Detailed Syllabus
(Core Subjects)

EC-701: 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-702: 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-703: 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-711: 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-712: 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-713: 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-714: 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-715: 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-716: 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-717: 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-718: 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-721: 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-222: 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-223: 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-224: 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-225: 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-226: 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-227: 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-228: 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.