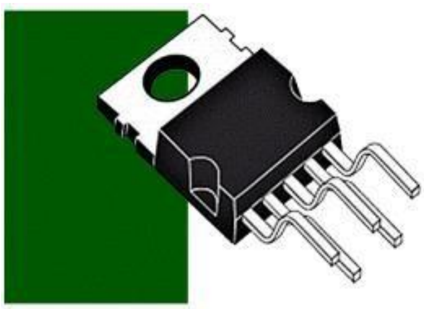
Національний технічний університет України
«КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ
імені ІГОРЯ СІКОРСЬКОГО»

Radio Engineering
Systems of Applied
Radio Electronics

[RE-9] CIRCUIT TECHNOLOGY



Work program of the academic discipline (Syllabus)

Details of the academic discipline

Level of higher education	***First (bachelor's)***
Field	***17 Electronics, Automation, and Electronic Communications***
Specialty	***172 Electronic Communications and Radio Engineering***
Educational program	***Radio engineering computerized systems Intelligent technologies of radio-electronic engineering Information and communication radio engineering Radio-electronic warfare technologies***
Status of the discipline	*Regulatory*
Form of study	*Full-time*
Year of training, semester	*2nd year, fall and spring semesters*
Scope of the discipline	*7 credits (Lectures 72 hours, Practical classes 36 hours, Laboratory classes 36 hours, Independent work 66 hours)*
Semester control/control measures	*Exam*
Class schedule	*https://rozklad.kpi.ua*
Language of instruction	*Ukrainian*
Information about the course director/teachers	Lecturer: *Ph.D., Associate Professor, Senior Researcher, Volodymyr Oleksiyovych PIDDUBNYI, tel. 0671929139,* *e-mail VAPoddubny@gmail.com* *Ph.D., Prof. Andrii Valeriyovych Movchanuk, tel. 0677443441* *e-mail – movchanuk@rtf.kpi.ua* Laboratory: *Ph.D., Senior Lecturer Igor Olegovich TOVKACH, e-mail – tovkach.igor@gmail.com* *Ph.D., Associate Professor Nataliia Oleksandrivna Lashchevska, e-mail – ivanyuk@ros.kpi.ua*
Course location	*Link to remote resource: Moodle http://iot.kpi.ua/lms/course/view.php?id=28* *https://do.ipo.kpi.ua/course/view.php?id=6394* *https://do.ipo.kpi.ua/course/view.php?id=6417*

Curriculum

1. Description of the course, its purpose, subject matter, and learning outcomes

The purpose of the credit module is:

- acquiring knowledge about the modern component base of electronic equipment; the structure and principle of operation, characteristics and parameters of electronic devices and integrated circuits (ICs), the main directions of their development;
- acquiring knowledge about the influence of designs and material properties on component characteristics, as well as the influence of technological variation and operating conditions on the main parameters of REA components, electronic devices, and ICs;
- learning to apply the acquired knowledge to make the right choice of circuit solutions when developing electronic equipment;
- acquiring skills in measuring parameters, electronic components, and objectively assessing the functional and parametric capabilities of the REA component base
- Analyze circuit solutions for individual amplification stages and amplification devices for various purposes;
- Develop technical specifications for the design of electronic devices;
- Develop structural and schematic diagrams of amplifying devices for various purposes;
- Design amplification stages and amplification devices for various purposes;
- Determine and measure the main parameters and characteristics of amplifying devices. The subject of the credit module is:
- passive components of radio-electronic equipment, including resistors, capacitors, and inductors;
- active components of radio-electronic equipment, including diodes, thyristors, bipolar and field-effect transistors, electronic tubes, hybrid and integrated circuits.
- Principles of circuit design and calculation of amplifier stages and amplifiers for various purposes, and analog signal processing devices. The discipline covers their circuitry, technology manufacturing and features use in modern radio engineering systems, their characteristics and properties.

In accordance with the educational and professional program, the discipline provides

General competencies (GC):

- Ability to apply acquired knowledge in practical situations (GC 02).
- Knowledge and understanding of the subject area and understanding of professional activity (GC 04).
- Ability to learn and master modern knowledge (GC 07).
- Ability to identify, set, and solve problems (GC 08).

Professional competencies (PC):

- Ability to perform computer modeling of devices, systems, and processes using universal application software packages (PC 04).
- Ability to perform installation, debugging, configuration, adjustment, experimental verification of performance, testing, and commissioning of telecommunications and radio engineering structures, facilities, and equipment (PC 10).
- Ability to perform calculations in the process of designing structures and means of information and telecommunications networks, telecommunications and radio engineering systems, in accordance with technical specifications using both standard and independently developed methods, techniques, and design automation software (PC 15).

Programmed learning outcomes (PLO):

- Analyze, argue, and make decisions when solving specialized tasks and practical problems in telecommunications and radio engineering, which are characterized by complexity and incomplete certainty of conditions (PLO 01).
- Apply the results of personal research and analysis of information to solve qualitative and quantitative problems of a similar nature in information and communication networks, telecommunications and radio engineering systems (PLO 02).

- Explain the results obtained from measurements in terms of their significance and relate them to the relevant theory (PLO 04).
- Adapt to changes in information and communication networks, telecommunications and radio engineering systems (PLO 06).
- Apply an understanding of the basic properties of the component base to ensure the quality and reliability of telecommunications, radio engineering systems, and devices (PLO 14).
- Understand and comply with domestic and international regulatory documents on the development, implementation, and technical operation of information and telecommunications networks, telecommunications and radio engineering systems (PLO 17).

2. Prerequisites and post-requisites of the discipline (place in the structural-logical scheme of training under the relevant educational program)

Interdisciplinary connections: the discipline is based on knowledge from the disciplines "Fundamentals of Circuit Theory" "Engineering and Computer Graphics" and is the basis for studying the discipline "Design of Elements of Intelligent Radio-Electronic Systems."

3. Content of the academic discipline

The academic discipline "Circuit Engineering" consists of two sections: Section 1 "Electronic Components" and Section 2 "Analog Circuit Engineering." Section 1 "Electronic Components" is taught in the third semester, and Section 2 "Analog Circuit Engineering" is taught in the fourth semester.

Contents of Section 1 "Electronic Components"

Topic 1. ***General characteristics of the REZ component base***

Component base of electronic equipment. General characteristics of the component base. General information about passive and active radio elements. Classification of electronic equipment by component base and design.

Topic 2. ***Passive radio components.***

Topic 2.1. Dielectric materials. Classification and purpose of dielectric materials. Passive and active dielectrics. Dielectrics used in REZ. Dielectric materials for printed circuit boards (foil-clad getinax, glass-clad laminate, polyethylene, and fluoroplastic), hybrid integrated circuits, and low-frequency and high-frequency ranges (sital, sapphire, silicon dioxide, silicon nitride, etc.). Structural elements (radio ceramics).

Topic 2.2. Capacitors. Purpose of capacitors. Classification. Main characteristics and parameters. Ranges of nominal capacitance values and tolerance ranges. High-frequency and low-frequency capacitors. Equivalent circuits. Design of fixed and variable capacitors. Surface mount capacitors. Capacitors with electrically controlled capacitance: varistors and varicaps. GIS capacitors and semiconductor integrated circuits (SI ICs).

Topic 2.3. Conductive materials. Basic properties and classification. High-conductivity materials for surface mounting, printed circuit boards, and ICs. Winding and radio assembly wires. High-resistance materials and their use in resistors. Thin-film resistive materials for ICs.

Topic 2.4. Resistors. Classification. Basic characteristics and equivalent circuits. Ranges of nominal resistance values and tolerance ranges. Design types of resistors for various purposes (for surface mounting and printed circuit boards, ultra-high frequency, etc.), resistors for GIS and NP ICs.

Topic 2.5. Magnetic materials. Characteristics of magnetic materials. Soft magnetic and hard magnetic materials. Transformer iron. Ferromagnetic and ferrimagnetic materials. Ferrites and magnetodielectrics. Magnetic films.

Topic 2.6. Inductors. Basic properties of inductors. Classification. Characteristics of inductors. High-frequency inductors and HF chokes. Their purpose and design. Calculation of inductance and number of turns. Variometers. Printed inductance coils. Inductance coils for GIS. Characteristics and parameters of chokes and transformers. Designs of low-frequency and high-frequency chokes and transformers. Features of operation at elevated (high) frequencies.

Topic 2.7. Contact and switching devices. Switches. Relays. Connectors. Contact and switching devices of microassemblies and microblocks.

Topic 2.8. Printed circuit boards. Classification. Printed circuit board materials. Printed circuit board design. Features of microwave range printed circuit boards. Single-sided, double-sided, and multilayer printed circuit boards. SMD components and technology.

Topic 3. ***Semiconductor materials.***

Topic 3.1. Physical fundamentals of semiconductors. Basic materials of semiconductor technology. Fundamentals of zone theory of semiconductors. Free charge carriers in intrinsic and doped semiconductors. Major and minor charge carriers. Generation and recombination of mobile charge carriers. Equilibrium and non-equilibrium states of a semiconductor.

Topic 3.2. Concentration of charge carriers. Concentration of charge carriers and Fermi level in intrinsic and doped semiconductors. Dependence of the Fermi level on temperature and impurity concentration.

Topic 3.3. Currents in semiconductors. Drift current: drift motion of charge carriers, mobility of charge carriers. Dependence of mobility on temperature, impurity concentration, electric field strength. Diffusion current: diffusion motion of particles, diffusion coefficient, diffusion length. Diffusion equation. Electrical conductivity of semiconductors. Surface phenomena: surface states, surface charge, surface recombination.

Topic 4. ***Semiconductor diode structures.***

Topic 4.1. Electrical transitions. Types of electrical transitions. Contact potential difference. Electron-hole transition in equilibrium (potential barrier, potential diagram, transition width) and non-equilibrium states (injection, extraction).

Topic 4.2. Volt-ampere characteristic (VAC) of an idealized transition. VAC of a real transition (recombination generation currents, base resistance, transition breakdowns, transition capacitances). Metal- semiconductor contact (ohmic and rectifying transitions). Heterojunctions.

Topic 4.3. Semiconductor diodes (rectifying and pulse). Structure, characteristics, basic parameters. Parallel and series connection of diodes. Diode operation in low and high injection modes. Schottky barrier diodes.

Topic 4.4. Zener diodes: connection diagram, VAC, parameters. Semiconductor light-emitting (light-emitting diodes) and light-sensitive devices (photoresistors, photodiodes, phototransistors, and photothyristors) and their areas of application. Optocouplers.

Topic 4.5. Variable capacitance diodes (varicaps, varactors). Microwave diodes (parametric, mixing, detector, tunnel diodes). Purpose, structure, parameters, application.

Topic 5. ***Bipolar transistors (BT).***

Topic 5.1. Structure and principle of operation of a bipolar transistor. Connection circuits, operating modes. Potential diagram and physical processes in active mode. Distribution of minority carriers.

Topic 5.2. Currents in a transistor. Emitter and base current transfer coefficients. Static VAC of a transistor in common base and common emitter circuits. Idealized transistor. Temperature drift of transistor characteristics.

Topic 5.3. Small-signal parameter systems. Determination of parameters on the I-V curve. Relationship between parameter systems and physical parameters. Low-frequency transistor replacement circuits (two-source circuit, P- and T-shaped circuits). Amplification properties of the transistor for three connection circuits. Calculation of amplification based on VAC.

Topic 5.4. Influence of carrier transit time through the base, emitter and collector junction capacitances, base resistance when operating at high frequencies. Cutoff and limit frequencies. Features of microwave transistors (drift and heterojunction bipolar transistors).

Topic 5.5. Transistor switch circuit. Features of transistor switch operation (accumulation and dispersion of volume charge in the base and collector). Transistor parameters in saturation and cutoff modes. Intrinsic noise in transistors, noise sources.

Topic 6. ***Thyristors.***

Topic 6.1. Four-layer switching devices (dynistors, thyristors). Classification, structure, principle of operation, VAC, application.

Topic 7. ***Field-effect transistors.***

Topic 7.1. Classification. Structure and processes in an MDN structure with an induced channel. Enrichment, depletion, and inversion modes. Static VAC of a transistor. Temperature drift of characteristics. Physical parameters: threshold voltage, slope, etc. Structure, principle of operation. I-V curve of an MDN transistor with an integrated channel. Long-channel transistor. Operation of an MDN transistor in amplifier and switch circuits. Pulse parameters. Frequency characteristics of a transistor.

Topic 7.2. Structure, principle of operation, VAC, and parameters of a field-effect transistor with a control p-n junction. Areas of application. Transistors for microwave applications with high electron mobility.

Topic 8. Design and technological fundamentals of microelectronics.

Topic 8.1. Integrated circuits (ICs). Classification of ICs according to design and technological features and functional purpose. Hybrid integrated circuits. Monolithic (semiconductor) ICs, VLSI, microassemblies.

Topic 8.2. Technological operations for IC manufacturing: epitaxy, impurity diffusion, ion doping, thermal oxidation, etching, thin film deposition, creation of connections and contacts, photolithography, submicron and nanolithography.

Topic 9. ***Hybrid integrated circuits (HICs).***

Topic 9.1. Types of HICs. HIC elements: film resistors, capacitors, inductors, conductors, and contact pads. HIC surface-mount components.

Topic 10. ***Semiconductor (monolithic) integrated circuits.***

Topic 10.1. Semiconductor bipolar ICs. Epitaxial-planar n-p-n transistor with combined and full dielectric insulation; p-n-p transistors; multi-emitter and multi-collector transistors, transistors with Schottky diodes. Diode connections of transistors. Passive elements of semiconductor ICs (semiconductor and film resistors, capacitors).

Topic 10.2. MDN transistors IC. Transistors with silicon self-aligned barriers. Features of the parameters and characteristics of short-channel MDN transistors for VLSI. Microwave IC elements. Microwave IC sublayers, microstrip transmission lines, passive elements

Topic 11. ***Fundamentals of digital and analog microcircuit technology.***

Topic 11.1. Fundamentals of digital circuitry. General characteristics and parameters of logic elements of digital integrated circuits. Logic elements of ICs.

Topic 11.2. Fundamentals of analog IC circuitry. Differential stages. The concept of an operational amplifier, its characteristics, parameters, and areas of application.

Topic 11.3. Charge-coupled devices. Principle of operation. Use in analog ICs.

Topic 12. *Introduction to functional electronics and nanoelectronics.*

Topic 12.1. Elements of acoustoelectronics. Delay lines, filters, and resonators on bulk and surface acoustic waves, amplifiers on SAW, signal generators on SAW, convolvers, and correlators. Elements of cryoelectronics, magnetoelectronics, chemotronics, dielectric, molecular, and biological electronics.

Topic 12.2. Principles of nanoelectronics. Physical foundations of nanoelectronics. Nanotechnology. Nanoelectronic devices (diode and transistor structures).

Contents of Section 2 "Analog Circuitry"

Topic 1. Introduction. Problems of analog circuitry. The place of circuitry in the training of modern specialists. Purpose and objectives of the discipline. Learning outcomes.

Topic 2. Principles of amplification by electronic devices. Equivalent circuits for alternating and direct currents. Classes of operation of amplifier stages. Element base of analog circuitry. Historical overview. Stages of designing analog electronic devices. Simulation packages.

Topic 3. Main characteristics of analog devices. Frequency response, phase response. Logarithmic characteristics. Frequency response and phase response of passive circuits.

Topic 4. Feedback. Classification. Basic definitions (useful and parasitic feedback, feedback loop, single- and multi-loop feedback, loop gain, feedback depth, frequency-dependent and frequency-independent feedback). Block diagrams of amplifiers with different methods of introducing and removing feedback. Effect of feedback on amplifier parameters (gain, gain instability, input and output impedance, linear and nonlinear distortion, self- noise level). Examples of circuit implementation of ZZ in amplifiers.

Topic 5. Idealized operational amplifiers. The principle of calculating circuits on operational amplifiers. Main functional units on OAs.

Topic 6. Bipolar transistor bias circuits. Fixed voltage and fixed current circuits. Bias circuits for field-effect transistors with an insulated gate. Bias circuits for field-effect transistors with an integrated junction.

Topic 7. Direct current sources on bipolar and field-effect transistors. Current mirrors. Reference voltage sources.

Topic 8. Active element connection circuits. Circuit analysis. Power supply circuits.

Topic 9. Analysis of frequency response in the low, medium, and high frequency ranges. Correction of amplitude-frequency characteristics.
Calculation of frequency distortions. Calculation of nonlinear distortions.

Topic 10. Noise factor, equivalent input power of amplifier stage noise. Amplifier noise band. Noise models of BT and PT. Calculation of noise characteristics of transistor stages. Ensuring low-noise operation of AE. Circuitry of low-noise amplifier stages. Noise factor of multistage amplifiers. Noise of a differential stage.

Topic 11. Composite stages on BT and PT. Active load. Differential amplifier. Circuitry and analysis.

Topic 12. Multistage amplifiers. Interstage coupling.

Topic 13. Push-pull amplifiers.

Topic 14. Resonant amplifiers. Stability of resonant amplifiers. Stability factor, stable gain factor, calculation methods. Methods for increasing stability. Schemes with neutralization.

Topic 15. Regulation in analog signal processing devices. Amplification regulation. Mode regulation. Regulation with interstage attenuators. Passband regulation. Types, circuit implementation. Regulation of the frequency response curve.

4. Teaching materials and resources

Recommended reading for section 1 Basic

1. Element base of radio-electronic equipment: Passive radio components In 4 parts. Part 1. [Electronic resource]: textbook for students majoring in 172 "Telecommunications and Radio Engineering" / Igor Sikorsky KPI; compiled by: V.O. Piddubny, I.O. Tovkach. – Electronic text data (1 file: 1.05 MB). – Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2021. – 98 p. URLhttps://ela.kpi.ua/bitstream/123456789/41346/1/EBRA_1.pdf
2. Element base of radio-electronic equipment: In 4 parts. Part 2. Semiconductors and diodes [Electronic resource]: textbook for students majoring in 172 "Telecommunications and Radio Engineering" / Igor Sikorsky Kyiv Polytechnic Institute; compiled by: V.O. Piddubny, I.O. Tovkach. – Electronic text data (1 file: 4.83 MB). – Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2021. – 117 p. URLhttps://ela.kpi.ua/bitstream/123456789/41347/1/EBRA_2.pdf
3. Element base of radio-electronic equipment: In 4 parts. Part 3. Multi-transition structures [Electronic resource]: textbook for students majoring in 172 "Telecommunications and Radio Engineering" / Igor Sikorsky Kyiv Polytechnic Institute; compiled by: V.O. Piddubny, I.O. Tovkach. – Electronic text data (1 file: 3.09 MB). – Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2021. – 134 p. URLhttps://ela.kpi.ua/bitstream/123456789/41348/1/EBRA_3.pdf
4. Element base of radio-electronic equipment: In 4 parts. Part 4. Fundamentals of Microelectronics [Electronic resource]: textbook for students majoring in 172 "Telecommunications and Radio Engineering" / Igor Sikorsky Kyiv Polytechnic Institute; compiled by: V.O. Piddubny, I.O. Tovkach. – Electronic text data (1 file: 2.22 MB). – Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2021. – 119 p. URLhttps://ela.kpi.ua/bitstream/123456789/41349/1/EBRA_4.pdf
5. Circuitry. Part 1. Electronic components: Physical properties of semiconductors [Electronic resource]: textbook for students majoring in 172 "Telecommunications and Radio Engineering" / Igor Sikorsky Kyiv Polytechnic Institute; compiled by: V.O. Piddubny – Electronic text data (1 file: 2.0 MB). – Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2023. – 72 p. – Title from the screen. https://ela.kpi.ua/handle/123456789/54655
6. Circuitry. Part 1. Electronic Components: Laboratory Practicum [Electronic resource]: textbook for students majoring in 172 "Telecommunications and Radio Engineering" / Igor Sikorsky KPI; compiled by: V.O. Piddubny, I.O. Tovkach. – Electronic text data (1 file: 3.5 MB). – Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2023. – 85 p. – Title from screen. https://ela.kpi.ua/handle/123456789/54658
7. Solid-state electronics [Electronic resource]: textbook for students majoring in 153 "Micro- and nanosystem technology" / O.V. Borisov, Yu.I. Yakimenko; Igor Sikorsky Kyiv Polytechnic Institute. – Electronic text data (1 file: 19.2 MB). – Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2018. – 484 p. URLhttps://me.kpi.ua/downloads/Borysov_Yakymenko_TTE_2018.pdf

Supplementary

1. *Trostyshyn, I.V*. Physical Fundamentals of Electronic Devices: Textbook / I.V. Trostyshyn – Khmelnytskyi: Khmelnytskyi State University. – 2004. – 488 p.
2. *Borisov O.V.* Solid-state electronics / O.V. Borisov, Yu.I. Yakimenko – Kyiv: BHV – NTUU "KPI", 2015. – 484 p.
3. Radio Engineering: Encyclopedic Educational Reference Book / Edited by Yu.L. Mazor, Ye.A. Machusky, V.I. Pravda. – Kyiv: Vyshcha Shkola, 1999. – 838 p.
4. *Shuaibov O.K.* Low-voltage pulse electronics / Shuaibov O.K., Shevera I.V., Malinina A.O., Malinin O.M. – Uzhhorod, Uzhhorod National University, 2018, –236 p.
5. *Pryshchepa M. M.*, Pogrebnyak V. P. Microelectronics. Microcircuit elements. Collection of problems. Textbook. / Edited by M. M. Pryshchepa. – Kyiv: Vyshcha shkola, 2005. – 167 p.
6. *Pryshchepa M. M.*, Pohrebnyak V. P. Microelectronics. In 3 parts. Part 1. Microelectronics components: Textbook. / Edited by M. M. Pryshchepa. – Kyiv: Vyshcha shkola, 2004. – 431 p.
7. *Pryschepa M.M.*, Pohrebnyak V.P. Microelectronics: In 3 parts. Part 2. Elements of Microcircuit Technology: Textbook. / Edited by M.M. Pryschepa. – Kyiv: Vyshcha Shkola, 2006. – 503 p.
8. *Asadi F*. Essential Circuit Analysis Using Ni Multisim (tm) and MATLAB®. – Springer Nature, 2022.

The distance learning course is available on the Moodle MicroTik distance learning platform http://iot.kpi.ua/lms/course/view.php?id=28 and on the NTUU KPI Sikorsky platform, discipline "Circuit Engineering. Part 1. Electronic Components" https://do.ipo.kpi.ua/course/view.php?id=6394
You can view materials on differential amplifiers, a video lecture on theoretical material, and practical laboratory work (for reference) at https://www.youtube.com/watch?v=UPMSP3MSNyU - lecture and https://www.youtube.com/watch?v=FmlpvqyG_0k – laboratory work.

Recommended reading for section 2 Basic

1. Sedov, S. O. Analog signal processing. Circuitry. Calculations [Electronic resource]: textbook / S. O. Sedov; Igor Sikorsky KPI. – Electronic text data (1 file: 4.93 MB). – Kyiv: Igor Sikorsky KPI, Polytechnika Publishing House, 2018. – 298 p.
2. Signal processing based on operational amplifiers. Circuitry. Calculations: Textbook / Serhii Oleksiiovych Sedov. – Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2017. – 132 p.: ill.
3. The Art of Electronics by Paul Horowitz, Winfield Hill, 3rd edition, 2015, 1220 pages, ISBN-10: 978052180926
4. Learning the Art of Electronics: A Hands-On Lab Course - Hayes, Thomas C., Horowitz, Paul, 2016, ISBN: 9780521177238
5. The Art of Electronics: The x Chapters - Horowitz, Paul, Hill, Winfield, 2020, ISBN: 9781108499941
6. Joseph D. Greenfield / Practical Transistors and Linear Integrated Circuits Paperback - January 1, 1988. P.233
7. Jones M. H. et al. A practical introduction to electronic circuits. – Cambridge University Press, 1995.
8. Baker B. A Baker's Dozen: Real analog solutions for digital designers. – Elsevier, 2005.

Supplementary

1. Kaufman M., Seidman A. H. (ed.). Handbook of electronics calculations for engineers and technicians. – McGraw-Hill Companies, 1988.
2. Boylestad R. L., Nashelsky L. Electronic devices and circuit theory. – Prentice Hall, 2012.
3. Fish P. J. Electronic noise and low noise design. – Macmillan International Higher Education, 2017.
4. Palumbo G., Pennisi S. Feedback amplifiers: theory and design. – Springer Science & Business Media, 2002.

5. Schubert Jr T. F., Kim E. M. Fundamentals of Electronics: Book 2: Amplifiers: Analysis and Design. – Morgan & Claypool Publishers, 2015.
6. Pryschepa M. M., Pogrebnyak V. P. Microelectronics. In 3 parts. Part 1. Elements of Microelectronics: Textbook. / Edited by M. M. Pryschepa. - Kyiv: Vyshcha Shkola, 2004. - 431 p.: ill.
7. Pryschepa M. M., Pogrebnyak V. P. Microelectronics: In 3 parts. Part 2. Elements of Microcircuit Technology: Textbook. / Edited by M. M. Pryschepa. - Kyiv: Vyshcha Shkola, 2006. - 503 p.: ill.
8. Sukhov M.E. / Circuitry for High-Quality Sound Reproduction [Text] / M.E. Sukhov, S.D. Bat, V.V. Kolosov, O.G. Chupakov. - Kyiv: Technika, 1992. - 127 p.
9. Asadi F. Essential Circuit Analysis Using Ni Multisim (tm) and MATLAB®. – Springer Nature, 2022.
10. Báez-López D., Guerrero-Castro F. E., Cervantes-Villagómez O. D. Advanced circuit simulation using Multisim Workbench //Synthesis Lectures on Digital Circuits and Systems. – 2012. – Vol. 7. – No. 1. – P. 1- 144.
11. Asadi F. Electric and Electronic Circuit Simulation using TINA-TI®. – CRC Press, 2022.
12. Bruun E. CMOS Integrated Circuit Simulation with LTspice. – 2017.
13. Mohindru P., Mohindru P. Electronic Circuit Analysis Using LTSpice XVII Simulator: A Practical Guide for Beginners. – CRC Press, 2021.
14. Asadi F. Simulation of Electric Circuits with LTspice® //Essential Circuit Analysis using LTspice®. – Springer, Cham, 2023. – P. 1-175.

Educational content

5. Methodology for mastering the academic discipline (educational component)

Lectures (72 hours) are conducted in accordance with the content of the academic discipline in offline mode in accordance with the dean's schedule or in online mode in Zoom.

List of questions covered in lectures (section 1) (36 hours)

No	Lecture topic and list of main questions
1	REA components. General characteristics of the REA component base. General information about passive and active radio elements. Purpose and main characteristics of materials. Classification. Dielectric materials. Physical processes in dielectrics. Passive and active dielectrics. Dielectrics used in REA. Nonpolar RF polymers. Weakly polar LF polymers. Polar LF polymers. Composite dielectric materials. Varnishes, enamels, compounds. Dielectric materials for printed circuit boards and GIS. Radio ceramics. Ferrites, piezoelectrics, electrics. Gaseous and liquid dielectrics. Capacitors with constant and variable capacitance. Purpose. Classification. Main characteristics. Ranges of nominal capacitance values and tolerance ranges. High-frequency and low-frequency capacitors. Equivalent circuits. Designs of fixed and variable capacitors. Special-purpose capacitors: varistors and varicaps.
2	Conductive and resistive materials. Main properties of conductive materials. High-conductivity materials for surface mounting, printed circuit boards, and integrated circuits. Winding and radio assembly wires. High resistivity materials (manganin, constantan, nichrome, MLT alloy, kermet, carbon, metal silicides). Constant and variable resistance resistors. Basic characteristics and equivalent circuits. Series of nominal resistance values and tolerance series. Types resistors (surface-mount, for printed circuit boards, ultra-high frequency, and others). Resistors for hybrid and integrated circuits.
3	Magnetic materials. Characteristics of magnetic materials. Magnetically soft and magnetically hard materials. Transformer iron. Ferro- and ferrimagnets. Ferrites and magnetodielectrics. Magnetic films. Inductance coils. Characteristics

	of inductance coils. Types of windings. High-frequency inductance coils. Their purpose and design. Equivalent circuits. Variometers. Printed inductance coils. Gyrators. Special-purpose magnetic materials. Inductance coils for GIS. Chokes and transformers. Magnetic cores. Windings of transformers and chokes. Designs of low-frequency and high-frequency chokes and transformers. Features of operation at elevated frequencies. Classification of contact and switching devices. Equivalent circuits, basic parameters and characteristics. Switches. Relays. Connectors. Contact and switching devices of microassemblies and microblocks. Printed circuit boards and their classification. Printed circuit board materials. Printed circuit board design. Features of microwave range printed circuit boards (materials and boards). Boards for personal computers and other modern electronic equipment. SMD – components and technology.
4	Basic materials of semiconductor devices. Types of crystal lattices. Fundamentals of band theory. Charge carriers in intrinsic and doped semiconductors. Major and minor charge carriers. Generation and recombination of free charge carriers. Types of generation and recombination. Equilibrium and non-equilibrium states of semiconductors. Concentration of charge carriers in intrinsic and doped semiconductors. Fermi level for intrinsic and doped semiconductors. Dependence of the Fermi level Fermi on temperature and concentration of impurities. Fermi level Fermi – electrical potential.
5	Drift current of charge carriers, mobility of carriers, dependence of mobility on temperature, impurity concentration, electric field strength. Drift current density. Electrical conductivity of semiconductors. Diffusion current. Diffusion motion of particles, diffusion coefficient, diffusion length. Diffusion equation and its connection. Total current equation. Properties of semiconductor surfaces: surface states, their density, surface charge, and surface recombination. Field effect.
6	Types of electrical transitions. Contact potential difference. Metal-semiconductor contact: ohmic and rectifying transitions. VAC of the transition, parameters. Heterojunction. Electron-hole transition (p-n transition). Transition in equilibrium: potential barrier, potential diagram, transition width. Transition in a non-equilibrium state: injection, extraction, potential barrier, potential diagram, transition width. I-V curve of an idealized transition: thermal current, differential resistance. I-V curve of a real transition: generation currents, recombination, base resistance base, transition breakdowns, transition capacitance.
7	Classification of semiconductor diodes. Rectifier diodes. Structure, characteristics, basic parameters. Series and parallel connection of diodes. Pulse diodes. Diode operation in switching modes with low and high injection levels. Types of rectifier and pulse diodes. Silicon Zener diodes. VAC, parameters. Varicaps, varactors, parametric diodes: purpose, structure, characteristics, parameters, models. Semiconductor emitting devices. Detector and mixer diodes. Tunnel diodes, reverse diodes. Structure, principle of operation, characteristics, parameters, models. Application of diodes.
8	Bipolar transistors (BT). Types of BT, switching circuits, operating modes. Structure of a planar-epitaxial BT. Potential diagram and physical processes in active mode. Transistor currents. Distribution of minority carriers in a transistor. Principle of BT amplification.
9	Current transfer coefficients. Physical parameters. Static VAC of BT. Ebers-Moll model. VAC in circuits with a common base and a common emitter. Temperature drift of characteristics. Small-signal parameter systems. Determination of parameters by VAC. Relationship between parameter systems and physical parameters. Circuits with two sources, P- and T-shaped circuits. Transistor operation in a voltage amplification circuit at low frequency, graphoanalytical calculation of the amplification mode. Amplification properties of BT for three switching circuits.

10	Frequency properties of BT. The effect of carrier transit time, base resistance, and junction capacitance on transistor operation. Modeling of BT at high frequency. Cutoff and cutoff frequencies. Features of microwave transistors. Drift and heterojunction transistors. Equivalent circuits of a transistor at high frequency. Transistor switch circuit. Accumulation and dispersion of volume charge in the base and collector. Transition from cutoff mode to active mode and saturation mode. BT parameters in cutoff and saturation modes. Pulse parameters.
11	Intrinsic noise in transistors, noise sources. Noise parameters. Dependence of noise parameters on matching and operating modes. Low-frequency low-power transistors, high-frequency low-power transistors, microwave transistors, power transistors. Four-layer switching devices. Dynistors, thyristors. Classification. Structure, principle of operation, main parameters, VAC, application.
12	Types of field-effect transistors (FET). Structure and principle of operation of an MDN transistor with an induced channel. Physical processes in an MDN structure. Depletion, enrichment, and inversion modes. FT switching circuits. FT VCC family. Temperature drift of characteristics. MDN transistor parameters. Structure and principle of operation of an NPN transistor with an integrated channel. NPN transistor as a linear four-terminal network. System of small-signal parameters. Operation of an NPN transistor at high frequencies. Small-signal circuit of a PT at high frequencies. Influence of capacitances on the operation of a PT. Threshold and cutoff frequencies of the transistor.
13	Structure and principle of operation of a transistor with a controlled p-n junction. VAC and parameters. Transistors with a heterojunction. PT. Structure and principle of operation of a transistor. Static VAC of a transistor, differential parameters of a transistor. Temperature drift of VAC. Three transistor connection circuits. Integrated circuits (IC). Classification of ICs by design and technological features and functional purpose. Hybrid integrated circuits, semiconductor ICs, VLSI, microassemblies.
14	The main stages of IC creation. Technological operations: epitaxy, impurity diffusion, ion doping, thermal oxidation, etching. Thin film deposition, creation of connections and contacts. Photolithography and submicron lithography. Nanotechnology. Materials for GIS sublayers. GIS elements: film resistors, capacitors, inductors, conductors, and contact pads. The influence of GIS materials and design on accuracy characteristics and parameter dispersion. Basics of passive element calculation elements. Surface-mounted GIS components.
15	ICs on BT. Semiconductor bipolar ICs. Epitaxial-planar n-p-n transistor with combined and full dielectric insulation. Multi-emitter and multi-collector transistors, transistors with Schottky diodes. Diode switching transistors. Semiconductor and film resistors, capacitors, structures and parameters. Bipolar IC manufacturing technology. Basic properties of bipolar ICs. MDN transistors in semiconductor ICs. Transistors with silicon self-aligned barriers. Features of the parameters and characteristics of transistors with short channels for VLSI.
16	Concepts of microcircuit technology and its general principles, determined by integrated technology. Differences between microcircuit technology and circuit technology based on discrete components. Fundamentals of digital circuit technology. Transistor switches on BT. Switch load capacity. TTL, EZL, I-I-L logic. Their main parameters. Comparative characteristics of logic. Current switch. MDN transistor switches. Key with dynamic load. Complementary key. Noise immunity of keys. Logic elements ICs at n-channel and complementary MDN transistors, their structures, operating principles, and parameters. Programmable logic ICs.
17	Fundamentals of analog IC circuitry. Concepts of differential and operational amplifiers, their characteristics, parameters, and areas of application. and voltage generators, IC output stages. Introduction to functional electronics and

	nanoelectronics. Elements acoustoelectronics. Delay lines delay lines, filters and resonators on bulk and surface acoustic waves (SAW), amplifiers on SAW, signal generators on SAW, convolvers, and correlators.
18	Elements of cryoelectronics, magnetoelectronics, chemotronics, dielectric, molecular, and bioelectronics. Principles of nanoelectronics. Physical foundations of nanoelectronics. Nanotechnology. Nanoelectronic devices (diode and transistor structures). structures).

List of topics covered in lectures (section 2) (36 hours)

No.	Lecture topic and list of main questions
1	Introduction. Tasks of analog circuitry. The place of circuitry in the training of modern specialists. Purpose and objectives of the discipline. Learning outcomes.
2	Principles of amplification by electronic devices. Equivalent circuits for alternating and direct currents. Classes of operation of amplifier stages. Component base of analog circuitry. Historical overview. Stages of designing analog electronic devices. Simulation packages.
3	Basic characteristics of analog devices. ACF, frequency response. Logarithmic characteristics. Frequency response and logarithmic frequency response of passive circuits.
4	Feedback. The effect of feedback on parameters.
5	Idealized operational amplifiers. The principle of calculating circuits based on operational amplifiers.
6	Circuits offset bipolar transistors. Circuits with fixed voltage and fixed current. Bias circuits for field-effect transistors with an insulated gate. Bias circuits for field-effect transistors with an integrated junction.
7	Sources of constant current on bipolar and field-effect transistors. Current mirrors. Reference voltage sources.
8	Active element connection circuits. Circuit analysis. Power supply circuits.
9	Analysis of frequency response in the low, mid, and high frequency ranges. Correction of amplitude-frequency characteristics. Calculation of frequency distortions. Calculation of nonlinear distortions.
10	Calculation of noise characteristics of transistor cascades. Noise models.
11	Composite cascades on BT and PT. Active load. Differential amplifier. Circuitry and analysis.
12	Multistage amplifiers. Interstage coupling.
13	Push-pull amplifiers. Principles of construction and circuitry.
14	Twin-ended amplifiers. Power amplifiers.
15	Resonant amplifiers.
16	Stability of resonant amplifiers.
17	Control in analog signal processing devices.
18	Analog devices in modern ICs. End-to-end design of analog amplification devices. Computer modeling

Laboratory classes (section 1) (18 hours) Conducted for:

- deepening and consolidating theoretical knowledge;
- acquiring experimental research skills;
- acquiring skills in working with measuring equipment;
- acquiring skills in working with the Multisim computer circuit simulator (Trial);
- acquiring skills in assessing the reliability of the results obtained;
- acquiring skills in document preparation.

The following laboratory work is performed:

1. Study of a silicon Zener diode – 6 hours.
2. Study of the volt-ampere characteristics of a transistor and calculation of h-parameters – 6 hours.
3. Transistor operation in key mode – 6 hours.

At the end of the semester, students can perform (if desired) additional laboratory work (individual classes) to improve their rating: "Study of an integrated differential amplifier microcircuit."

In distance learning mode, laboratory work is performed on a home personal computer in accordance with the requirements specified in the distance learning course *http://iot.kpi.ua/lms/course/view.php?id=28* . Additional work is carried out in introductory mode using relevant materials (text documents with photos and videos on YouTube, explanations in Zoom).

Laboratory work begins with an introductory session in Zoom and is then carried out by students independently. When working in the laboratory, classes are held on laboratory models in room 208-17.

Laboratory classes (section 2) (18 hours)

The purpose of the laboratory classes is to experimentally verify theoretical knowledge, acquire skills in calculation, research, measurement, and evaluation of specific parameters of amplifying devices and their cascades. Laboratory classes are conducted in the form of a laboratory workshop on models in the laboratory. For distance learning, these laboratory works are adapted for use in the NI Multisim simulator program.

Students receive assignments for laboratory work in advance. Before the start of the class, a survey is conducted to assess the student's readiness to perform the work. After completing the work, the results are defended and discussed. A report on the laboratory work is prepared.

The following laboratory work is performed:

1. Laboratory work No. 1: Measurement of sound frequency amplifier parameters;
2. Laboratory work No. 2: Investigation of the parameters of an amplifier with negative feedback;
3. Laboratory work No. 3: Investigation of transistor cascade bias circuits;
4. Laboratory work No. 4: Investigation of transistor amplifier cascades in the mid-frequency range.

Practical classes (section 2) (36 hours) Topics of the computer workshop:

1. Transistor cascade bias circuits;
2. Bipolar transistor switching circuits;
3. Analysis of the frequency response of a transistor amplifier;
4. Study of an integrated circuit amplifier.

In distance learning mode, laboratory work is performed on a home personal computer. Additional work is carried out in familiarization mode using relevant materials (text documents with photos and videos on YouTube, explanations in Zoom).

Laboratory work begins with an introductory session in Zoom and is then carried out by students independently. When working in the laboratory, classes are held on laboratory models in room 512-17.

Individual assignments are planned for the study of the discipline (home test on section 1). The purpose of this individual assignment is:

- to master the curriculum in its entirety;
- acquiring skills in working with literature, preparing technical documentation in accordance with DSTU 3008-2015, preparing short abstracts for publication at scientific and technical conferences, performing calculations and evaluating their results;
- deepening and expanding on the material presented in lectures.

Individual assignments are completed on topics individually assigned to students.

The student has the right, in agreement with the teacher, to choose another topic related to the subject matter, or to clarify the list of questions selected from the list.

The deadlines for submitting work are specified in Moodle.

6. Independent work of the student

66 hours are allocated for independent work by students. It consists of preparation for section 1 (26 hours):

- Studying lecture materials – 9 hours;
- preparation for laboratory work, performing the necessary calculations and completing laboratory work reports, preparation for the defense of laboratory work – 6 hours;
- completing homework assignments – 9 hours;
- preparation for modular tests – 2 hours.

Preparation for section 2 (40 hours):

- Review of lecture material based on lecture notes – 9 hours;
- preparation for laboratory work, performing the necessary calculations and completing laboratory work reports, preparation for the defense of laboratory work – 6 hours;
- completing homework assignments – 3 hours;
- preparation for modular tests – 2 hours.
- preparation for the exam – 20 hours.

Policy and control

7. Policy of the academic discipline (educational component)

System of requirements that the teacher sets for the student:

- **Rules for attending classes** – all classes are held in the classroom or remotely, lectures and laboratory work are conducted in accordance with the schedule provided by the dean's office. Control is exercised during the class by the teacher, if it is held in the
  a classroom, or based on test results and reports on the completion of laboratory work if it is remote. Attendance at classes is mandatory.
- **Rules of conduct in class** – generally established rules of conduct in class must be followed. During tests, cheating and
  laptops or phones during tests. During laboratory work, the use of these devices is permitted and desirable.
- **Rules for protecting** laboratory work and individual assignments are specified in the section on the rating system for assessing learning outcomes. Incentive points are awarded
  for active participation in department seminars and penalty points for late submission of tests and lab reports.
- **Deadlines for submitting materials** are set individually and communicated to students on Moodle and sent to the students' group email or Telegram group. Students who
  who have earned a grade of less than 60 points during the semester may improve their grade before the start of the exam period, in consultation with the instructor, and be admitted to the exam.

The academic integrity policy is the responsibility of the students and is monitored by the instructor by comparing the content of individual assignments.

Students have the opportunity to gain knowledge on specific topics and sections of the academic discipline through training courses on the Sikorsky distance learning platform (*https://do.ipo.kpi.ua/course/view.php?id=6394* *https://do.ipo.kpi.ua/course/view.php?id=6417*) and the MicroTik platform (http://iot.kpi.ua/lms/course/view.php?id=28), as blended or additional learning in accordance with the Regulations on the recognition of learning outcomes acquired in non-formal/informal education at Igor Sikorsky KPI (https://osvita.kpi.ua/node/179).

8. Types of control and rating system for assessing learning outcomes (RSO)

Distribution of points by sections: section 1 – 30 points, section 2 – 30 points, exam – 40 points.

Section 1

Ongoing assessment: completion of laboratory work (reports – 5x3 points), laboratory work test (defense – 10x3 points), two MCR (20x2 points), home control work (5x1 points)

Calendar control: conducted twice per semester as monitoring of the current status of syllabus requirements fulfillment.

Semester assessment: none

Conditions for admission to semester assessment: minimum passing grade for individual assignments and completion of all laboratory work. Semester rating must be above 15 points.

The rating for section 1 of the RD discipline is calculated as the sum of the points for current academic performance.

The student's rating for the discipline consists of points received for:

1. Completion and defense of 3 laboratory works.
2. Completion of an individual assignment.
3. Modular control. Two 30-minute MCRs are performed (in Moodle).

Items 1-3 constitute the sum of points for current academic performance and are the basis for the discipline rating. The rating can be improved by completing an additional individual assignment.

Rating point system and assessment criteria:

1. Laboratory work.

Points are awarded for each LR class:

- report formatting in accordance with requirements – 5 points;
- defense of laboratory work (test in system Moodle, login via link iot.kpi.ua/lms, subject "Circuitry. Part 1. Electronic Components") – 10 points;

The maximum number of points for the course is 45 points.

2. The MCR modular control has 2 questions. Points are awarded for each question:

- complete answer – 10 points;
- sufficiently complete answer (has minor inaccuracies) – 8 points;
- answer does not fully cover the question, there are some errors – 8 points;
- no answer, incorrect answer – 0 points. The maximum number of points for one MCR is 20 points.

The total number of points for two MCRs is 40 points.

3. Individual (home) work is performed in the form of an essay. It is evaluated as follows:

- complete coverage of the topic, presence of well-founded conclusions, references to contemporary sources of information 5 points – "excellent";
- sufficiently complete answer (at least 80% of the required information is covered, or there are minor inaccuracies) 4 points – "very good";
- the topic is generally covered, conclusions are made, personal opinion is expressed – 3 points – "good";
- the topic is not fully covered, the essay is at a compilation level, references to outdated sources – 2 points – "satisfactory";
- topic is not revealed, no conclusions, references to outdated sources information – "unsatisfactory." The task is not counted.

Maximum number of points – 5 points

The maximum possible number of points for control measures (items 1-3) during the semester is:

RD= (15+10+5)/3= 30 points.

The semester grade is calculated automatically as the sum of the grades for all assignments and is forwarded to the instructor of section 2.

Section 2

Current assessment: completion of laboratory work and its defense (5x4 points), nine MCRs (9x3 points), RGR (13x1 points)

Calendar control: conducted twice per semester as monitoring of the current status of syllabus requirements fulfillment.

Semester assessment: none

Conditions for admission to semester assessment: a minimum passing grade for the individual assignment and completion of all laboratory work. The total semester rating must be more than 30 points.

The rating for the RD discipline is formed as the sum of the points for current academic performance and is calculated on a 60-point scale.

The student's rating for the discipline consists of points received for:

4. Completion and defense of 4 laboratory works.

5. Completion of an individual assignment (RGR).
6. Modular control. Nine MCRs are performed, each lasting 10 minutes.

Items 4-6 constitute the sum of points for current academic performance and are the main component of the discipline rating. The rating can be improved by completing an additional individual assignment.

Rating point system and assessment criteria:

4. Laboratory work.

Points are awarded for each lab session:

- preparation of a report in accordance with the requirements and timely defense of the results (within a week after completion of the work) – 5 points; preparation of a report in accordance with the requirements and late submission (more than a week after completion of the work) – 4 points; preparation of a report in accordance with requirements and incomplete answers during the defense – 3 points; preparation of a report in accordance with the requirements and inappropriate answers during the defense – 2 points; preparation of a report in accordance with the requirements – 1 point.

The maximum number of points for the LR is 20 points.

5. The MCR modular control has 3 questions. Points are awarded for each question:

- complete answer – 1 point;
- no answer, incorrect answer - 0 points. The maximum number of points for one MCR is 3 points.

The total number of points for nine MCRs is 27 points.

6. Individual (RGR) work is performed in the form of a calculation work in the form of solving 13 problems of increased complexity.

It is evaluated as follows:

- Complete solution to the problem – 1 point;
- Incorrect solution or no solution – 0 points.

Maximum number of points – 13 points

The maximum possible number of points for control measures (items 4-6) during the semester is:

RD= (20+27+13)/2= 30 points.

Based on the results of work on sections 1 and 2, the student receives a total rating. To be admitted to the exam, the total rating must be at least 40 points.

Exam

The exam is in written form and consists of written answers to test questions (5 practical and theoretical questions) (5x8 points). Each question is worth 8 points.

- Complete answer – 8 points
- sufficiently complete answer (with minor inaccuracies) – 6 points;
- answer does not fully cover the question, there are some errors – 4 points;
- no answer, incorrect answer – 0 points.

Examples of exam ticket questions:

1. Classification of amplifiers. Generalized amplifier structure and energy ratios. Schematic diagram of the simplest amplifier. Principle of amplifier operation.
2. Linear distortions (amplitude, phase), causes, their connection with frequency response and phase response. Methods of reducing linear distortions.
3. Feedback in amplifier devices. Types, classification. Generalized block diagram of an amplifier with feedback.
4. The effect of series feedback on the input resistance of amplifying devices (output impedance).
5. Temperature instability of operation. Causes. Ways to reduce.
6. Offset circuits with fixed base voltage. Characteristics, examples of circuit implementation. 7. Schematic diagram of a resistor cascade. Equivalent circuit and analysis of the frequency response of a resistor in the low-frequency range. Influence of element parameters on the frequency distortion coefficient Mnch (derivation of the formula).

8. Composite transistors. Darlington pairs, use in amplifying devices.

9. Basic AE connection circuits: with CE, CB, SC. Schematic and equivalent circuits. Features of use.

10. Selective amplifiers, basic parameters (Ko, passband, selectivity, unevenness at the edges of the spectrum, frequency response rectangularity coefficient).

The final grade consists of the semester component of section 1 (maximum 30 points), section 2 (maximum 30 points), and the exam component (maximum 40 points).

The final grades for the course are entered into the grade book and transcript.

Table of correspondence between rating points and grades on the university scale:

Number of points	*Grade*
100-95	Excellent
94	Very good
84	Good
74-65	Satisfactory
64-60	Sufficient
Less than 60	Unsatisfactory
Admission requirements not met	Not admitted

9. Additional information on the discipline (educational component)

The distance learning course is available on the Moodle MicroTik distance learning platform http://iot.kpi.ua/lms/course/view.php?id=28 and on the NTUU KPI Sikorsky platform. Discipline "Circuitry. Part 1. Electronic Components" https://do.ipo.kpi.ua/course/view.php?id=6394
"Circuitry. Part 2. Analog Circuitry" https://do.ipo.kpi.ua/course/view.php?id=6417

Description of material, technical, and informational support for Section 1 of the discipline For effective assimilation of the material, the following laboratory work is carried out: Name of laboratory work:

- Investigation of a silicon Zener diode (2 models)
- Investigation of the pulse properties of a semiconductor diode (2 models)
- Investigation of the volt-ampere characteristics of a transistor (2 models) - Operation of a transistor in key mode (2 models)
- Investigation of the basic element of transistor-transistor logic (2 models)
- Research on an integrated differential amplifier microcircuit (1 model)

Description of material, technical, and informational support for Section 2 of the discipline

The following laboratory work is carried out for effective assimilation of the material: Name of laboratory work:

- Measurement of amplifier parameters (8 models)
- Feedback in different variants. (8 models)
- Study of offset circuits (8 models)
- Study of switching circuits (8 models)

They provide in-depth and consolidation of theoretical knowledge; acquisition of experimental research skills; acquisition of skills in working with measuring equipment; assessment of the reliability of the results obtained; acquisition of document preparation skills

Work program for the academic discipline (syllabus):

Compiled by V.O. Piddubny, A.V. Movchanuk
Approved by the Department of Radio Engineering Systems (Minutes No. 06/2025 of June 21, 2025) and the Department of Applied Radio Electronics (Minutes No. 06/2025 of June 25, 2025)
Approved by the Methodological Commission of the Faculty/Research Institute [1] (Minutes No. 06/2025 dated June 26, 2025)

(1) By the Methodological Council of the university – for university-wide disciplines.