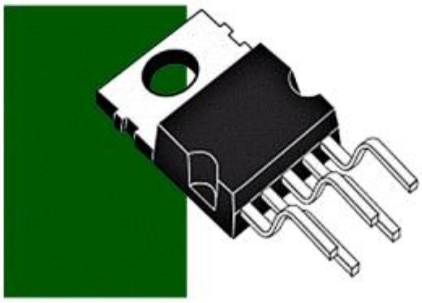
# [RE-9] CIRCUIT TECHNOLOGY. PART 1. ELECTRONIC COMPONENTS



## Curriculum (Syllabus)

| Course details | |
|---|---|
| **Level of higher education** | **First (bachelor's)** |
| **Field of knowledge** | **G - Engineering, manufacturing, and construction** |
| **Special** | **G5 - Electronics, electronic communications, instrument engineering, and radio engineering** |
| **Educational program** | **172B RTS - Radio Engineering Information Technologies (EDEBO id: 6842)172B ROS - Radio Communications and Signal Processing (EDEBO id: 6364)172B ITR Intelligent Technologies of Radio Electronics (EDEBO id: 49229)172B ICR - Information and Communication Radio Engineering (EDEBO id: 49228)172B RCS - Radio Engineering Computerized Systems (EDEBO id: 49227)172B ITRET+ - Intelligent technologies of radio-electronic engineering (EDEBO id: 57907)172B ICRI+ - Information and communication radio engineering (EDEBO id: 57910)172B RTKS+ Radio Engineering Computerized Systems (EDEBO id: 57920)172B TREB Radio Electronic Warfare Technologies (EDEBO id: 63920)** |
| **Discipline status** | Regulatory |
| **Form of study** | Full-time |
| **Year of training, semester** | 2nd year, fall semester |
| **Scope of the discipline** | 3 credits (Lectures 30 hours, Practical work 0 hours, Laboratory work 16 hours, Independent work 44 hours) |
| **Semester control/control measures** | Test |
| **Class schedule** | https://rozklad.kpi.ua |
| **Language of instruction** | Ukrainian |
| **Information about course director / teachers** | Lecturer: Ph.D., Associate Professor, Senior Researcher, Volodymyr Oleksiyovych PIDDUBNYI, tel. 0671929139, e-mail - VAPoddubny@gmail.com[1] |

[1] The instructor's email address or other contact information for feedback; office hours or hours for communication may be indicated if contact telephone numbers are provided. For the syllabus of a discipline taught by many teachers (e.g., history, philosophy, etc.), you can

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| | Laboratory: Volodymyr Oleksiyovych PIDDUBNYI, PhD, Associate Professor, Senior Researcher, tel. 0671929139, e-mail - VAPoddubny@gmail.com, Ph.D., TOVKACH Igor Olegovich, e-mail – tovkach.igor@gmail.com |
| **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 |

## Curriculum

### Description of the academic discipline, 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

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.

The discipline covers their circuitry, manufacturing technology, and features of use in modern radio engineering systems, their characteristics and properties.

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

**General competencies (GC):**

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indicate the website page where the contact information of teachers for the relevant groups, faculties, and institutes is presented.

- Ability to think abstractly, analyze, and synthesize (GC 01).
- 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, pose, 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).
- Willingness to promote the implementation of promising technologies and standards (PC 08).
- Ability to accept and master new equipment in accordance with current standards (PC 09).
- Ability to install, debug, configure, adjust, test, and commission telecommunications and radio engineering structures, facilities, and equipment (PC 10).
- Ability to compile regulatory documentation (instructions) for the operational and technical maintenance of information and telecommunications networks, telecommunications and radio engineering systems, as well as test programs (PC 11).

**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).
- Adapt to changes in information and communication network technologies, telecommunications and radio engineering systems (PLO 06).
- Analyze and evaluate the effectiveness of methods for designing information and telecommunications networks, telecommunications and radio engineering systems (PLO 09).
- 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).
- Understanding and complying 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).

## 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 Metrology" and "Introduction to the Specialty" and is the basis for studying all subsequent special disciplines, with which it creates the foundation for circuit engineering and design training, and is used as a basis for studying disciplines related to analog and digital circuit engineering.

## Content of the academic discipline

The academic discipline "Circuit Engineering. Part 1. Electronic Components" is taught in the third semester.

***Section 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.

**_Section 2. Passive radio components._**

*Topic 2.1.* Dielectric materials. Classification and purpose of dielectric materials. Passive and active dielectrics. Dielectrics used in electronic devices. 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.

**_Section 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.

**_Section 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.

***Section 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.

***Section 6. Thyristors.***

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

***Section 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.

***Section 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.

***Section 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.

***Section 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

***Section 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.

***Section 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).

## Teaching materials and resources

### Recommended reading

**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 KPI; 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 practical [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: 3.5 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. *Pryschepa M. M.*, Pogrebnyak V. P. Microelectronics. Microcircuit elements. Collection of problems. Textbook. / Ed. by . – Kyiv: Vyshcha shkola, 2005. – 167 p.
6. *Pryshchepa M.M.*, Pogrebnyak 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.*, 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.

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

Materials on differential amplifiers, video lectures on theoretical material, and practical laboratory work (for review) can be found at
https://www.youtube.com/watch?v=UPMSP3MSNyU - lecture
and https://www.youtube.com/watch?v=FmlpvqyG_0k – laboratory work.

## Educational content

### Methodology for mastering the academic discipline (educational component)

Lectures (30 hours) are conducted in accordance with the content of the academic discipline in offline mode in accordance with the dean's office schedule or in online mode in Zoom and on the Moodle Micro Tick platform – iot.kpi.ua/lms

**List of questions covered in lectures**

| No. | Lecture topic and list of key 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. Non-polar 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, liquid dielectrics. Capacitors of 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 specific resistance materials (manganin, constantan, nichrome, MLT alloy, kermet, carbon, metal silicides). Constant and variable resistance resistors. Basic characteristics and equivalent circuits. Ranges of nominal resistance values and tolerance ranges. Types of 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. Soft magnetic and hard magnetic materials. Transformer iron. Ferromagnetic and ferrimagnetic materials. Ferrites and magnetodielectrics. Magnetic films. Inductors. Characteristics of inductors. 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. Transformer and choke windings. 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 zone 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 on temperature and impurity concentration. Fermi level – electrical potential. |
| 5 | Drift current of charge carriers, mobility of carriers, dependence of mobility on temperature, impurity concentration, electric field strength. Drift current density. |

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| | Electrical conductivity of semiconductors. Diffusion current. Diffusion motion of particles, diffusion coefficient, diffusion length. Diffusion equation and its connection. Total current equation. Properties of the surface of a semiconductor: 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, transition breakdowns, transition capacitances. |
| 7 | Classification of semiconductor diodes. Rectifier diodes. Structure, characteristics, basic parameters. Series and parallel connection of diodes. Pulse diodes. Operation of a diode in switching modes with low and high injection levels. Types of rectifier and pulse diodes. Silicon Zener diodes. I-V curve, 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. Applications of diodes. |
| 8 | Bipolar transistors (BT). Types of BT, connection 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 V-I curves of BT. Ebers-Moll model. V-I curves in common base and common emitter circuits. Temperature drift of characteristics. Small-signal parameter systems. Determination of parameters from V-I curves. Relationship between parameter systems and physical parameters. Circuits with two sources, P- and T-shaped circuits. Transistor operation in a low-frequency voltage amplification circuit, graphoanalytical calculation of the amplification mode. Amplification properties of BT for three connection circuits. |
| 10 | Frequency properties of BT. The effect of carrier transit time, base resistance, and junction capacitance on transistor operation. High-frequency BT modeling. Cutoff and threshold frequencies. Features of microwave transistors. Drift and heterojunction transistors. High-frequency transistor equivalent circuits. Transistor switch circuit. Accumulation and dispersion of volume charge in the base and collector. Transition from cutoff mode to active mode and saturation mode. Transistor 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 (FETs). Structure and principle of operation of an MDN transistor with an induced channel. Physical processes in the MDN structure. Depletion, enrichment, and inversion modes. FT switching circuits. FT VAC family. Temperature drift of characteristics. Parameters of an MDN transistor. Structure, principle of operation of the VAC of an MDN transistor with an integrated channel. MDN transistor as a linear four-terminal network. System of small-signal parameters. Operation of an MDN transistor at high frequencies. Small-signal circuit of a PT at high frequencies. Influence of capacitances on the operation of a PT. Cutoff and limit frequencies of a transistor. |
| 13 | Structure and principle of operation of a transistor with a control p-n junction. VAC and parameters. Transistors with a heterojunction. PT. Structure and principle of operation of |

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| | 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 according to 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. GIS sublayer materials. HIS elements: film resistors, capacitors, inductors, conductors, and contact pads. The influence of HIS materials and design on accuracy characteristics and parameter dispersion. Basics of passive element calculation. HIS surface-mounted 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 of 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 short-channel transistors 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. Load capacity of the switch. 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 of ICs on n-channel and complementary MDN transistors, their structures, principle of operation, parameters. Programmable logic ICs. |
| 17 | Fundamentals of analog IC circuitry. Concepts of differential and operational amplifiers, their characteristics, parameters, and areas of application. Current and voltage generators, IC output stages. Introduction to functional electronics and nanoelectronics. Acoustoelectronic elements. Delay lines, filters, and resonators on bulk and surface acoustic waves (SAW), SAW amplifiers, SAW signal generators, 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). |

**Laboratory classes** (16 hours) are 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 (Trial) computer circuit simulator;
- acquiring skills in assessing the reliability of the results obtained;
- acquiring document preparation skills.

The following laboratory work is performed:

1. Investigation of a silicon Zener diode – 5 hours.
2. Investigation of the volt-ampere characteristics of a transistor and calculation of h-parameters – 5 hours.
3. Operation of a transistor 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 class 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.

**Individual assignments** (homework tests) are planned for the study of the discipline. 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;
- to deepen and expand 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.

### Independent work

Students are allocated 44 hours for independent work. It consists of:

- Studying lecture materials – 12 hours;
- preparation for laboratory work, performing the necessary calculations and completing laboratory work reports, preparation for the defense of laboratory work – 7 hours;
- completing homework assignments – 17 hours;
- preparation for modular tests – 3 hours;
- preparation for the test and the test itself – 5 hours.

## Policy and control

### 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 by the teacher during the class, if it is held in the classroom, or based on the results of tests and the submission of reports on the completion of laboratory work, if it is remote. Class attendance is mandatory (both lectures and lab work);
- **rules of conduct in class** – generally established rules of conduct in class must be followed. During tests, cheating and the use of laptops and phones are not allowed. During laboratory work, the use of these devices is allowed and desirable;
- **Rules for protecting** laboratory work and individual assignments are specified in the section on the rating system for assessing learning outcomes. Bonus points are awarded for active participation in department seminars, and penalty points are awarded for late submission of tests and laboratory work 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 have earned a rating of less than 30 points during the semester may improve their rating before the start of the exam session within a timeframe agreed upon 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) and the MicroTik platform (http://iot.kpi.ua/lms/course/view.php?id=28)as part of blended or supplementary 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).

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

*Current assessment:* completion of laboratory work (reports – 5x3 points), LR test (defense – 10x3 points), two MCRs (20x2 points), home control work (15x1 points)

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

*Semester assessment:* credit

*Conditions for admission to semester assessment:* minimum passing grade for individual assignments and completion of all laboratory work. Semester rating must be above 30 points.

The rating for the RD discipline (i.e., the semester grade) is calculated as the sum of the points for current academic performance and is calculated on a 100-point scale.

The student's rating for the discipline consists of points that he receives for:

1. Completion and defense of 3 laboratory works.
2. Completion of an individual assignment (essay).
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 system and assessment criteria:

1. Laboratory work.

Points are awarded for each LR class:

- preparation of a report in accordance with the requirements and timely submission (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) – 1 point;
- defense of laboratory work (test in the Moodle system, login at iot.kpi.ua/lms, discipline "Circuitry. Electronic Component Base") – 10 points;

The maximum number of points for the LR 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 – 4 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) assignments are completed in the form of a report.

It is assessed as follows:

- complete coverage of the topic, presence of well-founded conclusions, references to modern sources of information  15 points – "excellent";
- sufficiently complete answer (at least 80% of the required information is covered, or there are minor inaccuracies) 12 points – "very good";

- the topic is generally covered, conclusions are made, personal opinion is expressed – 10 points – "good";
- the topic is not fully covered, the essay is at a compilation level, references to outdated sources – 5 points – "satisfactory";
- the topic is not covered, there are no conclusions, references to outdated sources of information – "unsatisfactory." The thesis is not accepted.

Maximum number of points – 15 points

The maximum possible number of points for control measures (items 1-3) during the semester is: RD= 45+40+15= 100 points.

The final grade is calculated automatically as the sum of the grades for all assignments.

Students can improve their grade by completing an additional individual assignment (laboratory work LR4). The minimum grade required to pass is 30 points.

Students with an RC of less than 30 points are given the opportunity to improve their rating before the start of the exam session by revising the completed assignments and completing an additional assignment or taking an exam (only in offline mode).

Students who have scored 60-65 points can, if they wish, receive a "sufficient" grade or take the exam.

Students who have scored more than 65 points automatically receive the corresponding grade and can improve it by completing an additional individual assignment or taking a test (only in offline mode).

The test is conducted only during offline classes.

During the exam, students answer four questions from the exam paper. The list of questions is provided in the methodological guidelines for completing the credit module. Each question is worth 25 points.

The grading system for answers to questions is as follows:

- "excellent", complete answer (at least 90% of the required information) – 24-25 points;
- "very good", sufficiently complete answer (at least 80% of the required information, or minor inaccuracies) – 21-23 points;
- "good," sufficiently complete answer (at least 70% of the required information, or minor inaccuracies) – 19-21 points;
- "satisfactory," incomplete answer (at least 60% of the required information and some errors) – 16-19 points;
- "Adequate," incomplete answer (at least 50% of the required information, or some errors) – 15-16 points;
- "unsatisfactory," unsatisfactory answer – less than 15 points.

The overall grade is calculated as the sum of the answers to all four questions and is entered into the overall rating in the additional points column as the difference between the grade received on the test and during training.

RD course ratings 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 |

## 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 "Circuit Engineering. Part 1. Electronic Components" https://do.ipo.kpi.ua/course/view.php?id=6394

***Description of material, technical, and informational support for 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 characteristics 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)
- Investigation of the integrated circuit of a differential amplifier (1 model)

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):**

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**Approved by** the Department of Radio Engineering Systems (Minutes No. 06/25 of June 26, 2025)

**Approved by** the Methodological Commission of the Faculty/Institute[2] (protocol No. 06/2025 of June 26, 2025)

[2] The university's methodological council – for university-wide disciplines.