National Technical University of Ukraine
"Igor Sikorsky Kyiv Polytechnic Institute"

Department of Radio Engineering

Electrodynamics and Propagation of Radiowaves

Curriculum of the academic course (Syllabus)

Details of the academic course

Level of higher education	***First (bachelor's)***
Field of knowledge	*G Engineering, Manufacturing and Construction*
Specialty	*G5 Electronics, Electronic Communications, Instrument Engineering and Radio Engineering*
Educational program	*Information and Communication Radio Engineering*
Status of the course	*Compulsory*
Form of education	*Full-time (day)*
Year of training, semester	*2nd year, 4th semester*
Course Volume	*7 credits (Lectures 42 hours, practical classes 38 hours, laboratory classes 28 hours, independent work 102 hours)*
Semester control / control measures	*Examination*
Classes schedule	*https://schedule.kpi.ua*
Language of instruction	*Ukrainian*
Information about the course lecturer / teachers	Lectures: *Stepan Piltyay, PhD in Technical Sciences, Associate Professor, crosspolar@ukr.net* Practical classes: *Associate Professor Stepan Piltyay, Associate Professor Oleksandr Kupriy* Laboratory classes: *Associate Professor Stepan Piltyay, Associate Professor Oleksandr Kupriy, Assistant Maksym Kozachuk*
Course location	https://do.ipo.kpi.ua/course/view.php?id=642

Course curriculum

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

The academic course **"Electrodynamics and Propagation of Radiowaves"** is dedicated to study of the fundamental properties of electromagnetic field, and to students' acquisition of specific knowledge about the propagation of electromagnetic waves. Students learn to determine the basic characteristics of electromagnetic waves, to form electromagnetic waves with different types of polarization, to measure polarization diagrams and determine the polarization of waves based on them, to solve boundary problems of electrodynamics, to calculate and measure the parameters of transmission lines and resonators, to measure field distributions in transmission lines and resonators.

After having mastered the academic course "Electrodynamics and Propagation of Radiowaves", students must demonstrate the following learning outcomes:

Knowledge of:

- fundamental laws and foundations of electromagnetic field theory;
- methods for solving basic problems of electromagnetics;
- structure and characteristics of electromagnetic fields in free space, lossy media, transmission lines and resonators
- methods for measuring field distributions in waveguides and resonators.

Skills to:

- calculate the main parameters of plane electromagnetic waves;
- determine the reflection and transmission coefficients at the interface between media;
- solve boundary problems of electromagnetics for waveguides and resonators;
- operate with measuring equipment of the microwave frequency range.

Experience in:
- obtaining of electromagnetic waves with different types of polarization;
- measuring of polarization diagrams of electromagnetic waves with various polarizations;
- carrying out measurements of waveguide characteristics and field distribution in them;
- experimental study of resonators and determination of their parameters.

Program competencies

General competencies (GC)

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

Professional competencies (PC)

PC 03. Ability to use basic methods, methods and means of obtaining, transmitting, processing and storing information;
PC 06. Ability to carry out instrumental measurements in information and telecommunication networks, telecommunication and radio engineering systems.

Program learning results (PLR)

PLR 01. Analyze, argue, make decisions when solving specialized tasks and practical problems of telecommunications and radio engineering, which are characterized by complexity and incomplete determination of conditions;
PLR 02. Apply the results of personal search and analysis of information to solve qualitative and quantitative problems of a similar nature in information and communication networks, telecommunications and radio engineering systems;
PLR 03. To determine and apply in professional activity the methods of testing information and telecommunication networks, telecommunication and radio technical systems for compliance with the requirements of domestic and international regulatory documents;
PLR 04. Explain the results obtained from measurements in terms of their significance and relate them to the relevant theory;
PLR 07. Competently apply the terminology of the field of telecommunications and radio engineering;
PLR 08. Describe the principles and procedures used in telecommunication systems, information and telecommunication networks and radio engineering;
PLR 13. Apply basic and applied sciences to analyze and develop processes occurring in telecommunications and radio engineering systems;
PLR 18. Find, evaluate and use information from various sources necessary for solving professional problems, including reproduction of information through electronic search.

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

The academic course **"Electrodynamics and Propagation of Radiowaves"** is based on the knowledge acquired by students after studying the courses "Higher Mathematics", "General Physics", "Fundamentals of Circuit Theory". Students must possess the basic knowledge of vector analysis, electrostatics, electrodynamics, the theory of oscillations and wave processes, and the theory of transmission lines.

The knowledge and skills obtained after studying the course "Electrodynamics and Radiowaves Propagation" are used in the following courses, including "Microwave Devices", "Automated Design of Microwave Antennas and Devices", "Antennas", "Antennas of Electronic Warfare Systems", "Electromagnetic Compatibility", "Microwave Devices and Antennas", "Transceivers of Modern Radio Engineering Systems", when making course and diploma theses.

3. Contents of the academic course

Titles of sections and themes	Number of hours				
	Total	Including			
		Lectures	Practical classes	Laboratory works	Student's independent work
Section 1. ***Fundamentals of Electrodynamics***					
Theme 1. Object of study and areas of application of electrodynamics	4	2			2
Theme 2. Vector analysis	8	2	4		2
Theme 3. Basic concepts of electrodynamics. Maxwell's equations	8	2	2		4
Theme 4. Material equations. Classification of media	6	2			4
Theme 5. Boundary conditions at the interface of media	4	2			2
Theme 6. Electrodynamics equations in complex form	4	2			2
Theme 7. Energy characteristics of the electromagnetic field	4	2			2
Theme 8. Basic theorems and principles of electrodynamics	4	2			2
Theme 9. Analytical methods for solving electrodynamics problems	6	2			4
Theme 10. Static and stationary electromagnetic fields	10	2	4		4
Total under section 1	58	22	10		28
Section 2. ***Propagation, reflection and refraction of plane electromagnetic waves***					
Theme 1. Plane electromagnetic waves	18	2	8	4	4
Theme 2. Reflection and refraction of plane electromagnetic waves	14	2	4	4	4
Theme 3. Electromagnetic waves in anisotropic media	8	2		4	2
Module test 1	4				4
Calculation work, parts 1, 2	4				4
Total under section 2	48	6	12	12	18
Section 3. ***Transmission lines***					
Theme 1. Electromagnetic waves in guiding systems	4	2			2
Theme 2. Waveguides	10		6	2	2
Theme 3. Transmission lines with TEM-waves	10	2	4	3	2
Theme 4. Open transmission lines	4	2			2
Module test 2	2				2
Calculation work, parts 3, 4	2				2
Total under section 3	32	6	10	4	12

Section 4. ***Resonators***					
Theme 1. Cavity resonators	14	2	2	6	2
Theme 2. Open-type resonators	4	2			2
Theme 3. Methods of excitation of waveguides and resonators	3	1			2
Calculation work, part 5	2				2
Total under section 4	23	5	2	6	8
Section 5. ***Radiation and diffraction of electromagnetic waves***					
Theme 1. Main parameters of antennas. Hertz's dipole	8	2	2		2
Theme 2. Elementary magnetic emitters. Huygens element	5	2	2		2
Theme 3. Diffraction of electromagnetic waves	9	1		6	2
Total under section 5	20	6	4	6	6
Examination	30				30
Total hours	**210**	**42**	**38**	**36**	**102**

4. Teaching materials and resources

Recommended resources

1. Electrodynamics and Propagation of Radiowaves. Lecture notes: a textbook for bachelor's degree applicants in the educational programs "Information and communication radio engineering", "Intelligent technologies of radio electronic engineering", "Radio engineering computerized systems" of specialty 172 Electronic communications and radio engineering / S. I. Piltyay; Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2023. — 171 p. (in Ukrainian).
2. Electrodynamics and Propagation of Radiowaves. Part 1. Fundamentals of electromagnetic field theory: Textbook for university students / Edited by V. M. Shokalo and V. I. Pravda. — Kharkiv: KhNURE; Collegium, 2009. — 286 p. (in Ukrainian).
3. Electrodynamics and Propagation of Radiowaves. Part 2. Radiation and propagation of electromagnetic waves: Textbook for university students / Edited by V. M. Shokalo and V. I. Pravda. — Kharkiv: KhNURE; Collegium, 2010. — 435 p. (in Ukrainian).
4. D. M. Pozar. Microwave Engineering. — New Jersey: Wiley Press, 2012. — 732 p.
5. Technical Electrodynamics and Propagation of Radiowaves: a textbook for bachelor's degree applicants in the educational program "Electronic multimedia systems and Internet of Things devices" specialty 171 Electronics / V. V. Pilinsky, V. B. Shvaichenko; Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2025. — 343 p. (in Ukrainian).
6. Electrodynamics and Propagation of Radiowaves. Collection of problems: a textbook for students studying in specialty 172 "Telecommunications and radio engineering" / S. I. Piltyay; Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2022. — 88 p. (in Ukrainian).
7. Electrodynamics and Propagation of Radiowaves. Practical course: a textbook for students of specialty 172 "Telecommunications and radio engineering" / S. I. Piltyay; Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2021. — 54 p. (in Ukrainian).
8. Electrodynamics and Propagation of Radiowaves. Recommendations for performing calculation work: a textbook for bachelor's degree applicants in the educational programs "Information and communication radio engineering", "Intelligent technologies of radio electronic engineering", "Radio engineering computerized systems", "Technologies of radio electronic warfare" of specialty 172 Electronic communications and radio engineering / S. I. Piltyay; Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2024. — 157 p. (in Ukrainian).
9. Electrodynamics and Propagation of Radiowaves. Laboratory works course: a textbook for bachelor's degree applicants in the educational programs "Information and communication radio engineering", "Intelligent technologies of radio electronic engineering", "Radio engineering computerized systems" of specialty 172 Electronic communications and radio engineering / O. M. Kupriy, S. I. Piltyay, V. I. Naidenko; Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2023. — 93 p. (in Ukrainian).
10. Applied Electrodynamics of Information Systems / A. S. Andrushchak, Z. Yu. Gotra, O. S. Kushnir. — Lviv: Lviv Polytechnic Publishing House, 2012. — 304 p. (in Ukrainian).
11. Zakharia Y. A. Methods of Applied Electrodynamics. — Lviv: "Beskyd Bit", 2003. — 352 p. (in Ukrainian).

Educational content

5. Methods of mastering the academic discipline (educational component)

Lectures

Lectures are prepared in accordance with the recommended resource [1].

№	Lecture theme and list of key questions (list of teaching aids, references to literature, and assignments for independent study)
1	The object of study and areas of application of electrodynamics. Forms of matter. Properties of the electromagnetic field. Ultra-high frequency range. Features of electromagnetic fields and waves in the microwave range. Main advantages of the microwave range over other frequency ranges. Fields of science and technology where microwave range systems are used. References [1–5]. Task for independent work: Familiarize yourself with the fields of application of electrodynamics.
2	Vector analysis. Scalar and vector fields. Gradient of a scalar field. Lamé coefficients. Divergence of a vector field. Rotor of a field. Ostrogradsky-Gauss theorem. Stokes' theorem. Hamilton operator. Laplace operator. Green's theorems. Vortex field. Potential field. Basic identities of vector analysis. References [1–5]. Task for independent work: Prove the basic identities of vector analysis.
3	Basic concepts of electrodynamics. Maxwell’s equations. Concepts of electric charge and current, their densities. Basic properties and laws for electric charges and currents. Electric and magnetic fields. Maxwell’s equations in integral and differential forms. Physical meaning of Maxwell's equations. Conclusions from Maxwell’s equations. References [1–5]. Task for independent work: Derive Maxwell’s equations in differential form.
4	Material equations. Classification of media. Polarization of matter. Electric induction vector. Magnetization of matter. Magnetic induction of a medium. Ohm's law in differential form. Material equations. Classification of substances into conductors, semiconductors, and dielectrics. Classification of media according to their parameters. References [1–5]. Task for independent work: Derive material equations for gyrotropic media.
5	Boundary conditions at the interface between media. Boundary conditions for normal components of the electromagnetic field. Boundary conditions for tangential components of the electromagnetic field. Boundary conditions at the interface between an ideal dielectric and a conductor. References [1–5]. Task for independent work: Obtain boundary conditions at conductive tips and edges.
6	Electrodynamics equations in complex form. Features of harmonic electromagnetic oscillations and waves. Complex amplitude method. Maxwell’s equations in complex form. Complex permittivity. Material equations in complex form. Tangents of angles of electrical and magnetic losses of media. References [1–5]. Task for independent work: Write down and derive the Kramers-Kronig relation.
7	Energy characteristics of an electromagnetic field. Equation of balance of instantaneous power values. Poynting’s theorem in differential form. Poynting vector, its physical meaning. Poynting’s theorem in integral form. Energy characteristics of harmonic electromagnetic fields. Poynting’s theorem in complex form. Complex power balance equation. Active and reactive power balance equation. Conclusions from the complex power balance equation. References [1–5]. Task for independent work: Derive the active and reactive power balance equation.
8	Fundamental theorems and principles of electrodynamics. Classification of electrodynamics problems. Dirichlet’s problem. Neumann’s problem. Mixed boundary problem. Principle of superposition. Theorem of uniqueness of the solution of the internal problem of electrodynamics. Theorem of uniqueness of the solution of the external problem of electrodynamics. Sommerfeld radiation conditions. Lorentz lemma. Reciprocity theorem. Principle of commutative duality of Maxwell’s equations. References [1–5]. Task for independent work: Obtain Sommerfeld radiation conditions.
9	Analytical methods for solving electrodynamics problems. Wave equations for electric and magnetic fields. Helmholtz equations for electric and magnetic fields. Methods to solve Helmholtz equations. References [1–5]. Task for independent work: Helmholtz equation in the main coordinate systems.
10	Analytical methods for solving electrodynamics problems. Electrodynamic potentials and Hertz vectors. Helmholtz equations for potentials and Hertz vectors. Expressions for calculating potentials. References [1–5]. Task for independent work: Derive a formula for calculating electromagnetic vector potential.
11	Static and stationary electromagnetic fields. Definition of static and stationary fields. Maxwell's equations for electrostatic and magnetostatic fields. Capacitance of bodies and capacitors. Maxwell's equations for stationary fields. Inductance of circuits with current and coils. Methods for calculating capacitance and inductance. References [1–5]. Task for independent work: Mirror image method. Mutual inductance.

12	Plane electromagnetic waves. Definition of a wave. Wave front. Types of waves. Homogeneous plane electromagnetic wave. Wave parameters. Wavelength. Phase coefficient. Attenuation coefficient. Wave penetration depth. Phase velocity. Wave dispersion. Group velocity. Wave impedance of the medium. Shchukin-Leontovich boundary conditions. References [1–5]. Task for independent work: Derive formulas for attenuation and phase coefficients.
13	Plane electromagnetic waves. Wave polarization. Types of polarization. Polarization bases. Ellipticity coefficient. Poynting vector of plane electromagnetic waves. Energy propagation velocity. References [1–5]. Task for independent work: Ellipticity coefficient in different polarization bases.
14	Reflection and refraction of plane electromagnetic waves. Normal incidence of an electromagnetic wave on the boundary between an ideal dielectric and a conductor. Normal incidence of an electromagnetic wave on the boundary between two ideal dielectrics. Reflection and transmission coefficients. Oblique incidence of a plane wave on the boundary between an ideal dielectric and a conductor. Phase velocity and wavelength in the selected direction. References [1–5]. Task for independent work: Review the lecture material using the references.
15	Reflection and refraction of plane electromagnetic waves. Oblique incidence of a plane electromagnetic wave on the boundary. Plane of incidence of the wave on the surface. Parallel and perpendicular polarization. Snell's laws. Reflection coefficient. Transmission coefficient. Fresnel's formulas. Total internal reflection. Brewster's angle. Change in wave polarization. Total internal reflection. Dielectric waveguide. References [1–5]. Task for independent work: Review the lecture material using the references.
16	Electromagnetic waves in anisotropic media. Anisotropic media. Physical mechanism of ferrite anisotropy. Maxwell's equations in a gyrotropic medium. Propagation of electromagnetic waves in a gyrotropic medium. Faraday effect. Application of Faraday effect in engineering. Cotton-Mouton effect. Ferromagnetic resonance phenomenon. Application of ferromagnetic resonance. References [1–5]. Task for independent work: Review the lecture material using the references.
17	Electromagnetic waves in waveguide systems. Classification of transmission lines. Propagation of electromagnetic waves between two conducting planes. E-type and H-type waves. Helmholtz scalar equations for transmission lines and their solutions. General properties of waves in transmission lines. Power and attenuation of waves in waveguides. Orthogonality of electromagnetic waves in transmission lines. References [1–4]. Task for independent work: Review the lecture material using the references.
18	Waveguides. Definition of a waveguide. Types of waveguides. Types of waves in waveguides. Rectangular waveguide. Cutoff frequencies. Electromagnetic fields in a rectangular waveguide, structure of surface currents on its walls. The fundamental wave of a rectangular waveguide, its parameters. References [1–4]. Task for independent work: Review the lecture material using the references.
19	Waveguides. Circular waveguide. Critical frequencies. Fields in a circular waveguide. Fundamental wave of a circular waveguide, its parameters. References [1–4]. Task for independent work: Review the lecture material using the references.
20	Transmission lines with T-type waves (TEM). Definition of a T-type wave, its characteristics. Parameters of a TEM-wave. Wave impedance. Laplace’s equation for a T-type wave. Characteristic impedance. Two-wire transmission line, its fields and parameters. Coaxial transmission line, its fields and parameters. Strip transmission lines, their fields and parameters. References [1–4]. Task for independent work: Review the lecture material using the references.
21	Open transmission lines. General properties of dielectric waveguides. Planar dielectric waveguide. Circular dielectric waveguide. Structure and parameters of dielectric waveguides. Optical fibers. Quasi-optical transmission lines. References [1–4]. Task for independent work: Review the lecture material using the references.
22	Volumetric resonators. Types of volumetric resonators. Properties of free oscillations in a resonator. Resonance frequency. Quality factor. Quasi-stationary resonators. Coaxial resonator. Rectangular resonator. Cylindrical resonator. Application of resonators. References [1–4]. Task for independent work: Review the lecture material using the references.
23	Open-type resonators. Open dielectric resonators. Open-type waveguide resonators. Open mirror resonators, their designs and parameters. Applications of open-type resonators. References [1–4]. Task for independent work: Review the lecture material using the references.
24	Methods of excitation of waveguides and resonators. Excitation of waves in waveguides. Excitation elements, their designs and placement rules. Excitation of oscillations in volume resonators. Literature [1–4]. Task for independent work: Review the lecture material using the references.
25	Basic antenna parameters. Hertz dipole. Antenna directivity pattern. Directivity coefficient. Antenna radiation resistance. Hertz dipole. Features of Hertz dipole fields in induction and radiation zones. Electromagnetic characteristics of Hertz dipole. References [1–5]. Task for independent work: Review the lecture material using the references.

26	<u>Elementary magnetic emitters. Huygens element.</u> Elementary magnetic emitter, its characteristics. Loop antenna. Elementary slot antenna, its characteristics. Huygens element, its characteristics. References [1–5]. Task for independent work: Review the lecture material using the references.
27	<u>Diffraction of electromagnetic waves.</u> The essence of the phenomenon of diffraction. The criterion for the presence of diffraction. The Huygens-Fresnel principle. The Fresnel zone method. The radii of Fresnel zones The areas of Fresnel zones. Fresnel diffraction on a circular aperture and a half-plane. Fraunhofer diffraction on a perfectly conductive cylinder. Application of the phenomenon of diffraction in engineering. References [1–5]. Task for independent work: Review the lecture material using the references.

Practical classes

The purpose of practical classes is to acquire skills to solve electrodynamics problems and calculate the main parameters of transmission lines, resonators, and emitters. The topics of the practical classes are listed in the table.

№	Title of practical lesson and list of key questions (list of teaching aids and references to literature)
1	Proving the main identities and theorems of vector analysis. References [6, 7].
2	Vector analysis. Potential and vortex fields. References [6, 7].
3	Basic concepts of electrodynamics. Maxwell's equations. References [6, 7].
4	Static electromagnetic fields. Gauss's theorem. References [6, 7].
5	Stationary fields. Calculation of capacitances and inductances. References [6, 7].
6	Plane electromagnetic waves, calculation of basic parameters. References [6–8].
7	Fading of plane electromagnetic waves. References [6–8].
8	Polarization of plane electromagnetic waves. References [6–8].
9	The relationship between linear and circular polarization bases. References [6–8].
10	Reflection and refraction of plane electromagnetic waves. References [6–8].
11	Fresnel formulas. Change in polarization of electromagnetic waves. References [6–8].
12	Rectangular and circular waveguides. Types of waves and their parameters. References [6–8].
13	Single-wave mode of waveguides. Critical frequencies. References [6–8].
14	Calculation of waveguide excitation elements. References [6–8].
15	Transmission lines with T-type waves. Transmission line parameters. References [6–8].
16	Calculation of wave impedances of coaxial and strip lines. References [6–8].
17	Volumetric resonators. Resonant frequencies and quality factors. References [6–8].
18	Elementary emitters. Calculation of basic parameters. References [6, 7].

Laboratory classes

The main purpose of laboratory classes is to deepen the understanding of theoretical material and to enable students to acquire skills in experimental research of the properties of electromagnetic oscillations, waves, and structures in which they occur. Laboratory classes are supported by a textbook [9]. The topics of laboratory classes are presented in the table below. Students complete 6 out of 7 laboratory classes according to the team number and classes' schedule.

№	Title of laboratory class
1	Research on the polarization of electromagnetic waves
2	Research on the phenomena that arise during the propagation of electromagnetic waves in anisotropic media
3	Research on electromagnetic waves above a conducting plane
4	Study of the dispersion characteristics of fundamental waves in a rectangular waveguide and coaxial transmission line
5	Study of the field structure in metallic waveguides and resonators
6	Study of the diffraction of electromagnetic waves
7	Research on the radiation of electric and magnetic dipoles

6. Independent work of higher education applicants

Independent work can be carried out in accordance with resources [1–5].

№	Titles of topics and questions for independent study and references to recommended educational literature
1	The object of study and areas of application of electrodynamics. References [1–5].
2	Vector analysis. References [1–5].
3	The concepts of electric charge and current, their densities. The main properties of electric charges and currents. References [1–5].
4	Electric and magnetic fields. Maxwell's equations. Their physical meaning. References [1–5].
5	Material equations. Polarization and magnetization of media. References [1–5].
6	Electrical and magnetic properties of media. Classification of media according to their electromagnetic properties. References [1–5].
7	Boundary conditions on conductive tips and edges. References [1–5].
8	Kramers-Kronig relation. References [1–5].
9	Equation of active and reactive power balance. References [1–5].
10	Sommerfeld radiation conditions. References [1–5].
11	Helmholtz equation in the main coordinate systems. References [1–5].
12	Methods for calculating scalar and vector potentials. References [1–5].
13	Mirror image method. References [1–5].
14	Mutual inductance. Methods for calculating inductance. References [1–5].
15	Electromagnetic waves in conductive media. Wave attenuation. Wave penetration depth. Skin effect. References [1–5].
16	Polarization of electromagnetic waves. Types of polarization, their properties. Ellipticity coefficient in different polarization bases. References [1–5].
17	Snell's laws. Total internal reflection of electromagnetic waves, its application in engineering. References [1–5].
18	Fresnel's formulas for the coefficients of reflection and refraction of a plane electromagnetic wave at the boundary between media. References [1–5].
19	Faraday effect. Application of the Faraday effect in technology. Cotton-Mouton effect. References [1–5].
20	The phenomenon of ferromagnetic resonance. Application of ferromagnetic resonance in technology. References [1–5].
21	Preparation for the module test 1
22	Completion of parts 1 and 2 of the calculation work. References [8].
23	Transmission lines, their classification and application. References [1–4].
24	Propagation of electromagnetic waves between two conducting planes. E-type and H-type waves. References [1–4].
25	Wave parameters in waveguides, methods of their measurement. References [1–4].
26	П- and H-shaped waveguides, advantages and disadvantages. References [1–4].
27	Characterictic resistance of transmission lines. Methods of its measurement. References [1–4].
28	Coplanar transmission line. Its waves, fields, and parameters. References [1–4].
29	Single-mode and multi-mode fiber optic transmission lines. References [1–4].
30	Quasi-optical transmission lines, their designs and parameters. References [1–4].

31	Preparation for the module test 2
32	Completion of parts 3 and 4 of the calculation work. References [8].
33	Quasi-stationary resonators: designs, field and current distributions, main parameters, areas of application. References [1–4].
34	Coaxial resonator: design, field and current distributions, main parameters, areas of application. References [1–4].
35	Rectangular resonator: design, field and current distributions, main parameters, areas of application. References [1–4].
36	Cylindrical resonator: design, field and current distributions, main parameters, areas of application. References [1–4].
37	Open dielectric resonators: designs, field distributions, basic parameters, areas of application. References [1–4].
38	Open waveguide resonators: designs, field distributions, main parameters, areas of application. References [1–4].
39	Open mirror resonators: designs, field distributions, main parameters, areas of application. References [1–4].
40	Wave excitation in waveguides. Excitation elements, their designs, and placement rules. Calculation of forced waves. References [1–4].
41	Excitation of oscillations in volume resonators. Excitation elements. Calculation of forced oscillations. References [1–4].
42	Completion of part 5 of the calculation work. References [8].
43	Basic antenna parameters. Hertz dipole. References [1–5].
44	Elementary emitters. Huygens' element. References [1–5].
45	Diffraction of electromagnetic waves. References [1–5].
46	Preparation for the examination
47	Total hours

Individual tasks

Students are required to complete a calculation work (CW). The purpose of its implementation is to obtain the skills to solve problems in electrodynamics. CW contains 10 problems from the main sections of the course. In problems 1, 2, it is necessary to determine the parameters of plane electromagnetic waves. Problems 3, 4 are devoted to the processes of reflection and refraction of plane electromagnetic waves. In problems 5, 6, it is necessary to calculate the main parameters and depict the field components in rectangular and circular waveguides, and in problems 7, 8 it is necessary to calculate parameters of coaxial and microstrip transmission lines. Problems 9, 10 are devoted to determining the main parameters of electromagnetic oscillations in rectangular and circular cylindrical volumetric resonators.

Policy and control

7. Policy of the academic course (educational component)

Studying the educational component "Electrodynamics and Radio Wave Propagation" consists of listening to a lecture course, participating in practical classes, performing laboratory work, modular tests, and calculation work. Therefore, the main methodological requirement is to coordinate the time for studying the topics of the lecture course with the completion of relevant tasks of other types of training.

All materials necessary for studying the credit module and preparing for the exam are available in the distance learning course "Electrodynamics and Propagation of Radiowaves", access to which is provided to students. The distance learning course contains:

- lecture notes;
- lectures on themes with questions and tasks for self-testing;
- a collection of tasks and a workshop for practical classes;
- a study guide for performing laboratory work;
- recommendations for performing calculation work;
- a list of questions and problems for the examination.

Access to the distance learning course is provided to students at the beginning of the semester, which allows them to plan independent work.
Current quality control of mastering of the study material of the educational component "Electrodynamics and Radio Wave Propagation" takes place in accordance with the rating evaluation system, compiled in such a way as to encourage students to work rhythmically throughout the semester.
Rules for attending classes (both lectures and practical/laboratory classes)
All types of classes are compulsory: lectures, practical classes, and laboratory classes. All laboratory work must be completed. If these classes are missed, they must be made up during consultations or with other groups.
Defense of laboratory work
Laboratory work is defended on the day the laboratory work is completed. The defense takes the form of an interview. A mandatory condition for admission to the defense is the availability of a formalized protocol, which contains the results of the completed laboratory work in the form of corresponding graphs and calculations or screenshots of measurements in the case of remote work.
Completion and defense of the calculation work (CW)
As part of their independent work, students complete the CW assignment according to the option. Based on the results of the check, if the work is completed correctly, the student is assigned a date for the CW defense. The defense takes the form of an interview. Repeated CW defenses are not provided for.
Incentive points
Any type of assessment, except for laboratory work, can be replaced by incentive rating points for winning prizes (1, 2, 3) in a subject competition. Or by preparing abstracts for international scientific conferences on radio engineering in English and presenting a report at the conference: 1 abstract – 5 points (as agreed with the lecturer). Participation in the Olympiad is evaluated from 0 to 5 points depending on success.
Attendance
Attendance at lectures, practical classes, and laboratory classes is in accordance with the Regulations on the Organization of the Educational Process at Igor Sikorsky KPI. At least once every two weeks, the instructor holds consultations on various issues related to the credit module. During consultations, the teacher can provide assistance in studying the material of classes that were missed by students for various reasons and must be mastered independently.
In any case, students are encouraged to attend all types of classes, as they teach theoretical material and develop the skills necessary to complete homework, laboratory work, and computational work.
Announcement of test results
The defense of the completed section of the RR takes place in the form of an interview with the teacher. During the defense, the student must be able to explain the results obtained and answer the main theoretical questions on the topics of the sections. The results of the defense are announced to the student in their presence or remotely and are accompanied by specific comments and remarks regarding errors (remote communication via Zoom, Telegram with video and audio).
The results for the completed homework assignment are posted after its completion and defense, no later than the next class.
Missed tests
The result for a student who did not attend the test is zero. If a student misses a test for a valid reason, they are given the opportunity to complete it (write a module test) in the presence of the teacher. If the absence was without a valid reason, the issue of making up the test is decided with the teacher in consultation with the department management.
A missed test is not counted regardless of the reasons for the absence; in this case, the student receives a “did not show up” mark, and if they are eligible to take the test, they must take it during an additional session.
Academic integrity
The policy and principles of academic integrity are defined in Section 3 of the Code of Honor of the National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute.” For more information, please visit: https://kpi.ua/code.
Standards of ethical behavior
The standards of ethical conduct for students and employees are defined in Section 2 of the Code of Honor of the National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute.” For more information, visit: https://kpi.ua/code.
Procedure for appealing the results of control measures
Students have the opportunity to raise any issue related to the procedure for conducting and/or evaluating control measures and expect it to be considered in accordance with predefined procedures.
Students have the right to appeal the results of assessment measures, but must provide a reasoned explanation of which criteria they disagree with according to the assessment sheet and/or comments.

8. Types of control and learning rating system for learning results (LRS)

Rating system for assessing learning results

A student's rating in a course (RC) is the sum of the current academic performance points — the starting rating (SR) and exam points (EP):

$$RC = SR + EP.$$

The size of the starting scale SR is 70 points.
The size of the examination scale EP is 30 points.
The rating scale for the course RC is 100 points.

The SR rating point system and assessment criteria

SR consists of points received for completing the following tasks:

1. Preparation for each of the 6 laboratory works gives the following points:
   - excellent knowledge of the theoretical material on the topic of the work 1
   - satisfactory knowledge of the theoretical material on the topic of the work 0.5
   - unsatisfactory knowledge of the theoretical material on the topic of the work 0

   Maximal sum of points for readiness for 6 laboratory works 6
2. The defense of each of the six laboratory works is graded as follows:
   - complete answer (at least 80% of the required information) 4
   - incomplete answer (at least 60% of the required information) 2
   - unsatisfactory answer (less than 60% of the required information) 0

   Maximal sum of points for defending 6 laboratory works 24
3. Completing each test task on two MT gives the following rating points:
   - correct answer 1
   - incorrect answer 0

   Maximal sum of points for completing two MTs 20
4. Completing each of the 10 tasks in the calculation graphical work (CGW) gives the following rating points:
   - complete correct solution of the task and correct answer 2
   - partial solution to the task, with errors 1
   - unsatisfactory solution to the task or untimely completion 0

   Maximal sum of points for completing the CGW 20

The maximal SR is equal to: SR = 6 + 24 + 20 + 20 = 70 points.

Conditions for admission to the examination:

1. Submission of a fully completed calculation graphical work;
2. Completion of all laboratory works, preparation and submission of reports on them;
3. Obtaining at least 30 points of SR during the semester.

During the last week of the semester, students who have not earned 30 points are given the opportunity to increase their SR by retaking the MT.

EP rating point system and assessment criteria

During the exam, students complete a written test. Each test contains two theoretical questions and one problem from the main sections of the course. Each theoretical question is worth a maximum of 10 points. The problem is worth 10 points.

The answer to each theoretical question is awarded the following points:
- complete answer (at least 90% of the required information) 10
- sufficiently complete answer (at least 75% of the required information or minor inaccuracies) 7
- incomplete answer (at least 50% of the required information and some errors) 4
- unsatisfactory answer (less than 50% of the required information) 0

The solution to the problem gives the following points:
- complete correct solution to the problem and correct answer 10
- correct solution process, minor errors 7
- partial solution to the problem, significant errors present 4
- unsatisfactory or no solution to the problem 0

The maximum EP is equal to: EP = 10 + 10 + 10 = 30 points.

The rating system is communicated to students during the first lecture of the semester. The process of obtaining rating points is communicated to students by the teacher who performs the rating assessment. The rating points are summarized during the last lecture of the semester.

Table of correspondence between rating points and university scale grades

Number of points	*Grade*
100–95	Excellent
94–85	Very good
84–75	Good
74–65	Satisfactory
64–60	Sufficient
Less than 60	Unsatisfactory
Admission requirements not met	Not admitted

9. Additional information on the course (educational component)

<u>Questions for examination in the course “Electrodynamics and Propagation of Radiowaves”</u>

1. The object of study and areas of application of electrodynamics. Microwave range. Features of microwave electromagnetic fields. Advantages of the microwave range, its applications.
2. Scalar and vector fields. Gradient. Lamé coefficients. Divergence operator. Rotor operator. Ostrogradsky-Gauss theorem. Stokes theorem. Hamilton operator.
3. Hamilton operator. Laplace operator. Green’s theorems. Vortex field. Potential field. Basic identities of vector analysis.
4. Electric charge and current, their densities. Basic properties and laws for electric charges and currents. Electric and magnetic fields. Maxwell’s equations.
5. Maxwell’s equations in integral, differential, and complex forms. Physical meaning of Maxwell’s equations. Conclusions from Maxwell’s equations.
6. Polarization of medium. Electric induction vector. Magnetization. Magnetic induction. Specific conductivity. Material equations. Classification of media.
7. Material equations. Types of dielectrics and magnetic media. Division into conductors, semiconductors, and dielectrics. Classification of media according to their parameters.
8. Boundary conditions at the interface between two media for normal and tangential components of the electromagnetic field.
9. Boundary conditions at the interface between perfect dielectric and perfect electric conductor. Features of the electromagnetic field on the surface of a perfect conductor.
10. Features of harmonic oscillations and waves. Complex amplitude method. Maxwell’s equations in complex form. Complex permittivity, loss angles.
11. Instantaneous power balance equation. Poynting’s theorem in differential, integral, and complex forms. Poynting vector, its physical meaning.
12. Energy characteristics of harmonic electromagnetic fields. Complex power balance equation. Conclusions from the power balance equation.
13. Classification of electrodynamics problems. Dirichlet problem. Neumann problem. Mixed boundary problem. Superposition principle.
14. Internal problems of electrodynamics. Examples of internal problems. The uniqueness theorem for the solution of an internal problem of electrodynamics.
15. External problems of electrodynamics. The uniqueness theorem for the solution of an external problem of electrodynamics. Sommerfeld’s radiation conditions.
16. Lorentz lemma. Reciprocity theorem, its physical meaning and application.
17. The principle of commutative duality of Maxwell's equations. Lorentz's lemma and the reciprocity theorem with magnetic currents taken into account.
18. Wave equations for electric and magnetic fields. Helmholtz equations.
19. Electromagnetic potentials of electric and magnetic types. Lorentz calibration. Wave equations for electromagnetic potentials.
20. Hertz vectors. Wave equations and Helmholtz equations for electrodynamic potentials and Hertz vectors. Gradient invariance.
21. Analytical expressions for electromagnetic potentials. Green’s function.
22. Static and stationary fields, Maxwell's equations for them. The concepts of capacitance and inductance, examples. Methods for calculating capacitance and inductance.
23. Definition of a wave. Wave front. Types of waves. Homogeneous plane electromagnetic wave, its field structure. Wavelength. Phase and attenuation coefficients.
24. Wave penetration depth. Phase velocity. Wave dispersion. Group velocity. Wave impedance. Shchukin-Leontovich boundary conditions.
25. Polarization of electromagnetic waves. Types of polarization, their characteristics and properties. Axial ratio. Areas of application of different polarizations.
26. Normal incidence of a plane electromagnetic wave on the boundary between an ideal dielectric and a conductor. Reflection coefficients for the fields E and H.
27. Normal incidence of an electromagnetic wave on the boundary between two ideal dielectrics. Reflection and transmission coefficients. Matched media.
28. Oblique incidence of a plane electromagnetic wave on the boundary between a perfect dielectric and a perfect

conductor. Parallel polarization. Modes by directions. E- and TEM-waves.
29. Oblique incidence of a plane electromagnetic wave on the boundary between a perfect dielectric and a perfect conductor. Perpendicular polarization. Modes by directions. H-waves.
30. Oblique incidence of a plane electromagnetic wave on the boundary between two perfect dielectrics. Parallel polarization. Snell’s laws. Fresnel’s formulas.
31. Incidence of a parallel polarization electromagnetic wave on an optically more/less dense medium. Total internal reflection and reflection phenomena. Applications.
32. Oblique incidence of a plane electromagnetic wave on the boundary between two ideal dielectrics. Perpendicular polarization. Snell's laws. Fresnel’s formulas.
33. Incidence of an electromagnetic wave of perpendicular polarization into an optically more/less dense medium. Total internal reflection. Applications.
34. Propagation of electromagnetic waves in gyrotropic media. Permeability tensors. Faraday effect. Application of Faraday effect in engineering.
35. Transmission lines, their classification, main parameters, and areas of application.
36. Types of waveguides. Types of electromagnetic waves in waveguides, their characteristics and applications.
37. Parameters of electromagnetic waves in waveguides, their calculation and measurement methods.
38. TEM-type waves in transmission lines, their properties and main parameters.
39. Characteristic impedance of transmission lines. Methods for its calculation and measurement.
40. E and H electromagnetic waves. Their properties and parameters, methods of measurement.
41. Two-wire transmission line: design, basic wave type, field and current structure. Parameters of a two-wire transmission line, areas of application.
42. Coaxial transmission line: design, wave types, field and current structure. Coaxial transmission line parameters, areas of application.
43. Strip transmission lines: design, fundamental and higher wave types, field and current structure. Strip line parameters, areas of application.
44. Rectangular waveguide. Cutoff frequencies. Electromagnetic fields and surface currents in a rectangular waveguide. Fundamental mode, its parameters, excitation methods.
45. Circular waveguide. Cutoff frequencies. Electromagnetic fields and surface currents in a circular waveguide. Fundamental mode of a circular waveguide, its parameters.
46. Methods of excitation of waveguides, their features, advantages, and disadvantages.
47. Classification of volumetric resonators. Their parameters and methods of measurement.
48. Resonance frequency. Quality factor. Methods for their calculation and measurement. Approaches to increase the quality factor of microwave resonators.
49. Quasi-stationary resonators: designs, structure of electromagnetic fields and surface currents, basic parameters, excitation methods, areas of application.
50. Coaxial resonator: design, fundamental oscillation, electromagnetic fields and surface currents structure, parameters, excitation methods, areas of application.
51. Rectangular resonator: design, fundamental oscillation, electromagnetic fields and surface currents structure, parameters, excitation methods, areas of application.
52. Cylindrical resonator: design, fundamental oscillation, electromagnetic fields and surface currents structure, parameters, excitation methods, areas of application.

Problems for examination in the course “Electrodynamics and Propagation of Radiowaves”

1. Prove the identity of vector analysis $\operatorname{div}\operatorname{rot} A \equiv 0$ in an orthogonal curvilinear coordinate system, where A is an arbitrary vector field.
2. Prove the identity of vector analysis $\operatorname{rot}\operatorname{grad} U \equiv 0$ in an orthogonal curvilinear system of coordinates, where U is an arbitrary scalar field.
3. Prove the identity $\operatorname{div}(uA) = u \operatorname{div} \vec{A} + \vec{A} \cdot \operatorname{grad} u$ in an orthogonal curvilinear coordinate system, where u, A are arbitrary scalar and vector fields.
4. Prove the identity of vector analysis $\operatorname{div}(\vec{A} \times B) = B \cdot \operatorname{rot} A - A \cdot \operatorname{rot} B$ in the Cartesian coordinate system, where A and B are arbitrary vector fields.
5. Prove Green’s theorem in the second scalar form: $\int_V (u\, \nabla^2 v - v\, \nabla^2 u)\mathrm{d}V = \oint_S (u \operatorname{grad} v - v \operatorname{grad} u)\mathrm{d}S$.

6. Prove Green's theorem in the second vector form:

$$\int_V (\vec{B}\cdot \text{rot rot } \vec{A} - \vec{A}\cdot \text{rot rot } \vec{B})\mathrm{d}V = \oint_S (\vec{A}\times \text{rot } \vec{B} - \vec{B}\times \text{rot } \vec{A})\mathrm{d}\vec{S}.$$

7. Derive from Maxwell's equations in complex form the formula for the relationship between the transverse and longitudinal components of a plane electromagnetic wave propagating along the z-axis.
8. Derive a formula for the wave impedance of a coaxial transmission line with conductor radii a qnd b. The line is filled by a material with relative permittivity ε and permeability μ.
9. Derive frequency dependencies of the wave number β(ω) and attenuation coefficient α(ω) for a plane electromagnetic wave in a non-magnetic dielectric with losses.
10. Derive a formula for the dependence of group velocity on the frequency $v_{gr}(f)$ for a plane electromagnetic wave in a non-magnetic dielectric with losses.
11. Prove that in a lossy medium, the energy propagation velocity of a plane electromagnetic wave is equal to its phase velocity at any frequency.
12. Two plane electromagnetic waves with electric field phasors $\vec{E}_+ = Ae^{i\varphi_A}(\vec{e}_x + i\vec{e}_y)$; $\vec{E}_- = Be^{i\varphi_B}(\vec{e}_x - i\vec{e}_y)$ propagate along the z-axis. Determine axial ratio and angle of inclination relative to the x-axis of polarization ellipse's main axis for the electromagnetic wave, which is a superposition of given waves.
13. Two plane electromagnetic waves propagate along the z-axis. The phasors of their electric fields are $\vec{E}_1 = Ae^{i\varphi_A}\vec{e}_x$; $\vec{E}_2 = Be^{i\varphi_B}\vec{e}_y$. Determine axial ratio of the electromagnetic wave, which is a superposition of given waves.
14. A plane electromagnetic wave falls from air to a dielectric plate with parameters ε, μ and thickness l. Determine at which frequencies the plate is transparent. Plot the dependence of reflection coefficient on the frequency.
15. Determine the relative dielectric permittivity and thickness of the coating on the surface of a dielectric with relative permittivity ε, which ensures the absence of reflection of an electromagnetic wave at the frequency f_0 in case of normal incidence from the air.
16. A plane electromagnetic wave with frequency f_0 falls normally from air onto a dielectric plate with parameters ε, μ. Determine at which thickness l the plate is transparent for electromagnetic wave. Plot the dependence of reflection coefficient on the frequency.
17. A dielectric coating with a thickness l and relative permittivity ε/2 is applied to the surface of a dielectric with relative permittivity ε > 2. A plane electromagnetic wave with a wavelength λ_0 falls normally from air onto this structure. For what values of l the reflection coefficient is minimal? What is its minimal value?
18. For a plane electromagnetic wave falling normally from a vacuum into a non-magnetic dielectric the reflection coefficient is equal to $\dot{\Gamma} = \Gamma \cdot e^{i\cdot\varphi_\Gamma}$. Determine relative dielectric permittivity ε i and tangent of the dielectric loss angle tg δ.
19. Solve Helmholtz's equation for the longitudinal component of the magnetic field of the fundamental wave of a rectangular waveguide. Find and plot the field distributions.
20. Find frequency band of the single-mode operation of a rectangular waveguide with a cross section of $a \times 0.4a$. Plot the graphs of $v_{ph}(f)$ and $v_{gr}(f)$ within this frequency band. Plot their change when the waveguide is filled with a dielectric with permittivity ε.
21. Cutoff wavelength of the fundamental wave in a rectangular waveguide is λ_c, and for the TM_{11} mode it is L_c. Find dimensions of the waveguide cross section.
22. The mode TE_{10} propagates in a rectangular waveguide with a cross section of $a \times 0.4a$. It is known that wavelength $\lambda_g = 2a$. Find the transverse coordinates of the longitudinal planes in which the magnetic field intensity vector has circular polarization. Plot these planes.
23. A coaxial transmission line with diameters ratio $D_1/d_1 = e$ and relative dielectric permittivity $\varepsilon_1 = 9$ is connected to a line with parameters $D_2/d_2 = e^2$, $\varepsilon_2 = 4$. Find reflection and transmission coefficients at the plane of connection.
24. A coaxial transmission line with diameters ratio $D_1/d_1 = e^2$ and relative dielectric permittivity $\varepsilon_1 = 9$ is connected to a line with parameters $D_2/d_2 = e$, $\varepsilon_2 = 4$. Find power reflection and transmission coefficients at the plane of connection.
25. Determine the amplitudes of the electric and magnetic fields and the average value of the Poynting vector at a distance r from an isotropic radiator with power P.

Description of material, technical, and informational support for the course (educational component)

Main equipment: Laptop or desktop computer.

Equipment for laboratory works: Laboratory works on the course "Electrodynamics and Propagation of Radiowaves" are carried out in two laboratories of the Radio Engineering Faculty: 320-17, 326-17. In total, the laboratories contain 7 experimental setups (one for each work performed). Laboratory works are carried out on the following themes:

1) Research on the polarization of electromagnetic waves;

2) Research on the phenomena that arise during the propagation of electromagnetic waves in anisotropic media;

3) Research on electromagnetic waves above a conducting plane;

4) Study of the dispersion characteristics of fundamental waves in a rectangular waveguide and coaxial transmission line;

5) Study of the field structure in metallic waveguides and resonators;

6) Study of the diffraction of electromagnetic waves;

7) Research on the radiation of electric and magnetic dipoles.

Laboratory works are supported by the following equipment:

Laboratory work № 1: high-frequency signal generator Г4-109, millivoltmeter В3-38Б, 2 connecting cables, 2 coaxial-to-waveguide transitions 5.433.022-01, an experimental setup for studying electromagnetic waves with different types of polarization, which includes a waveguide power divider in the H-plane, 3 waveguide ferrite isolators 3ВВС-100Б, 2 polarization waveguide attenuators Д3-33А, polarization phase shifter, 5 waveguide bends by 90° in the H-plane, 4 segments of a standard rectangular waveguide with a cross section of 23 mm × 10 mm, and lengths of 200 mm, 70 mm, 45 mm, 11 mm, 4 transitions from a rectangular to a circular waveguide with a length of 120 mm, 2 transitions from rectangular to circular waveguide with length of 80 mm, 90° waveguide twist with 200 mm length, a rectangular waveguide bend by 90° in the E-plane, an orthomode transducer, a transition from a cross-shaped waveguide to a circular waveguide with length of 105 mm, transmitting conical horn antenna, receiving pyramidal horn antenna, supporting antenna rotator with angle scale, detector section with adjustable short circuit.

Laboratory work № 2: high-frequency signal generator Г4-109, 2 millivoltmeters В3-38А, milliammeter 45-55-1000Hz, 3 connecting cables, 2 coaxial-to-waveguide transitions 5.433.022-01, an experimental setup for studying the Faraday effect, which contains a waveguide ferrite isolator Е6-44, a rectangular waveguide bend by 90° in the E-plane, a transition from a waveguide of rectangular cross-section to a waveguide of circular cross- section, a device for rotating the polarization plane based on a circular waveguide with a ferrite rod and a magnetizing coil, a rotating device with an angular scale, 2 detector sections with fixed short circuits, a power supply, a sliding rheostat, an orthomode transducer with an integrated transition from a circular to a rectangular waveguide.

Laboratory work № 3: high-frequency signal generator Г4-111, millivoltmeter В3-38А, 2 connecting cables, a coaxial-to-waveguide transition, an experimental setup for studying electromagnetic waves above a conducting plane, which includes a pyramidal horn antenna, a supporting antenna rotator with an angular scale, a metal screen, a dipole antenna with a rigid coaxial transmission line, a measuring line ИВЛ140 with a vernier scale, a detector section 3.86–10.02 GHz.

Laboratory work № 4: high-frequency signal generator Г4-111, 2 millivoltmeters В3-38А, 5 connecting cables, 3 coaxial-to-waveguide transitions, waveguide power combiner in the H-plane, waveguide directional coupler with an H-plane bend, a segment of a standard rectangular waveguide with a cross section of 23 mm × 10 mm and a length of 80 mm, coaxial measuring line Р1-34 and a waveguide measuring line ИВЛ140 of the 110 series, a fixed coaxial short-circuit, an adjustable waveguide short-circuit, 2 adjustable coaxial probes with detector sections.

Laboratory work № 5: high-frequency signal generator Г4-129, high-frequency signal generator Г4-78, millivoltmeter В3-38А, 2 connecting cables, coupling loop, 2 fixing bolts, a rectangular cavity resonator with holes, a cylindrical cavity resonator with holes, a coaxial probe, a detector section 50–3000 MHz.

Laboratory work № 6: high-frequency programmable signal generator Г4-156, millivoltmeter В3-38А, a section of a rectangular waveguide with a cross section of 7.2 mm × 3.4 mm and a length of 87 mm, a pyramidal horn antenna, a detector section, a connecting cable, an experimental setup for studying the diffraction of electromagnetic waves, which consists of a dielectric housing with grooves and a linear scale, a Fresnel zone plate and a set of plates with circular holes of different radii in the metal and a metal plate without a hole.

Laboratory work № 7: high-frequency signal generator Г4-129, power amplifier Г4-128, spectrum analyzer П.Ч. С4-27, microwave unit С4-27, complex transmission coefficients meter Р4-11, sweep frequency generator К Р4-11, frequency converter К Р4-11, reflectometer 50Ω 1–610 MHz, coaxial matched load, 8 connecting cables, a log-periodic antenna, 3 dipole antennas, tripod support stand, tripod supporting rotator stand with angular scale.

Software: Distance learning is carried out using the Zoom platform.

Distance learning course on the "Sikorsky" Platform: ***https://do.ipo.kpi.ua/course/view.php?id=642***.

Curriculum of the academic course (syllabus):

Prepared by Associate Professor of the Department of Radio Engineering, PhD Stepan Piltyay;

Approved by the Department of Radio Engineering (minutes of the department meeting № 06/2025 dated 23.06.2025);

Approved by the Educational and Methodological Commission of the Radio Engineering Faculty (minutes of the EMC REF meeting № 06/2025 dated 26.06.2025).