GUJARAT TECHNOLOGICAL UNIVERSITY

Program Name: Bachelor of Engineering
Level: UG
Branch: Electrical Engineering
Subject Code: BE04009051

Course/Subject Name: Signals and Systems

w.e.f. Academic Year:	2024-25
Semester:	4
Category of the Course:	Professional Core Course

Prerequisite:	Basic knowledge of calculus, differential equations and complex numbers is required. Familiarity with trigonometric identities, exponential functions, and fundamental concepts of sequences and series will aid in understanding signal operations and system analysis techniques.
Rationale:	The course on Signals and Systems is designed to develop foundational analytical competencies essential for higher-level electrical engineering subjects. It systematically introduces continuous-time (CT) and discrete-time (DT) signals, their classification, and fundamental operations necessary for signal representation and manipulation. The syllabus addresses characterization of systems with respect to linearity, time-invariance, causality, and stability to facilitate accurate modeling and analysis. Core analytical tools, including convolution, Fourier series, Fourier transforms, Laplace transform, and z-transform, are incorporated for time- and frequency-domain studies. Sampling and reconstruction concepts strengthen the bridge between analog and digital domains, supporting applications in power electronics, electrical machines, power systems and control systems.

Teaching and Examination Scheme:

Teaching-Learning Scheme (in Hours per Semester)					Total Credits = TH/30	Assessment Pattern and Marks					Total Marks
						Theory		Tutorial / Practical			
L	T	P	PBL*	TH		ESE (E)	PA (M)	PA (I)	PBL (I)	ESE (V)	
45	0	30	15	90	3	70	30	20	30	50	200

Where L = Lecture, T= Tutorial, P= Practical, TW/SL = Term-Work / Self-Learning, TH = Total Hours, ESE = End-Semester Examination, PA = Progressive Assessment

*** Problem Based Learning (PBL) aims to accommodate learning beyond syllabus as per clause 9.4 of NBA manual.**

Course Content:

Unit No.	Content	No. of Hours	% Weightage	CO
1.	**Introduction to Signals:** Introduction to Continuous-Time(CT) and Discrete-Time(DT) Signals, Size of a Signal (CT & DT), Signal Energy and Power (CT & DT), Classification of Signals (CT & DT), Elementary signals (CT & DT), (Unit step function, Unit impulse function Exponential, Discrete-Time Sinusoid, Discrete-Time Complex Exponential) and their properties, Basic Operations on Signals (CT & DT) (Time Shifting, Time Scaling, Time Reversal, Addition, Subtraction, Multiplication), Even and Odd functions, Application in electrical engineering(e.g. Representation of input current waveform of 12 pulse rectifier as addition of periodic square and pulse signals)	7	15	CO1
2.	**Introduction to Systems:** Definition and representation of CT and DT systems, Classification of system (CT & DT) (Linear and Nonlinear Systems, Time-Invariant and Time-Varying Systems, Instantaneous and Dynamic Systems, Causal and Non-causal Systems, Invertible and Non-invertible Systems, Stable and Unstable Systems), Application of concepts learned in electrical engineering(e.g. Importance of linearity and time invariance in analysis of any electrical system, Linearization of a non-linear system about an operating point to analyse it a s a linear system)	8	18	CO2
3.	**Time-Domain Analysis of CT and DT Systems:** The Unit Impulse Response of CT and DT Linear Time-Invariant(LTI) Systems, Impulse response characterization of CT and DT LTI systems, The convolution sum and integral, Properties of convolution sum and integral, Application of convolution integrating in obtaining the response of series RL and RC circuit	7	17	CO3
4.	**Fourier analysis of CT and DT signals:** Periodic CT and DT Signal Representation by Trigonometric and Exponential Fourier Series, Fourier Spectra of a periodic CT and DT signal for trigonometrical and exponential Fourier series representation, Dirichlet's Conditions, Effect of wave symmetry on Fourier series coefficients, Properties of CT and DT Fourier series, Parseval's Theorem, CT and DT aperiodic signal representation by the Fourier Transform, Fourier Spectra of an periodic CT and DT signal, Properties of CT and DT Fourier Transform, Application of Fourier analysis in Electrical engineering (e.g. Fourier analysis of inverter output voltage and current to design a filter, Fourier analysis of utility voltage and current waveforms during fault to take protective action)	10	24	CO4

5.	**CT System Analysis using Laplace Transform and DT System Analysis using z-Transform:** Introduction to the Laplace Transform, Finding the Inverse Transform, Properties of Laplace Transform, Connection Between the Fourier and Laplace Transforms, Properties of Laplace Transform, Solution of Differential and Integro-Differential Equations, Introduction to the z-Transform, Inverse Transform by Partial Fraction Expansion and Tables, Inverse *z*-Transform by Power Series Expansion, Connection Between the DTFT and the *z*-Transform, Transforms, Properties of z-Transform, Solution of Linear Difference Equations using z-Transform	9	20	CO5
6.	**Sampling and Reconstruction:** Representation of a Continuous-Time Signal by Its Samples, The Sampling Theorem, Impulse-Train Sampling, Sampling with a Zero-Order Hold, Reconstruction of a Signal from Its Samples Using Interpolation, The Effect of Under sampling: Aliasing	4	6	CO5
	Total	**45**	**100**	

Course Outcome:

After Completion of the Course, Student will able to:

No	Course Outcomes
01	*Analyze* and *classify* continuous-time (CT) and discrete-time (DT) signals based on their characteristics (energy, power, periodicity, symmetry) and perform basic operations such as time shifting, scaling, and addition.
02	*Analyze* the behavior of CT and DT systems by *identifying* their linearity, time-invariance, causality, stability, and dynamic properties.
03	*Determine* the time-domain response of CT and DT Linear Time-Invariant (LTI) systems using convolution in integral and summation forms.
04	*Analyze* Fourier series and Fourier transform techniques to *examine* CT and DT signals and *evaluate* their frequency spectra.
05	*Apply* Laplace and z-transform techniques to *solve* differential and difference equations, and *illustrate* the principles of sampling and reconstruction.

Suggested Specification Table with Marks(Theory):

Distribution of Theory Marks					
RLevel	ULevel	ALevel	NLevel	ELevel	CLevel
15	15	25	25	20	0

Where R:Remember;U:Understanding; A:Application ,N:Analyze and E:Evaluate C:Create (as per Revised Bloom's Taxonomy)

References/Suggested Learning Resources:

(a) Books:

1. Linear Systems and Signals by B.P.Lathi, Oxford University Press
2. Signals and Systems by Alan V. Oppenheim, Alan S. Wilsky and Nawab, Prentice Hall
3. Signals and Systems by Simon Haykin and Bary Van Veen, Wiley- India Publications
4. Signal and Systems by Anand Kumar, 3rd Edition, PHI
5. Signals and Systems by K. Gopalan, Cengage Learning (India Edition)
6. Signals and Systems by Michal J. Roberts and Govind Sharma, Tata Mc-Graw Hill Publications

b) Open-Source Software:

1. **Scilab** (Link) – Free platform for numerical computation and signal processing, Has dedicated signal processing toolboxes.
2. **GNU Octave** (Link) – Ideal for signal operations, Fourier analysis, convolution, and transforms
3. **LTspice** (Link) – Circuit simulation for RC/RL circuit response, sampling circuits, and filters.

C) Websites for Learning and Simulation:

1. **Shah, K. K. Signals and Systems [MOOC-Hindi]. NPTEL-NOC [Link]**
2. **Jagannatham, A. K. Signals and Systems [MOOC]. NPTEL-NOC [Link]**
3. **Oppenheim, A. V. Signals and Systems [MOOC]. MIT-OCW [Link]**
4. **GeoGebra Graphing Calculator** (Link) – Web-based math and signal plotting tool, Useful for visualizing time-domain operations (shift, scale, reverse).
5. **PhET: Fourier – Making Waves** (Link) – An educational simulation that allows you to construct custom waveforms by combining sine and cosine waves directly. It's interactive and visually intuitive—excellent for concept building.

Suggested Course Practical List (15 Experiments)

1. To generate continuous-time (CT) and discrete-time (DT) signals such as step, impulse, exponential, and sinusoidal
2. To apply time-domain operations (shifting, scaling, and reversal) on a given signal and perform addition, subtraction, and multiplication with other signals to analyze their effects
3. To synthesize the input current waveform of a 12-pulse rectifier by adding phase-shifted periodic square/pulse signals and analyze its harmonic composition.
4. To test given CT/DT systems for linearity, time-invariance, causality, stability, and invertibility using input–output experiments.
5. To obtain impulse/step responses of CT/DT systems, relate them to system representation (difference/differential equations, transfer functions), and assess stability.
6. To linearize a nonlinear system around a chosen operating point and validate the small-signal linear model against the original nonlinear model.

7. To compute convolution (sum for DT, integral for CT) numerically, verify properties (commutativity, associativity), and compare with simulation results
8. To obtain the impulse and step responses of series RC and RL circuits, derive the impulse response (h(t)), compute transfer function H(s), and validate time-domain response via convolution.
9. To compute and visualize the trigonometric/exponential Fourier series approximation of a square and triangle wave, and study convergence as harmonic count increases.
10. To verify how even/odd symmetry affects Fourier series coefficients
11. To analyze the harmonic content of a 120 degree, 180 degree mode operated inverter or input current of a 12 pulse rectifier using Fourier series
12. To analyze the harmonic content of an inverter (or synthesized PWM) output using Fourier transform
13. To compute inverse Laplace transforms using partial-fraction expansion, obtain impulse and step responses from H(s), and verify time-domain signals by simulation.
14. To solve linear ordinary differential equations with given initial conditions using the Laplace transform and validate results with time-domain simulation.
15. To compute z-transforms of discrete sequences, invert them by partial fraction expansion and power-series expansion, and examine Region of Convergence (ROC) implications.
16. To solve linear constant-coefficient difference equations using the z-transform, implement the system in software, and analyze stability from pole locations and ROC.
17. To verify the sampling theorem by sampling a continuous-time sinusoidal signal at various sampling frequencies and observing aliasing when the sampling frequency violates the Nyquist criterion.
18. To simulate impulse-train sampling of a continuous-time signal and reconstruct it using a zero-order hold, observing the staircase effect.
19. To reconstruct a sampled signal using sinc (ideal) interpolation and compare with under-sampled cases to illustrate aliasing and reconstruction error.

List of Laboratory Resources Required:

1. Function Generators
2. Digital Storage Oscilloscope (DSO) with FFT/Spectrum Mode
3. Spectrum Analyzer
4. Power Quality Analyzer / Harmonic Analyzer
5. Dedicated Sampling and Reconstruction Trainer Kits

List of suggested activities for Problem Based Learning:

Sr. No.	Name of Activity	Activity Description and No. of Hours	Suggested Evaluation Criteria	Targeted CO
1.	Signal Operations Coding	Develop MATLAB/Scilab/Octave codes for time shifting, scaling, reversal, addition, and multiplication of CT & DT signals. **(6 hours)**	Correctness of code, output plots, explanation of results	CO1, CO2
2.	System Property Verification via Simulation	Simulate systems to check linearity, time-invariance, causality, and stability. **(6 hours)**	Simulation outputs, property justification	CO2
3.	Research and	Conduct a literature review or case study on	Relevance of case	CO2

	Case Study on System Properties	the role of **linearity and time invariance** in real-world electrical systems (small-signal linearization for buck converters, linearization of Synchronous Generator Swing Equation). Identify at least two practical scenarios where each property is significant. Prepare a **3–4 page report** with references. **(8 hours)**	studies, depth of analysis, clarity in explaining each property, use of authentic references ,quality of report presentation	
4.	Convolution in RC/RL Circuits	Apply convolution to find circuit response and verify via LT-spice simulation. **(6 hours)**	Correct convolution steps, simulation comparison	CO3
5.	Fourier Series Harmonic Analysis of PWM waveform	Derive Fourier series coefficients of PWM waveform and identify dominant harmonics **(8 hours)**	Coefficient derivation, harmonic spectrum plot, THD estimation	CO4
6.	Fourier Transform for Fault Signal Analysis	Perform FFT on fault current waveform and identify harmonic/frequency content relevant to relay operation. **(8 hours)**	Frequency-domain plot, interpretation of harmonic components	CO4
7.	Laplace Transform for Differential Equations	Solve a given difference equation using Laplace transform and obtain the time response **(4 hours)**	Correct inversion, numerical output, pole-zero plot	CO5
8.	z-Transform for Difference Equations	Solve a given difference equation using z-transform, reconstruct sequence **(4 hours)**	Correct inversion, numerical output, pole-zero plot	CO5
9.	Sampling & Aliasing Demonstration	Sample a sinusoidal signal at varying rates, demonstrate aliasing, reconstruct using ZOH/sinc **(8 hours)**	Sampling plots, reconstruction comparison, aliasing analysis	CO5
10.	DIY Mini Project: Sample-and-Hold Circuit	Build a sample-and-hold circuit using LF398/op-amp, observe sampling with DSO, and measure hold droop. **(10 hours)**	Working hardware, circuit diagram, measurement vs theory	CO5
11.	DIY Mini Project: Active Low-Pass Filter for Reconstruction	Design and implement an active low-pass filter to reconstruct sampled signal. **(10 hours)**	Frequency response, reconstruction accuracy, report	CO5
12.	Video-Based Learning Module	Watch selected NPTEL/MIT OCW lectures on signals and system and prepare a summary. **(10 hours)**	Summary sheet, key learning points, references	**CO1–CO5** (depending on topic)
13.	Research & Application	Explore applications of signals & systems in power electronics, machines, or protection	Relevance, quality of references, clarity of	CO1–CO5 (depending

	Review Report	systems, and write a 2–3 page technical note. **(8 hours)**	application link	on topic)

Note:

1. All the suggested activity should be related to the subject.
2. The number of hours is suggestive. Faculty can sub-divide the number of hours based on the activity. However, total number of hours is fixed.
3. Rubrics for the evaluation can be prepared by the faculty.
4. Preferably these activities should be conducted on some LMS and not using pen and paper. The LMS which can be used are as follows (But not limited to): Google Classroom, MS Teams, Moodle etc.
5. The usage of LMS platform shall be done for as many activities as possible. The assessment of these activities shall also be carried out on the some LMS platform.
6. The total work assigned should be of 30 hours to every student.
7. The faculty/teacher/teachers should display the distribution of Self Learning activities at the beginning of the semester.
8. The course file should include the Rubrics of the distribution of marks as per the distribution of activities.
9. All records pertaining to the evaluation and assessment of self-learning activities must be properly maintained and preserved at the institute level. These records should be made available to the university upon request.
10. Institutes are encouraged to utilize digital platforms, such as Microsoft Teams, for effective record-keeping and to ensure transparency in the evaluation and assessment of self-learning activities.

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