**New Call**

**Setting up Undergraduate Teaching Laboratories in Quantum Technologies under**

**National Quantum Mission (NQM), Department of Science & Technology**

1. Background

Department of Science & Technology is implementing the National Quantum Mission approved by the Union Cabinet. Under the Mission, DST has established four Thematic Hubs (T-Hubs) on key research areas viz., Quantum Computing at IISc Bengaluru, Quantum Communication at IIT Madras in association with C-DoT, New Delhi, Quantum Sensing & Metrology at IIT Bombay, and Quantum Materials & Devices at IIT Delhi. These four T-Hubs comprise of 14 Technical Groups having 17 Project teams involving 152 researchers from 43 institutes across India. The T-Hubs aim to drive Technology Development, Human Resource Development, Entrepreneurship and startup ecosystem development, and enhance International Collaboration.

To expedite the Human Resource Development under the four T-Hubs, by Quantum Technologies, it's imperative to focus on capacity building, targeting a diverse range of individuals including students, undergraduates, postgraduates, doctoral candidates, post-doctoral researchers, as well as skilled and semi-skilled manpower.

Additionally, National Quantum Mission (NQM), in collaboration with the All-India Council for Technical Education (AICTE), has launched an Undergraduate Minor Course in Quantum Technologies in December 2024, which is being adopted by a growing number of institutions across the country.

In line with this effort, NQM now invites proposals from eligible institutions for the establishment of Undergraduate Teaching Laboratories in Quantum Technologies under the four T-Hubs to strengthen hands-on education and experiential learning in quantum technologies for engineering undergraduates across India. The proposed teaching labs will provide practical training to support the theoretical modules of this program and build a foundational quantum-ready workforce. The labs set up should also cater to the requirements of networking labs in the nearby areas.

* **All interested applicants are invited to submit proposals in response to this fresh call.**
* **Applicants who had submitted proposals under the earlier call, which closed on 23rd July 2025, are also required to reapply (mandatory) within 30 days from the date of issuance of the fresh call as per the updated format.**
1. Objectives
* To promote experiential learning in quantum technologies at the undergraduate level.
* To build institutional capacity for hands-on quantum education and experimentation.
* To support the implementation of the UG Minor Course in Quantum Technologies with physical infrastructure and lab components.
* To nurture early-stage interest and skills in quantum computing, quantum communication, and quantum sensing.
1. Eligibility

Eligibility framework is proposed below:

* 1. **Institutional Eligibility**

Institutions must meet either of the following categories:

1. Government Funded/aided Institutions: Central or State Government funded/aided technical institutions/universities.

OR

1. Other AICTE/UGC recognized Institutions/Universities: Institutions must fulfil at least one of the following academic quality benchmarks:
	1. Recognised as an Institution of Eminence by AICTE/UGC
	2. 8th Edition of NIRF ranked Institutions (announcement made on 5th June 2023).
	3. QS World Ranking Asia-2024 (announcement made on 8th Nov 2023).
	4. Institutions having minimum of 30% eligible courses with NBA accreditation having validity till 30th April 2025. (The institutions should continue to get accreditation of their programs)
	5. Institutions with valid NAAC score of 3.01 and above on scale of 4.0.
	6. Institutions having conferred ‘Autonomous Status’ by UGC/Autonomy by AICTE.
	7. Institutions having more than 80% admission consecutively for last 5 Academic Years.
	8. **Faculty and Programme Readiness**
2. Institutions must demonstrate proven capabilities in Quantum Technologies, faculty commitment and preparedness to launch the B.Tech Minor program in Quantum Technologies, along with the capability to maintain and operate the associated laboratory.
3. There must be a minimum of two faculty members with relevant expertise in quantum technologies, each dedicating at least one-third of their academic time to the lab and its activities. Evidence based expertise in the university/institution
	1. **Laboratory Infrastructure**
4. A dedicated teaching laboratory space of at least 2000 sq. ft. must be available for setting up the quantum technologies lab.
5. Institutions must appoint at least one full-time dedicated laboratory technician/personnel with appropriate qualifications and experience in relevant areas.
	1. **Academic Approvals**
* Institutions must have received Senate/Governing Body approval for launching the UG Minor Programme in Quantum Technologies.

OR

* Submit a formal written commitment indicating intent to start the programme upon obtaining the necessary approval\*.

\**Funding support will be provided only after the required academic approvals are secured*

1. **Funding Support**
2. Government/Government aided institutions/universities: 100% support by DST.
3. Other AICTE/UGC recognized Institutions/Universities: 75% by NQM, DST and 25% by the Grantee Institution of total project cost and/ or actual expenditure within the total project cost (whichever is less).
4. The selection will be through a peer review mechanism and visit to the laboratories, if necessary.
5. No additional Maintenance supports will be provided. Guarantee institutions should include/negotiate for extended warranty of the equipment at the time of purchase for up to March 2031 and commit to maintain the facility beyond the period of support.
6. Duration of support: Till the National Quantum Mission period i.e. March 2031.

*Support to Other AICTE/UGC recognized Institutions/Universities institutions will be considered, provided they comply with the cost-sharing arrangement and statutory requirements.*

1. **Lab Operationalization and Reporting**
2. Since funds are routed via Thematic Hubs (T-Hubs) under NQM, reporting mechanisms and oversight responsibilities will be defined by the respective T-Hub.
3. Labs must also adhere to the T-Hub’s technical roadmap, timelines, and deliverables for the Human Resource Development component.
4. The host institution shall report progress, outcomes, and fund utilization to the T-Hub, which will retain supervisory and quality assurance authority.
5. **Technology Domains**

The Teaching Labs proposed to be setup must holistically cover the 4 verticals under NQM.

* Quantum Computing
* Quantum Communication
* Quantum Sensing & Metrology
* Quantum Materials & Devices
1. UG Minor Course in the area of Quantum Technologies:

Placed at Annexure III for reference

1. Type of Equipment in the Teaching Lab

The List of approved equipment are placed at Annexure IV.

1. Instructions for submission of proposals

To ensure smooth and standardized submission of proposals for setting up Undergraduate Teaching Laboratories in Quantum Technologies, the following guidelines are to be adhered to by all applicant institutions:

1. Proposals must be submitted online only through the designated NQM portal. Hard copy submissions will not be entertained.
2. All proposals must be submitted by the last date. Late submissions will be automatically rejected.
3. Proposals must be submitted in the prescribed format only as given in Annexure I.
4. Evaluation and Selection Process
5. All proposals will undergo peer-review by committees of domain experts constituted by DST.
6. Shortlisted applicants may be invited for an online/offline presentation.
7. Final selection will be based on:
	* Faculty readiness, availability of qualified support staff to setup and maintain the laboratories and general infrastructure availability
	* Financial and institutional commitment
	* Alignment with the UG Minor course developed by NQM and AICTE
8. Contact Information

For any queries or clarifications, institutions may contact:

Dr. Swati Rawal Dang,

Scientist-D,

National Quantum Mission (NQM),

Department of Science and Technology,

Ministry of Science and Technology,

Technology Bhawan, New Mehrauli Road,

New Delhi -110016.

Email Id: swatirawal.dang@gov.in

1. Attachments and Enclosures

All the documents provided in Annexure II need to be appropriately submitted by the institutions.

12.1 Annexure I

 Format of Submission of Proposal

1. Proposal Summary
2. Core Proposal

12.2 Annexure II

1. Template 1: Details of Project Implementation Group
2. Template 2: Profile of Faculties and the Laboratory Supervisor/Technician involved
3. Template 3: Endorsement of Institute.
4. Terms and Conditions.

 12.3 Annexure III

 Course Structure of UG Minor Program on Quantum Technologies.

 12.4 Annexure IV

 List of Equipment for Teaching Lab.

Annexure I

Format of Submission of Proposal

CONTENT

|  |  |  |
| --- | --- | --- |
| S. No | ITEM | Page No(s) |
| I | Proposal Summary  |  |
| II | Core Proposal |  |
| III | Project Implementation Group |  |
| IV | Bio-Data of faculties and Collaborators |  |
| IV | Endorsement Letters |  |

I. PROPOSAL SUMMARY

For Setting up Undergraduate Teaching Laboratories in Quantum Technologies
Under the National Quantum Mission (NQM)

1. **General Information**
	1. Name of the Institution:
	2. Type of Institution:

☐ Central Government Funded

☐ State Government Funded

☐ Central Government-Aided

☐ State Government-Aided

☐ Other AICTE/UGC Recognised Institution

* 1. Institution Address:

City/State/PinCode:

* 1. Website:
	2. Name and Designation of Head of Institution (with contact details):
* Name:
* Designation:
* Email:
* Phone:
	1. Name and Contact of Proposal Coordinator:
* Name:
* Designation:
* Department:
* Email:
* Phone:
1. **Institutional Eligibility Details *(Please tick the applicable category and attach supporting documents)***
	1. **Government Funded/Aided Institution:**

☐ Central Government funded

☐ State Government funded

☐ Central/State Government-aided

☐ Not Applicable

(OR)

* 1. **AICTE/UGC Recognized Institution:**

☐ Recognised as an Institution of Eminence by AICTE/UGC

☐Featured in the 8th Edition of NIRF Rankings (5th June 2023)
    NIRF Rank: \_\_\_\_\_\_\_\_\_\_

☐Listed in QS World Ranking Asia 2024 (8th November 2023)
    QS Asia

Rank: \_\_\_\_\_\_\_\_\_\_

☐Minimum 30% eligible courses accredited by NBA (valid till 30th April 2025)

Percentage of Accredited Courses: \_\_\_\_\_\_\_\_\_\_

☐ Valid NAAC Score of 3.01 or above (on a 4.0 scale)

NAAC Score: \_\_\_\_\_\_\_\_\_\_

☐Autonomous Status granted by UGC / AICTE
    Year of Grant: \_\_\_\_\_\_\_\_\_\_

☐ More than 80% admissions consecutively for the last 5 Academic Years
    Admissions in last 5 years (attach year-wise data): \_\_\_\_\_\_\_\_\_\_

**Attach scanned copies of documentary evidence for the above as Annexure.**

1. **Project Details**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Project cost (*Amount in Crores)* | Recurring /General:  | Non-Recurring / Capital:  | Total*:* |
|  | Duration *(in years)* |  |
|  | Project Coordinator* Name:
* Institute:
 |  |
|  | Member Faculties * Name:
* Designation
* Department
 |  |
|  | Objectives |  |
|  | Methodology  |  |

 Annexure I

II. CORE PROPOSAL

Proposal must be prepared using the prescribed format only.

1. **Institutional Information**

| Field | Details |
| --- | --- |
| Name of Institution |  |
| Type Central Government fundedState Government fundedCentral Government-aidedState Government-AidedOther AICTE/UGC Recognised Institution |  |
| Address |  |
| Website |  |
| Year of Establishment |  |
| AICTE/UGC/Other Accreditation Status |  |
| Institutional NIRF Ranking (if any) |  |
| NAAC Grade (if applicable) |  |
| Target Beneficiaries (Departments and Students Strength) |  |
| No. of students adopting the B.Tech Minor Course on Quantum Technologies |  |
| Contact Person (Head of Institution) |  |
| Designation |  |
| Email |  |
| Phone |  |

1. **Project Coordinator& Team Details (Number of Team Members may vary)**

| Field | Project Coordinator | Team Member 1 | Team Member 2 | Team Member 3(Full Time project Associate/Lab Technician) |
| --- | --- | --- | --- | --- |
| Name |  |  |  |  |
| Designation |  |  |  |  |
| Department |  |  |  |  |
| Email |  |  |  |  |
| Mobile |  |  |  |  |
| Job profile, qualifications & experience |  |  |  |  |
| Area of Expertise, Quantum Training |  |  |  |  |
| Role in Project |  |  |  |  |

1. **Execution/Implementation schedule with specific time-frame (PET Chart)**
2. **Laboratory Infrastructure**

| Activity | Description |
| --- | --- |
| Total available space (minimum 2000 sq. ft.) |  |
| Existing lab facilities |  |
| List of relevant equipment currently available |  |
| Existing Labs Infrastructure related to Quantum or Advanced Physics |  |

**D. Technical Details**

| Section | Details |
| --- | --- |
| Objectives | Clear and concise goals of the proposed lab |
| Target Audience | UG programs, student levels, departments |
| Lab Modules / Experiments | Detailed description of proposed modules (title, learning outcomes, equipment used) |
| Curriculum Integration |  |
| Innovation & Uniqueness | Any novel approaches, indigenous development, or interdisciplinary components |
| Scalability & Outreach | Potential for expanding to other institutions or disciplines |

**E. Financial Details**

| Head | Item Description | Quantity | Unit Cost (INR) | Total Cost (INR) | Justification |
| --- | --- | --- | --- | --- | --- |
| Non-Recurring  |  |  |  |  |  |
| Sub Total |  |  |  |  |  |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Budget Head | 2025-26 | 2026-27 | 2027-28 | 2028-29 | 2029-30 | 2030-31 | Total |
| Recurring |  |  |  |  |  |  |  |
| Sub Total |  |  |  |  |  |  |  |

Total: Recurring + Non-Recurring (Only in first year)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Budget Head | 2025-26 | 2026-27 | 2027-28 | 2028-29 | 2029-30 | 2030-31 | Total |
| Recurring+ Non Recurring |  |  |  |  |  |  |  |

2. Institute’s Committed Financial Contribution (if applicable)

| Type of Institution | Cost-Sharing  | Contribution Amount |
| --- | --- | --- |
| Other AICTE/UGC Recognized Institution | 25%  | ₹ |
| Govt. / Govt.-aided Institution | Not applicable | ₹ |

3. Total Funding Requested from DST

| From DST (based on type) | Amount |
| --- | --- |
| For Govt./Govt.-aided Institutions (100%) | ₹ |
| For Other AICTE/UGC Recognized Institutions (75%) | ₹ |

 Annexure II

Template 1

Project Implementation Group (PIG)

The Project Implementation Group (PIG) will be responsible and accountable for the smooth implementation of the DST-NQM Project. It should have 4-5 faculty members with at least two faculties having the domain expertise in Quantum Technologies and a full time Project Associate/Lab Technician to maintain and set up the Teaching Labs.

| S. No. | Name | Designation | Phone | Email | Role in PIG | Faculty contributing 1/3 of the time in lab activities (Yes/No) | Domain Expertise | Qualification & Experience(Details can be added in template 2) |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 |  |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |  |  |
| 5 |  |  |  |  |  |  |  |  |

Date:

 Seal:

 Signature of the

 Head of the Department/ Participating Department

Date:

 Seal:

 Forwarded with Signature of the

 Head of the Organization / College

Annexure II

Template 2

Proforma for Profile of Members of Project Implementation Group

(Fill separate sheets for each)

1. Name of the Project Coordinator/Faculty
2. Role in PIG
3. Is at least one-third of time being dedicated to laboratory activities? (Yes/No)
4. Contact Information:

Email:

Phone Number:

Address:

1. Personal Information:

Date of Birth:

Gender:

1. Professional Affiliation:

Current Position/Designation

Name of the Institute/Organization

Department/Faculty

1. Academic Qualification (Undergraduate Onwards)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| S.No. | Degree | Year | Subject | University/Institution | % of Marks |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

1. Work Experience (in chronological order)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| S.No. | Position held | Institution | From | To | Pay Scale |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

1. Research Experience:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| S.No. | Position held | Institution | From | To | Research Focus/Interests |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

1. Expertise in Quantum Technologies Relevant to the Proposal

Provide a summary of your expertise and experience in the area of quantum technologies relevant to the proposal. Include details about your involvement in related projects, collaborations, or contributions to the field.

1. Professional Recognition/ Awards/ Prizes/ Certificates/ Fellowships received

|  |  |  |  |
| --- | --- | --- | --- |
| S.No. | Name of Award | Awarding Agency | Year |
|  |  |  |  |
|  |  |  |  |

1. Notable Publications/Patents/Research Grants/Projects etc. (To be Added as an Annexure)
2. Any other relevant Information (maximum 500 words)

Include any additional information that you believe is pertinent to your qualifications and suitability for leading the proposed consortium.

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Annexure II

Template 3

Endorsement Letter from the Coordinator and Head of the Institution on its Letter Head

This is to certify that:

1. Dr. ……………………………………….., the Head, of the Department/ School/ Centre …………………… or Principal of the College ……………………. will assume full responsibility for implementing this project proposed under NQM Program of the Department of Science and Technology, New Delhi during………………………….
2. The Head or Coordinator will be governed by the rules and regulations of the University/Institute and will be under administrative control of the University/ Institute for the duration of the NQM project.
3. The grant-in-aid by the Department of Science & Technology will be used to meet the expenditure on the NQM project and for the period for which the project has been sanctioned as indicated in the sanction letter/ order.
4. No administrative or other liability will be attached to the Department of Science & Technology at the end of the NQM project.
5. The University/ Institute will provide basic infrastructure and other required facilities to the investigator for implementing the NQM project.
6. The University/ Institute will take into its books all assets received under this sanction and its disposal would be at the discretion of Department of Science & Technology.
7. Institute assumes to undertake the financial and other management responsibilities of the NQM project.
8. Organizing institute will participate in the monitoring/ reviewing of the NQM Project whenever they were asked to do so.
9. The Institute/University (if not Government funded) will be ready to contribute from their end, 25% of the funds requested under this proposal.
10. The Institute will be ready to dedicate full-time resources under this proposal.
11. Atleast 2 Faculties will give 1/3 of their time (…Names of Faculties..) in the activities pertaining to the Laboratory set up under NQM
12. The Institute should have senate approval for the program or should submit their commitment to start the quantum technologies program with the approval of Senate/Highest Governing Body\*.

\*Funding support will be provided only after the approval.

Signed by Signed by

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Head of the Department/ Centre Head of the University / Institute

or Principal of College

 Annexure II

 GOVERNMENTOF INDIA

Ministry of Science & Technology

Department of Science & Technology

No. …..

Technology Bhawan, New Delhi

Dated: …..

Terms &Conditions

1. The grantee organization shall furnish to the Thematic Hub/Department of Science & Technology, financial year wise Utilization Certificate (UC) in the proforma prescribed as per GFR 2017 and audited statement of expenditure (SE) along with up-to-date progress report (Vis-a-Vis Target Vs-Achievement) at the end of each financial year. This is also subject to the condition of submission of the final consolidated statement of expenditure, utilization certificate financial year wise and project completion report within one year from the scheduled date of completion of the project.
2. The grantee organization will have to enter & upload the Utilization Certificate financial year wise in the PFMS portal besides sending it in physical form to this Division. The subsequent/final installment will be released only after confirmation of the acceptance of the UC by the Division and entry of all previous Utilization Certificate in the PFMS.
3. If the grants-in-aid has been released under Non-recurring/capital head through separate sanction order under the same project for purchase of equipment(s), separate SE/UC (financial year wise) has to be furnished for the grants-in-aid so released.
4. The grant-in-aid being released is subject to the condition that: -
5. A transparent procurement procedure in line with Provisions of General Financial Rules 2017 shall be followed by the Institute/Organization under the appropriate rules of grantee organization while procuring capital assets sanctioned for the above-mentioned project and a certificate to this effect will be submitted by the Grantee organization immediately on receipt of the grant.
6. While submitting Utilization Certificate/Statement of Expenditure, the organization has to ensure about submission of supporting documentary evidences with regard of the purchase of equipment/capital assets as per the provisions of GFR 2017. Subsequent release of grants under the project shall be considered only on receipt of the said documents.
7. As per the GFR 2017 Rule 230 (17) “the Grantee Institute should agree to make reservations for Scheduled Castes and Scheduled Tribes or OBC in the posts or services under its control on the lines indicated by the Government of India”

Signed by Signed by

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Head of the Department/ Centre Head of the University / Institute

or Principal of College

1. DST reserves sole rights on all the assets created out of grants. Assets acquired wholly or substantially out of government grants (except those declared as obsolete and unserviceable or condemned in accordance with the procedure laid down in GFR 2017), shall not be disposed of without obtaining the prior approval of DST.
2. The account of the grantee organization shall be open to inspection by the sanctioning authority and audit (both by C&AG of India and Internal Audit by the Principal Accounts Office of the DST), whenever the organization is called upon to do so, as laid down under Rule 236(1) of General Financial Rules 2017.
3. Due acknowledgement of technical support/financial assistance resulting from this project grant should mandatorily be highlighted by the grantee institute/organization/recipient of the GIA in bold letters in all publications / media releases as well as in the opening paragraphs of their Annual Reports during and after the completion of the project.
4. Failure to comply with the terms and conditions of the Bond will entail full refund with interest in terms of Rule 231 (2) of GFR 2017.
5. It is mandatory to use EAT module in PFMS, failing which no further funds shall be released.
6. Goods (Consumable/Equipment) available in GeM portal are to be procured mandatorily online through GeM only as per the provisions of Rule 149 of GFR, 2017 along with other necessary compliances under GFR-2017, any other relevant orders/guidelines as issued by GoI/MoF/DoE from time to time and engagement of manpower, in alignment with DST norms.
7. The Grantee Institute/organization/recipient of the GIA should follow Global Tendering Enquiry (GTE) conditions as per Department of Expenditure ID Note No:4/1/2021-PPD dated 10.09.2021.
8. It is mandatory to comply to the Rule 177-206 of GFR regarding procurement of services.
9. If One-time assistance or Non-recurring grant as Grant-in-Aid for Rs.10.00 lakhs to Rs.50.00 lakhs is provided, it should be included in the Annual Report of the Institute/GI.
10. The Grantee Institute/organization/recipient of the GIA must ensure compliance to any other provisions of GFR-2017 (https://doe.gov.in/order- circular/general-financial-rules2017-0) and guidelines/amendments issued by the Govt. of India from time to time.
11. The grant being released under the scheme is for strengthening infrastructure of the identified department for research and shall be spent exclusively for this purpose. The Dept./ College shall constitute a “Project Implementation Group (PIG)” with 4-5 Faculty Members including younger faculty members under the overall supervision of the Head/ Chairman/ Dean of the Dept. The PIG would be responsible and accountable to DST for all aspects of implementation of such project during its project duration. Whoever occupies the positions of Head, Chairman, Dean of the Department, or Principal of the college shall automatically become a member of the PIG.
12. Facility created under shall not be kept with the custody of an individual faculty member in the Department and shall be made accessible to all the faculty members all the time.
13. There should not be any deviation from the Budget Heads as approved by DST/T-Hub.
14. The grants-in-aid is to provide infra-structural facilities for teaching and research activities in the department. Therefore, no provision of Overhead Charges is admissible. Please note that the scheme does not allow any provision for building/ construction and recruitment of staff etc.
15. All the assets acquired from the grant will be the property of the Government of India and should not, without the prior sanction of the Department, be disposed off or encumbered or utilized for purposes other than those for which the grant has been sanctioned.
16. DST reserves the right to terminate the support at any stage if it is convinced that the grant has not been properly utilized or appropriate progress is not being made.
17. A register of the permanent/semi-permanent assets acquired wholly or mainly out of this grant should be maintained in the prescribed form and a copy thereof furnished to the T-Hub. Such register of assets and the accounts maintained shall be available or open to scrutiny by Audit.

Signed by Signed by

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Head of the Department/ Centre Head of the University / Institute

or Principal of College

1. DST reserves sole rights on the assets created out of grants. Assets acquired wholly or substantially out of government grants shall not be disposed of without obtaining the prior approval of DST. All the procurement should be as per procedure laid down in GFR 2017.
2. Special seminar/s on usage and upkeep of scientific instruments might be conducted from time to time by the beneficiary organization to ensure smooth functioning as well as maximum uptime of the established facility.
3. To maintain transparency and accountability, the facilities acquired should be mapped to Indian Science Technology and Engineering facilities Map i.e. I-STEM portal (www.istem.gov.in) and should be accessible to the scientific community and industry. DST and T-Hub should be informed after mapping the research facilities in the I-STEM Portal.
4. A task-force of DST/T-Hub would undertake random check on the status of utilization of the major facilities supported by DST, as and when needed.
5. The Grantee Institution should promote services of NQM facilities to the demands of outside faculties, researchers, scientists and students at other academic institutes, universities, nearby colleges national laboratories, R&D Labs, Startups, and Industries to enable them to carry out R&D activities to promote NQM collaborative research endeavors.
6. The funds released to the Grantee Institute shall not be parked in bank account of any other agency.
7. Interest earned on previous unspent balance (if any) should be reflected appropriately in the Financial Statement of each year submitted to the Department of Science & Technology and the same need to be deposited back to Consolidated Fund of India by using the Non-Tax Receipt Portal (NTRP) i.e., www.Bharatkosh.gov.in
8. Any unspent amount sanctioned/ interest accrued would be surrendered to the Government through the Bharatkosh site (www.Bharatkosh.gov.in) and the receipt of the same may be enclosed with financial documents.
9. The Grantee Institution (GI) is directed to use the Expenditure-Advance-Transfer (EAT) module of PFMS, and next release will be made only after mapping and following EAT modules by the GIs.
10. Due acknowledgement of technical support / financial assistance resulting from NQM grant of Department of Science & Technology should mandatorily be highlighted by the grantee organization in bold letters in all publications/ thesis /Patents/Prototypes, Media releases as well as in the opening paragraphs of their Annual Reports during and after the completion of the project.
11. The Grantee Institution should adopt and implement the Scientific Research Infrastructure sharing, Maintenance and Networks (SRIMAN) Policy guidelines of Ministry of Science and Technology, GoI released in May 2022.
12. The Grantee Institute should adopt and follow the Scientific Social Responsibility (SSR) guidelines of Ministry of Science and Technology, GoI released in May 2022 while utilizing the grants earmarked towards industrial R&D support and SSR activities. It must be ensured that the guidelines are implemented both in letter and spirits.
13. To give visibility to the identified department, the department may be called as “DST-NQM Sponsored Department”. The Public Notice displaying the Logo of the NQM Program may be suitably displayed in this regard.
14. Any other term and condition, as decided by DST, which may be added after the selection of the project.

Signed by Signed by

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Head of the Department/ Centre Head of the University / Institute

or

Principal of College

Annexure III

Course Structure of UG Minor Program on Quantum Technologies

Preamble:

Quantum technology is an emerging new paradigm that promises to disrupt and revolutionize computing, communication and sensing in the coming decades. Keeping in mind the immense strategic potential, and possibilities for unforeseen breakthroughs in research, the global investment from Governments alone exceeds 40 B$. In the Indian context, the National Quantum Mission from the Government of India is a decisive step in accelerating the nation’s research in this field. To fulfil the mandates of the mission, India needs to develop a highly skilled workforce through immediate initiatives in teaching and training. The training imparted to this workforce must enable them to reach global standards,and simultaneously address the multi-disciplinary needs of quantum technology development -- from core hardware and back-end engineering support to algorithms for cryptography and machine learning. To create a thriving quantum-trained ecosystem in India it is thus imperative to introduce a dedicated curriculum at the undergraduate level, as well as at the post graduate level, along with programmes for faculty members and teachers involved in undergraduate and post graduate education. While institutes of national importance have begun programs to this end, expanding such training to a larger pool of institutes across the country enables the nation to tap into the vast resource of students who can then participate in the mission to accelerate its progress towards its goals.

In this context we propose the course structure for a minor program in Quantum Technologies at the undergraduate level. Here we consider Quantum Technologies to include all four verticals -- Quantum computation and simulation, Quantum communications and cryptography, Quantum sensing, Quantum materials and devices. We propose a curriculum spanning a minimum of 18 credits. We propose both theory and lab courses in this curriculum. We assume each course amounts to 3 credits (1 credit translating to 1 in-class contact hour per week for a theory course or 1 session of lab for 3 hours for a lab course), thereby making the minor program span a minimum of 6 courses. We propose a pool of courses amounting to 30+ credits, out of which any given institution may choose 18 credits depending on the availability of teachers in that institution. However, to retain the core mandate of the minor, we propose to make a couple courses mandatory. This flexibility in the curriculum, we believe, will allow institutions to readily start training students in one or more verticals of quantum technologies. We also believe that many of the listed courses may also be chosen as electives by students who do not opt for a minor in quantum technology. We also encourage institutions and students to incorporate project-based learning approaches wherever possible to enhance the impact of the curriculum.

We have designed the curriculum keeping in mind the diversity in the institutions, as well as the different engineering disciplines. We believe that this minor program can be taken up by students of ALL engineering disciplines from their third or fourth semester (assuming an 8 semester or 4-year undergraduate program as the standard format). The students undertaking this course need to be familiar with basic engineering mathematics (basic linear algebra, complex numbers, probability and statistics) and physics at high school level (newton’s laws, optics, thermodynamics), along with the basics of programming (simple arithmetic operations, basic sorting and search algorithms). These basic prerequisites are easily met by most students after their first year of undergraduate engineering/science education. We designed the curriculum to contain a quick review of all the requisite basics to acknowledge the possibility that some students may not have them covered and still want to pursue this minor.

We believe that extensive training programs for teachers are necessary to enable them to do justice to the goals of the minor program. Such sustained teacher training efforts will also enhance the quality of the training imparted to students over the years leading to long-term benefits and enable India to become a world leader in this field. We also believe that a text-book writing exercise should be carried out, such that topics in quantum technologies

Proposed structure of the program:

Minimum credits to fulfil – 18

* A 3:0 course amounts to at least 36 hours of lectures (considering holidays, exam days etc) per semester, assuming an average length of 14 weeks for the semester.
* A n:m lab course has n hours of lectures and m sessions (2 hours each) of lab per week.
* The proposed course structure is only to provide a guideline. Based on the available teaching resources, an institute may choose to add more modules, having covered the ones mentioned here.
* Project Based Learning (PBL) is encouraged and institutes must try to incorporate projects related to the domain of the minor degree wherever possible.

Table of Courses

|  |  |  |
| --- | --- | --- |
| Course code | Title | Credits (Theory: Lab) |
| QT00, QT 01 and QT 02 are both Mandatory |
| QT00 | Foundations of Quantum Computing: Physics, Engineering, and Mathematics Computing | 3.0 |
| QT 01 | Survey of Quantum technologies and Applications | 3:0 |
| QT 02 | Foundations of Quantum Technologies | 3:0 |
|  |  |  |
| At least one of QT 03 and QT 04 is Mandatory |
| QT 03 | Basic Programming Lab | 2:1 |
| QT 04 | Basic Laboratory Course for Quantum Technologies | 2:1 |
|  |  |  |
| At least one of QT 05, QT 06, QT 07, QT 08 is Mandatory |
| QT 05 | Introduction to Quantum Computation | 3:0 |
| QT 06 | Introduction to Quantum Communication | 3:0 |
| QT 07 | Introduction to Quantum Sensing | 3:0 |
| QT 08 | Introduction to Quantum Materials | 3:0 |
|  |  |  |
| Optional / Additional Courses |
| QT 09 | Engineering Foundations of Quantum Technologies | 3:0 |
| QT 10 | Solid State Physics for Quantum Technologies | 3:0 |
| QT 11 | Quantum Optics | 3:0 |

Detailed Syllabus

Prerequisites for all courses: Engineering Mathematics (Linear Algebra, Complex algebra, basics of 2nd of ODEs and initial value problems, 2nd order PDEs and boundary value problems, Probability and Statistics, Random variables). Maxwell’s equations and EM theory at the level of the core physics syllabus from AICTE model curriculum.

QT 00: Foundations of Quantum Computing: Physics, Engineering, and Mathematics Computing, 3:0 (Mandatory)

*This course is meant for laying down the central theoretical core principles of linear algebra, statistics and probability, EM theory, computer architecture and digital circuits required for quantum systems.*

Course Content and syllabus:

* Linear Algebra (12-14 lectures):

(This segment provides the foundational concepts of linear algebra. Since quantum states are represented as vectors in a Hilbert space and operators as matrices, it is essential to understand eigenvalues, eigenvectors, and matrix operations before diving into the more advanced concepts of quantum computing)

* + 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 (7-8 lectures)

(Quantum computing relies on probability and statistics, especially in the behavior of qubits and how measurement outcomes are interpreted. Understanding these principles is essential for designing quantum algorithms, analyzing quantum systems, and dealing with the inherent uncertainties and noise in quantum computation.)

* + Introduction to Statistics
	+ Data Representation
	+ Descriptive Statistics
	+ Probability
	+ Random Variables and Probability Distributions
	+ Specific Probability Distributions and the Central Limit Theorem
* Hamiltonian and Lagrangian Mechanics (5-6 lectures)

(Classical mechanics, especially the Hamiltonian and Lagrangian formulations, serve as the foundation for understanding quantum mechanics. Quantum mechanics is often introduced in terms of wavefunctions and operators, and these can be derived by classical Hamiltonian mechanics.)

* + Classical Mechanics Overview
	+ Lagrangian Formulation
	+ Hamiltonian Mechanics
	+ Applications to Quantum Mechanics
* EM theory (6 lectures)

(This segment provides foundational knowledge that prepares quantum computing students to understand the role of EM theory in quantum systems)

* + 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
* Computer Architecture Basics and Von Neumann Architecture (5-6 lectures)

(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.)

* + Principles of Computer Design
	+ Basic Computer organization and Microprocessor
	+ Memory Hierarchy
* Digital Logic and Circuits (5-6 lectures)

(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.)

* + Digital Numbers representation
	+ Introduction to Digital Logic Gates
	+ Boolean Algebra and Simplification
	+ Combinational Circuits

Course Outcomes:

Students of this course learn

1. The necessary mathematical tools of linear algebra.
2. Classical mechanics, Hamiltonian and Lagrangian Mechanics
3. The basics of statistics and probability
4. The fundamentals of Electromagnetic theory
5. Basics of Computer Architecture
6. Basics of Digital Logic and Circuits

Course References:

1. Elementary Linear Algebra with Applications, Bernard Kolman, David A Hill, Pearson New International Edition, (2013).
2. Elementary Statistics: Picturing the World, Ron Larson, 8th edition, Pearson ( 2023)
3. Classical Mechanics" –3rd edition, Herbert Goldstein, Addisen Wesley Publisher
4. Introduction to Electrodynamics, Griffiths D. J., 4th edition, Cambridge University Press (2020)
5. Computer system architecture, M. Morris Mano, (3rd ed.). Prentice Hall, Inc. USA.
6. Digital Fundamentals, 11th Edition, Thomas L. Floyd, Pearson Publication
7. Digital Logic and Computer Design, M. Morris Mano, by Pearson Publication

 QT 01: Survey of Quantum Technologies and Applications 3:0 (Mandatory)

*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 Content and syllabus:

* Quantum Technologies – four verticals (1 lecture)
	+ Motivation for Quantum Technologies
* A qualitative overview of salient aspects of quantum physics (4-5 lectures)
	+ 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
* Quantum Computation (10-12 lectures)
	+ 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
* Quantum Sensing (8-10 lectures)
	+ Basics of quantum sensing
	+ Basics of Photon (single and entangled) generation and detection
	+ Gravimetry
	+ Atomic clock
	+ Magnetometry
	+ State of the art in Quantum Sensing
* Quantum Communications (8-10 lectures)
	+ 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
* *Topics on Quantum Materials are to be covered in the other portions of the course wherever required and are not listed separately here.*

Course Outcomes:

Students of this course:

1. Learn about the general physical principles of realising qubits for computation
2. Learn about the various hardware implementations of qubits for computation
3. Learn about the basic ideas of quantum sensing
4. Learn about the applications of quantum sensing
5. Learn about the implementations of quantum communications protocols in fibre-based and free-space

Course References:

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

QT 02: Foundations of Quantum Technologies, 3:0 (Mandatory)

*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 Content and syllabus:

* Quantum Mechanics (16 - 18 lectures):
	+ Brief overview of classical physics (This segment is meant for the student to understand what a Hamiltonian is, which will feature later in quantum mechanics)
		- 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
		- 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
* Statistical Physics (8-10 lectures)
	+ 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
* Information Science (3-4 lectures)
	+ Digital communication and information
		- Quantifying information in terms of Shannon entropy
	+ Basic ideas of quantum information
	+ Decoherence and noise
	+ Introductory ideas of Kraus operators
* Brief overview of Computational Complexity (5-6 lectures)
	+ 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)

Course Outcomes:

Students of this course learn

1. The most relevant mathematical techniques
2. Basic postulates of quantum mechanics and applications
3. Basics of Statistical Physics
4. Basics of Information Science
5. Basics of computational complexity

Course References:

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

QT 03: Basic Programming Lab (2:1)
(Out of QT 03 and QT 04, at least ONE is mandatory)

*This course is meant to provide students a quick hands-on experience in scientific computing and its applications to areas within Quantum Technologies.*

Course Content and syllabus:

* Basics of programming
	+ Data structures, classes, Object-oriented programming
	+ Data storage and retrieval, Memory allocation
	+ Scientific plotting, documentation of codes
* Simple algorithms and benchmarking run time
	+ Sorting
	+ Searching
	+ Arithmetic algorithms like GCD, Prime factorisation
* Numerical Integration and differential equations
	+ Linear 2nd Order ODEs with constant coefficients
	+ Linear 2nd order ODEs with variable coefficients
	+ Boundary value problems
		- Poisson equation
		- Laplace equation
		- Wave equation
		- Diffusion Equation
* Numerical techniques in linear algebra
	+ Matrix inverse
	+ Eigenvalue problem
	+ Diagonalisation of matrices
	+ Singular value decomposition
* Numerical techniques in Probability and Statistics
	+ (Pseudo) Random number generation
	+ Computing statistical moments for data samples
	+ Least Squares fitting
	+ Error Analysis
	+ Hypothesis Testing
	+ Monte Carlo sampling
* Applications to Quantum Mechanics (can be done using openly available modules in languages like Python, Julia etc.)
	+ Eigen energies of coupled two level systems
	+ Eigen energies of two-level system coupled to oscillator (Jaynes-Cummings Model)
	+ Driven two-level system – Rabi Problem
	+ Driven damped oscillator — coherent states
* Applications to EM theory (e.g. magnetic field simulation)
	+ Electrostatic charge distributions
	+ Magnetostatic current distributions
	+ Finite Element techniques for electromagnetic simulations

Course outcomes:

In this course the students will learn

1. Basics of programming
2. To write programs to solve scientific problems
3. Techniques for scientific computing
4. Applications to quantum mechanics and electromagnetism

Course References:

Computational Physics, Nicholas Giordano, Hisao Nakanishi, 2nd edition, Pearson-Addison Wesley (2005)

QT 04: Basic Laboratory Course for Quantum Technologies (2:1)

(Out of QT 03 and QT 04, at least ONE is mandatory)

Course Content and syllabus:

* 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
* Digital circuits
	+ Adder, Multiplier
	+ Encoder, Decoder
	+ D flipflop, shift registers
	+ How to use common Integrated Circuit chips
* 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
* 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
* Quantum Simulators
	+ Running quantum protocols in a quantum simulator
	+ Implementing simple quantum algorithms on cloud-based quantum computers (depending on availability of time on such machines)
* Running simple algorithms on cloud-based quantum processors (optional)

Course outcomes:

This course teaches the student to

1. Learn basic experimental techniques in optics
2. Learn Basic experimental techniques in characterising resonators and RLC circuits
3. Learn basic digital circuits
4. Learn fundamental techniques in RF engineering
5. Learn interfacing instruments with computers and carry out data acquisition

Course References:

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

QT 05: Introduction to Quantum Computation 3:0

(Out of QT 05, QT 06, QT 07 and QT 08, at least ONE is mandatory)

Course Content and syllabus:

* 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
* Review of Turing machines and classical computational complexity
	+ Time and space complexity (P, NP, PSPACE)
* Reversible computation
* Universal quantum logic gates and circuits
* 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.
* Quantum complexity classes – Q, EQP, BQP, BPP, QMA
* Additional Topics in Quantum Algorithms
	+ Variational Quantum Eigensolver (VQE)
	+ HHL
	+ QAOA
* Introduction to Error correction
	+ Fault-tolerance
	+ Simple error correcting codes
* Survey of current status
	+ NISQ era processors
	+ Quantum advantage claims
	+ Roadmap for future

Course outcomes:

Students of this course will learn

1. To review the basic postulates of quantum mechanics
2. The theoretical basics of qubits and their physical realisations
3. To work with density operators and time evolution for mixed states
4. The basic ideas of quantum gates
5. The working of important quantum algorithms
6. The basics of quantum error correction

Course References:

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

QT 06: Introduction to Quantum Communication

(Out of QT 05, QT 06, QT 07 and QT 08, at least ONE is mandatory)

Course Content and syllabus:

* Basics of Polarization optics
	+ Quarter and half-wave plates
	+ Polarizing beam splitters
* Basics of linear and square-law detectors
	+ Quadrature amplitude modulation
	+ Heterodyne and Homodyne demodulation and linear detectors
	+ Intensity measurements and square law detectors
	+ Photomultipliers, Avalanche Photo diodes
* Digital communication – information theory (basics)
	+ Information entropy
	+ Noiseless channel encoding
	+ Noisy channel encoding
* No cloning theorem
* Quantum Memories
* Quantum repeaters
* Entanglement and Bell Theorems
* Bell Measurements and Tests
* Quantum Teleportation protocol
* Quantum Dense coding
* Quantum Key Distribution protocols
	+ BB84
	+ E91
	+ BBM92.
	+ B92
	+ COW
	+ DPS
* Quantum Networks and Quantum Internet
* Survey of Hardware implementations
	+ Free space communications
	+ Satellite based communications
	+ Fibre optics-based communications

Course Outcomes:

Students of this course will learn

1. The basics of EM theory
2. The basics of photodetection
3. The basics of information theory
4. The central ideas in quantum communications

Course References:

1. Quantum computation and quantum information – Nielsen and Chuang Cambridge University Press, Cambridge (2010)
2. A Pathak, Elements of Quantum Computation and Quantum Communication, Boca Raton, CRC Press (2015)

QT 07: Introduction to Quantum Sensing 3:0

(Out of QT 05, QT 06, QT 07 and QT 08, at least ONE is mandatory)

Course Content and syllabus:

* Classical sensing
	+ photo detection
* Classical Noise
	+ Johnson Noise, Telegraph noise, flicker or 1/f noise
* Sensitivity of classical measurements
	+ Classical Fisher information
	+ Cramer - Rao bounds (information theory basics may be required here).
* Quantum measurements
	+ projective/orthogonal measurements
	+ Approximate/non-orthogonal measurements
	+ Weak continuous measurements
	+ Error-disturbance relations
	+ Standard quantum limits
	+ Quantum non-demolition measurements
* States of light
	+ fock states
	+ Coherent states
	+ Squeezed states
	+ Tomography
	+ Wigner quasi-probability distribution
	+ P-distribution
	+ Husimi Q function
* Quantum photo detection
	+ Square-law detectors, Intensity measurements and Photo-detection
	+ Linear Detectors and Quadrature Measurements
* Quantum Cramer-Rao bounds
* Single photon-based sensing applications
* Entanglement based sensing applications
* Atomic state-based sensing, solid-state spin-based sensing applications (gravimetry, magnetometry)

Course Outcomes:

In this course, students will learn

1. The basics of classical sensing
2. Aspects of quantum measurement
3. Ways to quantify quantum sensing
4. About measurements of quantum states of light
5. About the applications of quantum sensing

Course References:

1. Quantum Measurement and Control , Howard Wiseman and David Milburn, Cambridge University Press (2014)
2. Quantum Measurement , Vladimir Braginsky and Farid Ya Khalili, Cambridge University Press (1995)
3. Quantum Information Science – Manenti R., Motta M., 1st Edition, Oxford University Press (2023)

QT 08: Introduction to Quantum Materials 3:0

(Out of QT 05, QT 06, QT 07 and QT 08, at least ONE is mandatory)

Course Content and syllabus:

* Band theory basics
	+ Metals, Semiconductors and Insulators
	+ Band structure of solids
	+ Survey of semiconducting devices for quantum technologies (electronic, quantum optical devices and principle of operation)
* Correlated systems
* Magnetism
	+ Para, ferro magnetism basics
	+ Magnetic measurements, hall effect, magnetoresistance
	+ Faraday and Kerr effects
* Superconductivity
	+ BCS theory
	+ Ginzburg Landau
	+ Josephson Effect – AC and DC Josephson effects
	+ Survey of superconducting devices for quantum technologies
* 2D materials
	+ Graphene and its properties – single and few layers
	+ Transition Metal Dichalcogenides – Electronic and Optical Properties
* Topological Phases of matter
	+ Basics of Topology
	+ Geometric phases - Berry Phase
	+ Aharonov Bohm effect
	+ Topological phases of matter
* Survey of material growth techniques
	+ Molecular beam epitaxy
	+ Chemical vapor deposition, MOVPE
	+ Pulsed laser deposition, etc.
	+ Crystal growth techniques

Course Outcomes:

In this course, students will learn

1. The basic idea of quantum materials
2. The basics of band theory of solids
3. The basics of magnetism
4. The basics of superconductivity
5. About new 2D materials like graphene, TMDCs
6. About topology and topological phases of matter

Course References:

1. Condensed Matter Physics , M P Marder, 2nd Edition, John Wiley and Sons, 2010
2. Introduction to Superconductivity, Michael Tinkham, standard ed., Medtech (2017)

QT 09: Engineering Foundations of Quantum Technologies 3:0 (optional / additional)

*This course is meant to cover topics in electrical, electronics and communication engineering, as well as in computer science that are relevant to Quantum computation, Communications and Sensing. This is a survey course and not meant for a rigorous treatment of each topic.*

Course Content and syllabus:

* Electrical Networks (4 hours)
	+ Analog RLC circuits – resonances, impedances, quality factors
	+ Transmission line basics (2 hours)
		- Telegrapher equations, wave impedance, impedance matching, transmission line resonators
* Computer Science (15 hours)
	+ Basics of computer architecture (1 hour)
		- Arithmetic Logic Unit
		- Memory
	+ Abstract models of computation (12 hours)
		- Finite State Machine
		- Turing Machines
		- Overview of Hierarchy of languages – Regular, Context-Free, Turing Decidable and Turing Recognisable
	+ Complexity Theory (2 hours)
		- Time and Space complexity
		- P vs NP, NP-completeness
* Electrical Communications (1 hour)
	+ Analog Communications (1 hour)
		- Quadrature amplitude modulation
		- Heterodyne and Homodyne demodulation
* Noise and Signals (6 hours)
	+ Characterising Noise
	+ Types of Noise
		- Shot Noise
		- Johnson-Nyquist Noise
		- Telegraphic noise or flicker or 1/f noise
	+ Signal conditioning and noise mitigation
	+ Amplification and Added Noise
		- Linear Amplifier theory
		- Signal-Noise Ratio, Added Noise, Noise Figure of amplification
		- Dynamic Range
		- Noise temperature
		- Quantum limits on noise in linear amplifiers
* Digital Communications (4 hours)
	+ Information entropy
	+ Noiseless channel encoding
	+ Noisy channel encoding
* Basics of cryptography (6 hours)
	+ Basics of Number Theory
	+ Random Number Generation
	+ One time pad, Private key, public key, symmetric and asymmetric cryptography protocols
	+ RSA and DH
	+ Post Quantum Cryptography (PQC)

Course Outcomes:

Students of this course learn

1. Relevant topics from Electrical Networks to design and analyse analog circuits
2. Relevant topics from RF and Microwave Engineering to design systems
3. Relevant topics in Theory of computation to benchmark algorithms
4. Relevant topics in analog and digital communications
5. Basics of cryptography

Course References:

1. Art of Electronics, Paul Horowitz and Winfield Hill, 3rd edition, Cambridge University Press (2015)
2. Digital Design, Morris Mano, Michael D. Cilletti, 6th edition, Pearson Education (2018)
3. Microwave Engineering, David Pozar, 4th edition, Wiley (2013)
4. Information Theory, Robert B. Ash, Dover Publications (2003)
5. Introduction to the Theory of Computation, Michael Sipser, 3rd edition, Cengage India Pvt. Ltd. (2014)
6. Protecting Information – From Classical error correction to quantum cryptography, Susan Loepp and William K. Wootters, Cambridge University Press (2006)

QT 10: Solid State Physics for Quantum Technologies 3:0 (optional / additional)

Course Content and syllabus:

* Structure of solids –
	+ Symmetry, Bravais lattices
	+ Laue equations and Bragg’s law,
	+ Brillouin Zones
	+ Atomic scattering and structure factors.
* Characterisation of crystal structures – XRD etc.
* Bonding in solids –
	+ van der Waals and Repulsive interactions,
	+ Lennard Jones potential,
	+ Madelung constant
* The Drude theory of metals –
	+ DC & AC electrical conductivity of a metal;
	+ Hall effect & magnetoresistance,
	+ Density of states, Fermi-Dirac distribution, Specific heat of degenerate electron gases
	+ Free electron model
* Beyond the Free electron model
	+ Kronig-Penney Model
	+ Periodic potential – Bloch Theorem
	+ Band theory
	+ Tight binding model
* Phonons in Solids
	+ One dimensional monoatomic and diatomic chains
	+ Normal modes and Phonons
	+ Phonon spectrum
	+ Long wavelength acoustic phonons and elastic constants
	+ Vibrational Properties- normal modes, acoustic and optical phonons.
* Magnetism
	+ Dia-, Para-, and Ferromagnetism
	+ Langevin's theory of paramagnetism
	+ Weiss Molecular theory
* Superconductivity:
	+ Phenomenological description – Zero resistance, Meissner effect
	+ London Theory
	+ BCS theory
	+ Ginzburg-Landau Theory
	+ Type-I and type-II superconductors
	+ Flux quantization
	+ Josephson effect.
	+ High Tc superconductivity

Course Outcomes:

The students of this course will learn the

1. Basics of solid states physics
2. Various approximations for electronic states in matter
3. The theory of phonons in solids
4. The theory of magnetism
5. The theory of superconductivity

Course References:

1. Introduction to Solid State Physics, Charles Kittel, Wiley India Edition (2019)
2. Condensed Matter Physics, M P Marder, 2nd Edition, John Wiley and Sons (2010)
3. Introduction to Superconductivity, Michael Tinkham, standard edition, Medtech (2017)

QT 11: Quantum Optics 3:0 (optional / additional)

Course Content and syllabus:

* Quantization of the electromagnetic field
	+ Number states, coherent states, squeezed states
	+ Hanbury-Brown and Twiss experiments – Photon bunching, Photon anti bunching
	+ Hong-Ou-Mandel interference
* Theory of Optical coherence
	+ Young’s double slit experiment and first order coherence
	+ Coherence functions of arbitrary order
	+ Normal ordering, symmetric ordering and ani-normal ordering of operators
	+ Interferometry
* Phase-space representations of states of light
	+ Wigner distribution
	+ P-function and the notion of non-classicality with some examples of nonclassical states like squeezed states and their applications
	+ Husimi Q function
* Light-matter interaction
	+ Classical model of light-matter interaction
	+ Semi-classical model of light-matter interaction-
	+ Quantum light-matter interaction
	+ Rabi Model
	+ Jayne’s-cummings model
* Open quantum systems
	+ Fermi golden rule
	+ Born-Markov Lindblad Master Equation

Course Outcomes:

In this course, students will learn

1. To quantise the electromagnetic field
2. The various experimental techniques in photonics
3. The various representations of states of light
4. Classical, semi-classical and fully quantum models of light-matter interaction
5. Modelling decoherence through Master equation

Course References:

1. Introductory Quantum Optics, Christopher Gerry and Peter Knight, Cambridge University Press (2004)
2. Quantum Optics, D. F. Walls, Gerard J. Milburn, 2nd Edition, Springer (2008)
3. Quantum Optics: An introduction, Mark Fox, Oxford University Publishers (2006)
4. Quantum Optics for Beginners, Z. Ficek and M. R. Wahiddin, 1st edition, Jenny Stanford Publishing (2014)

Annexure IV

List of Equipment for Teaching Lab

|  |  |
| --- | --- |
| Type of experiments | Experiment details |
| Basic optics | Polarization optics – PBS, HWP, QWP |
| OpticsInterferometry – wavelength measurements, intensity measurementsDiffraction – single slit, grating |
| Michaelson interferometer kit |
| Quantum optics/communications | Quantum Cryptography Analogy Demonstration Kit |
| Quantum sensing modules | To study Zeeman Effect |
| General electronics equipment           | Analog and digital electronics components |
| Power Supplies (DC) |
| RF-VNA (frequency up to 6 GHz) |
| RF CW signal generators |
| Function Generator |
| Oscilloscope high Frequency |
| Spectrum Analyser |
| RFSoC boards for FPGA programming training |
| Microwave Components – Amplifiers, double balanced Mixers, IQ mixers, Directional Couplers, Circulators, Isolators, Filters (high pass, low pass, bandpass), Cables, Attenuators etc. |
| IQ modulator |
| PC for measurements |