M. Tech. in Optoelectronics and Communication Systems (Lasers and Electro-optics)

One of the greatest scientific discoveries of the twentieth century that has led to technological advancement touching all aspects of human life is the LASER. Applications of lasers range from medical applications, communications, and industrial applications to military applications. An understanding of laser technology is essential for an engineer working in many of the present-day cutting-edge technologies. The aim of this program is to train the students in the field of lasers, fiber optics, electro-optics, and photonics that would enable them to meet the challenges in this rapidly developing field.

Stakeholders:

(i) Sponsored candidates from Army, Navy, Air Force, DRDO Laboratories, Public Sector Undertakings, and other departments

(ii) Graduates in the relevant field of science/technology from recognized Universities across the country.

Eligibility for Students:

The candidate should possess Master degree or equivalent in Physics, Applied Physics, Engineering Physics, Electronic Science, Photonics, Optics, Material Science, Instrumentation Science or any equivalent branch

OR

B. E./ B. Tech (Any discipline)

Organization: The M. Tech. programme is of four-semester duration. In each of the first two semesters there are six theory courses and one laboratory course. There will be three continuous evaluation examinations and a final semester examination for every course. Half yearly evaluation of the project takes place at the end of the third semester. At the end of the final semester, the student submits a dissertation and makes a presentation about the work carried out by him/her on the project, which is evaluated by the Internal and External examiners. Course syllabus is updated periodically to keep pace with the contemporary technological advancement.

PROGRAMME EDUCATIONAL OBJECTIVES (PEOs)

PEO1: The M Tech in Lasers and Electro-Optics programme aims at developing skilled human resources in the field of Optics, lasers and Electro-optics. It will ensure the understanding of applied optics, physics and engineering laser technology, fiber optics, semiconductor photonic devices, laser systems and its various applications, catering to the emerging multidisciplinary problems faced by defence industry and civilization.

PEO2: With a focus on the DRDO requirements, the students will be trained to use their knowledge for the benefit of society and made aware of their social duty. This will enable them to pursue career in research, academics and industry.

PEO3: At the end of the programme the officer or student should be able to undertake state of the art R&D in lasers and electro-optic systems and competitively work towards development of the latest technology in line with national programmes like Make in India.

PROGRAMME OUTCOMES (POs)

PO_01 : Having an ability to apply mathematics and science in engineering applications.

PO_02 : Having an ability to design a component or a product applying all the relevant standards and with realistic constraints, including public health, safety, culture, society and environment

PO_03 : Having an ability to design and conduct experiments, as well as to analyse and interpret data, and synthesis of information

PO_04 : Having an ability to use techniques, skills, resources and modern engineering and IT tools necessary for engineering practice

PO_05 : Having problem solving ability- to assess social issues (societal, health, safety, legal and cultural) and engineering problems

PO_06: Having adaptive thinking and adaptability in relation to environmental context and sustainable development

PO_07: Having a clear understanding of professional and ethical responsibility

PO_08: Having a good cognitive load management skill related to project management and finance

PROGRAMME SPECIFIC OUTCOMES (PSOs)

On completion of M. Tech. (Lasers and Electro-Optics) programme, graduates will be able to

PSO1: The M. Tech in Lasers and Electro-Optics aims at developing a skilled knowledgeable Human task force in the field of Lasers and Electro-Optics serving the needs of the Defence Research and

Development Organization & Tri – services (Army, Navy & Air force), Coast Guard, DGQA, DQA, Defence Public Sector units, in addition to the civilians in general. After completing M. Tech. course, the students develop an ability to carry out independent research in the area of optical devices.

PSO2: The dissertation work of the M. Tech. students leads to publications in high impact international journals which trains them in technical documentation and report writing.

PSO3: The goal of the M. Tech. in Lasers and Electro-Optics course is to generate highly competent human resources in the areas of laser development, electro-optic systems, fibre optics, applied optics, and computational photonics.

Semester I

Sl No	Course Code	Course Name	Credits		Total Credits
			L	P/T (in Hr)	
1	AP 621	Fundamentals of Laser and Laser Systems	3	1	4
2	AP 622	Optical Electronics	3	1	4
3	AP 623	Introduction to Fiber Optics	3	1	4
4	AP 624	Semiconductor Photonic devices	3	1	4
5	AP 625	Quantum mechanics for Engineers	3	1	4
6	AP 701	Laser & Optical Communication Laboratory – I	0	8	4
7	PGC-601	Research Methodology and IPR	2	0	2
		TOTAL	**17**	**9**	**26**

Semester II

Sl No	Course Code	Course Name	Credits		Total Credits
			L	P/T (in Hr)	
1	AP 631	Laser Applications	3	1	4
2	AP 632	Computational Photonics	3	1	4
3	AP 702	Laser & Optical Communication Laboratory – II	0	**8**	4
4	AP 6XX	Elective – I	3	1	4
5	AP 6XX	Elective – II	3	1	4
6	AP 6XX	Elective – III	3	1	4
7	PGC-602	Audit 1 and 2	2	0	2
		TOTAL	**17**	**9**	**26**

Semester III:

Sl. No.	Course Code	Course Name	Credits		Total Credits (*)
			L	T / P	
1.	AP 681	M.Tech Dissertation Phase – I	28**		14
		Total	28		14

Semester IV:

Sl. No.	Course Code	Course Name	Credits		Total Credits (*)
			L	T / P	
1.	AP 682	M. Tech. Dissertation Phase – II	28**		14
		Total	28		14

***** 1 Credit in Theory/Tutorial means 1 contact hour and 1 credit practice/Project Thesis means 2 contact hours in a week.

****Contact Hours/ week**

List of Electives

Sr. No.	**Course Code**	**Course**
Elective I, II & III		
1	AP 641	High Power Lasers
2	AP 642	Terahertz Devices and Applications
3	AP 643	Free Space Optical Communication
4	AP 644	Nanophotonics
5	AP 645	Non-linear and Quantum Optics
6	AP 646	Integrated Optics and Silicon Photonics
7	AP 651	Broadband Communication Systems
8	AP 652	Advanced Optical Communication
9	AP 653	Optical Networks

AP-621 – Fundamentals of Laser and Laser Systems

Course Outcomes:

CO-1	Interpret the concepts of laser technology
CO-2	Analyze the working principle of lasers
CO-3	Examine the laser radiation beams
CO-4	Illustrate and construct the practical laser systems
CO-5	Summarize different types of laser systems and its working principals

Syllabus:

Units Divisions	Syllabus Details
Unit I:	Light-matter interaction: Interaction of radiation with atomic systems, Einstein's coefficients, spontaneous emission, stimulated emission, Linewidth of the laser, line broadening
Unit II:	Lasers Oscillation: Theory of laser oscillation; Threshold condition, Rate equation, Optical amplification and feedback, Condition for laser oscillation, Characteristics of laser output power, Spectral distribution, Spatial distribution and polarization, Hole burning, Properties of laser beam, Pumping techniques.
Unit III	Laser Resonators and Gaussian Beams: The Ray Matrix, Resonator Stability, Paraxial Wave Equation, Gaussian Beams, ABCD Law for Gaussian Beams, Gaussian Beam Modes, Hermite–Gaussian and Laguerre–Gaussian Beams, Resonators for He–Ne Lasers, Diffraction, Diffraction Theory of Resonators, Beam Quality, Resonators for High-Power Lasers.
Unit IV	Laser Systems 1: Ruby Lasers, Neodymium-Based Lasers, Titanium Sapphire Laser, He–Ne Laser, Argon Ion Laser, CO2 laser, Excimer Laser and Fiber Lasers & Amplifiers.
Unit V	Laser Systems 2: Semiconductor Lasers, Optical Gain in Semiconductors, Quantum Well Lasers, Quantum Dot Laser, and Quantum Cascade Laser

References Textbooks:

1. A. K. Ghatak and K. Thyagarajan, Lasers: Theory & Applications, Macmillan India Limited, 2003.
2. O. Svelto, Principles of Lasers, Plenum Press, New York, 1998.
3. P. W. Milonni and J. H. Eberly, Lasers, Willey Inter Science, 1988
4. B. E. A. Saleh, M. C. Teich, Fundamentals of Photonics, John Wiley & Sons, Inc., 2nd Ed. (2007)
5. P. Bhattacharya, Semiconductor Optoelectronic Devices, Prentice Hall of India (1995).

AP-622 – Optical Electronics

Course Outcomes:

CO-1	Interpret the concepts of optical electronics
CO-2	Analyze the working principle of ME Theory, EO, MO and AO effects
CO-3	Examine the working mechanism of different types of Optical components, EO, MO and AO effects
CO-4	Illustrate the practical use of Optical components, EO, MO and AO effects
CO-5	Summarize different applications of optical electronics devices

Syllabus:

Units Divisions	**Syllabus Details**
Unit I:	**Electromagnetic fields and Anisotropic media:** Wave equation, Plane waves, Reflection and Refraction of plane waves, Fresnel Formula, Wave propagation in stratified medium, propagation of Electromagnetic waves in Uniaxial and biaxial crystals, the dielectric constant tensor and the 'index ellipsoid'
Unit II:	**Polarisation of light and Basic optical components:** Electromagnetic theory of light, Dielectric media, Monochromatic EM waves, Absorption and dispersion, Polarisation of light, Jones Calculus, Poincare sphere. Polarisers, Quarter, Half, and Full waveplates, Beam splitters: polarizing and non-polarizing, wavelength filters, dichroic mirrors, Lenses.
Unit III	**Electro-optics:** Basic principles: Pockel and Kerr effects, Electro-optic devices: modulators, switches, and scanners, E.O. effect in liquid crystals; LCDs and SLMs, Applications.
Unit IV	**Acousto-optics:** Strain waves in solids and liquids, the strain-optic tensor; theory of Raman-Nath and Bragg diffraction; small-angle and large-angle Bragg diffraction. Accousto-optic devices: Modulators, deflectors, scanners, interconnections, and acoustooptic tunable filters.
Unit V	**Magneto-optics**: Principles, Faraday effect, Gyrotropic permittivity, Kerr rotation and Kerr ellipticity, Applications.

References Textbooks:

1. A. K. Ghatak & K. Thyagarajan, Optical Electronics, Cambridge University Press,1989. References
2. A. Yariv, P. Yeh, Photonics: Optical Electronics in Modern Communications, The Oxford

Series in Electrical and Computer Engineering, 2006.
3. B. E. A. Saleh, M. C. Teich, Fundamentals of Photonics, John Wiley & Sons, Inc., 2nd Ed. (2007)
4. S. Sugano, N. Kojima (Eds.), Magneto-Optics, Springer Series in Solid-State Sciences, Vol. 128, 2000.
5. O. Svelto, Principles of Lasers, Plenum Press, New York, 1998.
6. P. W. Milonni and J. H. Eberly, Lasers, Willey Inter Science, 1988.
7. A. K. Ghatak and K. Thyagarajan, Lasers: Theory & Applications, Macmillan India Limited, 2003.

AP-623 – Introduction to Fiber Optics

Course Outcomes:

CO-1	Understand the basics concepts of Fiber Optic Communication
CO-2	Understand all the sub-components of Fiber Optics
CO-3	Examine the working mechanism of Fiber Optics
CO-4	Illustrate the practical implementation of Fiber Optic Communication
CO-5	Summarize different applications of Fiber Optic Communication

Syllabus:

Units Divisions	**Syllabus Details**
Unit I:	**Optical Fibers:** Light Propagation in Optical Fibers, Optical fiber Modes and Configurations, Mode Theory for Circular waveguides, SM and GI Fibers, Fiber Materials, PhC fibers, Fiber fabrication. **Optical Fibers Characteristics:** Fiber Attenuation, Absorption losses, scattering losses, Radiation losses, Bending losses, Measurement of losses, Dispersion in fibers, Effect of dispersion in the communication link, Dispersion reduction, and compensation techniques.
Unit II:	**Power Launching and Coupling:** Source to Fiber launching and Launching Schemes for Coupling Improvements. Fiber to Fiber joints, Laser coupling to SM fiber, Fiber splicing, Optical Fiber Connector. **Optical Receivers:** Basic Concepts, Common Photodetectors, Receiver Design, Receiver Noise, Coherent Detection, Receiver Sensitivity, Sensitivity Degradation, Receiver bandwidth, and Performance

Unit III	**Fiber Amplifier:** Optical Amplification in rare-earth-doped fibers, Types of Fiber Amplifiers, EDFA, Amplifier Noise, Optical SNR, System Application, Raman Amplifiers, Wideband Optical Amplifier
Unit IV	**Optical Fiber Sensors:** Introduction, Classification and Types of Optical Fiber Sensors, Sensor Modulation techniques, Fiber Bragg Grating Sensors: Principle and Applications.
Unit V	**Overview of Optical Fiber Communication:** Lightwave communications, Optical Spectrum Bands, and Visible Units, Network Information rate and WDM concepts. Key Elements of fiber optics system, Standards for Optical fiber communications.

References Textbooks:

1. A.K.Ghatak & K.Thyagarajan, Introduction to Fiber Optics, Cambridge University Press 1998
2. G. Kaiser, Optical Fiber Communication, 4th Edition, Tata McGraw Hill 2008
3. J.C. Palais, Fiber Optic Communications, 4th Ed., Prentice-Hall Inc 1998
4. J.P. Dakin & B Culshaw, Optical Fiber Sensors, Vol. 1&2., Artech House 1998
5. K.T.V. Grattan & B.T. Meggitt, Optical Fiber Sensor Technology, Vol. 2, 1988

AP-624 – Semiconductor Photonic devices

Course Outcomes:

CO-1	Understand the basics of Semiconductor Physics
CO-2	Interpret all the optical properties and processes in semiconductors
CO-3	Examine the working mechanism of different kinds of LEDs and LASERs
CO-4	Illustrate the implementation of Modulation and Switching Devices
CO-5	Explain different types of photodiodes and photodetectors

Syllabus:

Units Divisions	**Syllabus Details**
Unit I:	**Review of Semiconductor Physics:** Energy Bands, Density of States, Fermi-level, PN Junction, Homo and Hetero Junction, Quantum Wells. Semiconductor Optoelectronic materials, Electron-hole pairs
Unit II:	**Light Emitting Diodes:** The electroluminescence Process, LED materials, Device configuration and Efficiency, LED structures, LED performance characteristics, Frequency response and Modulation bandwidth. LEDs for display and Lighting.
Unit III	**Semiconductor Lasers:** Junction Laser Operating Principles, Threshold Current, Heterojunction Laser, Distributed Feedback Lasers and Distributed Bragg Reflector, Ring Lasers: Single and Double, Master Oscillator Power Amplifier. VCSELS and Laser Diode

	Arrays. Advanced Semiconductor Laser: Quantum Well and Quantum Cascade Laser, Laser Modulation Bandwidth.
Unit IV	**Modulation and Switching Devices:** Analog and Digital Modulation of light sources, Franz-Keldysh and Stark-effect based Modulators, QW Electro-absorption modulator.
Unit V	**Photodetectors:** Types of photodetectors, Photoconductors, Junction photodiode, PIN photodiode and APD, Quantum Well IR Detectors, High Speed Measurements, Detectors for long wavelength operation, Wavelength selective detection, Coherent detection. CCDs and PICs.

References Textbooks:

1. P. Bhattacharya, Semiconductor Optoelectronic Devices, Prentice Hall of India (1995).
2. G. Ghione, Semiconductor Devices for High-Speed Optoelectronics, Cambridge University Press (2009)
3. A. Yariv and P. Yeh, Photonics: Optical Electronics in Modern Communication, Oxford University Press (2007), 6th Ed., Ch.15-17.
4. G. Keiser, Optical Fiber Communications, McGraw-Hill Inc., 3rd Ed. (2000), Ch.4, 6.
5. J. Singh, Semiconductor Optoelectronics: Physics and Technology, McGraw-Hill Inc. (1995).
6. J. M. Senior, Optical Fiber Communication: Principles and Practice, Prentice Hall of India, 2nd Ed.(1994), Ch.6-8.
7. B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics, John Wiley & Sons, Inc., 2nd Ed. (2007), Ch.16, 17, and 18.

AP-625 – Quantum mechanics for Engineers

Course Outcomes:

CO-1	Understand the basic concepts of quantum mechanics Physics
CO-2	Interpret the physical meaning of formulation in quantum mechanics
CO-3	Examine different 1D problems in quantum mechanics
CO-4	Illustrate the implementation to 1 electron atoms
CO-5	Explain Quantum mechanics to Lasers

Syllabus:

Units Divisions	**Syllabus Details**
Unit I:	Introduction: Thermal radiation, Plank’s postulates, The Schrödinger equation, Statistical interpretation, probability, normalization, momentum, the uncertainty principle
Unit II:	Time Independent Schrödinger: stationary states, infinite square well, harmonic oscillator, free particle, delta function potential, finite square well
Unit III	Formalism: Hilbert’s space, observables, eigen function of Hermitian operator, statistical interpretation, Dirac notation
Unit IV	One electron atoms: solution of Schrödinger equation in 3D, eigen values, quantum numbers, and degeneracy, orbital angular

Unit V	Quantum statistics: indistinguishability and quantum statistics, quantum distribution functions, Boltzmann distribution as an approximation to quantum distributions, The Lasers

References Textbooks:

1. Quantum Physics of Atoms, molecules, solids nuclei and particles by Robert Eisberg and Robert Resnick Wiley publishing
2. Introduction to Quantum Mechanics by David Griffiths Pearson Publishing
3. Quantum Mechanics by B H Bransden and C J Joachain Pearson Publishing

AP-631 – Laser Applications

Course Outcomes:

CO-1	Familiarize to a variety of applications on lasers
CO-2	Interpret how laser-based metrological techniques work
CO-3	Understand laser spectroscopy applications
CO-4	Investigate various methods of how a laser can be used for defence applications
CO-5	Summarize different applications of lasers

Syllabus:

Units	Syllabus Details
Unit I:	**Laser Metrology: Laser** for measurement of distance, length, velocity, acceleration; rotation sensing; RLG and FOG.
Unit II	**Laser Spectroscopy:** IR absorption Spectroscopy, Laser Raman spectroscopy, Laser induced breakdown spectroscopy (LIBS), laser-induced fluorescence (LIF), Tunable diode laser spectroscopy (TDLS), Terahertz spectroscopy, Photoacoustic spectroscopy, Instrumentation in laser spectroscopy, Isotope Separation & Enrichment. Bio-Medical Application of Lasers
Unit III	**Holography:** Holographic interferometry and applications; Holography for non – destructive testing – Holographic components
Unit IV	**Industrial Application of Laser:** Laser cutting, Laser welding, Laser drilling, Laser marking, Photolithography, Laser-based unmanned ground vehicles
Unit V	**Defence Applications:** Low power laser applications including Laser Range finders-LRF (DPSSL, Eye Safe & High PRF) & Laser Target Designators; Dazzlers, Laser Warning receivers, Infrared counter measures, Laser Guidance; Laser-based navigation; Laser-based imaging; Laser-based remote sensing: Laser radar, laser radar seekers, LIDAR basic concept and applications

References Textbooks:

1. J.F. Ready, Industrial Applications of Lasers. Academic Press, 1997 2nd Edition

2. G.K. Ackermann & J. Eichler, Holography: A practical approach, John Wiley & sons, 2008

3. H. Wichel, Laser Beam Propagation in the Atmosphere, SPIE Press 1990

4. K. Bharat, Laser Safety Tools and Training, CRC Press 2009

5. K. Nagothu, New Paradigms for Underwater Communication, ProQuest 2009

AP-632 – Computational Photonics

Course Outcomes:

CO-1	Interpret the concepts of Simulation and Modelling methodology
CO-2	Analyse the modelling results of photonics devices
CO-3	Examine the working photonics devices with different methods
CO-4	Demonstrate the practical implementation
CO-5	Understand the nanofabrication

Syllabus:

Units Divisions	**Syllabus Details**
Unit I:	**Mode Solver Method:** Theory of fully vectorial mode solvers in 2D and 3D structures, low-index polymer waveguides, high-index silicon (SOI) and GaAs/AlGaAs waveguides, buried, etched (rib, ridge), and diffused geometries commonly used in opto-electronics slot waveguides, slanted-wall and graded structures, plasmonic and microwave waveguides,
Unit II:	**Beam Propagation Method:** Theory and working of beam propagation method, Tutorials on MMI couplers, optical gratings, co-directional couplers or polarization converters.
Unit III	**FDTD Method:** Theory and working of FDTD method, Tutorials on photonics band gap simulation: 2D and 3D of different crystal lattices.
Unit IV	**Fiber Optics Modeling:** Simulation and modeling of single mode and multimode optical fiber using mode solver, FBG and Chirped FBG synthesis, photonic crystal fiber simulation
Unit V	**Nanodesign:** Mask designing for nanofabrication of different device geometry

References Textbooks:

1. S. Sujecki, Photonics Modelling and Design, CRC Press, 2015.
2. K. Okamoto, Fundamentals of Optical Waveguides, Academic Press, 2000.
3. A. Taflove, Computational Electrodynamics: The Finite-Difference Time Domain Method. Norwood, MA: Artech House, 1995.

AP-641 – High Power Lasers

Course Outcomes:

CO-1	Interpret the concepts of HPL technology
CO-2	Analyze the working principle of different types of HPLs
CO-3	Examine the working mechanism of High Power Fiber Lasers
CO-4	Demonstrate the practical implementation of HPLs
CO-5	Understand the Safety & legislations related to HPL

Syllabus:

Units Divisions	**Syllabus Details**
Unit I:	**High Power Lasers Source:** Criteria for High Power Capability, High Power Laser Resonators and Beam Quality Considerations, High Power Lasers: HF, DF, COIL, CO_2 Gas Dynamic Laser, Alkali Laser, High Power Solid State Laser, Free electron laser (FEL), HPL beam combining techniques, Thermal management.
Unit II:	**High Power Fiber Laser and Amplifiers:** Introduction, Materials, Fiber design, Fiber laser components, High Power Pulse Fiber Lasers, High Power cw Fiber Laser Systems, High Energy ns and fs Fiber Laser Systems, Mode-Locked fs Fiber Lasers, Single Frequency Fiber Lasers, Beam Combining.
Unit III	**Beam Director Technology**: Design considerations for beam director, threat alerting system, target acquisition & tracking system, laser beam pointing, target sightline stabilization, system processor & boresight functions, HPL beam control, battle damage assessment, Effects of atmosphere on HPL beam propagation; Adaptive optics
Unit IV	Applications to protect against military threats: laser protection from missiles, laser to address threat of new nuclear weapons, protecting assets from directed energy lasers, lidar protects from chemical/biological weapons
Unit V	**Safety aspects of laser & legislation:** Effective laser safety, laser safety standards; hazard classification of lasers, maximum permissible exposure (MPE), hazard distances, zones, calculation of NOHD; Potential hazard to personnel: eye anatomy & hazards, hazards to skin, other potential hazards(non-beam hazards; common causes of laser

	incidents; safety operating guidelines/procedures; field testing & planning, range laser safety officer; Legislation: Protocol IV .

References Textbooks:

1. High Power Lasers–Directed Energy Weapons Impact on Defence and Security, A. Mallik, DRDO MONOGRAPHS/SPECIAL PUBLICATIONS SERIES, 2012
2. H. Injeyan and G. Goodno, High Power Laser Handbook, McGraw-Hill Professional; 1 edition (April 25, 2011)
3. AK Jha, Infrared Technology: Applications to Electro-Optics, Photonic Devices and Sensors, Wiley, 2000
4. Ter-Mikirtychev and Vartan, Fundamentals of fiber lasers and fiber amplifiers, Springer Series in Optical Sciences, Vol. 181, 2014.
5. B. Zohuri, Directed Energy Weapons Technologies, CRC Press, 1 ed., 2012.
6. V VApollonov, High-Power Optics: Lasers and Applications, Springer International Publishing, Switzerland, 2015
7. Alastair D. McAulay, MILITARY LASER TECHNOLOGY FOR DEFENSE: Technology for Revolutionizing 21st Century Warfare, John Wiley & Sons, Singapore, 2011

AP-642 – Terahertz Devices and Applications

Course Outcomes:

CO-1	Interpret the concepts of terahertz technology
CO-2	Analyze the working principle of different types of terahertz signal sources
CO-3	Examine the working mechanism of different types of terahertz detectors
CO-4	Illustrate the practical implementation of fabrication of components and circuits for terahertz systems
CO-5	Summarize different applications of terahertz technology for imaging, sensing and communications

Syllabus:

Units	**Syllabus Details**
Unit I:	**Basics of Terahertz Technology:** Electromagnetic radiation and propagation fundamentals, Introduction to terahertz technology, Background, Terahertz gap, Key technological issues for terahertz technology, Advantages and limitations of terahertz waves, Material properties at mm and sub-mm frequencies

Unit II	**Terahertz Sources:** Terahertz sources based on electronics: Diodes, transistors, resonant tunnelling diodes, vacuum electronics; Terahertz sources based on photonics: Non-linear crystals, quantum cascade lasers, plasma-based source; Terahertz sources based on optoelectronics: Photomixer, photoconductive antenna and its types; Noises at terahertz frequencies in different sources
Unit III	**Terahertz Detectors:** Terahertz detectors based on electronics: HOT electron bolometer, Heterodyne SIS receivers: Theory and design, Superconducting tuning circuitries, HEB heterodyne receivers: Theory and design, Terahertz MMICs: Theory and design, Terahertz detectors based on photonics
Unit IV	**Terahertz Components:** Terahertz components: Metamaterials and plastic fibers, HEMT cryogenic amplifiers: Theory and design, Antennas, Filters, Waveguides, Beam Splitter, Beam Combiner, Polarizer, Mirrors, Isolator, Circulator, Cameras, Fabrication Technologies
Unit V	**Terahertz Applications:** Terahertz applications: Time domain Colinear and Non-colinear terahertz spectroscopy, Optical-pump-THz-probe Spectroscopy, Terahertz Imaging, Terahertz sensing and analysis, Terahertz wireless communication, Terahertz remote-sensing, 3D terahertz tomography system, Industrial applications, Space Communication, Cutting-edge terahertz technologies

References Textbooks:

1. A. Rostami, H. Rasooli, H. Baghban, Terahertz Technology: Fundamentals and Applications, Germany, Springer, 2011.
2. R. E. Miles, P. Harrison, D. Lippens, Terahertz Sources and Systems “, Dordrecht: Kluwer, Springer, 2000.
3. K. Sakai, Terahertz Optoelectronics, Springer, 2004.
4. H.-J. Song, T. Nagatsuma, Handbook of Terahertz Technologies, Devices and applications, Pan Stanford Publishing Pte. Ltd., 2015.
5. D. Saeedkia, Handbook of Terahertz Technology for Imaging, Sensing and Communications, Woodhead Publishing, 2013.

AP-643 – Free Space Optical Communications

Course Outcomes:

CO-1	Interpret the concepts of Free Space Optical Communication
CO-2	Understand all the sub-components
CO-3	Examine the working mechanism of FSOC
CO-4	Illustrate the practical implementation of FSOC

CO-5	Summarize different applications of FSOC such as VLC/UWOC

Syllabus:

Units Divisions	Syllabus Details
Unit I:	**Introduction FSOC/OWC,** Basic Link configuration of FSOC, various application areas of FSOC, Indoor Channel modelling, various link configurations, Artificial light interference effects in indoor channel.
Unit II:	**Channel Modelling -Outdoor channel,** Atmospheric channel loss related issues, Atmospheric turbulence effects, Measurement of C_n^2 , Various atmospheric turbulence models, Effects of atmospheric turbulence on laser beam propagation, Realization of atmospheric effects on OWC test beds
Unit III	**Modulation Techniques:** Importance of modulation in FSO, various modulation formats, selection criteria for modulation, basic modulation schemes OOK,PPM, PIM, DH-PIM, BPSK etc. and error propagation **FSO link Performance under atmospheric turbulence:** performance of FSO link in various modulation formats, comparison across the modulation formats, the turbulence-induced penalty in FSO link
Unit IV	**Mitigation techniques:** introduction, aperture averaging, various diversity techniques, spatial diversity, time diversity coding techniques, adaptive optics and other techniques.
Unit V	**Laser beam Tracking, pointing & acquisition:** Acquisition and Tracking systems, System description, Acquisition methodology, tracking and pointing control system, RF cross-link system design, link equation

References Textbooks:

1. Arun K. Majumdar, Free-Space Laser Communications Principles and Advances. Springer Publications

2. Hemani Kaushal, Free Space Optical Communication. Springer Publication

3. J. Franz and V.K. Jai, Optical Communication Systems. Narosa Publications

4. Morris Katzman, Laser Satellite Communications. Prentice Hall Inc 1991

5. Infrared Technology: Applications to Electro-Optics, Photonic Devices and Sensors, A.K. Jha

AP-644 – Nanophotonics

Course Outcomes:

CO-1	Familiarization to the concept of Metamaterials
CO-2	Illustration of Optical Properties in Metamaterials
CO-3	Examine Surface Plasmon Resonance
CO-4	Analyze Photonic Bandgap Crystals in different dimensions
CO-5	Understanding the Importance of Silicon Photonics and Its Applications

Syllabus:

Units Divisions	**Syllabus Details**
Unit I:	**Introduction:** Definition of Metamaterials (MTMs) and Left-Handed (LH) MTMs, **Fundamentals of LH MTMs** Left-Handedness from Maxwell's Equations, Entropy Conditions in Dispersive Media, Boundary Conditions, Reversal of Doppler Effect, Reversal of Vavilov-˘Cerenkov Radiation, Reversal of Snell's Law: Negative Refraction, Focusing by a "Flat LH Lens"
Unit II:	**Metamaterial in Optics:** Optical Properties of Metal-Dielectric Composites, Optical Magnetism, Negative-refractive Index, Perfect lens and Cloaking objects.
Unit III	**Surface Plasmon Resonance:** Evanescent waves, Surface Plasmon dispersion equations, resonance, excitation od surface plsmons, surface Plasmon properties, SPR spectroscopy
Unit IV	**Photonic band gap crystals:** Photonics Band-Gap: Introduction to Photonics crystal, Photonic Band Structures, One dimensional, Photonic crystal: Origin of Photonics Band Gap, Size of the band gap, Evanescent Modes in Photonics Band gaps, Two-dimensional Photonic crystal: Two-dimensional Bloch States, Square Lattices (Dielectric Columns and Veins), Three-dimensional Photonic crystal: Three-dimensional lattices, Designing photonics crystal for application: A Mirror, A Waveguide and A Cavity.
Unit V	**Silicon Photonics**: Introduction to Silicon Photonics, Silicon-on-Insulator (SOI) Photonics: Coupling to the Optical Circuit, Optical Modulation Mechanisms in Silicon, Fabrication of Silicon Waveguide Devices, Prospects for Silicon Light-emitting Devices, Advantages and Disadvantages of Silicon Photonics.

References Textbooks:

1. Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications, Christophe Caloz, Tatsuo Itoh, John Wiley and Sons,2006
2. Optical Metamaterials, Fundamentals and Applications, Wenshan Cai Vladimir Shalaev, Springer, 2010.
3. John D. Joannopoulos, Steven G. Johnson, Joshua N. Winn, and Robert D. Meade, Photonic Crystal: Molding Light Flow of Light, Princeton University Press, 2008.

4. Graham T. Reed and Andrew P. Knights, Silicon Photonics: An Introduction, John Wiley and Sons Ltd, 2004
5. Metamaterials: Physics and Engineering Explorations, Nader Engheta Richard W. Ziolkowski, Wiley and Sons,2006
6. Negative-Refraction Metamaterials Fundamental Principles and Applications, G. I. Eleftheriades K. G. Balmain, Wiley and Sons, 2005

AP-645 – Nonlinear and Quantum Optics

Course Outcomes:

CO-1	Interpret the concepts of nonlinear process
CO-2	Analyse the optical response of NLO devices
CO-3	Examine the working principal of different NLO devices
CO-4	Illustrate the application of NLO for ultrashort pulse generation
CO-5	Understand the quantum optics

Syllabus:

Units Divisions	**Syllabus Details**
Unit I:	**Nonlinear optics basics**: Simple Harmonic Oscillator model, Anharmonic oscillator model, Nonlinear polarization, Nonlinear wave equation, Nonlinear susceptibilities and mixing coefficients
Unit II:	**Second order nonlinear effects**: Second harmonic generation, Phase matching condition, Various phase matching techniques, Characterization of second order nonlinear optical materials, Periodically poled materials and their applications in nonlinear optical devices. Sum and difference frequency generation, Optical parametric amplification (OPA) and oscillation (OPO), Analysis of OPA and OPO; practical device configurations and applications.
Unit III	**Third order and Higher order effects**: Third harmonic generation, Four wave mixing and Self-phase-modulation Optical Kerr effect, Self-focusing, Optical Solitons; Optical phase conjugation and Optical bistability. Stimulated Raman Scattering and Stimulated Brilluoin Scattering.
Unit IV	**Ultrafast Optics**: Introduction to ultrashort pulses, Ultrashort pulse generation through mode-locking, Nonlinear Schrödinger equation, Supercontinuum generation.
Unit V	**Quantum Optics**: Review of Quantum Mechanics basics, Quantization of electromagnetic fields, Number states, Coherent states and squeezed states of light and their properties, Beam splitters and interferometers, spontaneous parametric down

	conversion, concept of quantum entanglement, application of optical parametric processes to generate squeezed states of light and entangled states, applications of quantum optics.

References Textbooks:

1. A. Yariv and P. Yeh, Optical waves in crystals: propagation and control of laser radiation, Wiley, New York, 2002.
2. Peter E. Powers, Fundamentals of Nonlinear Optics, CRC Press, 2011.
3. A. Yariv, Quantum Electronics, John Wiley, 1989.
4. Y. R. Shen, The Principles of Non-linear Optics, John Wiley & Sons, 2003
5. R. W. Boyd, Nonlinear Optics, Academic Press, 2008.
6. H.M. Moya-Cessa and F. Soto-Eguibar, Introduction to Quantum Optics (Rinton Press 2011).
7. B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics, 2nd ed..John Wiley, 2007.
8. A. M. Weiner, Ultrafast Optics, Wiley Books, 2008
9. Gerry, Christopher; Knight, Peter, Introduction to Quantum Optics. Cambridge University Press, 2004.
10. L. Mandel, E. Wolf, Optical Coherence and Quantum Optics (Cambridge 1995).
11. D. F. Walls and G. J. Milburn, Quantum Optics (Springer 1994).

AP-646 – Integrated Optics and Silicon Photonics

Course Outcomes:

CO-1	Familiarization to the concept of Optical Waveguides
CO-2	Analysis of Guided Wave Interaction
CO-3	Understanding of Planner and Channel Waveguide Devices
CO-4	Illustrate the Silicon-on-Insulator (SOI) Photonic devices
CO-5	Advanced demonstration of Silicon Photonic Devices

Syllabus:

Units Divisions	**Syllabus Details**
Unit I:	**Optical waveguides:** Introduction to optical waveguides Differences between optical and microwave waveguides, Planar and channel waveguides, General characteristics of guided waves, Formation of optical waveguides on LiNb03, GaAs, InP, Si substrates. Electromagnetic analysis of modes in optical waveguides; The asymmetric planar waveguide, TE and TM modes in planar waveguides. Rectangular and channel waveguides; modal solutions using the effective index and perturbation methods.

Unit II:	**Guided-wave interactions**: Coupled mode analysis of coupled waveguide structures., Examples of coupled mode analysis - the grating reflection filter, and the directional coupler.
Unit III	**Planar and Channel waveguide devices:** Excitation and detection of planar guided waves, Diffraction, focusing, and collimation in planar waveguides, Diffraction devices, The Star coupler, Passive waveguide components; The power divider, Wavelength filters/multiplexers, Waveguide reflectors, Resonators, The optical time delay line. Segmented waveguides; electro-optic and acousto-optic waveguide devices. Directional couplers, optical switch; phase and amplitude modulators, Y-junction, power splitters, Arrayed waveguide devices. Tapered couplers, nonlinear effects in integrated optical waveguides.
Unit IV	**Silicon-on-Insulator (SOI) Photonics:** Introduction, Silicon-on-Insulator waveguides, Effective Index Method of Analysis, Large Single-mode Rib Waveguides, Refractive Index and Loss Coefficient in Optical Waveguides, Coupling to the Optical Circuit; Grating Couplers, Butt Coupling and End-fire Coupling. Optical Modulation Mechanisms in Silicon, fabrication of Silicon Waveguide Devices.
Unit V	**Photonic Devices:** Optical Phase Modulators and Variable Optical Attenuators, MachZehnder Interferometer, Waveguide Bend, Waveguide-to-Waveguide Coupler, Arrayed Waveguide Grating (AWG), Waveguide Couplers for Small-dimension Waveguides, Advantage and Disadvantage of Silicon Photonics. Silicon **Light-emitting Devices:** Erbium Doping, Low-dimensional Structures, Dislocation-engineered Emitters, Raman Excitation.

References Textbooks:

1. William S. C. Chang, Fundamentals of Guided-wave optoelectronics devices, Cambrige University Press,2009
2. G. T. Reed and A. P. Knights, Silicon Photonics An Introduction, John Wiley & Sons, 2004
3. T. Tamir, Ed. Integrated Optics, Springer, 2nd Ed., 1983.
4. R. Hunsperger, Integrated Optics: Theory and Technology" 6th Ed., Springer - 2009.
5. H. Nishihara, M. Haruna, and T. Suhara “Optical Integrated Circuits", McGraw-Hill, 1988.
6. K Okamoto, Fundamentals of Optical Waveguides, Academic Press, 2005.
7. *Ghatak* . A.K., and K. *Thyagarajan* , Optical Electronics, Cambridge, 1989.

AP-651 – Broadband Communication Systems

Course Outcomes:

CO-1	Familiarize to the concepts of Communication technology
CO-2	Interpret the working principle of different types of conventional and Broadband technologies, in terms of signal modulation used
CO-3	Understand working of Cellular Communication systems
CO-4	Analyse the working of GSM Technology and complex modulation techniques used
CO-5	Summarize different applications from 4G to 6G Communication systems

Syllabus:

Units	Syllabus Details
Unit I:	Introduction to Basic Conventional Communication Systems – Modulation, Digital & Analog Communication systems. Introduction to Broadband Network Architectures, Concept of layered Models, OSI Layers and TCP/IP Models
Unit II	Basic Broadband Technologies: Internet Protocol Suite, IPv6, Basics of Intranet & Extranet technologies, X.25 Technology, Frame Relay, Frame Relay Standards, Types of VPN and General Architecture, Fiber Channel Technology & topologies.
Unit III	Cellular Communication: Analog Cellular Communications, The Cell site, The Mobile Telephone Switching Office (MTSO), Cell site Configurations, Tiered sites, Reuse of Frequencies, Allocation of Frequencies
Unit IV	Global Services Mobile Communications (GSM), Wireless Data Communication (Mobile IP) and GPRS: Analog to Digital Movement, GSM Architecture, Mobile Equipment (MS), BTS, BSC, BSS, MSC, VLR, IP Routing, Applications That Demand Mobile IP, Variations in Data Communications (Wireless), Possible Drawbacks with Wireless, Wireless Data Technology Options, The GSM Phase II Overlay Network, Circuit−Switched or Packet−Switched Traffic, GPRS Radio Technologies, PDP Contexts,
Unit V	Wireless Technology and Evolution of Modulation Technique – QAM, FDM, Orthogonal FDM, Adaptive Modulation Techniques. 4G & 5G: Introduction to 4G Standards, Introduction to 4G Architecture, components & basic internet & communication call flows. Introduction to 5G standards, basic 5G architectures, 5G services, Recent trends and applications in 5G, Massive Multiple-Input Multiple-Output (MIMO) Wireless Systems

References Textbooks:

1. Cajetan M. Akujuobi, Matthew N.O. Sadiku, Introduction to Broadband Communication Systems, Chapman and Hall/CRC, 2007.
2. Robert C. Newman, Broadband Communications Prentice Hall, NJ, USA, 2001.
3. Rajiv Ramaswami, Kumar N. Sivarajan and G. H. Sasaki, “Optical Networks: A Practical

Perspective", Elsevier, Third Edition, 2010.
4. B Sklar, "Digital Communications: Fundamentals and Applications" PH, 2001
5. Kuhn Paul J., Ulrich, Roya, "Broadband Communications" 1998.
6. Sofoklis Kyriazakos, River Publishers, 4G Mobile and Wireless Communications Technologies.
7. Jonathan Rodriguez, Wiley Publications, Fundamentals of 5G Mobile Networks

AP-652 – Advanced Optical Communication

Course Outcomes:

CO-1	Familiarize to the basics of Optical Communications
CO-2	Analyze the working principle of different types of Optical Components, Modules, and Subsystems
CO-3	Scrutinize the Advanced Modulation and Multiplexing Techniques
CO-4	Illustrate the practical implementation of Loss and Dispersion Management in Optical Fiber Communication
CO-5	Summarize different types of Nonlinear Effects in Fibers

Syllabus:

Units	Syllabus Details
Unit I:	**Basics of Optical Communications:** Model of Optical Communication, Signal Propagation Effects in Optical Fibers, Fiber Attenuation and Insertion Losses, Chromatic Dispersion Effects, Polarization-Mode Dispersion (PMD), Fiber Nonlinearities, Generalized Nonlinear Schrödinger Equation, Noise Sources in Optical Channels,
Unit II	**Optical Components, Modules, and Subsystems:** Key Optical Components, Optical Transmitters, Optical Receivers, Optical Signal-To-Noise Ratio, Receiver Sensitivity and Q Factor, Optical Amplifiers, Optical Couplers, Optical Filters, Optical Isolator, Optical Circulator, WDM Multiplexers and Demultiplexers, OFDM, Principles of Coherent Optical Detection, Coherent Optical Balanced Detectors
Unit III	**Advanced Modulation and Multiplexing Techniques:** Channel Capacity Theorem, Signal Space Theory, Pulse amplitude modulation (binary and M-ary, QAM), Pulse position modulation (binary and M-ary), Carrier modulation (M-ary ASK, PSK, FSK, DPSK), Continuous phase modulation (QPSK and variants, MSK, GMSK), Trellis Code Modulation, Probability of Error & Bit Error Rate, MIMO Fundamentals, Optical Time-Division Multiplexing, Subcarrier Multiplexing, Code-Division Multiplexing, Polarization-Division Multiplexing (PDM) and 4-D Signalling
Unit IV	**Loss and Dispersion Management:** Compensation of Fiber Losses, Role of Dispersive Effects, Periodically Amplified Lightwave Systems, Dispersion Problem in SMF,

	Dispersion-Compensating Fibers, Fiber Bragg Gratings, Dispersion-Equalizing Filters, Optical Phase Conjugation, Channels at High Bit Rates,
Unit V	**Nonlinear Effects in Fibers:** Origin of Linear and Nonlinear Refractive Indices, Second and Third Order nonlinearities, Self-phase modulation, Cross Phase modulation, Four-wave mixing, Combined Effect of Dispersion and SPM, Stimulated Raman scattering, Stimulated Brillouin scattering, Solitons communication systems.

References Textbooks:

1. G. P. Agarwal, Fiber-Optic Communication Systems, 4th Ed., Wiley, 2010.
2. Advanced Electronic Communications Systems, by Wayne Tomasi, 6 Edition Pearson Education.
3. Kumar, Shiva, and M. Jamal Deen. Fiber optic communications: fundamentals and applications. John Wiley & Sons, 2014.
4. Djordjevic, Ivan B. Advanced optical and wireless communications systems. Heidelberg: Springer, 2018.

AP-653 – Optical Networks

Course Outcomes:

CO-1	Familiarize to the basics of Optical Networks
CO-2	Analyze the working principle of different WDM Network elements, its control and management
CO-3	Scrutinize the Advanced Modulation and Multiplexing Techniques
CO-4	Illustrate the practical implementation of Loss and Dispersion Management in Optical Fiber Communication
CO-5	Describe different FTTx Installation, Testing and Management

Syllabus:

Units	**Syllabus Details**
Unit I:	**Introduction to the Basics of Optical Networks:** Telecommunications Network Architecture, Services, Circuit Switching and Packet Switching, The Optical Layer, Transparency and All-Optical Networks, Optical Packet Switching, Transmission Basics, Network Evolution, SONET/SDH, Optical Transport Network, Generic Framing Procedure, Ethernet, IP, Multiprotocol Label Switching, Resilient Packet Ring, Storage-Area Networks

Unit II	**WDM Network elements, Control and Management:** Optical Line Terminals, Optical Line Amplifiers, Optical Add/Drop Multiplexers, Optical Crossconnects, Network Management Functions, Optical Layer Services and Interfacing, Layers within the Optical Layer, Multivendor Interoperability, Performance and Fault Management, Configuration Management, Optical Safety
Unit III	**Network Survivability and WDM Network Design:** Basic Concepts, Protection in SONET/SDH, Protection in the Client Layer, Why Optical Layer Protection, Optical Layer Protection Schemes, Interworking between Layers, Network Reliability and Security, Cost Trade-Offs: A Detailed Ring Network Example, LTD and RWA Problems, Dimensioning Wavelength-Routing Networks, Wavelength Conversion in WDM Network, Statistical Dimensioning Models, Traffic Grooming in Optical Networks.
Unit IV	**Photonic Packet Switching and FTTx:** Optical Time Division Multiplexing, Synchronization, Header Processing, Buffering, Burst Switching, Testbeds, Introduction to FTTx, Fiber to the Home Architectures, FTTH in MDUs (Multiple Dwelling Units), FTTH PON Types, FTTH PON (Passive Optical Network), Triple Play Systems (BPON, GPON, EPON, RFOG) WDM and PON Other Uses for PONs, FTTX hardware and components (Cables, Splitters, Cabinets, Subscriber components).
Unit V	**FTTx Installation, Testing and Management:** Outdoor cable installation, Duct, aerial, direct burial, Micro-duct solutions, Drop cable installation, Fiber terminations on with pigtail, Splicing and joint closing, Testing FTTH (Key factors affecting network, Testing during construction, Testing for commissioning).

References Textbooks:

1. Rajiv Ramaswami, Kumar N. Sivarajan and G. H. Sasaki, “Optical Networks: A Practical Perspective”, Elsevier, Third Edition, 2010.

2. P.E. Green, Jr., “Fiber Optic Networks”, Prentice Hall, NJ, 1993.

3. C. Siva Ram Moorthy and Mohan Gurusamy, “WDM Optical Networks: Concept,Design and Algorithms”, Prentice Hall of India, IstEdition, 2002.

4. Djordjevic, Ivan B. Advanced optical and wireless communications systems. Heidelberg: Springer, 2018.

5. Biswanath Mukherjee, “Optical WDM Networks”, Springer, 2006.

6. Gerd Keiser, Wiley-IEEE “FTTx Concepts and Applications”

7. James Farmer, Brian Lane, Kevin Bourg, Weyl Wang, “FTTx Networks” 1st Edition November 2016.

AP 701 Laser & Optical Communication Laboratory 1

Pre-requisite: Laser safety tutorials/video demonstration of Laser safety followed by written test

1. Michelson Interferometer: Setting up Michelson interferometer using a highly monochromatic laser source, evaluation of laser wavelength by fringe counting.
2. Beam Width, Divergence and M^2 measurement of He-Ne/Diode Laser with and without collimation lens.
3. Determination of the Electrical and Optical Characteristics of LED and Laser diode.
4. Detection of polarisation states using polarisation components like polarizers, waveplates etc.
5. Analysis of various light source spectra using OSA.
6. Determination of the refractive index profile of a multimode and single mode fiber by the transmitted near field scanning technique and measurement of NA.
7. Macro and Microbending loss in optical fibers and its application
8. Measurement of Photodiode characteristics
9. Study of Fraunhofer diffraction pattern of a rectangular and circular aperture.
10. Fiber optic link design
11. Measurement of attenuation and dispersion in optical fibers
12. Fiber to Fiber splicing and splicing loss measurement.
13. Setting up of Mach-Zender interferometer
14. Measurement of Photoluminiscence of an active materials using PL measurement setup.
15. Design of driver circuit for LED and Laser diode
16. Characterisation of Erbium Doped Fiber Amplifier
17. Pulse width measurement of different laser using autocorellator.
18. Holography
19. One Mini project (**compulsory for all**)

Note: Every student should perform a minimum of 15 experiments from the above list.

AP 702 Lasers & Optical Communication Laboratory-II

1. Characterization of Fiber Bragg grating
2. Phase Sensitive detection technique using lock-in amplifier.
3. Power budget analysis using Optical Time Domain Reflectometer (OTDR)
4. Study of Time Division Multiplexing of digital signals
5. Study of a Wavelength Division Multiplexing(WDM) in optical fiber link
6. Study of Add/drop multiplexer
7. Study of Bit error rate and Eye pattern analysis
8. Setting up a Free space Laser Communication experiment link
9. Study of Electro-optic effect (Pockel and Kerr)
10. Measurement of third order nonlinear optical coefficient using Z-scan
11. Study of Faraday effect
12. Design of a fiber optic sensor
13. Line coding and decoding, voice coding
14. Measurement of insertion loss of an isolator, coupler and multiplexer
15. Beat length measurement in bi-refringent fibers.
16. Laser Raman Spectroscopy Experiments
17. M^2 measurement of different lasers
18. Mini project (**compulsory for all**)

Note: Every student should perform a minimum of 15 experiments from the above list.