Course Title: **Quantum Signal Processing**

Credit Hrs: 3

Prerequisites:

- Undergraduate Level Linear Algebra, Quantum Mechanics,
- Classical Signal Processing: Fourier transforms, convolution, filters
- Introductory Quantum Computing

Course Description:

This course introduces Quantum Signal Processing (QSP) and related frameworks such as Quantum Singular Value Transformation (QSVT). It generalizes classical signal processing concepts Fourier analysis, filtering, convolution into the quantum computing paradigm. Applications include Hamiltonian simulation, quantum sensing, optical coherence, and noise analysis. The course emphasizes both mathematical foundations and practical implementations in simulators like Qiskit

Course Objectives:

- To provide a solid understanding of **Quantum Signal Processing (QSP) and Quantum Singular Value Transformation (QSVT)** and their theoretical foundations.
- To develop the ability to **embed operators into quantum circuits** using block encoding and polynomial approximations.
- To relate **classical DSP concepts -** Fourier transforms, filters, and convolution—to quantum algorithms.
- To implement **QSP algorithms in simulators** such as Qiskit or Pennylane.
- To explore **applications in Hamiltonian simulation, quantum linear systems, and quantum sensing.**
- To analyze **algorithm performance, accuracy, and robustness** under realistic conditions.

Course Learning Outcomes (CLOs)

- Explain QSP and QSVT theory with derivations from core textbooks.
- Apply block encoding and qubitization to embed operators in quantum circuits.
- Relate classical DSP concepts (filters, convolution) to quantum polynomial transformations.
- Implement QSP algorithms in simulators (Qiskit/Pennylane).
- Analyze QSP applications in Hamiltonian simulation, quantum sensing, and optical systems.

Course Contents

Week	Contents
1	Introduction to QSP - Qubits, unitaries, controlled operations
2	Classical DSP Foundations - Fourier transforms, filters, convolution
3	Operator Functions in Quantum Computing - Eigen decomposition, matrix functions
4	Quantum Phase Estimation - Eigenvalue extraction
5	Quantization & Polynomial Approximations - Chebyshev polynomials, block encoding
6	Core QSP Concepts - Polynomial transformations via single-qubit rotations
7	Midterm Exam
8	From QSP to QSVT - Singular-value transformations, matrix inversion
9	Hamiltonian Simulation - Polynomial vs Trotter methods
10	Quantum Linear Systems & Filtering - Classical Wiener filters vs quantum linear solvers
11	Circulant Matrices & Convolution - Quantum convolution, circulant synthesis
12	Quantum Sensing - Introduction to quantum sensing principles, interferometry basics, conceptual examples of precision measurement using quantum states of light.
13	Applications of Quantum Sensing - Detailed study of quantum states of light (coherent, squeezed states), applications in sensing, QSP simulations of interferometry, conceptual problem-solving.
14	Error & Resource Analysis - Accuracy vs degree, robustness, noise analysis
15	Sensing simulation, Hamiltonian simulation, convolution filter design
16	Final Exam

Textbooks/ References:

- Nielsen & Chuang - Quantum Computation and Quantum Information, 10th Anniversary Edition
- Mandel & Wolf - Optical Coherence and Quantum Optics
- MacDonald - Noise and Fluctuations: An Introduction
- Oppenheim & Schafer - Discrete-Time Signal Processing

Assessments:

- Assignments: 10%
- Quizzes: 10%
- Midterm Exam: 30%
- Final Exam: 50%