

MINISTRY OF SCIENCE AND HIGHER EDUCATION OF THE RUSSIAN FEDERATION
Federal State Autonomous Educational Institution
of higher education
NORTH CAUCASUS FEDERAL UNIVERSITY

APPROVED BY:

Faculty of Mathematics and Computer
Science named after Professor
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Full name

Assessment Tools Fund on the Discipline
MODERN DIGITAL SIGNAL PROCESSING / СОВРЕМЕННАЯ ЦИФРОВАЯ
ОБРАБОТКА СИГНАЛОВ

Discipline (module) title

Training program	02.04.01 Mathematics and Computer Sciences
Directivity (profile)	Training Program for Electronic Information
Year of admission	2026
Mode of study	intramural
Implemented in	2

Developed by

PhD, Head of the Department of
Mathematical Modelling

Lyakhov P.A.

Introduction

1. Purpose: The Assessment Tools Fund (ATF) is intended for the objective assessment of the level of competencies formation in the discipline "Modern Digital Signal Processing / Современная цифровая обработка сигналов" for students studying in the Master's program 02.04.01 Mathematics and Computer Sciences, profile "Training Program for Electronic Information".

2. Scope: The ATF is an application to the work program and provides structured instruments for continuous monitoring of student progress and intermediate certification in Semester 2. Competencies assessed: UC-2.1, OPC-2.1, OPC-3.1, PC-2.1.

3. Developer: Lyakhov P.A., Head of the Department of Mathematical Modeling.

4. The ATF assessment was conducted.

Expert group members:

Chairperson:

Poddubnaya N.A., Chairperson of the Teaching and Methodological Complex, Faculty of Mathematics and Computer Science named after Professor N.I. Chervyakov

Commission members:

Gladkov A.V., Member of the Teaching and Methodological Complex, Department of Computational Mathematics and Cybernetics;

Andrukhiv L.V., Member of the Teaching and Methodological Complex, Department of Mathematical Modeling;

Kopytkova L.B., Member of the Teaching and Methodological Complex, Department of Mathematical Analysis, Algebra, and Geometry.

Employer representative: Lapin V.G., Head of the Automated Control Systems Department, Stavropol Regional Clinical Consultative and Diagnostic Center.

Expert opinion: The ATF assessment for the discipline "Modern Digital Signal Processing / Современная цифровая обработка сигналов" allows for assessing the level of competence development. Recommend for use in the educational process.

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5. The ATF validity period is determined by the implementation period of the educational program.

1. Description of criteria for assessing competencies at various stages of their formation, description of assessment scales

Competency (ies), Indicator (s)	Level of competencies formation			
	Minimum level not reached (Unsatisfactory) 2 grade points	Minimum level (Satisfactory) 3 grade points	Medium level (Good) 4 grade points	High level (excellent) 5 grade points
Competency: UC-2 Able to conduct independent research and analyze complex technical problems using modern mathematical and computational methods				
Learning outcomes for the course: <i>Indicator:</i> UC-2.1 Applies time-frequency representations, spectral estimation, and transform-domain models to design robust signal processing pipelines for real-world time-series and sensor data	Struggles to select appropriate transforms for a given signal analysis task; cannot justify method choice based on stationarity or bandwidth constraints	With guidance, selects basic frequency-domain methods; provides limited justification for windowing or sampling parameters	Independently selects appropriate representations (DFT vs. STFT vs. wavelet) for a given task; justifies choices with reference to noise characteristics and computational constraints	Expertly designs hybrid pipelines combining multiple representations ; provides rigorous justification based on signal properties, sampling theory, and efficiency requirements
Competency: OPC-2 Able to design, implement, and optimize computational algorithms for processing and analyzing discrete signals				
Learning outcomes for the course: <i>Indicator:</i> OPC-2.1 Implements core DSP algorithms from scratch using Python, NumPy, and SciPy, demonstrating understanding of numerical stability, computational complexity, and algorithmic assumptions	Code fails on basic test cases; relies entirely on high-level library calls without understanding underlying difference equations or transform properties	Core functionality works for clean data; minor reliance on library shortcuts; limited numerical precision handling	Implements algorithms correctly with attention to numerical stability; includes basic edge-case handling and documentation	Implements algorithms with optimized numerical routines; demonstrates understanding of complexity trade-offs; includes comprehensive testing and validation
Competency: OPC-3 Able to plan and execute experimental studies, validate algorithmic				

performance against theoretical models, and critically interpret results				
Learning outcomes for the course: <i>Indicator:</i> OPC-3.1 Designs complete processing pipelines, performs ablation and sensitivity analysis, and documents methodological limitations and failure modes	Cannot structure a complete processing workflow; fails to evaluate results against theoretical expectations or spectral benchmarks	Constructs basic pipeline with guidance; performs simple validation against reference outputs	Designs complete workflow with appropriate parameter tuning; conducts comparative analysis against theoretical models	Designs robust, reproducible pipelines with ablation studies; critically evaluates failure modes (aliasing, leakage, instability) and proposes principled improvements
Competency: PC-2 Able to develop mathematical models and software systems for system identification, spectral analysis, adaptive filtering, and hybrid classical-AI signal processing				
Learning outcomes for the course: <i>Indicator:</i> PC-2.2 Solves system identification and spectral estimation problems, designs optimal and adaptive filters, and reconstructs signal characteristics using linear prediction, AR/MA models, and convex optimization on parameter manifolds	Cannot formulate Z-domain stability conditions; filter design results are numerically unstable or violate causality constraints	Performs basic filter design with reasonable parameters; limited spectral error analysis	Correctly estimates system parameters; validates frequency response and stability; interprets spectral residuals	Performs adaptive tracking with convergence analysis; handles non-stationary inputs; integrates statistical estimation with optimization on parameter manifolds

The assessment of the level of development of competence in the discipline is carried out on the basis of the "Regulations on the current monitoring of academic performance and midterm assessment of students in higher education programs - bachelor's programs, specialist programs, master's programs - at the federal state autonomous educational institution of higher education "North Caucasus Federal University" in the current version.

ASSESSMENT TOOLS FOR CHECKING THE LEVEL OF DEVELOPMENT OF COMPETENCIES

Task Number	Correct Answer	Question Content	Competency
		Semester 1	
1.		Derive the frequency-domain representation of an ideally sampled signal.	UC-2.1
2.		Explain the Nyquist-Shannon condition and mathematically demonstrate how aliasing occurs when the sampling rate is insufficient, including the reconstruction error bound.	UC-2.1
3.		Justify why spectral leakage occurs in finite-length DFT analysis. Compare rectangular, Hamming, and Kaiser windows in terms of main-lobe width, side-lobe attenuation, and their impact on resolving closely spaced sinusoids.	UC-2.1, OPC-3.1
4.		FDerive the region of convergence (ROC) for a causal vs. anti-causal LTI system. Explain how pole locations in the z-plane determine BIBO stability and causality, and analyze how finite-precision coefficient quantization can destabilize a marginally stable IIR filter.	PC-2.1
5.		Derive the impulse response of an ideal low-pass filter via inverse DTFT.	OPC-2.1, UC-2.1
6.		Explain the Gibbs phenomenon and mathematically justify how windowing mitigates it, comparing the trade-off between transition bandwidth and stopband attenuation for different window functions.	OPC-2.1, UC-2.1
7.		Derive the bilinear transformation mapping from the analog s-domain to the digital z-domain. Explain frequency warping, demonstrate pre-warping compensation, and analyze phase distortion implications compared to impulse invariance.	PC-2.1, OPC-3.1
8.		Compare decimation and interpolation in multirate DSP.	OPC-2.1, UC-2.1
9.		Derive the aliasing condition for downsampling, explain the role of anti-imaging/reconstruction filters, and mathematically justify how polyphase decomposition reduces computational complexity.	OPC-2.1, UC-2.1
10.		Derive the Yule-Walker equations for an autoregressive (AR) process. Explain how Burg's method improves spectral resolution compared to the autocorrelation method, and discuss the bias-variance trade-off in parametric vs. non-parametric PSD estimation.	PC-2.1

11.		Analyze the convergence properties of the LMS adaptive algorithm.	UC-2.1, OPC-3.1
12.		Derive the step-size stability bound in terms of the input signal's maximum eigenvalue, and explain the fundamental trade-off between convergence speed and steady-state misadjustment.	UC-2.1, OPC-3.1
13.		Compare STFT and Discrete Wavelet Transform (DWT) for non-stationary signal analysis. Explain the Heisenberg uncertainty principle limitation in time-frequency resolution, and justify when multiresolution wavelet analysis outperforms fixed-window Fourier methods.	UC-2.1, PC-2.1
14.		Formulate the alias cancellation and perfect reconstruction conditions for a two-channel quadrature mirror filter (QMF) bank. Explain how polyphase matrix representation simplifies the design and guarantees linear phase.	PC-2.1, OPC-2.1
15.		Formulate convexity conditions for least-squares system identification in the presence of colored noise. Explain the role of regularization (e.g., Tikhonov) and manifold constraints in preventing overfitting during adaptive parameter estimation.	UC-2.1, OPC-3.1
16.		Formulate a complete computational pipeline for real-time adaptive noise cancellation in non-stationary environments. Justify the choice of algorithm (LMS vs. RLS vs. NLMS), specify convergence criteria, design the preprocessing/feature extraction stage, and define a validation protocol with metrics and failure mode analysis.	UC-2.1, OPC-2.1, OPC-3.1, PC-2.1

2. Description of the rating scale

Under the rating system, student performance in the course "Modern Digital Signal Processing / Современная цифровая обработка сигналов" is assessed through ongoing assessments and midterm assessments. The rating system for assessing student knowledge is based on a set of assessment activities (checkpoints) optimally spaced throughout the course. The principles of the rating system for assessing student knowledge are based on the requirements described in the Regulation on the Organization of the Educational Process Based on the Rating System for Assessing Student Knowledge at the North Caucasus Federal University. Student performance is assessed through ongoing assessments culminating in a Pass/Fail defense.

3. Competencies assessment criteria

The grade “**excellent**” is given to a student if he/she:

systematically identifies complex signal processing challenges, conducts rigorous mathematical analysis, and diagnoses root causes of spectral distortion, aliasing, or system instability; confidently searches, selects, and systematizes theoretical foundations and algorithmic approaches to design optimal processing pipelines; precisely evaluates numerical risks (e.g., finite-precision effects, convergence bounds, spectral leakage, filter instability) and selects the most robust solution based on computational and theoretical constraints; communicates technical findings clearly, collaborates effectively in code reviews and peer validation, and adheres strictly to reproducible research standards and academic integrity policies; demonstrates deep conceptual mastery of time-frequency analysis, digital filter theory, adaptive estimation, and hybrid classical-AI architectures. Competencies UC-2.1, OPC-2.1, OPC-3.1, PC-2.1 have been mastered to the maximum level.

The grade “**good**” is given to a student if he/she:

correctly identifies standard signal processing tasks and performs structured analysis using established mathematical frameworks; systematically searches and selects appropriate transform-domain or statistical methods to address processing objectives; accurately evaluates algorithmic trade-offs (e.g., filter order vs. transition width, convergence speed vs. steady-state error, window main-lobe vs. side-lobe levels) and selects functionally sound solutions; engages constructively in technical discussions, follows documentation standards, and maintains basic reproducibility practices; shows solid understanding of core DSP principles, Z-domain stability, and parametric spectral estimation. Competencies UC-2.1, OPC-2.1, OPC-3.1, PC-2.1 have been mastered at an intermediate level.

The grade “**satisfactory**” is given to a student if he/she:

identifies basic signal processing problems with occasional gaps in mathematical formulation; analysis relies partially on guided examples, standard templates, or high-level library abstractions; selects conventional methods with limited justification of parameter choices or domain assumptions; evaluates algorithmic limitations superficially, occasionally overlooking numerical stability, aliasing effects, or convergence criteria, but arrives at functionally acceptable solutions; participates in collaborative work with basic technical communication skills and follows core submission requirements; demonstrates foundational knowledge of DSP concepts with room for deeper analytical rigor and independent validation. Competencies UC-2.1, OPC-2.1, OPC-3.1, PC-2.1 have been mastered at a minimum level.

The grade “**unsatisfactory**” is given to a student if he/she:

struggles to formally define signal processing problems or conduct systematic mathematical analysis; relies heavily on trial-and-error or unverified library calls without understanding underlying difference equations, transform properties, or stability conditions; fails

to appropriately select or justify algorithmic approaches for given signal characteristics; overlooks critical risks such as spectral folding, pole-zero instability, or divergence in adaptive routines, resulting in non-functional or theoretically invalid implementations; demonstrates inadequate technical communication, does not adhere to reproducibility or citation standards, and cannot independently validate results against theoretical expectations; lacks foundational understanding of sampling theory, frequency-domain representations, and statistical signal modeling. Competencies UC-2.1, OPC-2.1, OPC-3.1, PC-2.1 have not been mastered at the minimum level.