practical context.	<ul style="list-style-type: none">▪ It requires a well-structured and managed learning environment.▪ It can be challenging to deal with complex issues.
E-Learning	<ul style="list-style-type: none">▪ It provides flexibility and accessibility of learning from different places and at different times.▪ It can be more efficient to distribute information and materials via the Internet.	<ul style="list-style-type: none">▪ It requires a well-structured course and appropriate technologies.▪ You may face challenges such as lack of personal interaction and motivation.

These methods are based on the use of various technologies and software tools to support learning in engineering sciences and practices. They focus on integrating modern technology into the educational process in order to improve the learning experience and develop key skills and competencies of students.

Web-based resources and platforms: Internet and web-based educational platforms contain a variety of materials and resources that are used for learning in engineering education. They are online systems that provide educational materials, tools and resources for training and learning activities via the Internet. They offer a variety of forms of learning, including courses, lectures, exercises, visuals, and other educational resources. Some of the main features and functionalities of web-based learning resources and platforms are accessibility, variety of educational materials, interactivity, personalization, social learning, and mobility.

1.2. Previous experience of using technology-based decisions in teaching at the Faculty of Physics and Technology

The Faculty of Physics and Technology has many years of experience in the creation and implementation in education of various innovative educational systems and technology-based methods.

Dipseil

"The Dipseil system is an Internet-based system that presents a project-based learning method at the Plovdiv University "Paisii Hilendarski"." This system provides an interactive way to deliver the learning content. Dipseil is based on core pedagogical methods to implement, facilitate and promote learning experiences." (Tokmakov, D. 2011, 2013) "E-learning has become a necessity in higher education and is being implemented in educational institutions around the world." (Islam, N., Beer, M., & Slack, F. 2015).

QR codes and augmented reality

"The superimposition of virtual content (text, animation, graphics, audio, video, 3D objects) on real objects. The concept of mixing virtual data with what we see in the real world brings with it new expectations regarding access to information and new learning opportunities." (Stoyanova, D. 2023) Augmented reality can be used with a computer and with mobile devices. Augmented reality can be based on geolocation and real image recognition, or a so-called marker can be used. Most often, these are square black-and-white images, similar to a 2D/QR barcode, marking a specific location or real object from the environment. After the augmented reality software reads the marker, the user can see the virtual content associated with it." (Stoyanova, D. 2016)

CHAPTER TWO

MODEL OF TECHNOLOGY-BASED DECISIONS IN ENGINEERING EDUCATION

2.1. Technology-based decisions in the education of engineering students

In the university environment, education is traditionally conducted face-to-face. The COVID-19 pandemic has accelerated the process of distance learning in an electronic environment. The ubiquitous digitization of learning has made e-learning the preferred choice for educators and students in certain situations and contexts. This type of education is increasingly entering as an alternative method to face-to-face learning.

Traditional education

The traditional way of learning takes place in a classroom setting. It focuses on the acquisition of theoretical knowledge and a direct, permanent relationship with the teacher, which allows for direct communication. Traditional training follows a structured schedule with specific times and duration of exercise.

Technologies provide interactive learning. Educational technologies such as educational apps, simulations, and interactive videos engage students in active learning. These tools make complex concepts easier to understand and retain by allowing students to interact with the material in a hands-on way. The adaptive learning software, on the other hand, tailors instruction to each student's individual needs, pace, and learning style. This personalized approach ensures that students receive targeted instruction and support where they need it most, leading to better learning outcomes.

In the education of engineering students, technology can find significant application in the context of modern educational concepts. Two main technology-based educational methods are identified: distance learning and distance learning through simulations. However, there is still not enough research conducted on the effectiveness of the application of these technological teaching methods in the preparation of engineering students in specific disciplines.

Remote access learning

Distance learning is a form of online learning where students have the opportunity to learn from anywhere in the world and access the learning materials at any time convenient for them. With the continuous development of technology, remote access to laboratories is becoming more and more accessible to a large number of students. This teaching method

allows for a "personalized approach, adapted to the individual needs of students, focused on improving theoretical knowledge and understanding models. E-learning provides the latest technology and better opportunities compared to traditional learning methods."

All the listed characteristics of this type of education argue for the choice of remote access learning as one of the learning methods to be included in the research conducted within the framework of this dissertation. For the purposes of the thesis, remote access to an electronics laboratory was implemented by designing and building connectivity between a NI ELVIS III prototype test platform and the Measurements Live client application. Thus, it is possible to conduct measurements and laboratory exercises in real time by means of remote access. The designed connectivity is described in Chapter 3 of this dissertation.

Distance learning with simulation

Simulations are increasingly used in education. They allow students to do complex experiments and procedures, in a safe and secure environment for them, without the risks that can occur during face-to-face learning.

A key element in delivering this type of education is the correct selection of suitable simulation software that matches the learning objectives and curriculum. The instructor is responsible for integrating the simulations into the learning materials and for setting clear instructions on how students can access and interact with the simulations. Providing access to the simulation platforms is essential. Students must have access to the necessary hardware and software to run the simulations.

Through distance learning with simulations, active learning is facilitated, students are encouraged to actively engage with the simulations by asking questions, assigning tasks and facilitating discussions related to the simulation scenarios. In this way, critical thinking and problem solving are encouraged.

The advantages that distance learning with simulations offers in the preparation of engineering students argue for the choice of this learning as the other main learning method to be included in the research carried out within the framework of this dissertation.

2.2. Model of "Technology-Based Decisions in Engineering Education"

Based on the analysis of the advantages and limitations of the use of technology in education, a model for technology-based decisions in engineering education has been developed, which includes:

- development of a methodology for conducting exercises in engineering disciplines,

- building a system for remote access to an engineering laboratory,
- conduct of pedagogical research and analysis of the obtained results.

The system included in the model for technology-based decisions in engineering education consists of laboratory exercises, which are conducted using three teaching methods:

- **face-to-face learning;**
- **remote access education;**
- **distance learning with simulation.**

In order to investigate **the effectiveness of the model for technology-based decisions in engineering education**, laboratory exercises were developed in the discipline "Electronics". The discipline was chosen due to the fact that it is studied by the students from four of the professional areas in which the Faculty of Physics and Technology of the University of Plovdiv teaches, namely 5.1. Mechanical engineering, 5.2. Electrical engineering, electronics and automation, 5.3. Communication and computer technology, 4.1. Physical sciences.

Three laboratory exercises with different difficulty of realization and implementation by the students were chosen to be developed. The aim is to investigate the effectiveness of the developed system of exercises, included in the model of technology-based decisions in engineering education, for the three learning methods.

Research participants

Participants in the research are students from the engineering majors "Information and Computer Engineering", "Telecommunications and Information Systems" and "Telecommunications with Management", who are divided into three groups and are learning respectively through: face-to-face learning - 13 students, remote access education – 12 students, and distance learning with simulations – 14 students. The training was conducted within the 4th semester in the academic year 2022-2023.

System of laboratory exercises

In developing the laboratory exercises in the discipline "Electronics", the following equipment, elements and software are used for the three teaching methods:

- in the face-to-face exercises, the NI ELVIS III platform is used, from which the measuring instruments given for the specific laboratory exercise are used. NI ELVIS III is an

integrated educational platform created by National Instruments for learning electronics, sensors, measurements and virtual programming environments. This platform combines hardware and software components that are ideal for learning in engineering and science academic environments. The Faculty of Physics and Technology has purchased 11 platforms. NI ELVIS III is a hardware foundation that includes built-in measurement and control facilities such as analog and digital inputs and outputs, power supply, built-in signal generation functions, and more. The platform is connected to NI ELVIS III PC software, which offers a graphical user interface for visualizing measurement data, managing hardware, and running experiments. NI ELVIS III integrates with a variety of software tools, providing programming and simulation capabilities such as LabVIEW and Multisim that facilitate electronic system development and simulation. The platform is designed to be easy to use and accessible for learning in educational institutions, providing the flexibility and functionality needed to conduct various learning activities and projects.

- in the exercises that will be accessed remotely, through simulations, the Multisim software is used to design the scheme, by the students themselves, for the specific laboratory exercise. This software is licensed by the Faculty of Physics and Technology. Multisim is electronic circuit simulation software that offers a wide range of functionalities. Multisim allows users to create electrical schematics by dragging and dropping components from the software's library. Users can connect components with wires and create complex circuits. Once a circuit is created, Multisim provides the ability to simulate the electrical parameters of the circuit. Users can perform various types of simulations, such as DC, AC, and timing simulations, to analyze circuit behavior under various conditions. Multisim offers a variety of circuit analysis tools, including calculation tools that allow users to measure various parameters such as voltage, current, and power in a circuit. Multisim provides the ability to visualize simulation results through graphs and charts that help users analyze and understand circuit behavior. Multisim allows users to share schematics and data with other users, facilitating team collaboration and information sharing.

- for the exercises that will be done via remote access, the circuit is already designed using the Measurements Live software and pre-implemented on the NI ELVIS III platform by the electronics lab instructor. For this purpose, a system for remote access to an engineering laboratory was designed and implemented.

Three laboratory exercises have been developed in the discipline "Electronics", which are fully adapted to the curriculum and the needs of students from the engineering and physics majors. Methodologies have been prepared for the exercises "Investigation of transmission characteristics of bipolar transistors", "Investigation of bipolar transistors as an amplifier" and "Investigation of analog-to-digital converters", and the methodology provides a theory of the functioning, components and mode of operation of the investigated devices, then the way of working with the specific device is described step by step and how the exercise itself should be performed, finally the performance tasks that the students have to work out are given.

The laboratory exercises are aimed at studying some of the applications of transistors and their use, as well as with the study of an analog-to-digital converter.

In the methodology for the exercises, which are done remotely, through simulations, the Multisim software is used to implement the studied scheme. They again have a theoretical part and tasks to perform. The students must build the investigated circuit in the Multisim software by themselves, the method of implementation is described in detail in the methodology that is attached to each of the exercises. With this method, there is no teacher to help the students in case of any difficulties they may have, they have to cope with the task they have been given. Each of the students works individually.

The methodology, which was developed for the laboratory exercises, which are made by the students through remote access, consists of a theoretical part and tasks to be performed. In this method, the NI ELVIS III platform is used, on which the teacher has already implemented the scheme studied for the particular exercise. The methodology describes in detail how the students access the scheme through remote access, by providing the IP address of each of the installations, after which the students log in one by one in an hour determined by the teacher, this hour corresponds to the length of one lesson. This saves the time available to the group doing the exercises in person. After accessing the realized experimental setup, students use Measurements Live to explore the circuit and complete their assigned tasks accordingly.

Objectives of the laboratory exercises:

Familiarizing the students with the operation of bipolar transistor, to gain knowledge about volt-ampere characteristic, use of bipolar transistor (BPT), modes of operation of BPT, input control of BPT for key mode operation, principle of operation of ADC.

•Laboratory exercise "Investigation of transmission characteristics of bipolar transistors"

For the implementation of the "Investigation of Bipolar Transistor Transmission Characteristics" exercise in face-to-face learning, students can use external measuring instruments to connect to the NI ELVIS III mock-up. The use of this additional measuring equipment becomes impossible for the exercises that are performed with remote access. This requires creativity in creating the experimental setting on the part of the teacher. Here, the use of two platforms is required, which are connected in an optimal way, in advance by the teacher. Thus, students will have the opportunity to carry out correct and accurate measurements without difficulty within the laboratory exercise.

Necessary tools and materials:

- ***Face-to-face learning***

1 NI ELVIS III model is required, on which the following measuring instruments are used: Current-Voltage Analyzer, Digital Multimeter (DMM), Variable Power Supply (VPS). Also needed 2N3904 transistor under test, 33 k Ω resistor, 100 Ω resistor, digital multimeter.

- ***For remote access:***

2 NI ELVIS III models are required, on which the following measuring instruments are used: Current-Voltage Analyzer, Digital Multimeter (DMM), Variable Power Supply (VPS). Tested transistor 2N3904 transistor, 33 k Ω resistor, 100 Ω resistor, digital multimeter are also needed.

- ***In distance learning with simulations:***

Multisim software is required.

According to the specifics of the used teaching method, three methodologies for performing the exercise have been developed:

A. Methodology for performing the laboratory exercise during face-to-face training:

After the students become familiar with the theory, they can begin to implement the assigned tasks. The first task to perform is the implementation on the NI ELVIS III platform of the bipolar transistor circuit presented in Figure 9.

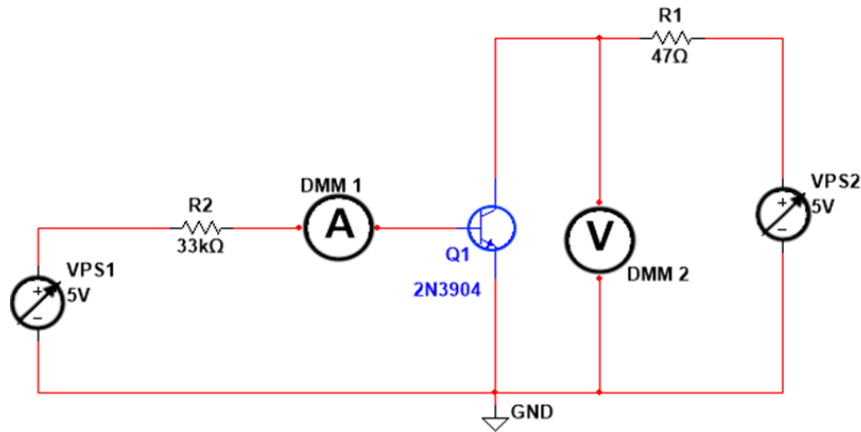


Fig. 9 Schematic of the laboratory exercise

The tasks are specified in the full methodology given in Appendix 1.

B. Methodology for performing the laboratory exercise in distance learning through simulations:

After a detailed introduction to the theory, students simulate the behavior of a bipolar transistor in Multisim Live. The methodology given in Appendix 1 provides students with a detailed description of the actions they need to take in order to implement the laboratory exercise. Fig. 10 shows the basic circuit diagram, which is implemented and studied in the laboratory exercise.

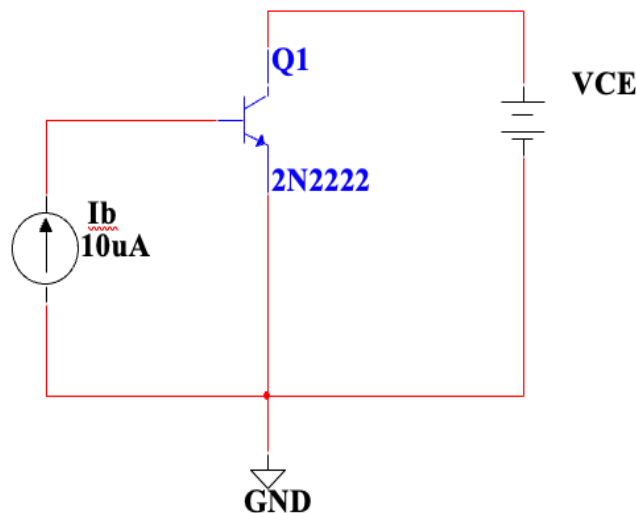


Fig. 10 Test circuit

C. Methodology for performing the laboratory exercise in remote access learning:

When performing the exercise, through remote access, the circuit is already

implemented on the prototype board of the NI ELVIS III platform (Fig. 12). Two NI ELVIS III lab rigs, a Current-Voltage Analyzer, two Digital Multimeters (DMMs) and two Adjustable Power Supplies (VPSs) are required to investigate the transistor characteristics. For the implementation of the exercise, it is necessary to use external measuring devices to be connected to the NI ELVIS III model. The use of this additional measuring equipment, however, is impossible for the exercises that are performed with remote access. That is why it is necessary to use two platforms that are connected in an optimal way, in advance by the teacher. The tasks to be performed are specified in the full methodology given in Appendix 1.

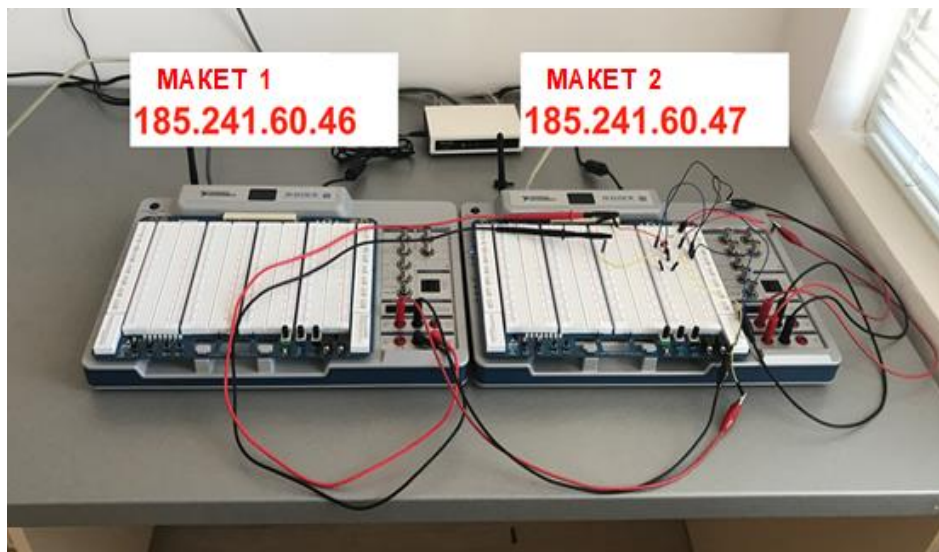


Fig. 12 The experimental setup

- **Laboratory exercise "Amplifiers with bipolar transistors"**

Tools and Materials Required:

- ***Face-to-face learning***

1 NI ELVIS III model is required, on which the following measuring instruments are used: IV Analyzer (Current-Voltage Analyzer); Function Generator (Functional Generator); Oscilloscope (Oscilloscope); Bode analyzer; Variable Power Supply (Adjustable power supply source). A 560 Ω resistor is also required; 1 k Ω resistor; 8.2 k Ω resistor; 18 k Ω resistor; 1 μ F capacitor; 22 μ F capacitor; 100 μ F capacitor; NPN 2N3904 transistor; 2 k Ω resistor; 5 k Ω r resistor; 20 k Ω resistor; NPN 2N3904 transistor.

- ***For remote access learning:***

Requires 1 NI ELVIS III model using the following meters: Current-Voltage Analyzer, DMM, VPS. Tested transistor 2N3904 transistor, 33 k Ω resistor, 100 Ω resistor, digital

multimeter are also needed.

- ***In distance learning with simulations:***

Multisim software is required.

According to the specifics of the used teaching method, three methodologies for performing the exercise have been developed:

After a detailed introduction to the theory of the exercise, (Appendix 2) students begin to perform the assigned tasks according to the three methods of performing the laboratory exercise.

A. Methodology for performing the laboratory exercise during face-to-face training:

One of the tasks to be performed is the construction of a common emitter transistor amplifier circuit, on the NI ELVIS III platform. The schematic is shown in Figure 14.

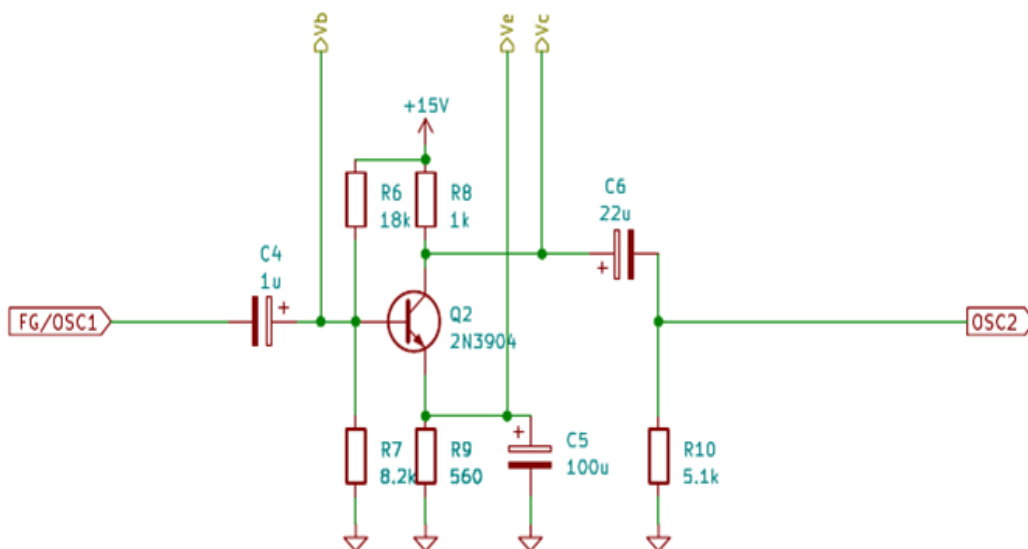


Fig. 14 Schematic diagram of a transistor amplifier OE

After the successful completion of the assigned tasks according to the methodology of the exercise (Appendix 2), the students fill in tables with the data from the conducted research, answer the questions and draw conclusions.

B. Methodology for performing the laboratory exercise in distance learning through simulations:

After a detailed introduction to the theory, students simulate the behavior of a transistor

amplifier in Multisim Live. The exercise methodology given in Appendix 2 provides students with a detailed description of the actions that students must take to be able to implement the laboratory exercise.

After the successful completion of the assigned tasks according to the methodology of the exercise (Appendix 2), the students fill in tables with the data from the conducted research, answer the questions and draw conclusions.

C. Methodology for performing the laboratory exercise in remote access learning:

This laboratory exercise requires the design and implementation of a schematic solution to extend the capabilities of the NI ELVIS III platform available in the laboratory, as this platform has a limited set of measurement instruments. This is related to a serious preliminary preparation of the experimental setup for remote access learning by the teacher, as he is required to create the corresponding concept for expanding the platform's functionalities.

When studying electronic circuits by taking measurements on a real structure, several measurements are usually required at different nodes or loops of the circuit. The easiest way to conduct such measurements is to connect to each of the measuring points a separate measuring device with the possibility of remote reading of the measurements. In fig. 17 is a diagram of a single-stage transistor amplifier OE, and at the points marked V_C , V_E and V_B , the values of constant voltages must be measured.

A prototype NI ELVIS III platform provides a limited number of meters with remote readout. The following options are possible for measuring the three voltage values at the above-mentioned points with local access:

1. A digital multimeter (DMM) provided by the platform is connected to one of the points, additional laboratory multimeters to the other two.
2. The DMM available in the platform connects in time sequence to each measurement point.

For remote measurement, the first option is possible if additional DMMs have a remote access interface. The second option is possible for remote measurement with the implementation of the additional schematic solution proposed in fig. 17.

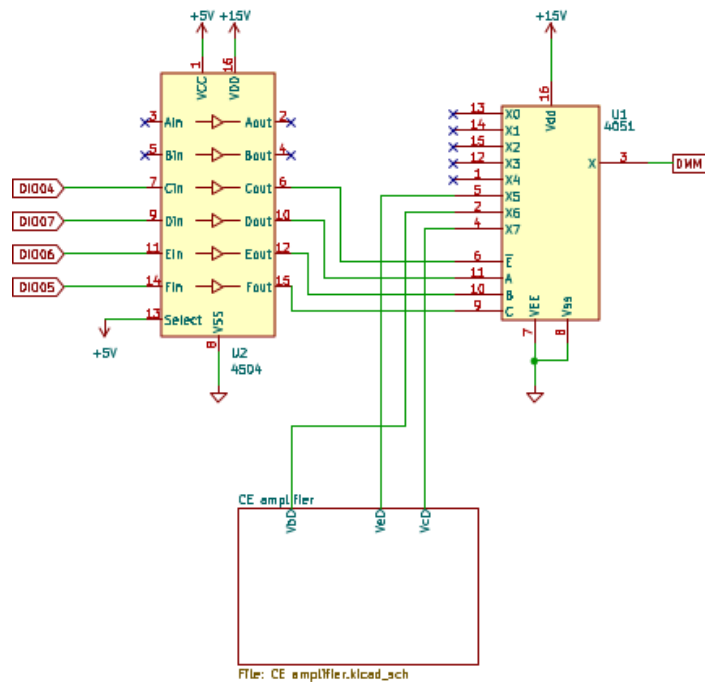


Fig.17 Method for remote measurement of voltages in several nodes of a circuit diagram

A key component in the circuit is the eight-input analog multiplexer U1 CD4051. A value of the measured voltage is output at output X, to which the DMM of the platform is connected. Selection of measurement point (V_C , V_E or V_B) is done by setting appropriate logic levels on the digital inputs/outputs (DIO04 – DIO07) in record mode. In the NI ELVIS III platform, the digital inputs/outputs are integrated into a standalone Digital I/O instrument. They are grouped in two banks (A and B) with two groups of 8 inputs/outputs each. Each input/output group can work in one of two modes - input (Read), output (Write). Table 8 presents the logic function for measuring voltages at points V_C , V_E and V_B :

Table 8 the logic function for measuring voltages at points V_C , V_E and V_B

Точка	A/DIO07	A/DIO06	A/DIO05	A/DIO04
V_C	1	1	1	0
V_E	1	0	1	0
V_B	0	1	1	0
Забранен	1/0	1/0	1/0	1

The logical combinations of outputs A/DIO04 - A/DIO07 are given in the methodology for the laboratory exercise.

A photo of the realized technical solution for remote conducting of the laboratory exercise is presented in fig. 18 below:

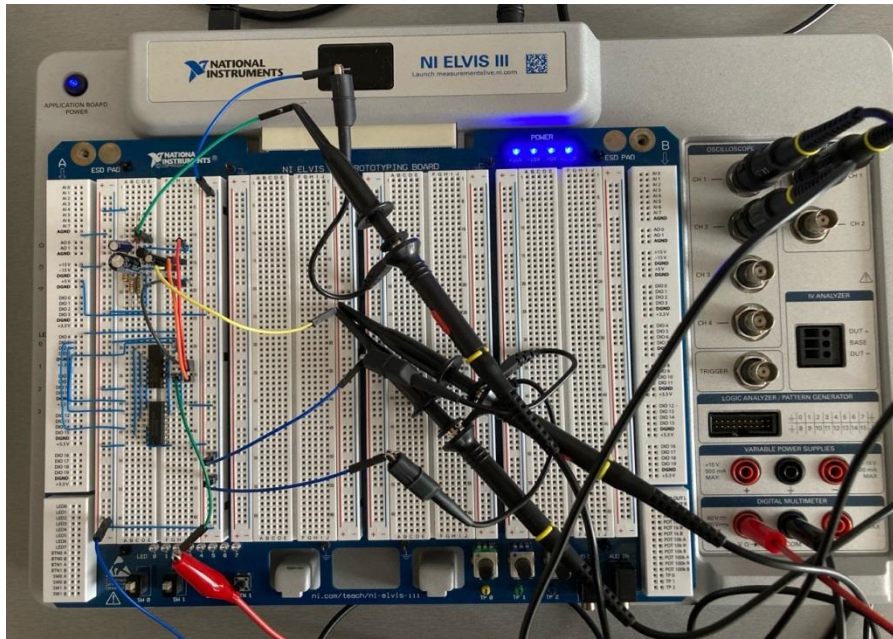


Fig. 18 Implementation of a solution for conducting the laboratory exercise remotely

- **Design and study of an analog-to-digital converter with uniform step variation of the compensating voltage (Appendix 3)**

In the implementation of the exercise "Construction and investigation of an analog-to-digital converter with a uniform step change of the compensating voltage" in face-to-face training, it is necessary for the teacher to provide a large set of different elements and connecting cables, so that all students have a workplace in the laboratory of electronics, on which they can correctly complete the assigned tasks. This problem does not exist when performing the exercise through simulations. No need for physical components here. In distance learning, the scheme has already been implemented by the teacher on the model. Each student is given a time slot in which they can access the scheme. This eliminates the need for multiple components and ensures that the learning process runs smoothly and efficiently.

- ***Face-to-face learning***

1 NI ELVIS III platform is required, from which the following built-in measurement tools are used: one adjustable power supply (VPS), one function generator (FG), oscilloscope.

- ***For remote access learning:***

1 NI ELVIS III platform is required, from which the following built-in measurement tools are used: one adjustable power supply (VPS), one function generator (FG),

oscilloscope.

- ***In distance learning with simulations:***

Multisim software is required.

In fig. 19b is a diagram of the investigated analog-to-digital converter.

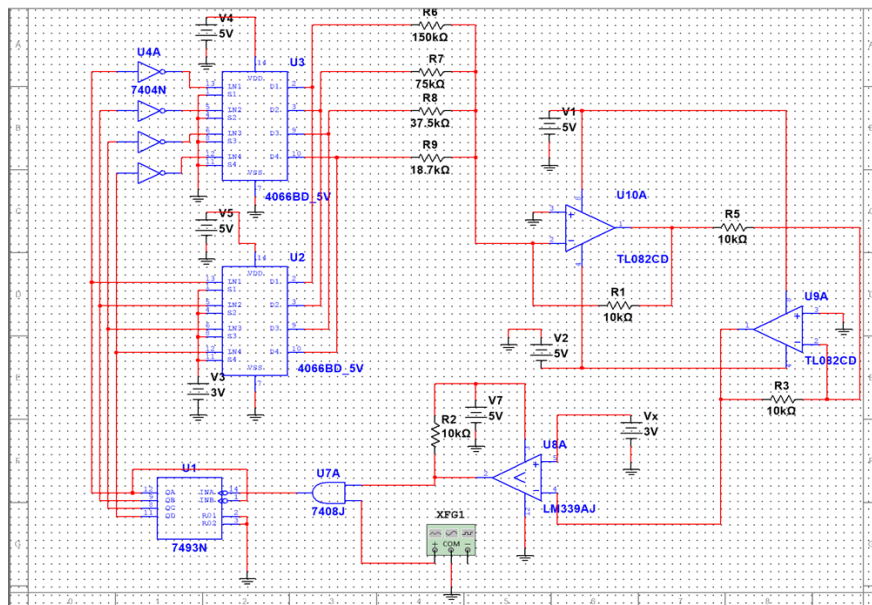


Fig. 19b Structural diagram of an analog-to-digital converter (ADC) with a uniform step change of the compensating voltage

A. Methodology for performing the laboratory exercise during face-to-face training:

Students implement the scheme on the NI ELVIS III platform. The following integrated circuits are used in the construction of the DAC: SN7404 (U4A) which contains 4 inverters, two digital-analog switches CD4066 (U2, U3), operational amplifiers TL 082 (U10A, U9A) and resistors R6, R7, R8, R9.

Due to the complexity of the scheme, the implementation of the analog-digital converter was done in several stages, which are described in detail in the methodology for the laboratory exercise (Appendix 3). The aim is to examine the functions of the basic modules from which the ADC is built.

B. Methodology for performing the laboratory exercise in distance learning through simulations:

After a detailed introduction to the theory, students will simulate the research behavior of an analog-to-digital converter in Multisim Live. The methodology provides students with a detailed description of the actions that students must take in order to implement the laboratory exercise.

C. Methodology for performing the laboratory exercise in remote access learning:

When performing the exercise, which is performed via remote access, the scheme has already been created by the teacher on the NI ELVIS III platform (Fig. 21).

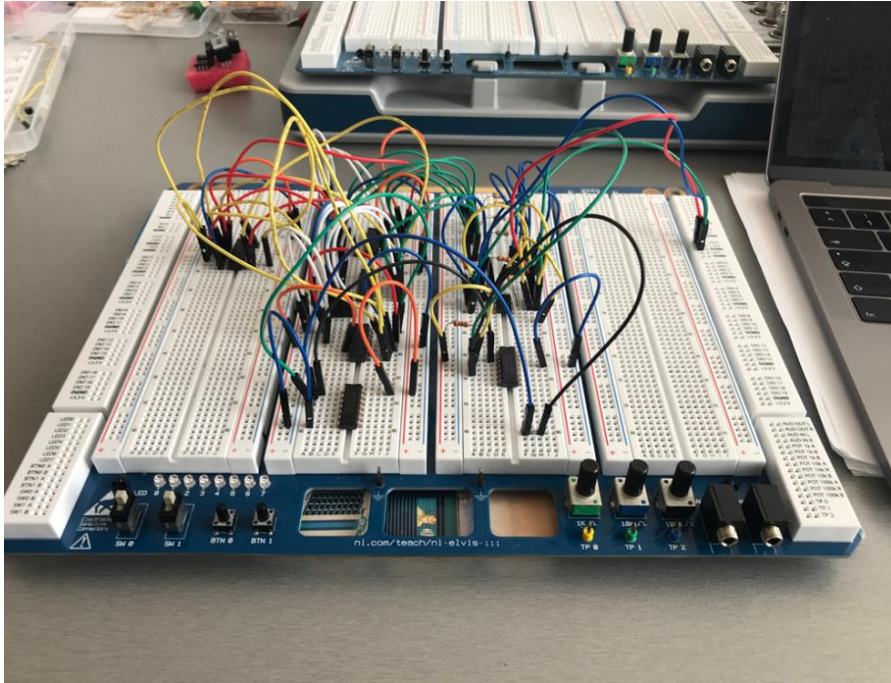


Fig. 21 Realized circuit of a 4-bit analog-to-digital converter

Students complete the performance tasks, fill in the relevant tables and draw conclusions according to the complete methodology of the exercise (Appendix 3).

CHAPTER THREE

REMOTE ACCESS SYSTEM FOR REAL-TIME LAB EXERCISES

For the purposes of the thesis, connectivity between the NI ELVIS III prototype test platform and the Measurements Live client application was designed and built to perform real-time measurements.

Measurements Live is a WEB based application running in a browser environment supporting WebSocket protocol for communication with NI ELVIS III. The application and NI ELVIS III connectivity is Point-to-Point (P2P) and provides real-time two-way exchange of information without the need to generate requests from the client application.

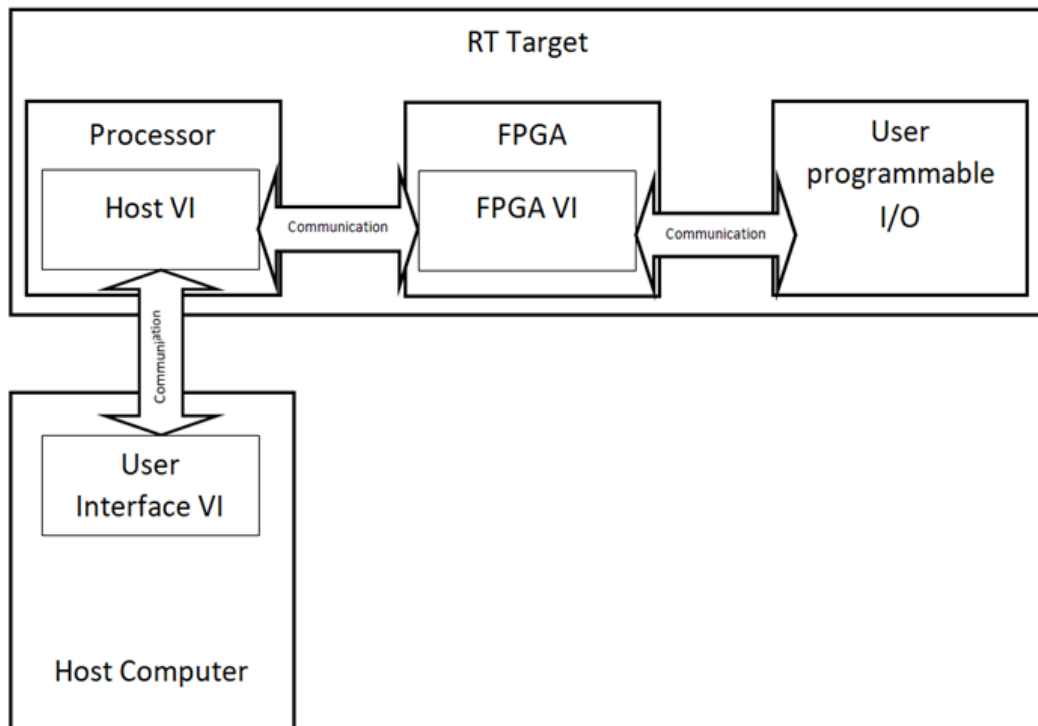


Fig. 22 Measurement Live and NI ELVIS III prototype test system architecture

The components of the system and their purpose:

Host Computer – a computer on which software packages for developing virtual instruments (VI) and the Measurement Live application for setting parameters of measurements and visualization of results (User Interface VI) are installed.

RT-Target - an NI network prototype test platform that integrates a computer system with a real-time operating system (Processor), a programmable logic array (FPGA) and user programmable analog and digital inputs and outputs (User programmable I/O). Network access to the platform is possible through three interfaces: Ethernet, Wi-Fi and USB.

The distributed architecture of the NI test system offers the ability to remotely conduct measurements on pre-prepared prototypes. The test systems with the prepared prototypes are connected to the local university network. In order to build P2P connectivity between a computer running on the Internet and a test system, the following three approaches have been tested for the purposes of the dissertation work:

1. Local to Public IP Address Translation (Network Address Translation).
2. A virtual local network (VPN, Virtual Private Network) to which a tunnel interface is created for a computer running on the Internet.
3. Using Signal Server and STUN (Session Traversal Utilities for NAT).

Local to Public IP Address Translation (NAT)

With the development of the Internet and the increase in the number of corporate and home networks, the number of IP addresses in the IPv4 address space turns out to be insufficient. An opportunity to expand computer networks by limiting the use of addresses from IPv4 provides the separation of address ranges from this space (local) for home and corporate networks and their presentation on the Internet with a limited number of the remaining addresses (public). Local IP addresses are divided into three ranges:

- Class A – 10.0.0.0-10.255.255.255 (prefix 10/8)
- Class B – 172.16.0.0-172.31.255.255 (prefix 172.16/12)
- Class C – 192.168.0.0-192.168.255.255 (prefix 192.168/16)

Access to network resources on a networked device with local addresses in the resource range is done in a standard packet-switched manner. Access to the same resources from a device using a public IP address requires additional changes in the address part of the packet, which are called NAT (Network Address Translation). NAT is the process of mapping a local network device's IP address/port to a public IP address/port. This matching is done by a device attached to both the public and local networks (usually a router). According to the way in which the correspondence between the local and public IP addresses is done, the following types of NAT are defined:

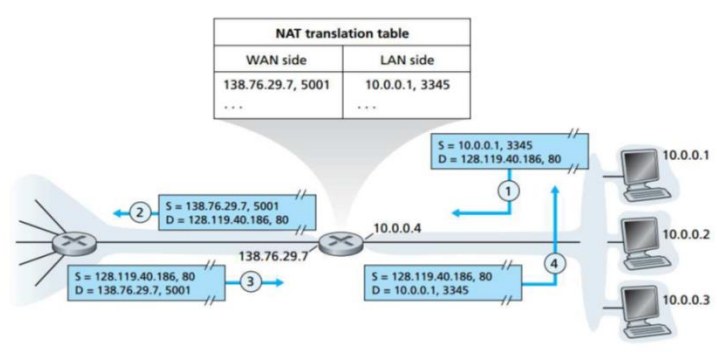


fig. 23 Principle of operation of NAT <https://www.transtutors.com/questions/1-consider-the-network-setup-in-figure-4-25-suppose-that-the-isp-instead-assigns-the-6411198.htm>

- Static NAT - a correspondence between local and public IP addresses is configured on a one-to-one basis (Fig. 24). This NAT method is extremely useful for accessing an internal device from a device running on a public network.

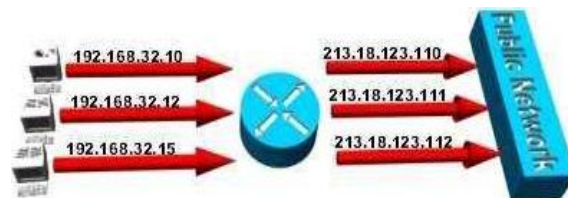


Fig. 24 Static NAT <https://skminhaj.wordpress.com/2016/02/15/configuring-nat-on-cisco-ios-routers/>

- Dynamic NAT – the correspondence between local and public IP addresses is configured at the time of the connection establishment request (Fig. 25). The public address is allocated from a fixed set of addresses and may be different for each local network device connectivity.

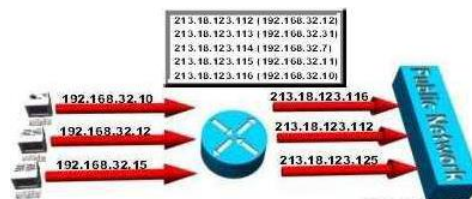


Fig. 25 Dynamic NAT https://cio-wiki.org/wiki/Network_Address_Translation_%28NAT%29

- Translation of an address in a port (Port Address Translation - PAT) - a correspondence of a local IP address with a public IP address and port is configured (Fig. 26).

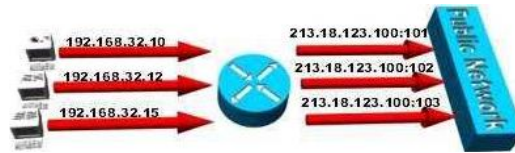


Fig. 26 PAT https://cio-wiki.org/wiki/Network_Address_Translation_%28NAT%29

Advantages of NAT:

- It is supported by all modern routers;
- No additional configuration is required in devices from the public network - certificates, configuration files, etc.

Disadvantages of NAT:

- Increases the need to increase the computer resource of the device (router) in which the NAT configuration is implemented;
- There is no possibility of authentication and encryption of the exchanged information, low degree of protection against malicious access.

For the thesis experiments in the university's BGW (Border Gateway Router), a static NAT was configured for each of the mocks.

Peer-to-Peer connectivity using a signaling server

The NI ELVIS III platform provides the ability to build encrypted peer-to-peer real-time connectivity with a client browser using the WebSocket protocol over SSL/TLS.

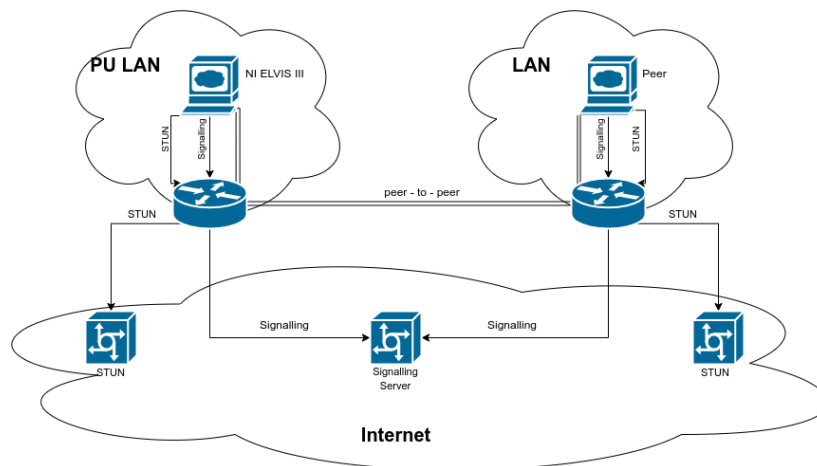


Fig.29 System architecture for building WebRTC peer-to-peer connectivity.

STUN is a standardized set of methods for providing NAT traversal data when establishing interactive P2P connectivity. The STUN service must be provided by a server with a publicly accessible URL, e.g. standard for NI ELVIS III - `stun:stun.multisim.com:3478`, `stun:stun.l.google.com:19302`, etc. Each of the correspondents of the established peer-to-peer connectivity provides the information received from the

STUN servers to the Signaling Server, which exchanges it between them to start the establishment. By default NI ELVIS III ships with a configuration to use `wss://sigserver.multisim.com:1339`. The Signaling Server is accessed through a public URL. Built-in connectivity is encrypted - WebSocket protocol over SSL/TLS. NI's Signaling Server is installed on the AWS cloud, but a javascript package is provided to install and configure your own publicly available Signaling Server.

CHAPTER FOUR

RESULTS ANALYSIS

This chapter presents the methods for researching the results of implementing the system for technology-based decisions in engineering education, the data, the results of the individual research methods carried out and their interpretation.

4.1. Results of the students' training through the developed model of technology-based decisions, applied in the laboratory exercises in the discipline "Electronics"

When conducting the experiment, a study was made of the effectiveness of the developed model of technology-based decisions in its application in the education of future engineering students in the three types of conducted education: face-to-face, remote learning through simulations and remote access learning. The study includes an evaluation of the results achieved by the students of the three groups. Protocols have been developed for the three laboratory exercises to be completed by the students and evaluated by the teacher. For each of the exercises, the protocols are the same for the three teaching methods. In this way, the aim is to obtain a very accurate comparative assessment of the perception of the material studied by the relevant method and the degree of coping of the students with the laboratory exercise.

ПЛОВДИВСКИ УНИВЕРСИТЕТ "ПАИСИЙ ХИЛЕНДАРСКИ" ФИЗИКО-ТЕХНОЛОГИЧЕН ФАКУЛТЕТ			
Студент:.....	Курс:.....	Група:.....	Фак.номер:
Специалност:	Дата:	Учр.№:1	
Тема на управлението:	БИПОЛЯРЕН ТРАНЗИСТОР		Проверител:
Разработчик на Управлението:			

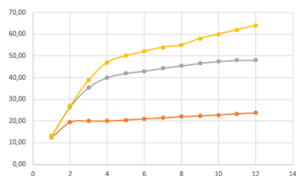
РАБОТНИ ФОРМУЛИ:

$$I_C = I_B \cdot \beta$$

2. РЕЗУЛТАТИ ОТ ИЗМЕРВАНИЯТА:

- За $I_B = 098\mu A, 199\mu A, 278\mu A$,

12,50	12,2	13	1
15,50	26,5	27	2
20,00	35,5	39	3
20,00	40	47	4
20,50	42	50	5
21,00	43	52	6
21,50	44,4	54	7
22,00	45,5	55	8
22,30	46,6	58	9
22,80	47,5	60	10
23,40	48	62	11
23,70	48	64	12



1. Какво представлява БПТ?
 - a) БПТ е устройство с два терминала, способно да усилват сигнал с постоянно ток.
 - b) БПТ е устройство с два терминала, способно да усилват сигнал за променлив ток.
 - c) БПТ е устройство с три терминала, способно да усилват сигнали.
 - d) БПТ е устройство с три терминала, способно да контролират текущия поток.
2. При каква приблизителна стойност на напрежението различните характеристики започват да се отклоняват една от друга?

При първото ($I_B = 098\mu A$) и второто ($I_B = 199\mu A$) измерване отделните значения при U_{CE} в между второто ($I_B = 199\mu A$) и третото ($I_B = 278\mu A$) отделните значения при U_{CE} .
3. Относително постоянни ли е β в във всички точки?
 - A. Да
 - B. Не

Ако да, каква е разликата?
 $\beta_1 = I_{C1} / I_{B1} ; \beta_2 = I_{C2} / I_{B2} ; \beta_3 = I_{C3} / I_{B3}$
4. Избройте най-важните характеристики и приложения на биполярните транзистори.

Те са полупроводников кристал с два P-N прехода, в зависимост от резултата на словените могат да бъдат PNP или NPN, имат 3 терминала: база, колектор и емитер. Използват се за усилване, преобразуване и генериране на електроенергия, сигнали.
5. Обяснете различните режими на работа на биполярен транзистор.

В схема обща база транзистора намира приложение в генераторите и усилвателите. В схема общ емитер е добра за усилване на малки сигнали. В схема общ колектор намира приложение при съгласуване на съпротивленията.

fig. 30 Completed protocol

After completing the protocols and evaluating them, the following results were obtained for the three groups of students.

Tab. 11 Face-to-face learning

№ студент	Лаб.1	Лаб.2	Лаб.3
1	6	4,5	-
2	6	5	-
3	5,5	3,5	-
4	5	3,2	-
5	5,2	3,5	-
6	6	4,2	-
7	5,6	4	-
8	6	5,5	-
9	6	3,2	-
10	6	4	-
11	6	3	-
12	5,5	5	-
13	5,2	5,5	-

Tab. 12 Distance learning with simulations

№ студент	Лаб.1	Лаб.2	Лаб.3
1	5,5	5,5	6
2	5,6	6	-
3	5	6	-
4	5	5,5	6
5	5	5,2	5,5
6	5,5	5,6	6
7	6	6	-
8	6	6	-
9	5,5	5,6	6
10	6	6	5,5
11	6	6	-
12	5,5	6	6

Tab. 13 Remote access learning

№ студент	Лаб.1	Лаб.2	Лаб.3
1	6	5,5	6
2	6	6	5,6
3	6	6	6
4	5,5	6	6
5	5,2	5,5	6
6	6	5,5	5,5
7	6	6	5,5
8	6	5,6	6
9	6	6	5,6
10	6	6	6
11	6	6	5,5

12	6	6	5,6
13	6	5,5	6
14	6	6	6

After the assessment of the students, an interview was conducted with each of the groups about their perception of the method in which they were taught.

Analysis of the results of the students' education by means of the developed model of technology-based decisions, applied in the laboratory exercises in the discipline "Electronics".

1. The exercise "Investigation of transmission characteristics of bipolar transistors" was not difficult for any of the groups. The results obtained from the control protocols were excellent in almost all of the students. However, it is important to note here that more than half of them in the simulation group and the remote access group would prefer real interaction with the teacher as well as constructing the integrated circuit themselves.

2. Students doing the "Research on Bipolar Transistors as an Amplifier" in face-to-face learning had some difficulties in constructing the circuit, resulting in inaccuracies in filling out the protocols. The groups that do the exercise remotely through simulations and through remote access do better because the task execution lacks the difficulty of connecting the circuit.

3. In the exercise "Design and study of an analog-to-digital converter with uniform step variation of the compensating voltage" the best results were shown by the remote access group. Due to the complexity of the scheme itself, the students in the present group experienced difficulties in connecting the scheme within the class time. Some of them managed to connect the circuit within the lesson, but had to be checked by a teacher who found connection errors and the students had to start from the beginning, which again led to the problem of limited time. There were no protocols handed down to them due to the lack of a related scheme for them to examine.

Students who were in the simulation group also had difficulty simulating the circuit, despite the advantage of not constructing the circuit in a real environment and not working with the physical components that could slow down the process. Some of them did not manage to do it within the class time, respectively; they did not submit the control protocols for knowledge verification. The part of them that had managed with the task had submitted satisfactory completed reports.

The students in the remote access group did best with the diagram of the exercise

"Design and study of an analog-to-digital converter with uniform step variation of the compensating voltage" due to the fact that it was already constructed by the teacher himself. They quickly and easily performed the tasks required of them, were able to understand the principle of operation of analog-to-digital converters, and filled out the protocols correctly and completely.

Conclusions

The advantages of face-to-face learning are that real components are used, the scheme is constructed independently, and only in this method students touch the real work of constructors. In face-to-face learning, they can receive direct help from the teacher. From the conducted research, it is clear that despite the many positive characteristics of face-to-face learning, it also has its drawbacks. They can be systematized as follows: errors in the construction of the schemes, which leads to the correction of the errors and delay in the execution of the exercise; possible damage to the equipment; insufficient equipment for all students, the limited time available to students to complete the exercise.

Distance learning through simulations, on the other hand, is very fast, easy and safe to implement and work, there is no need to correct errors by the teacher. With it, it is possible to make analyses that are not applicable to educational conditions.

Another disadvantage of face-to-face learning, which is overcome by implementing remote access, is that the operation and accuracy of the devices depends on their design, manufacturer, and their depreciation.

Exercises done via remote access do not have a prerequisite a mistake on the part of the students when constructing the scheme, since it is already connected by the teacher, the check is quick, easy and safe. The method makes it possible to do exercises with schemes that would not be possible within the classroom due to reasons such as complexity, limited time, etc.

A major disadvantage of remote access learning is that it is impossible for students to change the studied scheme of the experimental setup in the process of work, as they do not have the opportunity to see and correct the real scheme.

Based on the feedback provided by the students from the three groups, the following conclusions are drawn:

- Students, the face-to-face group, have difficulty applying technology-based decisions to understanding and designing the circuit and selecting the circuit board elements themselves. At the same time, greater opportunities for team interactions emerge. As noted by

Agosto, Copeland & Zach (2013) “the main strengths of face-to-face learning include increased interaction and discourse with the instructor, easier structures for cooperative learning” (Denise E. Agosto, Andrea J. Copeland, Lisl Zach, 2013).

- Students in distance learning with simulations have difficulty applying technology-based decisions when selecting the elements of the MultiSim platform itself.

- Students from the group with remote access learning experience difficulties in implementing technology-based decisions when connecting to the Internet with the e-learning platform, when choosing the individual functionalities of the NI ELVIS III platform.

CONTRIBUTIONS

Scientific - applied contributions:

1. A comprehensive review of technology-based learning methods, as well as various technologies and software tools that are integrated into the educational process, is made.
2. A model of technology-based decisions in engineering education is developed.
3. A system of laboratory exercises in the discipline "Electronics" has been developed for the following teaching methods: face-to-face learning; remote access learning and distance learning through simulation, which are fully tailored to the curriculum and the needs of engineering students. According to the specifics of the different training methods, an individual author's approach was applied in the application of technology-based solutions in the development of the laboratory exercises.
4. A system of laboratory exercises in the discipline "Electronics" has been developed for the following teaching methods: face-to-face learning; remote access learning and distance learning through simulation, which are fully tailored to the curriculum and the needs of engineering students. According to the specifics of the different teaching methods, an individual author's approach was applied in the application of technology-based decisions in the development of the laboratory exercises.
5. A VPN using the WireGuard protocol was established for the experiments with remote access to the prototypes for researching constructed laboratory circuits.
6. An author's experiment on "Technology-Based Decision Making in Engineering Education" was conducted for three learning models: face-to-face learning; distance learning with simulations and remote access.

PUBLICATIONS RELATED TO THE DISSERTATION

1. T. Ivanova, N. Kafadarova (2023). Self-Effectiveness of Engineering Students In Face-To-Face, Distance And Remote Access Learning. EDULEARN23 Proceedings, pp. 6043-6049. [10.21125/edulearn.2023.1578](https://doi.org/10.21125/edulearn.2023.1578)
2. T. Ivanova, N. Kafadarova, S. Milev (2023). Development of a System of Laboratory Exercises For The Discipline “Electronics” Using The Methods: Face-To-Face Learning, Distance Learning With Simulations And Remote Access Learning. EDULEARN23 Proceedings, pp. 6071-6075. [10.21125/edulearn.2023.1583](https://doi.org/10.21125/edulearn.2023.1583)
3. Ivanova T., Mileva N. (2022) Creative Strategies for Making Technology-Based Decisions in Education ISSN: 2758-0989 – The European Conference on Arts, Design; Education 2022 Official Conference Proceedings [https://doi.org/10.22492/issn.2758-0989.2022.35 - 40/20 - 20](https://doi.org/10.22492/issn.2758-0989.2022.35-40/20-20)
4. V. Mengov, D. Stoyanova, T. Ivanova (2021). Exploring Students’ and Teachers’ Perceptions on Using Remote Laboratory In Fundamentals of Telecommunications Course. 4th annual International Conference of Education, Research and Innovation. Online Conference. 8-9 November, 2021 ISSN: 2340-1095. [10.21125/iceri.2021.1215](https://doi.org/10.21125/iceri.2021.1215)
5. Ivanova, T., Levterova-Gadjalova, D., Tsokov, G., Mileva, M. (2021). Challenges for Inclusive Higher Education. In: Human, Technologies and Quality of Education. Cilvēks, tehnoloģijas un izglītības kvalitāte. Rīga, University of Latvia. 1148 p., Ed. L. Daniela, p. 434-445, ISBN 978-9934-18-735-3, <https://doi.org/10.22364/htqe.2021.32>
6. Ivanova, T., Levterova-Gadjalova, D., S. Ilieva (2021). Technology-based decision making in inclusive education. In: Human, Technologies and Quality of Education. Cilvēks, tehnoloģijas un izglītības kvalitāte. Rīga, University of Latvia. 1148 p., Ed. L. Daniela, p. 412-423, ISBN 978-9934-18-735-3 <https://doi.org/10.22364/htqe.2021.30>
7. Ivanova, Ts. (2021). Active learning through technologically-based decisions. ISEIC - International Conference on Innovations in Science and Education, March 18-20, 2021. Book of Abstracts - p.45. <https://www.cbuic.cz/wp-content/uploads/BoA/BoA2021.pdf>
8. Ivanova, Ts. (2021). Technology-based learning for students with SEN. EDULEARN 21. Palma de Majorca. 5-6 July 2021. 13th International Conference on Education and New Learning Technologies Online Conference. 5-6 July, 2021. ISBN: 978-84-09-31267-2 / ISSN: 2340-1117. doi: 10.21125/edulearn.2021 Publisher: IATED. pages: 11772-11776. **(under review process by Web of Science ISI Citation Index)**