Department of Electronics and Communication Engineering

National Institute of Technology Silchar, Silchar, Assam, India

M. Tech. in RF and Terahertz Communications

About M. Tech. in RF and Terahertz Communications

M. Tech. in RF and Terahertz Communications is a Postgraduate Program running in the Department of Electronics and Communication Engineering at National Institute of Technology Silchar. This M. Tech. program provides a theoretical foundation for understanding the design, development, and operation of wireless communication systems working at RF and Terahertz Frequency Range. The Master of Technology in RF and Microwave Communications degree program provides depth for future study as well as knowledge and abilities for employment in RF and Terahertz and related disciplines in Communication Engineering. This M. Tech program is career-oriented and offers several prospects on completion graduation.

Department of Electronics and Communication Engineering

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M. Tech. in RF and Terahertz Communications

Course Structure

Semester I					
Subject Codes	**Course Name**	**L**	**T**	**P**	**Credits**
EC 5301	Advanced Electromagnetic Theory & Wave Propagation	3	0	0	3
EC 5302	Fundamentals of THz Communication	3	0	0	3
EC 5303	Antenna Theory for RF and THz Applications	3	0	0	3
EC 5304	Microwave and THz Engineering Lab	0	0	3	2
EC 533X	Elective I	3	0	0	3
EC 534X	Elective II	3	0	0	3
EC 5310	Seminar	0	0	2	1
				Total Credits	18
Semester II					
Subject Codes	**Course Name**	**L**	**T**	**P**	**Credits**
EC 5311	RF and THz Integrated Circuits Design	3	0	0	3
EC 5312	Computational Electromagnetics	3	0	0	3
EC 5313	Microwave and mm-Wave Measurement Techniques	3	0	0	3
EC 5314	Simulation and Measurement Lab	0	0	3	2
EC 535X	Elective III	3	0	0	3
EC 536X	Elective IV	3	0	0	3
EC 5320	Colloquium	0	0	2	1
				Total Credits	18
Semester III					
Subject Codes	**Course Name**	**L**	**T**	**P**	**Credits**
EC 6398	Project Phase-I	0	0	28	6
				Total Credits	6
Semester IV					
Subject Codes	**Course Name**	**L**	**T**	**P**	**Credits**
EC 6399	Project Phase-II	0	0	28	8
				Total Credits	8

Elective I
EC 5331: RF and Microwave Integrated Circuits
EC 5332: Dielectric Resonator based Components
EC 5333: Microwave Remote Sensing
EC 5334: Satellite Communication
EC 5335: Microwave Digital Communication
EC 5336: THz Integrated Circuits
EC 5337: Advanced Signal Processing for HF Applications
EC 5338: Wireless Networking
Elective II
EC 5341: EM Signal Processing
EC 5342: High Power Millimeter/Terahertz Wave Engineering
EC 5343: Radar Engineering and Applications
EC 5344: Adaptive Beam Forming and Smart Antennas
EC 5345: Microwave and Optoelectronic Devices
EC 5346: Green Communications
EC 5347: MIMO Communications
EC 5348: Detection and Estimation Theory
Elective III
EC 5351: Artificial Engineered Materials
EC 5352: Microwave and mm-Wave MEMS
EC 5353: RF Energy Harvesting and Applications
EC 5354: RF Microelectronics
EC 5355: EMI/EMC
EC 5356: High Power THz Radiation Sources
EC 5357: Electronic Infrastructure for Tera Scale Communication
EC 5358: Machine Learning for RF and THz
Elective IV
EC 5361: Optimization Techniques in Engineering
EC 5362: Soft Computing Techniques in Engineering Applications
EC 5363: Optical Communication System
EC 5364: Microwave Imaging Systems
EC 5365: Guided Wave Optical Components and Devices
EC 5366: Large Scale Sensing Arrays for Imaging
EC 5367: Light-wave Technology
EC 5368: THz Radar Technology

Detailed Syllabus
(Core Subjects)

EC-5301: Advanced Electromagnetic Theory & Wave Propagation		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Basic Fundamentals:** Coordinate systems; Maxwell's equations for time-varying fields and boundary conditions; Poynting vector; Wave equation; Wave polarization; Wave propagation in perfect and lossy dielectrics; Reflection of waves on a material boundary; Wave functions.	**4**
2	**Boundary Conditions and Electrical Properties of Matter:** Boundary Condition for Finite Conductivity Media, Infinite Conductivity Media and Sources Along Boundaries. Dielectrics, Polarization, and Permittivity, Magnetics, Magnetization, and Permeability, Current, Conductors and Conductivity, Semiconductors, Superconductors and Metamaterials. Linear, Homogeneous, Isotropic, and Nondispersive Media. A.C. Variations in Materials, Complex Permittivity, Complex Permeability, and Ferrites.	**8**
3	**Wave Equation and its Solutions:** EM Wave Equation Solutions in Rectangular, Cylindrical, and Spherical Coordinate Systems for Source-Free, Lossless and Lossy Media, Transverse Electromagnetic Modes and Transverse Electromagnetic Modes in Lossy Media,	**10**
4	**Wave Polarization:** Transverse Electromagnetic Modes, Uniform Plane Waves in an Unbounded Lossless Medium—Principal Axis, Electric and Magnetic Fields, Wave Impedance, Phase and Energy (Group) Velocities, Power, and Energy, Densities, Standing Waves, Uniform Plane Waves in an Unbounded Lossless Medium—Oblique Angle, Electric and Magnetic Fields, Wave Impedance, Phase and Energy (Group) Velocities, Power and Energy Densities. Transverse Electromagnetic Modes in Lossy Media, Uniform Plane Waves in an Unbounded Lossy Medium and Uniform Plane Waves in an Unbounded Lossy Medium. Polarization- Linear Polarization, Circular Polarization, Elliptical Polarization,	**10**
5	**Reflection, Transmission and Propagation:** Normal Incidence—Lossless Media, Oblique Incidence—Lossless Media, Perpendicular (Horizontal or E) Polarization and Parallel (Vertical or H) Polarization. Total Transmission–Brewster Angle and Total Reflection–Critical Angle, Lossy Media, Reflection and Transmission of Multiple Interfaces, Polarization Characteristics on Reflection, and Metamaterials. Impact of the Earth Surface on Propagation of Ground Waves, and Atmospheric Effects in Radio Wave Propagation, Plane wave propagation in anisotropic and uniaxial crystals; TEM wave propagation in Ferrites; Faraday rotation	**10**

Text/Reference Books:

1. C.A. Balanis, Advanced Engineering Electromagnetics, John Wiley & Sons, Second Edition
2. R.F. Harrington, "Time-harmonic Electromagnetic Fields", Wiley-IEEE Press.
3. Artem Saakian, Radio Wave Propagation Fundamentals, Artech House, Second Edition.
4. Les Barclay, Propagation of Radiowaves, Second Edition, IET, London, UK
5. Ramo, S., Whinnery, J.R., and Van Duzer, T., Fields and Waves in Communication Electronics, 3rd Ed., John Wiley & Sons.

Course Outcomes: At the end of the course, the student will be able to
CO-1: Understand the fundamentals of electromagnetics.

CO-2: Solve the wave equation in different modes.
CO-3: Solve the boundary valued problems on different conditions.
CO-4: Understand the polarization concept of EM Waves.

EC-5302: Fundamentals of THz Communication		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Wireless Fundamentals:** Evolution, mathematical representation of wireless systems, channel characteristics, multi-antenna systems, multi-carrier modulation schemes	**5**
2	**Sub-6 GHz and mmWave Wireless Systems:** Motivation and system model, time and frequency division duplexing, uplink and downlink transmissions, benefits and challenges, relevance in 5G and beyond 5G systems, spectral and energy efficiency.	**7**
3	**THz Communication:** Motivation, differences between microwave, mmWave and THz communication, propagation and characteristics, power consumption, multi-antenna signal processing, applications of THz	**12**
4	**Channel Models:** MIMO and massive MIMO channel modeling, spatial channel models, 3GPP channel models, mmWave channel models, THz channel model	**12**
5	THz devices, THz transceiver technologies, mmWave and THz modulation, industrial and wireless communications applications of THz waves	**6**

Text/Reference Books:

1. Saim Ghafoor, Mubashir Husain Rehmani, Alan Davy, ``*Next Generation Wireless Terahertz Communication Networks*'', CRC Press, 2021
2. Ali Rostami, Hassan Rasooli, Hamed Baghban, "*Terahertz Technology: Fundamentals and applications*," New York, Springer, 2011
3. E. Bjorson, J. Hoydis, and L. Sanguinetti, *Massive MIMO Networks: Spectral, Energy, and Hardware Efficiency*, now Publishers, 2018
4. T. S. Rappaport, R. W. Heath Jr., R. C. Daniels, and J. M. Murdock, *Millimeter Wave Wireless Communication*, Pearson Education, 2015
5. A Goldsmith, "*Wireless Communication*," Cambridge University Press, 2005

Course Outcomes: At the end of the course, the student will be able to
CO1: Understand the fundamentals of wireless channels, multi-antenna and multi-carrier systems.
CO2: Familiarize with different frequency bands of 5G communications.
CO3: Appraise the basic architecture of THz communication system.
CO4: Analyze the channel models for mmWave and THz communication system.
CO5: Understand the basic components required for THz communications.

EC-5303: Antenna Theory for RF and THz Applications		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Antenna Fundamentals:** Performance parameters of Antennas, Vector potentials, electromagnetic theorems, and concepts: uniqueness, image theory, field equivalence principle, reciprocity.	**4**
2	**Broadband Antennas:** Helical Antennas, Design Concepts, Frequency Independent Antennas - Equiangular Spiral Antennas, Log Periodic Antennas, Design Concepts. **Aperture Antennas:** Huygens' Principle, radiation from rectangular and circular apertures, design considerations, Babinet's principle, Horn and Reflector Antennas: Radiation from sectoral and pyramidal horns, design concepts, Radiation from the parabolic reflector and Cassegrain antennas.	**4+4**
3	**Microstrip and other planar antennas**: Basic Characteristics, Rectangular Patch Transmission Line Model, Design Concepts, Various types of feeding methods for microstrip antenna (Co-axial, Inset, Aperture/Slot Coupled, Proximity coupled, and corporate feeding for Arrays); Analysis of rectangular Patch Antenna, Cavity/ Modal Expansion Technique.	**10**
4	**Antenna Arrays:** Array factor, Excitation, Mutual coupling, Gain and Directivity, Multidimensional arrays, Phased Array Antenna and Switched array antennas - Feed networks, Power Pattern, Beam Steering, Degree of Freedom, Optimal Antenna, Adaptive Antenna, Smart Antenna, Microstrip Array - feeding methods, Mutual coupling. **Antenna Synthesis-**Synthesis of antenna arrays using the Fourier transform method, and Woodward-Lawson sampling method. **Method of Moments-**Solution to Pocklington Integral Equation, MOM Method, Basis Function and Sources.	**5+5**
5	**Antennas for Millimeter-Wave systems**: mm-wave design consideration, printed mm-wave antennas, On-chip and In package mm-wave antennas, Techniques to improve the gain of on-chip antennas, Implementation for mm-wave in adaptive antenna arrays	**10**

Text/Reference Books:

1. Antenna Theory Analysis and Design, C. A. Balanis. 2nd Edition, 2004, John Wiley, ISBN-9780471592686.
2. Antennas and Wave Propagation, John D Kraus, Ronald J Marhefka and Ahmad S Khan, 4th Edition 2010,Tata McGraw Hill, ISBN- 987-0-07-067155-3.
3. Antenna Theory and Design, Stutzman, and Thiele, 2nd Edition, 2013, John Wiley and Sons Inc., ISBN-978-0-470-57664-9.
3. Phased Array Antennas, By A. A. Ollinerand G.H. Knittel, Artech House

Course Outcomes: At the end of the course, the student will be able to
CO1: Explain different parameters of antenna and antenna systems.
CO2: Apply knowledge gained on modeling and performance analysis of various antenna types.
CO3: Design, synthesize, and analyze the types of antennas.
CO4: Model and Compute the radiation characteristics and other performance parameters

Detailed Syllabus
(Elective I Subjects)

EC-5311: RF and Microwave Integrated Circuits		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Analysis of MIC:** Introduction, Types of MICs and their technology, Propagating models, Analysis of MIC by conformal transformation, Numerical method, Hybrid mode analysis, Losses in microstrip, Introduction to slot line and coplanar waveguide.	**8**
2	**Couplers and Lumped Elements in MIC:** Introduction to coupled microstrip, Even and odd mode analysis, Branch line couplers, Design and fabrication of lumped elements for MICs, Comparison with distributed circuits	**8**
3	**Passive and Active Components in MIC:** Ferromagnetic substrates and inserts, Microstrip circulators, Phase shifters, Microwave transistors, Parametric diodes and amplifiers, PIN diodes, Transferred electron devices, Avalanche diodes, IMPATT, BARITT devices	**8**
4	**MIC Circuits and its Applications:** Introduction, Impedance transformers, Filters, High power circuits, Low power circuits, MICs in radar and satellite.	**8**
5	**Fabrication Process in MIC:** Fabrication process of MMIC, Hybrid MICs, Dielectric substances, Thick film and thin film technology and materials, Testing methods, Encapsulation, and mounting of devices.	**8**

Text/Reference Books:

1. L. G. Maloratsky, “Passive RF and Microwave integrated circuits,” Elsevier, 2004.
2. K. C. Gupta and A. Singh, “Microwave integrated circuits,” John Wiley, 1975
3. R. K. Hoffman, “Handbook of microwave integrated circuits,” Artech House, Boston,1987.
4. D. M. Pozar, “Microwave Engineering”, 3rd Ed., John Wiley & Sons, 2004.
5. R. Sorrentino and Giovanni Bianchi, “Microwave and RF Engineering” John Wiley & Sons, 2010.

Course Outcomes: At the end of the course, the student will be able to

CO1: Understand different analysis models to analyze MICs.
CO2: Acquire knowledge of different active and passive RF components.
CO3: Be able to design and analyze lumped, distributed elements and different RF circuits.
CO4: Gain knowledge of the fabrication process of MICs.

EC-5312: Dielectric Resonator-based Components		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Resonance Fundamentals:** Review of Resonance Concept in Electrical Circuits, Microwave Resonators,	**3**
2	**Eigenoscillations of Coupled Dielectric Resonators:** Coupled Oscillations of the Dielectric Resonator Systems, Coupled Oscillations of One-Dimensional Structures in the Transmission Lines,	**9**
3	**Eigenmode Analysis:** Eigenmodes of Dielectric Resonators in the Open Space, Natural Oscillations of the Coupling Dielectric Resonators in the Parallel-Plate Metal Waveguide, Eigenmodes of the Spherical Cavity Screened by One-Dimensional Dielectric Lattice, Eigenoscillations of the Optical Micro-resonator Lattices.	**10**
4	**Multi-section Filters on Dielectric Resonators' Lattices:** Band-Stop Filters on Lattices of Dielectric Resonators in the Microwave Transmission Lines, Bandpass Filters on Dielectric Resonators' Lattices, Dual-Band Dielectric Filters, Filters of Quasi-Optical Bands	**10**
5	**Antenna Structures on Lattices of Dielectric Resonators:** Single-Resonator Antenna Structures of Millimeter and Optical Wavelength Ranges, One-Dimensional Antenna Lattices, Two-Dimensional DR Antenna Lattices, Three-Dimensional Antenna Lattices of the Dielectric Resonators.	**10**

Text/Reference Books:

1. Fundamentals of Electrical Engineering, Bobrow Second Edition, Oxford Series
2. Dielectric Resonators, Darko Kajfez and Pierre Guillon, Noble Publishing Corporation, Second Edition, 1998.
3. Lattices of Dielectric Resonators, Alexander Trubin, Springer.
4. Dielectrics in Electric Fields, Gorur Govinda Raju, Second Edition, CRC Taylor & Francis

Course Outcomes: At the end of the course, the student will be able to
CO1: understand the fundamental concept of resonating phenomena in electrical circuits
CO2: learn of using Eigen Analysis of Dielectric Resonators.
CO3: analyse dielectric resonator as dielectric resonator filter.
CO4: analyse dielectric resonator as dielectric resonator antenna.

EC-5313: Microwave Remote Sensing		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Introduction:** Basic of Remote Sensing, Microwave Remote Sensing and its advantages. Active and passive systems. Sensors for Microwave Remote Sensing.	**4**
2	**Passive Microwave systems**: Formulation for microwave radiation and measurement. Applications in various fields, oceanography and meteorology.	**10**
3	**Active Microwave systems:** Basic principles of Radar, Radar range equation, Resolution, Phase and Angular measurements, Microwave scattering and its measurement, Relationships between scene and sensor parameters.	**10**
4	**Imaging systems:** Imagery – their characteristics and interpretation, Applications in various fields, Land use/Land cover, Soil/ Rock, Hydrology.	**10**
5	**Microwave Interferometry and DEM generation**: Theory and Mathematical background, Differential Interferometry, Applications, DEM generation, Glacial Movement, Various applications.	**10**

Text/Reference Books:

1. Fawaz T. Ulaby, Microwave Remote Sensing – Active and Passive, Wesley Publishing,1986.
2. Ulaby F. T., Moore R. K. & Fung A. K. 1986. Microwave Remote Sensing. *Active and Passive*. Vol. 3, Cambridge University Press.
3. Sabins F.F., Jr., Remote Sensing Principles and Interpretation - W.H. Freeman and company,1986.
4. Lillesand T.M and Kiefer R.W, Remote Sensing and Image Interpretation - John Wiely and Sons,2007.

Course Outcomes: At the end of the course, the student will be able to
CO1: Understand the ideologies of microwave remote sensing
CO2: Identify the working mechanism of active and passive systems for microwave remote sensing
CO3: Analyse various geological and terrestrial information
CO4: Apply for study different Geological information and parameters findings.

EC-5314: Satellite Communications		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0 Contact Hours**
1	**Architecture of Satellite Communication System:** Principles and architecture of satellite Communication, Brief history of Satellite systems, advantages, disadvantages, applications, and frequency bands used for satellite communication and their advantages/drawbacks.	**4**
2	**Orbital Analysis:** Orbital equations, Kepler's laws of planetary motion, Apogee and Perigee for an elliptical orbit, evaluation of velocity, orbital period, angular velocity etc of a satellite, concepts of Solar day and Sidereal day, Satellite launch mechanisms and launching vehicles.	**6**
3	**Satellite sub-systems:** Architecture and Roles of various sub-systems of a satellite system such as Telemetry, tracking, command and monitoring (TTC & M), Attitude and orbit control system (AOCS), Communication sub-system, power sub-systems, antenna sub-system, Transponder systems.	**8**
4	**Typical Phenomena in Satellite Communication:** Solar Eclipse on satellite, its effects, remedies for Eclipse, Sun Transit Outage phenomena, its effects and remedies, Doppler frequency shift phenomena and expression for Doppler shift.	**8**
5	**Satellite Link Budget:** Flux density and received signal power equations, Calculation of System noise temperature for satellite receiver, noise power calculation, drafting of satellite link budget and C/N ratio calculations in clear air and rainy conditions, Case study of Personal Communication system (satellite telephony) using LEO.	**8**
6	Modulation and Multiple Access Schemes used in satellite communication. Typical case studies of VSAT, DBS-TV satellites and few recent communication satellites	**8**

Text/Reference Books:

1. T. Pratt, C. Bostian, and J. Allnutt, Satellite Communications, 2nd ed. John Wiley & Sons, 2003.
2. Tri T. Ha, "Digital Satellite Communications", Tata McGraw Hill, 2009.
3. Dennis Roddy, "Satellite Communication", McGraw Hill, 4th Edition, 2008.

Course Outcomes: At the end of the course, the student will be able to

CO1: Visualize the architecture of satellite systems as a means of high speed, high range communication system.
CO2: State various aspects related to satellite systems such as orbital equations, sub-systems in a satellite.
CO3: Choose appropriate modulation and multiple access schemes for a given satellite communication application.
CO4: Solve numerical problems related to orbital motion and design of link budget for the given parameters and conditions.

EC-5315: Microwave Digital Communications		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Microwave Radio Overview:** Introduction, Digital Signaling, Noise Figure, Noise Factor, Noise Temperature, and Front-End Noise, Digital Pulse Amplitude Modulation (PAM), Radio Transmitters and Receivers, Modulation Format, QAM Digital Radios, Channel Equalization, Channel Coding, Trellis Coded Modulation (TCM), Orthogonal Frequency Division Multiplexing (OFDM), Radio Configurations, Cross-Polarization Interference Cancellation (XPIC)	**8**
2	**Designing and Operating Microwave Systems & Hypothetical Reference Circuits:** Why Microwave Radio? Radio System Design, Designing Low Frequency Radio Networks, Designing High Frequency Radio Networks, Hub and Spoke, Nested Rings, Field Measurements, User Data Interfaces, Operations and Maintenance, Fault Management, Alarms and Status, Performance Management, Maintaining the Network, International Telecommunication Union Availability Objectives, Residual BER, Burst Errored Seconds,	**10**
3	**Rain Fading:** Point (Single-Location) Rain Loss (Fade) Estimation, Path Rain-Fade Estimation, Point-to-Path Length Conversion Factor, Single-Location Rain Rate R, City Rain Rate Data for North America, New Rain Zones, Worst-Month Rain Rates, Point Rain Rate Variability, Examples of Rain-Loss-Dominated Path Designs **Ducting and Obstruction Fading:** Introduction, Power Fading, Super refraction (Ducting), Subrefraction (Earth Bulge or Obstruction), Minimizing Obstruction Fading, Path Clearance (Antenna Vertical Placement) Criteria, Obstruction Fading Model, Obstruction Fading Estimation, Bell Labs Seasonal Parameter Charts, Refractivity Data Limitations, Reviewing the Bell Labs Seasonal Parameter Charts, Obstruction Fading Parameter Estimation, Evaluating Path Clearance Criteria, Worldwide Obstruction Fading Data	**8**
4	**Digital Receiver Interference:** Composite Interference (ΔT/T) Criterion, Carrier-to-Interference Ratio (C/I) Criterion, Measuring C/I, Estimating C/I, Threshold to Interference (T/I) Criterion, Why Estimate T/I, T/I Estimation—Method One, T/I Estimation—Method Two **Network Reliability Calculations:** Hardware Reliability, System Reliability, Equipment in Series, Multiple Equipment in Parallel, Nested Equipment, Meshed Duplex Configuration, Communication Systems, Application to Radio Configurations, Spare Unit Requirements, BER Estimation, Time to Transmit N Digits	**8**
5	**Path Performance Calculations:** Union—Radiocommunication Sector (ITU-R) Path Performance Calculations, Flat Fading—ITU-R, Dispersive Fading—ITU-R, Cross-Polarization Discrimination Degradation Outages—ITU-R, Upfading—ITU-R, Shallow Flat Fading—ITU-R, Space Diversity Improvement—ITU-R, Dual-Frequency Diversity Improvement—ITU-R, Quad (Space and Frequency) Diversity—ITU-R, Angle Diversity Improvement—ITU-R, Other Diversity Improvements—ITU-R, Rain Fading and Obstruction Fading (NA and ITU-R), Comparing the North American and the ITU-R Flat-Fading Estimates	**8**
Text/Reference Books: (1) Digital Microwave Communication: Engineering Point-to-Point Microwave Systems, IEEE Press, GEORGE KIZER. (2) Wireless Communications, Cambridge, Andrea Goldsmith		
Course Outcomes: At the end of the course, the student will be able to **CO1:** **CO2:** **CO3:** **CO4:**		

EC-5316: Terahertz Integrated Circuits		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	***Introduction*: Overview of Terahertz Technology, Terahertz Applications, CMOS THz Electronics, CMOS THz Applications, Recent progress of terahertz CMOS circuits, technical background of terahertz CMOS circuit design, Terahertz CMOS building-block design, Recent progress of terahertz integrated circuits for communications.	**6**
2	***CMOS Metamaterial Devices (Non-Resonant-Type)*:** Introduction, Non-Resonant-Type Metamaterial-Composite Right-/Left-Handed T-Line, Magnetic Plasmon Waveguide.	**10**
3	***CMOS Metamaterial Devices (Resonant-Type)*:** Resonant-Type Metamaterial: T-Line Loaded with Split Ring Resonator, T-Line Loaded with Complementary Split Ring Resonator, CMOS Coherent THz Electronics by Metamaterial.	**10**
4	***CMOS THz Modelling*:** Introduction, Fractional-Order T-Line Model-Fractional Calculus, Fractional-Order Capacitance and Inductance, Fractional-Order T-Line Model, Fractional-Order CRLH T-Line Mode.	**12**
5	***CMOS THZ Signal Generation:*** Oscillator- Frequency Tuning by Loaded Transformer.	**4**

Text/Reference Books:

1. Design of CMOS Millimetre-Wave and Terahertz Integrated Circuits with Metamaterials- Hao Yu Yang Shang, CRC Press (2016 Taylor & Francis Group).
2. Design of Terahertz CMOS Integrated Circuits for High-Speed Wireless Communication- Minoru Fuji Shima and Shuhei Amakawa, The Institution of Engineering and Technology (2019).

Course Outcomes: At the end of the course, the student will be able to
CO1: Acquire the knowledge on terahertz technology, Applications and CMOS terahertz building blocks
CO2: Analyse CMOS Non-Resonant-Metamaterial Devices with help of equivalent circuits.
CO3: Analyse CMOS Resonant-Metamaterial Devices with help of equivalent circuits.
CO4: Examine CMOS THz modelling circuits using different fractional order techniques.
CO5: Analyse THz Oscillator circuits using different tunning methods.

EC-5317: Advanced Signal Processing for THz Applications		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Introduction to Signal Processing**: Basic concepts of signals and systems, Time-domain and frequency-domain representations, Analog and digital signal processing, Fourier Analysis and Frequency Domain Techniques: Fourier series and Fourier transforms, Discrete Fourier transform (DFT) and fast Fourier transform (FFT).	**5**
2	**Digital Filter Design:** FIR (Finite Impulse Response) filters, IIR (Infinite Impulse Response) filters, Filter design methods (e.g., Butterworth, Chebyshev, elliptic), Filter specifications and trade-offs,	**10**
3	**Multirate Signal Processing:** Sampling rate conversion, Polyphase representation, Decimation and interpolation, Applications of multirate techniques in HF systems.	**10**
4	**Adaptive Signal Processing:** Basics of adaptive filters, LMS (Least Mean Square) algorithm, Recursive least squares (RLS) algorithm, Applications of adaptive filters in HF systems.	**10**
5	**Advanced Topics:** Digital beamforming, Software-defined radio (SDR) techniques, Channel estimation and equalization in HF systems, Noise reduction and interference cancellation techniques	**7**

Text/Reference Books:

1. "Digital Signal Processing: Principles, Algorithms, and Applications" by John G. Proakis and Dimitris G. Manolakis
2. "Digital Signal Processing: A Practical Guide for Engineers and Scientists" by Steven Smith
3. "Adaptive Signal Processing" by Bernard Widrow and Samuel D. Stearns
4. "Multirate Systems and Filter Banks" by P. P. Vaidyanathan
5. "Modern Digital and Analog Communication Systems" by B. P. Lathi

Course Outcomes: At the end of the course, the student will be able to

CO1: Understand the fundamental concepts of signal processing and their relevance to HF applications.

CO2: Design and implement digital filters, including FIR and IIR filters, for signal processing in HF systems.

CO3: Demonstrate knowledge of multirate and adaptive signal processing techniques and their application in HF systems.

CO4: Gain knowledge of advanced topics such as digital beamforming, channel estimation, and equalization in HF systems.

EC-5318: Wireless Networking		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0 Contact Hours**
1	**Introduction:** Overview of current wireless systems and standards.	**2**
2	**Large-Scale Path Loss:** Wireless channels, Error/Outage probability over fading channels, Reflection, Diffraction and scattering, Free space propagation model, Two ray ground reflection model, Log-distance path loss model, Log-normal shadowing, Outdoor propagation models, Longley-Rice model, Okumura model, Hata model, Link power budget analysis. **Small-Scale Fading and Multipath:** Parameters of mobile multipath channels, Types of small-scale fading, Rayleigh and Rician distributions, Jakes Doppler spectrum.	**8**
3	**Diversity Techniques:** Diversity in wireless communications, non-coherent and coherent reception, error probability for uncoded transmission, realization of diversity, time diversity, frequency diversity, DSSS and OFDM, receiver diversity, SC, EGC and MRC, transmit diversity, space-time codes.	**8**
4	**Multiple Access Technique:** Introduction to FDMA, TDMA, CDMA and SDMA schemes, introduction to spread spectrum, Orthogonal spreading codes, Benefits of spreading (Jamming Margin, Graceful degradation, Universal frequency reuse, Multipath diversity), Multi-user CDMA, Performance analysis of CDMA downlink with multiple users, Performance analysis of CDMA uplink with multiple users, Asynchronous CDMA, Near far problem, Power control, CDMA receiver synchronization, Introduction to MC-CDMA.	**8**
5	**OFDM:** Introduction to multicarrier modulation, Importance of cyclic prefix, Adaptive modulation and coding techniques. OFDM issues, PAPR, Frequency and timing offset, ICI mitigation techniques, Introduction to SC-FDMA-PAPR analysis with localized and interleaved schemes.	**8**
6	**MIMO and Recent Trends:** Spatial multiplexing, Decomposition of MIMO channel, Pre-coding, Optimal MIMO power allocation, MIMO beamforming, Nonlinear MIMO receivers-V-BLAST, D-BLAST, Requirements of 5G, Drawbacks of OFDM, Introduction to Filter Bank Multicarrier System (FBMC), Massive MIMO, Millimeter wave technology, Dense network, Cognitive radio technology, Smart antennas, Multi-hop relay networks.	**8**

Text/Reference Books:

1. Simon Haykin, Michael Moher, Modern Wireless Communications, 2011, 1st Edition, Pearson Education, India.
2. A. J. Goldsmith, Wireless Communications, Cambridge University Press, 2005.
3. Wireless Communication Networks and Systems, by Cory Beard and William Stallings.
4. Fundamentals of Wireless Communication [T & V], by David Tse and Pramod Viswanath.

Course Outcomes: At the end of the course, the student will be able to
CO1: Describe the effect of large scale and small-scale fading on signal transmission.
CO2: Design and implement diversity coding techniques to overcome the effect of fading.
CO3: Design the transmitter and receiver blocks of OFDM for better transmission through multipath channel.
CO4: Design spatial multiplexing schemes and low-complexity receivers to maximize the spectral efficiency.

Detailed Syllabus
(Elective II)

EC-5321: EM Signal Processing		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Overview of Signal Processing:** Review of Linear Continuous-time signal processing: Fourier transform & properties; LTI systems and convolution, properties of LTI systems; Sampling in time and frequency domain, base band sampling, bandpass sampling, effect of sampling in time domain in frequency domain and vice-versa. Review of Discrete time signal processing: DTFT, DFT, FFT; Multi-rate signal processing. Review of simultaneous time-frequency analysis: Windowing signals; Short-time-Fourier transform, spectrograms; theory of Wavelet transform: shifting, dilation, basic wavelet functions, time-frequency analysis, uncertainty principle, multi-resolution analysis.	**8**
2	**Radar Signal Processing**: Angle-of-Arrival Estimation in the Presence of Multipath: The Low-Angle Tracking Radar Problem, Spectrum Estimation Background, Thomson's Multi-Taper Method, Some Popular Spectrum Estimation Procedures, Multi-taper Spectrum Estimation, F-Test for the Line Components, Experimental Data Description for a Low-Angle Tracking Radar Study. **Time–Frequency Analysis of Sea Clutter:** An Overview of Nonstationary Behavior and Time–Frequency Analysis, Theoretical Background on Non-stationary, High-Resolution Multi-taper Spectrograms.	**12**
3	**Wavelets in EM-Signal Processing:** Quadrature mirror filters, approximating a function using wavelet; Solution of Operator Equations; Solution of one-dimensional problems using wavelet-like basis, problem modelling, choosing proper basis for solution; Solution of $\nabla^2 u(x,y) + k^2 u(x,y) = F(x,y)$, boundary conditions, application to waveguide problems.	**12**
4	**Real Time Signal-Systems and Applications:** Electromagnetic Phasers; Passive coupled-line all-pass phasers, phaser topology, Group-delay response, C-section all-pass phasers. Chirping, chirp spectrum, chirp spread-spectrum (LoRa: Long Range Rx, Tx), chirp compression; Applications of Radio-Analog signal processing in radio-frequency identification (RFID) systems, active and passive RFIDs, real time Fourier transformers, frequency-division-modulators (FDM).	**12**

Text/Reference Books:

1. Proakis, John G., and Dmitris K. Manolakis. *Digital Signal Processing*. 4th ed. Upper Saddle River, NJ: Prentice Hall, 2006. ISBN: 9780131873742.
2. Oppenheim, Alan V., Ronald W. Schafer, and John R. Buck. *Discrete-Time Signal Processing*. 2nd ed. Upper Saddle River, NJ: Prentice Hall, 1999. ISBN: 9780137549207.
3. I. Haykin, Simon S, "Rader Adaptive signal processing", John Wiley & Sons.
4. Mark A Richards, "Fundamentals of Radar signal processing", M C Graw Hill.
5. Tapan K. Sarkar Magdalena Salazar-Palma Michael C. Wicks, "Wavelet Applications in Engineering Electromagnetics".

Course Outcomes: At the end of the course, the student will be able to
CO1: Revise the basic concepts of Signal Systems.
CO2: Understand concepts of time-frequency relationship in Fourier and wavelet transforms.
CO3: Understand the concepts of spectrum estimation and apply in case of radars.
CO4: Analyze behavior of sea-clutter with signal processing techniques in time-frequency domain.

CO5: Understand the theory of wavelets and apply in problem modelling and solving in electromagnetics.

EC-5322: High Power Milimeter/Terahertz Wave Engineering		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Review of Gyro-Devices:** Introduction, Classification of Fast Wave Microwave Sources, Overview of Gyro-Devices, Basic Principle of Gyrotrons and Gyroklystrons, Eigenmodes of Tapered, Open Cavities, Eigenmodes of Closed cavities, Physical Model for the High-Frequency Fields in a Resonator cavity.	**4**
2	**Calculation of RF Behaviour and Practical Considerations:** Equation of Motion, Self-Consistent Calculations, Dimensionless Variables, Mode Competition in Gyrotron devices, Time-Dependent Formulation, Current Neutralization, Choice of Beam Radius, Fresnel Parameter, Starting Current.	**8**
3	**Electron Optical and Guiding System:** Introduction, Magnetron Injection Gun-General Remarks, Preliminary Design, Design Procedure of MIGs, Beam Guidance, Beam Dump-Collecting System-General Remarks, Theory of Depressed Collectors, Magnetic Decompression, Design of Depressed Collectors.	**10**
4	**Output Taper, Quasi-optical Launcher and RF Window:** Output Taper, Methods of Taper Analysis and Synthesis, Quasi-optical Mode Converter, Basic Principle of Quasi-optical Mode Converters, High Power RF Windows	**10**
5	**Applications and Examples:** *Industrial Applications*-ECRH, ECR Discharges, High-Frequency Broadband ESR Spectroscopy, Material Processing, *RADAR Applications*- mm-wave Radar, *Scientific Applications*-Colliders, Nuclear Fusion, *Medical Applications* - X-rays, CT-scans, non-invasive applications, *Examples*-Multi-frequency Gyrotron, Multi-cavity Gyroklystrons.	**10**

Text/Reference Books:

1. Gregory S. Nusinovich "Introduction to the Physics of Gyrotrons," John Hopkins Univ. Press., 2004.
2. A. S. Gilmour, Jr. "Klystrons, Traveling Wave Tubes, Magnetrons, Crossed-Field Amplifiers, and Gyrotrons," Artech House, 2011.
3. Kartikeyan, Borie & Thumm. "Gyrotrons: High Power Micorwave and Millimeter Wave Technology," Springer, 2004.
4. State-of-the-Art of High-Power Gyro-Devices. Update of Experimental Results, Yearly.

Course Outcomes: At the end of the course, the student will be able to
CO1: Understand the physics of Gyro-devices.
CO2: perform RF behavior of gyro devices.
CO3: Design and analyze input optic systems.
CO4: Design and analyze output optic systems.

EC-5323: Radar Engineering and Applications		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Introduction:** Historical background, radar terminology, radar band designations, Radar block diagram, and radar equation: detection of signals in noise and signal-to-noise ratio, Probabilities of detection & False alarm, integration of radar pulses, radar cross-section, distributed targets, Transmitted power, pulse-repetition frequency, antenna parameters & system losses, introduction to radar clutter.	**6**
2	**Radar Types:** Pulse radars and CW radars, Advantages of coherent radar, Doppler radar and MTI: Doppler effect, delay-line cancellers, blind speeds, staggered PRFs, Digital filter bank, Moving Target Detector, limitations of MTI, tracking with radar, mono pulse tracking, conical scan, limitation to tracking accuracy.	**8**
3	**Radar Signals & Clutter:** Basic radar measurement, theoretical accuracy of radar measurements, Range and velocity ambiguities, the ambiguity diagram, pulse compression-principles, the matched filter, chirp waveforms, Waveform design: nonlinear FM, phase codes, waveform generation and compression. Descriptions of land & sea clutter, statistical models for surface clutter, detection of targets in clutter.	**8**
4	**Tracking and Imaging Radar:** Tracking with Radar, Monopulse tracking, Conical scan and Sequential lobing, Low angle tracking, Air surveillance radar, Introduction to Synthetic aperture radar (SAR), tracking in range and Doppler, Acquisition.	**8**
5	**Navigation and Aids to Approach and Landing:** Introduction to navigation and different methods, Instrument Landing System, Ground controlled Approach System, Microwave landing system, Distance Measuring Equipment, TACAN Doppler navigation-Doppler Effect, New configuration, Doppler frequency equations, Track stabilization.	**6**
6	**Recent trends in Satellite Navigation:** GPS principle of operation, Position location determination, principle of GPS receiver and applications, Global Satellite Navigation system, Martitime Satellite, Satellite Constellations, Navigation Satellites of different countries such as Glonas and Compass, GAGAN, IRNSS, NAVIC Receiver and applications.	**6**

Text/Reference Books:

1. M. I. Skolnik, “Introduction to Radar Systems ", Tata- MacGraw Hill, 3rd Edition, 2001.
2. M. H. Carpentier, “Principles of Modern Radar”, Artech House, 3rd Edition, 2010.
3. Elements of Electronic Navigation Systems", Tata McGraw-Hill
4. Radar Engg. Hand Book M.I. Skolnik, Publisher: McGraw Hill

Course Outcomes: At the end of the course, the student will be able to
CO1: Introduce the fundamental concepts of RADAR and Navigation aids.
CO2: Introduce idea of radar signals & clutter.
CO3: Explain the students to different types of RADAR and Navigation systems.
CO4: Make students learn modern radar and navigational techniques.

EC-5324: Adaptive Beamforming and Smart Antennas		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Fundamental Parameters of Antenna:** Radio communication link with transmission and receiving antenna, radiation patterns, antenna equivalent circuits, reciprocity theorem, beam area, beam width, directivity, gain, antenna apertures, effective height, field zones, radiation resistance, radiation efficiency, antenna polarization. Potential functions and the electromagnetic fields, oscillating electric dipole-derivations for E and H field components in spherical coordinate systems, power radiated by a current element.	**5**
2	**Narrow Band Processing:** Introduction to Smart Antenna, Benefits of Smart Antennas, Signal model conventional beam former, null steering beam former, optimal beam former, Optimization using reference signal, beam space processing.	**8**
3	**Adaptive Processing:** Sample matrix inversion algorithm, unconstrained LMS algorithm, normalized LMS algorithm, Constrained LMS algorithm, Perturbation algorithms, Neural network approach, Adaptive beam space processing, Implementation issues.	**8**
4	**Broadband Processing:** Tapped delay line structure, Partitioned realization, Derivative constrained processor, Digital beam forming, Broad band processing using DFT method.	**8**
5	**Direction of Arrival Estimation Methods:** Spectral estimation methods, linear prediction method, Maximum entropy method, Maximum likelihood method, Eigen structure methods, Music algorithm – root music and cyclic music algorithm, the ESPRIT algorithm.	**8**
6	**Combining Techniques:** Combining techniques for Macroscopic diversity, combining techniques for microscopic diversity – Selective combining, switched combining, Maximal ratio combining, equal gain combining and feed combining technique, optical combiner.	**5**

Text/Reference Books:

1. F.B.Gross - Smart Antennas for Wireless Communications, McGraw-Hill., 2005.
2. C.A. Balanis and P.I. Ioannides, "Introduction to smart antennas" Morgan & Claypool Publishers, 2007. 3. Robert A Monzingo, Randy L. Haupt and Thomas W. Miller, Introduction to Adaptive Arrays, 2nd Ed., Yesdee publishers
4. S. Chandran, Adaptive antenna arrays, Trends and Applications, Springer, 2009.

Course Outcomes: At the end of the course, the student will be able to
CO1: understand the various antenna parameters.
CO2: demonstrate basic understanding of smart antennas for broad frequency range.
CO3: demonstrate basic understanding of wire and aperture antennas.
CO4: analyze the broadband antennas for different applications.
CO5: interpret the different microstrip antennas for smart antenna applications.

EC-5325: Microwave and Optoelectronic Devices		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Microwave Semiconductor Device:** Microwave bipolar transistor, Microwave FET, Tunnel diode, Gunn diode, IMPATT diode, TRAPATT diode, Varactor diode, Schottky diode.	**10**
2	**Microwave Passive Components:** Rectangular waveguides resonator isolator, types of attenuators, fixed attenuators, step attenuators, variable attenuators, salient features of directional coupler, parameters of directional coupler, coupling factor, directivity, applications of directional coupler.	**10**
3	**Light Sources and Detectors:** Light-Emitting Diodes, Light-Emitting – Diodes Operating Characteristics, Laser Principles, Laser Diodes, Laser-Diode Operating Characteristics, Distributed – Feedback Laser Diode, Optical Amplifiers, Fiber Laser, Vertical-Cavity Surface-Emitting Laser Diodes Principles of Photodetection, Photomultiplier, Semiconductor Photodiode, PIN Photodiode, Avalanche Photodiode.	**10**
4	**Couplers and Connectors Principles:** Fiber end Preparation, Splices, Connectors, Source Coupling, Distribution Networks and Fiber Components, Distribution Networks, Directional Couplers, Star Couplers, Switches, Fiber Optical Isolator, Wavelength-Division Multiplexing, Fiber Bragg Gratings, Other Components: Attenuator, Circulator and Polarization Controller.	**12**

Text/Reference Books:

1. Microwave Devices and Circuits, S.M. Liao, Pearson
2. Microwave Engineering: Passive Circuits, Peter A. Rizzi, PHI
3. Senior, J.M., “Optical Fiber Communications”, 2nd Ed., Prentice-Hall of India. 1999
4. Keiser, G., “Optical Fiber Communications,” 3rd Ed., McGraw-Hill. 2000

Course Outcomes: At the end of the course, the student will be able to
CO1: understand the microwave waveguides, passive & active devices, tubes and network analysis.
CO2: analyze typical microwave networks using impedance, admittance, transmission and scattering matrix representations.
CO3: Design microwave matching networks using L section, single and double stub and quarter wave transformer.
CO4: Explain working of microwave passive circuits such as isolator, circulator, Directional couplers, attenuators etc.
CO5: Describe and explain working of microwave tubes and solid-state devices.

EC-5326: Green Communications		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Fundamental Tradeoffs on the Design of Green Radio Networks:** Insight from Shannon's capacity formula, impact of practical constraints and latest research and directions, algorithms for energy harvesting wireless networks, energy harvesting technologies – PHY and MAC layer optimization for energy harvesting wireless networks.	**10**
2	**Modulation:** Green modulation and coding schemes in energy constrained wireless networks, energy consumption of uncoded scheme, energy consumption analysis of LT coded modulation	**10**
3	**Cooperative Techniques for Energy Efficient Wireless Communications:** Energy efficiency metrics for wireless networks, cooperative networks, optimizing the energy efficiency performance of co-operative networks, energy efficiency in cooperative base stations	**10**
4	**Base Station Power Management Techniques for Green Radio Networks:** Opportunistic spectrum and load management for green radio networks, energy saving techniques in cellular wireless base stations, power management for base stations in a smart grid environment	**12**

Text/Reference Books:

1. E. Hossain, V. K. Bhargava, G. P. Fettweis, Green Radio Communication Networks, Cambridge.
2. D. N. K. Jayakody, J. T. S. Chatzinotas, S. Durrani, "Green Communication and Networking, J. L. Mauri, J. J. P. C. Rodrigues, Springer
3. S. Khan, J. L. Mauri, "Green Networking and Communications: ICT for Sustainability", CRC Press

Course Outcomes: At the end of the course, the student will be able to

CO1: *U*nderstand the principles of green communications and the trade-offs exist in it while satisfying the user demands in the network.

CO2: Design the green networks by optimizing its different layers to solve the coexistence problems due to huge power dissipation.

CO3: Design the self-sustainable cooperative networks by energy harvesting the ambient sources and optimal power management over the operating devices.

CO4: Study the challenges in simultaneous wireless information and power transfer (SWIPT) along with the optimization of resource allocations.

EC-5327: MIMO Communications		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Introduction:** Diversity-multiplexing trade-off, transmit diversity schemes, advantages and applications of MIMO systems	**8**
2	**Analytical MIMO channel models:** Uncorrelated, fully correlated, separately correlated and keyhole MIMO fading models, parallel decomposition of MIMO channel.	**8**
3	**Power allocation in MIMO systems:** Uniform, adaptive and near optimal power allocation. **MIMO channel capacity:** Capacity for deterministic and random MIMO channels, Capacity of i.i.d., separately correlated and keyhole Rayleigh fading MIMO channels.	**8**
4	**Space-Time codes:** Advantages, code design criteria, Alamouti space-time codes, SER analysis of Alamouti space-time code over fading channels, Space-time block codes, Space-time trellis codes, Performance analysis of Space-time codes over separately correlated MIMO channel, Space-time turbo codes. **MIMO detection:** ML, ZF, MMSE, ZF-SIC, MMSE-SIC, LR based detection	**10**
5	**Advances in MIMO wireless communications:** Spatial modulation, MIMO based cooperative communication and cognitive radio, multiuser MIMO, cognitive-femtocells and large MIMO systems for 5G wireless.	**8**

Text/Reference Books:

1. B. Clerckx and C. Oestges, MIMO wireless networks, Elsevier Academic Press, 2nd ed., 2013.
2. T. M. Duman and A. Ghrayeb, Coding for MIMO communication systems, John Wiley and Sons, 2007.
3. N. Costa and S. Haykin, Multiple-input multiple-output channel models, John Wiley & Sons, 2010.
4. J. Choi, Optimal Combining & Detection, Cambridge University Press, 2010.
5. A. Chokhalingam and B. S. Rajan, Large MIMO systems, Cambridge University Press, 2014.

Course Outcomes: At the end of the course, the student will be able to

CO1: Understand the basic concept of antenna diversity schemes.
CO2: Analyse the signal processing of MIMO in 4G LTE Communication
CO3: Compare the channel capacity of MIMO system under different channel conditions.
CO4: Understand the problems related to Alamouti coding and BLAST structure of MIMO system.
CO5: Analyze the Massive MIMO environment in 5G systems.

EC-5328: Detection and Estimation Theory		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Contact Hours**
1	**Review of Random Process:** Review of probability theory, Random Variable, Two random variable, Random process definition and classification, stationary and non-stationary process, special random process (white Gaussian noise, wiener Levy Processes, Special random processes).	**10**
2	**Optimum Filtering:** Matched Filter for deterministic signals in white and coloured Gaussian noise, Weiner filter, Kalman filter, Linear filtering of Stochastic Processes, AR, MA and ARMA Processes, Detection of known Signals.	**12**
3	**Hypothesis Testing:** Bayes, Minimax and Neyman-Pearson criteria, Types of estimates and error bounds, General Gaussian problem, Detection and estimation in coloured noise, Elements sequential and non-parametric detection.	**10**
4	**Application to communication system:** Digital communication, spread spectrum communication, Radar systems, Radar Target Models, Target Detection, Parametric estimation in radar systems, Dynamic Target Tracking	**10**

Text/Reference Books:

1. H.V. Poor, An introduction to signal Detection and Estimation ,2nd Ed., Springer-Verlag,1994
2. H.L. Van Trees, Detection, Estimation and Modulation Theory, Parts 1 and 2, John Wiley Inter-Science.
3. M.D. Srinath, P.K. Rajasekaran and R. Vishwanaathan, An introduction to Statistical Signal Processing with Applications, Prentice-Hall,1996
4. A. Papoulis & S.U. Pillai, Probability, Random variables and Stochastic processes
5. A D Whalen, Detection of Signals and Noise.

Course Outcomes: At the end of the course, the student will be able to
CO-1: Acquire basics of statistical decision theory used for signal detection and estimation, Classical and Bayesian Estimation Approaches.
CO-2: Comprehend the elements and structure of random and non-random parametric Estimation Methods-Maximum Likelihood Estimation, Maximum A Posterior i Estimation, Minimum Mean Square Error Estimation, Linear Minimum Mean Square Error Estimation.
CO-3: Learn Basic Estimation Performance Bounds such as Cramer-Rao Bound/inequality.
CO-4: Analyze sequential and non-parametric detection in discrete-time domain using filters.
CO-5: Gain ability to apply estimation methods to real engineering problems.

Department of Electronics and Communication Engineering

National Institute of Technology Silchar, Silchar, Assam, India

M. Tech. in RF and Terahertz Communications

Second Semester

Course Structure

Semester II					
Subject Codes	**Course Name**	**L**	**T**	**P**	**Credits**
EC 5311	RF and THz Integrated Circuits Design	3	0	0	3
EC 5312	Computational Electromagnetics	3	0	0	3
EC 5313	Microwave and mm-Wave Measurement Techniques	3	0	0	3
EC 5314	Simulation and Measurement Lab	0	0	3	2
EC 535X	Elective III	3	0	0	3
EC 536X	Elective IV	3	0	0	3
EC 5320	Colloquium	0	0	2	1
				Total Credits	18

Elective III
EC 5351: Artificial Engineered Materials
EC 5352: Microwave and mm-Wave MEMS
EC 5353: RF Energy Harvesting and Applications
EC 5354: RF Microelectronics
EC 5355: EMI/EMC
EC 5356: High Power THz Radiation Sources
EC 5357: Electronic Infrastructure for Tera Scale Communication
EC 5358: Machine Learning for RF and THz
Elective IV
EC 5361: Optimization Techniques in Engineering
EC 5362: Soft Computing Techniques in Engineering Applications
EC 5363: Optical Communication System
EC 5364: Microwave Imaging Systems
EC 5365: Guided Wave Optical Components and Devices
EC 5366: Large Scale Sensing Arrays for Imaging
EC 5367: Light-wave Technology
EC 5368: THz Radar Technology

EC 5311: RF and THz Integrated Circuits Design		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	**Introduction:** Types of MICs and their technology, different analysis models. Overview of Terahertz Technology, CMOS THz Electronics, CMOS THz Applications, technical background of Terahertz CMOS circuit design, Terahertz CMOS building-block design.	**6**
2	**RF and THz Circuits and their Applications:** Introduction, Impedance transformers, Filters, High power circuits, Low power circuits, MICs in radar and satellite, Recent progress of terahertz CMOS circuits, Recent progress of terahertz integrated circuits for communications.	**6**
3	**CMOS Metamaterial Devices (Non-Resonant-Type)**: Introduction, Non-Resonant-Type Metamaterial-Composite Right-/Left-Handed T-Line, Magnetic Plasmon Waveguide.	**9**
4	**CMOS Metamaterial Devices (Resonant-Type):** Resonant-Type Metamaterial: T-Line Loaded with Split Ring Resonator, T-Line Loaded with Complementary Split Ring Resonator, CMOS Coherent THz Electronics by Metamaterial.	**9**
5	**CMOS THz Modelling:** Introduction, Fractional-Order T-Line Model Fractional Calculus, Fractional-Order Capacitance and Inductance, Fractional-Order T-Line Model, Fractional-Order CRLH T-Line Mode	**12**

Text/Reference Books:

1. D.M. Pozar, “Microwave Engineering”, 3rd Ed., John Wiley & Sons, 2004.
2. L.G. Maloratsky, “Passive RF and Microwave integrated circuits,” Elsevier, 2004.
3. K.C. Gupta and A. Singh, “Microwave Integrated Circuits,” John Wiley, 1975
4. Design of CMOS Millimetre-Wave and Terahertz Integrated Circuits with Metamaterials- Hao Yu Yang Shang, CRC Press (2016 Taylor & Francis Group).
5. Design of Terahertz CMOS Integrated Circuits for High-Speed Wireless Communication- Minoru Fuji Shima and Shuhei Amakawa, The Institution of Engineering and Technology (2019).

Course Outcomes: At the end of the course, the student will be able to
CO-1: Understand different analysis models for MICs, and terahertz technology.
CO-2: Acquire knowledge of different RF & THZ integrated circuits.
CO-3: Analyse CMOS Non-Resonant-Metamaterial Devices with the help of equivalent circuits.
CO-4: Analyse CMOS Resonant-Metamaterial Devices with the help of equivalent circuits.
CO-5: Examine CMOS THz modeling circuits using different fractional order techniques.

EC 5312: Computational Electromagnetics		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	**Module 1: Review of basic EM principles:** Maxwell's equations, Applications of Computational Electromagnetics, Green function, Boundary conditions, Linear algebra for computational EM	**6**
2	**Module 2: Method of Moments (MoM)** 2D vs 2.5D vs. 3D Formulations, Electrostatic Formulation: Capacitance matrix extraction, Magnetostatic Formulation: Inductance matrix extraction, Electric Field Integral Equation (EFIE): S-parameter extraction, Partial Element Equivalent Circuit (PEEC) Method, Magnetic Field Integral Equation (MFIE) and Combined Field Integral Equation (CFIE), PMCHWT Formulation: Dielectric modeling, Parallelization techniques	**10**
3	**Module 3: Finite Difference Time Domain (FDTD) Method** Basics of FDTD: Finite Differences, FDTD Solution of Maxwell Equations in simple cases, Scattered field vs total field formulation, Implementation issues, Outer Radiation Boundary Conditions, Yee cell, Yee algorithm for 3D Formulation of FDTD, Perfectly Matched Layer ABC, Frequency Domain Results from Time Domain Output of FDTD, Computational issues: Stair casing errors, numerical dispersion, Frequency-Dependent Materials	**10**
4	**Module4: Finite Element Method (FEM)** Bary-centric coordinate systems, Lagrange interpolation polynomials, applying FEM to solve Poisson equations, vector finite element basis functions, solving dielectric waveguides using vector finite element methods, modeling three-dimensional inhomogeneous cavities, and application of vector finite element methods to 3D vector wave equations	**10**
5	**Module-5: Integral Equation Methods** Integral equation methods for computing capacitances for multiple arbitrarily shaped conductors, numerical integrations for smooth and weakly singular kernels, RWG basis functions, EFIE, MFIE, CFIE	**6**

Text/Reference Books:

1. Andrew F. Peterson, Scott L. Ray, Raj Mittra: Computational Methods for Electromagnetics, 1st Ed., IEEE Press Series on Electromagnetic Wave Theory
2. Karl F. Warnick: "Numerical Methods for Engineering: An Introduction Using MATLAB and Computational Electromagnetics Examples," SciTech Publishing, 2010
3. Matthew N.O. Sadiku: "Numerical Techniques in Electromagnetics with MATLAB," Third Edition, CRC Press
4. A. F. Peterson, S. L. Ray, and R. Mittra, "Computational Methods for Electromagnetics" (IEEE Press, New York, 1998).
5. Jianming Jin, Theory and Computation of Electromagnetic Fields, Wiley, Dec. 2010
6. J. M. Jin, "The Finite Element Method in Electromagnetics", 2nd ed., John Wiley & Sons, New York, 2002.

Course Outcomes: At the end of the course, the student will be able to
CO-1: Understands fundamentals of computational electromagnetics (CEM).
CO-2: Apply the concept of computational electromagnetics (CEM) to solving problems.
CO-3: Analyse the performance of different computational electromagnetics (CEM) methods.
CO-4: Evaluate the rigorous coupled wave method.
CO-5: Create the computational electromagnetics (CEM) for the real-life problem(s).

<table>
<tr><th colspan="3">EC 5313: Microwave and mm-Wave Measurement Techniques</th></tr>
<tr><th rowspan="2">Unit No.</th><th rowspan="2">Detailed Syllabus</th><th>L:3 T:0 P:0</th></tr>
<tr><th>Hours</th></tr>
<tr><td>1</td><td>Transmission Lines, Scattering Parameters:
Transmission Lines - Basic principles, Structures, and Properties of Transmission Lines, lossless waveguides. Scattering parameters and circuit analysis, uncertainty and confidence in measurements, application of Smith chart in microwave networks, slotted line technique, measurement of unknown impedance using slotted line, and coaxial connectors in measurement.</td><td>8</td></tr>
<tr><td>2</td><td>RF Power, Frequency & Impedance Measurement:
Power sensors, power measurements and calibration, calibration and transfer standards, power splitters, couplers, and time domain reflectometry.
Frequency Measurement- Different techniques to measure frequency, Slotted Line Technique, maxima & minima, wavelength & frequency measurement.
Impedance Measurement- Measurement of unknown load impedance of a transmission line, Slotted Line Technique to measure unknown impedance.</td><td>8</td></tr>
<tr><td>3</td><td>Attenuation, RF Voltage & Noise Measurement:
Attenuation Measurement- Basic principles, Measurement systems, and important considerations when making attenuation measurements.
RF Voltage Measurement- RF voltage measuring instruments, impedance matching, and mismatch errors.
Noise Measurements- Types of noise, types of noise source, measuring noise, measurement accuracy, mismatch effects, automated noise measurements.</td><td>8</td></tr>
<tr><td>4</td><td>Vector Network Analyzer (VNA):
Concept of vector network analyzer, Basic block diagram of vector network analyzer (VNA), Application of vector network analyzers. Scalar Network Analyzer (SNA): Definition of network analyzer, Difference between SNA & VNA, Basic block diagram Scalar Network Analyzer.</td><td>8</td></tr>
<tr><td>5</td><td>Spectrum Analyzer:
Basic block diagram of a spectrum analyzer, functions & applications of a spectrum analyzer.
Time Domain Electrometer (TDR) & IC Technology: Introduction to Electrometer, Measurement of reflection coefficient using electrometer technique, Basic block diagram of a time domain electrometer.</td><td>8</td></tr>
<tr><td colspan="3">Text/Reference Books:
1. D. M. Pozar, Microwave Engineering, Wiley
2. Ginzton, EL, Microwave Measurements, McGraw Hill-1957
3. Richard Collier & Douglas Skinner, Microwave Measurements, 3rd Edition, IET, 2007
4. A. Das and S. K. Das, Microwave Engineering, McGraw Hill Education
5. K.C. Gupta, Microwaves, New Age International
6. T.H. Lee, “Planar Microwave Engineering: A Practical Guide to Theory, Measurement, and Circuits, Cambridge University Press</td></tr>
<tr><td colspan="3">Course Outcomes: At the end of the course, the student will be able to
CO-1: Understand, plan, and execute the properties of transmission lines
CO-2: Solve the Practical problem in RF power measurement
CO-3: Implement the method of attenuation and noise measurement.
CO-4: Learn the different operations and measurements by using a Network Analyzer.
CO-5: Learn the different operations and measurements by using Spectrum Analyzer.</td></tr>
</table>

EC 5314: Simulation and Measurement Lab		
Unit No.	**Detailed Syllabus**	**L:0 T:0 P:3**
		Hours
1	Design a microstrip patch antenna using simulation software (e.g., HFSS or CST) and analyze its performance parameters such as return loss, bandwidth, and radiation pattern.	
2	Simulate basic RF circuits such as filters and amplifiers using Advanced Design System (ADS) software and analyze their S-parameters and frequency response.	
3	Perform S-parameter measurements for a given RF/microwave device using a Vector Network Analyzer (VNA) and compare the results with simulated data.	
4	TDR (Time-Domain Reflectometry) to measure the impedance characteristics of transmission lines and identify faults or discontinuities.	
5	Simulate the propagation of THz waves in different media using full-wave simulation tools, and analyze the impact of material properties on wave propagation.	
6	Design and simulate bandpass and bandstop filters for THz applications, focusing on their frequency response and insertion loss characteristics.	

Course Outcomes: At the end of the course, the student will be able to
CO-1: Design an antenna and evaluate its performance parameters.
CO-2: Design filter and amplifier and analyze their performance.
CO-3: Evaluate S-parameters of microwave/THz devices.
CO-4: Study impedance parameters for different applications.
CO-5: Study material properties in RF and THz frequency ranges.

EC 5351: Artificial Engineered Materials		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	**Introduction to Artificial Engineered Materials:** History, Definition and significance, Overview of electromagnetic properties: permittivity, permeability, refractive index, Classification: Metamaterial, Photonic Crystals, Plasmonic Materials, etc., Natural vs. Artificial Materials. Basic Principles: Maxwell's equations and wave propagation, Effective medium theory, Homogenization techniques, Negative refraction and negative index materials, Sub-wavelength imaging, and superlensing.	**10**
2	**Electromagnetic Metamaterial:** Negative index materials, Design and modeling of split-ring resonators (SRRs) and wire arrays, Applications: Superlensing, cloaking, and antennas. Acoustic Metamaterials: Fundamentals and sound manipulation, Acoustic cloaking and sound barriers, noise reduction and soundproofing applications.	**8**
3	**Photonic Crystals and Plasmonics: Photonic Crystals:** Periodic dielectric structures and bandgap theory, 1D, 2D, and 3D photonic crystals, Applications in waveguides, filters, and optical fibers. **Plasmonic Materials:** Surface plasmons and localized surface plasmon resonances (LSPRs), Plasmonic nanostructures for enhanced light-matter interaction, Applications: Sensing, imaging, and photodetectors.	**8**
4	**Advanced Materials and Fabrication Techniques: Nonlinear and Active Materials:** Nonlinear optical materials, Phase-change materials and tunable metamaterials, Active metamaterials with integrated electronics. **Fabrication Techniques:** Top-down and bottom-up fabrication, Nanolithography, self-assembly, and 3D printing, Characterization techniques: SEM, TEM, AFM, and optical spectroscopy.	**8**
5	**Applications in Technology and Industry:** Optical Devices: Metamaterial-based lenses and cloaking devices, Photonic crystal lasers and LEDs, Plasmonic waveguides and circuits. **Telecommunications:** Metamaterial antennas for wireless communication, Photonic crystals in optical communication networks, Filters, switches, and modulators. **Energy Systems:** Solar and RF energy harvesting using engineered materials, Thermophotovoltaics and radiative cooling, and Plasmonic-enhanced photocatalysis.	**8**

Text/Reference Books:

1. "Metamaterials: Theory, Design, and Applications" by Tie Jun Cui, David R. Smith, and Ruopeng Liu.
2. "Photonic Crystals: Molding the Flow of Light" by John D. Joannopoulos, Steven G. Johnson, Joshua N. Winn, and Robert D. Meade
3. "Plasmonics: Fundamentals and Applications" by Stefan A. Maier
4. Research papers and articles from journals like Nature Materials, Advanced Materials, IEEE Transactions on Antennas and Propagation, etc.

Course Outcomes: At the end of the course, the student will be able to

CO-1: Understanding of the concept of artificially engineered materials.

CO-2: Apply the acquired knowledge in developing artificially engineered materials.

CO-3: Design artificial engineered materials using simulation software/numerical methods.

CO-4: Acquire practical skills in fabricating artificial materials using techniques like nanolithography/3D printing.

CO-5: Demonstrate the ability to apply artificially engineered materials for different applications.

Department of Electronics and Communication Engineering
National Institute of Technology Silchar, Silchar, Assam, India
M. Tech. in RF and Terahertz Communications
Second Semester

EC 5352: Microwave and mm-Wave MEMS		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0 Hours**
1	**Introduction:** RF MEMS for microwave applications, MEMS technology and fabrication, mechanical modeling of MEMS devices, MEMS materials, and fabrication techniques. MEMS Switches: Introduction to MEMS switches; Capacitive shunt and series switches: Physical description, circuit model and electromagnetic modeling; Techniques of MEMS switch fabrication and packaging; Design of MEMS switches	**6**
2	**RF MEMS Filters and Phase Shifters:** RF MEMS Filters: Modeling of mechanical filters, Micromachined filters, surface acoustic wave filters, and micromachined filters for millimeter wave frequencies. Phase shifter: MEMS phase shifters, Ferroelectric phase shifters, types, limitations. Case Study: Ka-Band RF MEMS Phase shifter for RADAR system application	**8**
3	**RF MEMS Resonators and Oscillators:** Transmission line planar resonators, cavity resonators, micromechanical resonators, film bulk acoustics wave resonators, High-Q 8 MHz MEM Resonators filter, RF MEMS Oscillators – fundamentals. Case Study: A14GHz MEM Oscillator, A Ka-Band Micro machined cavity oscillator	**6**
4	**Micromachined Microwave Structures:** Micromachined Transmission lines and Antennas: Micromachined transmission lines, losses in transmission lines, coplanar transmission lines, micromachined waveguide components; Micromachined antennas: Design parameters, Micromachining techniques to improve antenna performance, reconfigurable antennas. Case Study: Microfabricated Thick-Cu PZT-MEMS Millimeter-Wave Topologies and Devices, Millimeter-Wave MEMS Tunable Low Pass Filter with Reconfigurable Series Inductors and Capacitive Shunt Switches	**8**
5	**Advanced Applications and Integration and Packaging:** MEMS-based radar and imaging systems, Recent research and advancements in MEMS technology, Case studies- A 60 to 77 GHz Switchable LNA in an RF-MEMS Embedded BiCMOS Technology, Ka-Band Micromachined Cavity Oscillator. Monolithic Millimeter-Wave MEMS Waveguide.Role of MEMS packages, types of MEMS packages, module packaging, packaging materials, and reliability issues.	**8**

Text/Reference Books:

1. RF MEMS Circuit Design for Wireless Communications, Héctor J. De Los Santos, Artech House, ISBN 1-58053-329-9
2. RF MEMS: Theory, Design and Technology, Gabriel M. Rebeiz, Wiley-Interscience; 1st edition ISBN-10:0471201693
3. RF MEMS and Their Applications, Vijay K. Varadan K.J. Vinoy K.A. Jose Pennsylvania State University, USA, John Wiley & Sons Ltd, ISBN 0-470-84308-X
4. Advanced RF MEMS, Editor: Stepan Lucyszyn, Cambridge University Press, ISBN: 9780521897716, 0521897718
5. Handbook of Mems for Wireless and Mobile Applications, 1st Edition - August 31, 2013, Editor: Deepak Uttamchandani, Language: English, eBook ISBN: 9780857098610

Course Outcomes: At the end of the course, the student will be able to
CO1: Learn the fundamentals of MEMS technology and microwave frequencies.
CO2: To apply mechanical and electromagnetic theories to design RF MEMS devices.
CO3: Analyze MEMS-based RF microwave components.
CO4: Design tunable and reconfigurable RF MEMS structures.
CO5: Explore cutting-edge MEMS applications and trends.

EC-5353: RF Energy Harvesting and Applications		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	**Module-1: Introduction:** Introduction to Energy Harvesters, RF Energy Harvesters, Wireless Power Transfer, SWIPT, Key Components of a Rectenna, Historical Perspectives	**6**
2	**Module-2: Antenna Circuits:** Circularly Polarized Antenna Circuits, High Gain Antenna Circuits, Broad-Band and Wide-Band Antenna Circuits, Multi-Frequency and Multi-Band Antenna Circuits, High Efficiency Antenna Circuits, Low Power Antenna Circuits, Metamaterial and Metasurface Antennas	**10**
3	**Module-3: Rectifier Circuits:** High Efficiency Rectifiers, Multi-Frequency Rectifiers, Multi-Band Rectifiers, Low-Power and High-Power Rectifiers, Dynamic Range Rectifiers	**10**
4	**Module-4: Rectenna Circuits:** Circularly Polarized Rectenna Circuits, Broad-Band and Wide-Band Rectenna Circuits, Multi-Frequency and Multi-Band Rectenna Circuits, High Efficiency Rectenna Circuits, Low Power and High Rectenna Circuits,	**10**
5	Impedance Matching Circuits, Diverse Applications of RF Energy Harvesters	**6**

Text/Reference Books:

1. Taimoor Khan, Nasimuddin, Yahia M.M. Antar, "Elements of Radio Frequency Energy Harvesting and Wireless Power Transfer Systems" 1st Edition, CRC Taylor Francis
2. Olfa Kanoun, "Energy Harvesting for Wireless Sensor Networks: Technology, Components and System Design", De Gruyter Oldenbourg
3. Carlos Manuel Ferreira Carvalho and Nuno Filipe Silva Verissimo Paulino, "CMOS Indoor Light Energy Harvesting System for Wireless Sensing Applications", Springer

Course Outcomes: At the end of the course, the student will be able to
CO1: Understand the fundamental principles of RF energy harvesting (RFEH).
CO2: Apply knowledge in designing antenna, rectifier used in rectenna system.
CO3: Analyze performance characteristics of antenna, rectifier and rectenna using simulation software.
CO4: Evaluate the performance of RFEH systems in multi-band and broadband scenarios.
CO5: Develop RF energy harvester for different applications.

EC 5354: RF Microelectronics		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	Basic Concepts in RF Design, Architecture, Transmission media and Reflections, Maximum power transfer, Scattering Parameters	**8**
2	Modern IC technologies (CMOS, Si-Ge, SoI), fundamental limitation of speed & gain of transistors in various technologies, RF transceivers architecture and design	**8**
3	Low Noise Amplifiers: SNR, LNA topologies, power-constrained noise optimization, linearity, and large signal performance. Linearity considerations include 1-dB compression, IIP, and THD estimation.	**8**
4	Passive and Active Mixers: multiplier-based mixers, sub-sampling mixers, and diode-ring mixers. RF Passive Components: Characteristics of passive IC components at RF frequencies – interconnects, resistors, capacitors, inductors, and transformers – Transmission lines.	**10**
5	Oscillators: Basic Principles, Cross-Coupled VCO, Phase Noise concept, Phase-locked loops, Frequency Synthesizers. RF power amplifiers – Class A, AB, B, C, D, E, and F amplifiers, modulation of power amplifiers, linearity considerations.	**10**

Text/Reference Books:

1. Behzad Razavi, RF Microelectronics, Pearson Education India, 2nd edition, 2012.
2. Thomas H. Lee, The Design of CMOS Radio-Frequency Integrated Circuits, Cambridge University Press, 2nd edition, 2004.

Course Outcomes: At the end of the course, the student will be able to
CO1: Learn various architectures of today’s digital radio transmitters and receivers.
CO2: Use CMOS technology for the design of basic RF building blocks.
CO3: Analyze passive RF components and Transmission lines
CO4: Evaluate noise and other parameter for the design of LNA
CO5: Model Mixer/Oscillator/ power amplifiers a part of RF circuits.

EC 5355: EMI/EMC		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	**Introduction:** Introduction to EMI and EMC, Sources of EMI, Conducted and Radiated EMI emission and susceptibility, Radiation hazards to humans, EMC Testing categories, Practical experiences and concerns, frequency spectrum conservations, Mechanisms of EMI generation, EMI Testing and Measurement, Methods of mitigation of EMI and Biological effects of EMI.	**10**
2	**EMI from Apparatus/Circuits:** Introduction, Electromagnetic Emissions, Noise from relays and Switches, Nonlinearities in Circuits, Passive Intermodulation, Cross-Talk in Transmission lines, Transients in Power Supply Lines calculation of induced Voltages and Currents, Surges on Mains Power Supply, EMI- Radiation coupling, Conduction coupling, Combination of both Radiation and Conduction coupling.	**10**
3	**EMI Measurements:** Basic principles of RE, CE, RS and CS measurements, EMI measuring instruments- Antennas, LISN, Feed through capacitor, current probe, EMC analyzer and detection technique open area site shielded anechoic chamber, TEM cell.	**8**
4	**EMI Control Methods and Fixes:** Shielding, Grounding, Bonding, Filtering, EMI gasket, Isolation transformer, opto isolator.	**6**
5	**EMC Design and EMI/EMC Standards:** Cable routing and connection, Component selection and mounting, PCB design- Trace routing, Impedance control, decoupling, Zoning and grounding, National/International EMC standards, military and civilian standards.	**6**

Text/Reference Books:

1. Dr. V.P. Kodali, Engineering Electromagnetic Compatibility, IEEE Printed in India by S. Chand & Co. Ltd., New Delhi, 2000.
2. Henry W. Ott, Electromagnetic Compatibility Engineering, John Wiley & Sons Inc, New York, 2009
3. Clayton R. Paul, Introduction to electromagnetic compatibility, John Wiley and Sons, Inc. 1991.
4. Dr Kenneth L Kaiser, 2005. The Electromagnetic Compatibility Handbook, CRC Press.

Course Outcomes: At the end of the course, the student will be able to
CO-1: Understand EMI Environment, Coupling principles, Different sources, and Mitigation Techniques.
CO-2: Apply the concept of Electromagnetic emissions, radiation, and conduction coupling.
CO-3: Analyse various Measurement Techniques for Conducted Interference.
CO-4: Investigate EMI control techniques such as bonding mechanisms.
CO-5: Design EMC and components for EMI/EMC standards.

EC 5356: High Power THz Radiation Sources		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0 Hours**
1	**Introduction to Microwave Tubes:** Classification of Microwave Tubes: O-type and M-Type tubes, Cherenkov radiation, transition radiation, and bremsstrahlung radiation types, Slow-Wave and fast-wave tubes, Fast-Wave Gyro-Devices: Dispersion Relation, Cyclotron resonance maser (CRM) instability, Phase-Bunching, Classification of Gyro-Devices	**10**
2	**Gyrotrons:** Basic operating principles and Gyrotron Cavities**,** Calculation of RF Behaviour, Practical Considerations for Gyrotron Design, Electron Optical and Guiding System, Output Taper and Quasi-optical Launcher, RF Window, Examples, Applications.	**8**
3	**Gyro Klystrons:** Introduction, Basic Operating Principle, Construction, Design Methodology, Nonlinear Analysis, Types of Gyroklystron Amplifier: Clustered-Cavity, Frequency Multiplying, PBG cavity, Coaxial-cavity gyroklystron, Applications.	**8**
4	**GYRO-TWT:** Introduction, Basic Operating Principle, Construction, Design Methodology, Nonlinear Analysis, Types of Gyro-TWT Amplifier: Metal PBG Waveguide Type, Applications.	**8**
5	**Introduction to HPM (High Power Microwave) Devices:** Origin and Classification of HPM, Construction and Working Principle of: Reltron, Relativistic Magnetron, Relativistic Klystron, Relativistic BWO, MILO, Applications.	**8**

Text/Reference Books:

1. G. S. Nuscinovich, Introduction to the Physics of Gyrotrons, JHU Press, 2004.
2. James Benford, John A. Swegle, Edl Schamiloglu, High Power Microwaves, CRC Press, 2019.
3. M. V. Kartikeyan, E. Borie, M. K. A. Thumm, Gyrotrons High-Power Microwave and Millimeter Wave Technology, Springer, Berlin, 2004.

Course Outcomes: At the end of the course, the student will be able to

CO-1: Understand the concept of various microwave tubes and their classifications.
CO-2: Outline the operation, construction, design, and input and output systems of Gyrotron oscillators.
CO-3: Analyse the construction of the Gyrklystron amplifier and its design methodology with RF interaction circuits.
CO-4: Understand the Gyro-TWT amplifier’s construction, operation, and RF interaction circuit design methodology.
CO-5: Identify the construction and operation of various high-power microwave devices.

EC 5357: Electronic Infrastructure for Tera Scale Communication		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	**Overview of Tera Scale Communication Infrastructure:** Technological requirements, bandwidth, data rates, and latency considerations; role of RF, THz, and photonic components; scalability challenges in tera-scale communication	**08**
2	**Electronic Components and Materials for THz Communication:** THz emitters and detectors, amplifiers for THz frequencies; overview of semiconductor materials like GaAs, InP, and graphene; integration of THz components with existing infrastructure	**08**
3	**High-Speed Data Processing and Transmission:** Algorithms and techniques for high-speed processing, design challenges for high-frequency applications, electrical and optical interconnects for tera-scale data transmission	**09**
4	**Power Management in Tera Scale Communication:** Design considerations of power amplifiers for efficiency at THz frequencies, cooling techniques and materials for high-power THz systems, energy harvesting for powering THz communication devices	**09**
5	**Advanced Infrastructure:** THz Antenna Design, Monolithic Microwave Integrated Circuits (MMICs) and System-on-Chip (SoC) for THz Applications	**08**

Text/Reference Books:

1. Thomas Kürner, Daniel M. Mittleman, Tadao Nagatsuma, THz Communications: Paving the Way Towards Wireless Tbps, Springer, 2021.
2. Jae-Sung Rieh, Introduction to Terahertz Electronics, Springer, 2020.
3. Arindam Biswas, Aritra Acharyya, Palash Das, Generation, Detection and Processing of Terahertz Signals, Springer, 2021.
4. Uri Nissanov, Ghanshyam Singh, Antenna Technology for Terahertz Wireless Communication, Springer, 2021.

Course Outcomes: At the end of the course, the student will be able to
CO-1: Understand the technological requirements and challenges in tera-scale communication
CO-2: Apply high-speed data processing techniques suitable for tera-scale communication.
CO-3: Analyze the performance of high-speed data processing techniques for tera-scale communication.
CO-4: Acquire knowledge in design and implementation of electronic components and systems operating at THz frequencies.
CO-5: Explore future trends and innovations in the field of tera-scale communication infrastructure

EC 5358: Machine Learning for RF and THz		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	**Introduction to RF and THz Systems:** Basics of RF and THz frequencies and technologies, Key applications: communication, sensing, and imaging, Challenges in RF/THz system design and performance **Fundamentals of Machine Learning:** Overview of supervised, unsupervised, and reinforcement learning, Key algorithms: Decision Trees, SVM, Neural Networks, k-NN, Evaluation metrics, and model selection	**10**
2	**Machine Learning in RF System Design:** ML techniques for RF signal processing and modulation, Channel estimation and interference mitigation, Spectrum management, and cognitive radio **Machine Learning for THz Systems:** Application of ML in THz spectroscopy and imaging, THz signal analysis and feature extraction, Optimization of THz system performance using ML	**10**
3	**Advanced ML Techniques for RF/THz:** Deep learning models for RF/THz applications Reinforcement learning for dynamic spectrum access Transfer learning and domain adaptation in RF/THz systems	**8**
4	**Practical Implementations:** Software tools and frameworks for ML in RF/THz (e.g., Python, MATLAB, TensorFlow), Case studies and projects on ML applications in RF/THz systems, Data acquisition, preprocessing, and model deployment	**8**
5	**Challenges and Future Trends:** Security and privacy concerns in ML for RF/THz, Explainability and interpretability of ML models, Emerging trends: Quantum ML for RF/THz, 6G networks	**6**

Text/Reference Books:

1. "Machine Learning for Signal Processing" by Max A. Little
2. "Deep Learning for Wireless Communications" by Yonina C. Eldar and Andrea Goldsmith
3. "Terahertz Technology and Its Applications" by Peter H. Siegel
4. Research papers and articles on current advancements in ML for RF/THz systems

Course Outcomes: At the end of the course, the student will be able to
CO-1: Understand the fundamentals of machine learning and its applications in RF and THz systems.
CO-2: Apply machine learning to model and simulate RF/THz systems.
CO-3: Optimize RF/THz system performances using machine learning algorithms.
CO-4: Create practical skills in implementing machine learning models for real-world RF/THz applications.
CO-5: Recognize the challenges and future directions in the integration of machine learning with RF/THz technologies.

EC 5361: Optimization Techniques in Engineering		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	**Introduction to Optimization:** Definition and scope of optimization, Engineering applications of optimization, Classification of optimization problems: linear vs. nonlinear, constrained vs. unconstrained, single vs. multi-objective **Linear Programming (LP):** Formulation of LP problems, Simplex method and duality, Sensitivity analysis and applications in engineering	**10**
2	**Nonlinear Programming (NLP):** Unconstrained optimization techniques: gradient-based methods, Newton's method, Constrained optimization: Lagrange multipliers, Karush-Kuhn-Tucker (KKT) conditions, Numerical methods for solving NLP problems **Integer and Mixed-Integer Programming:** Formulation and applications of integer programming, Branch-and-bound method, Mixed-integer linear programming (MILP) and its applications	**8**
3	**Multi-Objective Optimization:** Concepts of Pareto optimality, Techniques for multi-objective optimization: weighted sum, ε-constraint, goal programming, Applications in engineering design and decision-making **Dynamic Programming (DP):** Principles of optimality and Bellman's equation, Applications of DP in resource allocation and control systems, Limitations and computational challenges	**8**
4	**Metaheuristic Optimization Techniques:** Introduction to evolutionary algorithms: genetic algorithms, differential evolution, Swarm intelligence: particle swarm optimization, ant colony optimization, Simulated annealing and tabu search **Optimization in Machine Learning:** Role of optimization in training machine learning models, Gradient descent and its variants, Hyperparameter optimization techniques	**8**
5	**Optimization Software and Tools:** Introduction to optimization software: MATLAB, LINGO, GAMS, and others, Implementing optimization algorithms using Python, Case studies and hands-on projects **Advanced Topics and Emerging Trends:** Robust optimization and uncertainty quantification, Large-scale optimization techniques, Applications of optimization in emerging fields like renewable energy, smart grids, and supply chain management	**8**

Text/Reference Books:

1. S.S. Rao, "Engineering optimization: Theory and Practice", New age international.
2. "Practical Optimization: Algorithms and Engineering Applications" by A. Antoniou and Wu-Sheng Lu
3. "Linear and Nonlinear Programming" by David G. Luenberger and Yinyu Ye
4. "Multi-Objective Optimization Using Evolutionary Algorithms" by Kalyanmoy Deb
5. K. Deb, "Optimization for Engineering Design: Algorithms and Examples", PHI.

Course Outcomes: At the end of the course, the student will be able to
CO-1: understand fundamental concepts of optimization and its role in engineering problem-solving.
CO-2: understand various optimization methods for different engineering applications.
CO-3: Apply optimization techniques to real-world engineering problems.
CO-4: Explore modern optimization methods, including GA, PSO and other metaheuristic techniques.
CO-5: Develop optimization algorithms using software tools and programming languages.

EC 5362: Soft Computing Techniques in Engineering Applications		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0**
		Hours
1	**Introduction to Soft Computing:** Definition and characteristics of soft computing, Comparison with hard computing, Importance and applications of soft computing in engineering	**6**
2	**Fuzzy Logic Systems:** Basics of fuzzy sets and operations, Fuzzy relations and membership functions, Fuzzy inference systems: Mamdani and Sugeno models, Fuzzy logic controllers and their applications in engineering **Artificial Neural Networks (ANN):** Biological inspiration and basic concepts of neural networks, Perceptron, multilayer perceptron, and backpropagation algorithm, Training and learning in neural networks, Applications of ANN in pattern recognition, control, and signal processing **Genetic Algorithms (GA):** Fundamentals of genetic algorithms: selection, crossover, and mutation, Fitness function and population dynamics, Applications of genetic algorithms in optimization and search problems, Case studies on GA in engineering design and decision-making	**9**
3	**Hybrid Systems:** Integration of neural networks and fuzzy logic (Neuro-Fuzzy Systems), Genetic-fuzzy systems and their applications, Hybrid neuro-genetic systems for optimization problems, Real-world applications of hybrid soft computing techniques **Swarm Intelligence and Evolutionary Computing:** Introduction to swarm intelligence: particle swarm optimization, ant colony optimization, Evolutionary strategies and differential evolution, Applications of swarm intelligence in robotics, network design, and optimization, Case studies on swarm intelligence in engineering	**9**
4	**Optimization using Soft Computing Techniques:** Application of soft computing techniques in multi-objective optimization, Comparison of soft computing methods with traditional optimization techniques, Case studies on optimization of engineering systems using soft computing **Soft Computing in Control Systems:** Fuzzy logic controllers and their design, Neural network-based control systems, Genetic algorithm-based optimization of control parameters, Case studies on the application of soft computing in control engineering	**9**
5	**Applications in Signal Processing and Robotics:** Application of neural networks and fuzzy logic in signal processing, soft computing techniques in image processing and pattern recognition, Robotic system design using soft computing methods, Case studies on soft computing in autonomous systems **Advanced Topics and Emerging Trends:** Deep learning and its relation to soft computing, Recent advancements in hybrid soft computing systems, Future trends in soft computing and its potential applications in emerging technologies	**9**

Text/Reference Books:

1. Timothy J. Ross, “Fuzzy Logic with Engineering Applications”, Wiley.
2. Simon Haykin, “Neural Networks and Learning Machines”, Pearson.
3. Melanic Mitchell, “Optimization Problems An Introduction to Genetic Algorithm”, MIT Press
4. by Fakhreddine O. Karray and Clarence De Silva, “Soft Computing and Intelligent Systems Design: Theory, Tools, and Applications”
5. "Introduction to Evolutionary Computing" by A.E. Eiben and J.E. Smith

Course Outcomes: At the end of the course, the student will be able to
CO-1: Understand the concepts of soft computing and its role in solving real-world engineering problems.
CO-2: Apply various soft computing techniques, including fuzzy logic, ANN and GA.
CO-3: Analyse various soft computing techniques to optimize and model engineering systems.
CO-4: Optimize the hybrid soft computing techniques for complex problem-solving.
CO-5: Develop soft computing algorithms for different applications.

EC 5363: Course Name: Optical Communication System		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	**Introduction to Optical Communication:** Characteristics of optical transmission media, optical fibers- preparation and transmission characteristics, loss and dispersion mechanisms	**6**
2	**Optical Sources:** principles of operation, modulation characteristics and driver circuits, LED, laser diodes, light source linearity, modal, and partition and reflection noise Power Launching and Coupling: Source to fiber power launching, lensing schemes for coupling improvement, fiber to fiber joints, couplers, multiplexers and splices Photo detectors: principles of operation, circuits and performance, preamplifiers and post-detection amplifiers	**8**
3	**Optical Fiber Systems:** intensity modulation/direct detection system, link budget using direct detection, coherent system, wavelength converters, coherent and WDM systems, Photonic switching.RWA: Different Wavelength Assignment (WA) Techniques. Different Quality Estimation Technique.	**10**
4	**Optical Detectors:** Device types, optical detection principles, Absorption, III-V alloys, Quantum efficiency, Responsivity, Long wavelength cut-off, Semiconductor photodiodes without internal gain: p-n photodiode, p-i-n photodiode speed of response and travelling wave photodiode, Noise	**8**
5	**Receiver Performance:** Direct detection receiver performance considerations: Noise: Thermal noise, dark current noise, quantum noise, digital signaling quantum noise, analog signaling transmission quantum noise. Receiver noise: p-n and p-i-n photodiode receiver, APD, Gain bandwidth product	**10**

Text/Reference Books:

1. Keiser, Optical Fiber Communications, McGraw Hill, 2008
2. John M. Senior, Optical Fiber Communications: Principles and Practice, PHI, 2008
3. Jones, William B. Jones, Introduction to Optical Fiber Communications Systems, Oxford University Press, 1995
4. A. J. Rogers, Understanding Optical Fiber Communications, Artech House, 2001

Course Outcomes: At the end of the course, the student will be able to

CO1: Understand the fundamentals of Optical communication and systems
CO2: Identify various optical sources and their mechanism of operation.
CO3: Analyze Optical fiber system in view of different modulation and detection techniques.
CO4: Classify various optical sources-LASER, LEDs and their characteristics.
CO5: To evaluate different noise parameters in direct detection receiver performance.

EC 5364: Microwave Imaging Systems		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	**Electromagnetic Scattering:** Maxwell's equation, interface conditions, constitutive equations, Wave Equations and Their Solutions, Volume Scattering by Dielectric Targets, Volume Equivalence Principle, Integral Equations, Surface Scattering by Perfectly Electric Conducting Targets.	**8**
2	**Electromagnetic Inverse Scattering Problem:** Two-Dimensional Inverse Scattering, Discretization of the Continuous Model, Scattering by Canonical Objects: The Case of Multilayer Elliptic Cylinders	**6**
3	**Imaging Configurations and Model Approximations:** Objectives of the Reconstruction, Multi illumination Approaches, Tomographic Configurations, Scanning Configurations, Configurations for Buried-Object Detection, Born-Type Approximations, Extended Born Approximation, Rytov Approximation, Kirchhoff Approximation.	**8**
4	**Qualitative Reconstruction Methods:** Generalized Solution of Linear IllPosed Problems, Regularization Methods, Singular Value Decomposition, Regularized Solution of a Linear System Using Singular Value Decomposition, Qualitative Methods for Object Localization and Shaping, Synthetic Focusing Techniques, Qualitative Methods for Imaging Based on Approximations.	**8**
5	**Imaging Techniques:** Back projection, w-k, beamforming, synthetic aperture imaging, Kirchoff"s method	**6**
6	**Microwave Imaging Apparatuses, Systems and Applications:** Scanning Systems for Microwave Tomography, Antennas for Microwave Imaging, Civil and Industrial Applications, Medical Applications of Microwave Imaging, Shallow Subsurface Imaging.	**6**

Text/Reference Books:

1. Matteo Pastorino, “Microwave Imaging”, Wiley & Sons, 2010.
2. V. C. Chen and H. Ling, “Time-Frequency Transforms for Radar Imaging and Signal Analysis”, Artech House, 2002.
3. Bernard D. Steinberg, “Microwave Imaging Techniques”, Wiley & Sons, 1991.
4. Taylor, D.J., “Introduction to Ultra-wideband Radar Systems”, CRC Press, 1995.

Course Outcomes: At the end of the course, the student will be able to
CO-1: Understand the concept of electromagnetic scattering and wave equation in materials.
CO-2: Apply the concept of two dimensional inverse scattering for various applications.
CO-3: Analyze the knowledge of different imaging configurations and approximations.
CO-4: Identify and solve the image reconstruction problems.
CO-5: Create various imaging techniques and their systems.

EC 5365: Guided Wave Optical Components and Devices		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	Integrated optics, electromagnetic analysis of symmetric dielectric planar waveguide, TE and TM modes, power associated with the modes, asymmetric planar waveguides and their modal analysis, single-polarization single-mode waveguides, 2-D waveguides and their analysis, effective index method, perturbation method.	**10**
2	Guided wave devices, directional couplers, modulators, Mach-Zhender inteferrometer, waveguide gratings, arrayed waveguide gratings. Weakly guiding optical fiber, LP modes of a step-index optical fiber, single mode optical fiber and its characteristics, attenuation, pulse dispersion, dispersion shifted fiber, dispersion compensating fiber, fiber fabrication.	**10**
3	Fused fiber coupler, beam splitter/combiner, WDM coupler, wavelength interleaver, side-polished optical fiber and its applications, polarization controller, isolator, circulator.	**8**
4	Optical fiber amplifiers, erbium-doped fiber amplifiers (EDFAs), mechanism of optical amplification in EDFA, noise figure, Raman amplifiers, gain spectrum.	**8**
5	Fiber gratings, fiber Bragg gratings, coupled mode analysis, reflection spectrum, add/drop multiplexer, dispersion compensation, strain and temperature sensing, fabrication techniques, long-period gratings, WDM filter, gain flattening of EDFA, mode converters.	**6**

Text/Reference Books:

1. Pal B. P., “Guided Wave Optical Components and Devices,2006
2. Ghatak A. and Thyagarajan K., “Introduction to Fiber Optics,” Cambridge University Press,1998
3. Agrawal G. P., “Optical Fiber Communication System,” Wiley Interscience,2003
4. Keiser, G., “Optical Fiber Communication,” McGraw Hill Education,2014
5. Shenoy, M. R., Khijwania, S. K., Ghatak, A. K., and Pal, B. P., “Fiber optics through experiments,” Viva Books,2014

Course Outcomes: At the end of the course, the student will be able to
CO1: Understand the behavior of waveguides for optical communication.
CO2: Identify various guided wave devices.
CO3: Analyze the characteristics of guided optical fiber.
CO4: evaluate various coupling mechanisms in optical fiber.
CO5: Design different optical amplifiers fiber gratings.

EC 5366: Large Scale Sensing Arrays for Imaging		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	**Introduction:** Imaging concepts, techniques, applications, Types of imaging.	**4**
2	**Large-scale Nanophotonic Phased Array:** Basic array characteristics, Linear array pattern synthesis, array elements and feeds, mutual coupling, Reflect-arrays.	**10**
3	**Adaptive Arrays:** Adaptive array concept, considerations, performance, limitations. Optimal array processing.	**10**
4	**Adaptive algorithms:** Gradient based algorithms, The Howells-Applebaum Adaptive Processor, Direct Inversion of the Sample Covariance Matrix, Recursive methods for Adaptive Array Processing	**10**
5	**Smart CMOS Image Sensors:** Fundamentals, Smart structures & materials, smart imaging.	**8**

Text/Reference Books:

1. Matteo Pastorino, “Microwave Imaging”, Wiley & Sons, 2010.
2. R.C. Hansen, “Phased Array Antennas”, Wiley & Sons, 2009.
3. R.A Monzingo, R.L. Haupt, T.W. Miller, “Introduction to Adaptive Arrays”, Scitech Publishing Inc., 2011.
4. Jun Ohta, “Smart CMOS Image Sensors and Applications”, CRC Press, 2020

Course Outcomes: At the end of the course, the student will be able to
CO-1: Understand the concept of imaging.
CO-2: Acquire the knowledge of nanophotonic phased arrays.
CO-3: Acquire the knowledge of nanophotonic adaptive arrays.
CO-4: Analyze the array using different adaptive algorithms.
CO-5: Acquire the knowledge of smart CMOS image sensors.

Department of Electronics and Communication Engineering

National Institute of Technology Silchar, Silchar, Assam, India

M. Tech. in RF and Terahertz Communications
Second Semester

EC 5367: Light Wave Technology		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	**Introduction to Light Wave Technology:** History and Evolution of Optical Communication, Advantages of Optical Communication over Conventional Systems, Basic Components of LightWave Communication Systems, Optical Fiber: Types, Step index fiber, Graded index fiber, Fiber materials, Mode theory for circular waveguides, wave equations in step-index fibers, Modes in step-index fiber and Graded index fiber	**8**
2	**Optical Wave Propagation and Attenuation:** Electromagnetic Theory of Light, Wave Equation and Solutions in Free Space, Polarization, Dispersion, and Scattering in Optical Fibers, Modes in Optical Fibers: Single-Mode and Multi-Mode Fibers. Attenuation mechanisms: Absorption, Scattering losses, Bending losses, Core cladding losses, Signal distortion in single-mode fibers, Polarization mode dispersion, Intermodal dispersion, Design optimization of single mode fibers	**10**
3	**Optical Sources, Modulators, and Amplifiers:** Light Emitting Diodes (LEDs) and Laser Diodes, Principles of Laser Action and Characteristics of Lasers, Modulation Techniques: Direct and External Modulation, Electro-Optic and Acousto-Optic Modulators, Transmission Link Analysis, Point to point links, Link Power budget. Semiconductor Optical Amplifiers (SOAs), Erbium-Doped Fiber Amplifiers (EDFAs), Raman Amplifiers and Parametric Amplifiers, Optical Switches, Couplers, and Multiplexers	**8**
4	**Optical Detectors and Receivers:** Photodetectors: PIN Diodes and Avalanche Photodiodes, Noise in Optical Receivers, Receiver Design and Sensitivity Analysis, Bit Error Rate (BER) and System Performance. Optical Fiber Technology: Types of Optical Fibers: Step-Index, Graded-Index, and Photonic Crystal Fibers, Fiber Fabrication Techniques, Fiber Losses: Absorption, Scattering, and Bending Losses, Dispersion Management in Optical Fibers	**8**
5	**Advanced LightWave Communication, Photonic Network, and Applications:** Dense Wavelength Division Multiplexing (DWDM), Coherent Optical Communication Systems, Optical Time-Domain Reflectometry (OTDR), Nonlinear Effects in Optical Fibers and Their Mitigation, Optical Networking Principles and Architectures, Passive Optical Networks (PONs), Optical Network Topologies: Ring, Mesh, and Star, Applications of Light Wave Technology in Telecommunication and Sensing	**8**

Text/Reference Books:

1. Optical Fiber Communications by Gerd Keiser
2. Fiber-Optic Communication Systems by Govind P. Agrawal
3. Introduction to Optical Communication, Lightwave Technology, Fiber Transmission, and Optical Networks by Subir Kumar Sarkar
4. Photonics: Optical Electronics in Modern Communications by Amnon Yariv and Pochi Yeh
5. Lightwave Technology: Components and Devices by Govind P. Agrawal and N.K. Dutta

Course Outcomes: At the end of the course, the student will be able to

CO1: Understand the properties of Optical fiber and photonic devices

CO2: Analyze wave propagation and losses in optical fiber

CO3: Study various optical sources and modulators:

CO4: Identify Optical detectors, receivers, and amplifiers.

CO5: Develop advanced light wave technology for long-range optical communication

EC 5368: THz Radar Technology		
Unit No.	**Detailed Syllabus**	**L:3 T:0 P:0** **Hours**
1	Introduction to Terahertz (THz) Band, review of properties of THz waves, THz applications	**8**
2	Vacuum device sources: Klystrons, Travelling-Wave Tubes (TWTs), Backward Wave Oscillators (BWOs), Gyrotrons, Free Electron Lasers (FELs), Magnetrons.	**10**
3	Thermal detectors, diode detectors, transistor circuit detectors, array detectors.	**8**
4	Overview of THz imaging, active imaging, passive imaging, real-time imaging, Tomographic imaging, near field imaging, Terahertz time-domain spectroscopy (THz TDS).	**8**
5	Overview of THz Radars, Pulse Radars, CW Radars.	**8**

Text/Reference Books:

1. Jae-Sung Rieh, Introduction to Terahertz Electronics, Springer.

Ho-Jin Song & Tadao Nagatsuma, Handbook of Terahertz Technologies: Devices and Applications, CRC Press, PAN Stanford Publishing.

Course Outcomes: At the end of the course, the student will be able to

CO-1: Understand, and plan technologies of THz.
CO-2: Understand the use of THz sources.
CO-3: Understand the use of THz detectors.
CO-4: Realize and apply imaging techniques using THz signals.
CO-5: Understand the THz Radar technologies.

Programme Outcomes (POs)

PO1: Acquire in-depth knowledge of RF and Terahertz with an ability to analyze, synthesize, evaluate present and new technologies.

PO2: Learn and apply modern engineering tools to solve complex engineering problems.

PO3: Engage in life-long learning independently, to contribute for multidisciplinary research work.

PO4: Independently carry out research/investigation and development work to solve practical problems.

PO5: Write and present a substantial technical report/document.

PO6: Demonstrate a degree of mastery over the area Radio Frequency and Terahertz Communication. The mastery would be at a higher than the requirements in the appropriate bachelor program.

Programme Educational Objectives (PEOs)

PEO1: Deliver comprehensive education in Communication & Signal processing Engineering to ensure that the graduates have the core competency to be successful in versatile jobs in the relevant industries and pursue higher studies.

PEO2: Provide the theoretical and experimental fundamental in the Communication & Signal processing Engineering required to formulate, analyze and solve the real-world problems and pursue the research in the Communication and Signal Processing Engineering.

PEO3: Train students to work as teams to comprehend, analyze, design and create innovative solutions to real life problems.

PEO4: Inculcate a sense of ethics, professionalism and effective communication skills amongst graduates.

PEO5: Provide an academic environment that gives adequate opportunity to the students to cultivate lifelong skills needed for a successful professional career.