Indian Institute of Technology Patna
Electrical & Electronics Engineering Department

M. Tech – Electrical and Electronics Engineering (Signal Processing & Communication Systems)

Course Curriculum

Semester I

S.No		Course Number	Course Title	L	T	P	C
1	Core	EE520	Advanced Digital Signal Processing	3	0	0	3
2		EE560	Information Theory and Coding	3	0	0	3
3	Elective	EE5xx	Elective-I	3	0	0	3
4		EE5xx	Elective-II	3	0	0	3
5		EE5xx	Elective III	3	0	0	3
6		EE5xx	Signal Processing System Lab	0	0	3	1.5
7		HSS 513	Technical Communications	3	0	0	3
Total				15	0	7	**19.5**

Semester II

Sl. No.		Course Number	Course Title	L	T	P	C
1	Core	EE530	Advanced Digital Communication	3	0	0	3
2		EE534	Wireless Communication	3	0	0	3
3	Elective	EE5xx	Elective-IV	3	0	0	3
4		EE5xx	Elective-V	3	0	0	3
5		EE5xx	Elective-VI	3	0	0	3
6		EE5xx	Seminar	0	0	0	2
7		EE5xx	Communication System Lab	0	0	3	1.5
8		EE5xx	Mini Project				2
Total				12	0	9	**20.5**

Semester III

Sl. No.	Course Number	Course Title	L	T	P	C
1	EE595	Project Part-I				20
2	EE5xx	Grand Viva				4
Total						**24**

Semester IV

Sl. No.	Course Number	Course Title	L	T	P	C
1	EE596	Project Part-II				24
Total						**24**

Total Credits = 19.5+20.5+24+24=88

Elective Courses:

1. Semester-I

1. EE523-Advanced Bio-Medical Signal Processing
2. EE525-Digital Image Processing
3. EE527- Pattern Recognition and Applications
4. EE532- Optical Communication
5. EE535-Communication Network
6. EE538-Satellite Communication
7. EE543-Internet of Things
8. EE561- Antenna Theory and Design
9. EE563-VLSI Architectural Design and Implementation
10. EE 587- A First Course in Optimization
11. CS564-Foundations of Machine Learning
12. MA525- Operations Research

+Relevant electives from other/EE departments pertaining to signal processing, communication, machine and deep learning.

2. Semester-II

1. EE526-Digital Video Processing
2. EE528-Deep learning for video surveillance
3. EE537-Optical Networks
4. EE562-Embedded Computing Systems and Interfacing
5. EE539-Multimedia Communication
6. EE555-Random Signals & Stochastic Processes
7. EE565-Telecommunication Management
8. EE5xx-Emerging Wireless Technologies
9. EE5xx-Pattern Recognition and Machine Learning (Newly added elective)
10. MA502-Numerical Optimization
11. EExxx-Silicon Phontonics (Newly added elective)

+ Relevant electives from other/EE departments pertaining to signal processing, communication, machine and deep learning.

Laboratory

1. Semester-I: EE5xx-Signal Processing System Lab: Signal processing systems include experiments related to image and video processing, biomedical/speech/audio signal processing and processing of other miscellaneous signals

2. Semester-II: EE5xx-Design & Simulation of Communication System Lab: Experiments related to digital communication, wireless communication, networking, optical communication

Program Learning Outcomes (PLO):

The graduates of this program will have

- a successful career in an Academia/Industry/Entrepreneur
- strong fundamental knowledge in communications and signal processing related subjects.
- good understanding of latest technologies in communication and signal processing.
- ability to design prototypes for real world problems related to electronics, communications and interdisciplinary fields.

- ability to develop diverse skills such as time managements, problem-solving, leadership, capability to work in both team as well as individual in a professional manner.

Semester - I

EE520 Advanced Digital Signal Processing 3 0 0 3

Multi-rate Digital Signal Processing: Brief review of digital signal processing, discrete cosine transforms (DCT), Multi-rate digital signal processing, Sampling rate conversion of bandpass signals, Filter design and implementation for sampling rate conversion, Multistage implementation of sampling rate conversion, Applications of multi-rate signal processing. Time-Frequency Methods: STFT, Wigner-Ville transformation, Introduction to wavelets, The Haar wavelet, The Haar multi-resolution analysis, The Haar filter bank, Haar bank filter bank analysis and synthesis, Z-domain analysis of multi-rate filter bank, Two channel filter bank, Perfect reconstruction, Brief introduction to Daubechies wavelets, The uncertainty principle, Spectral Estimation and Linear Prediction: Non-parametric spectrum estimation, Periodogram, Bartlett, Welch and Blackman, Tukey methods, Parametric methods for rational spectra (ARMA, MA, AR processes) and line spectra, Autocorrelation and model parameters; Linear prediction, Forward and backward linear prediction, Solution of the normal equations, Properties of linear prediction-error Filter, AR lattice and ARMA Lattice-Ladder filters, AR (Auto-Regressive) process and linear prediction, Yule-Walker, Burg and Least squares methods, Sequential estimation, Moving average (MA) and ARMA models. Subspace algorithms - MUSIC, ESPRIT, Root-MUSIC, Minimum variance method, Piscaranko's harmonic decomposition methods.

References:

1. Proakis JG and Manolakis DG Digital Signal Processing Principles, Algorithms and Application, PHI.
2. Openheim AV & Schafer RW, Discrete Time Signal Processing PHI.
3. PetreStoica and Randolph Moses, Spectral analysis of signals, Prentice Hall, 2005.
4. P Sircar, Mathematical Aspects of Signal Processing, Cambridge.

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to recognize some of the most important advanced signal processing techniques, including multirate processing and its applications.
2. to use time-frequency analysis techniques for audio signals and its applications.
3. to explain the relationship between time and frequency domain interpretations and implementations of signal processing algorithms.
4. to describe fundamental statistical signal processing concepts of signal detection and parameter estimation.

EE560 Information Theory and Coding 3 0 0 3

The concept of Amount of Information, Average Information, Entropy, Information rate, Source Coding: Fixed and Variable Length Codes, Kraft Inequality, Shannon-Fano Algorithm, Huffman Algorithm.
Shannon's Theorem, Channel Capacity, Capacity of a Gaussian Channel, Bandwidth-S/N Trade-off. Channel Coding, Channel Models, Channel Capacity Theorem, Shannon Limit.
Error Control Coding: Introduction, Forward & Backward error Correction, Hamming Weight and Hamming Distance, Linear Block Codes, Encoding and decoding of Linear Block-codes, Parity Check Matrix, Syndrome Decoding, Hamming Codes.
Convolutional and Turbo Codes: Introduction, Polynomial description of Convolutional Codes, Generating function, Matrix description of Convolutional Codes, Viterbi Decoding of Convolutional codes,
Turbo Codes, Turbo Encoder and Decoder, LDPC, Encoder and Decoder of LDPC

Texts/References:

1. R. Bose, Information Theory and applications, 2nd Edition, TMH, (2008)
2. J. G. Proakis, Digital Communications, McGraw-Hill, (1995)
3. D. Tse, P. Viswanath, Fundamentals of Wireless Communications, Cambridge Press, (2005)

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to know about the fundamental concepts of information theory
2. to understand coding, quantification, storage, and communication of information
3. to analyse source coding and channel coding
4. to get familiar with the basics of the error control coding

EE523 Advanced Bio-Medical Signal Processing 3 0 0 3

1: Introduction of Biomedical Signals: Nervous system, Neuron anatomy, Basic Electrophysiology, Biomedical signal's origin and dynamic characteristics, biomedical signal acquisition and processing, Different transforms techniques; 2: The Electrical Activity of Heart: Heart Rhythms, Components of ECG signal, Heart beat Morphologies, Noise and Artifacts, Muscle Noise Filtering, QRS Detection Algorithm, ECG compression techniques, Parameter Extraction: Heart rate variability, acquisition and RR Interval conditioning, Spectral analysis of heart rate variability; 3: The Electrical Activity of Brain:Electroencephalogram, Types of artifacts and characteristics, Filtration techniques using FIR and IIR filters, Independent component analysis, Nonparametric and Model-based spectral analysis, Joint Time-Frequency Analysis, Event Related Potential, Noise reduction by Ensemble Averaging and Linear Filtering, Single-Trail Analysis and adaptive analysis using basis functions; 4: The Electrical Activity of Neuromuscular System: Human muscular system, Electrical signals of motor unit and gross muscle, Electromyogram signal recording, analysis, EMG applications; 5: Frequency-Time Analysis of Bioelectric Signal and Wavelet Transform: Frequency domain representations for biomedical Signals, Higher-order spectral analysis, correlation analysis, wavelet analysis: continuous wavelet transform, discrete wavelet transform, reconstruction, recursive multi resolution decomposition, causality analysis, nonlinear dynamics and chaos: fractal dimension, correlation dimension, Lyapunov exponent.5: Biomedical Signal Processing and Applications: Support Vector Machine, Hidden Markov Model, Neural Networks, Deep learning techniques, Application of Event Related Potential in understanding human psychology, Cognitive neuroscience and higher order brain function, Application of EEG and ECG signal processing.

Text Books

1. *Rangaraj M. Rangayyan, "Biomedical Signal Analysis: A Case-Study Approach", John Wiley & Sons, 2002*
2. *Eugene N. Bruce, "Biomedical Signal Processing and Signal Modeling",* John Wiley & Sons, 2006.
3. *Leif Sornmo and Pablo Laguna, "Bioelectrical Signal Processing in Cardiac and Neurological Applications", Academic Press, 2005*

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to understand the basic concepts and tools for modeling and analyzing biomedical signals, nonstationary and multivariate physiological time series.
2. to understand advanced statistical tools and numerical methods to describe the temporal dynamics of biomedical signals.
3. to know how to evaluate data-driven predictive models, and how to use these models to simulate physiological time series.

EE525 Digital Image Processing 3 0 0 3

Introduction to Digital Image Processing & Applications, Sampling, Quantization, Basic Relationship between Pixels, ImagingGeometry, Image Transforms, Image Enhancement, Image Restoration, Image Segmentation, Morphological Image Processing,Shape Representation and Description, Object Recognition and Image Understanding, Texture Image Analysis, Motion Picture Analysis, Image Data Compression.

Texts/References

1. Rafael C. Gonzalez and Richard E. Woods, Digital Image Processing, Pearson
2. Milan Sonka, Vaclav Hlavac and Roger Boyle, Image Processing, Analysis and Machine Vision, Springer
3. Anil K. Jain, Fundamentals of Digital Image Processing, Prentice Hall

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to understand the fundamental concepts of digital image processing, including filtering, transforms, morphology, colour and image analysis.
2. to implement basic image processing algorithms in C or Matlab or Python.
3. to get familiar with the necessary pre-requisites to further explore advanced topics in Digital Image Processing.

EE527 Pattern Recognition and Applications 3 0 0 3

Introduction: Feature extraction and Pattern Representation, Concept of Supervised and Unsupervised Classification, Introduction to Application Areas. Statistical Pattern Recognition: Bayes Decision Theory, Minimum Error and Minimum Risk Classifiers, Discriminant Function and Decision Boundary, Normal Density, Discriminant Function for Discrete Features, Parameter Estimation. Dimensionality Problem: Dimensionality Reduction, Fisher Linear Discriminant and Multiple Discriminant Analysis. Nonparametric Pattern Classification: Density Estimation, Nearest Neighbour Rule, Fuzzy Classification. Linear Discriminant Functions: Separability, Two Category and Multi Category Classification, Linear Discriminators, Perceptron Criterion, Relaxation Procedure, Minimum Square Error Criterion, Widrow-Hoff Procedure, Ho-Kashyap Procedure, Kesler's Construction. Neural Network Classifier: Single and Multilayer Perceptron, Back Propagation, Learning Hopfield, Network Fuzzy and Neural Network. Time Varying Pattern Recognition: First Order Hidden Markov, Model Evaluation, Decoding Learning. Unsupervised Classification: Clustering, Hierarchical Clustering, Graph Based Method, Sum of Squared Error Technique, Iterative Optimization.

Texts/References:

1. Richard O. Duda, Peter E. Hart and David G. Stork, Pattern Classification, John Wiley & Sons, 2001.
2. Earl Gose, Richard Johsonbaugh and Steve Jost, Pattern Recognition and Image Analysis, Prentice Hall, 1999.

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to know various tools and techniques of pattern recognition.
2. to develop skills to characterize and implement big data analytics.
3. to understand the application of pattern recognition in different real-life problems.

EE532 Optical Communication 3 0 0 3

Optical Fiber Characteristics: Loss, Group velocity dispersion (GVD) (2nd order GVD and 3rd order GVD), Polarization modedispersion. Fiber Nonlinearity: Self phase modulation (SPM). Pulse Propagation through Optical Fiber: Nonlinear Schröding erequation, split step Fourier method. Optical Sources and Detectors: LED, LD, DFB-laser, PIN photodetector, APD. MultiplexingTechniques: WDM, OFDM, Optical CDMA. Optical System Performance Metrics: Eye opening penalty, Q, BER, OSNR. Link Analysis:Single channel point to point, WDM point-to-point. Nonlinearity in WDM and High Bit Rate Systems: XPM, FWM, IFWM, IXPM. Optical Amplifier: Erbium doped fiber amplifier, Semiconductor optical amplifier (SOA), Stimulated Raman scattering, Stimulated4Brillouin scattering, Distributed Raman amplifier (DRA). Optically Amplified Systems. Active and Passive Optical Components and Sub-Systems: Coupler, MUX/DEMUX, OADM, ROADM, Filter, FBG, CFBG, MZI, EAM, AWG, DGE, GVD and PMD equalizer,Wavelength converter, Power equalizer, 2R and 3R all-optical regenerator, Optical switches, Nonlinear optical loop mirror (NOLM).
Dispersion and Nonlinearity Management: Dispersion map, Advanced modulation formats, Optical equalization, Electronicequalization, Error correction codes, Optical phase conjugation, Coherent detection. Optical Network Design Strategies based onPhysical Parameters. Passive Optical Network (PON): Structure, Components. Introduction on Silicon on Insulator: Passive and Active devices.

Texts/References:

1. Rajiv Ramaswami, Kumar N. Sivarajan, Galen Hajime Sasaki, Optical Networks: A Practical Perspective, Elsevier direct, 2009.
2. Govind P. Agrawal, Nonlinear fiber optics, 4th Edition, Academic Press.
3. Govind P. Agrawal, Fiber-optic communication systems, 3rd Edition, Wiley India Pvt Ltd, 2007.
4. MiloradCvijetic, Optical transmission systems engineering, Artech House Publishers, 2004.
5. AshwinGumaste, Tony Antony, DWDM network designs and engineering solutions, Cisco Press, 2002.

6. Pallab Bhattacharya, Semiconductor optoelectronic devices, 2nd Edition, Phi Le

Course Learning Outcome (CLO):
After learning this course, the students will be able

1. to know the basic elements of optical fiber transmission link.
2. to know about the design and operating principle of modern optical communication systems.
3. to get familiar with various components used in optical communication systems.
4. to understand the different kind of losses, distortions, and other degradation factors caused during signal transmission.

EE535 Communication Networks 3 0 0 3

Introduction; Protocol hierarchies: OSI and TCP/IP reference models; Physical layer: Transmission media and topology, circuitswitching and packet switching, Telephone network; Data link layer: Framing, error control, simplex stop and wait, sliding windowprotocol, SONET/SDH, ISDN switches, Medium access protocols: Aloha, slotted aloha, CSMA, CSMA CD, and collision – free protocols, FDDI, token ring, wireless LAN protocol, IEEE standard 802 for LANs and MANs, Bridges, Network layer: Routingalgorithms, IP protocol, ICMP, ARP, RARP, Mobile IP; Transport layer: Establishing and releasing connection, TCP and UDP, Socketsinterface, sockets programming; Application Layer: SNMP, Authentication, Encryption, electronic mail, WWW; Admission controlin Internet, Concept of Effective bandwidth, Measurement based admission control, Differentiated Services in Internet; MPLS5switching, MPLS architecture and framework. MPLS Protocols. Traffic engineering issues in MPLS, Lamda Switching, DWDM Networks.

Texts:
1. W. Stallings, Data and Computer Communications, 7th Ed, Prentice Hall, 2004.
2. Alberto Leon Garcia, I. Widjaja, Communication Networks, 2nd Ed., Tata McGraw Hill, 2010

Course Learning Outcome (CLO):
After learning this course, the students will be able

1. to understand the fundamentals of data communication, layered model, protocols and interworking between computer networks.
2. to understand the functions performed by a network management system to establish Internet connection.
3. to understand the concept of flow control, error control and networking protocols.
4. to analyze the performance of various communication protocols.

EE538 Satellite Communication 3 0 0 3

Introduction to Satellite Communications: Origin, History, Current Technology State and Overview of Satellite System Engineering. Orbital Aspects of Earth Satellites: Orbital Mechanics and Orbital Elements, Azimuth and Elevation, Coverage Angle and Slant Range, Placement of a Satellite in a Geostationary Orbit. Satellite Link Design: Basic Radio Transmission Theory, System Noise Temperature and G/T Ratio, Uplink and Downlink Design, Interference Analysis, Carrier-to-Noise plus Interference Ratio, Interference to and from Adjacent Satellite Systems, Terrestrial Interference, Cross-polarization Interference, Intermodulation Interference, Design of Satellite Links for Specified Carrier-to-Noise plus Interference Ratio, Digital Satellite Link. Propagation on Satellite-Earth Paths and Its Influence on Link Design: Absorbitive Attenuation Noise by Atmospheric Gases, Rain Attenuation, Noise due to Rain, Rain Depolarization, Tropospheric Multipath and Scintillation Effects. Multiple Access Techniques in Satellite Communications: Frequency Division Multiple Access, FDMA, SCPC, MCPC. Time Division Multiple Access, TDMA: random (ALOHA, S-ALOHA) and time synchronized access. Code Division Multiple Access, CDMA, Fixed and On-demand Assignment. Satellite Networking: Advantages and Disadvantages of Multibeam Satellites, Interconnection by Transponder Hopping, Interconnection by On-board Switching, Interconnection by Beam Scanning, On-Board Processing, Intersatellite Links. Types of Satellite Networks: Fixed Point Satellite Network, INTELSAT, Mobile Satellite Network, INMARSAT, Low Earth Orbit and Medium Earth Orbit Satellite Systems, Very Small Aperture Terminal (VSAT) Network, Direct Broadcast Satellite Systems, Global Positioning System.

Texts:

1. Digital Satellite Communications, 2/e, McGraw-Hill, 1990.Tri T. Ha
2. Satellite Communications, John Willey and Sons, 2000T. Pratt, C.W. Bostian
3. Satellite Communications Systems Engineering, Pearson Education, 2/e; 2003 W.L. Prichard, H.G. Suyderhoud and R.A. Nelson

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to get familiar with the satellite communication architecture.
2. to know about different frequency allocations for satellite services and their transmission characteristics.
3. to understand the various aspects related to satellite systems such as orbital equations, sub-systems in a satellite, link budget, modulation and multiple access.
4. to understand the challenges associated with the data transmission between the earth space and satellite.

EE543 Internet of Things 3 0 0 3

Overview: Motivation, Applications and Objectives of Internet of Things (IoT), Cyber-Physical Systems and Wireless Sensor Networks; **Identification/Devices in IoT**: Sensors and Actuators, Sensor Types, Sensor Characteristics, Actuator Types, Controlling IoT Devices; Radio Frequency Identification (RFID) Technology, Mobile Sensing, Network Topology; Connectivity Protocols in IoT: Bluetooth Low Energy, 6LoWPAN, ZigBee, NFC, Sigfox and LoRa; Data messaging Protocols in IoT: Message Queue Telemetry Transport (MQTT), Hyper-Text Transport Protocol (HTTP), Constrained Application Protocol (CoAP), Data Distribution Service (DDS); **IoT Protocols**: IoT Standardization, Open Systems Interconnection (OSI), Transmission Control Protocol/Internet Protocol (TCP/IP), Internet Protocol (IP) Suite: IPv4, IPv6 and Internet Routing; **Localization in IoT**: Localization using Received Signal Strength (RSS), Phase, Time domain phase difference of arrival (TD-PDOA), Frequency domain phase difference of arrival (FD-PDOA), Space domain phase difference of arrival (SD-PDOA); Event Detection and Tracking using Signal Processing Methods; **Signal Processing and Machine Learning for Data Analytics**: Computation and Decision Making for Heterogeneous Devices. Feature Engineering, Validation Methods, Understanding the Bias–Variance Tradeoff, Sensor Fusion, Edge Computing; **Security and Privacy Issues in IoT**: Examples of Cyber-Physical Infrastructure Threat, Smart Car Hacking, Smart Home Hacking, Wearable Device Vulnerabilities; Techniques to Secure IoT: Segmentation, Defence-In-Depth, Defence-In-Breadth, User-Configurable Data Collection, Pattern Obfuscation, End-To-End Security, Tamper Security; **Use Cases of IoT for Smart Environments**: Development of IoT Projects for Healthcare, Agriculture, Smart City, Retail, Manufacturing, amongst others using hardware such as Arduino, Raspberry Pi and Libelium Wasp Mote.

Text Books:

1) *The Internet of Things: Enabling technologies, platforms, and use cases, Raj, Pethuru, and Anupama C. Raman, Auerbach Publications, 2017.*
2) *Internet of Things from hype to reality: the road to digitization, Rayes, Ammar, and Samer Salam, Springer, 2016.*

Reference Books:

3) *Handbook on Securing Cyber-Physical Critical Infrastructure: Foundations and Challenges, S. K. Das, K. Kant and N. Zhang, Morgan Kauffman, 2012.*
4) *Smart Environments: Technology, Protocols and Applications, D. J. Cook and S. K. Das, John Wiley, 2005*
5) *Cyber-physical systems: foundations, principles and applications, Song, Houbing, et al., eds, Morgan Kaufmann, 2016.*
6) *The Internet of things: from RFID to the next-generation pervasive networked systems, Yan, Lu, et al., eds, CRC Press, 2008.*
7) *Learning internet of things, Waher, Peter, Packt Publishing Ltd, 2015.*
8) *IoT technical challenges and solutions, Pal, Arpan, and BalamuralidharPurushothaman, Artech House, 2016.*

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to understand the building blocks of an IoT system.
2. to get familiar with the key technologies and protocols employed in IoT system.

3. to design an IoT system involving prototyping, programming and data analysis.

EE561 Antenna Theory and Design 3 0 0 3

Antenna fundamentals and definitions; Radiation integral and Auxiliary Potential Functions, Reaction and reciprocity theorems; Wire antennas – infinitesimal dipole, small dipole, finite length dipole, half-wave dipole, and loop antennas; Antenna arrays – two-element array, N-element linear array, planar array, and circular array; **Different Types of Antennas:** Dipoles and Matching Techniques, Travelling Wave Antennas, Broadband Antennas, Frequency Independent Antennas, Antenna Miniaturization, and Fractal Antennas, Aperture, and Horn Antennas, Microstrip Antennas, Antenna Polarization, Microstrip Patch Antennas, Reflector Antennas; **Antenna Measurements:** Antenna Ranges, Radiation Patterns, Gain Measurements, Directivity Measurements, Radiation Efficiency, Impedance Measurements, Current Measurements, Polarization Measurements; **Antennas for millimeter-wave communication**;

Main References

1. C.A. Balanis, "Antenna Theory Analysis and Design", Wiley & Sons, Third Edition.
2. Gosling, William. "Radio Antennas and Propagation: Radio Engineering Fundamentals", Elsevier, 1998.
3. Kraus, John Daniel, and Ronald J. Marhefka. "Antennas for all applications.",aaa. 2002.
4. Kraus, John D., Ronald J. Marhefka, and Ahmad S. Khan, "Antennas and wave propagation", Tata McGraw-Hill Education, 2006.
5. Sharawi, Mohammad S., "Printed MIMO antenna engineering", Artech House, 2014.

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to understand the fundamental concepts of antenna engineering through homework and problem analysis.
2. to get an exposure to the historical aspects that relate to the current state of the art and future technology advances in antenna engineering.
3. to become mindful of some non-antenna engineering aspects (manufacturability, reliability, consumer demand, constraints in materials) and contributions in research and industry.
4. to understand the basic knowledge on millimeter-wave communication antennas.

EE563 VLSI Architectural Design and Implementation 3 0 0 3

Introduction: Digital Systems and its applications to Signal Processing and Communication Systems; Digital Systems on hardware. Design and Implementation Challenges: Timing, Area, power issues in Digital Systems; Design and implementation Methodologies (Full custom and Semicustom): Design Flow, Design Optimization, Design Implementation using PLD, FPGA and ASIC; Architectural mapping with examples: Data path, Control path Synthesis; Control Strategies: Hardware implementation of various control structures; Micro-program control techniques; Introduction to Digital System Design and verification using HDL, FSM Architecture and Implementation with example, Semiconductor Memory and Peripheral Architectures. Computer arithmetic Architectures and complexity analysis: Fast Adder/Subtractors, Sequential and Array multipliers and dividers, square root, Absolute Difference Value, Floating Point arithmetic. Hardware architecture design and performance analysis: Sequential/Folding architectures; bit and word serial architecture; pipelined/unfolding Architecture; parallel and Systolic Array architecture with examples; Throughput and Latency analysis; Basic Hardware Architectures for Digital Signal and Communication Systems: CORDIC, FFT/IFFT, DCT, DWT, DHT, LFSR, FIFO, CRC, RS Encoder and Decoder Architectures, Digital Filter Architectures. Introduction to Mixed Signal Architectures: ADC, DAC and DPLL Introduction to VLSI Chip testing and validation Architectures: Introduction to Chip Fault Model, conventional chip testing and validation methodologies, DFT Architecture, BIST Architecture.

Texts/References:

1. Architectures for Digital Signal Processing, Peter Pirsch, John Willy & sons.
2. Digital VLSI Systems design, S. Ramachandran, Springer
3. VLSI Digital Signal Processing Systems: Design and Implementation, K. K. Parhi, A Wiley-Interscience publications.

4. Computer Arithmetic: Algorithm and Hardware Design, BehroozParhami, Oxford University Press.
5. Real World FPGA Design with Verilog, Ken Coffman, Prentice Hall.
6. Application Specific Integrated Circuit, Michael John Sebastian Smith, Addison Wesley.
7. VerilogHDL: A Guide to Digital Design and Synthesis, S. Palnitkar, Pearson.

Course Learning Outcome (CLO):
After learning this course, the students will be able

1. to understand the mathematical methods and circuit analysis models in analysis of CMOS digital electronics circuits.
2. to create models of moderately sized CMOS circuits that realize specified digital functions.
3. to understand the characteristics of CMOS circuit construction and the comparison between different state-of-the-art CMOS technologies and processes.
4. to complete a significant VLSI design project having a set of objective criteria and design constraints.

EE 587 A First Course in Optimization 3 0 0 3

Motivation. mathematical review , matrix factorizations, sets and sequences, convex sets and functions, linear programming and simplex method, Weierstrass' theorem, Karush Kuhn Tucker optimality conditions, algorithms, convergence, unconstrained optimization, Line search methods, method of multidimensional search, steepest descent methods, Newton's method, modifications to Newton's method , trust region methods, conjugate gradient methods, quasi-Newton's methods. constrained optimization, penalty and barrier function methods, augmented Lagrangian methods, polynomial time algorithm for linear programming, successive linear programming, successive quadratic programming.
Text/References

1. R. Fletcher Practical Optimization (2nd Edition) John Wiley & Sons, New York, 1987.

2. M.S.Bazaraa , H.D.Sherali and C.Shetty , Nonlinear Programming, Theory and Algorithms, John Wiley and Sons, New York, 1993.

Course Learning Outcome (CLO):
After learning this course, the students will be able

1. to develop the theoretical foundation to formulate and solve the optimization problems.
2. to understand different types of optimization problems and their solution methodology.
3. to identify the appropriate optimization technique to solve complex problems.

Semester-II

EE530 Advanced Digital Communication 3 0 0 3

Overview of Random Variables, Random Processes and Linear Algebra: Signal Space Concepts, Orthogonal Representation of Signals, Gram-Schmidt Procedure and Karhunen-Loeve (KL) Expansion. Communication Channel Models, Bandpass & Lowpass Signals
Digital Modulation Schemes and their Performance Analysis: Memoryless and with Memory Modulation Methods, Pulse Amplitude Modulation (PAM), Phase Modulation, Quadrature Amplitude Modulation (QAM), Continuous-Phase Frequency-Shift Keying (CPFSK), and Continuous-Phase Modulation (CPM)
Optimum Receiver in Presence of Additive White Gaussian Noise: Maximum a Posteriori Probability (MAP) and Maximum Likelihood (ML) Receivers, Coherent versus Non-coherent Detection, Binary Signal Detection in AWGN, M-ary Signal Detection in AWGN. Probability of Error Analysis
Receiver Synchronization: Signal Parameter Estimation, Carrier Phase Estimation, Symbol Timing Estimation, Joint Estimation of Carrier Phase and Symbol Timing
Channel Estimation and Equalization: Zero-Forcing Algorithm, Least-Mean-Square (LMS) Algorithm, Recursive Least Square

Algorithms, Linear and Decision Feedback Equalization, Channel Impulse Response, Pilot Symbol, Non-Data-aided and Data-aided Channel Estimation

Texts/References:

1. J. G. Proakis, M. Salehi, Digital Communications, McGraw Hill, 5thEdition, 2008.
2. R. G. Gallager, Principles of Digital Communication, Cambridge University Press, 2009
3. P. B Crilly, A. B. Carlson, Communication Systems, Tata McGraw-Hill Education, 5th Edition, 2011.
4. U. Madhow, Fundamentals of Digital Communication, Cambridge University Press, 2008
5. S. Haykin, Digital Communications, Wiley-India, 2011
6. J.M Wozencraft, I.M. Jacobs, Principles of Communication Engineering, JohnWiley, 1965.
7. I. A. Glover, P. M. Grant, Digital Communications, Pearson, 5th Impression, 2012.
8. P. Z. Peeples, Digital Communication Systems, Prentice Hall International, 1987.

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to understand different modulation schemes and their application to real world.
2. to understand the various degradations caused at the receiver side.
3. to design the optimal receivers and their performance evaluation.
4. to understand the basics of channel estimation.

EE534 Wireless Communication 3 0 0 3

Random Signal Theory: Joint Probability, Statistical independence, Cumulative Distribution function and Probability Density function, Error function, Rayleigh and Gaussian Probability Density, Stationary and Ergodic Process, Power Spectral Density of digital data.
Propagation & Fading: Propagation path loss, Free-space propagation model, Outdoor propagation models (Okumura model & Hata model), Indoor propagation, Multipath fading, time dispersive and frequency dispersive channels, delay spread and coherence bandwidth, LCR and ADF.
The Cellular Concept: Frequency Assignment and Channel Assignment, Frequency Reuse, Handoff, Sectoring, Microcell zone, Spectral efficiency.
Code Division Multiple Access (CDMA): Spreading Codes, Pseudo-Noise (PN) Sequene, Multi-Users CDMA, Near-Far Problem, Power Control and Advantages of CDMA
Orthogonal Frequency-Division Multiplexing (OFDM): Overview of Multicarrier Communications, Cyclic Prefix, Bit Error Rate, Frequency Offset, Peak-to-Average Power Ratio (PAPR), and SC-FDMA.
Multiple-Input Multiple-Output (MIMO): Zero Forcing Receiver, MIMO MMSE Receiver, SVD and MIMO Capacity, Asymptotic MIMO Capacity, Alamouti and Space-time Codes, OSTBC and V-Blast Receivers. MIMO-OFDM.
Multiuser Detection: Linear and Non-Linear Multiuser Detectors, BER Analysis, Turbo Multiuser Receiver, Iterative Interference Cancellation, Capacity Analysis, BER Analysis, Multiuser Detection for 4G/5G wireless Systems.

Texts/References:

1. D. Tse, P. Viswanath, Fundamentals of Wireless Communications, Cambridge Press, (2005)
2. G. L. Stuber, Principles of Mobile Communication, Kluwer Acdemic, (1996)
3. J. G. Proakis, Digital Communications, McGraw-Hill, (1995)
4. T. S. Rappaport, Wireless Communications: Principles and Practice, Prentice Hall, (1996)
5. A. J. Viterbi, CDMA Systems: Principles of Spread Spectrum Communication, Addison Wesley, (1995)
6. S. Verdu, Multiuser Detection, Cambridge University Press, (1998)
7. H. Wymeersch, Iterative Receiver Design, Cambridge University Press, (2007)

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to understand the concepts of the cellular architecture.
2. to understand the basics of radio propagation.
3. to develop mathematical skills to model communication system.

4. to understand the challenges associated with data transmission over wireless medium.
5. to get familiar with the mitigation strategies to achieve reliable communication over wireless medium.

EE526 **Digital Video Processing** **3 0 0 3**

Representation of digital video: Introduction and fundamentals; Time-varying image formation models: Motion models, Geometric image formation; Spatio-temporal sampling: Sampling of analog and digital video, Two-dimensional rectangular and periodic sampling, Sampling of 3-D structures, Reconstruction from samples; Sampling structure conversion: Sampling rate change, Sampling lattice conversion; Two-Dimensional Motion Estimation: Optical flow based methods, Block-based methods, Pel-recursive methods, Bayesian methods based on Gibbs Random Fields; Image Compression: Lossless compression, DPCM, Transform coding, JPEG, Vector Quantization, Sub-band Coding; Video compression: Inter-frame compression methods (3-d waveform and motion-compensated waveform coding), Video compression standards (H.26X and MPEG-X); Applications of video processing: Video Indexing, Summarization, Browsing and Retrieval, Video Surveillance.

Text:
1. A. M. Tekalp, "Digital Video Processing", Prentice Hall.
References:
2. R. C. Gonzalez, and R. E. Woods, "Digital Image Processing", Addison-Wesley.
3. Dudgeon &Mersereau, "Multi-dimensional Digital Signal Processing", Prentice Hall.
4. C. Poynton, "A Technical Introduction to Digital Video", Wiley.
5. Y. Wang, J. Ostermann, and Y. Zhang, "Video Processing and Communications", Prentice Hall.
6. K. Castleman, "Digital Image Processing", Prentice Hall.
7. S. Mitra, "Digital Signal Processing", 2nd Edition, McGraw Hill.

Course Learning Outcome (CLO):

After learning this course, the students will be able
1. to possess basic and advanced knowledge within the area of video technology, with emphasis on representing, analyzing, compressing and processing video.
2. to understand the research frontier in selected topics of video analysis especially of relevance to video surveillance, video-based navigation and video guided surgery applications.
3. to use relevant and suitable methods when carrying out further research and development activities in the area of video analysis and processing.

EE528 **Deep Learning for Video Surveillance Systems (DLVSS)** **3 0 0 3**

Introduction to Video Surveillance Systems: Introduction to image processing methods, Edge detection and linking, Image transforms, Introduction to video processing techniques, Video compression standards. Motion detection using optical flow method, motion modeling, Background modeling, Basic building blocks of video surveillance systems; **Introduction to Deep Learning:** Introduction to neural networks with linear algebra, Matrix mathematics and probability, Introduction to multilayer perceptron networks, forward and back propagation, Hyper-parameter tuning, Regularization and optimization in neural networks, Introduction to tensor-flo; **Convolutional Neural Nets:** Introduction to convolutional neural networks, Key concepts like convolution and pooling. Stacking convolutional layers for object detection; **Recurrent Neural Nets**: Introduction to recurrent neural networks (RNN, LSTM, GRU) for sequence level tasks (time series, video). Bidirectional and deep recurrent nets. Use them for activity recognition; **Object Detection and Classification using Deep Learning:**Haar like feature based object detection, Viola Jones object detection framework, Deep learning based object classification; **Object Tracking using Deep Learning:** Video monitoring for detection and tracking of single as well as multiple interacting objects, Region-based tracking, Contour-based tracking, Feature-based tracking, Model-based tracking, KLT tracker, Mean-shift based tracking; **Deep Learning based Human Activity Recognition:** Template based activity recognition, CNN based activity recognition, RNN based activity recognition, Abnormal behavior detection in crowded environments using deep learning; **Camera Networks for Surveillance:** Types of CCTV (closed circuit television) camera- PTZ (pan-tilt zoom) camera, IR (Infrared) camera, IP (Internet protocol) camera, wireless security camera, multiple view geometry, camera network calibration, PTZ camera calibration, camera placement, smart imagers and smart cameras, Introducing graph signal processing, consensus networks.

Text Books

1. M H Kolekar, "Intelligent Video Surveillance Systems: An Algorithmic Approach", CRC press Taylor and Francis Group, 2018

2. Q. Huihuan, X. Wu, Y. Xu, "Intelligent Surveillance Systems", Springer Publication, 2011.

3. Ian Goodfellow, YoshuaBengio and Aaron Courville, "Deep Learning", The MIT Press, 2017.

Reference Books

1. Murat A. Tekalp, "*Digital Video Processing*", Prentice Hall, 1995.
2. Pradeep K Atrey, Mohan Kankanhalli, A Cavallaro, "Intelligent Multimedia Surveillance: Current Trends and Research" Springer Publication, 2013.
3. Y. Ma and G. Qian (Ed.), "*Intelligent Video Surveillance: Systems and Technology*", CRC Press, 2009.
4. H. Aghajan and A. Cavallaro (Ed.), *Multi-Camera Network: Principles and Applications*", Elsevier, 2009.

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to possess basic and advanced knowledge within the area of video technology, with emphasis on surveillance.
2. to understand the basics of the deep learning techniques and models.
3. to use relevant deep learning techniques for object detection and classification.
4. to use relevant deep learning techniques for human activity recognition.

EE537 Optical Networks 3 0 0 3

Overview of optical communication system; Switching techniques: Circuit switched paradigm, Packet switched paradigm; Client layer: SONET/SDH, IP, MPLS, GMPLS; WDM network elements: Optical line terminals, Optical add/drop multiplexers, Optical crossconnects; WDM network design: Traffic models, Static and dynamic traffic grooming techniques; Formulation of network optimization problem: linear, Integer, Mixed integer linear programming problem, Lightpath topology design, Routing and wavelength assignment problem, NP-Completeness, Heuristic solution; Survivability in WDM networks, 1+1, 1:1, 1: N protection, Dynamic Restoration; Optical Packet Switching: Slotted networks, Unslotted networks, Packet format, Contention resolution in OPS networks, Optical buffering; Optical Access Networks: Passive Optical Network standards, Ethernet PON, WDM PON access network, architecture, PON transreceivers, Upstream and downstream transmission, Bandwidth allocation algorithm.

Texts/References:

1. Rajiv Ramaswami, Kumar N. Sivarajan and Galen H. Sasaki, Optical Networks; A Practical Perspective, Elsevier, 3rd Edition, 2010.

2. Biswanath Mukherjee, Optical WDM Networks, Springer, 2006.

3. Cedric F. Lam, Passive Optical Networks: Principles and Practice, Elsevier, 2007.

4. Jun Zheng, Hussein T. Mouftah, Optical WDM Networks: Concepts and Design Principles, Wiley-interscience, 2004.

5. C. Siva Ram Murthy, WDM Optical Networks: Concepts, Design and Algorithms, PHI Learning, 2001.

6. Pin-han Ho, Hussein T. Mouftah, Optical Networks: Architecture And Survivability, Kluwer Academic Publishers, 2010.

7. Ashwin Gumaste, Tony Antony, DWDM network designs and engineering solutions, Cisco Press, 2002

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to get familiar with different elements and components used in optical networks.
2. to understand different protocols used in optical networks.
3. to develop analytical skills to to solve network optimization problem.
4. to design optical networks by considering both physical transmission properties and optical networking constraints.

EE562 Embedded Computing Systems and Interfacing 3 0 0 3

Introduction to Embedded Systems: Introduction to Embedded Systems, Embedded System Applications, Block diagram of embedded systems, Trends in Embedded Industry, Introduction to Embedded system Models and Architectures, Embedded System development cycle, Challenges for Embedded system Design, Evolution of computing systems and applications, Introduction to Processor Architectures, Evolution of Embedded Bus protocols and Architectures, Introduction to I/O interfacing techniques in Embedded platform. Embedded Processor and applications: ARM Architecture, ARM organization and Implementation, Instruction Set, programming model, Addressing Mode, Assembly and high level language programming, Embedded C and UML, Interrupt Controller, Architectural support for System Development, ARM Processor Core, Memory Hierarchy and organization, Introduction to Embedded OS and RTOS, Introduction to Embedded ARM applications, Embedded I/O Interfacing controllers and Devices. FPGA platform Embedded System: Introduction to reconfigurable devices, Advanced FPGA Architectures, IP Cores: Processor, Memory, IOs. Design and Implementation techniques using FPGA platform: Integrated Software environment, System design: Hardware and Software design, Partitioning, Spatial design, Case Studies: FPGA platform for Communication Systems. Introduction to Embedded Device and Drivers for Communication Systems: serial and parallel communication bus, SPI, I2C, CAN, USB, Ethernet, Bluetooth, GPS, RFID, Wi-Fi.

Texts/References:

1. Introduction to Embedded Systems, Shibu K V, Tata McGraw Hill Publications
2. Embedded Systems: Architecture, Programming and Design, Raj Kamal, McGraw Hill Publications.
3. Embedded Systems Architecture, Tammy Noergaard, Newnes, Elsevier.
4. Embedded Microcomputer Systems and Real Time Interfacing, J. W. Valvano, Cengage Learning.
5. ARM System-On-Chip Architecture, Steve Furber, Pearson publication.
6. ARM System Developer's Guide: Designing and Optimizing System Software, Andrew N. Sloss, Dominic Symes, Chris Wright. Morgan Kaufmann
Publisher, Elsevier.
7. Embedded Systems Design with Platform FPGA, Ron Sass and Andrew G. Schmidt, Morgan Kaufmann Publisher, Elsevier.
8. FPGA- Based System Design, Wayne Wolf, Pearson Publisher

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to understand the fundamental knowledge on the principles of embedded system design.
2. to design an embedded system considering the trade-off between designing functionality in hardware versus software.
3. to perform design analysis and modular implementation for a complete system.
4. to develop programming skills in embedded systems for various applications.

EE539 Multimedia Communication 3 0 0 3

Introduction to Multimedia System: Architecture and components, Multimedia distributed processing model, Synchronization, Orchestration and Quality of Service (QOS) architecture. Audio and Speech: Data acquisition, Sampling and Quantization, Human Speech production mechanism, Digital model of speech production, Analysis and synthesis, Psycho-acoustics, low bit rate speech compression, MPEG audio compression. Images and Video: Image acquisition and representation, Composite video signal NTSC, PAL and SECAM video standards, Bilevel image compression standards: ITU (formerly CCITT) Group III and IV standards, JPEG image compression standards, MPEG video compression standards. Multimedia Communication: Fundamentals of data communication and networking, Bandwidth requirements of different media, Real time constraints: Audio latency, Video data rate, multimedia over LAN and WAN, Multimedia conferencing. Hypermedia presentation: Authoring and Publishing, Linear and non-linear presentation, Structuring Information, Different approaches of authoring hypermedia documents, Hyper-media data models and standards. Multimedia Information Systems: Operating system support for continuous media applications: limitations is usual OS, New OS support, Media stream protocol, file system support for continuous media, data models for multimedia and hypermedia information, content based retrieval of unstructured data.

Texts/ References:

1. Ralf Steinmetz and KlaraNahrstedt, Multimedia Systems, Springer.
2. J. D. Gibson, Multimedia Communications: Directions and Innovations, Springer.
3. K. Sayood, Introduction to Data Compression, Morgan-Kaufmann.

4. A. Puri and T. Chen, Multimedia Systems, Standards, and Networks, Marcel Dekker.
5. Iain E.G. Richardson, H.264 and MPEG-4 Video Compression, John Wiley.
6. BorivojeFurht, Handbook of Multimedia Computing, CRC Press.

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to understand the fundamental knowledge on multimedia system and Multimedia Communication.
2. to understand the knowledge on Multimedia Information Systems.
3. to understand the real-time constraints in Multimedia Communication.
4. to develop problem statement on Multimedia Communication for research direction.

EE5xx Random signals & Stochastic Processes 3 0 0 3

Prerequisite: Nil

Probability and statistics of multivariable (a quick revision): Bayes theorem, multiple random variable, discrete random variable, probability mass function and probability density function, a few well known distributions, moments. Random process: Concept of random process, ensemble, mathematical tools for studying random process, correlation function, stationarity, ergodicity, a few known stochastic processes: random walk, Poisson process, Gaussian random process, Markov chains, Brownian motion etc., pseudorandom process, nonlinear transformation of random process. Random process in frequency domain: Peridogram and power sprectral density, Weiner-Khintchine-Einstein Theorem, concept of bandwidth, spectral estimation. Linear system: Discrete time and continuous time LTI system, concept of convolution, system described in frequency domain, state space description of the system. Linear systems with random inputs: Linear system fundamentals, response of a linear system, convolution, mean, autocorrelation and cross correlation function in LTI system, power spectral density in LTI, cross power spectral density in LTI. Processing of random signals: Noise in systems, noise bandwidth, SNR, bandlimited random process, noise reduction, matched filter, Wiener filter. The Kalman filter: Mean square estimation, discrete Kalman filter, innovation, Kalman filter vs Wiener filter, properties of Kalman filter, Kalman Bucy filter, engineering examples.

Texts/References:

1. Miller, Scott, and Donald Childers, "probability and random processes: with applications to signal processing and communications", Academic Press, 2012.
2. Wim C. van Etten, "Introduction to random signals and Noise", Chichester, England: Wiley, 2005.
3. Peyton Z. Peebles, "Probability, random variables, and random signal principles". McGraw Hill Book Company, 1987.
4. Geoffrey R. Grimmett, and David Stirzaker, "Probability and random processes", Oxford university press, 2001.
5. Alberto Leon-Garcia, "Probability, statistics, and random processes for Electrical engineering", Upper Saddle River, NJ: Pearson/Prentice Hall, 2008.
6. Grewal, Mohinder, and Angus P. Andrews, "Kalman filtering: theory and practice with MATLAB", John Wiley & Sons, 2014.
7. Alberto Leon-Garcia, "Probability, statistics, and random processes for Electrical engineering", Upper Saddle River, NJ: Pearson/Prentice Hall, 2008.
8. Kay, Steven M, "Fundamentals of statistical signal processing", Prentice Hall PTR, 1993.
9. H.L. Van Trees, "Detection, estimation, and modulation theory, part I", New York, NY: John Wiley & Sons, Inc., 1971.
10. Brown, Robert Grover, and Patrick YC Hwang., "Introduction to random signals and applied Kalman filtering", New York: Wiley, 1992.
11. Shovan Bhaumik, and Paresh Date, "Nonlinear estimation: methods and applications with deterministic Sample Points", CRC Press, 2019.
12. Steven Key, "Intuitive probability and random processes using MATLAB®", Springer Science & Business Media, 2006.
13. D. J. Gordana, "Random signals and processes primer with MATLAB", Springer Science & Business Media, 2012.

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to get familiar with the frequently encountered random variables
2. to understand the mathematical tools to analyze random process
3. to develop analytical skills to model systems exhibiting random behavior

EE565 Telecommunications Management 3 0 0 3

Introduction to telecom scenario:- Acts and regulations covering telecom services, DOT,TRAI and TDSAT – their roles, Telecom growth, FDI policies in services, manufacturing. Licensing policies of various telecom services and OTT services, Active and passive sharing of infrastructure. Technologies trends and forecast for broadband, wireless and other services: Technologies, support, price, security, obsolescence and up gradation and their impact on business. Business models: managed services, managed capacity revenue models. Spectrum management: Frequency bands and their deployments, auction methodology, spectrum planning A business case study

Texts/References:

1. The Telecom Revolution in India: Technology, Regulation and Policy by Varadharajan Sridhar, Oxford Press
2. ITA 1885, TRAI Act 1997, National Telecom Policy 2015.
3. Telecommunication Management by Nolan Vincent Jones. Virtualbookworm.com publishing Aug 5 2004

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to understand about the regulation and policy related to telecom sector
2. to get familiar with the role of different regulatory agencies
3. to understand the business model of telecom sector

EE5XX Emerging Wireless Technologies 3 0 0 3

UNIT-1: FUNDAMENTALS OF COMMUNICATION SYSTEM [10 L]

- Random process and variables
- Cdma
- Ofdm
- Wirless communication channels
- Channel estimation and equalization
- Multiuser receiver

Unit-2: MIMO, Multiuser MIMO and Massive MIMO: **[12L]**

- Fundamentals of multiple-input multiple-output (MIMO);
- Capacity of MIMO systems, when channel state information (CSI) is known to trans-mitter, to receiver, or to both.
- MIMO transmission/detection techniques;
- Multiuser MIMO: principles, characteristics and transmission/detection techniques;
- Massive MIMO: principles, characteristics and transmission/detection techniques;
- Pilot contamination in massive MIMO;
- Implementation challenges and standardisation.

Unit-3: Duplexing and Multiple-Access Techniques for Future Wireless Systems:**[10L]**

- Overview of duplex techniques;
- Principles and challenges of full-duplex;
- Self-interference and self-interference cancellation in full-duplex;
- Full-duplex: opportunities for system design and implementation challenges;
- Non-orthogonal multiple-access (NOMA): principles, advantages, and implementation techniques for NOMA;
- Signal detection in NOMA systems.

Unit-4: Millimetre Wave (MmWave) Communications:**[10L]**

- MmWave promise and applications - a new frontier;
- Basics in ultra wide band digital communications: ultra wideband signalling, modulation, coding, and equalisation;
- MmWave propagation and channel models;
- Beam forming for MmWave communications: Analog beam forming, digital beam forming and hybrid Beam forming.

Texts/References:

1. *T.S. Rappaport, R.W. Heath Jr., R.C. Daniels and J.N. Murdock (2015). Millimeter Wave Wireless Communications: Systems and Circuits.*
2. *K.J.R. Liu, A.K. Sadek, W. Su and A. Kwasinski (2008). Cooperative Communications and Networking.*
3. *Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li and K. Higuchi (2013). Non-Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access. Vehicular Technology Conference, 2013 IEEE 77th. , pp. 1-5.*
4. *Robertson, N. Somjit and M. Chongcheawchamnan (2016). Microwave and Millimetre-Wave Design for Wireless Communications.*
5. *L.-L. Yang (2009). Multicarrier Communications.*
6. *R.S. Zahidur (2015). Cooperative Wireless Communications and Networking Paperback.*
7. *H.L.V. Trees (2005). Optimum Array Processing: Part V of Detection, Estimation, and Modulation Theory.*
8. *J. Schaepperle and A. Ruegg (2009). Enhancement of throughput and fairness in 4G wireless access systems by non-orthogonal signalling. Bell Labs Technical Journal. ,13 , pp. 59-78.*
9. *S. Haykin (1996). Adaptive Filter Theory.*
10. *T.M. Cover and J.A. Thomas (1991). Elements of Information Theory.*
11. *D. Tse and P. Viswanath (2005). Fundamentals of Wireless Communication.*

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to understand the various technologies to be used in next generation wireless network.
2. to develop analytical skill to model communication system.
3. to get familiar with the transmission characteristics at very high frequency bands.

EE5xx **Computer Vision** **3 0 0 3**

Fundamentals of Image processing, Camera geometry, Stereo geometry, Feature detection and description, Feature matching and model fitting, Color processing, Range image processing, Clustering and classification, Dimensionality reduction and sparse representation, **Image Descriptors and Features**: Interest or Corner Point Detectors, Histogram of Oriented Gradients, Scale Invariant Feature Transform, Speeded up Robust Features, Saliency, **Fundamentals of Machine Learning**: Linear Regression, Basic Concepts of Decision Functions, Elementary Statistical Decision Theory, Parameter Estimation, Clustering for Knowledge Representation, Dimension Reduction, Linear Discriminant Analysis.

Applications of Computer Vision: Artificial Neural Network for Pattern Classification, Convolutional Neural Networks, Autoencoders. Gesture Recognition, Motion Estimation and Object Tracking, Programming Assignments. Deep neural architecture and applications

Deep Learning for Computer Vision: Introduction to Deep Learning, Bayesian Learning, Decision Surfaces Linear Classifiers, Linear Machines with Hinge Loss Optimization Techniques, Gradient Descent, Batch Optimization Introduction to Neural Network, Multilayer Perceptron, Back Propagation Learning Unsupervised Learning with Deep Network, Autoencoders Convolutional Neural Network, Building blocks of CNN, Transfer Learning Revisiting Gradient Descent, Momentum Optimizer, RMSProp, Adam Effective training in Deep Net- early stopping, Dropout, Batch Normalization, Instance Normalization, Group Normalization Recent Trends in Deep Learning Architectures, Residual Network, Skip Connection Network, Fully Connected CNN etc.

Classical Supervised Tasks with Deep Learning, Image Denoising, Semanticd Segmentation, Object Detection etc. LSTM Networks Generative Modeling with DL, Variational Autoencoder, Generative Adversarial Network Revisiting Gradient Descent, Momentum Optimizer

Text/References:
1.Deep Learning- Ian Goodfelllow, Yoshua Benjio, Aaron Courville, The MIT Press
2.Pattern Classification- Richard O. Duda, Peter E. Hart, David G. Stork, John Wiley & Sons Inc.

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to understand and master basic knowledge, theories and methods in computer vision and fundamental knowledge on machine learning.
2. to identify, formulate and solve problems in image processing and computer vision.
3. to design and develop practical and innovative computer vision applications or systems.
4. To develop tendency to use deep learning techniques for computer vision applications.

EE5xx Silicon Photonics 3 0 0 3

Introduction to Silicon Photonics. SOI platform. SOI, SiN, InP, and LNOI platforms. Guided modes in Silicon Photonic Waveguides. Concept of effective index. Coupled Mode theory. Coupling of light to waveguides: grating couplers, butt coupling, mode transformers, inverted tapers. Waveguides loss mechanisms: absorption scattering. Plasma dispersion effect, thermo-optic effect, and stress-optic effect. Passive silicon photonic devices: Mach Zehnder interferometer, ring resonator, directional couplers, waveguide bends, multiplexers. Active silicon photonic devices: Source, Modulators, photodetector. Fundamentals of silicon photonics device fabrication and integration. Applications of silicon photonic devices.

Text / References:
1. G T Reed & AP Knights, "Silicon Photonics: An Introduction", Wiley 2004
2. G T Reed, "Silicon Photonics: The state of the art", Wiley 2008
3. L. Pavesi & D J Lockwoodt, "Silicon Photonics", Springer 2004
4. Lorenzo Pavesi & David J. Lockwood, "Silicon Photonics III Systems and Applications", Springer 2016
5. M J Deen & P K Basu, "Silicon Photonics: Fundamentals and Devices", Wiley 2012
6. Jameel Ahmed, Mohammed Yakoob Siyal, Freeha Adeel, Ashiq Hussain, Optical Signal Processing by Silicon Photonics, 2013, Springer
7. Amnon Yariv and Pochi Yeh, "Photonics", Sixth Edition, Oxford University Press

Course Learning Outcome (CLO):

After learning this course, the students will be able

1. to understand the fundamental concepts and operating principles of silicon photonic devices and circuits.
2. to design primary passive and active silicon photonic integrated circuits and interconnects.
3. to get familiar with different applications of silicon photonic devices.

EE5xx RF Systems 3 1 0 4

EM Fundamentals:
Review on Fundamentals of Electromagnetics- Review of basic microwave theory: Transmission Lines and waveguides, Concepts of characteristic impedance, reflection coefficient, standing and propagating waves. Modes and evanescent waves. Network analysis: S, Z, and other multi-port parameters, impedance matching and tuning. Implementation in simulators. Smith Chart Concept.
Transmission Lines, Filters and Power Dividers: Planar transmission lines: Quasi-static analysis, full wave analysis, and numerical techniques, Filter Design by Insertion Loss Method, Filter Transformations, Filter Implementation, T-Junction Power Divider, Wilkinson Power Divider, Quadrature (90^o) Hybrid, The 180^o Hybrid-
Active Microwave Devices: Diodes, Bipolar Junction Transistors, Field Effect Transistors, Microwave Amplifier Design: Stability, Transistor Amplifier Design, Power Amplifiers, Oscillators and Mixers: RF Oscillators, Frequency Multipliers, Mixers.
Microwave Systems: Wireless Communications. Radar Systems, Microwave Propagation, Noise and Non-linear Distortion: Noise in Microwave Circuits, Noise Figure, Nonlinear Distortion, Dynamic Range, Communication Blocks Designing and Development.
Experimental Description-

Designing Fabrication and Characterization of Microstrip Line
Designing, Fabrication and Characterization of LPF.
Designing, Fabrication and Characterization of Power Divider.

Designing, Fabrication and Characterization of Branch Line Copular
Characterization of Microstrip Patch Antenna in anechoic Chamber
RF Characterization of any sample surface under test.

References-

1. David M. Pozar, “Microwave Engineering”, Wiley, 4th Edition.
2. Liao, Samuel Y. Microwave devices and circuits. Pearson Education India, 1989.
3. Mongia, R. K., Hong, J., Bhartia, P., & Bahl, I. J., “RF and microwave coupled-line circuits” Artech house, 2007.
4. Maas, Stephen A., “The RF and microwave circuit design cookbook” Artech House, 1998.

EE5xx Design and Characterisation of High-Frequency Systems 3 0 0 3

Generation of EM Waves, Propagation of EM waves in Guided and Unguided Media, Transmission Lines, Microstrip Lines, Fabrication Techniques; Network Parameters, High-Frequency Network Parameters, Scattering Parameters, Signal Flow Graphs, Smith Chart Concepts, Impedance Matching, Microstrip Line Designing, and Characterization; Noise in Microwave Circuits, High-Frequency measurement Techniques, The calibration techniques, error, and post-calibration; High-Frequency Future Generation Communication Networks, 5G and Beyond, Architecture and Deployments, Characterization Techniques for High-Frequency Circuits, Measurement Techniques; mm Wave Wireless Communications, Radar Systems, Detection and Ranging, High Power Microwave Propagation, FMCW Radars, High-Frequency Detection using AI and ML Techniques;

- *Main References-*

1. David M. Pozar, “Microwave Engineering”, Wiley, 4th Edition.
2. Robert E. Collin, “Foundations for Microwave Engineering”, Wiley, 2nd Edition.

- *Additional References-*

1. Liao, Samuel Y. Microwave devices and circuits. Pearson Education India, 1989.
2. Mongia, R. K., Hong, J., Bhartia, P., & Bahl, I. J., “RF and microwave coupled-line circuits” Artech house, 2007.
3. Maas, Stephen A., “The RF and microwave circuit design cookbook” Artech House, 1998.
4. Gilmore, Rowan, and Les Besser, “Practical RF Circuit Design for Modern Wireless Systems: Active Circuits and Systems”, Volume 2. Vol. 1. Artech House, 2003.
5. Howe, Harlan. Stripline circuit design. Dedham, MA: Artech House, 1974.

EE5xx Microwave and Millimetre Wave Integrated Circuits 3 0 0 3

Introduction to Microwaves and Millimeter Waves, Transmission Lines for Microwave and Millimeter Waves-Microstrip, Suspended Microstrip, Suspended Stripline, Fin-lines, Dielectric Integrated Guides, Microwave and Millimeter wave Switches, P-i-n diode switches: basic configurations, Insertion loss and isolation of series and shunt switches, Series and shunt switches in microstrip, Device reactance compensation, Isolation improvement techniques, SPDT switches, Application of p-i-n diode switches, Design Examples.

Microwave and Millimeter Wave Phase Shifters- Analog versus digital Phase Shifters, Principle of ferrite Phase Shifters, Reciprocal versus non-reciprocal phase shifters, Different types of p-i-n diode phase shifters, Reflection and Transmission type phase shifter: Switched line, loaded line, hybrid coupled, low pass type, Series and shunt type switched line phase shifters, Broad banding techniques, MEMS Switches and phase shifters, Design Examples.

Small Signal Amplifiers, Low Noise, Maximum Gain, Stability, Narrow band Design, Broadband Design, Noise Analysis, Power amplifiers, Design Examples.

Main References

1. B.Bhat and Shiban K Koul, Strip line like transmission line for Microwave Integrated Circuits, New Age Publishers, Delhi.
2. Shiban K Koul and B.Bhat, Microwave Phase shifters, Volume-I and II, Artech House, USA
3. T.C.Edwards et al, Microstrip Circuit Design, John Wiley, USA
4. T.T.Ha, Microwave Amplifier Design, John Wiley, USA
5. G.Gonzales, Microwave Transistor Amplifiers, Prentice Hall, USA