Curriculum

M.Tech. in Microwave and Photonic Technologies

Department of Electronics Engineering
Indian Institute of Technology Jodhpur

Background

The rapid evolution of modern communication, defence & aerospace, sensing, and imaging technologies has significantly driven progress in both microwave and photonic technologies, underlining their individual importance across a wide range of applications. There is a growing global need for professionals in microwave and photonic technology domain including the areas like 5G and 6G wireless networks, satellite communications, quantum photonics, RADAR, LiDAR, and terahertz imaging. The **Department of Electronics Engineering** at IIT Jodhpur offers a comprehensive **M.Tech.** program in **Microwaves and Photonic Technologies** to address national and global challenges and opportunities in the above-mentioned areas. This program stands on fundamental concepts including electromagnetic theory, microwave engineering, optical systems, and prioritizing cutting-edge research, practical experiential learning, and robust collaboration between industry and academia.

Objectives of the Program

The primary objective of this program is to cultivate advanced technical learning and R&D oriented skills in microwave, millimeter-wave, photonic and optical systems. This program will prepare students to pursue careers in the industries (aerospace, defence and emerging communication systems), research organizations and academia. Following are the key objectives of the proposed M.Tech. program.

1. To equip students with strong theoretical foundations in the subject matters.
2. Hands-on training in the design, analyses, testing of the microwave and photonic systems using modern tools/software.
3. To encourage innovative problem-solving abilities in the emerging field of RF-microwave and photonics.
4. To train the students on modern CAD tools, cutting edge equipment used in microwave and photonics.

Graduate Attributes

- In depth theoretical and practical understanding of EM wave propagation, RF-microwave active and passive circuits, photonic devices.
- Ability to design, analyze, and characterize circuits and systems at microwave, millimetre-wave and optical frequencies.
- Proficiency in industry standard simulators like Ansys HFSS, CST, Agilent ADS, MATLAB.
- Ability to handle academic and industrial projects.

Learning Outcomes

Graduates will gain knowledge in the field of

- In-depth knowledge of RF-microwave and millimeter-wave components, circuits and systems, RF front-end for modern communication systems, antenna arrays, advanced metasurfaces, guiding structures (both microwave and optical), photonic circuits, imaging systems.
- Hands-on experience with high-end microwave/mm-wave and optical equipment.
- Knowledge of various CAD tools like CST Microwave Studio, Ansys Electronics Desktop (HFSS), COMSOL, Keysight ADS, CADENCE, and MATLAB.
- Proficiency in designing of RFICs, MMIC, and photonic circuits.
- Knowledge in Printed Circuit Board (PCB) layout designing and prototyping, cleanroom fabrication techniques.

Program Structure

S.No.	*Category*	*Course category title*	*Total Courses*	*Total Credits*
1	C	*COMPULSORY*	6	14
2	E	*ELECTIVES*	4	12
3	NG	*Non-Graded*	2	0
4	T	*Thesis*	2	32
5	T	*Thesis during summer break*	1	8
		Total		**66**

The thesis work must be aligned with the objectives of the enrolled program.

Semester-wise Distribution of Credits

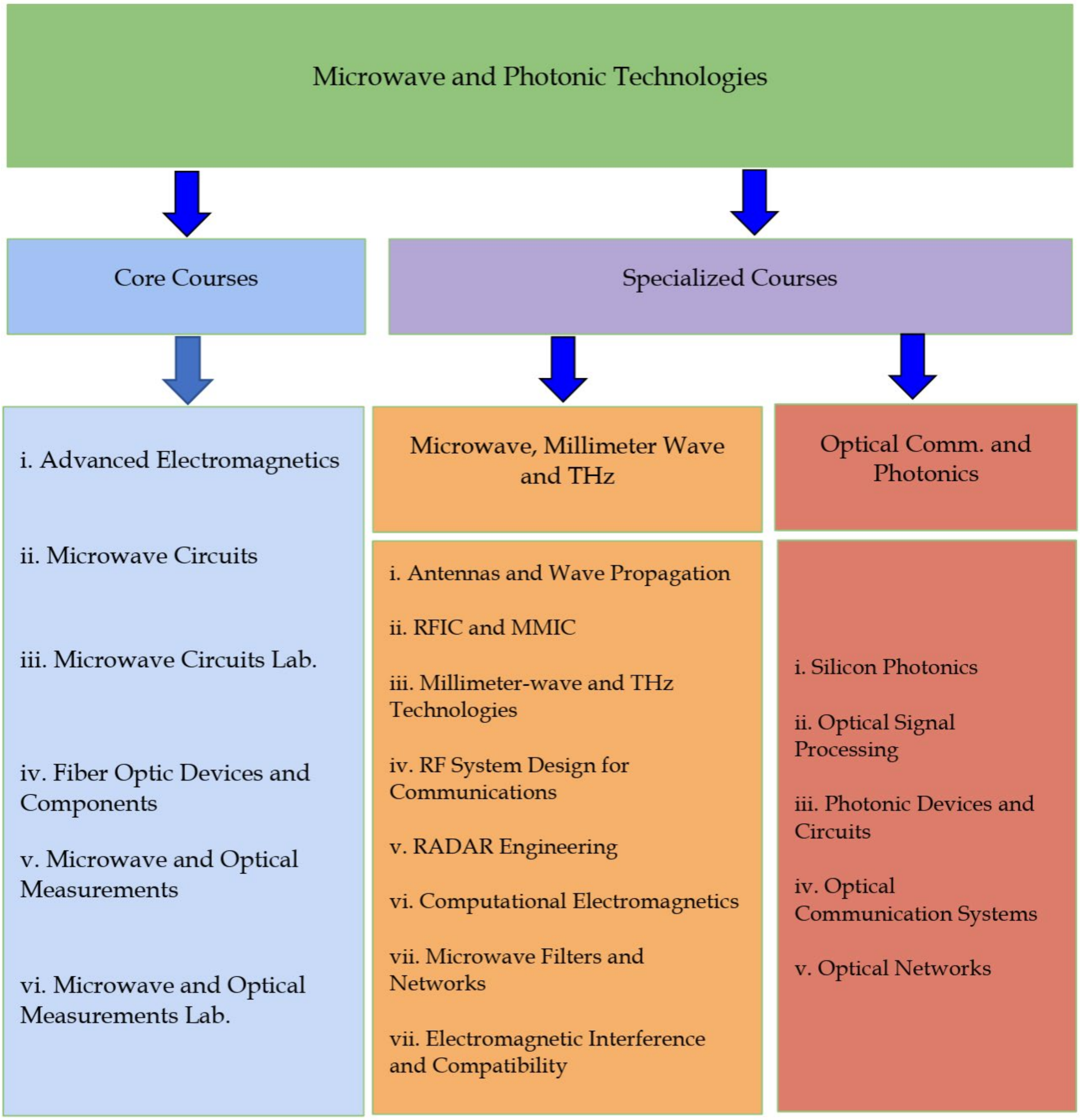
Cat.	*Course Number, Course Title*		*L-T-P*	*Credits*		*Cat.*	*Course Number, Course Title*		*L-T-P*	*Credits*
Semester-I						**Semester-II**				
C	ECL7XX0	Advanced Electromagnetics	3-0-0	3		C	ECL7XX0	Microwave and Optical Measurements	3-0-0	3
C	ECL7XX0	Microwave Circuits	3-0-0	3		C	ECL7XX0	Microwave and Optical Measurements Lab.	0-0-2	1
C	ECL7XX0	Fiber Optic Devices and Components	3-0-0	3		E	ECL7XX0	*Elective*	3-0-0	3
C	ECL7XX0	Microwave Circuits Lab.	0-0-2	1		E	ECL7XX0	*Elective*	3-0-0	3
E	ECL7XX0	Elective	3-0-0	3		E	ECL7XX0	*Elective*	3-0-0	3
NG1	LAN7XX0	Technical communication	1-0-0	S/U		NG2	OAL7XX0	Innovation and IP management	1-0-0	
			Total	**13**					*Total*	**13**
						Summer term				
						ECT7XXX		Thesis		8
									Total	**8**
III Semester						**IV Semester**				
T	ECT7XXX	Thesis		16		T	ECT7XXX	Thesis		16
			Total	**16**					*Total*	**16**
Total credit										**66**

List of Electives

S.No.	*Course Title*	L-T-P	Credit
1	*Antennas and Wave Propagation*	3-0-0	3
2	*RFIC and MMIC*	3-0-0	3
3	*Millimeter-Wave and THz Technologies*	3-0-0	3
4	*RF system design for Communications*	3-0-0	3
5	*RADAR Engineering*	3-0-0	3
6	*Optical Signal Processing*	3-0-0	3

7	*Computational Electromagnetics*	3-0-0	3
8	*Photonic Devices and Circuits*	3-0-0	3
9	*Optical Communication Systems*	3-0-0	3
10	*Optical Networks*	3-0-0	3
11	*IR Detectors and Imaging*	3-0-0	3
12	*Machine Leaning*	*3-0-0*	3

Courses



Detailed Course Contents

Core courses

Title	Advanced Electromagnetics	Number	ECL7XX
Department	Electronics Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (IV Year), M.Tech., and PhD	Type	C
Prerequisite	Engineering Electromagnetics		

Objectives
1. To gain the knowledge of advanced Electromagnetics.
2. To familiarize the students with radiation, wave propagation in unbounded medium, inside waveguides, and transmissions line.

Learning Outcomes
1. Ability to solve EM wave equations, design of waveguides.
2. Understanding the transmission lines.
3. Ability to compute modes and analyze the propagation behavior in dielectric waveguides.

Contents

Introduction to EM wave [10 lectures**]**
Concept of E, D, B, and H, Boundary conditions, polarization of dielectric and displacement vector, Maxwell's equations, homogeneous and inhomogeneous wave equations and its solutions, EM theorems
Interaction of EM wave in different medium [8 lectures**]**
Types of Medium, EM wave propagation in unbounded medium, EM scattering, Geometric theory of diffraction, Green's function and integral transform techniques
Waveguides [12 lectures**]**
Modes inside rectangular and circular waveguides, cut-off frequency, wave impedance, loss inside waveguide, waveguide resonators, losses in a resonator, resonator Q-factor, partially filled waveguide, ridge waveguide
Optical planar waveguides [9 lectures]
Reflection and Refraction, Fresnels' law, Ray propagation, Goos-Haenchen Shift, Asymmetric dielectric slab waveguide, Effective width, group velocity, Wave propagation, TE and TM modes, dispersion relations, cut-off, power flow, weakly guiding approximation

Textbooks:
1. D. J. Griffiths, "Introduction to Electrodynamics," 3rd edition, Prentice-Hall (1995).
2. R. E. Collin: Field theory of Guided Waves, Wiley IEEE press.
3. R. F. Harrington: Time Harmonic Electromagnetic Fields, McGraw-Hill, 1961
4. Yariv and Yeh, Photonics: Optical Electronics in Modern Communication, 2006. Oxford Series in Electrical and Computer Engineering

Self-learning Materials
1.http://ocw.mit.edu/OcwWeb/Physics/8-02Spring-2007.Electromagnetic theory NPTEL (IIT Kanpur), https://onlinecourses.nptel.ac.in/noc18_ee04/preview

Preparatory Course Materials
1. MNO Sadiku, Elements of Electromagnetics, Oxford Univ. Press.

Title	Microwave Circuits	Number	ECL7XX
Department	Electronics Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (IV Year), M.Tech., and PhD	Type	C
Prerequisite	Engineering Electromagnetics, Analog circuits		

Objectives

1. To introduce the fundamentals of transmission lines and microwave/mm-wave circuit analysis.
2. To introduce the students with the active circuit designing at microwave and millimeter-wave frequencies.

Learning Outcomes

1. Understanding the design of integrated circuits at high frequencies.
2. Practical implementation of various circuits required to build a transceiver system.
3. Learning about the design of various active components like mixers, LNAs, power amplifiers at RF and microwave frequencies.

Contents

Fundamentals of transmission line and matching networks [6 lectures**]**
Overview of transmission lines, coaxial cables, power flow and losses, transients, microstrip transmission line, co-planar waveguide (CPW), coaxial line, losses and cut off frequencies, S-parameters, signal flow graphs, impedance matching techniques, microwave network analysis.

Three and four port microwave networks [6 lectures**]**
Wilkinson power divider, hybrid coupler, directional coupler, power combiners, circulators, attenuators, Magic-Tees.

Amplifier design [8 lectures**]**
Concepts of nonlinearity, IM products, third order intercepts, model of MOS transistors and BJT, HEMT at high frequencies, stability analyses, design of biasing and stability networks, transmission line realization, design of maximum gain amplifier, wideband amplifiers, constant gain amplifier, low noise amplifier (LNA), power amplifiers (PA), combining networks.

Oscillators and Voltage Controlled Oscillators (VCO) [6 lectures**]**
Basic topologies of oscillators, phase noise, design of oscillator, VCO, Noise-power trade-off, quadrature, and single-sideband generators.

Mixers [7 lectures**]**
Mixer Noise figure, diode based mixers, FET mixer, Gilbert cell mixer, port to port feed-through, single-balanced and double balanced mixers.

Introduction to Phase-Locked Loops (PLL) [6 lectures**]**
Basic architecture, phase detector, loop stability, tracking, Type I and Type II PLL's, PLL Non-idealities, phase noise, jitter.

Textbooks

1. T. H. Lee, the Design of CMOS Radio-Frequency Integrated Circuits. Cambridge, UK: Cambridge University Press, 1997.
2. B. Razavi, RF Microelectronics, 2nd Edition, Pearson Education, 2014.
3. G. Gonzalez, Microwave Transistor Amplifiers: Analysis and Design, 2nd ed., Pearson,Aug-1996.

Self-learning Materials

1. RF Integrated Circuits, NPTEL, Dr. S. Chatterjee, IIT Delhi, http://nptel.ac.in/courses/117102012/#
2. High Speed Communication Circuits, MIT, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-776-high-speed-communication-circuits-spring-2005/lecture-notes/

Preparatory Course Materials

1. D. M. Pozar, Microwave Engineering, 4th edition, New York, NY, USA: Wiley, 2011.

Title	Microwave Circuits Lab	Number	ECL7XX
Department	Electronics Engineering	L-T-P [C]	0–0–2 [1]
Offered for	B.Tech. (IV Year), M.Tech., and PhD	Type	C
Prerequisite	Engineering Electromagnetics, Analog circuits		

Objectives

1. To introduce the students with the active circuit designing using CAD tools, 3-D simulators, circuit simulators at microwave and millimeter-wave frequencies.

Learning Outcomes

1. Working with high frequency circuit design CAD tools.
2. Ability to design matching networks, microwave circuit components like low noise amplifier, Power amplifier, scillators, mixers.

Contents

Introduction to HFSS, CST, ADS. Modelling and simulations of discrete circuit components, design of matching networks, maximum and specific gain amplifier design, LNA design, PA design.

Textbooks

1. B. Razavi, RF Microelectronics, 2nd Edition, Pearson Education, 2014.
2. G. Gonzalez, Microwave Transistor Amplifiers: Analysis and Design, 2nd edition, Pearson, Aug-1996.

Self-learning Materials

1. RF Integrated Circuits, NPTEL, Dr. S. Chatterjee, IIT Delhi, http://nptel.ac.in/courses/117102012/#
2. High Speed Communication Circuits, MIT, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-776-high-speed-communication-circuits-spring-2005/lecture-notes/

Preparatory Course Materials

1. D. M. Pozar, Microwave Engineering, 4th edition, New York, NY, USA: Wiley, 2011.

Title	**Fiber Optic Devices and Components**	**Number**	**ECL7XX**
Department	Electronics Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech, M.Sc. Physics, M.Tech. and PhD	Type	C
Prerequisite	Engineering Electromagnetics		

Objectives
1. Provide the fundamental principles of fiber waveguides and various devices and components based on optical fiber.
2. Enable the appreciation of the developments in optical fiber technology.

Learning Outcomes
The students are expected to have the ability to implement a fiber optic link using various devices, components, and various modules for different requirements.

Contents
Optical fibers [20 Lectures**]**
Vector Nature of Light, Optical Fiber – Single and Multimode, Step index and Graded Index Fibers, Ray and Wave picture of propagation, Cut-off, mode field diameter, group delay, Gaussian field approximation. Propagation characteristics of few modes, multicore and photonic crystal fibers. Fiber Fabrication Methods.
Transmission Characteristics: Attenuation and dispersion in Optical Fibers, Material, Waveguide, Polarization, Intermodal and Intramodal Dispersion, Group velocity Dispersion, Dispersion modified single mode fibers
Link components [16 Lectures**]**
Fiber joints, connectors, Splicing operation, OTDR, Design of splitter, couplers, Fiber Bragg Gratings, Isolators, Circulators, Multimode Interference devices, mode field convertors, wavelength MUX/DEMUX, fiber to chip coupling, Fiber Amplifiers: EDFA, Raman and Brillouin, SOA.
System planning [3 Lectures**]**
Choice of components for optical fiber communication, Link Design, Impact of nonlinear effects on communication systems.

Textbooks
1. J. M. Senior, Optical Fiber Communications: Principles and Practice, Prentice Hall, 3rd Edition, 2010.
2. Raman Kashyap, Fiber Bragg Gratings, Academic Press, 2009.
3. G. Agrawal, Fiber optic Communication Systems, John Wiley and sons, 4th Edition 2010.

Self-learning Material
1. NPTEL Lectures on Advanced Optical Communication by Prof. R.K. Shevgaonkar, IIT Bombay(https://nptel.ac.in/courses/117101002/)
2. The RP Photonics Encyclopedia (https://www.rp-photonics.com/encyclopedia.html)

Preparatory Course Material:
1. Concepts from "M.O. Sadiku and S.V. Kulkarni, Principles of Electromagnetics", Oxford University Press, 6th edition, 2015.

Title	Microwave and Optical Measurements	Number	ECL7XX
Department	Electronics Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (IV Year), M.Tech., and PhD	Type	C
Prerequisite	Microwave Engineering		

Objectives
1. To introduce the students with the measurement equipment used in microwave to optical domain.s
2. To introduce the students with the measurement techniques at microwave and optical frequencies.

Learning Outcomes
1. Working and calibration of high-end measurement instruments used for the measurements at microwave and optical frequencies.
2. Understanding the measurements of integrated circuits, optical modulators, detectors.

Contents
Overviews [5 lectures**]**
Review of S-parameters, X-parameters, effects of non-linarites, noise floor, dynamic range, spurious free dynamic range.
Basics of calibration techniques [2 lectures**]**
Overview of signal flow graph, basics of reflectometer, error models, scalar calibration, vector calibration, TRL calibration.
Scalar analyzer [5 lectures**]**
Architecture of scalar analyzer, working principle, Reflection bridge and calibration
Vector analyzer [8 lectures**]**
Architecture of VNA, source, signal separation, receiver module, reference plane and de-embedding, Vector measurement system, twelve term error model, signal detection.
Six ports [2 lectures**]**
General six port network calibration, multi state reflectometer
Noise figure [4 lectures**]**
Noise figure measurement, Y-factor method, cold source method, noise figure meter calibration, noise measurement by spectrum analyzer
Optical measurement techniques [13 lectures**]**
Optical measurement techniques for different physical parameters using Interferometric methods. Passive device testing. Fiber operation techniques such as OTDR and Splicing. Free-space optical beam characterization, propagation, parameter measurements, and data processing. Characterization of Laser Sources, photodetectors, and amplifiers. Implementation of techniques such as WDM and SDM. Optical Modulation Techniques. Holography. Quantum nature of light.

Textbooks
1. G.H. Bryant, Principles of Microwave Measurements, IEE Electrical measurement series
2. Niknejad Ali Electromagnetics for High-Speed Analog and Digital Communication Circuits. Cambridge University Press, 2007
3. Michael Bass - Handbook of Optics, Vol. 2, Devices, Measurements, and Properties-McGraw-Hill Professional (1994).
4. Ajoy K. Ghatak, K. Thyagarajan, An Introduction to Fiber Optics, Cambridge University Press, 1998.

Preparatory Course Materials
1. D. M. Pozar, Microwave Engineering, 4th edition, New York, NY, USA: Wiley, 2011.

Title	**Microwave and Optical Measurements Lab**	**Number**	**ECL7XX**
Department	Electronics Engineering	L-T-P [C]	0–0–2 [1]
Offered for	B.Tech. (IV Year), M.Tech., and PhD	Type	C
Prerequisite	Microwave Engineering		

Objectives
1. To introduce the students with the high-end measurement instruments.
2. Measurement and characterization of microwave, millimeter wave and optical circuit components.

Learning Outcomes
1. Handling the high frequency measurement instruments like VNA, power meter, waveform generators, optical detectors.
2. Measurements associated with microwave amplifiers, mixers, RADAR, optical modulators.

Contents
Calibration of VNA (SOLT and TRL), familiarization with spectrum analyzer and RF generators, optical spectrum analyzers, power meters, ultra-narrow pulse measurements, coherent RADAR measurement, optical modulators, optical detector circuits, antenna measurement, measurements of multiport microwave and optical passive devices, measurement of LNA, mixer characterization, microwave PA measurement.

Textbooks
1. G.H. Bryant, Principles of Microwave Measurements, IEE Electrical measurement series
2. Michael Bass - Handbook of Optics, Vol. 2, Devices, Measurements, and Properties-McGraw-Hill Professional (1994).
3. Ajoy K. Ghatak, K. Thyagarajan, An Introduction to Fiber Optics, Cambridge University Press, 1998.

Preparatory Course Materials
1. D. M. Pozar, Microwave Engineering, 4th edition, New York, NY, USA: Wiley, 2011.

Electives

Title	Antennas and Wave Propagation	Number	ECL7XX
Department	Electronics Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. IV Year, M. Tech., PhD	Type	E
Prerequisite	Engineering Electromagnetics		

Objectives
1. Introduce the various concepts of antenna design.
2. familiarize the students with the application of different type of antennas

Learning Outcomes
1. Design low profile antennas and high gain antenna arrays for practical applications
2. Utilize simulation software for designing Antenna systems and test RF and microwave antennas

Contents
Introduction to Antennas [4 lectures]
Radiation mechanism, near and far field, Review of Antenna Parameters; Friis Transmission formula, Radar Range equation
Radiation integrals and auxiliary potential function [4 lectures]
Vector potential for electric current source and magnetic current source, inhomogeneous vector potential wave equation, duality theorem, reciprocity theorem
Radio wave propagation [6 lectures]
Ground wave propagation, Sky wave and space wave propagation, atmospheric effects, ground effects, plasma effects, attenuation, scattering, diffraction, link budget, link margin.
Linear wire and loop antenna [7 lectures]
Infinitesimal dipole, small dipole, half-wavelength dipole, loop antenna
Antenna arrays [5 lectures]
Analysis of Two element array, N-element linear array (uniform and nonuniform amplitude excitation: Binomial, Dolph-Tschebyscheff, Taylor distribution), planar array, Phased Array Antennas
Aperture antenna [4 lectures]
Field equivalence principle, Fourier series technique, Radiation equation, Rectangular aperture, circular aperture, Babinet's principle, E-Plane Horn Antenna, H-Plane Horn Antenna, Pyramidal Horn antenna
Microstrip and dielectric resonator antennas [4 lectures]
Rectangular patch antenna, feeding methods, transmission line model, cavity model, Metallic vs Dielectric Antennas, Dielectric Resonator Antennas.
MIMO antennas [2 lectures]
Single-antenna vs multi-antenna systems, spatial and polarization diversity, channel capacity, MIMO performance metrics.
Antenna prototyping [3 lectures]
Materials used in antenna fabrication, substrate selection, traditional prototyping method, printable dielectric and conductive materials, 3D printing for fabrication, challenges in 3D printing.

Textbooks
1. Balanis C. A., (2016), *Antenna Theory, Analysis and Design*, 4thedition, Wiley Press.
2. Krauss J. D., (2006),*Antennas and Wave Propagation*, 4thedition, TMH Education.
3. Elliott R. S., (2006), *Antenna Theory and Design*, Wiley Press.
4. Volakis J. L., (2019), *Antenna Engineering Handbook*, 5thedition, McGraw Hill.
5. Chen Z. N., (2016), *Handbook on Antenna Technologies*, Springer.
6. Gao S., Luo Qi, Zhu F., (2014), Circularly Polarized Antennas, Wiley-IEEE Press.

Self-Learning Materials

1. Kumar, G., *Antennas*, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Bombay, https://onlinecourses.nptel.ac.in/noc17_ee03/preview
2.Ferraro, A., *Antenna Engineering*, Video Lectures, Penn State Univ., USA, http://www.engr.psu.edu/cde/courses/ee438/index.htm.

Preparatory Course Materials

1.Kumar, P., *Electromagnetic Theory*, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108104087/.
2. Kumar, G., *Microwave Theory and Techniques*, Department of Electrical Engineering, Indian Institute of Technology Bombay, https://nptel.ac.in/courses/108101112/

Title	RFIC and MMIC	Number	ECL7XX
Department	Electronics Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (IV Year), M.Tech., and PhD	Type	E
Prerequisite	Analog electronics, Communication engineering, Microwave engineering		

Objectives
1. To introduce the students with the integrated circuit designing at radio frequencies.
2. Introduction of various circuits and building blocks for communication applications.

Learning Outcomes
1. Understanding the design of integrated circuits at high frequencies.
2. Practical implementation of various circuits required to build a transceiver system.
3. Learning about the design of various active components like mixers, LNAs, power amplifiers at RF and microwave frequencies.

Contents

Introduction to RFIC & MMIC technology [8 lectures**]**
Component Technology and Foundry Choice, passive and active Components, substrate material, wafer processing, CMOS, MESFET, HEMT, HBT modelling.

Foundry Use and Economics [4 lectures**]**
MMIC Production Costs. Simulation and Component Models-Passive and Active Component Models. Process Design for Product Yield. Sensitivity and Tolerance Analysis.

On chip Design [15 lectures**]**
Inductors, transformers, transmission line, varactors, constant capacitors. Active Baluns, Switch Design-Phase shifters. Switched-Path Attenuators, LNA topologies, gain switching, band switching, high IP3 LNA, Passive and active downconverter mixer, up converter mixer, self mixing LO**,** Design-Large Signal Effects on Active Devices, Power Amplifier, Power budget, Thermal management, SWaP-C (size, weight and power-cost)

MMIC Layout [12 lectures**]**
Layout Files, preparation, The Circuit Layout Process, Layout Checking, Chip Arraying, Processing Technology-Substrate Material Growth. Wafer Production. Surface Layers. Photolithography. Wafer Thinning. Through-Substrate Vias. Chip Separation. Quality Assurance. Test-Process Control & Monitoring. DC Test and Stability Problems. RF Test and Calibration**.**

Textbooks
1. T. H. Lee, the Design of CMOS Radio-Frequency Integrated Circuits. Cambridge, UK: Cambridge University Press, 1997.
2. B. Razavi, RF Microelectronics, 2nd Edition, Pearson Education, 2014.
3. Practical MMIC Design by Steve Marsh (Artech House)

Self Learning Materials
1. RF Integrated Circuits, NPTEL, Dr. S. Chatterjee, IIT Delhi, http://nptel.ac.in/courses/117102012/#
2. High Speed Communication Circuits, MIT, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-776-high-speed-communication-circuits-spring-2005/lecture-notes/

Preparatory Course Materials
1. B. P. Lathi, Z. Ding, Modern Digital and Analog Communications Systems, 4th edition, Oxford university press, July-2017.
2. D. M. Pozar, Microwave Engineering, 4th edition, New York, NY, USA: Wiley, 2011.

Title	Millimeter-wave and THz Technologies	Number	ECL7XX
Department	Electronics Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M.Tech., and PhD	Type	E
Prerequisite	Microwave engineering		

Objectives
1. Introduction of the phenomenon and circuit characteristics at mm-wave frequency ranges.
2. introduce various guiding structures, antennas, and switches at mm-wave frequencies.

Learning Outcomes
1. Understanding the design problems and challenges at mm-wave frequencies.
2. Ability to design various mm-wave guiding structures, passive and active circuits.

Contents

Introduction to millimeter-wave and THz technology [5 lectures**]**
Mm-wave and THz frequency bands, Terahertz gap, atmospheric losses, Propagation and path losses, Friis equation, link budget and power budget calculation, applications in wireless communication, security, and space, quasi-optical system, properties of gaussian beam.

Guiding structures for mm-wave/THz circuits [10 lectures**]**
losses in planar circuits (conductor loss, leakage loss, dielectric loss, surface waves), Air filled waveguides, dielectric guides, NRD guide, substrate integrated waveguides (SIW), Substrate Integrated NRD (SINRD), dielectric image line, planar air filled waveguide, Waveguide and planar resonators, dispersion, circular dielectric waveguide, polymer/plastic waveguides, plasmonic waveguides, loaded, unloaded, and external Q-factors

Beam-forming network [8 lectures**]**
Hybrid coupler, crossover, phase shifter, butler matrix, Nolen matrix, Rotman lens, beamforming antennas, hybrid and digital beamforming techniques, adaptive phased arrays.

Advanced antennas [7 lectures**]**
Problem with traditional antennas, SIW based slot and cavity antenna, leaky wave antenna, waveguide slot array, on chip antennas, surface-wave antenna, metasurface antennas, nano-antennas, wearable antennas.

Terahertz sources and detectors [6 lectures]
Semiconductor-based sources, THz pulse generation using photo-mixing, free electron laser, diode-based detectors, photoconductive antennas, heterodyne and up-conversion detection.

Selected topics in THz [3 lectures]
Terahertz wireless communication, THz Channel Propagation Characteristics, Terahertz time-domain spectroscopy (THz-TDS), mm-wave/THz Sensing and NDE, Metamaterials and metasurfaces for THz applications.

Textbooks
1. Koul S. K., (1997), Millimeter Wave and Optical Dielectric Integrated Guides and Circuits, Wiley-Blackwell
2. Courtney D. Liu, B. Gaucher, U. Pfeiffer, and J. Grzyb, (2009), Advanced millimeter wave technologies, Wiley.
3. Rieh Jae-Sung, (2021), Introduction to Terahertz Electronics, Springer.

Self Learning Material
1. Mandal M. K., Millimeter-wave technology, NPTEL course material, Department of Electronics and Electrical Communication Engineering, IIT Kharagpur, https://nptel.ac.in/courses/117105139/
2. TI Training & Vedios, (2017), mmWave RADAR in ADAS Applications, https://training.ti.com/mmwave-radar-adas-applications

Preparatory Course Material
1. D. M. Pozar, (2011), Microwave Engineering, 4th Ed. New York, NY, USA: Wiley.

Title	RF System Design for Communications	Number	ECL7XX0
Department	Electronics Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M.Tech., and PhD	Type	E
Prerequisite	Engineering Electromagnetics, Communication systems, RF Circuits		

Objectives

1. Familiarize behaviour of cascaded blocks in RF system and effect of specification of blocks on system performance.
2. Provide basic understanding about behaviour of intermodulation products, spurious responses.
3. Provide basic understanding of linearity of a system.

Learning Outcomes

1. Formulate and analyse system specification to control gain requirement, noise figure of the system.
2. Obtain basic understanding of linearity of a cascade from specifications on its modules.
3. Obtain basic understanding of the spurious responses in a conversion scheme.

Contents

Introduction to wireless communication systems [6 lectures**]**
Review of antenna concepts, Radio Channel and modulation requirements, bits, symbols and waveforms, wireless system building blocks, system specification, quadrature amplitude modulation (QAM), quadrature phase shift keying (QPSK)

Gain [5 lectures**]**
T and X parameter, Module Gain, Overall Response, Standard Cascade, Bilateral Modules, small and large signal conditions

Noise [4 lectures**]**
Fundamentals of noise, Noise Figure (NF), NF of cascaded systems, noise floor, impedance dependence of Noise Figure, phase noise, noise floor, sensitivity, SFDR

Nonlinearities [5 lectures**]**
Representing Nonlinear responses, gain compressions, harmonics and intermodulation (IM) products, measuring IMs, AM-PM and PM-AM conversions, non-linearities of cascaded stages

Transceiver architectures [14 lectures**]**
Receiver architecture, super heterodyne, direct down conversion and low IF receivers, problem of images, self-image, flicker noise, direct RF-sampling receiver, down sampling, transmitter architectures, heterodyne and direct conversion transmitters.

Contaminating Signals [5 lectures**]**
Frequency conversion basics, spurs, two-signal IMs, hard & soft limiting, mixing through the LO Port - AM Suppression, FM Transfer, single-sideband transfer, mixing between LO components.

Textbooks

1. William Egan, (2003), Practical RF System Design, by William Egan, 6th Edition, John Wiley & Sons
2. Ulrich L. Rohde, David P. Newkirk, (2000), RF/ Microwave Circuit design for wireless applications, John Wiley & Sons
3. B. Razavi, RF Microelectronics, 2nd Edition, Pearson Education, 2014.

Self Learning Material

1. Kumar P., RF Integrated Circuits, Department of EE, Indian Institute of Technology Madras, https://nptel.ac.in/courses/117102012/#

Title	RADAR Engineering	Number	ECL7XX0
Department	Electronics Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech., M.Tech., and PhD	Type	E
Prerequisite	Engineering Electromagnetics, Communication systems, RF Circuits		

Objectives
1. Teaching the fundamentals RADAR.
2. Teaching building blocks and different types of RADAR.

Learning Outcomes
The students are expected to have the ability to:
1. Understand the building blocks and working principles of RADAR.

Contents
Introduction [4 lectures**]**
Working principle, RADAR range equations, maximum unambiguous range, pulse repetition frequency, radar block diagram, Probability of detection, False alarm, radar cross section of targets.
Types of RADAR [10 lectures**]**
Pulse radars and CW radars, MTI RADAR, over the horizon RADAR, SAR and ISAR, Doppler RADAR, delay-line cancellers, blind speeds.
Moving target and tracking [8 lectures**]**
Moving target detector, limitations of MTI, tracking with radar, monopulse tracking, conical scan.
RADAR measurements [8 lectures**]**
RADAR measurement and accuracy, Range and velocity ambiguities, the ambiguity diagram, static and dynamic RCS, monostatic and bistatic measurements.
Pulse shaping [4 lectures**]**
Pulse compression-principles, matched filter, chirp waveforms, Descriptions of land & sea clutter, detection of targets in clutter.
RADAR transceiver [5 lectures**]**
Transmitter architecture, isolation between transmitter and receiver, duplexers, Receiver architecture, heterodyne receiver, noise figure.

Textbooks
1. Skolnik M.I., (2017), *Introduction to RADAR systems*, 3rd Ed., McGraw Hill.
2. Richards M.A., (2005), *Fundamentals of RADAR signal processing*, Indian Ed., McGraw Hill.
3. Carpentier M.H., (1988), *Principles of modern RADAR systems*, Artech house publishers.

Self Learning Materials
O'Donnell R.M. , *Introduction to RADAR systems*, MIT open course, MIT Lincoln Laboratory, https://ocw.mit.edu/resources/res-ll-001-introduction-to-radar-systems-spring-2007/

Title	**Optical Signal Processing**	**Number**	**ECL7XX0**
Department	Electronics Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M.Tech., and PhD	Type	E
Prerequisite	Electromagnetism and optics, Signals and systems		

Objectives
1. Introduction to the basics of nonlinearities in optical devices and how they can be harnessed for processing of light waves.
2. Explaining the working, modelling and characterization of various optical signal processing devices along with their advantages and limitations.

Learning Outcomes
1. Ability to design, characterize and analyze basic optical signal processing circuits.
2. Appreciate the advantages of optical signal processing over conventional electronic signal processing techniques.

Contents
Nonlinear optics for signal processing [15 lectures**]**
Nonlinear optical susceptibility, time-domain description of optical nonlinearities, Kramers-Kronig relations, intensity dependent refractive index of materials
Third order nonlinearities [15 lectures**]**
Theory and modeling of Optical Kerr Effect, Self Phase Modulation and Cross Phase Modulation processes, Optical phase conjugation, Four Wave Mixing and Third Harmonic Generation, Photon-phonon interaction, Stimulated Brillouin, Raman and Rayleigh scattering, two Photon Absorption.
Optical signal processing devices [9 lectures**]**
Optical Fourier Transform, optical correlators, pulse compression, pulse shaping, optical interconnects, multiplexers, mixers, wavelength conversion, tunable optical delay.

Textbooks
1. Boyd, R. W., (2013), *Nonlinear optics*. Elsevier.
2. Dragoman D., and Dragoman M. (2013), *Advanced optoelectronic devices*. Vol. 1. Springer Science and Business Media..
3. Saleh, B.E.A, and Teich M.C., (1991), *Fundamentals of photonics*. Vol. 22. New York: Wiley.

Self-Learning Materials
1. Singh B.P and Rustagi K.C., *Nonlinear Optics,* NPTEL Course Material, Department of Physics, Indian Institute of Technology Bombay,
https://nptel.ac.in/courses/115/101/115101008/

Preparatory Course Materials
1. Roy S., *Introduction to Nonlinear Optics and its Applications,* NPTEL Course Material, Department of Physics, Indian Institute of Technology Kharagpur,
https://nptel.ac.in/courses/115/105/115105105/

Title	Computational Electromagnetics	Number	ECL7XX0
Department	Electronics Engineering	L-T-P[C]	3–0–0 [3]
Offered for	B. Tech., MTech., and PhD	Type	E
Prerequisite	Engineering Electromagnetics		

Objectives
1. Introduce the basic analytical and numerical techniques in electromagnetics.
2. familiarize the students with different numerical techniques used in commercial electromagnetic solvers.

Learning Outcomes
1. Solve the electromagnetic problems analytically and numerically.
2. To understand the commercial simulators like HFSS, CST, and COMSOL.

Contents

Review of Maxwell's equation [7 lectures**]**
Boundary condition, wave equation, separation of variables in different coordinate system, orthogonal functions, Strum-Liouville differential equation, Green's Function

Finite Difference methods [6 lectures**]**
Finite difference approximations, boundary conditions, finite differencing of different PDEs, accuracy and stability of FD methods, some practical examples.

Finite Difference Time Domain (FDTD) analysis [10 lectures**]**
Wave equation and solution for waveguide modes, Yee algorithm, numerical dispersion and stability, common source waveforms for FDTD simulations, FDTD analysis in 1D, FDTD in 2D/3D, Absorbing Boundary Conditions (ABC), Perfectly Matching Layer (PML), dispersive materials modelling, practical examples.

Finite Element Method (FEM) [10 lectures**]**
Discretization, governing equations, basis functions, FEM analysis in 1D, boundary conditions, accuracy and numerical dispersion, solution of 2D wave equation, mesh generation.

Method of Moments (MoM) [6 lectures**]**
Introduction to MoM, basis functions, classification of integral equations, solution of integral equations using MoM, thin wire approximation, thin wire excitations, Hallen integral equation, Pocklington equation.

Assignments to be given on MATLAB and commercial software.

Textbooks
1. Garg R., (2008), *Analytical and Computational Methods in Electromagnetics*, Artech House.
2. Sadiku M. N. O., (2018), *Computational Electromagnetics With MATLAB*, 4th Edition, Taylor and Francis Group.

Title	Photonic Devices and Circuits	Number	ECL7XX
Department	Electronics Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech. (IV Year), M.Tech., and PhD	Type	E
Prerequisite	Engineering Electromagnetics		

Objectives

1. To introduce the students with various Lasers and Photodetectors, and integrated photonic circuit elements.

Learning Outcomes

1. Understanding of the structure, design and working of various photonic devices.
2. Knowledge about the theoretical model and practical implementation of the photonic devices and circuits.
3. Ability to design photonic integrated circuits using the basic building blocks .

Contents

Sources [11 lectures]

Light matter interaction, Spontaneous and stimulated emission, Einstein Coefficients, Line Broadening, Theory of laser amplification, Amplifier Pumping, Common laser amplifiers, nonlinearity, noise in amplifiers, laser oscillation, Types of lasers: Pulsed lasers, Q switching, Mode locking.

Rate equations and operating characteristics, transient response, modulation response, noise characteristics, external optical feedback effects in semiconductor lasers.

Photodetectors [10 lectures]

Materials, heterostructures, p-i-n, avalanche and Schottky junction photodiodes, gain and responsivity, single photon APDs, Array detectors, noise in photodetection: spectral density functions, shot noise, johnson noise, avalanche noise.

Integrated Photonic Circuits [10 lectures]

Materials and fabrication techniques for Photonic Integrated circuits, Propagation in rectangular dielectric waveguides: effective index method, losses. Elements of integrated circuits: Waveguide Couplers, Y branches, Angular and Circular bends, Crossovers, Polarization control, multimode interference devices, Diffraction Gratings, Wavelength filters and modulators.

Machine Learning for Photonics [8 lectures]

Introduction to Machine Learning in Photonics; Regression Analysis, Accuracy Assessment; Introduction to Neural Networks: Lost Function, Forward & Backward Propagation; Inverse Photonic Design with NNs.

Textbooks

1. B.E.A. Saleh, M.C. Teich, Fundamentals of Photonics, Wiley.
2. Amnon Yariv, Pochi Yeh, Photonics: Optical Electronics in Modern Communication, Oxford University Press.
3. Richard Osgood Jr., Xiang Meng, Principles of Photonic Integrated Circuits, Springer.

Title	Optical Communication Systems	Number	ECL7XX0
Department	Electronics Engineering	L-T-P[C]	3–0–0 [3]
Offered for	B.Tech., M.Tech., and PhD	Type	E
Prerequisite	Communication systems		

Objectives

1. Provide students an understanding of the concepts related to transmission and reception. techniques for high speed optical communication systems.

Learning Outcomes

1. Analyze basic and high speed optical communications systems.
2. Compare and contrast the features of various optical communication techniques.

Contents

Introduction to optical communication systems [2 lectures]
Basic building blocks, optical transmitters, optical receivers, optical channel, optical amplifiers.

Optical channel considerations [8 lectures]
Attenuation, dispersion, pulse broadening and chirping, line coding schemes, eye pattern, channel noise effects, turbulence models, weather conditions viz. fog, haze, drizzle, under-water impairments.

Lasers and modulation [12 lectures]
Coherence, population inversion and feedback, spontaneous and stimulated emission, injection LASERS, gain and index guided LASERS, DFB, DBR Lasers. LiNbO3 - MZ, III-V semiconductor EAM modulators, high speed silicon modulators: operating principles, design, performance criterion, modulator drivers, reliability and bias control.

Photo-detection [5 Lectures]
P-I-N, APD, responsivity, quantum efficiency, noise, SNR, NEP, bandwidth, low, high and transimpedance receivers.

System performance [10 Lectures]
Principles of Coherent and Incoherent systems, intensity modulation/direct detection system, SIM, homodyne and heterodyne detection, SNR, BER performance in coherent and non-coherent modulation schemes and channel impairments, Rise time and Power budgeting, channel capacity.

Textbooks

1. Keiser, G. (2017), *Optical Fiber Communications*, 5th Edition, McGraw Hill.
2. J. M. Senior, Optical Fiber Communications: Principles and Practice, Prentice Hall, 3rd Edition, 2010.
3. Chadha, D. (2013), *Terrestrial Wireless Optical Communications*, 1st Edition, McGraw Hill.
4. Chen A. and Murphy, E. (2011), *Broadband Optical Modulators: Science, Technology and Applications*, 1st Edition, CRC Press.
5. Jia-Ming Liu (2016), Principles of Photonics, 1st Edition, Cambridge University Press.

Self Learning Materials

1. Kumar, K. P., *Fiber-Optic Communication Systems and Techniques*, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Kanpur, https://nptel.ac.in/courses/108/104/108104113/

Title	Optical Networks	Number	ECL7XX0
Department	Electronics Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M.Tech., and Ph.D	Type	E
Prerequisite	Basics of Fiber Optic Communications		

Objectives

1. Introduction to the elements and components of an optical networking solution.
2. Exploring the capabilities and limitations of different network topologies.

Learning Outcomes

1. Ability to identify the required network topology for a given requirement.
2. Solving capability of WDM network design problems.

Contents

Introduction to Optical Networks [8 lectures**]**
Types of traffic, Services, optical packet and circuit switching, optical layered architecture. Optical Network elements

Local Area Network [6 lectures**]**
Network topologies, multiplexing and multiple access techniques, network resource sharing, network capacity, Medium Access Protocols.

Optical Access Networks [8 lectures**]**
PON architecture, EPON, GPON, WDM-PON, multi point control protocol, dynamic bandwidth allocation, FTTx networks

Metropolitan and wide area networks [6 lectures**]**
SONET/SDH, Optical Transport Network, Wavelength Routing Network, Routing and Assignment Algorithm.

Network control, management and survivability [6 lectures**]**
Network management system architecture, Functionality, GMPLS, Impairment, Survivability, Protection and Restoration.

Free-Space optical networks [5 lectures**]**
Classification, FSO network topologies, Design factors, FSO Network applications.

Textbooks

1. Chadha D. (2019), *Optical WDM networks: from static to elastic networks*, Wiley-IEEE Press.
2. Grobe K. and Eiselt M. (2013), *Wavelength Division Multiplexing, A Practical Engineering Guide*, Wiley.
3. Ramaswami R., Sivarajan K.N. and Sasaki G.H. (2010), *Optical Networks: A Practical Perspective*, 3rd Edition, Morgan Kaufmann Publishers.

Preparatory Course Material

1. Keiser G. (2013), *Fibre Optic Communication*, McGraw-Hill, 5th Edition.

Title	IR Detectors and Imaging	Number	ECL7XX0
Department	Electronics Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech., M.Tech., and Ph.D	Type	E
Prerequisite	Basics of Electromagnetism and Optics		

Objectives

The instructor will:

1. Introduce the fundamentals of IR detection and various types of detectors.
2. Introduce the processing of information in the form of images through IR elements.

Learning Outcomes

The students are expected to have the ability to:

1. Use various detectors for their design of an IR system
2. Bridge the gap between theory and practice with real time image processing using IR elements.

Contents

IR Basics [10 lectures**]**

Infrared radiation, irradiance scattering, spectral bands, materials, coatings, blackbody radiation, impact of environmental conditions.

IR Detectors [14 lectures**]**

Characteristics, performance parameters: noise, responsivity, sensitivity. thermal detectors: thermopile, bolometers, pyroelectric detectors. photon detectors: photoconductive, photovoltaic, PN, PIN, APD, Schottky-Barrier diode, metal-semiconductor-metal, photo emissive detectors, III-V detectors, HgCdTe Detectors, IV-VI detectors, quantum well and superlattice detectors, focal plane array architectures.

Imaging [15 lectures**]**

Fourier transformation, spatial frequency spectrum, Fraunhofer and Fresnel diffraction with various apertures, Huygen's principle, Kirchoff's Integral, Rayleigh criterion, Fresnel-Kirchhoff Theory. Concept of coherence, mutual coherence function, propagation of mutual coherence function. fourier transform property of lens, image formation, coherent information processing systems: spatial filtering, area modulation, optical correlation, applications in image restoration, SAR, LIDAR and processing of broadband signals.

Textbooks

1. Antonio Rogalski , Infrared Detectors, CRC Press.
2. Infrared Thermal Imaging, Wiley, 2018 Michael Vollmer Klaus-Peter Möllmann.
3. Franscis T.S. Yu, Optical Information Processing, Wiley Interscience, 1983.
4. Max Born and Emil Wolf, Principles of Optics, Cambridge University Press.