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

Department of Radio Engineering Systems

# [RE-44] ELECTRONIC AND QUANTUM DEVICES OF ULTRA-HIGH FREQUENCIES


## Work program of the academic discipline (Syllabus)

## Course details

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|---|---|
| Level of higher education | First (bachelor's) |
| Field of knowledge | 17 - Electronics, Automation, and Electronic Communications |
| Specialization | 172 - Electronic Communications and Radio Engineering |
| Educational program | All educational programs |
| Discipline status | Elective (F-catalog) |
| Form of higher education | Full-time |
| Year of training, semester | Available for selection starting from the 3rd year, fall semester |
| Course load | 4 credits (Lectures 18 hours, Practical classes 36 hours, Laboratory work 36 hours, Independent work 66 hours) |
| Semester Control/control measures | Credit |
| Class schedule | https://schedule.kpi.ua |
| Language of instruction | Ukrainian |
| Information about the course leader/teachers | Lecturer: O. V. Tureyeva, Lab: O. V. Tureyeva, Independent work: O. V. Tureyeva |
| Course location | https://do.ipo.kpi.ua/course/view.php?id=801 |

## Curriculum

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

The modern development of special-purpose radio engineering systems, namely radar stations, radio countermeasure and electronic warfare systems, and information satellite systems operating in the frequency range from 1 to 300 GHz, requires powerful generators and amplifiers (from several kW and above). The generator and amplifier functions in such systems can only be achieved with the use of electron-vacuum devices: klystrons, magnetrons, forward and reverse wave tubes.

**The aim** of the course is to develop students' **competencies**:

- the ability to evaluate design, technological, engineering, and scientific and technical solutions and take into account the peculiarities of the operation of microwave electronic devices in terms of compliance with safety, energy efficiency, and environmental requirements;
- ability to explain the physical principles of operation of electronic and quantum microwave devices and the principles of engineering and design implementation of electronic vacuum and quantum devices for operation in the microwave range;
- the ability to analyze and measure the main characteristics of electronic and quantum devices in the microwave range, taking into account current trends in the development of radio-electronic systems;

**The subject** of study of the discipline "**Electronic and Quantum** Microwave **Devices**" is the physical principles of operation of electronic and quantum microwave devices; the principles of engineering and design implementation of electronic-vacuum and quantum devices for operation in the microwave range, and the specifics of their application in radio engineering systems.

In accordance with educational programs**, the program outcomes are:**

**knowledge of:**

- the principles of operation and design features of type "O" microwave devices with concentrated distributed interaction of the electron flow with the electromagnetic field;
- the physical principles of operation and design features of microwave devices with crossed fields of the "M" type;
- principles of engineering and design implementation of electronic and quantum devices for operation in the microwave and optical ranges.

**Skills:**

- analyze the operation, evaluate, and measure the main characteristics of microwave vacuum devices;
- measure the main characteristics of electronic and quantum devices in the microwave range;
- be familiar with the modern element base of radio-electronic equipment, the characteristics and parameters of microwave electronic and quantum devices, and the criteria for the use of devices in the construction of radio-electronic systems.

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

Interdisciplinary connections: provided by the study of such disciplines as "General Physics," "Higher Mathematics," " " "Fundamentals of Circuit Theory," "Electrodynamics and Radio Wave Propagation."

The knowledge and skills acquired after studying the discipline "Electronic and Quantum Microwave Devices" are further used in the disciplines "Transceivers of Modern Radio Engineering Systems," "Fundamentals of Radar Systems," "Radio Countermeasure Systems," and "Radio Navigation Systems," as well as in coursework and thesis projects.

## 3. Contents of the course

***Section 1. Introduction. Physical fundamentals of microwave electronic devices.***

***Topic 1.1*** Introduction. Features of microwave and optical range devices. Areas of application of microwave electronic and quantum devices.

***Topic 1.2*** Physical principles of microwave electronic devices. Equation of motion of an electron in an alternating electric field. Energy exchange between an electron and an alternating electric field. Time and angle of electron flight.

***Section 2. Devices with short-term interaction with the field***

***Topic 2.1*** Principle of operation of devices with short-term interaction of electrons with a field. Grouping of electron beams by velocity and density in a double-resonator fly-by klystron, space-time diagram. Grouping parameter. Dependence of convection current on the grouping parameter.
Generator based on a double-resonator fly-by klystron.

***Topic 2.2*** Multi-resonator klystrons. Device and connection diagram. Frequency-phase characteristics, power, efficiency. Limitations in the growth of output power with an increase in anode voltage and electron beam current. Use of a traveling wave klystron as a signal amplifier. The effect of the reflection coefficients of the signal amplifier output and load on the operating mode of the transmission line (feeder) and power in the load.

***Topic 2.3*** Reflective klystron. Electron grouping, space-time diagram. Generation zones, power, efficiency. Electronic and mechanical frequency tuning. Designs, areas of application.

***Section 3. Devices with prolonged interaction of electrons with the field***

***Topic 3.1*** Structure and general characteristics of traveling wave tubes (TWTs) and their areas of application. Deceleration systems, the concept of spatial harmonics, dispersion characteristics of deceleration systems. Electron grouping in a traveling wave field. Conditions for interaction of an electron beam with a traveling wave field. Conditions for phase synchronism of the electron cluster flow with the field of the working spatial harmonic of the traveling wave.

***Topic 3.2*** Type "O" reverse wave tubes (RWTs). Structure and principle of operation. RWT as a generator with distributed internal feedback. Electronic tuning of the generation frequency. Output power, efficiency. Application of RWTs.

***Section 4. Microwave devices with crossed fields***

***Topic 4.1*** Physical principles of operation of microwave devices with crossed M-type fields. Effect of the Lorentz force on the trajectory of an electron moving in a constant magnetic field. Cyclotron frequency. Cylindrical diode in a constant magnetic field, concept of critical magnetic induction.

***Topic 4.2*** Movement of electrons in crossed electric and magnetic fields. Grouping of electrons in M- type devices. Features of energy transfer from the electron flow to the high-frequency field in M-type devices. The principle of phase synchronism for M-type devices.

***Topic 4.3*** Classification of microwave devices of the "M" type according to the type of deceleration system and electron flow. Magnetron as a device of the "M" type with a closed electron flow. Features of the formation of electron flow and the transfer of its energy to a high-frequency field in a magnetron.
Operating type of oscillations. Operating characteristics. Power, efficiency. Areas of application.

***Section 5. Fundamentals of quantum device construction.***

***Topic 5.1*** Physical fundamentals of the operation of quantum devices in the microwave and optical ranges. Energy levels, normal and inverse population of levels, spontaneous and induced transitions between levels.

***Topic 5.2*** Optical quantum generators (lasers). Conditions for self-excitation. Types of lasers

by active medium, pumping methods, operating mode. Optical resonators. Structure of a ruby pulsed laser.
Characteristics. Areas of application.

### 4. Teaching materials and resources

***Basic literature.***

1. Panfilov I.P., Fleita Yu.V. Electronic and quantum microwave devices: Textbook for universities. Module 1. – Odessa: O.S. Popov ONAT, 2010. – 120 p.

2. Shokalo V.M., Pravda V.I., Usin V.A., Vuntesmeri V.S., Grechikh D.V. Electrodynamics and Radio Wave Propagation. Part 1. Fundamentals of electromagnetic field theory: Textbook for university students / Edited by V.M. Shokalo and V.I. Pravda. Kharkiv: KNURE; Collegium, 2009. 286 pp.

***Supplementary.***

3. David M. Pozar, Microwave Engineering, John Wiley & Sons, 2011.

## Educational content

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

Laboratory work is planned to familiarize students with samples of microwave electronic devices and study their characteristics using microwave radio measuring equipment. Laboratory work is carried out on the following topics:

- studying the characteristics of a magnetron generator;
- investigation of the characteristics of an O-type reverse wave tube;
- research into the operating modes and characteristics of a reflective klystron;
- researching the characteristics of a traveling wave tube amplifier.

**Individual assignments:**

Homework assignment.

The purpose of the homework assignment is to deepen understanding of the theoretical course material and reinforce the skills of independently applying the acquired knowledge. The assignment covers all sections of the lecture material.

### 6. Independent work of the student

Students are allocated 66 hours for independent work. It consists of:

- studying lecture material – 8 hours;
- preparation for laboratory work - 20 hours;
- preparation for the modular test - 10 hours;
- completing homework assignments - 12 hours
- preparation for the exam – 16 hours;

## Policy and control

## 7. Academic discipline (educational component) policy

***Recommended teaching methods:***

- problem-based learning method: problem-based presentation in individual lectures, and research method when performing laboratory work;
- personality-oriented - in the form of educational debates during laboratory work;
- use of computer tools when performing homework assignments.

***Class attendance rules.*** Attendance at lectures and laboratory classes is mandatory, as they cover theoretical material and develop the skills necessary to complete semester tests. The assessment system is focused on obtaining points for the timeliness and quality of laboratory work, as well as the completion of homework assignments.

***Awarding of bonus and penalty points.*** Bonus points are awarded for: active participation in lectures and laboratory classes. The number of bonus points is limited to 5. Penalty points may be awarded for: failure to complete assignments or late completion of assignments.
The number of penalty points shall not exceed 5.

***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 details, please visit: https://kpi.ua/code.

***Standards of ethical conduct*** 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.

***Foreign language instruction*** The academic discipline "**Electronic and Quantum Microwave Devices**" is taught in Ukrainian. Materials and sources in Ukrainian and English are used in the teaching of this academic discipline.

## 8. Types of control and rating system for assessing learning outcomes

The rating assessment for the discipline RA (i.e., the exam grade for the semester) is calculated as the sum of the current academic performance points and exam points. RA is calculated on a 100-point scale. The student's rating consists of points received for:

- express control of laboratory classes. Control is carried out in the form of an individual survey on the topic of the laboratory class;
- completion and defense of laboratory work;
- modular control work;
- completion of the Home Control Work;
- answers to the test;

**Penalty and incentive points:**

- non-admission to laboratory work due to incorrect answer on the express test — minus 2 points
- active participation in classes — plus 5 points

**Rating point system and assessment criteria for the semester**

1. There are 4 LPs during the semester. Points are awarded for each LP:

Express control of laboratory classes

- full answer 4 points
- full answer with minor errors 2 points
- incorrect answer 0

Maximum number of points for express control 16 points Defense of laboratory work

(LR)

- Full answer during the defense of LR 4
- Incomplete answer when defending LR 2 points • unsatisfactory answer during the defense of the thesis 0 points

Maximum number of points for the LR **4x4+4x4=32 points**

1. Modular control MCW:

- complete answer 12 points
- the answer has minor inaccuracies 6 points
- answer is incomplete, contains significant errors 3
- unsatisfactory answer, no answer 0

Maximum number of points for the MCW **12**

1. Homework assignment (HA)

- correct calculation with a detailed description
- and the program provided, conclusions drawn 16
- incomplete calculation with minor errors 8 points
- calculation is incorrect 0 points

Maximum number of points for HCW **16 points Calculation of the rating scale**

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

$R_{sem}$ = 32 + 12 + 16 = 60 points

The exam grade on the RD scale is 40% and equals 40 points:

RD= $R_{sem}$ + $R_{exam}$ = 60 + 40 = 100 points

The condition for admission to the exam is a total score of at least 0.5* Rsem, i.e. > 30 points, no outstanding laboratory work, and completion of the DKR. Students with an Rsem of less than 30 points are given the opportunity to increase their Rsem during the last week of the semester and be admitted to the semester exam.

Grade point averages for the discipline are converted to a table of correspondence between grade point averages and grades on the university scale for inclusion in the exam record and grade book:

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

| Number of points | Grade |
|---|---|
| 100-95 | Excellent |
| 94 | 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 discipline (educational component)

Distance learning course - https://do.ipo.kpi.ua/course/view.php?id=801 Approximate list

of questions for the MCW.

1. Explain the physical phenomenon that excites oscillations in the second resonator of a dual-resonator klystron.
2. What is the grouping parameter? What values does it depend on and why?
3. Explain the process of cluster formation in the flight interval of a double-resonator klystron using a space-time diagram.
4. A double-resonator klystron is often used as a frequency multiplier. Why is this possible? What needs to be done with its structural elements to increase the output power at the desired harmonic?
5. An electron flies into the gap between two externally connected electrodes. The electron velocity is ***Ve***, and the distance between the electrodes is ***d***. Plot the time dependence of the induced current.
6. How are the values of the convection current and the induced current between two connected plates, the gap between which is excited by this current, related?
7. What explains the low actual efficiency of a double-resonator klystron?
8. What increases the power gain and electronic efficiency in multi-resonator klystrons?
9. Provide the formula for the steepness of the electronic frequency tuning of the generator on the reflective klystron and explain the meaning of the values included in this formula.
10. What negative phenomena occur in a vacuum triode amplifier when the input signal frequency increases?
11. Why are there many generation zones in a generator on a reflective klystron?
12. What is the one-decibel compression level of a klystron amplifier?
13. Explain the principle of operation of a magnetron using the example of an 8-resonator device.
    a. What are the group and phase velocities of an electromagnetic wave? Which velocities are the same and which are different for spatial harmonics?
14. Explain the process of frequency tuning in a reverse wave tube generator.
15. It is known that the dynamic range of an amplifier on an LBA is limited at the top– the output power begins to drop as the input power increases. What design measures are taken to "extend" the linear characteristic?
16. Why, in principle, can the efficiency of an LBG not be high?
17. It is known that in crossed electric and magnetic fields, the trajectory of an electron starting with zero initial velocity is a cycloid. What will be the trajectory of this electron if the electric and magnetic fields are directed in the same way?
18. Why does an electromagnetic wave slow down in a magnetron generator?
19. What type of wave is used in the deceleration system of a reverse wave lamp?
20. Why is the most commonly used type of oscillation in the resonator block of a multi-resonator magnetron the π-type oscillation (π-mode)?
21. Which component of the alternating electric field of the wave is responsible for grouping electrons in a multi-resonator magnetron?
22. Name at least two reasons for the high efficiency of a magnetron compared to a traveling wave tube.

***Description of material, technical, and informational support for the discipline***

The purpose of the laboratory work is to familiarize students with samples of microwave electronic devices and to study their characteristics using microwave radio measuring equipment.

Laboratory work No. 1 - Investigation of operating modes and characteristics of a reflective klystron

Equipment: the generator under study on a 4-cm band reflector klystron, a stabilized power supply unit of type 3-490 M, sawtooth voltage generator, oscilloscope, MZ-10 (M4-2) power meter, CH3-68 frequency meter, waveguide path, coaxial-waveguide transition, detector section, variable knife-type attenuator, directional coupler. 2 stands, 6 workstations.

Laboratory work No. 2 - Investigation of the characteristics of an O-type reverse wave lamp

(LZH-O) Equipment: test generator on an O-type reverse wave lamp with a 3 cm range OV-19, power supply, frequency meter 42-30, amplifier U2-1 A oscilloscope, power meter Y2M-66, frequency meter CH3-66, waveguide path, waveguide switch, coaxial-waveguide transition, detector section, attenuator, valve, directional coupler. 1 stand, 4 workstations.

Laboratory work No. 3 - Investigation of the characteristics of a magnetron generator

Equipment: test magnetron unit based on a continuous-wave packaged magnetron, power supply unit, MZ-10 (M4-2) power meter, BB-1 visual wave meter, waveguide path, full-impedance transformer, coaxial-waveguide transition,
detector section, attenuator, valve, directional coupler. 1 stand, 4 workstations.

Laboratory work No. 4 - Investigation of the characteristics of an O-type traveling wave tube (LBH - O).

Equipment: O-type traveling wave tube amplifier under study (LBH-O) 3 cm range, microwave signal generator G4-32A, power supply, power meters MZ-10
(M4-2) power meters, waveguide path, coaxial-waveguide transition, detector section, attenuator, valve, directional coupler. 1 stand, 4 workstations.

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Work program for the academic discipline (syllabus):
**Compiled by** O. V. Tureyev;
**Approved by** the RTS Department (Minutes No. 06/2024 dated 06/27/2024)
**Approved by** the methodological commission of the faculty/research institute (protocol No. 06/2024 dated 28.06.2024)