Department of Electronics and Communication Engineering, JNTUH

Course Structure and Syllabus for a Minor Degree in Quantum Technologies

Minor Degree *(4 Semesters)*

	Theory (# Credits)	Laboratory (# Credits)	Total Credits
II Year II Sem	Foundations of Quantum Technologies (3)	–	3
III Year I Sem	Engineering Foundations of Quantum Technologies (3)	Basic Programming Lab (1)	4
III Year II Sem	Introduction to Quantum Sensing (3)	Basic Laboratory Course for Quantum Technologies (1)	4
IV Year I Sem	Introduction to Quantum Communication (3)	--	3
IV Year II Sem	Project/ Experiential Learning (4)	--	4
		Total Credits	**18**

Foundations of Quantum Technologies

B.Tech II Yr II Sem **L T P C 3 0 0 3**

Course Objectives:

- To provide a rigorous foundation in the mathematical and theoretical aspects of quantum mechanics.
- To develop an intuition for quantum states using Dirac notation and Hilbert space.
- To bridge the gap between classical statistical mechanics and quantum statistics.
- To introduce the fundamental concepts of information theory and computational complexity in the quantum regime.

Course Outcomes: After completion of this course, the student will be able to:

1. Apply Hamiltonian mechanics and mathematical techniques to quantum systems.
2. Formulate quantum problems using postulates, operators, and state vectors.
3. Distinguish between classical and quantum statistics for Bosons and Fermions.
4. Analyze information quantification using Shannon entropy and quantum decoherence.
5. Classify computational problems into classical (P, NP) and quantum (BQP) complexity classes.

SYLLABUS

UNIT – I: Foundations of Quantum Mechanics

Historical Evolution: Planck's quantum hypothesis, Photoelectric effect, Atomic spectra, Bohr's quantization principle, De Broglie's Wave-particle duality.

Classical to Quantum Transition: Brief overview of classical physics; Hamiltonian function and Hamilton's equations, Phase-space description of a system. Connection and Equivalence with Newton's laws for simple systems: Free particle, Particle moving in a conservative potential, Harmonic oscillator, and Hydrogen atom.

UNIT – II: Postulates and Formalism

Mathematical Framework: State vectors and Hilbert Space, Dirac Bra-Ket notation, Measurables and Hermitian Operators, Unitary Transformations.

The Schrodinger Picture: Schrodinger Equation and Time evolution of quantum states, Measurement Postulate, Schrodinger vs. Heisenberg vs. Interaction pictures.

Operators and Principles: Eigenvalues, Expectation values, and Matrix elements; Heisenberg's Uncertainty principle. Density operator formalism – Pure and Mixed states.

UNIT – III: Applications and Quantum Systems

Standard Models: Applications of postulates: Particle in a box, Hydrogen atom, Harmonic Oscillator. Number states, ladder operators, and Coherent states of a harmonic oscillator.

Advanced Concepts: Superposition and Entanglement in quantum mechanics, No-cloning theorem.

Spin Dynamics: Spin and Angular momentum – spin half particles; Rabi problem of a spin-half particle in a rotating magnetic field. Intro to Bosons and Fermions.

UNIT – IV: Statistical Physics and Information Science

Statistical Mechanics: Review of first and second laws of thermodynamics; Thermal Equilibrium and Gibbs principle. Applying Gibbs principle to Classical and Quantum harmonic oscillators. Quantum statistics: Fermi-Dirac and Bose-Einstein distributions.

Information Science: Digital communication and information; Quantifying information in terms of Shannon entropy. Basic ideas of quantum information, Decoherence and noise, Introductory ideas of Kraus operators.

UNIT – V: Computational Complexity and PQC

Classical Complexity: Qualitative ideas of a Turing machine (Deterministic and Non-deterministic). Time and Space complexity: P vs NP, PSPACE.

Quantum Complexity: Quantum complexity classes: Q, EQP, BQP, BPP, QMA.

Future Trends: Introduction to Post-Quantum Cryptography (PQC) and its necessity in the quantum era.

TEXT BOOKS:

1. *Physics (Quantum Mechanics for Engineers)*, A. B. Bhattacharya & Atanu Nag, Khanna Publishing House (2025).
2. *Introduction to Quantum Mechanics*, Griffiths D. J., 3rd Edition, Cambridge University Press (2024).
3. *Introduction to the Theory of Computation*, Michael Sipser, 3rd edition, Cengage India (2014).

REFERENCE BOOKS:

1. *Principles of Quantum Mechanics*, Shankar, R., 2nd edition, Springer (2014).
2. *Quantum computation and quantum information*, Nielsen M. A., and Chuang I. L., Cambridge University Press (2010).
3. *Statistical Mechanics*, Pathria R. K., Paul D. Beale, 4th edition, Academic Press (2021).
4. *Quantum Information Science*, Manenti R., Motta M., Oxford University Press (2023).

ENGINEERING FOUNDATIONS OF QUANTUM TECHNOLOGIES

B.Tech III Yr I Sem **L T P C 3 0 0 3**

Course Objectives:

1. **To understand classical RLC networks and transmission lines as foundations for quantum resonators.**
2. **To study abstract models of computation and complexity classes relevant to quantum benchmarking.**
3. **To analyze noise sources and signal-to-noise ratios (SNR) in linear amplification.**
4. **To explore classical and digital communication theories including entropy and channel encoding.**
5. **To provide a foundation in classical cryptography and the transition to Post-Quantum Cryptography (PQC).**

Course Outcomes: After completion of this course, the student will be able to:

1. **Analyze analog RLC circuits and transmission line resonators for quantum hardware interfaces.**
2. **Evaluate computational problems using Turing machines and Hierarchy of languages.**
3. **Quantify noise types (Shot, Johnson-Nyquist) and understand the quantum limits of amplification.**
4. **Apply information entropy concepts to noiseless and noisy channel encoding.**
5. **Distinguish between symmetric/asymmetric cryptography and evaluate PQC protocols.**

SYLLABUS

UNIT – I: Electrical Networks and Transmission Lines

Analog Networks: Study of RLC circuits: Resonances (Series and Parallel), Impedance analysis, and Quality factors (Q). Microwave Foundations: Transmission line basics: Telegrapher equations, Wave impedance, and Impedance matching.Resonators: Design and analysis of Transmission line resonators relevant to superconducting quantum circuits.

UNIT – II: Computer Architecture and Theory of Computation

Architecture Basics: Overview of the Arithmetic Logic Unit (ALU) and Memory hierarchies. Computation Models: Finite State Machines (FSM) and Turing Machines. Overview of the Hierarchy of languages: Regular, Context-Free, Turing Decidable, and Turing Recognizable.Complexity Theory: Fundamentals of Time and Space complexity; Introduction to P vs NP and NP-completeness.

UNIT – III: Noise, Signals, and Amplification

Noise Characterization: Types of Noise: Shot Noise, Johnson-Nyquist Noise, and 1/f (Flicker) noise. Signal conditioning and noise mitigation strategies. Linear Amplifiers: Linear Amplifier theory: Signal-to-Noise Ratio (SNR), Added Noise, Noise Figure, and Dynamic Range.

Quantum Limits: Introduction to Noise temperature and the fundamental quantum limits on noise in linear amplifiers**.**

UNIT – IV: Analog and Digital Communications

Analog Communication: Fundamentals of Quadrature Amplitude Modulation (QAM). Demodulation techniques: Heterodyne vs. Homodyne detection. Information Theory: Concept of Information Entropy; Shannon's theorems for Noiseless and Noisy channel encoding.

UNIT – V: Cryptography and Quantum Security

Foundations: Basics of Number Theory and Random Number Generation (RNG). Classical Protocols: Private key and Public key systems; Symmetric and Asymmetric cryptography. Detailed overview of One-time pad, RSA, and Diffie-Hellman (DH) protocols. Quantum Transition: Introduction to Post-Quantum Cryptography (PQC) and the evolution of cryptographic universes.

TEXT BOOKS:

1. Architectures and Cryptographic Universes, A. B. Bhattacharya, Khanna Publishing House (2025).

2. Introduction to the Theory of Computation, Michael Sipser, 3rd edition, Cengage India (2014).

3. Microwave Engineering, David Pozar, 4th edition, Wiley (2013).

REFERENCE BOOKS:

1. The Art of Electronics, Paul Horowitz and Winfield Hill, 3rd edition, Cambridge University Press (2015).

2. All-in-One Electronics Simplified, A.K. Maini, Khanna Book Publishing Co. (2022).

3. Information Theory, Robert B. Ash, Dover Publications (2003).

4. Foundations of Quantum Technologies, A. B. Bhattacharya, Khanna Publishing House **(2025).**

5. Protecting Information – From Classical error correction to quantum cryptography, Susan Loepp and William K. Wootters, Cambridge University Press (2006).

BASIC PROGRAMMING LAB IN QUANTUM TECHNOLOGIES

B.Tech III Yr I Sem **L T P C 0 0 2 1**

Course Objectives:

1. To implement Object-Oriented Programming (OOP) for scientific computing.
2. To solve complex differential equations and linear algebra problems numerically.
3. To apply statistical methods and Monte Carlo simulations to data sets.
4. To simulate fundamental quantum mechanical models (Rabi, Jaynes-Cummings) using Python/Julia.

Course Outcomes: After completion of this course, the student will be able to:

1. Design efficient programs using classes and advanced data structures.
2. Solve Boundary Value Problems (Poisson, Laplace) using numerical techniques.
3. Perform matrix diagonalizations and SVD for quantum state analysis.
4. Execute Monte Carlo sampling and error analysis for statistical data.
5. Simulate quantum two-level systems and electromagnetic field distributions.

LIST OF EXPERIMENTS

1. **OOP for Science:** Create a Python/Julia class for "Complex Numbers" or "Quantum States" to perform addition, multiplication, and normalization using Object-Oriented principles.
2. **Memory & Storage:** Write a program to demonstrate efficient data retrieval from large CSV/HDF5 files and monitor memory allocation for large arrays.
3. **Algorithmic Efficiency:** Implementation of Sorting (QuickSort) and Searching algorithms with a comparison of their execution time (Benchmarking).
4. **Mathematical Foundations:** Write recursive and iterative functions to compute GCD and Prime Factorization for large integers.
5. **ODE Solvers:** Numerical solution of 2nd Order Linear ODEs with constant and variable coefficients (e.g., Damped Harmonic Oscillator).
6. **Partial Differential Equations (PDEs):** Solving the **Poisson and Laplace equations** using the Finite Difference Method (FDM).
7. **Wave & Diffusion:** Numerical simulation of the 1D Wave equation and Diffusion equation with visualization of time-evolution.
8. **Matrix Operations:** Write scripts to compute Matrix Inverse and solve the **Eigenvalue Problem** for Hermitian matrices (relevant to Quantum Hamiltonians).

9. **Decomposition Techniques:** Implementation of **Singular Value Decomposition (SVD)** and Matrix Diagonalization for data compression or state reduction.
10. **Statistical Computing:** Generation of Pseudo-random numbers to compute statistical moments (Mean, Variance, Skewness) and performing **Least Squares Fitting** on experimental data.
11. **Stochastic Methods:** Implementing **Monte Carlo sampling** and performing Hypothesis Testing with Error Analysis.
12. **Coupled Systems:** Solving for the Eigen-energies of a coupled two-level quantum system.
13. **Light-Matter Interaction:** Simulation of the **Jaynes-Cummings Model** (Two-level system coupled to an oscillator) to find energy levels.
14. **Quantum Dynamics:** Numerical solution of the **Rabi Problem** for a driven two-level system and plotting the Coherent States of a damped oscillator.
15. **EM Field Mapping:** Simulation of Electrostatic charge distributions and Magnetostatic current distributions using **Finite Element Techniques (FET)**.

SUGGESTED SOFTWARE TOOLS:

- **Primary Language:** Python (NumPy, SciPy, Matplotlib, QuTiP) or Julia.
- **Documentation:** Jupyter Notebooks / LaTeX for report generation.

REFERENCES:

1. **AICTE Prescribed Textbook:** *Physics (Quantum Mechanics for Engineers)*, A. B. Bhattachraya & Atanu Nag, Khanna Publishing House (2025).
2. *Computational Physics*, Nicholas Giordano & Hisao Nakanishi, 2nd Edition, Pearson Addison Wesley.
3. *Engineering Physics*, A. B. Bhattachraya, Khanna Publishing House (2025).
4. *Numerical Recipes: The Art of Scientific Computing*, Press et al., Cambridge University Press.

INTRODUCTION TO QUANTUM SENSING

B.Tech III Yr II Sem **L T P C 3 0 0 3**

Course Objectives:

1. To understand the transition from classical photodetection to quantum-limited sensing.
2. To analyze classical and quantum noise sources and their impact on measurement sensitivity.
3. To study the mathematical framework of Quantum Cramer-Rao bounds and Fisher Information.
4. To explore non-classical states of light (Squeezed, Fock) and their Wigner distributions.
5. To examine real-world applications in gravimetry, magnetometry, and single-photon sensing.

Course Outcomes: After completion of this course, the student will be able to:

1. Differentiate between classical noise (Johnson, Flicker) and quantum measurement limits.
2. Formulate measurement strategies using projective and non-demolition (QND) techniques.
3. Characterize quantum states of light using Tomography and Husimi Q functions.
4. Calculate sensitivity limits using Quantum Cramer-Rao bounds.
5. Evaluate the performance of atomic and solid-state spin sensors for field applications.

SYLLABUS

UNIT – I: Classical Sensing and Sensitivity Limits

Foundations: Basics of Classical sensing and Photo detection. **Classical Noise:** Characterization of Johnson Noise, Telegraph noise, and Flicker (1/f) noise. **Information Theory in Sensing:** Sensitivity of classical measurements; introduction to Classical Fisher Information and Cramer-Rao bounds (CRB).

UNIT – II: Quantum Measurement Theory

Measurement Paradigms: Projective and orthogonal measurements; Approximate and non-orthogonal measurements. **Continuous & Weak Sensing:** Weak continuous measurements and Error-disturbance relations. **Breaking the Limit:** Standard Quantum Limits (SQL) and Quantum Non-Demolition (QND) measurements for precision tracking.

UNIT – III: States of Light and Phase Space

Non-Classical States: Study of Fock states, Coherent states, and Squeezed states. **Tomography:** Quantum state tomography and the reconstruction of density matrices. **Quasi-Probability Distributions:** Wigner quasi-probability distribution, P-distribution, and Husimi Q function.

UNIT – IV: Quantum Detection and Information Bounds

Photodetection: Quantum theory of square-law detectors; Intensity measurements vs. Linear Detectors for Quadrature Measurements. **Quantum Estimation:** Derivation and application of

Quantum Cramer-Rao bounds. **Enhanced Sensing:** Fundamentals of Single photon-based sensing and Entanglement-based sensing protocols.

UNIT – V: Atomic Sensing and Applications

Spin-Based Sensors: Atomic state-based sensing and Solid-state spin-based sensing (e.g., NV centers in diamond). **Field Applications:** Quantum Gravimetry (measuring local gravity) and Quantum Magnetometry (ultra-sensitive magnetic field detection).

Survey: Future trends in quantum-enhanced imaging and navigation.

TEXT BOOKS:

1. *Physics (Quantum Mechanics for Engineers)*, AICTE Prescribed Textbook, Khanna Publishing House (2025).
2. *Quantum Information Science*, Manenti R., Motta M., 1st Edition, Oxford University Press (2023).
3. *Quantum Measurement and Control*, Howard Wiseman and David Milburn, Cambridge University Press (2014).

REFERENCE BOOKS:

1. *Quantum Measurement*, Vladimir Braginsky and Farid Ya Khalili, Cambridge University Press (1995).
2. *Quantum Computing Mechanics*, A. B. Bhattacharya, Khanna Publishing House (2025).
3. *Principles of Quantum Methods in Sensing*, Relevant Journal Reviews/Open Access Materials.

QUANTUM TECHNOLOGIES LABORATORY

B.Tech III Yr II Sem **L T P C 0 0 2 1**

Course Objectives:

1. To master precision optical measurements using interferometry and polarization optics.
2. To characterize RLC resonators and RF networks using Vector Network Analyzers (VNA).
3. To understand digital logic and data acquisition systems essential for quantum control.
4. To implement quantum protocols and algorithms on cloud-based quantum simulators.

Course Outcomes: After completion of this course, the student will be able to:

1. Conduct wavelength and intensity measurements using optical interferometers.
2. Characterize high-frequency 2-port and 3-port networks using S-parameters.
3. Design and test digital circuits including flip-flops and encoders.
4. Execute signal demodulation and digitisation techniques for data acquisition.
5. Program and run quantum circuits on cloud-accessible quantum processors.

LIST OF EXPERIMENTS

1. **Interferometric Measurements:** Determination of wavelength and intensity profiles using Michelson and Fabry-Perot interferometers.
2. **Diffraction Analysis:** Study of single-slit and grating diffraction patterns to determine track pitch and slit width.
3. **Polarization Control:** Characterization of Polarization Beam Splitters (PBS), Half-Wave Plates (HWP), and Quarter-Wave Plates (QWP).
4. **Microscopy:** Measuring magnification and characterizing spherical/chromatic aberrations in optical systems.
5. **Resonance Characterization:** Verifying Quality Factor (Q) formulae for series and parallel RLC circuits and extracting intrinsic losses.
6. **Combinational Logic:** Implementation of Adders, Multipliers, Encoders, and Decoders using Integrated Circuit (IC) chips.
7. **Sequential Logic:** Designing D-Flip Flops and Shift Registers for temporary data storage and state management.
8. **Oscilloscope Dynamics:** Measuring Ring-up and Ring-down times of RLC circuits and analyzing various pulse shapes from a function generator.
9. **VNA Basics:** Measurement of Transmission (S_{21}) and Reflection (S_{11}) of a coaxial cable under Open, Short, and Matched terminations.

10. **Impedance Matching:** Measurement of Voltage Standing Wave Ratio (VSWR) and Quality factor using Smith Chart plots on a VNA.
11. **Multi-port Networks:** Characterizing S-parameters for 3-port networks (Directional Couplers, Circulators, and Isolators).
12. **Noise Analysis:** Using a Spectrum Analyser to measure thermal noise from a resistor at varying temperatures (Johnson-Nyquist noise).
13. **Digital Data Acquisition:** Interfacing instruments with a computer to perform Signal Demodulation (Heterodyne vs. Homodyne) and Mixing.
14. **Sampling & Digitization:** Demonstrating Aliasing in under-sampled signals and Noise reduction through oversampling and interpolation.
15. **Quantum Protocol Execution:** Running simple quantum algorithms (e.g., Deutsch-Jozsa or Grover's) on cloud-based quantum processors (IBM Quantum/Rigetti) or local simulators.

EQUIPMENT & SOFTWARE REQUIREMENTS:

- **Hardware:** Vector Network Analyzer (VNA), Spectrum Analyzer, Digital Storage Oscilloscope (DSO), Optical Bench, NodeMCU/Arduino for interfacing.
- **Software:** LabVIEW/MATLAB (for DAQ), Qiskit/Cirq (for Quantum Simulation).

REFERENCES:

1. *Optics*, Eugene Hecht, 5th Edition, Pearson (2019).
2. *Microwave Engineering*, David Pozar, 4th Edition, Wiley (2013).
3. *Introduction to Quantum Communication*, A. B. Bhattacharya, Khanna Publishing House (2025).
4. *The Art of Electronics*, Horowitz and Hill, 3rd Edition, Cambridge University Press.

INTRODUCTION TO QUANTUM COMMUNICATION

B.Tech IV Yr I Sem **L T P C 3 0 0 3**

Course Objectives:

1. **To understand the role of polarization optics and photon detection in quantum links.**
2. **To bridge classical information theory with quantum constraints like the No-Cloning theorem.**
3. **To master the fundamental protocols of teleportation, dense coding, and entanglement swapping.**
4. **To study the architecture of Quantum Key Distribution (QKD) and Quantum Repeaters.**
5. **To survey the physical hardware implementations of quantum networks via fiber and satellite.**

Course Outcomes: After completion of this course, the student will be able to:

1. **Design optical setups using wave plates and beam splitters for photon manipulation.**
2. **Compare linear and square-law detectors, including APDs and Photomultipliers.**
3. **Apply the No-Cloning theorem and Bell's inequalities to communication security.**
4. **Implement QKD protocols such as BB84 and E91 for secure key exchange.**
5. **Analyze the challenges of the Quantum Internet and satellite-based quantum links.**

SYLLABUS

UNIT – I: Optical Foundations and Photodetection

Polarization Optics: Basics of Polarization; manipulation of light using Quarter-wave plates (QWP), Half-wave plates (HWP), and Polarizing Beam Splitters (PBS). Detection Systems: Basics of linear and square-law detectors. Intensity measurements and square-law detectors. Hardware Components: Photomultipliers (PMT), Avalanche Photo Diodes (APD). Quadrature Amplitude Modulation (QAM) in the context of Heterodyne and Homodyne demodulation.

UNIT – II: Information Theory and Quantum Constraints

Classical Foundations: Digital communication basics; Information entropy, Shannon's Noiseless channel encoding, and Noisy channel encoding. Quantum Principles: The No-Cloning Theorem and its implications for security. Introduction to Quantum Memories and the necessity of Quantum Repeaters in long-haul communication.

UNIT – III: Entanglement and Primitive Protocols

Bell's Framework: Entanglement as a resource; Bell Theorems, Bell Measurements, and experimental tests of non-locality. Core Protocols: The Quantum Teleportation protocol (transferring states without matter transfer) and Quantum Dense Coding (increasing classical bit capacity).

UNIT – IV: Quantum Key Distribution (QKD)

Discrete Variable Protocols: Detailed study of BB84, B92, and E91 (entanglement-based) protocols. Advanced QKD: Introduction to BBM92, Coherent One-Way (COW), and Differential Phase Shift (DPS) protocols. Security analysis and eavesdropping detection.

UNIT – V: Quantum Networks and Hardware

Network Architecture: Evolution from point-to-point links to Quantum Networks and the global Quantum Internet. Hardware Implementation Survey: * Free Space: Terrestrial line-of-sight links.Satellite: Space-to-ground quantum communications and global coverage.Fibre Optics: Challenges of attenuation and the role of quantum repeaters in existing fiber infrastructure.

TEXT BOOKS:

1. Introduction to Quantum Communication, A. B. Bhattacharya, Khanna Publishing House (2025).

2. Elements of Quantum Computation and Quantum Communication, A. Pathak, CRC Press (2015).

3. Quantum Computation and Quantum Information, Nielsen & Chuang, Cambridge University Press (2010).

REFERENCE BOOKS:

1. Optical Quantum Information and Quantum Communication, A. Pathak and A. Banerjee, SPIE Press (2016).

2. Quantum Communications, Gianfranco Conti, Wiley (2021).

3. Principles of Quantum Communication Theory, Stefano Pirandola (Online/Cambridge).

PROJECT

B.Tech IV Yr II Sem **L T P C 0 0 4 4**

COURSE OBJECTIVES:

1. To enable students to identify a real-world problem statement through an extensive literature survey and market analysis.
2. To provide hands-on experience in designing, simulating, and implementing a technical solution using modern engineering tools (Python, Qiskit, HFSS, NodeMCU, etc.).
3. To foster the ability to work in a collaborative team environment and manage project timelines effectively.
4. To develop professional skills in technical writing, patent filing, and oral presentation of research findings.
5. To instill an understanding of ethical practices, sustainability, and the societal impact of the proposed engineering solution.

COURSE OUTCOMES (COs):

At the end of the project work, the student will be able to:

1. **Analyze:** Conduct a systematic literature review to define a research gap and formulate a clear technical problem statement.
2. **Design:** Create high-level architectural designs, flowcharts, and circuit schematics for the proposed system or algorithm.
3. **Implement:** Execute the project using appropriate hardware (Sensors/FPGAs) or software (Quantum Simulators/Deep Learning frameworks) and troubleshoot integration issues.
4. **Evaluate:** Perform rigorous testing and validation of the results using standard metrics (Error rates, PQ/SQ/RQ for segmentation, or Fidelity for quantum circuits).
5. **Communicate:** Draft a comprehensive technical report/thesis in the prescribed JNTUH format and present the work before an external examination committee.
6. **Innovate:** Assess the feasibility of the project for patent application, startup potential, or publication in peer-reviewed journals/conferences.