MARRI LAXMAN REDDY
INSTITUTE OF TECHNOLOGY AND MANAGEMENT
(AN AUTONOMOUS INSTITUTION)
(Approved by AICTE, New Delhi & Affiliated to JNTUH, Hyderabad)
Accredited by NBA and NAAC with 'A' Grade & Recognized Under Section2(f) & 12(B)of the UGC act,1956

Department of Computer Science and Engineering
Minor Degree Program
Quantum Computing

S. No.	Semester	Course Title	Hours Per Week			Credits	Scheme of Examination Maximum Marks		
			L	T	P		Internal (CIA)	External (SEE)	Total
1	V	Foundations of Quantum Computing	3	0	0	3	40	60	100
2		Survey of Quantum Technologies and Applications	3	0	0	3	40	60	100
3		Foundations of Quantum Technologies	3	0	0	3	40	60	100
4	VI	Introduction to Quantum Computation	3	0	0	3	40	60	100
5		Basic Laboratory Course for Quantum Technologies	2	0	2	3	40	60	100
6	VII	Industry Oriented Project	0	0	6	3	40	60	100
Total Credits			**14**	**0**	**8**	**18**	**240**	**360**	**600**

Foundations of Quantum Computing

Course Overview:
Quantum computing relies on probability and statistics, provides the foundational concepts of linear algebra,Classical mechanics which serves as the foundation for understanding quantum mechanics. This provides the foundation of understanding classical computer systems. This helps in understanding hardware and software interfaces and supports the understanding of the difference between classical and quantum computers.Classical digital circuits and Boolean logic will bridge the gap when transitioning to quantum circuits, where quantum gates perform operations like classical gates but with quantum states.

Course Objectives: The students will try to
Understand the fundamental concepts of vectors, matrices, and linear transformations, basic principles of probability distributions, random variables, and statistical inference.
Understand the principles of Newtonian, Lagrangian, and Hamiltonian mechanics.
Remember Maxwell's equations and the fundamentals of electromagnetic fields.
Understand the basic structure and functioning of computer systems.
Remember the principles of logic gates, Boolean algebra, and digital circuit design

Course Outcomes:
Apply the concepts of vectors, matrices, and linear transformations for solving problems. probability and statistical methods to analyze data and solve problems.
Analyze the principles and applications of Hamiltonian and Lagrangian mechanics
Remember the core principles of electromagnetic theory in physical and engineering contexts.
Understand the structure, functioning, and interactions of computer system components.
Create basic digital circuits using logic gates and Boolean algebra.

Module - I
Linear Algebra: Vectors and Vector Spaces,Linear Transformations,Complex Vectors and Matrices,Eigenvalues and Eigenvectors,Inner Product Spaces, Orthogonality and Hilbert Spaces, Diagonalization, Applications to Quantum computing .

Probability and Statistics: Introduction to Statistics , Data Representation , Descriptive Statistics , Probability , Random Variables and Probability Distributions , Specific Probability Distributions and the Central Limit Theorem .

Module - II
Hamiltonian and Lagrangian Mechanics: Classical Mechanics Overview,Lagrangian Formulation, Hamiltonian Mechanics, Applications to Quantum Mechanics.

Module –III

EM theory: Introduction to Electromagnetic Theory, Maxwell's Equations, Maxwell equation in phasor form.

Electromagnetic Wave :Wave propagation in free space, wave propagation in conducting medium, Rectangular waveguides, Electromagnetic Waves in Different Media (dielectric, conducting) , Quantization of EM waves , Electromagnetic wave in optical fibre.

Module –IV

Computer Architecture Basics and Von Neumann Architecture : Principles of Computer Design , Basic Computer organization and Microprocessor , Memory Hierarchy.

Module – V

Digital Logic and Circuits: Digital Numbers representation , Introduction to Digital Logic Gates, Boolean Algebra and Simplification, Combinational Circuits.

REFERENCES:

Elementary Linear Algebra with Applications, Bernard Kolman, David A Hill, Pearson New International Edition, (2013).

Elementary Statistics: Picturing the World, Ron Larson, 8th edition, Pearson (2023)

Classical Mechanics" –3rd edition, Herbert Goldstein, Addisen Wesley Publisher

Introduction to Electrodynamics, Griffiths D. J., 4th edition, Cambridge University Press (2020)

Computer system architecture, M. Morris Mano, (3rd ed.). Prentice Hall, Inc. USA.

Digital Fundamentals, 11th Edition, Thomas L. Floyd, Pearson Publication

Digital Logic and Computer Design, M. Morris Mano, by Pearson Publication

Survey of Quantum Technology and Applications

L T P C
3 0 0 3

Course Overview:
This course is meant to give an overview of the field of quantum technologies and make the students familiar with the state-of-the-art in all four verticals. The emphasis is not on depth in this course, but on covering the exciting aspects of the field.

Course Objectives: The students will try to
Understand the fundamental physical principles underlying the realization of qubits for computation.
Remember the various hardware implementations of qubits
Understand the basic principles and mechanisms of quantum sensing
Analyze practical applications of quantum sensing in science and engineering
Understand the principles of quantum communication protocols in fibre-based and free-space channels.

Course Outcomes:
Analyze the physical principles behind qubit realization
Evaluate different hardware implementations of qubits
Apply the foundational ideas of quantum sensing
Analyze the applications of quantum sensing in scientific and engineering contexts.
Analyze implementations of quantum communication protocols in fibre-based and free-space systems.

Module - I
Quantum Technologies – four verticals :Motivation for Quantum Technologies
Module - II
A qualitative overview of salient aspects of quantum physics:Quantum States, Wavefunctions, Probabilistic interpretation,Physical observables, Hermitian operators, expectation values , Heisenberg uncertainty principle , Schrodinger equation, Time evolution , distinction from classical physics ,Heuristic description of Superposition, Tunnelling and entanglement , No cloning theorem , Simulating classical systems – Feynman's idea of a quantum simulator and the birth of the field.

Module –III
Quantum Computation :Basics of qubits -- what is a qubit?,How is it different from a classical bit? – Review of classical logic gates,Di Vincenzo criteria for realising qubits,Basics of qubit gates and quantum circuits,Physical implementation of qubits (very qualitative description).
Solid State Qubits : Semiconducting Qubits – quantum dots, spins,Superconducting Qubits – charge, flux and phase , Topological Qubits – proposals and advantages , Atoms and Ions , Trapped ions , Rydberg atoms, Neutral atoms , Photonic Qubits , Conventional linear optical l setups , Integrated Photonics , NMR qubits , Conventional NMR qubits , NV centres , Overview of applications and recent achievements , RSA and Shor's algorithm , Quantum Advantage , Long term goals and strategies being followed , Error correction

Module –IV
Quantum Sensing : Basics of quantum sensing , Basics of Photon (single and entangled) generation and detection , Gravimetry , Atomic clock , Magnetometry , State of the art in Quantum Sensing.
Module – V
Quantum Communications : Basics of digital communication , Quantifying classical information – Shannon entropy , Basic ideas of quantum communication, security, eavesdropping , Overview of quantum communication achievements , Terrestrial – fibre-based , Free space, Satellite-based.

REFERENCES:
Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press (2023)
Quantum computation and quantum information – Nielsen M. A., and Chuang I. L., 10th Anniversary edition, Cambridge University Press (2010)
Elements of Quantum Computation and Quantum Communication, A. Pathak, Boca Raton, CRC Press (2015)
An Introduction to Quantum Computing, Phillip Kaye, Raymond Laflamme, and Michele Mosca, Oxford University Press (2006)
Quantum computing explained, David McMahon, Wiley (2008)

Foundations of Quantum Technologies

Course Overview:
This course is meant for laying down the central theoretical aspects of quantum mechanics in a rigorous manner where students learn the techniques and develop a good intuition for quantum physics.

Course Objectives: The students will try to
Remember the fundamental mathematical techniques required for advanced studies in physics and computation
Understand the basic postulates of quantum mechanics
Remember the foundational ideas of statistical physics.
Understand the key principles of information science.
Remember the foundational concepts of computational complexity.

Course Outcomes:
Apply mathematical techniques for solving physical and computational problems.
Understand the postulates of quantum mechanics and Apply them to analyze basic applications.
Remember the foundational ideas of statistical physics
Apply fundamental concepts of information science in communication and computation.
Evaluate algorithms based on computational complexity.

Module - I
Quantum Mechanics :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, examples of Harmonic oscillator, hydrogen atom , Historical evolution of quantum mechanics ,Planck's quantum hypothesis ,Photo electric effect , Atomic spectra ,Bohr's quantisation principle , De Broglie's Wave particle duality ,Postulates of Quantum Mechanics ,State vectors and Hilbert Space ,Dirac Bra-Ket notation, Measurables and Hermitian Operators ,Unitary Transformations,Schrodinger Equation and Time evolution of quantum states ,Measurement Postulate ,Schrodinger, Heisenberg and Interaction pictures ,Eigen values, Expectation values and Matrix elements

Module - II
Heisenberg's Uncertainty principle : Density operator formalism of quantum mechanics – pure and mixed states ,Superposition and Entanglement in quantum mechanics ,No cloning theorem ,Applications of postulates –Particle in a box, Hydrogen atom, Harmonic Oscillator ,Number states, ladder operators and Coherent states of a harmonic oscillator ,Spin and Angular momentum – spin half particles , Rabi problem of a spin-half particle in a rotating magnetic field , Bosons and Fermions.

Module –III

Statistical Physics : Quick review of first and second laws of thermodynamics ,Thermal Equilibrium and Gibbs principle ,Applying Gibbs principle to Classical and Quantum harmonic oscillators , Bosons and Fermions and Quantum statistics – Fermi-Dirac and Bose-Einstein distributions.

Module –IV

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.

Module – V

Brief overview of Computational Complexity : Qualitative ideas of a Turing machine, Types of Turing machines ,Time and Space complexity – P vs NP, PSPACE ,Quantum complexity classes – Q, EQP, BQP, BPP, QMA ,Post Quantum Cryptography (PQC)

REFERENCES:

Introduction to Quantum Mechanics, Griffiths D. J., 3rd Edition, Cambridge University Press (2024)
Introduction to Electrodynamics, Griffiths D. J., 4th edition, Cambridge University Press (2020)
Principles of Quantum Mechanics, Shankar, R., 2nd edition, Springer (2014)
Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press (2023)
Quantum computation and quantum information – Nielsen M. A., and Chuang I. L., 10th Anniversary edition, Cambridge University Press (2010)
A Pathak, Elements of Quantum Computation and Quantum Communication, Boca Raton, CRC Press (2015)
Information Theory, Robert B. Ash, Dover Publications (2003)
Introduction to the Theory of Computation, Michael Sipser, 3rd edition, Cengage India Pvt. Ltd. (2014)
Statistical Mechanics, Pathria R. K., Paul D. Beale, 4th edition, Academic Press, (2021)

Introduction to Quantum Computation

Course Overview:
This Course is meant to cover all the Computation in Quantum Technology which includes Mechanics and Complexities .

Course Objectives: The students will try to
Remember the fundamental postulates of quantum mechanics and the theoretical foundations of qubits and their physical implementations.
Understand the concepts of density operators and mixed states.
Remember the fundamental ideas of quantum gates.
Understand the principles of important quantum algorithms
Understand the fundamental ideas of quantum error correction.

Course Outcomes:
Apply the fundamental postulates of quantum mechanics and) the theory of qubits and Analyze their physical realisations.
Analyze density operators and time evolution in mixed states.
Remember the fundamental concepts of quantum gates.
Analyze the working principles of quantum algorithms
Apply the basic techniques of quantum error correction.

Module - I
Qubits versus classical bits : Spin-half systems and photon polarizations , Trapped atoms and ions , Artificial atoms using circuits , Semiconducting quantum dots ,Single and Two qubit gates – Solovay - Kitaev Theorem , Quantum correlations , Entanglement and Bell's theorems .

Module - II
Review of Turing machines and classical computational complexity , Time and space complexity (P, NP, PSPACE) , Reversible computation , Universal quantum logic gates and circuits .

Module –III
Quantum algorithms : Deutsch algorithm , Deutsch Josza algorithm , Bernstein - Vazirani algorithm , Simon's algorithm , Database search-Grover's algorithm , Quantum Fourier Transform and prime factorization - Shor's Algorithm

Module –IV
Quantum complexity classes – Q, EQP, BQP, BPP, QMA
Additional Topics in Quantum Algorithms : Variational Quantum Eigensolver (VQE) , HHL ,QAOA.

Module – V

Introduction to Error correction , Fault-tolerance , Simple error correcting codes , Survey of current status , NISQ era processors , Quantum advantage claims , Roadmap for future.

REFERENCES:

Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press (2023)
Quantum computation and quantum information – Nielsen M. A., and Chuang I. L., 10th Anniversary edition, Cambridge University Press (2010)
A Pathak, Elements of Quantum Computation and Quantum Communication, Boca Raton, CRC Press (2015)
Quantum error correction and Fault tolerant computing, Frank Gaitan, 1st edition, CRC Press (2008)
Quantum computing explained, David McMahon, Wiley (2008)
Introduction to Quantum Computing: From a lay person to a programmer in 30 steps, Hui Yung Wong, 1st edition, Springer-Nature Switzerland AG (2022)

Basic Laboratory Course for Quantum Technologies

Course Overview:
This Course is meant for the Hands on experience for the Students to develop a case Study on RF Engineering,Optics,RLC Circuits and Digital Circuits

Course Objectives: The students will try to
Remember the fundamental experimental techniques in optics.
Understand the experimental methods for characterizing resonators and RLC circuits.
Understand the principles of digital circuits.
Understand the fundamental techniques of RF engineering.
Understand the concepts of instrument interfacing with computers.

Course Outcomes:
Understand fundamental optical experimental methods.
Apply fundamental optical experimental methods.
Remember the concepts of digital circuits.
Apply RF engineering methods, and Analyze their performance in experiments
Create systems for data acquisition using instrument interfacing

Module - I
Optics : Interferometry – wavelength measurements, intensity measurements , Diffraction – single slit, grating , Microscopy – magnification, aberration , Polarization optics – PBS, HWP, QWP , RLC circuits , Series and parallel RLC circuits – Verifying the quality factor formulae , Extracting intrinsic losses.

Module - II
Digital circuits : Adder, Multiplier , Encoder, Decoder ,D flipflop, shift registers , How to use common Integrated Circuit chips

Module –III
Radio Frequency Technology: Using Oscilloscope : Ring-up and ring-down time measurements of RLC circuits , Measurements of different pulse-shapes generated by a function generator.
Using Vector Network Analyser : Transmission and reflection measurements of coaxial cable in open, short and matched termination , Voltage standing wave ratio measurement , Amplitude and Phase quadrature, In-phase and Out-of-phase quadrature plots and Quality factor measurement of RLC circuits , Characterising S-parameters, ABCD and Z matrices of common 2 port networks – coaxial cable, attenuator, low pass high pass bandpass filters etc. , Characterising 3 port networks – directional couplers, circulators, isolators , Using a spectrum analyser , Noise from a resistor at different temperatures.

Module –IV
Interfacing instruments with a computer

Data acquisition : Signal demodulation – heterodyne vs Homodyne, Mixing of signals , Sampling, digitisation using ADCs – under-sampling and aliasing, oversampling and noise , Averaging and interpolation techniques.

Module – V
Quantum Simulators : Running quantum protocols in a quantum simulator , Implementing simple quantum algorithms on cloud-based quantum computers , Running simple algorithms on cloud-based quantum processors.

REFERENCES:
Optics, Eugene Hecht, A. R. Ganesan, 5th edition, Pearson (2019)
Art of Electronics, Paul Horowitz and Winfield Hill, 3rd edition, Cambridge University Press (2015)
Digital Design, Morris Mano, Michael D. Cilletti, 6th edition, Pearson Education (2018)
Microwave Engineering, David Pozar, 4th edition, Wiley (2013)
Discrete-time signal processing, Alan V. Oppenheim and Ronald W. Shaffer, 4th edition, Pearson (2009)
Optical quantum information and quantum communication, A. Pathak and A. Banerjee, SPIE Spotlight Series, SPIE Press (2016)