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

Department of Radio Engineering Systems

[RE-59] BASICS OF RADAR SYSTEMS THEORY

Curriculum of the academic discipline (Syllabus)

Course details

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
Subject status	Elective (F-catalog)
Form of higher education	Full-time
Year of training, semester	Available for selection starting from the 4th year, spring semester
Scope of the discipline	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 coordinator/teachers	Lectures: V. O. Chmelov, Labs: V. O. Chmelov
Course location	

Course program

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

Description of the academic discipline. Mastering the academic material of the discipline gives students the opportunity to study the theoretical foundations of radar systems (RLS), the principles of their construction and the features of their application, in accordance with various tasks related to monitoring air, space, and surface space. Approaches to the detection and tracking of moving objects with different parameters and dynamics of their movement in complex conditions, when passive and active interference actively affects the effective operation of the RLS, are studied. Various scientific and technical solutions for improving the effectiveness of the RLS are studied, and comparative analysis, and determines their advantages and disadvantages depending on the selected radar configuration.

The aim of the course is to teach students to select the principles of radar design and structure based on the specified tactical and technical characteristics of the radar system they are designing; to formulate requirements and technical characteristics for devices and instruments that are part of the specified radar system; to evaluate the effectiveness of the technical solutions adopted.

Subject of study: fundamentals of radar theory, principles of radar construction, its structure: methods of combating active and passive interference, evaluation of the effectiveness of technical solutions.

The main objectives are:

In accordance with the requirements of the course, after mastering the course material, students should demonstrate the following learning outcomes:

knowledge:

- current trends in the development of radar and prospects for its use in various fields of science and technology;

- methods of radar detection of moving targets;

- basic methods of analysis and synthesis of devices for detecting and processing radar signals and measuring their parameters;

- principles of creating systems determining the movement parameters of the detected target.

Skills:

calculate the main technical characteristics of the radar:

- the range of different types of radars;
- threshold signal level;
- operating characteristics of the signal detection path;
- probability of correct signal detection and probability of false alarm probability;
- the duration and bandwidth of the probing signal;
- amplitude and phase spectrum of the probing signal;
- the autocorrelation and cross-correlation functions of the probing signal;
- the uncertainty diagram of the probing signal;
- potential resolution of the probing signal in terms of range, speed, and bearing;
- errors in measuring the range, velocity, and bearing of the target;

Process experimental data obtained through statistical modeling on a computer to evaluate the effectiveness of radio-technical computerized systems.

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

Prerequisites: the discipline is based on knowledge of the following disciplines: "Electrodynamics and Radio Wave Propagation".

Post-requisites: The discipline provides additional competencies in the field of modern radar system development.

3. Content of the academic discipline

Training module No. 1. Fundamentals of radar system theory.

Topic 1. General principles of radar construction theory.

Topic 2. Basic equation of radar. Analysis of factors affecting the efficiency of radar operation.

Topic 3. Statistical criteria for signal detection.

Topic 4. Optimal filtering. Correlation reception.

Topic 5. Uncertainty function in radar.

Topic 6. Signal separation. Complex signals. Joint separation of signals by delay time and frequency.

Topic 7. LCM and complex signals with binary phase modulation

Topic 8. Fundamentals of signal parameter measurement theory

Training module No. 2. Radar systems.

Topic 9. Passive radar. Range of radiometers. Radiometer circuits

Topic 10. Methods of measuring angular coordinates.

Topic 11. Phase, amplitude, and amplitude-phase methods of measuring angular coordinates.

Topic 12. Range measurement methods

Topic 13. Automotive radar with LCM signal

Topic 14. Target speed measurement

Topic 15. Methods of space scanning, minimum and relative scanning period.

Topic 16. Combating active jamming of radar systems.

Topic 17. Systems for selecting moving targets and combating passive interference.

Topic 18. Approaches and ways of developing radar systems.

4. Teaching materials and resources

Basic literature:

1. Theory of Radar Systems (second edition): textbook/ B.F. Bondarenko, V.V. Vishnevsky,

V.P. Dolgushin et al.; edited by S.V. Lenkov. – Kyiv: Publishing and Printing Center "Kyiv University", 2011. – 383 p.
2. Methods of Secure Information Processing in Multi-Position Radar Systems radar monograph / Igor Parkhomey, Valery Kozlovsky, Sergey Gnatyuk, Miroslav Ryaby; National Aviation University, Kyiv: Center for Educational Literature, 2018. – 230 p.
3. Theory of radar and radio navigation systems: textbook for university students majoring in "Radio Engineering" / Ya. I. Lepikh; Odessa National Maritime Academy, Odessa : Ecology, 2008. -224 p.
4. Optimization of Radio Engineering Systems Design [Text]: Methodological guidelines for laboratory work in the discipline "Optimization of Radio Engineering Systems Design" for students of the Radio Engineering Faculty / Compiled by: S.Ya. Zhuk, S.V. Vyshnevyi - Kyiv: NTUU "KPI", 2012. – 62 p.
5. Chmelov, V. O. Radar systems. Laboratory practical [Electronic resource]: textbook for students majoring in 172 "Telecommunications and Radio Engineering" / V. O. Chmelov, P. Yu. Katin; Igor Sikorsky KPI. – Electronic text data (1 file: 5.89 MB). – Kyiv: Igor Sikorsky KPI, 2023. – 213 p. – Title from screen.https://ela.kpi.ua/handle/123456789/53171
6. Chmelov, V. O. Radar systems. Calculation and graphic work [Electronic resource]: textbook for bachelor's degree students in the educational program "Radio Technical Computerized Systems," specialty 172 "Electronic Communications and Radio Engineering" / V. O. Chmelov; Igor Sikorsky KPI. – Electronic text data (1 file: 1.14 MB). – Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2023. – 45 p. – Title from screen. https://ela.kpi.ua/handle/123456789/57291

Additional literature:

1. Chmelov V.O., Tereshchenko O.V., Oliinyk M.V. METHOD OF DECORRELATION OF PASSIVE INTERFERENCE SIGNALS IN THE SYSTEM OF SELECTION OF LOW-SPEED MOVING TARGETS / Bulletin of the Vinnytsia Polytechnic Institute. 2024. No. 2, pp. 109-115 ISSN 1997-9266. DOI:https://doi.org/10.31649/1997-9266-2024-173-2-109-115.
2. Serhii Zhuk, Viacheslav Chmelov, Oleksandr Tereshchenko Development of an adaptive multi-channel correlation sidelobe canceller for active noise interference based on the Gram-Schmidt orthogonalization procedure // Eastern-European Journal of Enterprise Technologies" Vol. 6 No. 5 (132) (2024): Applied physics. 33-40 c. DOI: https://doi.org/10.15587/1729-4061.2024.319253 (SCOUPUS)
3. Chmelov V. O., Nazarov I. S. APPROACHES TO IMPROVING METHODS FOR DETECTING DRONE SIGNALS AGAINST THE BACKGROUND OF ADDITIVE NOISE // XIII International Scientific and Technical Conference "Radio Engineering Problems, Signals, Devices and Systems" (RTPAS) . Kyiv, November 27–28, 2024: conference materials — Kyiv, 2024. pp. 72–75.

Educational content

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

Lectures

Training module No. 1. Fundamentals of radar system theory.

Topic 1. Subject and content of the discipline. General principles of radar theory. Classification. Radar range.

Literature: [1,2]

Assignments for SRC. General characteristics of radar. Frequency range standard.

Topic 2. Multifactorial analysis affecting the efficiency of radar operation.
Signal energy losses in the environment. Influence of the Earth's surface and curvature. The phenomenon of refraction.

References: [1,2,3]

Assignments for independent study. Key indicators of radar quality.

Topic 3. Fundamentals of signal detection theory. Statistical criteria for signal detection. Statistical characteristics of a signal. Bayes' formula. Multivariate random variables. References: [1,3,4]

Assignments for independent study. Target characteristics. Effective target cross-section. Radar range.

Topic 4. The uncertainty principle in radar.
Simultaneous measurement of distance and velocity. Uncertainty function. Intersection of uncertainty functions.

References: [1,2,5]

Assignments for independent study. Fundamentals of signal detection theory. Signal and noise models

Topic 5. Signal separation. Complex signals. Joint separation of signals by delay time and frequency.

References: [2,4]

Assignments for independent study. Statistical criteria for signal detection. Detection algorithm.

Topic 6. LCM and complex signals with binary phase modulation.

Types of LCM signals. Principles of FM. Features of the autocorrelation function of complex signals.

References: [1,5,7]

Assignments for independent study. Signal uncertainty function.

Topic 7. Optimal filtering. Correlation reception. Detection characteristics. Types of optimal filters. Advantages and disadvantages of correlation reception.

References: [2,4,7]

Assignments for independent study. Signal separation. Complex signals. Joint separation of signals by delay time and frequency.

Topic 8. Fundamentals of signal parameter measurement theory. Measurement optimization criteria. Dependence of measurement accuracy on radar parameters.

References: [1,5,9]

Assignments for independent study. The uncertainty principle in radar. LCM and phase-manipulated signals

Training module No. 2. Radar systems.

Topic 9. Methods of space surveillance. Space surveillance efficiency parameters. The influence of the antenna system on space surveillance efficiency.

References: [3,1,4]

Assignments for independent study. Fundamentals of the theory of measuring radar signal parameters.

Topic 10. Methods of measuring angular coordinates. Theoretical approaches. Tasks and parameters of measuring angular coordinates.

References: [1,5]

Assignments for independent study. Potential measurement accuracy.

Topic **11**. Phase, amplitude, and amplitude-phase methods of measuring angular coordinates.

Comparative analysis of methods. Accuracy characteristics of each method. References:

[1,3,5]

Assignments for independent study. Pulse method of range measurement

Topic 12. Range measurement methods. The principle of range measurement. Types of methods.

References: [1,4]

Assignment for independent study. Phase method of range measurement.

Topic 13. Automotive radar with LCM signal. Principle of construction. Features of operation. Characteristics and parameters.

References: [6,7]

Assignments for independent study. Frequency method of range measurement.

Topic 14. Target speed measurement. Doppler effect. Speed meter structure. References: [2,4,6]

Assignments for independent study. Methods of space scanning, minimum and relative scanning period.

Topic 15. Passive radar. Range of radiometers. Modulation, correlation, and compensation circuits of radiometers. Laws of radiation from a heated body. Purpose of radiometers. Literature: [1,4,6]
Assignments for independent study. Methods for measuring angular coordinates.

Topic 16. Combating active interference with radar operation. Types of interference. Methods of combating interference. Principles of constructing interference combating systems.

Literature: [1,2]

Assignments for independent study. Phase, amplitude, and amplitude-phase methods of measuring angular coordinates.

Topic 17. Systems for selecting moving targets and combating passive interference. Types of passive interference. Whitening filter. Types of SRC systems.

References: [5,8,]

Assignments for independent study. Measuring target velocity.

Topic 18. Approaches and ways of developing radar systems. UAV detection radar. Approaches to building ultra-high frequency radars. Digital radars.

References: [5,7,9]

Assignments for independent study. Use of FAR. MIMO antennas.

- **Laboratory classes**

•	Name of laboratory work	Number of hours
1.	Laboratory work "Research into methods of obtaining radar information. Research into the characteristics effective scattering surface characteristics of radar targets"	1
2.	Laboratory work "Research into methods for optimal processing of radar signals"	1
3.	Laboratory work "Research on the amplitude method for measuring the angular coordinates of targets"	1
4.	Laboratory work "Investigation of the phase method for measuring the angular coordinates of targets"	1
5.	Laboratory work "Investigation of the dependence of the threshold signal on the number of pulses in linear and exponential signal accumulation"	1
6.	Laboratory work "Study of the properties of a signal with linear frequency modulation on a virtual model system"	1
7.	Laboratory work "Investigation of signal properties with linear frequency modulation on a laboratory setup modulation"	1
8.	Laboratory work "Phase-manipulated signals. Investigation of the properties of pseudorandom sequences. M-sequences on a virtual model system"	1
9.	Laboratory work "Phase-manipulated signals. Investigation of the properties of pseudorandom sequences. Barker codes on a virtual model system"	1
10.	Laboratory work "Investigation of the properties of a phase-manipulated signal – Barker code"	1
11.	Laboratory work " Investigation of a radio direction finder. Amplitude methods for determining the direction of the source electromagnetic radiation"	1
12.	Laboratory work "Investigation of a radiometer. Passive radar methods for detecting the source electromagnetic radiation from a heated body"	2
13.	Laboratory work "Investigation of the operation of a radar system based on the Doppler effect. Remote radio measuring device for the radial velocity of a moving object"	1
14.	Laboratory work "Investigation of a radar system with a frequency-modulated continuous wave signal radiation"	2
15.	Laboratory work "Graphical interface of the operator of a digital radar system based on technologies Qt libraries"	2
	Total	18

6. Independent work by students

	Title of the topic for independent study	Number hours of independent work
1	General characteristics of radar. Classification. Frequency ranges.	1
2	Basic indicators of radar quality.	1
3	Target characteristics. Effective target scattering area. Radar range. range.	1
4	Fundamentals of signal detection theory. Signal and interference models.	1
5	Statistical criteria for signal detection. Detection algorithm.	1
6	Optimal filtering. Correlation method. Detection characteristics.	1
7	Signal separation. Complex signals. Joint signal separation by delay time and frequency.	1
8	The uncertainty principle in radar. LCM and phase-manipulated signals.	1
9	Fundamentals of the theory of measuring radar signal parameters.	1
10	Potential measurement accuracy.	1
11	Pulse range measurement method	1
12	Phase method of range measurement.	1
13	Frequency method of range measurement.	1
14	Methods of space scanning, minimum and relative scanning period.	1
15	Methods of measuring angular coordinates.	1
16	Phase, amplitude, and amplitude-phase methods for measuring angular coordinates.	1
17	Measurement of target velocity.	1
18	Passive radar. Range of radiometers. Modulation, correlation and compensation circuits of radiometers.	1

19	Preparation of a laboratory work report	22
20	*Preparation for the module test*	6
21	Preparation for the test	10
	Total	6

Policy and control

7. Policy of the academic discipline (educational component)

Recommended teaching methods: studying the main and supplementary literature on the topics of the lectures, performing laboratory work. Students are advised to take detailed notes during lectures. An important aspect of high-quality assimilation of the material and mastery of methods and algorithms for solving the main tasks of the discipline is independent work. It includes reading literature, reviewing literature on the topic, preparing for classes, tests, and exams. The purpose of laboratory work is to deepen and consolidate theoretical knowledge, acquire modeling skills using computer technology, acquire skills in assessing the reliability of the results obtained, and preparing documents. The software is implemented in the Matlab and Mathcad computing environments for scientific and engineering calculations.

Rules for attending classes. Attendance at lectures and laboratory classes is assessed. Students are encouraged to attend classes, as they cover theoretical material and develop the skills necessary to complete semester tests. The assessment system is focused on awarding points for the timely completion of laboratory work by students, as well as the completion of tasks that develop practical skills and abilities.

During lectures, it is forbidden to distract the teacher from teaching the material; all questions, clarifications, etc. should be asked at the end of the lecture during the time allotted for this purpose.

Assignment of incentive and penalty points. Incentive points are awarded for: active participation in competitions, preparation and publication of scientific articles and abstracts of reports at scientific conferences, participation in research work on a topic that corresponds to the topics of the discipline. **The number of incentive points is limited to 10**.

Penalty points may be awarded for late submission of laboratory work. **The number of penalty points shall not exceed 10.**

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, see: https://kpi.ua/code.

Ethical conduct standards Ethical conduct standards 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 details, please visit: https://kpi.ua/code.

Foreign language instruction The academic discipline is taught in Ukrainian.

Students have the opportunity to gain knowledge on specific topics and sections of the academic discipline through courses on the Coursera platform (https://www.coursera.org), Prometheus (https://prometheus.org.ua), etc., as blended or additional learning in accordance with the Regulations on the recognition of learning outcomes acquired in non-formal/informal education at Igor Sikorsky Kyiv Polytechnic Institute (https://osvita.kpi.ua/node/179).

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

8.1. Types of control

Current control: carried out through questioning during laboratory classes and during the completion of MCR.

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

Semester assessment: Credit.

8.1. Calendar interim assessment of students is carried out based on the student's current rating at the time of assessment. If the rating is not less than 50% of the maximum possible at the time of assessment, the student is considered certified. The condition for a positive first assessment is to receive at least 8 points. The condition for a positive second assessment is to obtain at least 22 points.

8.2 Rating system for assessing learning outcomes.

The first type of RSA involves assessing the results of the applicant's academic activity during the semester – passing or completing certain types of work provided for by current control measures (hereinafter – RSA-1).

8.2. Rating system for assessing learning outcomes.

1. Learning outcomes are assessed on a 100-point scale and then converted to grades on the university scale.

2. The applicant's rating consists of points received by the applicant based on the results of current control measures and incentive/penalty points.

3. The rating assessment is communicated to applicants during the penultimate class of the semester.

4. The regulations on the rating system for assessing academic performance are communicated during the first class of the discipline.

5. The RSA for a discipline, the semester assessment of which is in the form of an exam, consists of two components: initial – intended for assessing current assessment measures throughout the semester; the exam component, designed to assess individual questions (tasks) on the exam (clause 3.17 of the REGULATIONS on the system of assessing learning outcomes at Igor Sikorsky Kyiv Polytechnic Institute).

8.3. Criteria for awarding points.

1. Nine laboratory works are performed during the semester. The total number of points for completing and defending a laboratory work report is 10 points.
2. Completion and defense of laboratory work – **9x10=90 points.**
3. Modular control of MCR – **10 points**.
4. Completion of the test – **100 points**.

Modular control (MCW) has 2 questions. Points are calculated separately for each question. As a result,

the MCW score is:

- full answer – **10 points**

- complete answer with minor errors - 8 points

- complete answer with significant errors - 6 points

- incomplete answer - 4 points,

- content of the answer does not relate to the essence of the question, or there is no answer to the MCR question - 0 points

Report on the completion of laboratory work.

The student is not allowed to defend the report if it is not formatted in accordance with the

requirements. As a result of the report defense:

- full answer - **10 points**

- Complete answer with minor errors - 8 points

- complete answer with significant errors - 6 points

- incomplete answer - 4 points

- content of the answer does not relate to the essence of the laboratory work, or the results of the research during the laboratory work were not obtained - 0 points.

Assessment of the test (R_E).

Students provide written answers to questions.

The grading system for answers to questions:

- "excellent", complete answer (at least 90% of the required information) – 95-100 points;
- "Very good," sufficiently complete answer (at least 85% of the required information, or minor inaccuracies) – 85-94 points;
- "Good," a sufficiently complete answer (at least 80% of the required information, or minor inaccuracies) – 75-84 points;
- "Satisfactory," incomplete answer (at least 70% of the required information and some errors) – 65-74 points;
- **"sufficient"** 60-64 incomplete answer (at least 65% of the required information and gross errors)
- "unsatisfactory," unsatisfactory answer – 0 points, **the test is considered failed**.

The maximum possible number of points for control measures (items 1-3) during the semester (R_C) is 100 points.

The RSA for a discipline, the semester assessment of which is provided in the form of a test, for full-time education is developed according to the RSO-1 type and includes the assessment of current assessment measures for the discipline during the semester.

The applicant's rating consists of points received by the applicant based on the results of current control measures, incentive and penalty points.

The rating is communicated to applicants during the penultimate class of the semester.

Applicants who have fulfilled all the conditions for admission to the exam and have a rating of 60 points or more receive a grade corresponding to their rating without additional tests.

For applicants who have fulfilled all the conditions for admission to the exam and have a rating of less than 60 points, as well as those applicants who wish to improve their rating, the teacher conducts a semester assessment in the form of a final exam during the last scheduled class of the semester.

After completing the test, if the test score is higher than the rating, the applicant receives a grade based on the test results.

If the grade for the test is lower than the rating, the following option applies:
"strict" RSA – the applicant's preliminary rating (excluding points for the semester individual assignment) is canceled and he/she receives a grade based on the results of the test.

Grades for the educational component are determined according to the table:

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

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 discipline (educational component)

- The provisions of the grading system are explained during the first class of the discipline.
- The preliminary rating assessment for the discipline is communicated to students during the penultimate class of the discipline in the semester.
- Calendar assessment of students in the discipline is carried out by teachers based on the student's current rating at the time of assessment t. If the value of this rating is not less than 50% of the maximum possible (R_t) at the time of assessment $RD_t \geq 0.5R$, the student is considered to have passed. Otherwise, the assessment record will show "not assessed."
- Distance learning course at**: https://do.ipo.kpi.ua/course/view.php?id=6372**

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

The laboratory for practical classes and research on the basic principles of radar systems theory is located in room 204 of the educational building No. 17.

The auditorium has laboratory models for researching methods of determining the coordinates of radar objects in space, methods of increasing the probability of detecting signals against a background of radio interference, complex radar signals, and the principle of operation of a hydroacoustic locator.

There is a computer lab for mathematical modeling of the operation and calculation of the main parameters of radar systems.

The working program of the academic discipline (syllabus):
Compiled by V. O. Chmelov;
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)