Master of Technology

in

Communication Systems & Networks

Course Structure & Syllabus

Department of Electronics and Communication Engineering

National Institute of Technology Hamirpur

Hamirpur (HP) – 177005, India

SEMESTER-I

SN	Code	Subject	L	T	P	Hours/week	Credits
1	EC-631	Information Theory and Coding	4	0	0	4	4
2	EC-632	Mobile Communication	4	0	0	4	4
3	EC-633	Optical Networks	4	0	0	4	4
4	EC-634	Optical Communication Lab	0	0	4	4	2
5	EC-7MN	Programme Elective-I	4	0	0	4	4
6	EC-7MN	Programme Elective-II	4	0	0	4	4
	Total		20	0	4	24	22

SEMESTER-II

SN	Code	Subject	L	T	P	Hours/week	Credits
1	EC-641	Digital Signal Processing	4	0	0	4	4
2	EC-642	Broadband Wireless Technologies	4	0	0	4	4
3	EC-643	Modelling and Simulation of Communication Systems	4	0	0	4	4
4	EC-644	Communication System & Networks Simulation Lab	0	0	4	4	2
5	EC-7MN	Programme Elective-III	4	0	0	4	4
6	EC-70N	Open Elective	4	0	0	4	4
	Total		20	0	4	24	22

Note: List of Program Electives and Open Electives are attached as Annexure-I.

SEMESTER-III

SN	Code	Subject	Hours/ Week	Credits
1	EC-798	M Tech Dissertation	---	18
	Total			**18**

SEMESTER-IV

SN	Code	Subject	Hours/ Week	Credits
1	EC-799	M Tech Dissertation	---	18
	Total			**18**

Total Credit of the Programme = 80

ANNEXURE-I

List of Postgraduate (PG) Program Electives

PG Program Elective-I

EC-736	Advanced Digital Communication
EC-737	Advanced Optical Communication
EC-738	Soft Computing
EC-739	Wi-Fi, Bluetooth and Zigbee Technology
EC-740	Wireless Sensor Networks
EC-741	Optimization Tools and Techniques
EC-742	Applied Linear Algebra for Signal Processing, Data Analytics, and Machine Learning

PG Program Elective-II

EC-743	Electromagnetic Interference & Compatibility
EC-744	Advanced Engineering Electromagnetics
EC-745	RF and Microwave Circuit Design
EC-746	Advanced Antenna and Electromagnetic Metamaterials: Concept and Applications
EC-747	Nanophotonics and Plasmonics: Concepts and Applications
EC-748	Wavelet Transform and Applications
EC-749	mm-Wave Wireless Communication for 5G and Beyond

PG Program Elective-III

EC-750	Biomedical Signal Processing
EC-751	Statistical Signal Processing
EC-752	Radar Signal Processing
EC-753	Adaptive Signal Processing
EC-754	Multi-rate Signal Processing
EC-755	Advanced Spectrum Engineering
EC-756	6G and Terahertz Communication

List of Open Electives

EC-701	VLSI Design
EC-702	MEMS Design
EC-703	HDL Based Design
EC-704	Mobile Communication
EC-705	Communication Systems

Course Name: **Information Theory and Coding**
Course Code: **EC-631**
Course Type: **Core**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To impart knowledge about measuring the amount of information, capacities calculation of different channels in communication systems.
- To understand the theorems and inequalities used in information and coding theory field.
- To enable the students to design the source coding algorithms for improving transmission efficiency.
- To enable the students to design the block based error control coding algorithms for improving error performance of communication systems.

Course Content

Measures of Information and Channel Capacity; Entropy, Relative Entropy and Mutual Information, Basic Inequalities: Jensen Inequality and its Physical Application, Log–Sum Inequality and its Physical Application, Fano Inequality and its Physical Application, Data Processing Theorem and its Physical Application, Consequences of the Inequalities in the Field of Information Theory. Entropy Rate and Channel Capacity; Stationary Markov Sources: Entropy Rate and Data Compression, Definition of Capacity and its Computation of Discrete Memory Less Channels (BNC, BSC, BEC, Cascaded Channels, Noiseless Channels, Noisy Typewriter), The Channel Coding Theorem and the Physical Significance of Capacity. Data Compression by Fixed–To–Variable–Length Codes; Unique Decodability and the Prefix Condition, Kraft's Inequality, Relationship of Average Codeword Length to Source Entropy, Examples of Coding Techniques: Huffman, Shannon–Fano–Elias, Lempel–Ziv and Universal. Design of Linear Block Codes; Introduction of Linear Block Codes, Syndrome and Error Detection, Minimum Distance of a Block Code, Error Detecting and Error Correcting Capability of a Block Code, Design of Encoder and Syndrome Decoder for Linear Block Codes. Design of Cyclic Codes; Description Cyclic Codes, Generator and Parity Check Matrices of Cyclic Codes, Encoding of Cyclic Codes, Syndrome Computation and Error Detection, Decoding of Cyclic Codes, Cyclic Hamming Codes. Convolutional Codes; Encoding of Convolutional Codes, Structural Properties of Convolutional Codes, Distance Properties of Convolutional Codes, Design of Encoder and Decoder for Convolutional Codes.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the various terminologies to estimate information content in the communication system.
CO2: Apply various inequalities and quantities to evaluate the information content and entropy rate of a DMS.
CO3: Design lossless source codes for discrete memory-less source to improve the efficiency of information transmission.
CO4: Design block based error control codes for improving the error performance of information transmission systems.

Books and References

1. Elements of Information Theory by T.M. Cover and J.A. Thomas, John Wiley, 1991.
2. Error Control Coding by S. Lin and D. J. Costello, 2nd Edition, Pearson Education, 2010.
3. Information Theory and Reliable Communication by R. G. Gallager, John Wiley & Sons, 1969.

Course Name: **Mobile Communication**
Course Code: **EC-632**
Course Type: **Core**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To expose the students to understand mobile radio communication principles
- To study the recent trends adopted in cellular systems
- To introduce the students to recent wireless standards.

Course Content

Basic cellular systems, Performance criteria, Uniqueness of mobile radio environment, Operation of cellular systems, Concept of frequency reuse channels, Co–channel interference reduction factor, Desired C/I from a normal case in an Omni–directional antenna system, Handoff mechanism, Cell splitting. Cell coverage for signal and traffic, Obtaining the mobile point-to-point model, Propagation over water or flat open area, Foliage loss, Propagation in near-in distance, Long–distance propagation, Obtain path loss from a point–to–point prediction model, Cell–site antenna heights and signal coverage cells. Co-channel and adjacent-channel interference in mobile communications; Co-channel interference, Design of an Omni–directional antenna system in the worst case, Design of a directional antenna system, Lowering the antenna height, Power control, Diversity receiver, Adjacent–channel interference, Near–end–far–end interference, Effect on near-end mobile units**.** Frequency management, channel assignment and handoffs; Frequency management, Frequency–spectrum utilization, Set–up channels, Definition of channel assignment, Fixed channel assignment schemes, Non fixed channel assignment schemes, Concept of handoff, Initiation of a hard handoff, Delaying a handoff, Forced handoffs, Queuing of handoffs, Power–difference handoffs, Mobile assisted handoff, Soft handoffs, Cell–site handoff only, Intersystem handoff. Multiple access techniques and digital cellular systems; Multiple access techniques for mobile communications; Global system for mobile (GSM): GSM system architecture, GSM radio subsystem, GSM channel types, Frame structure for GSM, Signal processing in GSM; GPRS; EDGE; Overview of 3G and 4G cellular standards, 5G standard: Requirement, evaluation, architecture, frequency bands, channel type, 5G new radio (NR) network interfaces, Numerology, Layer overview.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Discuss the cellular system design and technical challenges.
CO2: Analyze the Mobile radio propagation, fading, diversity concepts and the channel modeling.
CO3: Analyze the design parameters, link design, smart antenna and multiple access systems.
CO4: Summarize the principles and applications of wireless systems and standards like GSM, GPRS, EDGE and 3G, 4G, 5G standards.

Books and References

1. Mobile Cellular Telecommunications: Analog and Digital Systems by W. C. Y. Lee, 2nd Edition, McGraw Hill Education, 2017.
2. Wireless Communications: Principles and Practice by T. S. Rappaport, 2nd Edition, Pearson Education India, 2010.
3. Wireless Communications and Networks: 3G and Beyond by ITI S. Misra, 2nd Edition, McGraw Hill Education, 2017.
4. Wireless Digital Communications: Modulation and Spread Spectrum Applications by K. Feher, Prentice Hall, 1995.

Course Name: **Optical Networks**
Course Code: **EC-633**
Course Type: **Core**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To understand optical networks, optical amplifiers and multiplexers.
- To impart the knowledge of client layers of optical layer, WDM network design and access network.

Course Content

Introduction to Optical Network: Services, Circuit switching, Packet switching, Optical networks, Optical layer, Transparency and all optical networks, Optical packet switching, Transmission basics, Network evolution; Optical Amplifiers: Emission, Spontaneous emission, Erbium doped fiber amplifiers, Raman amplifiers, Semiconductor optical amplifiers, Cross talk in SOAs; Multiplexers and Filters to Wavelength Converters: Gratings, Diffraction pattern, Bragg gratings, Fiber gratings, Fabry–Perot filters, Multilayer dielectric thin-film filters, Mach–Zehnder interferometers, Arrayed waveguide grating, Acousto–optic tunable filter, High channel count multiplexer architectures, Optoelectronics approach, Optical gating, Interferometric techniques, Wave mixing; Transmission System Engineering: System model, Power penalty, Transmitter, Receiver, Optical amplifiers, Cross talk, Dispersion, Fiber nonlinearities, Wavelength stabilization design of Soliton systems, Design of dispersion–managed soliton systems; Client Layers of the Optical Layer: SONET/SDH, ATM, IP, Storage area networks, Gigabit and 10–Gigabit Ethernet; WDM Network Elements & Design: Optical line terminals, Optical line amplifiers, Optical add/drop multiplexers, Optical cross connects, Cost trade–offs: A detailed ring network example, LTD and RWA problems, Dimensioning wavelength–routing networks, Statistical dimensioning models, Maximum load dimensioning models; Access Networks: Network architecture overview, Enhanced HFC, Fiber to the Curb (FTTC).

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the basics of optical network, optical network and optical packet switching.
CO2: Analyse the different types of optical amplifier.
CO3: Understand the multiplexer and filters to wavelength converters.
CO4: Understand the optical transmission system engineering and client layer of the optical layer.
CO5: Understand the WDM network elements, design and network architecture overview.

Books and References

1. R. Ramaswami, K. Sivarajan and G. Sasaki, “Optical Networks: A Practical Perspective,” 3rd Edition, Morgan Kaufmann Publication, 2007.
2. G. P. Agarwal, “Fiber-Optic Communication Systems,” 3rd Edition, John Wiley & Sons, New York, 2007.
3. J. H. Franz and V. K. Jain, “Optical Communications: Components and Systems,” 1st Edition, Narosa Publications, 2000.
4. G. Keiser, “Optical Fiber Communication,” 5th Edition, McGraw Hill Education, 2017.

Course Name: **Optical Communication Lab** Course Code: **EC-634** Course Type: **Core**	
Contact Hours/Week: **4P**	Course Credits: **02**

Course Objectives

- To study the design and deployment of optical fiber communication links.
- To understand the characteristics of optical fiber and losses in optical fiber communication link.

List of Experiments

1. Demonstrate two most used modulation formats in optical communication: non return to zero (NRZ) and return to zero (RZ).
2. To compensate fiber dispersion using the ideal fiber grating components.
3. To study the effect of optical receiver characteristics on a system's performance.
4. To set up an 850nm fiber optic analog link.
5. To set up 850nm and 650 nm digital link, and to measure the maximum bit rates supportable on these links.
6. To estimate the aperture of the 1-micron diameter.
7. To measure the losses in optical fiber communication link.
8. To analyse the v-I characteristics and p-I characteristics using LED module.
9. To study the characteristics of Avalanche photodiode (APD)
   (i). APD at zero bias
   (ii). APD at reverse bias.
10. To examine the technique of time division multiplexing (TDM)

Note: *The concerned Course Coordinator will prepare the actual list of experiments/problems at the start of semester based on above generic list.*

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the communication using optical fiber.
CO2: Set up the analog and digital communication links.
CO3: Analyse the characteristics of LED and Avalanche photodiode.

Course Name: **Digital Signal Processing**
Course Code: **EC-641**
Course Type: **Core**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To study and analyze discrete-time signals and systems in time-domain
- To study and analyze discrete-time signals and systems in transform-domain
- To design and implement FIR and IIR digital filters, and to understand the basic concepts of multirate digital signal processing.

Course Content

Introduction to discrete-time signals and systems: Discrete-time signals, Operations on sequences, Sampling process, Discrete-time systems, Time-domain characterization of LTI discrete-time systems; Transform-domain representation: Discrete-time Fourier transform, Discrete Fourier transform (DFT), DFT properties, Linear convolution using DFT, Fast Fourier Transform, Z-transform, Inverse Z-transform, Properties of Z-transform; Realization structures for digital filters: Block diagram representation, Signal flow graph representation, Direct form structures, Cascade form structures, Parallel form structures, Lattice structure realization; Digital filter design: General considerations, Review of analog filter design, IIR filter design using impulse invariance method and bilinear transformation method, FIR digital filter design using windows method and frequency sampling method; Multirate digital signal processing fundamentals: Introduction to sampling rate conversion, Decimation, Interpolation, Polyphase decomposition.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand, characterize and analyze discrete-time signals and systems in time-domain.
CO2: Analyze discrete-time signals and LTI discrete-time systems in transform-domain.
CO3: Design and implement FIR and IIR digital filters using different methods.
CO4: Understand the basic concepts of multirate digital signal processing.

Books and References

1. Digital Signal Processing: A Computer – Based Approach by S. K. Mitra, Tata McGraw Hill Publication
2. Digital Signal Processing – Principles, Algorithms, and Applications by J. G. Proakis and D. G. Manolakis, Pearson Education
3. Digital Signal Processing by A. V. Oppenheim and R. W. Schafer, PHI Publication
4. Digital Signal Processing by Monson H. Hayes, McGraw Hill Publication (Schaum's Outlines)

Course Name: **Broadband Wireless Technologies**
Course Code: **EC-642**
Course Type: **Core**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To understand mobile radio communication principles and to study the recent trends adopted in cellular systems and broadband wireless standards.
- To introduce the concepts of mobile radio propagation, fading, diversity and channel modeling for broadband wireless systems.

Course Content

Wireless Communications and Diversity and Broadband Wireless Channel Modeling: Fast Fading Wireless Channel Modelling, Rayleigh/Ricean Fading Channels, BER Performance in Fading Channels, Concept of Rake Receiver, Performance of RAKE Receiver in Multipath Fading Channel, Diversity Modelling for Wireless Communications, BER Performance Improvement with Diversity, Types of Diversity – Frequency, Time, Space, WSSUS Channel Modeling, RMS Delay Spread, Doppler Fading, Jakes Model, Autocorrelation , Jakes Spectrum, Impact of Doppler Fading. Principles of CDMA: The Concept oof Spreading, Capacity of CDMA System, Spreading Codes and Their Properties, Pseudo-Random Sequences, Maximal Length Linear Shift Register Sequence, Randomness Properties of MLSR Sequence. Galois Field and Primitive Polynomials, Mechanization of Linear Feedback Shift Register Binary Irreducible Polynomial, State Vector Variations For PN Sequence Phase Shifts, Shift Register Generator with Special Loading Vectors, Use of Mask To Select a Sequence Phase Shift. OFDM: Introduction to OFDM, Multicarrier Modulation and Cyclic Prefix , Channel Model and SNR Performance LTE Systems, OFDMA And SC-OFDMA, Synchronization And Channel Estimation Aspect, OFDM Issues – PAPR, Frequency and Timing Offset Issues. MIMO: Introduction to MIMO, MIMO Channel Capacity, SVD and Eigenmodes of MIMO Channel, MIMO Spatial Multiplexing – BLAST, MIMO Diversity – Alamouti, OSTBC, MRT, MIMO - OFDM. UWB (Ultrawide Band): UWB Definition and Features, UWB Wireless Channels, UWB Data Modulation, Uniform Pulse Train, Bit-Error Rate Performance of UWB. Waveform and air interfaces: FBMC (filter bank multi- carrier), UFMC (Universal filtered multi access), GFDM (generalized frequency division multiplexing), NOMA (Non orthogonal multiple access), Massive MIMO Systems: motivation and system model, advantages and challenges.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the cellular system design and technical challenges.
CO2: Analyze the Mobile radio propagation, fading, diversity concepts and the channel modeling.
CO3: Understand the design parameters, link design, smart antenna, beam forming and MIMO systems.
CO4: Understand Multiuser Systems, CDMA, MIMO, OFDMA and UWB Concepts

Books and References

1. Andrew J. Viterbi, “CDMA: Principles of Spread Spectrum Communication”, Addison-Wesley Publishing Company.
2. Jhong S. Lee and Leonard E. Miller, “CDMA Systems Engineering Handbook”, Artech House Publishers.
3. Vijay K Garg, “IS-95 CDMA and CDMA-2000,” Pearson Education. Ramjee Prasad, “OFDM for Wireless Communications Systems,” Artech House, Inc.
4. Fundamentals of Wireless Communications – David Tse and Pramod Viswanath, Publisher, “Cambridge University Press”.
5. MIMO Wireless Communications – EzioBiglieri – Cambridge University Press.
6. Henrik Schulze & Cristion Luders, “Theory application of OFDM and CDMA wideband wireless communication.” John Wiley & Son Ltd.
7. Wireless Communications: Andrea Goldsmith, Cambridge University Press.

Course Name: **Modeling and Simulation of Communication Systems**
Course Code: **EC-643**
Course Type: **Core**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To provide a thorough introduction to modeling & simulation techniques of communication systems.
- To provide in depth knowledge of estimation of parameter measures and testing process of the communication system.
- To introduce the concept of performance evaluation of any communication system including channel models.
- To introduce the concepts of queuing theory and its relevance for design of communication systems.

Course Content

Univariate and Multivariate Models; Probability Density and Distribution Functions, Random Variables, Independence of Random Variables, Transformations Between Random Variables, Expectations and Moments, Conditional Expectation and Conditional Variance, Bi- and Multivariate Distributions, Random Processes, Covariance and Spectral Density, Application of Different Probability Models, Bounds and Approximation of Random Variables, Introduction to Simulation and Modeling: Steps in Simulation and Modeling. Simulation of Random Variables and Random Process; Properties of Random Numbers, Generation of Random Numbers, Techniques for Generating Random Numbers: Linear Congruential Method and Combined Linear Congruential Method, Validation of Random Number Generators: KS Test, Chi-Square Test, Runs Test, Autocorrelation Test. Random Variate Generators; Inverse Transform Technique for Generating Discrete Random and Continuous Random Variables (Examples for Exponential, Uniform, Triangular, Poisson, Binomial Distributed Random Variables), Acceptance–Rejection Technique for Generation of Discrete and Continuous Random Variables, Some Special Generators: Box Muller Method, Sum–of–12 Method for Generating Normally Distributed Random Variables, Validation of the Generation Methods using Goodness of Fit Tests. Estimation of Performance Measures: Quality of an Estimator, Estimator of SNR, Probability Density Functions of Analog Communication System, BER of Digital Communication Systems, Unbiased Estimation of Expected Value, Unbiased Estimation of Variance, Monte Carlo Method and Importance Sampling Method for Estimating the Integral (Crude Monte Carlo Method, Acceptance– Rejection Monte Carlo, Stratified Sampling, Importance Sampling Methods and their Performance Comparison). Queuing Models: Characteristics of Queuing Models, Queuing Notation, Long Run Performance Measures of Queuing Systems, Steady State Behavior of M/M/1 and M/M/1/N Queuing Models, Little Formula, Burke's Theorem M/G/1 Queuing Model, Embedded Markov Chain Analysis of TDM Systems, Polling, Random Access Systems.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Analyze, model and simulate the communication networks and systems.
CO2: Generate, test and estimate parameters and performance measures used in communication systems and networks.
CO3: Apply this knowledge for detection, estimation and simulation of various communication networks
CO4: Simulate and evaluate the performance measures of queuing systems.

Books and References

1. Simulation of Communication Systems Modeling, Methodology and Techniques by M. C. Jeruchim, P. Balaban and K. S. Shanmugan, 2nd Edition, Springer, 2000.
2. Simulation Modelling and Analysis by A. M. Law and W. D. Kelton, 3rd Edition, McGraw Hill Higher Education,2000.
3. Discrete-Event System Simulation by J. Banks, J. S. Carson II, B. L. Nelson and D. M. Nicol, 5th Edition, Pearson, 2009.

Course Name: **Communication System & Networks Simulation Lab**
Course Code: **EC-644**
Course Type: **Core**

Contact Hours/Week: **4P** Course Credits: **02**

Course Objectives

- To provide skills for modeling and simulation of communication systems & networks on MatLab platform.
- To provide skills for writing MatLab programs and use communication and signal processing toolboxes.

List of Experiments

1. Familiarity with MatLab communication and signal processing toolbox.
2. Programs to generate uniformly distributed random variables between [0, 1] using Linear Congruential Generator.
3. Programs to generate discrete random variables based on inverse transform technique.
4. Programs to generate continuous random variables based on inverse transform technique.
5. Programs to generate discrete random variables based on acceptance rejection technique.
6. Programs to generate continuous random variables based on acceptance rejection technique.
7. Programs to validate random variable generators based on KS test.
8. Programs to validate random variable generators based on Chi square test.
9. Programs to validate independence of random variable generators based on Runs test.
10. Programs to validate independence of random variable generators based on Autocorrelation test.
11. Programs to use Monte Carlo techniques to estimate parameters of quantities used in communication system.
12. Programs to implement parameters and performance measures used in communication system design.
13. Designing the digital communication system to evaluate BER vs. SNR performance.
14. Simulation of spread-spectrum techniques (DS-CDMA, FH-CDMA) and comparison of their performance in a multipath fading channel.
15. Implementation and analysis of Carrier Sense Multiple Access (CSMA) and Carrier Sense Multiple Access with Collision Detection (CSMA/CD) protocols in a network.

Note: *The concerned Course coordinator will prepare the actual list of experiments/problems at the start of semester based on above generic list.*

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Identify and abstract the simulation model design of communication systems.
CO2: Design and develop modular programming skills on MatLab platform.
CO3: Trace, debug and validate simulation models.
CO4: Able to implement the algorithms required for discrete event simulation.
CO5: Able to implement the validation tests for discrete event simulation models.

Course Name: **Advanced Digital Communication**
Course Code: **EC-736**
Course Type: **Program Elective-I**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To study baseband data transmission over AWGN and band-limited channels
- To study different digital modulation schemes
- To study optimum receivers for different modulation schemes for AWGN channels
- To study different techniques for carrier recovery and symbol synchronization in signal demodulation

Course Content

Baseband pulse transmission: Matched filter, Properties of matched filters, Error rate due to noise, Intersymbol interference, Nyquist's criterion for distortionless baseband binary transmission, Ideal Nyquist Channel, Raised cosine spectrum, Correlative-level coding, Duobinary signaling, Modified duobinary signaling; Signal-space analysis: Geometric representation of signals, Gram-Schmidt orthogonalization procedure, Conversion of the continuous AWGN channel into a vector channel, Statistical characterization of the correlator outputs, Likelihood functions, Coherent detection of signals in noise, Maximum likelihood decoding, Correlation receiver, Equivalence of correlation and matched filter receivers; Digital Modulation Schemes: Representation of digitally modulated signals, Memoryless modulation methods, Pulse amplitude modulation, Phase modulation, Quadrature amplitude modulation, Signaling schemes with memory, Continuous-phase frequency-shift keying, Continuous phase modulation; Optimum Receivers for AWGN Channels: Optimal detection and error probability for bandlimited signaling (ASK, PSK, QAM), Optimal detection and error probability for power-limited signaling (orthogonal signaling), Optimum receiver for CPM signals, Optimum demodulation and detection of CPM; Carrier and Symbol Synchronization: Signal parameter estimation, Carrier recovery and symbol synchronization in signal demodulation, Carrier phase estimation, Maximum-likelihood carrier phase estimation, The phase-locked loop, Symbol timing estimation, Maximum-likelihood timing estimation, Joint estimation of carrier phase and symbol timing.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand baseband data transmission over AWGN and band-limited channels.
CO2: Understand and explain different digital modulation schemes.
CO3: Analyze the performance of optimum receivers for different modulation schemes for AWGN channels.
CO4: Analyze different techniques for carrier recovery and symbol synchronization in signal demodulation

Books and References

1. Communication Systems by Simon Haykin, Wiley-India Edition
2. Digital Communications by John G. Proakis and Masoud Salehi, McGraw-Hill
3. Digital Communications – Fundamentals and Applications by Bernard Sklar and P. K. Ray Pearson Education
4. Modern Digital and Analog Communication Systems by B. P. Lathi and Zhi Ding, Oxford University Press
5. Principles of Communication Systems by Herbert Taub and Donald L. Schilling, McGraw-Hill

Course Name:	**Advanced Optical Communication**
Course Code:	**EC-737**
Course Type:	**Program Elective-I**
Contact Hours/Week: **4L**	Course Credits: **04**

Course Objectives

- To introduce the students to various concepts of advanced optical communication systems.

Course Content

Correlation properties and power density spectrum of shot noise process; Laser phase noise modeling and Lorentzian power spectrum of lasers; Coherent optical communication systems: Homodyne and heterodyne detection schemes, BER analyses - super-quantum and shot noise limits for homodyne PSK, Synchronous and asynchronous FSK, Impact of finite laser linewidth on BER, Polarization control and diversity schemes, Frequency alignment schemes; Review of optical amplifiers - Semiconductor amplifiers, Erbium-doped fibre amplifiers (EDFAs) and Raman amplifiers, Analytical modeling of gain saturation in EDFAs, Gain equalization in EDFAs, ASE noise in EDFAs, Amplifier cascades, Amplifier spacing penalty; BER analysis of lightpaths in WDM backbones in presence of ASE noise and switch crosstalks; Optical duobinary modulation: Spectral efficiency, Basic scheme, BER analysis, Impact of fibre nonlinearities; Error detection and correction in optical links: Reed-Solomon codes, Interleaving; Pulse propagation in optical fibres: Propagation of chirped Gaussian pulse, Concept of nonlinear polarization, Nonlinear effects on pulse propagation, Soliton pulse propagation; Optical time division multiplexing techniques; Optical phase-locked loops.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Learn the Coherent optical communication systems.
CO2: Learn the concept of optical amplifiers.
CO3: Learn Error detection and correction in optical links.
CO3: Understand the optical multiplexing techniques.
CO4: Understand the concept of optical nonlinear polarization.

Books and References:

1. Cvijetic, Milorad, and Ivan Djordjevic. *Advanced optical communication systems and networks*. Artech House, 2013.
2. Optical Fiber Communications (Third Ed.) by Gerd Keiser, McGraw-Hill, 2000.
3. Optical Networks: A Practical Perspective (Third Ed.) by R Ramaswamiand and K.N. Sivarajan, Morgan Kaufman Publishers.

Course Name: **Soft Computing**
Course Code: **EC-738**
Course Type: **Program Elective-I**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To impart knowledge about Artificial Neural networks and deep learning.
- To introduce the fundamental concepts relevant to ANN, Optimization techniques and genetic algorithms.

Course Content

Introduction: History of Deep Learning, Deep Learning fundamentals, Training Deep Architectures, Intermediate Representations: Sharing Features and Abstractions across Tasks, Sigmoid Neurons, Gradient Decent, Feed-forward Neural Networks, Dropout, Back-propagation. Deep learning fundamentals: Principal component Analysis and its interpretations, Singular Value Decomposition, Greedy Layer wise Pre-training, Better activations, Better weight initialization methods, Batch Normalization, Introduction of deep learning, How deep learning works, Introduction to Tensor flow. Deep learning Algorithms: Gradient Descent and Back-propagation, Improving deep network, Multi-Layer Neural Networks, The Challenge of Training Deep Neural Networks, Deep Generative Architectures. Mini-batches, Unstable Gradients, and Avoiding Over-fitting, Applying deep net theory to code, Introduction to convolutional neural networks for visual recognition. Advanced Deep Architectures: RNNs, RNNs in practice, LSTMs and GRUs, LSTMs and GRUs in practice, Reinforcement Learning, Why Unsupervised Learning is Important, Training Auto Encoder. Applications for Communication Engineering: Shortened pipeline, error detection, correction, feature extraction, modeling.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Describe the key components of AI, Genetic algorithms and their relation and role in Communication Engineering.
CO2: Understand the alternatives to generic designs, optimization and modeling techniques.
CO3: Understand the importance of neural networks and related algorithms.

Books and References

1. Deep Learning: Methods and Applications by Li Deng and Dong Yu.
2. Neural Networks and Deep Learning by Michael Nielsen.
3. Hands-On Learning with Scikit-Learn and Tensor flow by Aurelien Geron and Oreilly.
4. Pattern Recognition and Machine Learning by Christopher Bishop.
5. Deep Learning by Ian Good fellow, Yoshua Bengio and Aaron Courville, An MIT Press book.

Course Name:	**Wi-Fi, Bluetooth and ZigBee Technology**
Course Code:	**EC-739**
Course Type:	**Program Elective-I**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To understand theoretical aspects of Wi-Fi, Bluetooth and Zigbee technology.
- To design and implement Wi-Fi/ Bluetooth/ Zigbee based ad hoc networks.

Course Content

Wi-Fi: Architecture and Functions: WLAN Roadmap via IEEE 802.11 Family Evolutions, IEEE 802.11 Architecture, Different Physical Layers, Data Link Layer, Medium Access Control Layer, Mobility, Security, IEEE 802.11 Family and Its Derivative Standards; Bluetooth Architecture and Functions: Introduction, Architecture and Throughputs, Physical Layer and Physical Channels, Baseband Layer, Link Manager Protocol, Logical Link Control and Adaptation Protocol, RFCOMM Protocol, Service Discovery Protocol, Profiles, Host Control Interface, Bluetooth Network Encapsulation Protocol; IEEE 802.15.4 and ZigBee: General Architecture, Physical Layer, 2450 MHz Physical Layer, 868/915 MHz Physical Layer, PDU Packet Format, MAC Layer, Channel Access, Energy Detection, Active and Passive Scan, Association Procedure, Guaranteed Time Slot, Security, Frame Structures, Beacon Frame, Data Frame.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Use suitable principles and standards of Bluetooth, IEEE 802.15.4 and Zigbee in design and evaluation of sensor networks and wireless communication protocols for small digital transmitter/receivers.

CO2: Use the knowledge for implementation of Wi-Fi networks.

CO3: Analyzing relevant results from research literature design and implement software and system solutions for wireless embedded systems.

CO4: Demonstrate an ability to read, critically evaluate, analyse and present (verbally or in written form) the content and Implications of research articles in the area.

Books and References

1. Wi-Fi™, Bluetooth™, Zigbee™ and WiMax™ by H. Labiod, H. Afifi and C. D. Santis, Springer.
2. Bluetooth Technology and Its Applications with Java and J2Me by R. A. Prathap and C. S. R. Prabhu, Prentice Hall India Learning Private Limited.
3. Bluetooth Demystified by N. J. Muller, McGraw-Hill Professional.
4. Bluetooth Application Developer's Guide by Jennifer Bray, Brain Senese, Gordon McNutt and Bill Munday, Syngress Media.

Course Name: **Wireless Sensor Networks**
Course Code: **EC-740**
Course Type: **Program Elective-I**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To impart knowledge about wireless sensor networks and their application areas.
- To introduce the fundamental concepts relevant to deployment and localization of wireless sensor networks.
- To enable the students to understand the synchronization and dissemination of information using wireless sensor network about the target area.

Course Content

Introduction, Wireless Sensor Networks: The Vision, Networked Wireless Sensor Devices, Applications of Wireless Sensor Networks, Key Design Challenges, Network Deployment: Structured Versus Randomized Deployment, Network Topology, Connectivity in Geometric Random Graphs, Connectivity using Power Control, Coverage Metrics, Mobile Deployment, Localization And Time Synchronization: Key Issues, Localization Approaches, Coarse-Grained Node Localization Using Minimal Information, Fine-Grained Node Localization Using Detailed Information, Network- Wide Localization, Theoretical Analysis of Localization Techniques, Key Issues of Time Synchronization, Traditional Approaches, Fine-Grained Clock Synchronization, Coarse grained Data Synchronization, Wireless Characteristics And Medium-Access: Wireless Link Quality, Radio Energy Considerations, The SINR Capture Model For Interference, Traditional MAC Protocols, Energy Efficiency In MAC Protocols, Asynchronous Sleep Techniques, Sleep-Scheduled Techniques, and Contention-Free Protocols, Sleep-Based Topology Control and Energy-Efficient Routing: Constructing Topologies for Connectivity, Constructing Topologies for Coverage, Set K-cover Algorithms, Cross-Layer Issues, Metric-Based Approaches, Routing with Diversity, Multi-Path Routing, Lifetime-Maximizing Energy-Aware Routing Techniques, Geographic Routing, Routing to Mobile Sinks, Data-Centric Networking: Data-Centric Routing, Data-Gathering with Compression, Querying, Data-Centric Storage and Retrieval, Database Perspective on Sensor Networks, Transport Reliability and Congestion Control: Basic Mechanisms and Tunable Parameters, Reliability Guarantees, Congestion Control, Real-Time Scheduling.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the principles and characteristics of wireless sensor networks.

CO2: Apply knowledge of wireless sensor networks to various application areas.

CO3: Analyse WSN protocols in terms of their energy efficiency and design new energy efficient protocols.

Books and References

1. Networking Wireless Sensors by Bhaskar Krishnamachari, Cambridge University Press.
2. Wireless Sensor Networks-An Information Processing Approach by Feng Zhao and Leonidas Guibas, Morgan Kauffman.
3. Wireless Sensor Networks-Technology, Protocols and Applications by K. Sohraby, D. Minoli and T. Znati, John Wiley & Sons.

Course Name: **Optimization Tools and Techniques**

Course Code: **EC-741**

Course Type: **Program Elective-I**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To teach basics and fundamentals of optimization.
- To build upon the theoretical and mathematical models for optimization techniques.
- To provide students with an opportunity to understand and practice optimized designing.

Course Content

Single Variable Non-Linear unconstrained optimization, One dimensional Optimization methods, Uni-modal function, Elimination methods, Fibonacci method, Golden section method, Interpolation methods, Quadratic & cubic interpolation methods. Multi variable non-linear unconstrained optimization: Direct search method, Univariant method, pattern search methods, Powell's- Hook -Jeeves, Rosenbrock search methods- gradient methods, gradient of function, Steepest decent method, Fletcher Reeves method, Variable metric method. Linear Programming: Formulation, Sensitivity analysis, Change in the constraints, Cost coefficients, Coefficients of the constraints, Addition and deletion of variable, Constraints. Integer Programming: Introduction, formulation, Gomory cutting plane algorithm, Zero or one algorithm, Branch and bound method Stochastic programming, Basic concepts of probability theory, Random variables, distributions, mean, Variance, Correlation, Co–variance, Joint probability distribution, Stochastic linear, Dynamic programming. Geometric Programming: Polynomials, arithmetic, Geometric inequality, Unconstrained, Non-traditional optimization Techniques: Genetic Algorithms, Steps, Solving simple problems Comparisons of similarities and dissimilarities between traditional and non-traditional techniques, Particle Swarm Optimization.

Course Outcomes

Upon successful completion of the course, the students will be able to:

CO1: Comprehend the insight of optimization requirements for any system.

CO2: Identify the conventional and new state of the art optimization techniques.

CO3: Apply principles of usage of optimization techniques for electronic design.

CO4: Assess and analyse the performance of optimized designs.

Books and References

1. Optimization Theory & Applications by S. S. Rao, John Wiley & Sons, 1978.
2. Optimization for Engineering Design: Algorithms and Examples by K. Deb, PHI Learning Private Limited, 2012.
3. Optimization: Theory and Practice by M. C. Joshi and K. M. Moudgalya, Cambridge Alpha Science International Ltd., 2004.

Course Name: **Applied Linear Algebra for Signal Processing, Data Analytics and Machine Learning**
Course Code: **EC-742**
Course Type: **Program Elective-I**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To introduce all the basic and advanced concepts in Linear Algebra with a strong focus on applications. Linear Algebra is one of the fundamental tools that has.
- To introduce applications of Linear Algebra in diverse fields such as Machine Learning, Data Analytics, Signal Processing, Wireless Communication, Operations Research, Control and Finance.
- To learn about the novel cutting edge applications of linear algebra in various fields such as Machine Learning, Data Analytics, Signal Processing, Wireless Communication.

Course Content

Introduction to vectors, properties and applications, Introduction to matrices and Applications Circuits, Graphs, Social Networks, Traffic flow, Eigenvalue decomposition, properties and Applications Principal component analysis (PCA), Eigen faces for facial recognition. Singular value decomposition (SVD) and Applications Beamforming in MIMO, Dimensionality reduction, Rate maximization in wireless, MUSIC algorithm, Linear regression and Least Squares. Applications: System identification, linear regression, Support vector machines (SVM), kernel SVMs, Optimal linear MMSE estimation. Applications MMSE Receiver, Market prediction and forecasting, ARMA models. Data analytics: Recommender systems, user rating prediction, Structure of FFT/ IFFT matrices, properties, System model for OFDM/ SC-FDMA, Signal processing in OFDM systems. Modeling of Dynamical systems Examples, Solution of autonomous linear dynamical systems (LDS), solution of with inputs and outputs, Unsupervised learning: Centroid based clustering, probabilistic model-based clustering and EM algorithm, Linear perceptron. Training a perceptron stochastic gradient. Compressive sensing, orthogonal matching pursuit for sparse signal estimation. Discrete time Markov chains Applications: supply chain management, forecasting, Operations research resource and inventory management.

Course Outcomes

Upon successful completion of the course, the students will be able to:

CO1: Understand the basics of Linear Algebra

CO2: Understand applications of Linear Algebra in diverse fields such as Machine Learning, Data Analytics, Signal Processing, Wireless Communication, Operations Research, Control and Finance

CO3: Understand Operations research resource and inventory management.

Books and References

1. Introduction to Linear Algebra: Gilbert Strang.
2. Fundamentals of Wireless Communication. David Tse, Pramod Viswanath.
3. Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow: Concepts, Tools, and Techniques to Build Intelligent Systems, Third Edition by Aurélien Géron Shroff/O'Reilly Publisher.

Course Name: **Electromagnetic Interference and Compatibility**
Course Code: **EC-743**
Course Type: **Program Elective-II**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To familiarize with the fundamentals that are essential for electronics industry in the field of EMI / EMC
- To understand EMI sources and their measurements.
- Concept of signal integrity in ICs, conducted emissions and electromagnetic radiation susceptibility, and crosstalk and shielding.
- To understand the various techniques for electromagnetic compatibility.

Course Content

Basic Concepts Introduction and Definition of EMI and EMC with examples, Various Parameters, Sources of EMI, EMI coupling modes - CM and DM, ESD Phenomena and effects, Transient phenomena and suppression, Various issues of EMC, EMC Testing categories. Coupling Mechanism Electromagnetic field sources and Coupling paths, Coupling via the supply network, Common mode coupling, Differential mode coupling, Impedance coupling, Inductive and Capacitive coupling, Radiative coupling, Ground loop coupling, Cable related emissions and coupling. EMI Mitigation Techniques Working principle of Shielding and Murphy's Law, LF Magnetic shielding, Apertures and shielding effectiveness, Choice of Materials for H, E, and free space fields, Gasketting and sealing, PCB Level shielding, Principle of Grounding, Isolated grounds, Grounding strategies for Large systems. Standard and Regulations Need for Standards, Standards for EMI/EMC, National and International EMI Standardizing Organizations: IEC, ANSI, FCC, AS/NZS, CISPR, BSI, CENELEC, and ACEC, Electro Magnetic Emission and susceptibility standards and specifications. Measurement Methods and Instrumentation EMI Shielding effectiveness tests, Open field test, TEM cell for immunity test, Shielded chamber, Shielded anechoic chamber, EMI measuring instruments.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Real-world EMC design constraints and make appropriate tradeoffs to achieve the most cost-effective design that meets all requirements.
CO2: Designing electronic systems that function without errors or problems related to electromagnetic compatibility.
CO3: Diagnose and solve basic electromagnetic compatibility problems.

Books and References

1. Introduction to Electromagnetic compatibility, C. R. Paul, Wiley & Sons.
2. Principles of Electromagnetic Compatibility, B. Keiser, Artech House.
3. Field Theory of Guided waves, R. E. Collin, Wiley-IEEE Press.
4. Elements of Electromagnetics, M. N. O. Sadiku, Oxford University Press.

Course Name: **Advanced Engineering Electromagnetics** Course Code: **EC-744** Course Type: **Programme Elective-II**	
Contact Hours/Week: **4L**	Course Credits: **04**

Course Objectives

- To impart knowledge about the propagation of electromagnetic wave and power carried by it.
- To introduce the fundamental concepts relevant to electromagnetic wave behaviour at media interface and its polarization.
- To enable the students to understand the electromagnetic wave propagation in different guided media and its nature if media is confined with electric and magnetic boundaries.

Course Content

Electromagnetics: Electrostatic Problems and their solutions, Separation of variables in rectangular, Cylindrical and spherical systems, Green's functions, Maxwell's equations, Electromagnetic Waves, Time domain equivalent and its relevance, Propagation of Waves in different medias like Dielectric interface etc. under oblique incidence plane waves in cylindrical system, Bessel's and Hankel's function, Scattering problems under different conditions, Wave functions in planar, Cylindrical and spherical form. Full wave analysis of different types of waveguides including solutions to TE/TM/HE modes, Parallel plate waveguide, Dielectric slab waveguide, Cylindrical dielectric waveguide, Strip line analysis, Microstrip line as resonator structure, Quasi TEM modes in microstrip line, Discontinuities in microstrip line, Boxed microstrip line, Resonant cavities: Cylindrical, and Dielectric resonators.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Describe the concept of wireless communication and how radio wave propagates.

CO2: Describe the fundamental concept of PCB circuit design.

CO3: Describe the design of low loss and high power electromagnetic wave guides.

CO4: Design dirrent types of resonator and how to use them for filters and antennas application.

Books and References

1. Time Harmonic Electromagnetic Fields, R. F. Harrington, Wiley-IEEE Press
2. Field Theory of Guided waves, R. E. Collin, Wiley-IEEE Press.
3. Elements of Electromagnetics, M. N. O. Sadiku, Oxford University Press.
4. Bluetooth Electromagnetism: Theory and Applications, Ashutosh and Pramanik, Prentice Hall India Learning Private Limited.

Course Name: **RF and Microwave Circuit Design** Course Code: **EC-745** Course Type: **Programme Elective-II**	
Contact Hours/Week: **4L**	Course Credits: **04**

Course Objectives

- To understand theoretical aspects of transmission line, network analysis, filters, couplers low noise amplifier and power amplifier.
- To understand use of Smith Chart for high frequency circuit design.
- To design filters, couplers, power dividers, low noise amplifier and power amplifiers.

Course Content

Transmission Lines theory: Waves propagation in transmission line, Parameters, Concepts of propagation constant, Characteristic impedance, Reflection coefficient, Wave velocities and dispersion, Smith chart, Impedance transformers, Generator and load mismatches, Lossy transmission lines. Network analysis: S (scatter), Z, Y, ABCD and other multi-port parameters, Impedance matching and tuning. Printed couplers, Filters, Power dividers, Directional couplers, Transmission line resonators. Two port power gains, Stability criterion, Low noise amplifier design for maximum gain, Constant gain and specific gain, Input and output matching networks using lumped element and distributed elements, large signal scattering parameters, Design of power amplifier, Introduction of microwave mixers, Mixer characterization, Microwave transistor oscillators.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Describe the transmission line concept.

CO2: Apply different network analysis theory in filters, power dividers, amplifiers etc.

CO3: Describe microwave filters, couplers, power dividers.

CO4: Describe the concept of low noise amplifier, power amplifier and microwave mixer.

Books and References

1. Microwave Engineering, D. M. Pozar, 4th Edition, Wiley, 2011.
2. Foundations of Microstrip Circuit Design, T. C. Edwards and M. B. Steer, 4th Edition, Wiley-IEEE Press, 2016.
3. Elements of Electrornagnetics, M. N. O. Sadiku, 3rd Edition, Oxford University Press, New York, 2001.
4. Microwave Active Circuit Analysis and Design, C. Poole and I. Darwazeh, Elsevier
5. Fundamentals of RF and Microwave Transistor Amplifiers, I. J. Bahl, John Wiley & Sons

Course Name: **Advanced Antenna and Electromagnetic Metamaterials: Concept and Applications**
Course Code: **EC-746**
Course Type: **Programme Elective-II**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To impart knowledge about the advanced concepts of antenna engineering.
- To introduce the design principle relevant to Advanced Antennas for different applications.
- To enable the students to understand the concept of Electromagnetic Metamaterials.
- To introduce the design principle relevant to Metamaterials for various applications.

Course Content

Definitions & Preliminary Information: Application areas of Antennas, Maxwell's Equations and Boundary conditions, Wave Equations, Infinitesimal (Hertzian) Dipoles, Monopoles, Inverted-F Antennas. Aperture-type and Microstrip Antennas: Radiation from apertures, aperture distribution, Transmission line and Cavity model for patch antennas, circularly polarized microstrip antenna, Microstrip patch and printed dipole arrays. Advanced Antennas: Travelling wave and Broadband Antennas, Frequency Independent Antennas, Antenna Miniaturization, and Fractal Antennas, Smart Antennas: Concept and Benefits of Smart Antennas, MIMO Antenna configurations, Pattern and polarization diversity, Mutual coupling reduction techniques, correlation coefficients, Massive MIMO system design. Metamaterials Background and Spatial Metamaterials: General Historical perspective and idea of Metamaterials (MTMs), Plane-wave propagation in simple medium, Dispersive model for the dielectric permittivity, Phase velocity and group velocity. Spatial Metamaterials: Metamaterials and homogenization procedure, Split-ring resonator media, Media with negative permittivity and permeability: theory and properties, Origins of negative refraction and other properties. Different Metamaterials and applications: Transmission Line Metamaterials: Ideal Homogeneous CRLH TLs (Composite Right-Left Handed Transmission Lines), LC Network Implementation and distributed 1D CRLH Structures, Conversion from Transmission Line to constitutive Parameters, Negative and Zeroth-Order Resonators. Meta-surface concepts: Artificial High-Impedance Surface design, EBG (Electromagnetic Bandgap Structures), Gain-enhancement in antennas using MTM, Miniaturization using MTM, Design of FSS Radomes for EMI Shielding and Absorbers, Beam-steering using Intelligent Reflecting Surfaces (IRS).

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Describe the antenna design principle for advanced antennas.

CO3: Apply principles of radiation from the conducting surfaces and aperture surfaces at RF frequencies and assess the numerical techniques for the analysis of the antennas.

CO4: Describe the need for metamaterials and their design principle.

CO5: Apply and design different metamaterials for specific applications.

Books and References

1. Field and Wave Electromagnetics, D. K. Cheng, Pearson Education Asia Ltd, Second Edition, 2006.
2. Antenna Theory: Analysis and Design, C. A. Balanis, John Wiley, Fourth Edition, 2016.
3. Antenna Theory and Design, W. L. Stutzman and G. A. Thiele, John Wiley & Sons Inc, 1981.
4. Antennas, J. D. Karus, McGraw Hill, 1988
5. Microstrip antennas, I. J. Bahl and P. Bhartia, Artech house, 1980.
6. Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications, The Engineering Approach, C. Caloz and T. Itoh, John Wiley & Sons, Inc., Hoboken, New Jersey, 2006.
7. Physics and Applications of Negative Refractive Index Materials, S. A. Ramakrishna and T. M. Grzegorczyk, CRC Press, Taylor & Francis Group and SPIE Press, 2009.
8. Negative Refraction Metamaterials: Fundamental Principles and Applications, G. V. Eleftheriades and K. G. Balmain Copyright: IEEE, John Wiley & Sons, Inc., Hoboken, New Jersey, 2005.

Course Name: **Nanophotonics and Plasmonics: Concept and Applications**
Course Code: **EC-747**
Course Type: **Program Elective-II**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

This course explains the concepts and applications of Nanophotonic and plasmonics for future communication devices. It focuses on the Photonic Crystals, Nanophotonics in metals, and Transmission through apertures and films, Simulation and Design of different photonic and plasmonics components.

Course Content

Introduction to Photonics: Electromagnetic waves; light; Maxwell equations; Wave equation; Modes, laser sources, semiconductor quantum wells, photo detectors, quantum dots, nanowires, Dielectric optical waveguides, directional coupler, Machzehnder interferometer, Optical microresonators etc. Photonic Crystals: Photonic bandgap (PGB). PBG structures, wave propagation, Construction methods, Applications: wave guides and photonic crystals fibres, optical microcavities, Photonic VLSI. Nanophotonics in metals: Electromagnetics of Metals, Electromagnetic Wave Propagation, Dielectric function and dispersion, Surface Plasmon polaritons, Single and multilayer systems, Exaction of surface Plasmon, plasmonic waveguides and resonators, localized surface plasmons, Nanoantennas. Metamaterials and Negative Index at Optical Frequencies. Transmission through apertures and films: Theory of Diffraction by Sub-Wavelength Aperture, Extraordinary Transmission, Directional Emission via Exit Surface Patterning, Localized Surface Plasmons and Light Transmission Through Single Apertures, Emerging Applications of Extraordinary Transmission, Transmission of Light Through a Film Without Apertures. Simulation and Design: Optical microresonators, guiding bending and splitting of light through photonic crystals, microcavity based MUX and DEMUX, photonic crystal fiber, plasmonic waveguides and resonators, Nanoantennas, Extraordinary transmission, Bull's eye structures, Metamaterials.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the basics of photonics.

CO2: Understand the photonic crystals and their application.

CO3: Understand the interaction of light with metal.

CO4: Understand and analyse the transmission through apertures and films.

CO5: Design and analyse the different photonics and plasmonic components for different applications.

Books and References

1. Fundamentals and Applications, Stefen A. Maer, Springer 2007.
2. Nanophotonics with Surface Plasmon, Vladimir M. Salaev, Part II, 2006, Photonic Spectra.
3. Photonic crystals: Molding the flow of light, J.D. Joannopoulos, 2nd Edition, 2008 Princeton University Press
4. Integrated Photonics: fundamentals, G. Lifante, Wiley.

Course Name: **Wavelet Transform and Applications**
Course Code: **EC-748**
Course Type: **Program Elective-II**

Contact Hours/Week: **4L** Course Credits: 04

Course Objectives

- To introduce the concepts of inner product space.
- To equip students with various topics related to wavelet transforms and multiresolution analysis.
- To introduce time-frequency analysis and its applications.

Course Content

Inner Product Spaces: Definition of Inner Product; The Spaces L2 and l2, Convergence in L2 Versus Uniform Convergence, Schwarz and Triangle Inequalities, Orthogonality, Orthogonal Projections, Gram–Schmidt Orthogonalization, Linear Operators and their Adjoints, Least Squares and Linear Predictive Coding, Biorthogonality Fourier theory and Continuous Wavelet Transform: Introduction, Computation of Fourier Series, The Complex Form of Fourier Series, Convergence Theorems for Fourier Series, Fourier transform, Discrete time Fourier transform, Discrete Fourier transform, Short-time Fourier transform, uncertainty principle; Continuous Wavelet Transform, Inversion Formula for the Wavelet Transform, time-frequency analysis, Haar Wavelet Analysis: Haar Wavelets, The Haar Scaling Function, Basic Properties of the Haar Scaling Function, The Haar Wavelet, Haar Decomposition and Reconstruction Algorithms, Decomposition, Reconstruction, Filters and Diagrams. Multiresolution Analysis: The Multiresolution Framework, Definition and axioms, The Scaling Relation, The Associated Wavelet and Wavelet Spaces, Decomposition and Reconstruction Formulas & implementation, Iterative Procedure for Constructing the Scaling Function The Daubechies Wavelets: Daubechies' Construction, Classification, Moments, and Smoothness, Computational Issues, The Scaling Function at Dyadic Points. Other Wavelet Topics: Computational Complexity of Wavelet Algorithm, Wavelet Packets, Wavelets in Higher Dimensions, Relating Decomposition and Reconstruction, Coiflets, Symlets, Biorthogonal wavelets

Course Outcomes:

Upon successful completion of the course, the students will be able to
CO1: Differentiate continuous and discrete wavelet analysis.
CO2: To analyze various methods of time-frequency analysis.
CO3: Gain the knowledge of wavelet transform, multiresolution Analysis and its applications.

Books and References:

1. A First Course in Wavelets with Fourier Analysis, 2nd Edition by Albert Boggess, Francis J. Narcowich.
2. A Wavelet Tour of Signal Processing, 3rd Edition, The Sparse Way by Stephane Mallat, Academic Press, December 2008.
3. Ten Lectures on Wavelets by Ingrid Daubechies.

Course Name:	**mm-Wave Wireless Communication for 5G and Beyond**
Course Code:	**EC-749**
Course Type:	**Program Elective-II**
Contact Hours/Week: **4L**	Course Credits: **04**

Course Objectives

- Learning the basics of past, present, and future standards and trends of mobile communications.
- Providing a basic understanding of the key technologies and enablers of 5G and beyond 5G communication systems.
- Be familiar with terminologies such as massive MIMO, mm-Wave, NOMA, wireless powered communications, machine learning for wireless communications, etc.
- Developing an analytical capability for solving various problems of next generation wireless communications.

Course Content

Transmitter-Receiver Structure of Advanced Communication System, Wireless Channel–A ray tracing model, Understanding of various channel related parameter statistics. Narrow band and broadband aspect, RMS Delay spread & Doppler Effect on channel, Time Varying Model, Doppler Impact on coherence BW. Introduction to time series, AR,ARMA,MA process, Doppler with AR process model, Coherence time and parameter summery, Basic ISI channel, Channel estimation and Equalizer, Precoder and MIMO, Basics of mm-wave spectrum Angle of arrival and angle of departure, 3D concepts, AoA, AoD , mm-Wave channel model with RX beaming, mm-Wave channel model with RX beaming, mm-wave channel model, mm-Wave channel model, Basics of Beamforming, Single Antenna beamforming, Concept of antenna many fold vector, 3D Concept of antenna many fold vector, Different Geometry of antenna from electrical point of view, Basics of Beamforming pattern, SISO Beamforming, MIMO Beamforming, Structural implementation of MIMO Beamforming, Different Level of Beamforming, MIMO Beamforming in Transmitter side, MIMO Beamforming in Receiver side, MIMO Beamforming in Receiver side, Mathematical description of MIMO Beamforming Equalizer based detector, Parameter to be designed in MIMO Beamforming, OFDM Data Model, OFDM Data model General OFDM, OFDM spectrum and CFO, MIMO OFDM structure , MIMO OFDM decode and beamforming, Design parameter estimation, CFO and other impairment and their effects, MU System, Multi User Hybrid beam and impairment and analysis

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Distinguish and understand the major cellular communication standards and wireless communications networks.

CO2: Understand the concepts of mm-Wave Wireless Communication for 5G and Beyond.

CO3: Understand the concepts of Beamforming, MIMO and OFDM.

CO4: Describe different technologies of 5G and beyond 5G communications

CO5: Apply the basic understanding to solve the existing problems of next-generation communications

CO6: Identify the state-of-the-art problems and apply the basic knowledge for finding out the required solutions.

Books and References

1. Fundamentals of Wireless Communication. David Tse, Pramod Viswanath, Cambridge University Press.
2. Wireless Communications by Andrea Goldsmith, Cambridge University Press.
3. Principles of Modern Wireless Communications Systems - Aditya Jagannatham, McGraw Hill Education.

Course Name: **Biomedical Signal Processing**
Course Code: **EC-750**
Course Type: **Program Elective-III**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To study the origin and process of acquisition of principal bioelectric signals like ECG, EEG, EMG etc.
- To understand the background material required for processing of the biomedical signals.
- To understand the utility of biomedical signals for disease diagnosis like ECG for Cardiovascular diseases and EEG for sleep disorders.
- To explore the utility of bioelectrical signals for developing other application.

Course Content

Introduction: Genesis and significance of bioelectric potentials, ECG, EEG, EMG and their monitoring and measurement, spectral analysis, digital and analog filtering, correlation and estimation techniques, AR/ARMA models, adaptive filters. ECG: Pre-processing, measurements of amplitude and time intervals, classification, QRS detection, ST segment analysis, baseline wander removal, waveform recognition, morphological studies and rhythm analysis, automated diagnosis based on decision theory ECT compression, evoked potential estimation. EEG: Evoked responses, epilepsy detection, spike detection, averaging techniques, removal of artifacts by averaging and adaptive algorithms, pattern recognition of alpha, beta, theta and delta waves in EEG waves, sleep stages. EMG: Wave pattern studies, biofeedback, zero crossing, integrated EMG, time frequency methods, and wavelets in biomedical signal processing.

Course Outcomes

Upon successful completion of the course, the students will be able to
CO1: Understand the acquisition methods for collecting ECG, EEG and EMG signals.
CO2: Develop mathematical models for analysis of biomedical signals.
CO3: Identify the characteristic points in an ECG waveform and understand their relevance.
CO4: Understand the EEG and EMG signal analysis and apply them to develop practical applications like BCI, prosthetic limbs.

Books and References

1. Biomedical Signal Analysis by R.M. Rangayyan, Wiley.
2. Biomedical Signal Processing: Principles and techniques by D.C. Reddy, Tata McGraw Hill, New Delhi.
3. Biomedical Signal Processing by Willis J Tompkins, Prentice Hall.
4. Bioelectrical Signal Processing in Cardiac & Neurological Applications by L. Sörnmo, Elsevier.

Course Name: **Statistical Signal Processing**
Course Code: **EC-751**
Course Type: **Program Elective-III**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives:

- To develop the ability to process discrete random signals.
- To study the algorithms for modeling of stochastic signals.
- To study the basic classical and Bayesian estimation techniques.
- To familiarize with non-parametric and parametric spectrum estimation techniques.

Course Content

Introduction: Signal Processing methods, Review of Probability Theory, Random Variables and Stochastic Processes. Random Signal Analysis: Discrete random signals, Spectral representation of discrete random signals, filtering random processes, Random signal models AR, MA and ARMA. Power spectrum and phase of the signal generating system, Least squares method, Padé approximation, Prony's method, finite data records, stochastic models, Levinson-Durbin recursion; Schur recursion; Levinson recursion. Spectrum Estimation: Nonparametric methods, minimum-variance spectrum estimation, maximum entropy method, parametric methods, frequency estimation, principal components spectrum estimation. Estimation Theory: Estimation of moments, classical and Bayesian estimation. MAP, ML, MMSE, and MAVE estimators for model parameters and signal. Cramer-Rao Bound on the minimum estimator variance. Introduction to Hidden Markov Models, Noise and Distortion.

Course Outcomes

Upon successful completion of the course, the students will be able to
CO1: Apply the principles of random processes for analysis of linear systems.
CO2: Model random signals and appreciate its utility in signal interpolation, signal prediction and signal compression.
CO3: Implement estimation techniques on signal processing problems and acquire ability to estimate parameters using them.
CO4: Understand the non-parametric and parametric spectrum estimation techniques.

Books and References

1. Probability, Random Variables and Stochastic Processes by A. Papoulis, McGraw Hill.
2. Statistical Digital Signal Processing and Modelling by Monson H. Hayes, John Wiley & Sons Inc.
3. Fundamentals of Statistical Signal Processing, Volume I: Estimation Theory by Steven M. Kay, Prentice Hall, USA.
4. Advanced Digital Signal Processing and Noise Reduction by Saeed V. Vaseghi, John Wiley & Sons, Ltd, Singapore.
5. Statistical and Adaptive Signal Processing by Dimitris G. Manolakis, Vinay K. Ingle and Stephen M. Kogan, McGraw Hill.
6. Detection, Estimation and Modulation Theory, Part 1 and 2 by Harry L. Van Trees, John Wiley & Sons Inc.
7. Optimal and Adaptive Signal Processing by Peter M. Clarkson, CRC Press London.

Course Name: **Radar Signal Processing**
Course Code: **EC-752**
Course Type: **Program Elective-III**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To introduce the students to the concepts of radar signal processing.
- Analyze radar waveforms for specific applications.
- Develop skills in radar signal detection and processing.

Course Content

Introduction to radar systems, History and applications of radar, Basic radar function, Radar classifications, elements of pulsed radar, The radar equation, A preview of basic radar signal processing.

Signal models, Components of a radar signal, Amplitude models, Clutter, Noise model and signal-to-noise ratio, Jamming, Frequency models: the Doppler shift, spatial models.

Sampling and quantization of pulsed radar signals, Domains and criteria for sampling radar signals, Sampling in the fast time dimension, Sampling in slow time: selecting the pulse repetition interval, Sampling the Doppler spectrum.

Radar waveforms, Introduction, The waveform matched filter, Matched filtering of moving targets, The radar ambiguity function, The pulse burst waveform, frequency-modulated pulse compression waveforms, The stepped frequency waveform, Phase-modulated pulse compression waveforms, Costas frequency codes.

Doppler processing, Alternate forms of the Doppler spectrum, Moving target indication (MTI), Pulse Doppler processing, Dwell-to-dwell stagger, Additional Doppler processing issues, Clutter mapping and the moving target detector.

Detection of radar signals in noise: detection fundamentals, detection criteria, Threshold detection in coherent systems, Threshold detection of radar signals, binary integration, CFAR detection, CA CFAR, Additional CFAR topics.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the radar signal processing fundamentals, including signal models, clutter characteristics, and Doppler processing techniques.

CO2: Design radar waveforms tailored to specific applications, optimizing radar performance in various scenarios.

CO3: Demonstrate proficiency in radar signal detection and processing techniques, including threshold detection, CFAR algorithms, and Doppler processing, enabling accurate target detection and tracking.

CO4: Develop problem-solving skills in radar signal processing, enabling them to analyze complex radar signal scenarios and apply appropriate techniques to address challenges effectively, contributing to improved radar system design and operation.

Books and References:

1. Fundamentals of Radar Signal Processing by Mark A. Richards, McGraw-Hill, 2005.
2. Adaptive Radar Signal Processing by Simon Haykin, John Wiley & Sons, 2006.
3. Introduction to Radar Systems by Skolnik, M.I., 2nd Ed., McGraw-Hill, 1997.

Course Name:	**Adaptive Signal Processing**
Course Code:	**EC-753**
Course Type:	**Program Elective-III**
Contact Hours/Week: **4L**	Course Credits: **04**

Course Objectives

- To introduce signal processing techniques for adaptive systems.
- To understand the applications of adaptive systems in the fields of communications, radar, sonar, seismology, navigation systems and biomedical engineering.
- To study the basic principles of adaptation, various adaptive signal processing algorithms for applications like adaptive noise cancellation, interference canceling, system identification, etc.

Course Content

Linear Optimum Filtering and Adaptive Filtering, Linear Filter Structures, Adaptive Equalization, Noise Cancellation and Beam Forming. Optimum Linear Combiner and Wiener-Hopf Equations, Orthogonality Principle, Minimum Mean Square Error and Error Performance Surface, Steepest – Descent Algorithm and its Stability. LMS Algorithm and its Applications, Learning Characteristics and Convergence Behaviour, Mis-Adjustment, Normalized LMS and Affine Projection Adaptive Filters, Frequency Domain Block LMS Algorithm. Least Squares Estimation Problem and Normal Equations, Projection Operator, Exponentially Weighted RLS Algorithm, Convergence Properties of RLS Algorithm, Kalman Filter as the Basis for RLS Filter, Square-Root Adaptive Filtering and QR- RLS Algorithm, Systolic-Array Implementation of QR – RLS Algorithm. Forward and Backward Linear Prediction, Levinson-Durbin Algorithm, Lattice Predictors, Gradient-Adaptive Lattice Filtering, Least-Squares Lattice Predictor, QR-Decomposition Based Least-Squares Lattice Filters.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Comprehend design criteria and modeling of adaptive systems and theoretical performance evaluation.
CO2: Design a linear adaptive processor.
CO3: Apply mathematical models for error performance and stability.
CO4: Comprehend the estimation theory for linear systems and modeling algorithms.

Books and References

1. Adaptive Filter Theory, Haykin, S., Pearson Education. 2002
2. Adaptive Signal Processing, Widrow, B. and Stearns, S.D., Pearson Education, 1985
3. Statistical and Adaptive Signal Processing, Manolakis, D.G., Ingle, V.K. and Kogon, M.S., Artech House, 2005
4. Statistical Signal Processing: Detection, Estimation, and Time Series Analysis by Scharf, L.L., Pearson.

Course Name: **Multi-rate Signal Processing** Course Code: **EC-754** Course Type: **Program Elective-III**	
Contact Hours/Week: 4**L**	Course Credits: **04**

Course Objectives

- To provide an in-depth treatment of both the theoretical and practical aspects of multirate signal processing.
- To provide the fundamentals of multirate, Sample rate conversion and efficient implementations using polyphase filters
- The filter bank theory and implementation, including quadrature mirror, conjugate quadrature, and cosine modulated filter banks along with their relationship to wavelet transform area also covered in this course.

Course Content

Fundamentals of Multirate systems: Introduction, Basic multirate operations, interconnection of building blocks, The polyphase representation, multistage implementation, some applications of multirate systems, special filters and filters banks. Maximally decimated filter bank: Introduction, Errors created in the QMF bank, A simple alias free QMF system, M-Channel filter bank, polyphase representation, perfect reconstruction systems, tree structure filter banks. Paraunitary Perfect Reconstruction Filter banks: Lossless Transfer matrices, filter banks properties induced by paraunitariness, Two channel FIR Paraunitary QMF banks, M –channel FIR paraunitary Filter bank. Cosine Modulated Filter Banks: The pseudo QMF bank, Design of the Pseudo QMF bank, Efficient polyphase structures, deeper properties of cosine matrices, Cosine modulated perfect reconstruction systems. Wavelet Transform and Its Relation to Multirate Filter Banks: Introduction, Short Fourier transform, The wavelet transforms, Discrete-time orthogonal wavelets, continuous time orthogonal wavelet basis.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the basic multirate operations.
CO2: Analyse the type M-channel filter bank.
CO3: Understand the perfect reconstruction filter bank.
CO4: Understand the cosine modulated filter banks.
CO5: Analyse the wavelet and its ralation to filter banks.

Books and References

1. Multirate Systems and Filter Banks, P. P .Vaidynathan, Pearson Education Inc.
2. Wavelets and filter banks, D. Strang and T. Nguyen, Wellesley-Cambridge Press.
3. Digital Signal Processing: Principles, Algorithms and Applications, J. G. Proakis and D. G. Manolakis, Pearson Education.
4. Multirate Digital Signal Processing, N.J. Fliege, John Wiley and Sons.

Course Name: **Advanced Spectrum Engineering** Course Code: **EC-755** Course Type: **Program Elective-III**	
Contact Hours/Week: **4L**	Course Credits: **04**

Course Objectives

- To impart knowledge about the basic spread spectrum techniques that are used in CDMA based cellular communication systems, including direct sequence spread spectrum and frequency-hopped spread spectrum.
- To introduce the fundamental mathematical concepts relevant to design aspects of the PN sequence generators.
- To enable the students to understand the factors that affect the practical implementation of IS-95, CDMA-2000 and WCDMA systems.

Course Content

Introduction: Concept of Multiple Access Systems, Narrowband and Broadband Systems, Advantages of Spread Spectrum Systems. Principles of Direct Spread Spectrum: Direct Spectrum System: Definition and Concepts, Spreading Sequences and Waveforms, Random Binary Sequence, Shift-Register Sequences, Periodic Auto Correlations, Polynomials over The Binary Field, Systems with PSK Modulation, Power Spectral Density of DSS-CDMA, Pulsed Interference, De-Spreading with Matched Filter. Spreading Code Acquisition and Tracking: Initial Code Acquisition, Acquisition Strategy: Serial Search, Parallel Search, Multi-Dwell Detection, False Alarm and Miss Probability for Matched Filter Receiver, False Alarm and Miss Probability for Radiometer, Mean Overall Acquisition Time for Serial Search. Performance of Spread Spectrum System: Link Performance of Direct Sequence Spread Spectrum CDMA In (I) Additive White Noise Channel (Ii) Multipath Fading Channel. Concept of Rake Receiver, Performance of RAKE Receiver in Multipath Fading. Frequency Hoped Systems: Concepts and Characteristics, Modulations, MFSK, Hybrid Systems, Frequency Synthesizers, Direct Frequency Synthesizer, Digital Frequency Synthesizer, Indirect Frequency Synthesizers. CDMA systems: CDMA-IS-95: Forward link Channels, Reverse link Channels, Power Controls and Handoff Procedure in IS-95, Overview of CDMA based 3G Systems (CDMA-2000 and WCDMA).

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Identify spread spectrum techniques that are used in CDMA based cellular communication systems, including direct sequence spread spectrum and frequency-hopped spread spectrum.

CO2: Apply the principles of linear algebra to design PN sequence generators.

CO3: Analyze the performance of CDMA systems in various wireless Channels.

CO4: Assess the practical implementation of IS-95, CDMA-2000 and WCDMA systems.

Books and References

1. Principles of Spread Spectrum Communication Systems by Don Torrieri, Springer Science & Business Media, Inc.
2. CDMA: Principles of Spread Spectrum Communication by Andrew J. Viterbi, Addison- Wesley Publishing Company.
3. Introduction to CDMA Wireless Communications by Mosa Ali Abu-Rgheff, Elsevier Academic Press.
4. Code Division Multiple Access-CDMA by R. Michael Buehrer, Morgan & Claypool Publishers Series.
5. CDMA Systems Engineering Handbook by Jhong S. Lee and Leonard E. Miller, Artech House Publishers.
6. IS-95 CDMA and CDMA-2000 by Vijay K Garg, Pearson Education.
7. OFDM for Wireless Communications Systems by Ramjee Prasad, Artech House, Inc.

Course Name: **6G and Terahertz Communication**
Course Code: **EC-756**
Course Type: **Program Elective-III**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To provide students with the necessary knowledge, skills and tools to contribute to the development of 6G wireless communication networks in the THz band.

Course Content

Introduction to the Terahertz Band, Properties of Terahertz Radiation, Applications in Communications and Sensing at the Macro and Nano Scales, Terahertz Device Technologies, Technology Pathways to Terahertz Front-ends Electronics, Photonics, Plasmonics, Antenna Systems, Antenna, Antenna Arrays and Reflect-arrays, Lenses and Metasurfaces, Ultra-broadband Digital Back-ends, Experimental Testbeds for Terahertz Communications Research, Terahertz Wave Propagation and Channel, modelling, Indoors/Outdoors, Line-of-sight Propagation, Non-line-of-sight Propagation, Multi-path Propagation, Extreme Environments, Intra-body Terahertz Propagation, Satellite Terahertz Propagation, Terahertz Communications and Signal Processing, Modulation, Multi-user Interference. Channel Coding and Error Control, Physical Layer Security, Ultra-massive MIMO, Terahertz Network Architecture and Protocol Stack, Medium Access Control, Neighbor Discovery, Relaying Routing, Regularization and standardization, Coexistence of Passive and Active Services above 100 GHz, Early standardization efforts: IEEE 802.15.3d.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Demonstrate knowledge of the main differences between THz communication networks and traditional wireless networks at lower (microwave, millimeter-wave) and higher (infrared, visible) frequency bands.

CO2: Identify and describe the main technologies at the basis of THz transceivers and antennas.

CO3: Design and numerically simulate utilizing finite-element-methods radiating ultra-directional antenna systems at THz frequencies.

CO4: Demonstrate knowledge of the main phenomena affecting the propagation of THz signals.

CO5: Interpret experimental data sets, including channel measurements and transmitted/received data traces.

Books and References

1. Handbook of Research on Design, Deployment, Automation, and Testing Strategies for 6G Mobile Core Network by "Senbagavalli G., T. Kavitha, Aruna Ramalingam, Velvizhi V. A.", IGI Global, 2022.
2. 6G Wireless Communications and Mobile Networking by "Xianzhong Xie, Bo Rong, Michel Kadoch", Bentham Books, 2021.

Course Name: **VLSI Design**
Course Code: **EC-701**
Course Type: **Open Elective**

Contact Hours/Week: 4**L** Course Credits: **04**

Course Objectives

- To introduce the fundamental concepts relevant to MOSFETs and physical design of VLSI circuits.
- To impart knowledge about various CMOS VLSI Design styles.
- To enable the students understand the parameters on which the circuit performance depends and their control strategies.

Course Content

Introduction to VLSI Design, Fundamentals of Enhancement Mode MOSFETs, Depletion Mode MOSFETs, Weak & strong Inversion Conditions, Threshold Voltage Concept in MOSFETs, Current-Voltage (IV), Characteristics of a MOSFET, Limitations in IV Model and MOSFET parasitic, Trends & Projections in VLSI Design & Technology, Flow of VLSI Circuit Design, Scaling in MOS devices. NMOS, CMOS Process flow, Noise Margin, Inverter Threshold Voltage, NMOS Inverter design and characteristics, CMOS Inverter Design and Properties, Delay and Power Dissipation, Parallel & Series Equivalent circuits, Static CMOS Circuit Design. Stick Diagrams, Physical Design Rules, Layout Designing, Euler's Rule for Physical Design, Reliability issues in CMOS VLSI, Latching. Static CMOS design Dynamic CMOS logic circuits. Transmission gate logic. MOS memories: ROM design, SRAM design and DRAMs.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understanding of conventional Semiconductor device MOSFET used in VLSI design.

CO2: Design of static and dynamic CMOS VLSI logic circuits for practical applications and memory design.

CO3: Use of VLSI design in designing various applications required in different engineering branches

CO4: Generate interest and competence in self-directed continuing professional development and for sustainable research and development in VLSI design for societal and global interest.

Books and References

1. CMOS Digital Integrated Circuits-Analysis & Design by S.M. Kang and Y. Leblebici, TMH.
2. Solid State Electronic Devices by B.G. Streetman and S. Banerjee, PHI.
3. Principles of CMOS VLSI Design- A Systems Perspective by Neil H E Weste and K. Eshraghian.
4. Introduction to VLSI by K. Eshraghian and Pucknell, PHI.

Course Name: **MEMS Design** Course Code: **EC-702** Course Type: **Open Elective**	
Contact Hours/Week: 4**L**	Course Credits: **04**

Course Objectives

- To impart knowledge about the need and applications of microsystem in engineering.
- To introduce the fundamental concepts relevant to fabrication and machining process of MEMS sensors and actuators.
- To enable the students to understand the various sensing and actuation mechanisms.

Course Content

Introduction to MEMS and Microsystems, MEMS Materials, Structural and Sacrificial Materials, Properties of Silicon, Polymers, Ceramics, and Composites, Basic Modeling of Elements in Electrical and Mechanical Systems, Sensors/Transducers, Sensors Characterization and Classifications, Microactuators, Application of MEMS. Silicon Growth, Additive Techniques: Oxidation, Physical Vapor Deposition, Chemical Vapor Deposition, Thin Film Deposition, Photolithography, Etching, Bulk and Surface Micromachining, Etch Stop Technique and Microstructure, Microstereolithography LIGA, and Wafer Bonding. Beam and Cantilever, Capacitive Sensors, Modeling a Capacitive Sensor, Capacitive Accelerometer, Pressure Sensors, Piezoresistance Effect and Its Modeling, Piezoresistive Sensor, Flow Measurement, Piezoelectricity, Piezoactuators, Inertial Sensors, Micro accelerometer, MEMS Gyroscope, and Parallel-Plate Actuator. Need and Classification, Temperature Coefficient of Resistance, Thermo-Electricity, Thermocouples, Thermal and Temperature Sensors, Heat Pump, Gas sensors, Micromachined Thermocouple Probe, Thermo-resistive Sensor, Thermal Flow Sensors, Pyroelectricity, Shape Memory Alloy, and Thermal Actuators. Properties of Light, Light Modulators, Beam Splitter, Microlens, Micromirrors, Digital Micromirror Devices, Light Detectors, Grating Light Valve, and Optical Switch.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Identify structural and sacrificial materials for MEMS.

CO2: Describe the fabrication steps in designing of various MEMS parts.

CO3: Apply principles for the design of Sensor and actuators.

CO4: Apply MEMS for different applications in various fields of engineering.

Books and References

1. Introductory MEMS Fabrication and Applications by T. M. Adams and R. A. Layton, Springer Publications.
2. Sensors and Transducers by M. J. Usher, McMillian Hampshire.
3. MEMS by N. P. Mahalik, Tata McGraw Hill.
4. Microsensors by R.S. Muller, Howe, Senturia and Smith, IEEE Press.
5. Analysis and Design Principles of MEMS Devices by Minhang Bao, Elsevier.
6. Semiconductor Sensors by S. M. Sze, Willy –Inderscience Publications.

Course Name: **HDL Based Design**
Course Code: **EC-703**
Course Type: **Open Elective**

Contact Hours/Week: 4**L** Course Credits: **04**

Course Objectives

- To impart knowledge about the Hardware Description Language based design approach.
- To Understand different modeling techniques used in HDL
- The ability to code and simulate any digital function in HDL.

Course Content

Introduction and levels of abstraction, Modeling and Hierarchical design concepts, Languages, Compilation & Simulation, concurrency, Logic value system, Role of CAD Tools in the VLSI design process. Lexical conventions, Data types, modules and ports, Behavioral modeling, Dataflow modeling, Structural modelling. Control & Data partitioning, Synthesis concepts, Non-synthesizable constructs, Operators, Expressions, Conditional statements, Post synthesis simulation. Procedures and timing control, Procedural blocks, Loops, Tasks and functions, Test bench modeling techniques, Path delay modeling, Timing analysis, User defined primitives, Compiler directives, and System tasks. Boolean equations, Encoders, Decoders, Multiplexers, Cascaded multiplexers, Adders, Serial adders, Comparators, Multipliers, Divider, Sorters, Shifters, Static and dynamic memories, Mealy & Moore finite state machine, Vending machines. FPGA architecture, Static timing analysis, Synchronization, Metastability, Verification methods, Implementation on FPGA, PLA based design.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Design digital circuits in HDL.

CO2: Verify behavioral and RTL models.

CO3: Synthesize and simulate RTL design to standard cell libraries and FPGAs.

Books and References

1. The Designer's Guide to VHDL (Second Ed.) by Peter J. Ashenden, Morgan Kaufmann Publishers, 2001
2. A Verilog HDL Primer by J. Bhasker, Star Galaxy Press, 1996.
3. Verilog HDL: A Guide to Digital Design and Synthesis by Samir Palnitkar, Prentice Hall, 1996.
4. The Complete Verilog Book by Vivek Sagdeo, Kluwer Academic Publishers.
5. HDL Chip Design: A Practical guide for Designing, Synthesizing and Simulating ASICs and FPGAs using VHDL or Verilog Douglas by J. Smith, Doone Pubns, 1996.
6. VHDL Coding Styles and Methodologies by Ben Cohen, Kluwer Academic Publishers, 1999.
7. A VHDL Primer by J. Bhasker (Third Ed.), Prentice Hall, 1998.

Course Name: **Mobile Communication**
Course Code: **EC-704**
Course Type: **Open Elective**

Contact Hours/Week: 4**L** Course Credits: **04**

Course Objectives

- To understand the basic cellular system concepts.
- To have an insight into the interference, frequency management and handoff management in cellular mobile system.
- To go in depth for understanding the popular GSM cellular mobile standard and wireless standards.

Course Content

Wireless Communication Systems, Applications of Wireless Communication Systems, Types of Wireless Communication Systems, Trends in Mobile Communication Systems. Basic Cellular Systems, Performance Criteria, Uniqueness of Mobile Radio Environment, Operation of Cellular Systems, Analog& Digital Cellular Systems. Concept of Frequency Reuse Channels, Co-channel Interference Reduction Factor, Desired C/I From a Normal Case in an Omnidirectional Antenna System, Handoff Mechanism, Cell Splitting. Co-channel Interference, Design of an Omnidirectional Antenna System in the Worst Case, Design of a Directional Antenna System, Lowering the Antenna Height, Power Control, Reduction in C/I by Tilting Antenna, Umbrella Pattern Effect Adjacent-Channel Interference, Near-end, Far-end Interference, Effect on Near-end Mobile Units. Frequency Management, Frequency-Spectrum Utilization, Set-up Channels, Fixed Channel Assignment Schemes, Non-Fixed Channel Assignment Schemes, Concept of Handoff, Initiation of a Hard Handoff, Delaying a Handoff, Forced Handoffs, Queuing of Handoffs, Power Difference Handoffs, Mobile Assisted Handoff, Soft Handoffs, Cell-site Handoff, Intersystem Handoff, Dropout Calls. GSM System Architecture, GSM Radio Subsystem, GSM Channel Types, Frame Structure for GSM, Signal Processing in GSM, GPRS and EDGE. Overview of Wi-Fi, WiMAX and Bluetooth Technology: Basic Features and Physical Specifications.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Discuss cellular radio concepts.
CO2: To have knowledge of the mobile system specifications.
CO3: Classify frequency and handoff management techniques in mobile communication.
CO4: Outline cellular mobile communication standards.
CO5: Analyze various methodologies to improve the cellular capacity.

Books and References

1. Mobile Cellular Telecommunications: Analog and Digital Systems by W. C. Y. Lee; Tata McGraw Hill Publication.
2. Wi-Fi, Bluetooth, Zigbee and WiMax by H. Labiod, H. Afifiand, C. D. Santis, Springer.
3. Wireless Communications: Principles and Practice by T. S. Rappaport; Pearson Publication.
4. Wireless Communications and Networks: 3G and Beyond by Iti S. Misra; Tata McGraw Hill Publication.
5. Wireless and Digital Communications by K. Feher; PHI Publication.

Course Name: **Communication Systems**
Course Code: **EC-705**
Course Type: **Open Elective**

Contact Hours/Week: 4**L** Course Credits: **04**

Course Objectives

- To understand the building blocks of analog, pulse and digital communication systems.
- To prepare mathematical background for communication signal analysis.
- To understand and analyze the signal flow in analog, pulse and digital communication systems.

Course Content

Communication process, sources of information, communication channels, base band and pass band signals, representation of signals and systems, classification and characterization of signals and systems. Amplitude modulation (AM), frequency spectrum of the AM wave, representation of AM, power relations in the AM wave, AM detector, vestigial side-band modulation.
Frequency spectrum of Frequency Modulation (FM) and Phase Modulation, generation of FM (direct and indirect method), demodulation of FM signal. Tuned Radio-Frequency (TRF) receiver, Super heterodyne receiver. Sampling process, Modulation and demodulation principles of : Pulse Amplitude Modulation (PAM), Time Division Multiplexing (TDM), Frequency Division Multiplexing (FDM), Pulse Width Modulation (PWM), Pulse Position Modulation (PPM). **:** Quantization process, Pulse Code Modulation (PCM), Differential Pulse Code Modulation (DPCM), Delta Modulation (DM), Adaptive Delta Modulation, Amplitude – Shift Keying (ASK), Frequency-Shift Keying (FSK), Phase-Shift Keying (PSK), QPSK.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Analyze the signals and systems used in communication systems in time domain and frequency domain.
CO2: Select and identify the functions of the blocks in the design of analog communication system.
CO3: Select and identify the functions of the blocks in the design of digital communication system.
CO4: Select and identify the functions of the blocks in the design of pulse modulation system.
CO5: Compare and analyze performance of communication systems in terms of bandwidth requirement, error performance and complexity in design.

Books and References

1. Electronic Communication Systems by George Kennedy
2. Communication Systems by Simon Haykin
3. An Introduction to Analog and Digital Communications by Haykin
4. Principles of Communication Systems by H. Taub and D.L. Schilling