Department of
Electronics Engineering

M. Tech. in Electronics and Communication Engineering (Signal Processing and AI)

Semester I

Sl. No	Course Type	Course Code	Course Title	Contact Hours/ Week		Credits
				L	P	
1.	PSC-1	EE602	Advanced Digital Signal Processing	3	0	3
2.	PSC-2	EE620	SOC and Embedded Systems	3	0	3
3.	PSC-3	EE667	Mobile and Satellite Communication	3	0	3
4.	PSC-4	EE668	Machine Learning for Signal Processing	3	0	3
5.	PE-I	E1/EE671	Elective 1/Convex Optimization for Signal Processing	3	0	3
6.	PSL/PSC/PE	EESL01	Signal Processing Laboratory I	0	6	3
7	PGC	PGC-601	Research Methodology and IPR	2	0	2
			Total	**17**	**6**	**20**

PSC: Program Specific Core; PSL: Program Specific Lab; PE: Professional Elective

Semester II

Sl. No	Course Type	Course Code	Course Title	Contact Hours/ Week		Credits
				L	P	
1	PSC-5	EE607	Detection and Estimation Theory	3	0	3
2	PSC-6	EE669	Deep Learning & Applications	3	0	3
3	PE-II	E2	Elective 2	3	0	3
4	PE-III	E3	Elective 3	3	0	3
5	PE-IV	E4	Elective 4	3	0	3
6	PSL/PSC/PE	EESL02	Signal Processing Laboratory II	3	6	3
7	PGC	PGC-602		2	0	2
			Total	**17**	**6**	**20**

* Four-week industrial practice school during summer vacation for scholarship students (optional)

Semester III

Sl. No	Course Type	Course Code	Course Title	Contact Hours /week	Credits
				P	
1	Dissertation & Seminar-Phase1	EE651	M. Tech. Dissertation Phase I	40	20
			Total	**40**	**20**

Semester IV

Sl. No	Course Type	Course Code	Course Title	Contact Hours /week	Credits
				P	
1	Dissertation & Seminar-Phase II	EE652	M. Tech. Dissertation Phase II	40	20
			Total	**40**	**20**

*1 Credit for Lecture/Tutorial means 1 contact hour in a week, and 1 credit for Practice/Dissertation means 2 contact hours in a week.

M. Tech. in Electronics and Communication Engineering (Radar and Communication)

Semester I

Sl. No	Course Type	Course Code	Course Title	Contact Hours/ Week		Credits
				L	P	
1.	PSC-1	EE601	RF and Microwave Circuits	3	0	3
2.	PSC-2	EE602	Advanced Digital Signal Processing	3	0	3
3.	PSC-3	EE604	Radar System Design	3	0	3
4.	PSC-4	EE620	SoC and Embedded Systems	3	0	3
5.	PE-I	E1/EE667	Elective 1/Mobile and Satellite Communication	3	0	3
6.	PSL/PSC/PE	EERL01	R&C Laboratory I	0	6	3
7	PGC	PGC-601	Research Methodology and IPR	2	0	2
			Total	**17**	**6**	**20**

PSC: Program Specific Core; PSL: Program Specific Lab; PE: Professional Elective

Semester II

Sl. No	Course Type	Course Code	Course Title	Contact Hours/ Week		Credits
				L	P	
1	PSC-5	EE609	Antenna Systems	3	0	3
2	PSC-6	EE610	Radar Signal Processing	3	0	3
3	PE-II	E2	Elective 2	3	0	3
4	PE-III	E3	Elective 3	3	0	3
5	PE-IV	E4	Elective 4	3	0	3
6	PSL/PSC/PE	EERL02	R&C Laboratory II	3	6	3
7	PGC	PGC-602		2	0	2
			Total	**17**	**6**	**20**

* Four-week industrial practice school during summer vacation for scholarship students (optional)

Semester III

Sl. No	Course Type	Course Code	Course Title	Contact Hours /week	Credits
				P	
1	Dissertation & Seminar-Phase1	EE651	M. Tech. Dissertation Phase I	40	20
			Total	**40**	**20**

Semester IV

Sl. No	Course Type	Course Code	Course Title	Contact Hours /week	Credits
				P	
1	Dissertation & Seminar-Phase II	EE652	M. Tech. Dissertation Phase II	40	20
			Total	**40**	**20**

*1 Credit for Lecture/Tutorial means 1 contact hour in a week, and 1 credit for Practice/Dissertation means 2 contact hours in a week.

M. Tech. in Electronics and Communication Engineering (Defence and Space Electronics)

Semester I

Sl. No	Course Type	Course Code	Course Title	Contact Hours/ Week		Credits
				L	P	
1.	PSC-1	EE601	RF and Microwave Circuits	3	0	3
2.	PSC-2	EE602	Advanced Digital Signal Processing	3	0	3
3.	PSC-3	EE604	Radar System Design	3	0	3
4.	PSC-4	EE654	Introduction to Space Technology	3	0	3
5.	PE-I	E1/EE667	Elective 1/Mobile and Satellite Communication	3	0	3
6.	PSL/PSC/PE	EEDL01	D&S Laboratory I	0	6	3
7	PGC	PGC-601	Research Methodology and IPR	2	0	2
			Total	**17**	**6**	**20**

PSC: Program Specific Core; PSL: Program Specific Lab; PE: Professional Elective

Semester II

Sl. No	Course Type	Course Code	Course Title	Contact Hours/ Week		Credits
				L	P	
1	PSC-5	EE609	Antenna Systems	3	0	3
2	PSC-6	EE614	EMI/EMC Design	3	0	3
3	PE-II	E2	Elective 2	3	0	3
4	PE-III	E3	Elective 3	3	0	3
5	PE-IV	E4	Elective 4	3	0	3
6	PSL/PSC/PE	EEDL02	D&S Laboratory II	3	6	3
7	PGC	PGC-602		2	0	2
			Total	**17**	**6**	**20**

* Four-week industrial practice school during summer vacation for scholarship students (optional)

Semester III

Sl. No	Course Type	Course Code	Course Title	Contact Hours /week	Credits
				P	
1	Dissertation & Seminar-Phase1	EE651	M. Tech. Dissertation Phase I	40	20
			Total	**40**	**20**

Semester IV

Sl. No	Course Type	Course Code	Course Title	Contact Hours /week	Credits
				P	
1	Dissertation & Seminar-Phase II	EE652	M. Tech. Dissertation Phase II	40	20
			Total	**40**	**20**

*1 Credit for Lecture/Tutorial means 1 contact hour in a week, and 1 credit for Practice/Dissertation means 2 contact hours in a week.

M. Tech. in Electronics and Communication Engineering (VLSI and Embedded Systems)

Semester I

Sl. No	Course Type	Course Code	Course Title	Contact Hours/ Week		Credits
				L	P	
1.	PSC-1	EE620	SOC & Embedded systems	3	0	3
2.	PSC-2	EE621	Digital IC Design	3	0	3
3.	PSC-3	EE638	Mixed Signal IC Design	3	0	3
4.	PSC-4	EE673	Real-Time Operating Systems	3	0	3
5.	PE-I	E1/EE646	Elective 1/Artificial Intelligence for Embedded Systems	3	0	3
6.	PSL/PSC/PE	EEVL01	VLSI & ES Lab-01	0	6	3
7	PGC	PGC-601	Research Methodology and IPR	2	0	2
			Total	**17**	**6**	**20**

PSC: Program Specific Core; PSL: Program Specific Lab; PE: Professional Elective

Semester II

Sl. No	Course Type	Course Code	Course Title	Contact Hours/ Week		Credits
				L	P	
1	PSC-5	EE622	RFIC Design	3	0	3
2	PSC-6	EE637	ASIC Verification using System Verilog	3	0	3
3	PE-II	E2	Elective 2	3	0	3
4	PE-III	E3	Elective 3	3	0	3
5	PE-IV	E4	Elective 4	3	0	3
6	PSL/PSC/PE	EEVL02	VLSI & ES Lab-02	3	6	3
7	PGC	PGC-602		2	0	2
			Total	**17**	**6**	**20**

* Four-week industrial practice school during summer vacation for scholarship students (optional)

Semester III

Sl. No	Course Type	Course Code	Course Title	Contact Hours /week	Credits
				P	
1	Dissertation & Seminar-Phase1	EE651	M. Tech. Dissertation Phase I	40	20
			Total	**40**	**20**

Semester IV

Sl. No	Course Type	Course Code	Course Title	Contact Hours /week	Credits
				P	
1	Dissertation & Seminar-Phase II	EE652	M. Tech. Dissertation Phase II	40	20
			Total	**40**	**20**

*1 Credit for Lecture/Tutorial means 1 contact hour in a week, and 1 credit for practice/dissertation means 2 contact hours in a week.

M. Tech. in Electronics and Communication Engineering (Semiconductor Chip Design)

Semester I

Sl. No	Course Type	Course Code	Course Title	Contact Hours/ Week		Credits
				L	P	
1.	PSC-1	EE621	Digital IC Design	3	0	3
2.	PSC-2	EE638	Mixed Signal IC Design	3	0	3
3.	PSC-3	EE620	SOC & Embedded Systems	3	0	3
4.	PSC-4	EE650	Semiconductor Devices for High-Speed and High-Power Applications	3	0	3
5.	PE-I	E1/EE655	Elective 1/IC Design: RTL to GDS implementation	3	0	3
6.	PSL/PSC/PE	EECL01	IC design Lab-I Device Design, FPGA & Front-End Design	0	6	3
7	PGC	PGC-601	Research Methodology and IPR	2	0	2
			Total	**17**	**6**	**20**

PSC: Program Specific Core; PSL: Program Specific Lab; PE: Professional Elective

Semester II

Sl. No	Course Type	Course Code	Course Title	Contact Hours/ Week		Credits
				L	P	
1	PSC-5	EE648	VLSI Fabrication Technology	3	0	3
2	PSC-6	EE656	IC Testing & Verification	3	0	3
3	PE-II	*E2	Elective 2	3	0	3
4	PE-III	*E3	Elective 3	3	0	3
5	PE-IV	E4	Elective 4	3	0	3
6	PSL/PSC/PE	*Lab	Laboratory	3	6	3
7	PGC	PGC-602		2	0	2
			Total	**17**	**6**	**20**

*Based on the elective course selection for E2, E3 & Lab from the **List of Electives-B**, the specialization stream will be from Analog & RF IC Design, Digital IC Design, and Microsystems Technologies verticals.

Semester III

Sl. No	Course Type	Course Code	Course Title	Contact Hours /week	Credits
				P	
1	Dissertation & Seminar-Phase1	EE651	M. Tech. Dissertation Phase I	40	20
			Total	**40**	**20**

Semester IV

Sl. No	Course Type	Course Code	Course Title	Contact Hours /week	Credits
				P	
1	Dissertation & Seminar-Phase II	EE652	M. Tech. Dissertation Phase II	40	20
			Total	**40**	**20**

*1 Credit for Lecture/Tutorial means 1 contact hour in a week, and 1 credit for practice/dissertation means 2 contact hours in a week.

M. Tech. in Electronics and Communication Engineering
(Hardware Security and Cryptology)

Semester I

Sl. No	Course Type	Course Code	Course Title	Contact Hours/ Week		Credits
				L	**P**	
1.	PSC-1	EE 620	SoC & Embedded systems	3	0	3
2.	PSC-2	EE 624	Digital System Design using FPGA	3	0	3
3.	PSC-3	EE 655	RTL to GDS Implementation	3	0	3
4.	PSC-4	CS 603	Applied Cryptography	3	0	3
5.	PE-I	E1/EE673	Elective 1/Real-Time Operating Systems	3	0	3
6.	PSL/PSC/PE	EEHL01	Hardware Security and Cryptology Lab-01	0	6	3
7	PGC	PGC-601	Research Methodology and IPR	2	0	2
			Total	**17**	**6**	**20**

PSC: Program Specific Core; PSL: Program Specific Lab; PE: Professional Elective

Semester II

Sl. No	Course Type	Course Code	Course Title	Contact Hours/ Week		Credits
				L	**P**	
1	PSC-5	EE674	Foundations of Hardware Security: Threats and Protections	3	0	3
2	PSC-6	CS612	Reverse Engineering & Malware Analysis	3	0	3
3	PE-II	E2/EE675	Elective 2/Side-Channel and Fault Attacks: Analysis and Countermeasures	3	0	3
4	PE-III	E3	Elective 3	3	0	3
5	PE-IV	E4	Elective 4	3	0	3
6	PSL/PSC/PE	EEHL02	Hardware Security and Cryptology Lab-02	3	6	3
7	PGC	PGC-602	Communication Skills & Personality Development	2	0	2
			Total	**17**	**6**	**20**

* Four-week industrial practice school during summer vacation for scholarship students (optional)

Semester III

Sl. No	Course Type	Course Code	Course Title	Contact Hours /week	Credits
				P	
1	Dissertation & Seminar-Phase1	EE651	M. Tech. Dissertation Phase I	40	20
			Total	**40**	**20**

Semester IV

Sl. No	Course Type	Course Code	Course Title	Contact Hours /week	Credits
				P	
1	Dissertation & Seminar-Phase II	EE652	M. Tech. Dissertation Phase II	40	20
			Total	**40**	**20**

*1 Credit for Lecture/Tutorial means 1 contact hour in a week, and 1 credit for Practice/Dissertation means 2 contact hours in a week.

List of Electives-A

Sl. No.	Course Code	Course Title	Contact hours/week		Credits
			L	T/P	
1	EE603	Wireless and Mobile Communication	3	0	3
2	EE605	Navigation System Concepts	3	0	3
3	EE606	Statistical Signal Processing	3	0	3
4	EE608	Modern Wireless Communications	3	0	3
5	EE611	Array Signal Processing	3	0	3
6	EE612	High Power Microwave Systems	3	0	3
7	EE613	Electronic Warfare	3	0	3
8	EE615	GNSS Receiver Design and Applications	3	0	3
9	EE616	Multi-Sensor Integrated Navigation	3	0	3
10	EE617	Inertial Navigation Systems	3	0	3
11	EE618	Indoor Navigation	3	0	3
12	EE619	Software Defined Radio	3	0	3
13	EE623	Semiconductor Devices	3	0	3
14	EE624	Digital System Design using FPGA	3	0	3
15	EE625	High-Performance DSP using FPGA	3	0	3
16	EE626	Compressed Sensing & Sparse Signal Processing	3	0	3
17	EE627	Signal Theory, Linear Algebra & Transform Techniques	3	0	3
18	EE628	Advanced Electronics Systems	3	0	3
19	EE629	Sonar Signal Processing	3	0	3
20	EE630	Sonar System Engineering	3	0	3
21	EE631	Satellite Communication	3	0	3
22	EE632	Advanced Communication Systems	3	0	3
23	EE633	Underwater Communications	3	0	3
24	EE634	Monolithic Microwave Integrated Circuit	3	0	3
25	EE635	Inertial Sensors and Systems	3	0	3
26	EE636	Navigation & Avionic Systems	3	0	3
27	EE639	Computer-Aided Design for VLSI Circuits	3	0	3
28	EE640	FPGA Architecture and Applications	3	0	3
29	EE641	VLSI Signal Processing	3	0	3
30	EE642	SoC Design and Verification	3	0	3
31	EE643	Digital Interface Design	3	0	3
32	EE644	MIMO Communications	3	0	3
33	EE645	Adaptive Signal Processing	3	0	3
34	EE646	Artificial Intelligence for Embedded Systems	3	0	3
36	EE647	RF Photonics	3	0	3
37	EE648	VLSI Fabrication Technology	3	0	3
38	EE649	Introduction to Electronics Systems	3	0	3
39	EE653	Quantum Transport in Nanoscale FETs	3	0	3
40	EE660	MEMS Sensors and Actuators	3	0	3

41	EE661	Microfabrication Techniques and Processes	3	0	3
42	EE666	Optical Space Communication	3	0	3
43	EE670	Time Frequency Analysis	3	0	3
44	EE672	Time Series Analysis and Forecasting	3	0	3
45	EE675	Side-Channel and Fault Attacks: Analysis and Countermeasures	3	0	3
46	QT621	Classical & Post Quantum Cryptography	3	0	3

List of Electives-B

Course	Analog & RF IC Design Vertical	Digital IC Design Vertical	Microsystems Technologies Vertical
*E2	EE653: Quantum Transport in nanoscale FETs	EE637: ASIC Verification using System Verilog	EE659: MEMS and Microsystems Design
*E3	EE657: Low Power & High-Speed Analog Design,	EE665: Low power digital IC design	EE662: RF MEMS
E4	EE622: RFIC Design	EE658: Hardware Accelerators	EE663: MEMS Packaging/ EE664: MEMS Packaging and Reliability
*Lab	EECL02: IC design Lab-II: Mixed signal-RF IC & Back-End Design Lab	EECL03: IC design Lab-III: Advanced SoC-CAO & Back-End Design Lab	EECL04: MEMS Design Lab

A. Program Outcomes (POs)

PO1: An ability to independently carry out research /investigation, and development work to solve practical problems.

PO2: An ability to write and present a substantial technical report/document.

PO3: Students should be able to demonstrate a degree of mastery over the area as per the specialization of the program. The mastery should be at a level higher than the requirements in the appropriate post-graduate program.

B. Program Specific Outcomes (PSOs)

(a) M. Tech. in ECE with Signal Processing and Artificial Intelligence

PSO-1: Advanced Signal Processing Expertise

Apply advanced mathematical and algorithmic techniques to analyze, model, and process signals (audio, speech, image, video, biomedical, etc.) for solving real-world engineering problems.

PSO-2: Integration of AI in ECE Systems

Design and implement intelligent electronic and communication systems by integrating machine learning, deep learning, and data-driven techniques with classical signal processing frameworks.

PSO-3: Research and Innovation in SP & AI Applications

Demonstrate the ability to conduct independent research, develop innovative solutions, and apply modern tools for emerging applications in areas such as communication systems, IoT, robotics, healthcare, and multimedia.

(b) M. Tech. in ECE with Radar and Communication

PSO-1: Proficiency in Radar and Communication Systems

Demonstrate in-depth knowledge and technical expertise in the design, analysis, and implementation of advanced radar and communication systems for defense, aerospace, and civilian applications.

PSO-2: Radar Signal Processing and System Integration Skills

Apply advanced signal processing techniques and system integration skills for the development, testing, and optimization of radar signal processing, detection, estimation, and wireless communication systems.

PSO-3: Innovation and Research in Electromagnetics and RF Systems

Conduct research and develop innovative solutions in the fields of RF/microwave/Millimeter wave engineering, antenna design, propagation, and embedded systems for modern radar and high-speed communication technologies.

(c) M. Tech. in ECE with Defence and Space Electronics

PSO-1: Specialized Knowledge in Defence and Space Systems

Apply advanced principles of electronics and communication engineering to design, develop, and analyze systems used in defence and space applications, including Antenna systems, electronic warfare, satellite communication, navigation systems, and EMI/EMC.

PSO-2: Proficiency in Embedded, RF, and Secure Communication Technologies

Demonstrate the ability to develop embedded systems, RF/microwave circuits, and secure communication protocols for mission-critical defence and aerospace environments.

PSO-3: Innovation, Research, and System Integration for Strategic Applications

Undertake research and system-level integration to develop reliable, rugged, and high-performance electronic systems meeting the stringent requirements of defence and space sectors, in line with national strategic priorities.

(d) M. Tech. in ECE with VLSI and Embedded Systems

PSO-1: Expertise in VLSI Design and Verification

Apply advanced concepts of digital and analog VLSI design, CMOS technology, and hardware description languages (HDLs) to design, simulate, and verify complex integrated circuits for real-world applications.

PSO-2: Embedded System Design and Development

Design, program, and integrate embedded systems using microcontrollers, FPGAs, real-time operating systems (RTOS), and IoT platforms for industrial, consumer, and automotive solutions.

PSO-3: Research and Innovation in System-on-Chip (SoC) and Low-Power Design

Conduct research and develop innovative, high-performance, and energy-efficient SoC architectures and embedded solutions for emerging technologies in AI, communication, and automation.

(e) M. Tech. in ECE with Semiconductor Chip Design

PSO-1: Proficiency in Semiconductor Device and Chip Design

Apply advanced knowledge of semiconductor physics, device modeling, and fabrication processes to design and develop integrated circuits (ICs) and system-on-chip (SoC) solutions using industry-standard tools.

PSO-2: Expertise in Design, Verification, and EDA Tools

Demonstrate competence in front-end and back-end chip design, including RTL coding, synthesis, timing analysis, place-and-route, and verification using Electronic Design Automation (EDA) tools like Cadence, Synopsys, and Mentor Graphics.

PSO-3: Innovation and Research in Advanced Chip Technologies

Engage in research and development of high-performance, low-power, and scalable semiconductor solutions for applications in AI accelerators, high-speed communication, automotive electronics, and edge computing.

(f) M. Tech. in ECE with Hardware Security and Cryptology

PSO-1: Secure Silicon Design and SoC Integration

Design and verify secure Integrated Circuits (ICs) and System-on-Chip (SoC) architectures by implementing hardware roots-of-trust, secure boot protocols, and anti-tamper mechanisms across the full RTL-to-GDSII flow.

PSO-2: Physical Attack Analysis and Countermeasures

Evaluate hardware vulnerabilities by performing side-channel analysis, fault injection, and reverse engineering, while developing robust hardware-level defenses to protect against physical and logical threats.

PSO-3: Implementation of Advanced Cryptographic Systems

Develop high-performance hardware accelerators for classical and post-quantum cryptographic algorithms, ensuring secure and efficient execution within resource-constrained embedded and real-time environments.

Detailed Contents

Course Code	Course Name	L – T – P	**Credits**
EE601	**RF and Microwave Circuits**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Impart knowledge about Transmission lines.
- Introduce the network analysis fundamentals
- Enable the students to understand passive and active microwave circuits
- Equip students with knowledge of measurement basics

Course Contents

Unit I: Introduction to EM Theory and Transmission Lines: Maxwell's equations, Electromagnetic waves, Characteristics of EM waves, Uniform plane waves, Boundary conditions, 3D and 2D transmission lines, Wave equation, Lossless transmission lines, Circuit model & Field analysis, Lossy transmission lines, TEM, TE, & TW wave solutions, Quarter-wave transformer, Relation between dB, dBm, and dBW.

Unit II: Microwave Network Analysis: Impedance, Z & Y parameters, Scattering parameters, transmission (ABCD) matrix, Conversion, Discontinuities and Model analysis, Excitation of waveguides, Lumped elements, stub tuning, tapered lines.

Unit III: Microwave Passive Devices and Circuits: Resonant circuits, Excitation of resonators, Cavity perturbations, Properties of Three port power dividers, Dividers & couplers, Wilkinson power dividers, Directional couplers, Quadrature (90˚) Hybrid, Filters, Filter transformation, Filter implementation, Stepped-impedance low-pass filters, coupled line filters, Filters using coupled resonators, Coupled line directional couplers, Lange couplers, Phase Shifters.

Unit IV: Microwave Active Devices and Circuits: Diode circuits, BJT- and FET-based circuits, Microwave integrated circuits, Microwave tubes, Oscillators, Frequency multiplier/mixers, Single-stage broadband transistor amplifier design, Power amplifiers, and LNAs.

Unit V: Microwave Measurements: S-parameter measurements, Calibration standards, Vector Network analyzer, Spectrum analyzer, Phase noise measurement, Power measurement, Microwave subsystem, and system characteristics.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understand the fundamentals of Maxwell's equations and Transmission line theory

CO2: Acquire knowledge of the various Two-port Parameters: Z-Matrix, Y-Matrix, ABCD-Matrix, S-Matrix

CO3: Understand the basics of microwave passive components: Directional Couplers, Filters, Power dividers

CO4: Design and develop microwave active circuits such as amplifiers, Oscillators, multipliers, etc.

CO5: Hands-on with Microwave measuring equipment and understanding the measurement of microwave circuits

Text Books
1. David M. Pozar, Microwave Engineering, John Wiley, India. 2. Robert E. Collin, Foundations of Microwave Engineering, John Wiley, USA.
Reference Books
1. Reinhold Ludwing and G. Bogdanov, RF Circuit Design: Theory and Applications, Pearson Education, Asia. 2. S Y Lio, Microwave Devices and Circuits, Prentice Hall, India. 3. K. D. Prasad, Antenna and wave propagation, Satyaprakash Publications, New Delhi. 4. Electromagnetic, John D. Kraus, McGraw-Hill.

Course Code	Course Name	L – T – P	**Credits**
EE602	**Advanced Digital Signal Processing**	3-0-0	**3**

Course Objectives:

- Build strong foundations in linear algebra for applications in signal representation, transformations, and system analysis.
- Understand probability, random variables, and stochastic processes to model and analyze random signals and systems.
- Develop skills in real-time digital system design and implementation, considering finite word-length effects and computational efficiency.
- Apply various mathematical transforms (Fourier, Laplace, Z, Wavelet, etc.) for analysis and processing of signals.
- Design and implement analog and digital filters for practical signal processing applications.

Course Contents

Unit I: Introduction to Linear Algebra, Signals and Systems: Linear algebra: vector spaces, subspaces, linear independence, dimension, norms, orthogonal bases and Gram-Schmidt orthogonalization, linear transformation, Kernel and range, inverse transformations, matrices of linear transformations, change of basis, similarity, eigenvalues and eigenvectors, diagonalization, orthogonal diagonalization of symmetric matrices, singular value decomposition.

Unit II: Probability, Random Variable and Random Process: Randomness, axioms of probability, repeated trails, random variable, distribution, and density function, conditional distribution and density, moments, characteristic function, one random variable, two random variables, correlation, covariance, independence, orthogonality, stochastic process, mathematical description of random signals, Concept of a random process, stationarity, Ergodicity, autocorrelation function, cross-correlation function, power spectral density function, white noise.

Unit III: Real-Time Digital System Design and Implementation: Finite word length effects: fixed-point and floating-point number representations, truncation and rounding errors, quantization noise, coefficient quantization error, product quantization error, overflow error. Implementation: scalar operation, vector operation, matrix operation, complex number representation, and operation.

Unit IV: Transforms: Fourier series, Fourier transform, discrete time Fourier transform, discrete Fourier transform, Laplace transform, Z-transform, Wavelet Transform, Hilbert transform, and their properties and inverse transforms. FFT computations using decimation in time and decimation in frequency, the overlap-add and overlap-save method.

Unit V: Filters: Analog and digital filters, FIR filter design, IIR filter design, and realization using direct, cascade, and parallel forms, lattice structures.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Learn the basics of linear algebra, signals, and systems.

CO2: Gain the theory of random variables, probability, and random processes.

CO3: Acquire the basics of transforms such as the Fourier transform, the Laplace transform, and the Hilbert transform

CO4: Learn the concept of analog and digital filters

CO5: Gain knowledge of FIR & IIR Filters

Text Books/Reference Books

1. S.K. Mitra, Digital Signal Processing: A Computer Based approach, 3rd Ed., Tata McGraw Hill.

2. J. G. Proakis& D. G. Manolakis, Digital Signal Processing: Principles, Algorithms & Applications, 4thEd., PHI.

3. Alan V Oppenheim & Ronald W Schaffer, Discrete Time Signal Processing, PHI.

4. Athanasios Papoulis, Probability, Random Variables, and Stochastic Processes, TATA McGraw Hill.

Course Code	Course Name	L – T – P	**Credits**
EE603	**Wireless and Mobile Communication**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Build strong foundations in wireless and cellular communication.
- Introduce Channel, BER, SER, and other performance parameters to assess the wireless link.
- Enable the students to develop skills in coding and modulation
- Understand mobile radio propagation
- Design and implement RFID readers and tags

Course Contents

Unit I: Wireless Communications and Diversity: Introduction to Wireless Communication, Motivation, Types of Wireless Communication, Wireless Channel Modeling, Random Variable, Fading Channels, Linear Transformation, Bit Error Rate (BER)

and Symbol Error rate (SER), BER and SER performance for Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), M-ary Pulse Amplitude Modulation (PAM) and M-ary PSK in Additive White Gaussian Noise (AWGN), Diversity Techniques, Issues in Wireless Communication. **Unit II: Wireless Channel Modeling:** Basics of Wireless Channel Modeling, Maximum Delay Spread, RMS Delay Spread, RMS delay based on power profile, Average Delay Spread in Outdoor Cellular Channels, Coherence Bandwidth in Wireless Communications, Inter symbol Interference (ISI), Doppler Fading in Wireless Systems, Doppler Impact on a Wireless Channel, Coherence Time of the Wireless Channel. **Unit III: Cellular Communications:** Introduction to Cellular Communications, Cell Capacity and Frequency reuse, Coverage Improvement, Multiple Access Technologies, Cellular Processes Call Setup, Handover, Teletraffic Theory, Equalization and Diversity Techniques, Modulation and Coding Techniques for Mobile Communication, GSM, CDMA, 4G, VOLTE and 5 G technologies, Introduction to Wireless OFDM – OFDM principles, system model – Generation of sub carrier using IFFT, windowing, choice of OFDM parameters, OFDM signal processing. **Unit IV: Mobile Radio Propagation:** Introduction to Mobile Radio Propagation, Reflection, Diffraction, Scattering, Propagation Models, Doppler Effect, Delay Spread, Ultra-Wideband Communication System, Fading, TDM, FDM, TDMA, FDMA, CDMA, OFDM. **Unit V: Near-field Wireless Communications:** Introduction to RFID System, RFID Reader and Tag Design, Compact RFID Readers, Propagation Channel, Conventional and Unconventional Applications of RFID, Link Budget, Multipath and Ground Reflections, Localization, RFID Standards, Specific Absorption Rate, Chip less RFID, NFC.
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Understanding of the basics of wireless communication, basic terms such as Bit error rate, symbol error rate, etc., and advantages and disadvantages of different wireless communication techniques. **CO2:** Grasp the basics of wireless channel modeling, Inter-symbol interference, and Doppler fading. **CO3:** Learn cellular communication, frequency reuse, handover, and various multiple access techniques. **CO4:** Acquire knowledge of multiple access techniques, understanding of phenomena such as reflection, refraction, scattering, and diffraction. **CO5:** Learn the basics of RFID, propagation channel in RFID, and various near-field and far-field wireless techniques.
Text Books/Reference Books
1. Fundamentals of Wireless Communications – David Tse and Pramod Viswanath, Publisher Cambridge University Press. 2. Wireless Communications: Andrea Goldsmith, Cambridge University Press. 3. Wireless Communications: Principles and Practice –Theodore Rapp port Prentice Hall. 4. MIMO Wireless Communications – Ezio Biglieri – Cambridge University Press. A joint venture by IISc and IIT

5. Introduction to Space Time Wireless Communications – Arogyaswami Paulraj – Cambridge University Press.
6. Digital Communications – John G Proakis – McGraw Hill Science/Engineering/Math.
7. Wireless Communications – Andreas Molisch – Wiley IEEE Press.
8. Mobile Wireless Communications – Mischa Schwartz – Cambridge University Press.

Course Code	Course Name	L – T – P	**Credits**
EE604	**Radar System Design**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Impart knowledge about various types of Radars and their working.
- Introduce the performance parameters of Radar.
- Impart the knowledge of the application of Radar.
- Provide practical knowledge of the design of Radar.

Course Contents

Unit I: Introduction to Radar: Basic principles of radar, Frequencies of operation, Classification of radars, their functionality and applications, Types of radar: CW, FMCW, Pulse Doppler, Radar Range Equation, Cross Range and Doppler/Velocity measurements and Resolutions, Peak power, Average power, and Duty Cycle, Target, Noise Power, and Noise Power density, False Alarm, Concept of Detection, Losses in Radar Equation, Signal Integration and Processing Gain, Radar Equation for Bistatic, Search and Tracking Radars, Equation for Beacon, Cover Up and Self Protection Jamming.

Unit II: Radar Cross Section (RCS), Clutter & Theory of Detection: Probability of Detection Pd, Probability of False Alarm PFA and Relation between Pd, Pfa, and SNR– statistical phenomenon of Noise. Target characteristics– RCS, RCS fluctuation, Swirling Models, SNR deviation for fluctuating targets, Ground/Surface, Sea clutter, Radar Equation for low Grazing Angle, Volume clutter – Rain, birds, chaff, Clutter discrete, Clutter characteristics of airborne radar – Clutter limited operation Vs Noise limited operation of radar, Losses.

Unit III: Tracking radar & Propagation: Concept of Tracking, Conical Scan Angle Tracking, Lobing Angle Tracking, Monopulse Tracking; Amplitude and Phase Comparison, Wideband Monopulse Tracking, Conventional 2D Surveillance radar: Battlefield Surveillance Radar, Coastal Surveillance radars, AESA radars, and Airborne Radars, Layers of the Atmosphere and Ray Travel, Interference and Diffraction Region, Refraction of EM Waves, Effective Earth Model, Anomalous Propagation, Ionosphere Refraction and Attenuation.

Unit IV: Radar Transmitter & Antenna Design: Functions of Radar Transmitters, Transmitter Features, Transmitter Sub-Systems, Active Device for Different Frequency Bands, Tube Transmitters, Solid State Transmitters, Concept of Distributed Transmitters, Function and Features of Radar Antenna, Types of Antennae, Phased Array Antenna, Antenna Elements, Architectures for phased array, Antenna-based architecture, Bandwidth-based architecture, function-based radar, electronic/mechanical steering phased array, Phase

shifters, and radiators, frequency scan array, beam agility, Interleaving of detection, Frame time, Radar Scheduling- Algorithms for scheduling. **Unit V: Duplexer/TR Switch & Radar Receiver:** Function and Characteristics, Types of Duplexers, Radar Receiver Characteristics, Receiver Parameters, Receiver Architectures, Digital Receiver, modern radar concepts **-** Synthetic Aperture Radar principle**, t**he SAR characteristics like cross range, aperture, Doppler, chirp, SAR modes: strip map, spotlight**,** Doppler beam sharpening, Inverse SAR**,** Advancements in Pulsed and CW radars, ECCM techniques.
Course Outcomes
On completion of this course, the students will be able to **CO1:** Analyze, design, and develop RADAR transmitter, receiver, and Antenna. **CO2**: Learn formulated RADAR equations for various types of RADARs (Bi-static, surveillance, and static) and also understands the concepts of jamming. **CO3**: Acquire knowledge of RADAR cross section, clutter, atmospheric propagation, and probability of false detection **CO4**: Apply knowledge and skills to design a RADAR transmitter and receiver. **CO5**: Apply skills to simulate a moving target RADARs, Measurement of Doppler shift, and other real-time situations.
Text Books
1. Mark A. Richards, Principles of Modern Radar: Basic Principles, Yes Dee Publishing Pvt., Ltd. 2. M.I. Skolnik, Introduction to Radar Systems, Tata MG Hill. 3. T.W. Jeffrey Phased-Array Radar Design, Scitech Publishing. 4. I.G. Cumming, Digital Processing of Synthetic Aperture Radar Data: Algorithms and Implementations, Artech House.
Reference Books
1. B.R. Mahafza, Radar System Analysis and Design Using, CRC press. 2. Peyton Z. Peebles, Radar Principles, Wiley. 3. Harold R. Raemer, Radar Systems Principles, CRC press. 4. George W. Stimson, Introduction to Airborne Radar, Scitech Publishing.

Course Code	Course Name	L – T – P	**Credits**
EE605	**Navigation Systems Concepts**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the basics of navigation
- Know the GNSS fundamentals.
- Impart the knowledge of inertial navigation.
- Provide practical knowledge of Satellite Navigation Processing, Errors, and Geometry.

Course Contents

Unit I: Introduction to Navigation: Navigation, Position Fixing, Dead Reckoning, Inertial Navigation, Radio and Satellite Navigation, Terrestrial Radio Navigation, Satellite Navigation, Feature Matching, The Complete Navigation System, Navigation Mathematics: Coordinate Frames, Kinematics, and the Earth: Coordinate Frames, Kinematics, Earth Surface and Gravity Models, Frame Transformations, Orbital Mechanics.

Unit II: GNSS: Fundamentals, Signals, and Satellites: Fundamentals of Satellite Navigation, The Systems: Global Positioning System, GLONASS, Galileo, Beidou, IRNSS, GNSS, Interoperability: Frequency Compatibility, User Competition, Multistandard User Equipment Augmentation Systems, System Compatibility, GNSS Signals, Navigation Data Messages, Comparison between GNSS, GPS, Galileo and other Nav Systems.

Unit III: Inertial Navigation: Inertial-Frame Navigation Equations, Earth-Frame Navigation Equations, Local-Navigation-Frame Navigation Equations, Navigation Equations Precision, Initialization and Alignment, INS Error Propagation, Platform INS, Horizontal Plane Inertial Navigation, types of GYROS: Mechanical, Ring Laser and Fiber Optic, Accelerometers.

Unit IV: Advanced Satellite and Terrestrial Navigation: Differential GNSS, Carrier-Phase Positioning and Attitude, Poor Signal-to-Noise Environments, Multipath Mitigation, Signal Monitoring, Semi-Codeless Tracking, Instrument Landing System, Receiver Hardware and Antenna, Relative Navigation, Tracking and Positioning, Ultra-wideband, Short-Range Communications Systems.

Unit V: Satellite Navigation Processing, Errors, and Geometry: Satellite Navigation Geometry, Ranging Processor, Range Error Sources, Navigation Processor, Attitude Measurement, Height and Depth Measurement, Barometric Altimeter, Depth Pressure Sensor, Radar Altimeter, Odometers, Pedestrian Dead Reckoning.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Learn the basics of navigation, position fixing, radio and satellite navigation, terrestrial radio navigation, understanding of coordinate frames, kinematics, earth surface, and gravity models.

CO2: Understand of satellite navigation, global positioning system, GNSS, and a detailed comparison between various navigation systems.

CO3: Pick up the basic understanding of Multipath Mitigation, Signal Monitoring, Semi-Codeless Tracking, Radio Positioning Configurations, and Methods.

CO4: Learn the basics of Aircraft Navigation Systems, Error Sources, Differential Loran, Ultra-wideband, Short-Range Communications Systems, Other Positioning Technologies, Receiver Hardware, and Antenna.

CO5: Gain knowledge of Attitude Measurement, Height and Depth Measurement, Other Dead-Reckoning Techniques, Sequential Processing, Laser TRN, Barometric TRN, Sonar TRN, Stellar Navigation, Magnetic Field Variation, and Measurement Models.

Text Books/Reference Books

1. Paul D. Groves, Principles of GNSS, Inertial, and Multisensor Integrated Navigation Systems, Artech House, 2008 and 2013 Second Edition.
2. Esmat Bekir, Introduction to Modern Navigation Systems, World Scientific Publishing Co Pte Ltd, 2007.
3.B. Hofmann Wollenhof, H. Lichtenegger, and J. Collins, GPS Theory and Practice, Springer Wien, New York, 2000.
4. Pratap Misra and Per Enge, "Global Positioning System Signals, Measurements, and Performance," Ganga-Jamuna Press, Massachusetts, 2001.
5. Ahmed El-Rabbany, Introduction to GPS, Artech House, Boston, 2002.
6. Bradford W. Parkinson and James J. Spilker, Global Positioning System: Theory and Applications, Volume II, American Institute of Aeronautics and Astronautics, Inc., Washington, 1996.

Course Code	Course Name	L – T – P	**Credits**
EE606	**Statistical Signal Processing**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand signal characterization and LTI system analysis, including sampling, DFT-based filtering, and cepstrum techniques.
- Apply linear prediction and optimum filtering methods for modeling stationary random processes and spectral estimation.
- Develop and implement least-squares and adaptive filtering techniques for system identification, prediction, and noise reduction.
- Analyze nonstationary signals using time–frequency methods, including STFT, spectrograms, and quadratic time–frequency distributions.
- Utilize wavelet transforms and filter banks for advanced signal analysis, noise suppression, and classification applications.

Course Contents

Unit I: Introduction: Characterization of Signals, Characterization of Linear Time-Invariant Systems, Sampling of Signals. Linear Filtering Methods Based on the DFT, the Cepstrum, Summary and References, Problems.

Unit II: Linear Prediction and Optimum Linear Filters: Innovations Representation of a Stationary Random Process, Rational power spectra, Forward and Backward Linear Prediction, Solution of the Normal Equations, Properties of the Linear Prediction-Error Filters, AR Lattice and ARMA Lattice-Ladder Filters.

Unit III: Least-Squares Methods and Filter Design: System Modeling and Identification, Least Squares Filter Design for Prediction and Deconvolution, Solution of Least-Squares Estimation Problems, Adaptive Filters, Adaptive Direct-Form FIR Filters, Adaptive Lattice-Ladder Filters, Wiener Filters for Filtering and Prediction.

Unit IV: Time Frequency Analysis: Time-Frequency Distributions: Fundamental Ideas, Global average, local average, shift invariance, Uncertainty Principle and Joint distribution, Short-Time Fourier Transform and Spectrogram, Wigner-Ville Distribution, Time-Varying Power Spectral Density Distribution, Filtered Function of Time, Instantaneous Power Spectra, Quadratic TFDs, Time-Varying Power Spectra of Nonstationary Random Processes.
Unit V: Wavelet Transform for Signal Analysis: Continuous wavelet transforms, Wavelet bases. Balian-Low theorem. Classes of wavelets: Haar, Daubechies, and bi-orthogonal. Discrete Wavelet Transform and Filter Banks. Orthogonal and biorthogonal two-channel filter banks, Design of two-channel filter banks. Wavelet methods for signal processing. Noise suppression. Representation of noise-corrupted signals using frames. Algorithm for reconstruction from corrupted frame representation. Audio classification. Gabor Wavelets for statistical signal processing.

Course Outcomes

On completion of this course, the students will be able to:
CO1: Generalize the properties of statistical models in the analysis of signals using Stochastic processes. Students will learn the forward and backward linear prediction for filter design.
CO2: Learn the last-square methods for filter design.
CO3: Acquire the basics of adaptive filters, time-frequency analysis, and the Wavelet transform.
CO4: Applying knowledge and skills to visualize different types of data/signals in the time domain, frequency domain, and time-frequency domain.
CO5: Acquire knowledge of statistical models and feature extraction.

Text Books

1. Algorithms for Statistical Signal Processing, John G. Proakis.

2. Probability & Random Processes with Applications to Signal Processing, 2001, 3Edn. Henry Stark and John W Woods, Prentice Hall

3. Adaptive Signal Processing Bernard Widrow, Samuel D. Stearns.

4. Time Frequency Analysis, 1995 by L. Cohen, Prentice Hall PTR.

5. A Wavelet Tour of Signal Processing, 2nd edition, S. Mallat, Academic Press, 1999.

Reference Books

1. Optimum signal processing: An introduction - Sophocles.J.Orfamadis, 2 ed., 1988, McGraw-Hill, Newyork

2. Adaptive signal processing-Theory and Applications, S.Thomas Alexander, 1986, Springer –Verlag.

3. Signal analysis – Candy, Mc Graw Hill Int. Student Edition

4. James V. Candy, Signal Processing: A Modern Approach, McGraw-Hill, International Edition, 1988.

5. Multiresolution and Multirate Signal Processing: Introduction, Principles and Applications - V.M. Gadre, A.S. Abhyankar, 2016, Mc Graw Hill Education (India) Private Limited.

Course Code	Course Name	L – T – P	**Credits**
EE607	**Detection and Estimation Theory**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Strengthen understanding of vector spaces and matrix theory, including PCA and SVD, for signal representation and dimensionality reduction.
- Analyze and model stochastic processes and their behavior through LTI systems, including cyclostationary processes and spectral analysis.
- Apply detection theory for signal identification in noise using statistical decision-making principles and optimal detectors.
- Develop estimation techniques using minimum variance methods, Cramer–Rao bounds, and system identification approaches.
- Implement Wiener and Kalman filtering methods for optimal signal estimation and tracking in discrete-time systems.

Course Contents

Unit I: Review of Vector Spaces: Vectors and matrices: notation and properties, orthogonality and linear independence, bases, distance properties, matrix operations, eigenvalues, and eigenvectors. Diagonalization of symmetric matrices, symmetric positive definite and semi-definite matrices, principal component analysis (PCA), and singular value decomposition.

Unit II: Stochastic Processes: Time average and moments, ergodicity, power spectral density, covariance matrices, response of LTI system to random process, cyclostationary process, and spectral factorization.

Unit III: Detection Theory: Detection in white Gaussian noise, correlator, and matched filter interpretation, Binary hypothesis testing, Neyman-Pearson theorem, Likelihood ratio test, Deflection coefficient, Receiver operating characteristic, Bayes' criterion of signal detection, Maximum likelihood detector, MAP, LMS, entropy detectors, detection in colored Gaussian noise, Karhunen-Loeve expansions and whitening filters.

Unit IV: Estimation Theory: Minimum variance estimators, Cramer-Rao lower bound, examples of linear models, system identification, Markov classification, clustering algorithms.

Unit V: Topics in Kalman and Weiner Filtering: Discrete time Wiener-Hopf equation, error variance computation, causal discrete time Wiener filter, discrete Kalman filter, extended Kalman filter, examples.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Learn the basics of vectors, matrices, basis functions, orthogonality, SVD, EVD, SSA, PCA. Moreover, the concept of ergodicity, PSD, covariance matrices, response of LTI system to a random process, and spectral factorization are grasped.

CO2: Learn the concepts of the last-square methods for filter design, detection in the noisy case, correlator and matched filter, Hypothesis testing, N-P theorem, Likelihood ratio test, Deflection coefficient, Receiver operating characteristic, Bayes' criterion of signal detection, ML detector, MAP, LMS, and entropy detectors.

CO3: Learn the basics of minimum variance estimators, CR lower bound, linear models, system identification, Markov classification, and clustering algorithms, basics of Wiener-Hopf equation, error variance computation, causal Wiener filter, and Kalman filter are given to students.

CO4: Apply knowledge and skills to visualize different types of data/signals in the time domain, frequency domain, and time-frequency domain. They are capable of designing various types of filters.

CO5: Acquire knowledge of designing Kalman and Weiner filters

Text Books/Reference Books

1. Fundamentals of statistical signal processing, vol. 1 and 2, S M Kay, Prentice Hall, 1998
2. Linear Estimation, Kailath, Sayed, and Hassibi, Prentice Hall, 2000.
3. An Introduction to Signal Detection and Estimation, H. Vincent Poor, 2nd Edition, Springer, 1998.

Course Code	Course Name	L – T – P	**Credits**
EE608	**Modern Wireless Communications**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the basics of advanced wireless schemes
- Understand the concept of MIMO
- Impart the knowledge of OFDM
- Know about the wireless standards

Course Contents

Unit I: Introduction to Wireless Communications: Motivation, Applications of Wireless Communication, Multipath Propagation, Wireless Channel Modeling, Fading Nature of the Wireless Channel, Probability Density Function of Amplitude and Phase, Deep Fade Phenomenon in Wireless Channels, Optimal Receiver Combining, SNR Performance, BER Performance with Diversity – Analysis, Diversity in Wireless Systems, Diversity Order, Types of Diversity, Antenna Spacing Requirement, Deep Fade Analysis with Diversity, Autocorrelation Function.

Unit II: Multiple Input Multiple Output (MIMO): Introduction to MIMO, MIMO System Model, MIMO Zero-Forcing and Minimum Mean Square Error (MMSE) Receivers, Introduction to Singular Value Decomposition (SVD), Examples of SVD and Eigenmodes of the MIMO Channel, MIMO Channel Capacity, MIMO Diversity – Alamouti, Orthogonal Spacetime Block Codes (OSTBC), MIMO Beamforming.

Unit III: OFDM: Introduction to OFDM, Multicarrier basics, Multicarrier transmission, Modulation and Cyclic Prefix in OFDM, impact of cyclic prefix in data rate, Bit-error rate for OFDM, Effect of frequency offset issue in OFDM, OFDM– Peak-to-Average Power Ratio (PAPR), SNR performance, MIMO-OFDM.

Unit IV: New Wireless Technology: Introduction to 5G Wireless Technologies, Massive Multiple Input Multiple Output, mm Wave, Non-orthogonal Multiple Access (NOMA), Filter Bank Multi Carrier (FBMC) Technique, and Full Duplex.

Unit V: Wireless Standards: IEEE 802.11 Wireless Standards, Comparison of IEEE 802.11 Wireless Standards, Wi-Fi, Bluetooth, Wireless Local Area Network (WLAN), Introduction to Long-Term Evolution (LTE), Introduction to Worldwide Interoperability for microwave Access (WiMAX), LTE-TDD and LTE-FDD, Frequency Bands and Technology Specs.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Acquire knowledge of modern wireless communication systems, understanding basic terms such as signal-to-noise ratio, diversity, fading, etc.

CO2: Learn MIMO, Singular Value Decomposition, and beamforming.

CO3: Gain knowledge of OFDM, OFDM-MIMO, and modulation techniques.

CO4: Develop understanding of new wireless technologies such as 5G, NOMA, FBMC, Massive MIMO, etc.

CO5: Acquire knowledge of various wireless standards.

Text Books/Reference Books

1. Andrea Goldsmith, Wireless Communication, Cambridge University Press, The Edinburgh Building, Cambridge, UK.
2. Tse, David and Viswanath, Pramod, Fundamentals of Wireless Communication, Cambridge University Press (2004).
3. Aditya Jagannatham, Principles of Modern Wireless Communication Systems, McGraw Hill, (2016)
4. Theodore Rappaport, Wireless Communications, principles and Practices, 2nd Edition, Pearson.
5. P. W. Wolniansky, G. J. Foschini, G. D. Golden, R. A. Valenzuela "V-BLAST: An Architecture for Realizing Very High Data Rates Over the Rich-Scattering Wireless Channel", Bell Labs Report, 1998.
6. Marco Di Renzo et. al, "Spatial Modulation for Generalized MIMO: Challenges, Opportunities and Implementation", Vol. 102, No.1, 2014.

Course Code	Course Name	L – T – P	**Credits**
EE609	**Antenna Systems**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Grasp basics of EM radiation and conventional antennas.
- Provide knowledge of Antenna arrays and beam forming.
- Grasp the basics of planar antennas of various configurations.
- Design and develop various types of aperture antennas
- Learn characterization of the antenna with the help of microwave measuring equipment.

PRE-REQUISITE: Introduction: Definition, Types, and Parameters of Antennas, Definition of Parameter: Radiation Patterns-Fields (E&H), Concept of Near and Far Fields, Solid Angle, Beam Width, Radiation Efficiency, Radiation Intensity, Directivity, Gain, Efficiency, Input Impedance, Radiation Resistance, Bandwidth, Circular Polarization, Antenna Noise Temperatures, Power Handling Capability: Voltage and Current Breakdown, Weathering Effect on Antennas.

Course Contents

Unit I: Basics of Radiation Mechanism: Concept of Electric and Magnetic Current Distribution of Antennas, Vector and Scalar Potentials (Electrical and Magnetic), Derivation of Radiation Patterns for Ideal, Small and Half Wavelength Dipole Antennas, Monopole, Loop, Yagi-Uda, Design of dipole and monopole antenna.

Unit II: Antenna Arrays: Analysis & Synthesis: Principles of Antenna Array: N element linear arrays – uniform amplitude and spacing, Directivity of Broadside and End fire arrays, Half Power Beam Width, Main lobe, Nulls, Side lobes, Inter-element spacing, Pattern multiplication, electronic scanning, Mutual Coupling, Grating lobes, Planar Arrays: array grid (Rectangular & Triangular), Selection of radiating elements for electronic scanning, scan loss, active impedance, scan blindness, Array Synthesis for beam formation: Binomial, Dolph-Tchebycheff, and Taylor distribution arrays.

Unit III: Planar/ Patch Antennas: Microstrip Antennas (MSAs): Principle of radiation of Rectangular Microstrip Antenna, Feeding Techniques of MSAs, E & H field, RLC model, basic design equation, impedance, and beam width characteristics, Circular and Triangular MSAs, Compact Microstrip Antennas, Broadbanding techniques. Printed Dipole and Monopoles – principles and broadbanding techniques. Design a Rectangular, Circular and Triangular Patch Antennas.

Unit IV: Aperture and Travelling Wave Antennas: Babinet–Brookner Theorm, Slot Antennas, Horn Antennas: E-plane Sectoral Horn, H-plane Sectoral Horn, Pyramidal Horn, Conical Horn, Aperture Matched Horn, Corrugated Horn, Broadband Horn Antenna, Reflector Antennas- Planar, Angular and Curved Reflector Antennas: Parabolic Reflector; Front feed, Cassegrain –feed and Gregorian- feed, Spherical Reflector, Design of a Pyramidal and Conical Horn Antenna, Concept of Frequency Independent and Travelling Wave Antennas, Self-Complementary Antennas, Biconical Antenna, Log Periodical Antennas, Helical Antennas: Normal and Axial Mode, Spiral Antennas.

Unit V: Antenna Measurements: Input impedance, Return Loss, VSWR, Bandwidth, Polarization, Radiation Patterns, Beam Width, Gain, etc.

Course Outcomes

On completion of this course, the students will be able to:
CO1: Understand the basics of EM radiation and conventional antennas.
CO2: Design and synthesis of Antenna arrays and beam forming.
CO3: Design of planar antennas of various configurations.
CO4: Understand various types of aperture antennas

CO5: Learn how to characterize the antenna with the help of microwave measuring equipment.
Text Books
1. Constantine A. Balanis, Antenna Theory: Analysis and Design, John Wiley & Sons, 2005. 2. Richard Poisel, Search Results Antenna Systems and Electronic Warfare Applications, Artech House. 3. Vijay Madisetti, Wireless, Networking, Radar, Sensor Array Processing, and Nonlinear signal processing, CRC press.... 4. Kai Chang, RF and Microwave Wireless Systems, Wiley series.
Reference Books
1. Mike Golio, Janet RF and Microwave Passive and Active Technologies, CRC press. 2. Frank Gustrau, RF and Microwave Engineering, Wiley.

Course Code	Course Name	L – T – P	**Credits**
EE610	**Radar Signal Processing**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Impart knowledge about Radar Signal Processing.
- Introduce processing schemes of Radar.
- Impart the knowledge of algorithms of Tracking Radar.
- Provide practical knowledge of modern Radar.

Course Contents

Unit I: Radar signal processing chain: Introduction, Radar receiver chain, derivation of Doppler frequency shift, N-pulse DLC, Moving Target Indictor (MTI), Optimum MTIs, Improvement Factor, Coherent Pulse integration – FFT, FIR filters, Concept of Constant False Alarm Rate(CFAR), CFARs for various scenarios, Clutter map CFAR, site adaptive Radar signal processing, Radar displays, convolutional models in range and angle, frequency domain models, Doppler processing, Matched filter (vector formulation), MTI and matched filter approximation.

Unit II: Pulse compression and micro-doppler processing: Radar modulation techniques, FMCW waveforms, Nonlinear FM, Stepped LFM, SFCW Radar, multi-frequency Radar, Bi-phase, poly-phase codes, Stretch Processing, Matched Filtering, Ambiguity diagram, Micro-Doppler effect - Phenomenon and application, modeling, and simulation.

Unit III: Tracking algorithms: Kalman Filters, Manouver Detection, Adaptive Kalman Filter, Interactive Multiple Model (IMM), Kalman Filter Track Initiation, False Track handling, Track Quality Tracking in Clutter, Data Association, Probabilistic Data Association, Multi-Target Tracking, Multiple Hypothesis Tracking on moving Platform, Tracking with Phased Array Radars, Performance Measures, Multi-Radar Tracking Schemes.

Unit IV: Data processing for phased array radar: Introduction, analog and digital beam forming, verification and Tracking, multi-target tracking, high precision tracking, adaptive

array processing, Introduction to photonics Radar. Introduction, General array, linear array, Adaptive array processing, Non-linear beam forming (LMS, ALMS), sidelobe cancellers. Spatial filtering beam forming. **Unit V: SAR/ISAR imaging algorithms:** Signal Processing, Waveform design – LPRF, MPRF, HPRF, and Platform Motion Compensation. Advanced Processing for Airborne Radars – Space Time Adaptive Processing, Principles, GLRT, AMF, Reduced Rank and Reduced Data STAP. Geometry of imaging radar, Doppler frequency and radar image processing, spherical wave front vs. planar wave front, quadratic phase Errors, Polar Format Algorithm, Range Migration Algorithm, Platform Motion Compensation, Future Growth of Modern Radar: UWB radar, Knowledge-based radar, Cognitive radar.
Course Outcomes
On completion of this course, the students will be able to: **CO1**: Gain Knowledge on Mathematical interpretation & operation in Signals, Radar receiver & its components, DLC & its application & limitation, MTI & matched filter approximation. **CO2**: Understand the fundamentals of Pulse compression requirements and its techniques. Radar based on pulse compression **CO3**: Know the basics of tracking algorithms & their components & their limitations & advancements in technology. Different Tracking Schemes **CO4**: Know the basics of Beam forming for different types of targets. Need for Photonic Radar and Its Components and Applications. **CO5**: Exposure to Signals & waveform techniques, need for airborne radar, understand the significance of Doppler frequency in radar applications, introduction to arrays & their advancement.
Text Books
1. Mark A. Richards, Fundamentals of radar signal processing, Tata McGraw-Hill. 2. Eyung W. Kang, Radar systems: analysis, design and simulation, Artech house. 3. B.R. Mahafza, Radar Signal Analysis and Processing using MATLAB, CRC Press. 4. George W. Stimson, Introduction to Airborne Radar, Scitech Publishing. 5. Ian G. Cumming and Frank H. Wong, Digital processing of synthetic aperture radar, Artech House
Reference Books
1. D. Curtis Schleher, MTI and Pulsed Doppler radar with MATLAB, Artech House. 2. Peyton Z. Peebles, Radar Principles, Wiley. 3. A. Farina, Radar Data Processing, John Wiley & Sons. 4. Bu-Chin Wang, Digital Signal Processing Techniques and Applications in Radar Image processing, Wiley.

Course Code	Course Name	L – T – P	**Credits**
EE611	**Array Signal Processing**	3-0-0	**3**
Course Objectives: The primary objectives of this course are to: • Impart knowledge about Spatial Signals. • Introduce different array configurations. • Impart the knowledge of beamforming.			

- Provide practical knowledge of algorithms for Array processing.

Course Contents

Unit I: Spatial signals: Array processing fundamentals, signals in space and time, spatial frequency, frequency wave number, direction vs. frequency, beam pattern, wave front, far field and near field, spatial sampling, Nyquist criterion, aliasing in spatial frequency domain, sensor arrays, spatial domain filtering, spatial DFT/FFT.
Unit II: Sensor arrays: Uniform linear arrays, electronic steering, array performance measures, non-isotropic element pattern, tapering, null steering, non-uniform linear arrays, beam space processing, planar and volumetric arrays, wideband arrays.
Unit III: Beamforming-1: Time delay beamforming, frequency domain beamforming, optimum beamformers: MVDR, MPDR, MMSE, Max SNR, LCMV, LCMP, GSC,
Unit IV: Beamforming-2: mismatched beam former, eigenvector beamformer, beam space beamformer, broadband beamformer, adaptive beam formers: LMS and RLS.
Unit V: Direction of arrival estimation: DoA estimation: ML, MAP, MUSIC, ESPRIT, for uncorrelated, correlated, and coherent signals.

Course Outcomes

On completion of this course, the students will be able to:
CO1: Learn the basics of the principle of spatial signals: Array processing fundamentals, signals in space and time.
CO2: Get the concepts of sensor arrays and Uniform linear arrays.
CO3: Learn the basics of beamforming-related concepts.
CO4 Apply knowledge and skills to understand the direction of arrival methods.
CO5: Acquire the knowledge of MUSIC and ESPRIT.

Text Books

1. H.L. Van Trees, "Optimum Array Processing, Part 4 of Detection, Estimation and Modulation Theory, John Wiley
& Sons, 2002.
2. Adaptive signal processing Bernard Widrow, Samuel D. Stearns.
3. A Mathematical Introduction to Compressive Sensing, Simon Foucart, Holger Rauhut, Springer New York.
4. Compressed Sensing: Theory and Applications, Yonina C. Elda, Cambridge University Press.

Course Code	Course Name	L – T – P	**Credits**
EE612	**High Power Microwave Systems**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Impart knowledge about HPM Systems.
- Introduce MW Basics.
- Impart the HPM Technologies.
- Provide practical applications of HPM.

Course Contents

Unit I: Introduction and Design of HPMW Systems: Introduction, HPM operating regimes, future directions in HPM, system approach, components linking, system issues, and advanced systems.

Unit II: MW Fundamentals: Introduction, Basic concepts in EMs, Periodic slow-wave structures, cavities, intense relativistic electron beam, rotating magnetically insulated electron layers, microwave-generating interactions, amplifiers and oscillators, high and low current operating regimes, and multispectral sources.

Unit III: HPM Technologies: Introduction, pulse power, electron beam generation/propagation, pulse compression, diagnostics, computational technology, HPM facilities, beamless systems, UWB switching technologies, UWB systems, and non-linear transmission lines.

Unit IV: HPM sources and structures: Introduction, design principles, operational features, R&D issues: Relativistic magnetrons, MILOs, BWOs, MWCGs and O-type Cerenkov devices, Klystrons and Reltrons, Vircators, Gyrotrons, Electron Cyclotron masers and free-electron lasers.

Unit V: HPM APPLICATIONS: HPM weapons, EM terrorism, counter DEW, High-power radar, power beaming, space propulsion, plasma heating, and particle accelerators.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Acquire knowledge of High-Power Microwave Systems and Microwave Fundamental Concepts.

CO2: Learn technological advancements in HPM and Microwave.

CO3: Gain knowledge of HPM Generation-related Structures and Their Studies.

CO4: Learn HPM sources and facilities.

CO5: Apply knowledge in HPM technologies in various areas.

Text Books/Reference Books

1. James Benford, John A. Swegle, and EdlSchamiloglu, High Power Microwave, CRC Press
2. Adaptive signal processing Bernard Widrow, Samuel D. Stearns.
3. Victor L. Granatstein, Igor Alexeff, High-power Microwave Sources, Artech House.
4. R. A Cairns, A. D. R. Phelps, Generation and Application of High-Power Microwaves, CRC Press.

Course Code	Course Name	L – T – P	**Credits**
EE613	**Electronic Warfare**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand electronic defence, intercept system characteristics, and functions.
- Acquire knowledge of crystal video receiver, IFM receiver, superheterodyne receiver, channelized receiver, and Bragg cell receiver.
- Understand various types of jamming and ECM techniques.
- Understand Search radar counter-countermeasures and tracking radar counter-countermeasures.
- Acquire knowledge of new electronic defence techniques and technology trends

Course Contents

Unit I: Introduction to Electronic Warfare: Electronic defence, electronic combat (ESM-ECM-ECCM), SIGNIT, intercept system characteristics and functions, frequency coverage,

analysis bandwidth, dynamic range, dynamic range requirements, sensitivity, noise figure, and Probability of intercept. **Unit II: Electronic Support Measures:** Typical ESM systems, sensitivity, receivers - crystal video receiver, IFM receiver, superheterodyne receiver, channelized receiver, Bragg cell receiver, compressive receiver, digital receivers. DoA/AoA measurement emitter location - the role of emitter location, emitter location geometry, emitter location accuracy, amplitude-based emitter location, interferometer direction finding, interferometric DF implementation, direction finding using the Doppler principle, time of arrival emitter location. **Unit III: Electronic Countermeasures:** Principles of electronic attack (EA), jamming-to-signal ratio, jamming types: burn-through, cover jamming, range deceptive jamming, inverse gain jamming, repeater jamming equations, noise jamming vs. deception, repeater vs. transponder, side lobe jamming vs. main lobe jamming, stand-off jamming, escort jamming, self-protection jamming. ECM techniques, on-board ECM systems, and off-board ECM systems **Unit IV: Electronic Counter-Countermeasures**: Search radar counter-countermeasures, tracking radar counter-countermeasures. **Unit V: New Electronic Defence Techniques:** New electronic defence techniques and technologies trend, shared apertures, anti-anti-radiation missile techniques, anti-stealth techniques, RF directed energy weapons, RWR, MAWS, Features and Capabilities of AEW&C and AWACS platforms, IFF Mark XII S
Course Outcomes
On completion of this course, the students will be able to: **CO1**: Acquire knowledge of Electronics warfare. **CO2**: To understand the support measure in EW. **CO3**: Gain knowledge of Electronics countermeasure. **CO4**: understanding of Electronics counter-countermeasure. **CO5**: understanding of advanced defence techniques.
Text Books/Reference Books
1. EW101: A First Course in Electronic Warfare, David Adamy, Artech House 2. EW102: A Second Course in Electronic Warfare, David Adamy, Artech House 3. Introduction to Electronic Defence Systems, Second Edition, Artech House by Filippo Neri 4. Introduction to Electronic Warfare, 1984, Schleher DC, Artech House 5. Microwave Receiver with EW applications, 1986, James Bao& Yen Tsui, Wiley and Sons 6. D. Curtis Schleher, Electronic Warfare in the Information Age, Artech House, Boston, London, 1999. 7. Skolnik, Radar hand book, Mc Graw Hill, 1972/1990. 8. Sergei A. Vakin, Fundamentals of Electronic Warfare, Artech House.

Course Code	Course Name	L – T – P	**Credits**
EE614	**EMI/EMC Design**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Impart knowledge about EMI and EMC basics.
- Introduce various near-field and far-field couplings.
- Impart the EMI Reduction methods.
- Provide practical applications of the EMI EMC topic

Course Contents

Unit I: Theory and principles of EMI/EMC: Sources of EMI, Conducted and Radiated EMI, Transient EMI, EMI/EMC definitions and units, Conducted, Radiated and Transient Coupling, Common Impedance Ground Coupling, Common Mode and Differential Mode coupling, Near-/Far-field coupling, Near Field Cable to Cable Coupling, Power Mains and Power Supply Coupling.

Unit II: EMI Tests and measurements, and control techniques: EMI Test Instrumentation/Systems, EMI Test, EMI Shielded Chambers, Open Area Test Site, TEM cell Antennas, Conducted Sensors/Injectors/Couplers, Military Test Method and Procedures (MIL-STD-461E), Calibration Procedures, Shielding, Filtering, Grounding, Bounding, Isolation Transformer.

Unit III: EMC Design of electronic systems: Requirements for Electronic Systems, System Design for EMC, PCB Traces Cross Talk, Impedance Control, Power Distribution Decoupling, Zoning, Transient Suppressors, Surge Protection Devices, Cable Routing, Signal Control, Component Selection and Mounting, Motherboard Designs, and Propagation Delay Performance Models.

Unit IV: EMI Standards and electromagnetic radiation hazards: Units of specifications, Civilian standards (CISPER, FCC, EN, IEC), Military standards -MIL-STD-461E, MIL-STD-1385, RADHAZ, HERO, NEMP, Biological Effects of EMR, Thermal and Non-Thermal, Prediction and Analysis of EMR Hazards, Mitigation Techniques.

Unit V: EMC Management concepts: Electromagnetic Environmental Effects (E3) Management, Spectrum Supportability Risk Assessment (SSRA), Spectrum Management and Requirements, Program management services to DoD and military departments, Military Department Operational Spectrum Management, EM Modeling and Simulation (M&S) services, steps for the proper development of an EMC control plan.

Course Outcomes

CO1: Learn the basics of EM interference and how it hampers the performance of other circuits, Basics of Electromagnetic Interference and Basics of EM Radiation, Components' behaviour at higher frequencies, Indian and International Standards of EMI/EMC.

CO2: Understand EMI Instruments and testing, shielded structures and their functioning, Techniques to detect the EMI disturbances and ways of calibration, Design of EMI-controlled circuitry.

CO3: Acquire knowledge of system-level analysis and design of EMI-controlled subsystems, Techniques to manage the ambient EMI, and related concepts.

CO4: Grasp knowledge of different testing levels of EMI, their classification, experimental validation of EMI concepts, interpretation, and inferences.

CO5: Gain working knowledge of EM modeling and simulation in an electromagnetic simulator, steps for designing and developing circuits and PCBs.

Text Books

1. Introduction to Electromagnetic Compatibility, 2nd Edition, Clayton R. Paul, ISBN: 978-0-471-75500-5, 1016 pages, December 2005, ©2006, Wiley publishers, Wiley Series in Microwave and Optical Engineering, 2006. **2.** Principles of Electromagnetic Compatibility, B Keiser, Artech house, 2008. **3.** V.P. Kodali, "Engineering Electromagnetic Compatibility", IEEE Publication, printed in India by S. Chand & Co. Ltd., New Delhi, 2000. Course Name: EMI/EMC DESIGN Course Code: EE614 2nd Ed. 333 **4.** Wilium DuffG., and Donald RJ, Series on "Electromagnetic Interference and Compatibility", Vol.5, EMI Prediction and Analysis Technique, 1972. **5.** Weston David. A., "Electromagnetic Compatibility, Principles and Applications", 1991. **6.** Kaiser BE., "Principles of Electromagnetic Compatibility", Artech House, 1987. **7.** "Electromagnetic Interference and Compatibility IMPACT series", IIT Delhi, **8.** Modules 1- 9. 7. C. R. Pal, "Introduction to Electromagnetic Compatibility", Ny, John Wiley, 1992.
Reference Books
1. Electromagnetic Compatibility Engineering, Henry W. Ott, ISBN: 978-0-470-18930-6, 872 pages, August 2009, Wiley Publishers. 2. Handbook for EMC- testing and measurement, Morgan D. 3. EMI & Compatibility Vol 1to 6 Electrical Noise & EMI SPEC, White, DON white 4. EMC for Product Designers, Tin Williams, Elsevier (2007). 5. Electromagnetic compatibility management guide for platforms, systems, and equipment, Standard Handbook, 1981 - Science - 125 pages, Pennsylvania State University.

Course Code	Course Name	L – T – P	**Credits**
EE615	**GNSS RECEIVER DESIGN AND APPLICATIONS**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Impart knowledge about the GNSS Receiver
- Introduce GNSS Sensitivity & Applications.
- Impart the knowledge on application-based GNSS Receiver modification.
- Provide practical knowledge for advanced application of GNSS.

Course Contents

Unit I: Understanding applications as a function of GNSS receiver design: Detailed explanation of a Receiver Input Output Diagram, and explanation of possible applications at various sub-system levels.

Unit II: GNSS Receiver design and modifications for high sensitivity applications: Detailed elaboration of receiver design for high sensitivity applications and its nuances. Case study of an application Module.

Unit III: GNSS Receiver design and modifications for high signal dynamic applications: Detailed elaboration of receiver design for high signal applications and its nuances. Case study of an application.

Unit IV: GNSS Receiver design and modifications for high-integrity applications: Detailed elaboration of receiver design for aerospace applications and its nuances. Introduction to SBAS. Case study of an application, Module, need for integration with other sensors, and its merits, case study of one integration concept Module.

Unit V: Introduction of GNSS in advanced system-level applications: Introduction and explanation of how GNSS is used in the determination of the attitude of a vehicle, precision farming, anti-collision techniques, say in a train, and a discussion on some new potential topics.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Familiarize with applications as a function of GNSS receiver design

CO2: Understand the basic concepts of GNSS receiver design and modifications for high-sensitivity applications, high signal dynamic applications

CO3: Learn analysis of GNSS receiver design and modifications for integration with other sensors.

CO4: Acquire knowledge of GNSS in advanced system-level applications.

CO5: Apply knowledge of GNSS in precision farming, anti-collision techniques, etc.

Text Books/Reference Books

1. B. Hofmann Wollenhof, H. Lichtenegger, and J. Collins, "GPS Theory and Practice", Springer Wien, new York, 2000.

2. Pratap Misra and Per Enge, "Global Positioning System Signals, Measurements, and Performance," Ganga Jamuna Press, Massachusetts, 2001.

3. Ahmed El-Rabbany, "Introduction to GPS," Artech House, Boston, 2002.

4. Bradford W. Parkinson and James J. Spilker, "Global Positioning System: Theory and Applications," Volume II, American Institute of Aeronautics and Astronautics, Inc., Washington, 1996.

Course Code	Course Name	L – T – P	**Credits**
EE 616	**Multi-Sensor Integrated Navigation**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Familiarize yourself with a navigation system and an introduction to the integrated navigation types of Navigation
- Understand basic concepts of estimation theory
- Acquire knowledge of Analysis of linear systems & Kalman filtering
- Provide knowledge of integrated navigation
- Deliver knowledge of Integration Schemes

Course Contents

Unit I: Navigation system and introduction to integrated navigation: Inertial Navigation, Terrestrial navigation, Radio Navigation, Satellite Navigation – Properties of Inertial Navigation System, Need for Navigation aids - Navigation Aids: Doppler Velocity Sensor, Radar Altimeter, Distance Measuring Equipment, Comparison of Inertial navigation systems with satellite navigation systems, concepts of integrated navigation.

Unit II & III: Basic concepts of estimation theory: Random signals, Random variables, Joint & conditional probability, Bayes Rule, continuous random variables, PDF, Gaussian Random variables, Correlation, covariance, independence, orthogonality, Transformation of random variables, General properties of random variables, Random process, stationary Process, Markov process, Ergodicity, Autocorrelation, Cross correlation, PSD, White noise & Colored noise, Decoloration, Random walk, and Wiener process problem of parameter estimation, Models for estimation of a parameter, Unbiased Estimators, Minimum Variance Unbiased Estimation - CRLB, Best Linear Unbiased Estimators(BLUE), MLE, LSE: Order-recursive Least squares, Sequential Least squares, Constrained Least Squares, Nonlinear Least Squares, Weighted LS, Recursive LS, Bayesian estimators: MMSE, MAP

Unit IV: Linear systems & Kalman filtering: Introduction to linear systems, Dynamic systems representation using State space, State space Analysis, Concepts of observability, state observer - Discrete time State space models – State Models for stochastic process - Linear state estimation – Basics of Kalman Filter, Continuous Time Kalman Filter, Discrete Time Kalman Filter, Derivations of K.F. equations in discrete domain, K.F. Properties, K.F. implementation issues, K.F. implementation for asynchronous measurements, Computational aspects of K.F - Sequential KF, Information Filtering, Joseph stabilized form, Nonlinear applications: Linearization, LKF, EKF, UKF.

Unit V: Integrated navigation: INS Mechanization equations, INS Error state dynamic equations, Pinson Error Model, Linearization, Augmented state equations with sensor errors, Navigation aiding measurements & Measurement Model, Observability analysis, GPS/INS integration, Integration by Complementary filtering, Integration using K.F., Kalman Filter Tuning, Integration Schemes: Uncoupled, Loosely coupled, Tightly coupled integration, Deep Integration/Ultra-tight Integration, Case studies: Barometer Aiding.

Course Outcomes

After completing this course, the students will be able to:

CO1: Familiarize with a navigation system and an introduction to the integrated navigation types of Navigation.

CO2: Understand basic concepts of estimation theory

CO3: Acquire knowledge of Analysis of linear systems & Kalman filtering

CO4: Gain knowledge of integrated navigation

CO5: Gain knowledge of Integration Schemes

Text Books/Reference Books

1. Fundamentals of Statistical Signal Processing: Estimation Theory by Steven M. Kay
2. Introduction to Random signals and Applied Kalman Filtering with Matlab exercises by Robert Grover
Brown & Patrick Y. C. Hwang.
3. Optimal state estimation: Kalman, H∞, and NonLinear Approaches by Dan Simon.
4. Estimation with Applications to tracking and navigation by Yaakov Bar-Shalom, X. Rong Li, Thiagalingam, Kirubarajan.
5. Mathematical techniques in multi-sensor data fusion, David L. Hall, Artech House, Boston.
6. Applied Mathematics in Integrated Navigation Systems, Robert M Rogers
7. Kalman Filtering Theory & Practice using Matlab, Mohinder S. Grewal.
8. Aided Navigation GPS with High-rate sensors, Jay A Farrell

Course Code	Course Name	L – T – P	**Credits**
EE617	**Inertial Navigation Systems**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Familiarize the basics of coordinate transformations: direction cosine matrix (DCM), Euler angles, quaternion; relation between DCM, Euler angles & quaternion.
- Know the concepts of strapdown inertial navigation and inertial measurements
- Grasp knowledge of the Inertial navigation system alignment
- Perform Navigation system simulation and error analysis

Course Contents

Unit I: Frames of references and inertial navigation fundamentals concept of frames of references: Inertial frames, non-inertial frames, geographic frame, geocentric frame, body frame; Principles of inertial navigation: types of inertial navigation, stabilized platform, and strap down systems, comparison; Earth models: ellipsoid geometry, ellipsoid gravity, earth gravity field, gravitational potential, gravity and gravitation, plum-bob gravity; Concepts of coordinate transformations: direction cosine matrix(DCM), Euler angles, quaternion; relation between DCM, Euler angles & quaternion.

Unit II: Concepts of strapdown inertial navigation inertial measurements: concept of specific force, basic principles of accelerometer: pendulous and vibrating beam, basic principle of gyroscope: mechanical and optical; Navigation equations formulation**:** forces in inertial & non-inertial frames, navigation equations in inertial & non-inertial frames, choice of reference frame, strap down system mechanization for different frames: inertial frames, earth-fixed frames, geographic frames.

Unit III: Strapdown inertial navigation computations sensor geometry: measurement model, concepts of DOP, failure detectability, optimal sensor geometry for different number of sensors; sensor modeling & compensation algorithms (scale factor, bias, misalignment, etc.), practical constraints; Failure detection and isolation: concepts of parity vectors, generalized likelihood test; Attitude propagation algorithm: using Euler angle, DCM, and quaternion; quaternion in terms of rotation vector, first and second order orientation vector algorithms for quaternion propagation, acceleration transformations, velocity & position update algorithms, numerical integration methods, comparison.

Unit IV: Inertial navigation system alignment: Initialization of inertial navigation system; Principle of alignment: alignment on a fixed platform: azimuth and level alignment, alignment on a moving platform: in-flight alignment and shipboard alignment: one-shot transfer alignment, measurement matching, methods of measurement matching; gyro-compassing; self-corrective alignment scheme.

Unit V: Navigation system simulation and error analysis: development of perturbation models, attitude response under angular vibration, velocity response under combined angular and linear vibration, size effect errors, and modeling of sensor assembly response to system

level vibration; specialized error analysis for strap down mechanization, INS Simulation**:** simulation of sensors, measurement electronics, and navigation algorithm; Navigation algorithm validation: comparison testing, closed loop simulations using NGC software together, hardware in-loop simulations; static navigation test, Monte Carlo & covariance analysis; General strap down algorithm validation**:** spin-cone, spin-accel, spin-rock-size.
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Familiarize with frames of reference and inertial navigation fundamentals, the concept of frames of reference **CO2:** Understand strapdown inertial navigation computations, sensor geometry, and inertial navigation system alignment **CO3:** Analyze navigation system simulation and error analysis **CO4:** Acquire knowledge of advanced navigation concepts **CO5:** Understand the navigation algorithm and error analysis
Text Books/Reference Books
1. David A Vallado; Fundamentals of astrodynamics and applications, 2. Kenneth R Britting; Inertial navigation system analysis 3. David H Titterton& John L Weston; Strap down inertial navigation technology. 4. Robert M Rogers; Applied mathematics in integrated navigation systems 5. Paul G Savage; Strapdown analytics 6. Mark A Sturza; Navigation System integrity monitoring using redundant measurements, Navigation: journal of institute of navigation, vol35, No.4, winter1988-89, 7. Oleg Salychev; Applied Inertial Navigation: Problems & Solutions

Course Code	Course Name	L – T – P	**Credits**
EE618	**Indoor Navigation**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the basics of Navigation
- Impart knowledge of positioning techniques
- Know and apply knowledge to build models
- Apply knowledge in localization and mapping

Course Contents

Unit I: Introduction: Location-Based Services (LBS), Indoor LBS and Ubiquitous Computing, Classical Research Areas Related to Indoor LBS, Classical Applications of LBS, Information Services, Navigation Service, Safety-of-Life Applications, Retail and Commerce, Management, Social Networking and Joint Activities, Gaming, A Short History of Navigation.
Unit II: Basic positioning techniques: Methods for Location Determination, Method of Least Squares, Lateration, Hyperbolic Lateration, Angulation, Proximity Detection, Inertial

Navigation, Fingerprinting, Properties and Evaluation of Positioning Systems, Examples of Positioning Systems, Pseudolites and High Sensitivity GNSS, Light-Based Systems, Camera-Based Systems, Radio-Based Systems, Inertial Navigation, Audio-Based Systems, Pressure-Based Systems. **Unit III: Building-modeling:** Coordinate Systems, Geometric Coordinate Systems, Symbolic Coordinate Systems, Location Models, Choice of Dimension, Vector Maps, Basic Algorithms for Vector Maps, Maps, Environmental Models, Set-Based Environmental Models, Graph-Based Environmental Models, Hybrid Approaches, Geometric Nearest Neighbors and Range Queries, Standardization, GML and City GML, Indoor OSM **Unit IV: Position-refinement & trajectory-computing:** Least Squares Estimation with Correlation, Recursive Least Squares Estimation, Discrete Kalman Filtering, The Extended Kalman Filter, Particle Filtering, Grid-Based Methods, Sampling Importance Resampling, The Process of Trajectory Computing, Trajectories, Trajectory Comparison, Hausdorff Distance, Fréchet Distance, Jaccard Distance, Closet Pair Distance, Euclidean Distance Sum, Dynamic Time Warping, Longest Common Subsequence (LCSS), Edit Distance on Real Sequences, Edit Distance with Real Penalties, Outlook, Trajectory Computing for Indoor LBS, Trajectory Computing for Positioning, Movement Patterns, Spatial Movement Patterns, Group-Based Motion Patterns. **Unit V: Event-detection for indoor LBS & simultaneous localization and mapping in buildings:** Event-Driven Applications, Event Sources for Indoor Navigation, Primary Events from Environmental Knowledge, Primary Events from Infrastructure, Primary Events from User Interface, Primary Events from Positioning, Primary Events from Activity Recognition, Secondary Events Relevant to the Navigational Task, Data Sources for SLAM, Data from Inertial Navigation Systems, Data from Laser Scanners, Data from Landmarks, Data from Camera Systems, Important Algorithms for SLAM Systems, Visual Feature Point Extraction, Optical Flow Estimation, Iterative Closest Points, Random Sample Consensus, Graph-Based Optimization Algorithms, Several Well-Known SLAM Approaches, Extended-Kalman-Filter SLAM, Fast SLAM, Grid-SLAM, Privacy and Security Considerations: Multiparty Computation, k-Anonymity, l-Diversity, Spatial and Temporal Cloaking, Differential Privacy, Private Information Retrieval, Quadratic Residues, Private Information Retrieval Using Quadratic Residuosity.
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Familiarize yourself with Location-Based Services (LBS), History of Navigation. **CO2:** Analyze Basic Positioning Techniques **CO3:** Build modeling maps, Indoor OSM, and position refinement. **CO4:** Apply the knowledge of Simultaneous Localization and Mapping in Buildings, Case Studies **CO5:** Acquire knowledge of event detection for indoor LBS
Text Books/Reference Books
1. Indoor Location-Based Services Prerequisites and Foundations, Werner, Martin, Publisher: Springer; 2014 Edition, ISBN-10: 3319106988.

2. Principles of GNSS, Inertial, and Multi-sensor Integrated Navigation Systems, Paul D. Groves Artech House, 2008 and 2013 Second Edition.
3. B. Hofmann Wollenhof, H. Lichtenegger, and J.Collins, "GPS Theory and Practice", Springer Wien, NewYork, 2000.
4. Pratap Misra and Per Enge, "Global Positioning System Signals, Measurements, and Performance," Ganga-Jamuna Press, Massachusetts, 2001.
5. Ahmed El-Rabbany, "Introduction to GPS," Artech House, Boston, 2002.
6. Bradford W. Parkinson and James J. Spilker, "Global Positioning System: Theory and Applications," Volume II, American Institute of Aeronautics and Astronautics, Inc., Washington, 1996.

Course Code	Course Name	L – T – P	**Credits**
EE619	**Software Defined Radio**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the fundamentals, architecture, and evolution of Software Defined Radio (SDR) systems.
- Explore hardware and signal processing platforms used in SDR and their power-performance trade-offs.
- Analyze various signal processing techniques and architectures for implementing SDR and cognitive radio systems.
- Understand cognitive radio concepts, spectrum sensing techniques, and their real-world applications

Course Contents

Unit I: Introduction to SDR: What is Software-Defined Radio? The Requirement for Software-Defined Radio, Legacy Systems, The Benefits of Multi-standard Terminals, Economies of Scale, Global Roaming, Service Upgrading, Adaptive Modulation and Coding, Operational Requirements, Key Requirements, Reconfiguration Mechanisms, Handset Model, New Base-Station and Network, Architectures, Separation of Digital and RF, Tower Top Mounting, BTS Hoteling, Smart Antenna Systems, Smart Antenna System Architectures, Power Consumption Issues, Calibration Issues, Projects and Sources of Information on Software Defined Radio,

Unit II: Basic architecture of a software defined radio: Software Defined Radio Architectures, Ideal Software Defined Radio Architecture, Required Hardware Specifications, Digital Aspects of a Software Defined Radio, Digital Hardware, Alternative Digital Processing Options for BTS Applications, Alternative Digital Processing Options for Handset Applications, Current Technology Limitations, A/D Signal-to Noise Ratio and Power 343 Consumption, Derivation of Minimum Power Consumption, Power Consumption Examples, ADC Performance Trends, Impact of Superconducting Technologies on Future SDR Systems.

Unit III: Signal processing devices and architectures: General Purpose Processors, Digital Signal Processors, Field Programmable Gate Arrays, Specialized Processing Units, Tilera Tile Processor, Application-Specific Integrated Circuits, Hybrid Solutions, Choosing a DSP Solution.

GPP-Based SDR, Non-real time Radios, High- Throughput GPP-Based SDR, FPGA-Based SDR, Separate Configurations, Multi- Waveform Configuration, Partial Reconfiguration, Host Interface, Memory-Mapped Interface to Hardware, Packet Interface, Architecture for FPGA-Based SDR, Configuration, Data Flow, Advanced Bus Architectures, Parallelizing for Higher Throughput, Hybrid and Multi-FPGA Architectures, Hardware Acceleration, Software Considerations, Multiple HA and Resource Sharing, Multi-Channel SDR, Airborne SDRs, Adhoc Network architecture for Airborne SDRs. **Unit IV: Cognitive radio: techniques and signal processing:** History and background, Communication policy and Spectrum Management, Cognitive radio cycle, Cognitive radio architecture, SDR architecture for cognitive radio, Spectrum sensing Single node sensing: energy detection, cyclostationary and wavelet-based sensing- problem formulation and performance analysis based on probability of detection vs SNR. Cooperative sensing: different fusion rules, wideband spectrum sensing- problem formulation and performance analysis based on probability of detection vs SNR. **Unit V: Cognitive radio: Hardware and applications:** Spectrum allocation models. Spectrum handoff, Cognitive radio performance analysis. Hardware platforms for Cognitive radio (USRP, WARP), details of USRP board, Applications of Cognitive radio.
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Familiarize yourself with Software-Defined Radio and its various systems **CO2:** Analyze General-Purpose Processors and Digital Signal Processors **CO3:** Classify Cognitive radio architecture, SDR architecture, Applications of Cognitive radio, Spectrum sensing, Single node sensing with its hardware platforms. **CO4:** Apply the knowledge and skills to simulate SDR Flow in SystemVue, FPGA, and GNU Radio Simulation Software. **CO5:** Understand hardware and application of cognitive radio
Textbooks/Reference Books
"RF and Baseband Techniques for Software Defined Radio" Peter B. Kenington, ARTECH HOUSE, INC © 2005. 2. "Implementing Software Defined Radio", Eugene Grayver, Springer, New York Heidelberg Dordrecht London, ISBN 978-1-4419-9332-8 (eBook) 2013. 3. "Cognitive Radio Technology", by Bruce A. Fette, Elsevier, ISBN 10: 0-7506-7952-2, 2006.

Course Code	Course Name	L – T – P	**Credits**
EE620	**SoC and Embedded Systems**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Know Embedded System Fundamentals
- Understand Networking and Communication
- Grasp knowledge of Advanced Embedded Technologies
- Understand Real-Time Operating Systems (RTOS)

Course Contents

Unit I: Introduction: Definition and Classification, Overview of Processors and hardware units in an embedded system, Software embedded into the system, Embedded Systems on a Chip (SoC), and the use of VLSI designed circuits. Design flow of ASIC, SoC, and FPGA. Comparison of various processors such as generic microprocessor, microcontroller, DSP processors, and Tesla parallel computing hardware. Memory Interfacing and I/O Interfacing with processors.

Unit II: Devices and buses for devices network: I/O Devices, Device I/O Types and Examples, Synchronous, I/o synchronous, and Asynchronous Communications from Serial Devices, Examples of Internal Serial-Communication Devices, UART, Parallel Port Devices, Sophisticated interfacing features in Devices/Ports, Timer and Counting Devices, I2C, USB, CAN, and advanced I/O Serial high speed buses, ISA, PCI,PCI-X, and advanced buses.

Unit III: Embedded computing: Embedded processors, ARM processor, Architecture, Instructions and programming, Case Studies, Parallel Computing, CUDA platform for radar Application.

Unit IV: Advanced embedded computing: Programmable System on Chip, Cypress PSoC Technology. Advanced DSP Processors. FPGA Technology towards Embedded system aspects-Pico blaze and micro blaze processors- Embedded RAM- Embedded multiplier FPGA coding using VHDL/ Verilog. Associated Labs: Assignments using Microcontroller kits, FPGA kits.

Unit V: RTOS: Introduction to RTOS: Task Management, Memory management, Device Management, File management, Time management Scheduling Interrupt Handling, Event handling, inter process communication, Inter process synchronization, Networking Hardware: computer architecture, microprocessors, memories, peripheral devices, interconnections Case study: VxWorks and RTLinux RTOS in computing systems: embedded system, real time system, parallel system, and distributed system; CASE STUDY: underwater gylider controller – Interfacing of various sensors such as inertial sensors and actuators using various processors and its performance comparison.

Course outcomes:

On completion of this course, the students will be able to:

CO1: Learn the memory interface concept and the I/O interface concept in microprocessors and microcontrollers.

CO2: Understand the various devices and buses, and network protocols in the various processors

CO3: Understand the DSP Processor, PSoc, and CUDA platform for various applications.

CO4: Acquire knowledge of the fundamentals of RTOS

CO5: Gain knowledge of RTOS

Text Books

1. ARM System-on-Chip Architecture (2nd Edition) Steve Furber.
2. Real-time digital signal processing: Based on the TMS320C6000, Nasser Kehtarnavaz Advanced FPGA Design: Architecture, Implementation, and Optimization, Steve Kilts, IEEE press, Wiley, 2007.

Reference Books

1. http://www.xilinx.com/publications/xcellonline: Xcell Journal.
2. Real-time digital signal processing: Based on the TMS320C6000, Nasser Kehtarnavaz.
3. Advanced FPGA Design: Architecture, Implementation, and Optimization, Steve Kilts, IEEE press, Wiley, 2007.

Course Code	Course Name	L – T – P	**Credits**
EE621	**Digital Integrated Circuit Design**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the fundamentals of MOS design, including pseudo NMOS and CMOS inverter logic.
- Learn how to design and analyze combinational and sequential MOS logic circuits.
- Explore the principles of dynamic logic circuits.
- Understand the operation and design of various semiconductor memories, including DRAM, SRAM, and flash memory.

Course Contents

Unit I: MOS Design: Pseudo NMOS Logic – Inverter, Inverter threshold voltage, output high voltage, output Low voltage, gain at gate threshold voltage, Transient response, Rise time, Fall time, Pseudo NMOS logic gates, Transistor equivalency, CMOS Inverter logic.

Unit II: Combinational MOS logic circuits: MOS logic circuits with NMOS loads, Primitive CMOS logic gates – NOR & NAND gates, Complex Logic circuits design – Realizing Boolean expressions using NMOS gates and CMOS gates, AOI and OIA gates, CMOS full adder, CMOS transmission gates, Designing with Transmission gates.

Unit III: Sequential MOS logic circuits: Behavior of bistable elements, SR Latch, Clocked latch and flip flop circuits, CMOS D latch and edge-triggered flip flop.

Unit IV: Dynamic logic circuits: Basic principle, Voltage Bootstrapping, Synchronous dynamic pass transistor circuits, Dynamic CMOS transmission gate logic, High-performance Dynamic CMOS circuits.

Unit V: Semiconductor memories: Types, RAM array organization, DRAM – Types, Operation, Leakage currents in DRAM cell and refresh operation, SRAM operation, Leakage currents in SRAM cells, Flash Memory, NOR flash and NAND flash. **Emerging memory technologies:** Phase Change Memory (PCM); Resistive Random-Access Memory, Magneto-resistive Random-Access Memory (MRAM); Ferroelectric Random-Access Memory (FeRAM); Comparison and future directions.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Acquire knowledge of the design of Combinational MOS Logic Circuits
CO2: Learn sequential MOS Logic circuits
CO3: Develop an understanding of large signal and small signal analysis of complex circuits
CO4: Develop the knowledge of Semiconductor memories
CO5: Apply the knowledge for the Simulation of circuits using PSpice and Microwind Backend Tools.

Text Books
1. Digital Integrated Circuit Design – Ken Martin, Oxford University Press, 2011 2. CMOS Digital Integrated Circuits Analysis and Design – Sung-Mo Kang, Yusuf Leblebici, TMH, 3rd Ed., 2011.
Reference Books
1. Introduction to VLSI Systems: A Logic, Circuit and System Perspective – Ming-BO Lin, CRC Press, 2011 2. Digital Integrated Circuits – A Design Perspective, Jan M. Rabaey, Anantha Chandrakasan, Borivoje Nikolic, 2nd Ed., PHI

Course Code	Course Name	L – T – P	**Credits**
EE622	**RFIC Design**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the basic principles and challenges in RF circuit design, including non-linearity and noise.
- Analyze and design key RF components like LNAs, mixers, oscillators, and synthesizers.
- Evaluate the performance of RF circuits for gain, distortion, impedance matching, and noise.
- Introduce system-level design concepts for RF transceivers, including transmitters, receivers, and synthesizers.

Course Contents

Unit I: Basic concepts in RF design: Time variance, Non-linearity, Effect of nonlinearity, Harmonic distortion, gain compression, Cross modulation, Intermodulation, Cascaded nonlinear stages, AM-PM conversion, Noise spectrum, effect of transfer function on noise, device noise, Sensitivity, Dynamic range.

Unit II: Components and devices: Integrated inductors, resistors, MOSFET and BJT AMPLIFIER DESIGN: Low Noise Amplifier Design – Wideband LNA - Design Narrowband LNA - Impedance Matching, Automatic-Gain-Control-Amplifiers.

Unit III: Mixers: Mixer - Qualitative Description of the Gilbert Mixer, Single balanced mixer, Double balanced mixer, Conversion Gain-Distortion Low Frequency Case: Analysis of Gilbert Mixer – Distortion - High-Frequency Case – Noise - A Complete Active Mixer. Switching Mixer - Distortion in Unbalanced Switching Mixer – Conversion Gain in Unbalanced Switching Mixer - Noise in Unbalanced Switching Mixer - A Practical Unbalanced Switching Mixer. Sampling Mixer - Conversion Gain in Single-Ended Sampling Mixer - Distortion in Single-Ended Sampling Mixer – Intrinsic Noise in Single-Ended Sampling Mixer - Extrinsic Noise in Single-Ended Sampling Mixer.

Unit IV: Frequency synthesizers: Phase Locked Loops - Voltage Controlled Oscillators – Phase Detector – Analog Phase Detectors – Digital Phase Detectors - Frequency Dividers - LC Oscillators – Ring Oscillators - Phase Noise - A Complete Synthesizer Design Example (DECT Application).

Unit V: Amplifiers and design concept: Power amplifiers, Adaptive Filters, Equalizers, Transceivers- system level considerations, Receiver design, Transmitter design, and Synthesizer design.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Generalize the basic concept/idea of RF transceiver, its design issues, linearity, non-linearity, and distortion. Students will learn about device noise.

CO2: Learn the basics of a low-noise amplifier, oscillator, and mixer.

CO3: Learn the concept of Gilbert mixer, single balanced mixer, and double balanced mixer, amplifier, and some parts of the power amplifier are given to students.

CO4: Acquire knowledge of designing synthesizers

CO5: Apply knowledge and skills to design a power amplifier, its use in a transmitter, and a multi-tier transceiver architecture.

Textbooks/Reference Books

1. B. Razavi, “RF Microelectronics”, Prentice-Hall ,1998
2. Bosco H Leung, “VLSI for Wireless Communication”, Pearson Education, 2002.
3. Thomas H. Lee, “The Design of CMOS Radio –Frequency Integrated Circuits”,
4. Cambridge University Press,
5. Emad N Farag and Mohamed I Elmasry, “Mixed Signal VLSI Wireless Design - Circuits
6. and Systems”, Kluwer Academic Publishers, 2000.
7. Behzad Razavi, “Design of Analog CMOS Integrated Circuits” McGraw-Hill, 1999.
8. J. Crols and M. Steyaert, “CMOS Wireless Transceiver Design,” Boston, Kluwer
9. Academic Pub., 1997.

Course Code	Course Name	L – T – P	**Credits**
EE623	**Semiconductor Devices**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand fundamental semiconductor physics and carrier transport mechanisms.
- Analyze the electrical behavior of key semiconductor devices like pn-junctions, MOSFETs, BJTs, and HBTs.
- Explore device modeling, fabrication techniques, and high-frequency characteristics.
- Introduce emerging transistor technologies and trends beyond traditional device scaling.

Course Contents

Unit I: Basic semiconductor physics: Crystal lattice, energy band model, density of states, distribution statistics – Maxwell-Boltzmann and Fermi-Dirac, doping, carrier transport mechanisms - drift, diffusion, thermionic emission, and tunneling; excess carriers, carrier lifetime, recombination mechanisms – SHR, Auger, radiative, and surface.

Unit II: Junctions: p-n junctions – fabrication, basic operation – forward and reverse bias, DC model, charge control model, IV characteristic, steady state and transient conditions, capacitance model, reverse-bias breakdown, metal semiconductor junctions –fabrication, Schottky barriers, rectifying and ohmic contacts, I-V characteristics.

Unit III: MOS Capacitors and MOSFETs: The MOS capacitor – fabrication, surface charge –

accumulation, depletion, inversion, threshold voltage, CV characteristics – low and high frequency; the MOSFET – fabrication, operation, gradual channel approximation, simple charge control model (SCCM), I-V characteristic, second order effects – Velocity saturation, short-channel effects, charge sharing model, hot-carrier effects, gate tunneling, subthreshold operation – drain induced barrier lowering (DIBL) effect, unified charge control model (UCCM), MESFETs –fabrication, basic operation, I-V characteristics, high frequency response, back gating effect, HEMTs – fabrication, modulation (delta) doping, analysis of III-V heterojunctions, charge control, I-V characteristics, SPICE model. **Unit IV: BJTs and HBTs:** Fabrication, basic operation, minority carrier distributions and terminal currents, I-V characteristic, switching, second-order effects – base narrowing, avalanche multiplication, high injection, emitter crowding, Kirk effect, etc.; breakdown, high-frequency response, Gummel-Poon model, SPICE model; HBTs: - fabrication, basic operation, technological aspects, I-V characteristics, SPICE model. **Unit V: Roadmap for next generation field effect transistors:** Disadvantages associated with Scaling of FETs, Future roadmap for FETs, Recent trends in FETs: Fully Depleted SOI MOSFET, Fin-FET, Gate all around Fin-FETs, Thin sheet Fin-FET, Negative Capacitance FET (NCFET), Tunnel FET (TFET), Impact Ionization MOS (IMOS), and Future Improvement Possibilities.
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Understand the fundamentals of Maxwell's equations and Transmission line theory **CO2:** Acquire knowledge of the various Two-port Parameters: Z-Matrix, Y-Matrix, ABCD-Matrix, S-Matrix **CO3:** Understand the basics of microwave passive components: Directional Couplers, Filters, Power dividers **CO4:** Design and develop microwave active circuits such as amplifiers, Oscillators, multipliers, etc. **CO5:** Hands-on with Microwave measuring equipment and understanding the measurement of microwave circuits
Textbooks/Reference Books
1. Ben G. Streetman, Solid State Electronic Devices, Prentice Hall, 1997. 2. Richard S. Muller and Theodore I. Kamins, Device Electronics for Integrated Circuits, JohnWiley,1986.

Course Code	Course Name	L – T – P	**Credits**
EE624	**Digital System Design Using FPGAs**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Impart knowledge about Digital System Techniques.
- Introduce different VHDL-based designs
- Impart the knowledge of Fault Modeling, Detection, and Test Pattern Generation Algorithms.
- Provide practical knowledge of Digital Interfacing.

Course Contents

Unit I: Digital system design techniques: Combinational Circuit Design - Synchronous Sequential Circuit Design - Mealy and Moore model - State machine design - Analysis of Synchronous sequential circuit - State equivalence - State Assignment and Reduction – Analysis of Asynchronous Sequential Circuit - flow table reduction – races - state assignment - Design of Asynchronous Sequential Circuit - Designing with PLDs – Overview of PLDs – ROMs - EPROMs – PLA – PAL - Gate Arrays – CPLDs and FPGAs, Designing with ROMs - Programmable Logic Arrays - Programmable Array logic. **Unit II: VHDL Basics and computation module designs:** Introduction to VHDL - Behavioral modeling - Data flow modeling - Structural modeling - Basic language elements – Entity – Architecture - Configurations – Arrays declaration - Subprograms & operator overloading - Packages & libraries – Advanced Features - Model simulation - Realization of combinational and sequential circuits using VHDL – Registers – Flip flops - counters – Shift registers – Multiplexers - sequential machine – Multiplier – Divider, ALU, MAC, CORDIC, Introduction to Synthesis. **Unit III: Fault modeling, detection and test pattern generation algorithms:** Introduction to testing – Faults in Digital Circuits – Modeling of faults – Logical Fault Models – Fault detection – Fault Location – Fault dominance – Logic simulation – Test generation for combinational logic circuits – Testable combinational logic circuit design - Introduction to Design for Testability - BIST. **Unit IV: Digital system design with real-time i/o interface:** Sensors interface - uni-polar & bi-polar A/D converter - D/A converter interface - display devices interface - RS232, USB, Ethernet, VGA interface - RF data link - high voltage switch control - realy/AC/DC motor & buzzer control - PWM signal generation - PS/2 key-board & matrix keypad interface – digital camera interface, arbitrary data/signal generation – sensor data acquisition and writing/reading to/from .xlsx and .doc file - implementation of modulation schemes. **Unit V: Contemporary designs and solutions:** Design of data path components, Control path components - Design of a simple RISC CPU - Debugging using Embedded Logic Analyzers - Audio codec (AC97) interface – Test-bench design – Chip Scope Pro Analyzer - introduction to floating/fractional/fixed-point arithmetic operations - Xilinx Sys-Gen tools - MATLAB/VHDL interface with Sys-Gen tools -BERT interface – implementation of DPCM, data encryption/decryption system, EC techniques, communication modules design, DA based computations.
Course Outcomes
CO1: Familiarize with the design of Combinational and Synchronous, and Asynchronous Sequential Circuits. Gave an Overview of PLDs and PALs **CO2**: Cover the basic introduction of VHDL and the basic language elements. Various Combinational and Sequential circuits were designed using VHDL **CO3:** Gain an In-depth analysis of Faults and testability in digital systems, including modelling and detection **CO4**: Interface with various sensors and reading/writing to/from various file formats. Implementing various modulation schemes. **CO5:** Design a RISC CPU, data and control path components, and various floating/fractional/fixed-point arithmetic operations, and implement a Data encryption/Decryption system, Error correction, communication modules, BERT
Text Books

1.Parag K. Lala, "Digital System Design using programmable Logic Devices", Prentice Hall, NJ, 1994. 2. Geoff Bestock, "FPGAs and programmable LSI; A Designers Handbook", Butterworth Heinemann, 1996. 3. Miron Abramovici, Melvin A. Breuer and Arthur D. Friedman, “Digital Systems Testing and Testable Design”, John Wiley & Sons Inc. 4. Parag K. Lala “Fault Tolerant and Fault Testable Hardware Design” B S Publications, 2002. 5. J. Bhasker, "A VHDL Primer", Addison-Weseley Longman Singapore Pte Ltd. 1992.
Reference Books 1. Jesse H. Jenkins, "Designing with FPGAs and CPLDs", Prentice Hall, NJ,1994 2. Fundamentals of Logic Design – Charles H. Roth, 5th ed., Cengage Learning. 3. Kevin Skahill, "VHDL for Programmable Logic", Addison -Wesley, 1996 4. Z. Navabi, "VHDL Analysis and Modeling of Digital Systems", McGRAW-Hill, 1998 5. Digital Circuits and Logic Design – Samuel C. Lee, PHI 6. Smith, "Application Specific Integrated Circuits", Addison-Wesley, 1997 7. P.K. Lala, “Digital Circuit Testing and Testability”, Academic Press, 2002

Course Code	Course Name	L – T – P	**Credits**
EE625	**High Performance DSP using FPGA**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Impart knowledge about High Performance DSP using FPGA.
- Introduce High-Performance Digital Computations
- Impart the knowledge of IP Core Design.
- Provide practical knowledge of System Implementation.

Course Contents

Unit I: Introduction to high performance digital computations: Digital system design, signal processing, fixed and floating point computations, standards for high resolution computing, Design with Vivado design suite (IP, SysGen for DSP and image processing, model composer, embedded development, AI and ML tools), testing with high speed logical analyzer, advanced features of modern FPGAs (Kintex-7, Virtex-7, Zynq-7000, Artix-7, Kintex Ultra Scale, Kintex Ultra Scale+,Virtex Ultra Scale, Virtex UltraScale+, ZynqUltraScale+ and RFSoC etc.,), external memory interface, designs with advanced VHDL, advanced design with the PlanAhead analysis/design-tools, debugging techniques using the ChipScope Pro tools, FPGA power optimization.

Unit II: System implementation using hybrid simulink-programming tools: Introduction to SysGen tools, integration of MATLAB & Simulink with SysGen platform, Model composer algorithms, integrated mixed language-based design, high level synthesis, MATLAB & simulink, C and LabVIEW based HLS designs, massive parallel computations, designs with advanced XDC and STA, debugging techniques using Vivado logic Analyzer, designing with the Xilinx analog mixed signal solution.

Unit III: IP Core library and design managements: IP core design flow, IP core subsystems and integrations, parallelism, full/partial reconfiguration, flexible DSP blocks and multipliers, processor cores, embedded block RAM, embedded designs, standard communication interfaces, mixed signals based design, Multi-Rate Systems, MAC-Based FIR, Distributed Arithmetic and Multipliers Realization, FIFO, creating and managing reusable IPs, designs using Xilinx IP with Third-Party Synthesis Tools, Programming and Debugging Embedded Processors, SoC Processor Design, Embedded Micro Blaze Processor.

Unit IV: Algorithm implementations using DSP Tools: Ultra-fast algorithm design methodology, reconfigurable FPGA-based DSP Systems, real-time DSP System on Chip (SoC), Graphical Representation of DSP Algorithms, FIR/IIR filters, Adaptive filters, CORDIC algorithm implementations, multirate signal processing, FT/T_F analysis, spectral estimation and analysis, optimum and estimation techniques, image and speech processing, implementations of advanced transforms, Wavelet based designs.

Unit V: Contemporary applications and solutions: Video and image processing, database and data analysis, control systems, high-speed, wired, wireless communications, network accelerations, test and M/m systems, HT generations/ detections, AI and machine learning algorithm implementations, 5G adaptive beamforming, RF transceiver modules interface, software driven DDS/SDR platform interface, Gbps Ethernet/optical-fiber dynamic switching, Designing an Integrated PCI Express System, IoE designs, soft controller designs.

Course Outcomes

CO1: Understand system design basics and design tools like Vivado, ISE, etc. Also, learning about the features of different FPGA boards

CO2: Learn different hybrid programming tools for system implementation, like integration of MATLAB & Simulink, C & LABVIEW, etc. Learning IP core design for various DSP applications

CO3: Learn design algorithms for real-time DSP systems and different transforms. Also, learning the applications of FPGA in modern technologies

CO4: Learn FPGA hardware and use it for real-time experiments

CO5: Understand Beamforming, transceiver designs, and implementation of AI and ML

Text Books/Reference Books

1. Michael P, Digital Signal Processing 101: Everything You Need to Know to Get Started, 2010, Elsevier.
2. Steve K, Advanced FPGA Design: Architecture, Implementation, and Optimization, 2007, IEEE.
3. Sanjay Churiwala, designing with Xilinx® FPGAs: Using Vivado, 2017, Springer.
4. Roger Woods et al., FPGA-based Implementation of Signal Processing Systems, 2017, Wiley.
5. Donald G. Bailey, Design for Embedded Image Processing on FPGAs, 2011, IEEE.
6. Uwe Meyer-Baese Digital Signal Processing with Field Programmable Gate Arrays, 2013, Springer.
7. Nasser Kehtarnavaz, Digital Signal Processing Laboratory: LabVIEW-Based FPGA Implementation, 2010,
Brown Walker press.
8. https://www.xilinx.com/support.html#knowledgebase.

Course Code	Course Name	L – T – P	**Credits**
EE626	**Compressed Sensing and Sparse Signal Processing**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the fundamentals of compressive sensing (CS) and its connection to linear algebra and sparse signal representation.
- Understand theoretical principles.
- Explore measurement matrix design and properties for reliable sparse signal acquisition.
- Learn and implement reconstruction algorithms, including convex optimization methods and greedy approaches.
- Develop practical skills in CS through MATLAB-based implementation, simulation, and performance evaluation of algorithms

Course Contents

Unit I: Introduction: Introduction to CS, Review of Linear Algebra

Unit II: Sparse Representations: Motivations and basic formulations, Uniqueness of sparse representation.

Unit III: Measurement Matrices: Null Space Property, Restricted Isometry Property (RIP), Johnson Lindenstrauss Lemma, Random Matrices and RIP**.**

Unit IV & V: Reconstruction Algorithms: Convex Optimisation methods, Basis Pursuit, Basis Pursuit Demonising, Introducing software packages like L1-magic, sparselab, etc. Greedy Algorithms: Matching Pursuit, Orthogonal Matching Pursuit, Subspace Pursuit, Compressive Sampling Matching Pursuit. Theoretical Guarantees of the algorithms, Implementation of the algorithms in Matlab, and simulations.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Generalize the concept of compressed sensing.
CO2: Gain the theory of the null space property and RIP.
CO3: Acquire the basics of convex optimization and basis pursuit
CO4: Apply knowledge and skills to demonstrate in a short project

Text Books/Reference Books

1. A Mathematical Introduction to Compressive Sensing, Simon Foucart, Holger Rauhut, Springer New York, 21-Jun-2013

2. Compressed Sensing: Theory and Applications, Yonina C. Elda, Cambridge University Press

Course Code	Course Name	L – T – P	**Credits**

EE627	**Signal Theory, Linear Algebra & Transform Techniques**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Develop a solid foundation in probability theory and random processes for modeling and analyzing stochastic signals.
- Apply transform techniques (Laplace, Z, Fourier, Wavelet) for signal analysis, system characterization, and efficient computation.
- Understand and utilize properties of Gaussian processes, stationarity, and spectral analysis in signal processing contexts.
- Strengthen knowledge of linear algebra concepts, including vector spaces, transformations, eigen analysis, and singular value decomposition.
- Integrate probability, transforms, and linear algebra to solve practical problems in signal and system analysis.

Course Contents

Unit I & II: Probability and Random variables: Random variables, Probability Distribution, and Density functions, Normal or Gaussian Random Variables, Multiple Random Variables, Correlation, Covariance and Orthogonality, Transformation of Random variables, Multivariate Normal Density Function, Linear Transformation and General Properties of Normal, Random Variables, Mathematical Description of Random Signals, Concept of a Random Process, Probabilistic Description of a Random Process, Gaussian Random Process,

Stationarity, Ergodicity, and Classification of Processes, Autocorrelation Function, Cross-Correlation Function, Power Spectral Density Function, Cross Spectral Density Function, White Noise.

Unit III: Transform Techniques: Laplace Transform: Introduction, Region of absolute convergence, Properties, Convolution, Inverse Laplace transform. Z TRANSFORM: Basic Properties, z-transform inversion, Difference equation. FOURIER TRANSFORM: Prelude to Fourier series, Transform properties, Discrete Fourier Transform, Properties, FFT, fast convolution. WAVELET TRANSFORM: Continuous wavelet transforms, Different wavelets, and multi-resolution analysis.

Unit IV & V: Linear Algebra: General (real) vector spaces, Subspaces, Linear independence, Dimension, Norms, Orthogonal bases and Gram-Schmidt orthogonalization, Linear transformation, Kernel and range, Inverse transformations, Matrices of linear transformations, Change of basis, Similarity, Eigen values and Eigen vectors, Diagonalization, Orthogonal diagonalization of symmetric matrices, Singular value decomposition, and its applications.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Learn the basics of random variables, probability, density functions, and correlation.

CO2: Gain the theory of the Laplace transform and the Wavelet transform.

CO3: Acquire the basics of orthogonal basis, linear independence ization convex optimization, and basis pursuit.

CO4: Learn the application of SVD and EVD to demonstrate using a short project.

Text Books
1. Linear Algebra and its Applications, 1980, Gilber-strang, Academic press 2nd Edn, 2. Probability, Random Variables, and Stochastic Processes, 1965, Athanasios Papoulis, McGraw Hill.
Reference Books
1. Probability & Random Processes with Applications to Signal Processing, 2001, 3Edn. Henry Stark and John W Woods, Prentice Hall. 2. Introduction to linear algebra, 1984, Roger C. Mecann, Harcourt Brace Jovancovich Publishers. 3. First Course in Linear Algebra, 1983, P.B. Bhattacharya, S.K. Jain and S.R. Nagpaul, Wiley Eastern. 4. Signal Processing, 1975, Mischa Schwartz and Leonard Shaw, New York, McGraw-Hill.

Course Code	Course Name	L – T – P	**Credits**
EE628	**Advanced Electronics Systems**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the Analog IC Design Flow
- Grasp knowledge about sensors
- Design and realize Analog ICs
- Design and realize Digital ICs

Course Contents

Unit I: Introduction: Analog IC Design Flow -Digital IC Design Flow- Bipolar and CMOS Technology.

Unit II: Sensors: Sensors as system components- Temperature sensors- Force and pressure sensors- Magnetic field sensors – Optical sensors - Microwave sensors - Miscellaneous sensors –MEMS-Fabrication steps.

Unit III: Analog IC Design: Analog Conditioning Circuits. Advanced Current Sources & sinks; Voltage Reference circuit, Operational amplifiers - Architectures-Instrumentation Amplifiers, feedback-Filter Design-ADC-DAC. Concepts of Virtual Instrumentation.

Unit IV: Digital IC Design: MOS inverter- Static and switching characteristics, Combinational MOS logic circuits –static logic, Synchronous system, and Sequential circuits design.

Unit V: RF Microelectronics: Low Noise Amplifier (LNA), Mixer, Oscillator, VCO and PLL, Power Amplifier-Transceiver Architecture.

Course Outcomes

On completion of this course, the students will be able to: **CO1:** Learn the basics of Analog IC Design Flow, Digital IC Design Flow, Sensors, and advanced topics **CO2:** Gain the theory of Analog IC Design **CO3:** Acquire the basics of Digital IC Design **CO4:** Learn the basics and applications of RF Microelectronics
Text Books/Reference Books
1. Jan M. Rabaey; Anantha Chandrakasan; BorivojeNikoli´c, "Digital Integrated Circuits A Design Perspective", (Second Edition) Prentice-Hall Electronics and VLSI Series. (2003) 2. Behzad Razavi," Design of Analog CMOS integrated circuits", McGraw Hill International Edition. 2001. 3. Behzad Razavi," RF Microelectronics", PHI International Second Edition. 2012. 4. Neil H.E. Weste, Kamran Eshraghian, "Principles of CMOS VLSI Design, Addison-Wesley Publishing Company. 5. Handbook of Modern Sensors by Fraden 6. D. V.S. Murthy, Transducers in instrumentation, Prentice Hall, 1995. 7. J. P. Bentley, Principles of measurement systems, Wiley, 1989 8. J. W. Gardner, Microsensors, principles and applications, Wiley, 1996. 9. S.M. Sze, Semiconductor Sensors, Wiley, 1994.

Course Code	Course Name	L – T – P	**Credits**
EE630	**Sonar Signal Processing**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the basics of sound propagation and sonar evolution.
- Understand underwater acoustic channel models.
- Study ambient and radiated noise and their impact on sonar performance.
- Analyze target reflection, scattering, and detection techniques.
- Explore shallow water acoustics and passive sonar classification methods.

Course Contents

Unit I: Historical Background and Basics of Sound: History of sonar evolution, basics of sound measurement, measurement parameters, sound velocity profile and variation, and medium parameters.

Unit II: Underwater Channel Models: Multipath Propagation, Ray Model, Helmholtz Equation, Wave Propagation, Adiabatic Model, PE model, Computational Ocean Acoustics.

Unit III: Ambient Noise in the Ocean and Sonar Equation: Sources of sound in the ocean, propagation impact, characteristics of the sources, and their impact on sonar performance. Sonar parameters, sonar equation for active and passive sonar, Components of radiated noise, transmission of the components, propulsion types and their characteristics, ship design, and stealth aspects.

Unit IV: Reflection and Scattering by Sonar Targets: Active sonar target characteristics, design and stealth aspects, Sensor performance and self-noise characteristics, ROC, statistical analysis for detection, State-of-the-art.

Unit V: Shallow Water Acoustics and Passive Sonar: Deep Vs Shallow waters, Propagation in Tropical Littoral Waters, Band-limited Channel Characteristics, Fluctuations of a Shallow Water Underwater Channel, Feature Extraction, Feature Transformation, Acoustic Signature Characteristics, Classification Algorithms, Practical Classifiers, Cepstral Features

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understand the basics of Sound and underwater channel models

CO2: Understand the ambient Noise and radiated noise in the ocean

CO3: Understand the reflection and scattering by sonar targets

CO4: Acquire knowledge of shallow water acoustics and a passive Sonar classifier

Text Books

1. Underwater Acoustic System Analysis, W S Burdic.
2. R. O. Nielsen, Sonar Signal Processing (Artech House, Boston, 1991).

Reference Books

1. Paul C. Etter, Underwater Acoustic Modelling and Simulation (Spon Press, Taylor and Francis Group, London and New York, third edition, 2003).

Course Code	Course Name	L – T – P	**Credits**
EE630	**Sonar System Engineering**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the fundamentals of underwater sound and sonar equations.
- Understand sonar array structures and beamforming techniques.
- Study sound propagation in the ocean and related models.
- Analyze various noise sources in sonar systems.
- Characterize and compare passive and active sonar systems.

Course Contents

Unit I: Sound: Wave motion, Sound pressure, Reference intensity, Source level, Radiated power, Limitations to sonar power, Cavitation, Interaction, Octave Bands, dB Scale, Far Field and Near Field Measurements, Projector sensitivity, Hydrophone sensitivity, Spectrum level, Sound in air and sea water.

Unit II: Sonar Equations: The Active and Passive Sonar Equation. Sonar Parameters, Sound Velocity Profile (SVP), Sonar Performance, Limitations of the Sonar Equation, Detection Threshold, and Receiver Operating Curve (ROC).

Unit III: Arrays: Beam Forming, Beam Steering, Beam Patterns, Uniform Linear Arrays (ULA), Cylindrical Arrays, Shading, Delay and Sum Beam forming, Conformal Arrays, Three-dimensional Arrays, Cross Arrays, Spherical Arrays, Receiver and transmitter Arrays, Directivity Index, Sonar Domes, transducer design and characteristics,

Unit IV: Propagation of Sound: Propagation loss, spreading losses, Absorption losses, Propagation in the real ocean, speed of sound, Sound speed profiles, Deep sound channel, multi-path propagation, SOFAR Channel, Surface duct propagation, Convergence zone propagation, Bottom bounce propagation, Propagation loss models, Ray theory and the wave propagation models, Channel models.

Unit V: Noise in Sonar Systems: Sonar System Noise, Self-Noise, Ambient Noise in the Ocean, Flow Noise, Radiated Noise, Noise Factor of a Sonar, Figure of Merit, Practical Noise Levels, Radiated Noise, Ambient Noise Characteristics, LOFAR & DEMON, Passive Sonar Detection, Passive Sonar Classifier, Operational Limitation of Passive Sonars, Evolution of Passive Sonars, Acoustic Signatures, Ranging, Pulse Characteristics, CW Sonars, Reverberation Levels, Target Strengths, Echo Characteristics, Sediment Classification, Doppler.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understand the SONAR Equation and its fundamentals
CO2: Learn array concepts and Beam forming in SONAR applications
CO3: Learn about various Noises in SONAR
CO4: Characterize Passive and Active SONAR

Text Books

1. Sonar for Practicing Engineers, Third Edition by A. D. Waite; WILEY, 2002.

Reference Books

1. Principles of Underwater Sound, R J Urick, Third Edition, 1983.

Course Code	Course Name	L – T – P	**Credits**
EE631	**Satellite Communication**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the basics of satellite systems, orbits, and launching methods
- Grasp knowledge of the Geostationary orbit & Space segment
- Understand the phenomenon related to ground and space
- Impart knowledge in DBS

Course Contents

Unit I: Overview of satellite systems, orbits, and launching methods: Introduction, Frequency Allocations for Satellite Services, Kepler's First Law, Kepler's Second Law, Kepler's Third Law, Definitions of Terms for Earth-orbiting Satellites, Orbital Elements, Apogee and Perigee Heights, Orbital Perturbations, Effects of a Non-spherical Earth, Atmospheric Drag, Inclined Orbits, Sidereal Time, Equatorial Coordinate System, Predicting Satellite Position.

Unit II: Geostationary orbit & Space segment: Introduction, Antenna look angles, Limits of visibility, Near-geostationary orbits, Earth eclipse of satellite, Sun transit outage, Power supply, Attitude control, spinning satellite stabilization, Station keeping, Transponders, Antenna subsystem.

Unit III: Earth segment & Space link: Introduction, Receive-Only Home TV Systems, Outdoor Unit, Indoor Unit for Analog (FM) TV, Master Antenna TV System, Transmit-Receive Earth Stations, Various losses in the systems, System noise, Carrier-to-Noise ratio for uplink and downlink, Effects of rain, Rain-fade margin, Downlink rain-fade margin, Intermodulation noise

Unit IV: Satellite access: Preassigned FDMA, Demand-Assigned FDMA, FDMA downlink analysis, Companion of uplink power requirements for FDMA & TDMA. On-board signal processing for TDMA/FDMA operation, Satellite switched TDMA, CDMA

Unit V: Direct broadcast satellite services: Introduction, Orbital Spacings, Power Rating and Number of Transponders, Frequencies and Polarization, Transponder Capacity, Bit Rates for Digital Television, MPEG Compression Standards, Forward Error Correction, Home Receiver Outdoor Unit (ODU), Home Receiver Indoor Unit (IDU), Downlink Analysis, Uplink, Problems, Satellite Mobile Services, VSATs, Radarsat, Global Positioning Satellite System.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understand the basics of Satellite Systems, learning about orbital systems and sub-systems

CO2: Learn Earth-to-Satellite linking and its calculations for losses

CO3: Understand the Earth segment and its link to space

CO4: Know about applications of direct satellite broadcasting, like GPS and other mobile services

CO5: Understand the Uplink & Downlink Analysis, Satellite Mobile Services, VSATs, GPS, etc.

Text Books/Reference Books

1. Satellite Communications, Dennis Roddy, McGraw-Hill Publication Third edition 2001.
2. Satellite Communications – Timothy Pratt, Charles Bostian and Jeremy Allnutt, WSE, Wiley Publications, 2nd Edition, 2003.
3. Satellite Communications Engineering – Wilbur L. Pritchard, Robert A Nelson and Henri G.Suyderhoud, 2nd Edition, Pearson Publications, 2003.
4. Timothy Pratt – Charles Bostian& Jeremy Allmuti, Satellite Communications, John Willy & Sons (Asia) Pvt. Ltd. 2004.
5. Wilbur L. Pritchars Henri G.SuyderHond Robert A. Nelson, Satellite Communication Systems Engineering, Pearson Education Ltd., Second edition 2003.
6. Satellite Communications: Design Principles – M. Richharia, BS Publications, 2nd Edition, 2003.

Course Code	Course Name	L – T – P	**Credits**
EE632	**Advanced Communication Systems**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the basic terms such as sampling, quantization, and various transforms
- Know about baseband and passband transmission
- Apply modulation and demodulation techniques for signals
- Know about information theory and channel capacity

Course Contents

Unit 1: Introduction: Block diagram of digital communication system, Review of Fourier Transform properties, Discrete Sequences, DTFT, Z-Transform, Channel capacity, Shannon's limit, sampling Theorem -Mathematical proof of sampling and reconstruction – ideal and Flat top sampling, Band pass sampling. Digital Representation of Analog Signals, Pulse code modulation, generation and detection of PCM, Uniform quantization and companding, Differential PCM; Delta modulation, Adaptive delta modulation; Signal-to-Noise Ratio calculations in PCM, DM.

Unit II: Base band data transmission: Communication over Band-limited AWGN Channel, ISI in band-limited channels, Zero-ISI condition- the Nyquist criterion, Solution for zero ISI, Raised cosine filters, Partial response signalling-Duo binary encoding, M-ary baseband system, eye pattern, adaptive Equalization.

Unit III: Modulation techniques: Binary Baseband Digital Modulation Techniques, digital modulation techniques: ASK, BPSK, BFSK, DPSK, QPSK, and M-ary signaling; M-ary Baseband Digital Modulation Techniques, PSK & QPSK, Offset QPSK, Minimum Shift Keying (MSK), Passband Waveforms for M-ary signaling, Passband Modulations for Band Limited Channels, Baseband & Passband Digital

Unit IV: Demodulation techniques: General Issues & Concepts, Matched Filters, Coherent Demodulation, Coherent Demodulation for Binary Wave Form, Coherent &Noncoherent Receivers for Orthogonal Signaling (OOK & FSK), Signal & Noise Statistics in Coherent &Noncoherent Receivers, Error Rates for Binary Signaling: Coherent Receivers, Performance of Non-Coherent FSK & Differential Phase Shift Keying, Demodulation of DPSK & M-ary Signals, Performance of M-ary Digital Modulations.

Unit V: Performance analysis information theory: Entropy, Joint Entropy and Conditional Entropy, Relative Entropy and Mutual Information, Chain Rules, Data-Processing Inequality, Fano's Inequality. Source Coding and Data Compression: Kraft Inequality, Huffman Codes, Optimality of Huffman Codes, Linear Binary Block Codes: Introduction, Generator and Parity-Check Matrices, Repetition and Single-Parity-Check Codes, Binary Hamming Codes, Error Detection with Linear Block Codes, Weight Distribution and Minimum Hamming Distance of a Linear Block Code, Hard-decision and Soft-decision Decoding of Linear Block Codes, Cyclic Codes, Parameters of BCH and RS Codes, Interleaved and Concatenated Codes, Convolutional Codes: Encoder Realizations and Classifications, Minimal Encoders, Trellis representation, MLSD and the Viterbi Algorithm, Bit-wise MAP Decoding and the BCJR Algorithm.

Course Outcomes

On completion of this course, the students will be able to:
CO1: Review the Fourier Transform, DTFT, Z-Transform, sampling theorem, PCM, DM, etc.
CO2: Understand the communication over the AWGN channel, coding, and equalization techniques
CO3: Acquire knowledge of digital modulation and demodulation techniques
CO4: Acquire knowledge of Signal & Noise Statistics in Coherent &Noncoherent Receivers
CO5: Develop a basic understanding of source coding and entropies

Text Books/Reference Books

1. Sam Shanmugam, "Digital and analog communication system", John Wiley,2005.
2. Herbert Taud, Donald L. Schiling, GoutamSaha, "Principles of Communication Systems", – 3rdEdition, McGraw-Hill, 2008.
3. Elements of Information Theory by Thomas Cover, Joy Thomas
4. Channel Codes: Classical and Modern by William Ryan, Shu Lin
5. Digital Communications –Simon Haykin, Jon Whiley,2005 2. Wayne Tomasi, "Electronic communications systems"-5th edition, Pearson publication
6. Information Theory and Reliable Communication by Robert Gallager.

Course Code	Course Name	L – T – P	**Credits**
EE633	**Underwater Communications**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the fundamentals of underwater acoustic communication systems.
- Explore the physical characteristics of underwater channels and their impact on signal transmission.
- Study modulation, coding, and signal processing techniques suitable for underwater environments.
- Analyze challenges such as noise, multipath, and Doppler effects in underwater communication.
- Learn about current technologies and applications in underwater communication networks.

Course Contents

Unit I: Introduction: Background and Context- Early Exploration of Underwater Acoustics-Underwater Communication Media, Underwater Systems and Networks,

Unit II: UWA Channel: UWA Channel Characteristics, Sound Velocity, Propagation Loss-Time-Varying Multipath-Acoustic Propagation Models-Ambient Noise and External Interference, Passband Channel Input– Output Relationship, Linear Time-Varying Channel with Path-Specific Doppler Scales, Linear Time-Varying Channels with One Common Doppler Scale, Linear Time-Invariant Channel-Linear Time-Varying Channel with Both Amplitude and Delay Variations-Linear Time-Varying Channel with Frequency Dependent Attenuation.

Unit III: UWA Modulation techniques: Modulation Techniques for UWA Communications, Frequency Hopped FSK, Direct Sequence Spread Spectrum, Single Carrier Modulation, Sweep-Spread Carrier (S2C) Modulation, Multicarrier Modulation.

Unit IV: MIMO-UWA: Multi-Input Multi-Output Techniques- Recent Developments on Underwater Acoustic Communications. **Unit V: OFDM Basics:** Zero-Padded OFDM, Cyclic-Prefixed OFDM -OFDM Related Issues- ZP-OFDM versus CP-OFDM -Peak-to-Average-Power Ratio -Power Spectrum and Bandwidth -Subcarrier Assignment- Overall Data Rate -Design Guidelines -Implementation via Discrete Fourier Transform -Challenges and Remedies for OFDM -Benefits of Diversity Combining and Channel Coding -MIMO OFDM.
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Learn the basics of Underwater Acoustics-Underwater Communication Media, Underwater Systems and Networks **CO2:** Gain the theoretical knowledge of UWA Channel Characteristics, Sound Velocity, and Doppler scale **CO3:** Acquire the basics of Modulation Techniques for UWA Communications **CO4:** Learn the application of Multi-Input Multi-Output Techniques for underwater Acoustic Communications
Text Books/Reference Books
1. Yong Soo Cho, Jaekwon Kim, Won Young Yang, Chung G. Kang, "MIMO-OFDM Wireless Communications with MATLAB", John Wiley & Sons Ltd, 2010. 2. Shengli Zhou, Zhaohui Wang, "OFDM for Underwater Acoustic Communications", John Wiley & Sons Ltd, 2014.

Course Code	Course Name	L – T – P	**Credits**
EE 634	**Monolithic Microwave Integrated Circuit**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Develop an understanding of planar technologies such as strip lines, microstrip lines, etc.
- Provide knowledge of microwave passive components such as branch line couplers, power dividers, circulators, phase shifters, etc.
- Equip students with knowledge of microwave active circuits, stability, and gain analysis through the Smith chart.
- Introduce CAD techniques for oscillator, mixer designs
- Foster the ability to critically evaluate and optimize MMIC, hybrid MIC

Course Contents

Unit I: Introduction to microwave integrated circuits and applications: Introduction, Micro strip Lines, Characteristic Impedance of Micro strip Lines, Losses in Micro strip Lines, Quality Factor Q of Micro strip Lines, Parallel Strip Lines, Distributed Lines, Characteristic Impedance, Attenuation Losses, Coplanar Strip Lines, CPW lines, Shielded Strip Lines. methods of analysis in MIC: Analysis of MIC by conformal transformation, Numerical method, Hybrid Mode analysis, Losses in microstrip, Introduction to slot line, and coplanar waveguide.

Unit II: Couplers and lumped elements: passive devices: Introduction to coupled micro strip, Even and odd mode analysis, coplanar circuits, Design and fabrication of microstrip

components: Branch line couplers, Filters, switches, attenuators, Directional couplers, lumped elements for 169 MICs: Inductors, capacitors, resistors, multilayer techniques, Ferromagnetic substrates and inserts, microstrip circulators, Phase shifters, micro-machined passive components, Comparison with distributed circuits. **Unit III: Microwave active devices:** Microwave transistors, parametric diodes and amplifiers, PIN diodes, transferred electron devices, Avalanche diodes, IMPATT, BARITT devices. RF CMOS devices, Microwave BJTs, GaAs FETs, MSFETs, low noise and power GaAs FETs, and their applications, Design principles, active device CAD techniques for large signal oscillators design, Phase noise, MMIC_VCO, mixers. **Unit IV: High & low power circuits:** Introduction, Impedance transformers, Filters, High power circuits, Low power circuits, MICs in Radar and satellite; Amplifiers: Stability & gain analysis, matching techniques, reactively matched amplifier design, LNA **Unit V: Fabrication methods:** Fabrication process of MMIC, Hybrid MICs, Dielectric substances, thick film and thin film technology and materials, testing methods, Encapsulation, and mounting of devices.
Course Outcomes
After completing this course, the students will be able to: **CO1:** Develop an understanding of planar technologies such as strip lines, microstrip lines, etc. **CO2:** Acquire knowledge of microwave passive components such as branch line couplers, power dividers, circulators, phase shifters, etc. **CO3:** Understand microwave active circuits, stability, and gain analysis through the Smith chart **CO4:** Understand CAD techniques for oscillator, mixer designs **CO5:** Acquire knowledge of MMIC, hybrid MIC
Text Books/Reference Books
1. Gupta K.C and Amarjit Singh, “Microwave Integrated Circuits”, John Wiley, New York, 1975. 2. Hoffman R.K “Hand Book of Microwave Integrated Circuits”, Artech House, Boston, 1987. 3. Ravender Goyal, “Monolithic MIC; Technology & Design”, Artech House, 1989. 4. Ulrich L. Rohde and David P.N., “RF / Microwave Circuit Design for Wireless Applications”, John Wiley, 2000. 5. C. Gentili, “Microwave Amplifiers and Oscillators”, North Oxford Academic, 1986. 6. Annapurna Das and Sisir K Das, “Microwave Engineering”, Tata McGraw-Hill Pub. Co. Ltd., 2004. 7. Samuel. Y. Liao, “Microwave Circuit Analysis and Amplifier Design”, Prentice Hall. Inc., 1987. 8. Mathew N.O. Sadiku, “Numerical techniques in Electromagnetic”, CRC Press, 2001.

Course Code	Course Name	L – T – P	**Credits**
EE635	**Inertial Sensors and Systems**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the Basic principles of navigation and inertial navigation
- Impart knowledge of the Gyroscope and its working principle
- Know about Pendulous servo accelerometers
- Apply knowledge in designing and realizing Inertial navigation systems

Course Contents

Unit I: Basic principles of navigation and inertial navigation: Gimbaled platform and Strap down Navigation systems, Overview of Inertial Sensors.

Unit II: Gyroscope working principle: Single degree of freedom rate gyro and rate integrating gyro. Dynamically Tuned Gyroscope: Principle of operation, Design features, Single gimbal and dual gimbal flexures, Rebalance loop configuration, DTG errors and error model. Ring Laser Gyro: Principle of operation and different types, Sagnac Effect, Design features, Lock-in and Dither, RLG errors and error model.

Fiber Optic Gyro: Principle of operation, Difference with RLG, Design features, open loop and closed loop operation, Error sources in FOG, difference between Fiber optic laser gyro and ring laser gyro. Hemispherical Resonator Gyro: Principle of operation, Design features, HRG errors, and error model. Other types of gyros: Nuclear Magnetic Resonance Gyro, Electrostatically Suspended Gyro, Atom Interferometric Gyro, etc.

Unit III: Pendulous servo accelerometers: Configuration, working principle, and design of pendulous servo accelerometers. Servo accelerometer errors and error model. Other types of accelerometers: Vibrating Beam Accelerometer, Fiber optic Accelerometers, Atom Interferometric Accelerometer, etc.

Unit IV: MEMS Inertial sensors: Introduction to MEMS Inertial Sensors, Overview of MEMS Fabrication Techniques, MEMS Accelerometers: Pendulous and non-pendulous accelerometers, Resonant beam accelerometer, MEMS Gyros: Coriolis Vibrating gyro principle, Tuning fork gyro, Comb structure and Ring structure mechanizations.

Unit V: Inertial navigation systems: Gimbaled platform technology and Strap down system technology, their mechanization. Redundant Inertial Navigation Systems: Basic concepts of sensor redundancy, redundant sensor configurations, Sensor Failure detection and Isolation. Strap down INS realization: Basic concepts of system configuration, vibration isolation, and temperature control/compensation. Testing of Inertial Sensors and Systems: Basic concepts and test philosophy. Gyroscope Testing: Multi-position test and Rate test, Frequency response test, Thermal test, Magnetic sensitivity test, Vibration test, and Shock test. Accelerometer Testing: Multi-position test, Centrifuge test, Frequency response test, Thermal test, Magnetic sensitivity test, Vibration test, and Shock test. Gyro and Accelerometer error modeling and compensation. INS Testing: Rate test and multi-position test, Attitude test, Static navigation test, Hardware in Loop tests, Environmental tests like EMI, Thermal, Vibration, and Shock.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understanding the fundamentals of Navigation and Inertial Navigation, the gyroscope working principle, and different types of gyroscopes

CO2: Acquire knowledge of the configuration, working principle, design of servo accelerometers, and their types

CO3: Know the basics of MEMS Inertial Sensors, and Testing of Inertial Sensors and Systems

CO4: Understand Inertial Navigation Systems, Gimbaled platform technology, Strap down INS realization, etc.

Text Books/Reference Books
1. Gupta K. C. and Amarjit Singh, "Microwave Integrated Circuits", John Wiley, New York, 1975. 2. Hoffman R. K. "Hand Book of Microwave Integrated Circuits", Artech House, Boston, 1987. 3. Ravender Goyal, "Monolithic MIC; Technology & Design", Artech House, 1989. 4. Ulrich L. Rohde and David P.N., "RF / Microwave Circuit Design for Wireless Applications", John Wiley, 2000. 5. C. Gentili, "Microwave Amplifiers and Oscillators", North Oxford Academic, 1986. 6. Annapurna Das and Sisir K Das, "Microwave Engineering", Tata McGraw-Hill Pub. Co. Ltd., 2004. 7. Samuel. Y. Liao, "Microwave Circuit Analysis and Amplifier Design", Prentice Hall. Inc., 1987. 8. Mathew N.O. Sadiku, "Numerical techniques in Electromagnetic", CRC Press, 2001.

Course Code	Course Name	L – T – P	**Credits**
EE636	**Navigation & Avionic Systems**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the navigational methods
- Provide knowledge of avionics and its need.
- Deliver knowledge of Radio and satellite navigation
- Provide knowledge of radar reflectors and beacons

Course Contents

Unit I: Introduction: Various navigation methods, Dead Reckoning position (DR), estimated position (EP) & Observed Position, Gyroscopes, Mechanical, electromechanical, Ring Laser gyro, Fiber-optic gyro, Accelerometers

Unit II: Inertial navigation system: INS components: transfer function and errors- The earth in inertial space, the Coriolis effect- Mechanization. Platform and Strap down, INS system block diagram, Different coordinate systems, Schuler loop, compensation errors, Gimbal lock, Alignment

Unit III: Avionics: Need for Avionics in civil and military aircraft and space systems, Integrated Avionics and Weapon system, typical avionics sub-systems, Design and Technologies, VHF avionics Communication system, data link, Telemetry

Unit IV: Radio navigation: Different types of radio navigation, ADF, VOR/DME, Doppler, LORAN, DECCA and Omega, TACAN, ILS, MLS, GLS - Ground controlled approach system surveillance systems-radio altimeter

Unit V: Satellite navigation and hybrid navigation: Introduction to GPS description, basic principles, position and velocity determination, signal structure, DGPS, Introduction to Kalman filtering, Estimation and mixed mode navigation, Integration of GPS and INS, utilization of navigation systems in aircraft, Navigation and traffic control using ground based radar and airborne radar, Tactical Air Navigation (TACAN), TACAN Equipment, Fischer Plotting, Radar

Navigation Aid: radar reflectors, radar beacons, Principle of superposition Navigation, Chart matching equipment, accuracy obtained by chart matching, PPI Simulations.
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Learn the basics of navigation methods, DR position, and EP **CO2:** Gain the theory of INS components **CO3:** Acquire the basics of different types of radio navigation, LORAN, and DECCA **CO4:** Learn the GPS, position, and velocity determination
Text Books/Reference Books
1. Myron Kyton, WalfredFried," Avionics Navigation Systems" John wliey& Sons, 2nd edition, 1997 2. Nagaraja, N.S. "Elements of Electronic Navigation", Tata McGraw-Hill Pub. Co., New Delhi, 2nd edition, 1975. 3. Sen, A.K. & Bhattacharya, A.B. "Radar System and Radar Aids to Navigation", Khanna Publishers, 1988 4. Data & Network Communication, Michael A. Miller – DELMAR (Thomson learning) / Vikas Publication.

Course Code	Course Name	L – T – P	**Credits**
EE637	**ASIC Verification using System Verilog**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the fundamentals of ASIC design and verification flow.
- Learn System Verilog language constructs for functional verification.
- Develop testbenches using System Verilog features like classes, constraints, and randomization.
- Apply assertions and functional coverage for effective verification.
- Gain hands-on experience with simulation tools and debugging techniques.

Course Contents

Unit I: Introduction to functional verification languages, Introduction to System Verilog, System Verilog data types. System Verilog procedures, Interfaces, and modports, SystemVerilog routines.
Unit II: Introduction to object-oriented programming, Classes and Objects, Inheritance, Composition, Inheritance v/s composition, Virtual methods. Parameterized classes, Virtual interface, Using OOP for verification, System Verilog Verification Constructs
Unit III: System Verilog assertions: Introduction to assertion, Overview of properties and assertion, Basics of properties and sequences, Advanced properties and sequences, Assertions in design and formal verification, some guidelines for assertion writing.
Unit IV: Coverage-driven verification and functional coverage in SV: Coverage Driven Verification, Coverage Metrics, Code Coverage, Introduction to functional coverage, Functional coverage constructs, Assertion Coverage, Coverage measurement, Coverage Analysis. SV and C interfacing: Direct Programming Interface (DPI)

Unit V: Case studies: System Verilog-based Verification of UART, 8-bit ALU, RISC CPU.
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Understand the basics of System Verilog- data types **CO2:** Understand the programming concept of System Verilog **CO3:** Acquire knowledge of the verification tool by assertion coverage **CO4:** Analyze the case studies of module verification by System Verilog
Text Books
1. "SystemVerilog for Design": A Guide to Using SystemVerilog for Hardware Design and Modeling Sutherland, Stuart, Davidmann, Simon, Flake, Peter2nd ed., 2006 2. "SystemVerilog for Verification": A Guide to Learning the Testbench Language Features, Chris Spear, 2006 3. "Hardware Verification with System Verilog": An Object-Oriented Framework Mintz, Mike, Ekendahl, Robert, 2007.
Reference Books
1. "A Practical Guide for System Verilog Assertions" Meyyappan Ramanathan

Course Code	Course Name	L – T – P	**Credits**
EE638	**Mixed Signal IC Design**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the fundamentals of analog, digital, and mixed-signal circuits.
- Learn design methodologies and key building blocks like ADCs, DACs, and PLLs.
- Develop skills in mixed-signal IC simulation, layout, and verification.
- Address challenges like noise, power management, and analog-digital isolation.
- Apply concepts to real-world applications through projects and case studies.

Course Contents
Unit I: Introduction and basic MOS Devices: Challenges in analog design- Mixed signal layout issues- MOS FET structures and characteristics, signal model– small signal model- single stage Amplifier- Source follower- Common gate stage – Cascode Stage. **Unit II: Submicron circuit design:** Submicron CMOS process flow, Capacitors and resistors, Current mirrors, Digital Circuit Design, Delay Elements – Adders-OP Amp parameters and Design. **Unit III: Data converters:** Characteristics of Sample and Hold -Digital to Analog Converters-architecture-Differential Non-Linearity-Integral Non-Linearity-Voltage Scaling- Cyclic DAC-Pipeline DAC-Analog to Digital Converters-architecture –Flash ADC Pipeline ADC-Differential Non-Linearity-Integral Non-Linearity **Unit IV: SNR in Data Converters:** Overview of SNR of Data Converters-Clock Jitters-Improving Using Averaging –Decimating Filters for ADC-Band pass and High Pass Sinc Filters-Interpolating Filters for DAC. **Unit V: Switched capacitor circuits:** Resistors, First-order low-pass Circuit, switched capacitor Amplifier, Switched Capacitor Integrator
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Develop the knowledge of Device modeling of MOSFET **CO2:** Illustrate the concept of small signal analysis of single and multi-stage amplifiers **CO3**: Learn designing switched capacitor circuits **CO4:** Demonstrate the Data converters and their applications **CO5:** Simulate circuits using PSpice and Microwind Backend Tools.
Text Books/Reference Books
1. Vineetha P. Gejji Analog and Mixed Mode Design, Prentice Hall, 1st Edition, 2011 Jeya Gowri Analog and Mixed Mode Design Sapna publishing House 2011. 2. Gray Paul R, Meyer, Robert G, Analysis and Design of Analog Integrated Circuits, 3rd edition, John Wiley & Sons. 3. Jacob Baker, "CMOS Mixed-Signal circuit design", A John Willy & Sons, inc., publication, 2003.

Course Code	Course Name	L – T – P	**Credits**
EE639	**Computer-Aided Design of VLSI Circuits**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the fundamentals of CAD tools used in front-end and back-end VLSI design.
- Develop proficiency in HDL-based modelling, simulation, and synthesis using industry tools.
- Understand layout algorithms, testing methodologies, and post-layout processes.
- Explore automated design flows including logic synthesis, physical verification, and test generation.

Course Contents
Unit I: Various CAD Tools for front-end and Back-end design, Schematic editors, Layout editors, and Place and Route tools. Introduction to VLSI Methodologies - VLSI Physical Design Automation - Design and Fabrication of VLSI Devices - Fabrication process. **Unit II: Introduction to Design Tools:** Introduction & Familiarity with Design Tools from various vendors e.g., Synopsis, CADENCE, Mentor Tools, etc. Verilog Basics - Modeling Levels - Data Types - Modules and Ports - Instances - Basic Language Concepts - Dataflow modeling - Behavioral Modeling and Simulation of systems/subsystems using Verilog HDL. Typical case studies. **Unit III:** Layout Algorithms Circuit partitioning, placement, and routing algorithms; Design rule verification; Circuit Compaction; Circuit extraction and post-layout simulation **Unit IV:** CAD Tools for Automatic Test Program Generation; Combinational testing D-Algorithm and PODEM algorithm; Scan-based testing of sequential circuits; Testability measures for circuits **Unit V: Modelling and synthesis:** Linting Tools, Logic Synthesis, CAD Tools for Logic Synthesis, Gate-level simulation, Formal verification. CAD Tools for Physical Verification and LVS.
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Develop knowledge about CAD tools used for digital VLSI design, digital logic simulation, and physical design, including test and verification, and develop an understanding of FPGA CAD flow for design and implementation. **CO2:** Model digital systems at different levels of abstraction and simulate using Verilog HDL, **CO3:** Develop an understanding of automatic test program generation, testing algorithms, and simulate and test circuits. **CO4:** Apply their knowledge and skills to model and synthesize logic circuits, do formal verification, and transfer a design from a version possible to simulate to a version possible to synthesize
Textbooks
1. N.A. Sherwani, “Algorithms for VLSI Physical Design Automation ", 1999. 2. S.H. Gerez, “Algorithms for VLSI Design Automation ", 1998.4. J. Bhasker, "A VHDL Primer", AddisonWeseley Longman Singapore Pte Ltd. 1992. 3. Drechsler, R., Evolutionary Algorithms for VLSI CAD, Kluwer Academic Publishers, Boston, 1998.
Reference Books
1. VERILOG HDL SYNTHESIS: A PRACTICAL PRIMER by J Bhaskar 2. Hill, D., D. Shugard, J. Fishburn and K. Keutzer, Algorithms and Techniques for VLSI Layout Synthesis, Kluwer Academic Publishers, Boston, 1989.

Course Code	Course Name	L – T – P	**Credits**
EE640	**FPGA Architecture and Applications**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the architecture, features, and programming of various programmable logic devices, including CPLDs and FPGAs.
- Analyze FPGA design flows, logic synthesis, routing, and technology mapping using industry-standard tools.
- Design and implement Finite State Machines (FSMs) and system-level digital designs on FPGAs.
- Apply FPGA-based design techniques to real-world digital systems and validate them using debugging tools.

Course Contents

Unit I: Programmable logic devices: ROM, PLA, PAL, CPLD, FPGA Features, Architectures, and Programming. Applications and Implementation of MSI circuits using Programmable Logic Devices.

Unit II: FPGAs: Field Programmable Gate Arrays- Logic blocks, routing architecture, design flow, technology mapping for FPGAs, Case studies Xilinx XC4000 & ALTERA's FLEX 8000/10000 FPGAs, Introduction to advanced FPGAs: Xilinx Virtex and ALTERA Stratix

Unit III: Finite state machines (FSM): Top-Down Design, State Transition Table, State assignments for FPGAs, Realization of state machine charts using PAL, Alternative realization for state machine charts using microprogramming, linked state machine, encoded state machine. FSM Architectures: Architectures Centered around non registered PLDs, Design of state machines centered around shift registers, One Hot state machine, Petrinets for state machines-Basic concepts and properties, Finite State Machine-Case study.

Unit IV: System level design: Controller, data path designing, Functional partition, Digital front end digital design tools for FPGAs. System-level design using mentor graphics/Xilinx EDA tool (FPGA Advantage/Xilinx ISE), Design flow using FPGAs.

Unit V: **Case studies:** Design considerations using FPGAs of parallel adder cell, parallel adder sequential circuits, counters, multiplexers, and parallel controllers. Debugging using Embedded Logic Analyzers.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understand the architecture, programming, and applications of various Programmable Logic Devices (PLDs).

CO2: Acquire fundamental knowledge on basic building blocks, routing architecture, and design flow of Field Programmable Gate Arrays (FPGAs) and advanced FPGAs.

CO3: Apply skills to design Finite State Machines (FSMs) based on a state transition table and the realization of various state machines.

CO4: Gain knowledge on the usage of different FPGA tools for data path, front-end, and system-level design using FPGAs.

CO5: Develop skills in FPGA design considerations using sequential and combinational circuits and debugging using Logic Analysers.

Text Books

1. Field Programmable Gate Array Technology - S. Trimberger, Edr, 1994, Kluwer Academic Publications.

2. Engineering Digital Design - RICHARD F. TINDER, 2nd Edition, Academic press. 3. Fundamentals of logic design-Charles H. Roth, 4th Edition Jaico Publishing House.
Reference Books
1. Digital Design Using Field Programmable Gate Array, P.K. Chan & S. Mourad, 1994, Prentice Hall. 2. Field programmable gate array, S. Brown, R.J. Francis, J. Rose, Z.G. Vranesic, 2007, BS.

Course Code	Course Name	L – T – P	**Credits**
EE641	**VLSI Signal Processing**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the fundamentals of VLSI architectures for digital signal processing.
- Learn techniques for designing high-speed, low-power, and area-efficient DSP systems.
- Explore pipelining, parallelism, and retiming for performance optimization.
- Develop skills in mapping DSP algorithms to hardware architectures.
- Apply VLSI design concepts to real-time signal processing applications.

Course Contents

Unit I: An overview of DSP concepts: Linear system theory- DFT, FFT- realization of digital filters- Typical DSP algorithms- DSP applications- Data flow graph representation of DSP algorithm - Loop bound and iteration bound Retiming and its applications.

Unit II: Algorithms for fast convolution: Algorithmic strength reduction in filters and transforms- DCT and inverse DCT- Parallel FIR filters- Pipelining of FIR filters- Parallel processing- Pipelining and parallel processing for low power.

Unit III: Pipeline interleaving in digital filters: Pipelining and parallel processing for IIR filters- Low power IIR filter design using pipelining and parallel processing- Pipelined adaptive digital filters.

Unit IV: Design of communication architectures for SOCs: State variable description of digital filters- Round off noise computation using state variable description- Scaling using slow-down, retiming, and pipelining.

Unit V: Adder and multiplier: Digital arithmetic, Fixed point and floating point. Fixed-point implementation of the FIR filter. IEEE 754 Floating point standards, Floating point arithmetic operations. Design of a floating-point adder and multiplier.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Realize the algorithm in the Data flow graph and Retiming and its applications
CO2: Perform parallel processing and the pipelining concept of the FIR Filter
CO3: Know the Pipelining in Adaptive Digital Filters
CO4: Acquire knowledge of digital arithmetic and the design of fixed-point and floating-point adders and multipliers

Text Books

1. K. K. Parhi, VLSI Digital Signal Processing Systems, John-Wiley, 1999. 2. Pirsch, P., Architectures for Digital Signal Processing, Wiley, 1999.
Reference Books
1. Allen, J., Computer Architectures for Digital Signal Processing, Proceedings of the IEEE, Vol 73, No. 5, May, 1985 2. Bateman, A., and Yates, W., Digital Signal Processing Design, Computer Science Press, New York. 3. S.Y. Kung, H.J. White House, T. Kailath, VLSI and Modern Signal Processing, Prentice Hall, 1985.

Course Code	Course Name	L – T – P	**Credits**
EE642	**SOC Design and Verification**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the chip design process.
- Develop and design macros.
- Gain expertise in SoC verification methodologies
- Analyze and design communication architectures

Course Contents

Unit I: System on Chip Design Process: A canonical SoC Design, SoC Design flow, waterfall vs spiral, top-down vs bottom-up. Specification requirement, Types of Specification, System Design process, System level design issues, Soft IP Vs Hard IP, Design for timing closure, Logic design issues, Verification strategy, On-chip buses and interfaces, Low Power, Manufacturing test strategies.

Unit II: Macro Design Process: Top-level Macro Design, Macro Integration, Soft Macro productization. Developing hard macros, Design issues for hard macros, Design, System Integration with reusable macros.

Unit III: SOC Verification: Verification technology options, Verification methodology, Verification languages, Verification approaches, and Verification plans. System-level verification, Block-level verification,

Hardware/software co-verification and Static net list verification.

Unit IV: Design of Communication Architectures For SOCS: On-chip communication architectures, System-level analysis for designing communication, Design space exploration, Adaptive communication architectures, Communication architecture tuners, Communication architectures for energy/battery efficient systems. Introduction to bus functional models and bus functional model-based verification.

Unit V: Verification architecture, Verification components, Introduction to VMM, OVM, and UVM.

Course Outcomes

On completion of this course, the students will be able to: **CO1:** Use different approaches to the chip design process and its requirements. Desi issues, verification, and test strategies. **CO2:** Design and develop a macro and the issues regarding designing it. **CO3:** Know about technology, methods, and verification on different levels. **CO4:** Design communication architecture, design analysis, need for adaptable communication architecture, understanding of base models.
Text Books
1. "SoC Verification Methodology and Techniques", Prakash Rashinkar Peter Paterson and 2. Leena Singh. Kluwer Academic Publishers, 2001. 3. "Reuse Methodology manual for System on A Chip Designs", Michael Keating, Pierre 4. Bricaud, Kluwer Academic Publishers, second edition, 2001.
Reference Books
1. "Design Verification: Simulation and Formal Method based Approaches", William K. 2. Lam, Prentice Hall. 3. "System- on -a- Chip Design and Test", Rochit Raj suman, ISBN. 4. "Multiprocessor Systemsonchips", A.A. Jerraya, W.Wolf, M K Publishers. 5. "The EDA Hand Book", Dirk Jansen, Kluwer Academic Publishers.

Course Code	Course Name	L – T – P	**Credits**
EE643	**Digital Interface Design**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand digital interface design, develop, and design macros.
- Develop skills in data converter interfacing gain expertise in SoC verification methodologies
- Explore wireless and GPS interfacing techniques, analyze, and design communication architectures

Course Contents

Unit I: Introduction: Definition and Classification, Overview of Robots and Hardware Units in Robotics, Introduction to Zed Board Embedded Systems on a Chip (SoC), and the use of FPGA in Robotics Applications. State Machines and Applications.

Unit II: Sensors and Actuators Interfacing: Sophisticated interfacing features in Devices/Ports, Timer and Counting Devices, 'I2C', 'USB', 'CAN'. PWM in HW for robot control, LCD interfacing with FPGA.

Unit III: Data Converters Interfacing: Introduction to ADC and DAC. Various Types and specifications, SPI interfacing in an FPGA.

Unit IV& V: Wireless and GPS Interfacing: Introduction to Bluetooth- ZigBee Interface. Introduction to Gyro and accelerometer – Gyro accelerometer interface using Complementary Filter - Case study: Underwater Glider motion controller. NI Compact RIO embedded control hardware for rapid prototyping.

Course Outcomes
On completion of this course, the students will be able to: **CO1:** Understand the fundamentals of Digital Interface Design, including hardware units of basic Robotics. They will also learn about the Zed Board Embedded Systems on a Chip (SoC). **CO2:** Hands-on experience/Knowledge of the Sensor and Actuator Interface. They will also know various Sophisticated interfacing knowledge on Devices/Ports used in Robotics. **CO3:** Gain expertise in Data Converters Interfacing. They will also be able to understand various specifications regarding robotics. **CO4:** Get a working knowledge of Wireless and GPS interfacing. They will also be theoretically experienced in various Interfacing problems through the case study.
Text Books / Reference Books
1. Steve Kilts, Advanced FPGA Design: Architecture, Implementation, and Optimization, IEEE Press Wiley 2007. 2. Yale Patt and Sanjay Patel, Introduction to Computing Systems: From Bits and Gates to C and Beyond, 2^{nd} edition, Publication Date: August 5, 2003 | ISBN-10: 0072467509 | ISBN-13: 978-0072467505. 3. Hamblen, James O., Hall, Tyson S., Furman, Michael D, Rapid Prototyping of Digital Systems: Springer 2008.

Course Code	Course Name	L – T – P	**Credits**
EE644	**MIMO Communications**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand Fading Channels, Bit-Error Rate (BER) Analysis, and Multiple Antenna Systems
- Develop skills in MIMO and Massive MIMO design.
- Explore cognitive radio and be ready with the design

Course Contents

Unit 1: Introduction: Modern multi-user communication technologies, Principles of Wireless Communication, Fading Channels, Bit-Error Rate (BER) Analysis, Multiple Antenna Systems, Diversity concept, Cross-layer procedures: Link Adaptation, HARQ, Packet Scheduling and Radio Resource allocation for Best Effort and Real Time Traffic.

Unit II: MIMO: Multiple-Input Multiple-Output (MIMO) Technology, MIMO signaling: Space Time coding, Diversity Multiplexing trade off, Multi-user MIMO and Network MIMO: Large MIMO; Small cells, relays and het-net (6); Green radio design considerations. MIMO Receivers, Multi-user MIMO, Beamforming, Precoding, Orthogonal Space Time Block Codes (OSTBC), Cooperative Communication, Optimal Combining, BER Analysis, and Diversity of Cooperative Communication, Optimal Power Allocation with Cooperation.

Unit III: Massive MIMO: Introduction to Massive MIMO, Analysis with Perfect CSI, Channel Estimation in Massive MIMO, Analysis with Imperfect CSI, Multi-cell Massive MIMO and Pilot Contamination

Unit IV: Schemes for 5G: New Modulation Schemes for 5G: Spatial Modulation (SM), Space shift keying, Generalized Spatial Modulation, Cooperative MIMO communication, Multi-Node Cooperation, AF and DF Protocols for Cooperation.

Unit V: Cognitive radio: Introduction to Cognitive Radio Technology, OFDM for CR, Spectrum Sensing in Fading Wireless Channels, MIMO systems, OFDM systems, Cooperative Spectrum Sensing, Eigenvalue-based Spectrum Sensing, Multi-User Transmission in Interweave CR Systems, MIMO for Underlay CR Systems, Game Theory for Cognitive Radio, Spectrum Auctions.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understand the Modern multi-user communication technologies

CO2: Understand MIMO technology, coding, and diversity techniques

CO3: Acquire knowledge of channel estimation in massive MIMO and analysis with imperfect CSI

CO4: Gain knowledge of new modulation schemes for 5G

CO5: Learn Cognitive radio technology, OFDM for CR, etc.

Text Books/Reference Books

1. Principles of Mobile Communications by G. Stuber, Springer, 2nd ed..
2. Wireless Communications by A. Goldsmith, Cambridge.
3. Introduction to Space Time Wireless Communications by A. Paulraj, Nabar and Gore.
4. LTE, UMTS and The Long-Term Evolution by Sesia, Toufik and Baker 5. OFDM for Wireless Communications by R. Prasad.
6. UMTS for LTE by Holma and Toshala.
7. Adaptive PHY-MAC Design for Broadband Wireless Systems by R. Prasad, S. S. Das and Rahman.
8. Single and Multi-Carrier MIMO Transmission for Broadband Wireless Systems by R. Prasad, Rahman and S. S. Das.

Course Code	Course Name	L – T – P	**Credits**
EE645	**Adaptive Signal Processing**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the fundamentals of adaptive filtering and the statistical concepts underpinning estimation and signal modeling**.**
- Analyze random processes and their parametric models (AR, MA, ARMA) for designing optimal FIR filters.

- Understand and implement the LMS algorithm and its variants, including convergence behavior and limitations.
- Develop and apply RLS algorithms and their variants for real-time adaptive filtering.
- Apply adaptive filtering techniques to practical problems such as channel equalization, echo and interference cancellation, and beamforming.

Course Contents

Unit I: Basic Principles of Adaptive Filtering: Estimation; probability, random variables, conditional and joint probability densities, statistical independence, correlation and covariance, Complex random variables, random vectors, correlation and covariance matrices, properties of Hermitian matrices (e.g., correlation/covariance matrices), positive definite forms.

Unit II: Random Process: Multivariate Gaussian density. Concepts of random processes, wide-sense stationary (WSS) processes and their correlation structures, power spectral density, parametric modelling of WSS processes – AR, MA, and ARMA processes. Optimal FIR filters, real and complex valued optimal filters, method of steepest descent.

Unit III: Least Mean Square (LMS) Algorithm: Convergence of LMS algorithm; normalized LMS, affine projection, Limitations of LMS algorithm.

Unit IV: Recursive Least Squares: Formulation of recursive least squares (RLS) based adaptive filters, Moore-Penrose pseudo inverse, matrix inversion lemma, Development of the RLS transversal adaptive filter, properties, variants of the RLS family.

Unit V: Channel Characterization: Examples of adaptive filters: channel equalization, echo cancellation, interference cancellation, line enhancement, beamforming, etc.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Learn the basic principles of adaptive filtering: estimation, probability, random variables, conditional and joint probability densities, statistical independence, correlation, and covariance.

CO2: Understand the concepts of random process: multivariate Gaussian density. concepts of random processes, wide-sense stationary (WSS) processes and their correlation structures, power spectral density, parametric modelling of WSS processes – AR, MA, and ARMA processes.

CO3: Learn the basics of the least mean square (LMS) algorithm.

CO4: Apply knowledge and skills to visualize the Formulation of recursive least squares (RLS) based adaptive filters.

CO5: Acquire knowledge of channel characteristics.

Text Books/Reference Books

1. Bernard Widrow and Samuel D. Stearns, Adaptive Signal Processing, Person Education, 2005.

2. Simon Haykin, Adaptive Filter Theory, Pearson Education, 2003.

3. John R. Treichler, C. Richard Johnson, Michael G. Larimore, Theory and Design of Adaptive Filters, Prentice-Hall of India, 2002

4. S. Thomas Alexander, Adaptive Signal Processing - Theory and Application, Springer Verlag.

5. D. G. Manolokis, V. K. Ingle and S. M. Kogar, Statistical and Adaptive Signal Processing, Mc Graw Hill International Edition, 2000.

Reference Books

1. Ali H. Sayed, Fundamentals of Adaptive Filtering, Wiley, 1st Ed., 2003.
2. Farhang-Boroujeny B., Adaptive Filters Theory and Applications, John Wiley & Sons, 1st Ed., 1998.
3. Mohamed Ibnkahla (Edited), Adaptive Signal Processing in Wireless Communications, CRC Press, Taylor & Francis Group, 1st Ed., 2009.
4. "Adaptive Filters", S. Haykin, Prentice-Hall India
5. "Adaptive Filters", A. H. Sayed, Wiley-Interscience, New York, USA

Course Code	Course Name	L – T – P	**Credits**
EE646	**Artificial Intelligence for Embedded Systems**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the principles of machine learning, including supervised, unsupervised, semi-supervised, and reinforcement learning, with practical implementation.
- Develop an understanding of probability, statistics, and scientific computing tools in Python for AI model development and data analysis.
- Enable students to design, train, and deploy TinyML models on embedded platforms and microcontrollers for real-time applications.
- Impart knowledge of AI-based embedded applications such as audio classification, wake-word detection, person detection, and gesture recognition using TensorFlow Lite.

Course Contents

Unit I: Introduction to Machine Learning: Machine Learning, Aspects of Machine Learning, Machine Learning Application, Linear Regression, Correlation, Regression Analysis of. Supervised and Unsupervised Learning, Supervised Learning Model, UnSupervised Learning Model, Semi Supervised Learning, comparison, Case Study. Reinforcement Learning: Reinforcement Learning model, Markov Decision Problem, Q-Learning, Temporal Decision Learning, Learning Automata, Case Study, Cluttering: k-means, Fuzzy, Hierarchical, Similarity, Machine Learning programming for Supervised and Unsupervised Learning models

Unit II: Probability and Statistics with Introduction to Python: Introduction to Probability and Statistics, Need for Probability and Statistics, First Order Linear Model, Least Square Regression Line Model, Introduction to Scientific, Libraries in Python-NumPy, Introduction to Scientific Libraries in Scipy, Estimated Coefficients, Problems related to linear model, Importing dataset using Pandas, Altering dataset using Pandas, Selection Operator, Plotting Libraries, Introduction and basic analysis using ScikitLearn, Introduction to Keras, Introduction to Tensor Flow, Programming in Basic Mathematical and Scientific Operations using NumPy & SciPy, Analysis of a Dataset (CSV) using Pandas with plots, Basic Mathematical Operations using Keras and Tensor flow.

Unit III: Tiny ML in an embedded platform: Building and Training a Model, Applications, Deploying to Microcontrollers, building on embedded Microcontroller model, training our model, Converting the model for Tensor Flow Lite, SparkFun edge, ST Microelectronics. Model Training in Edge Impulse, deploy a Trained Model to embedded platform, Anomaly Detection, Programming to Model Deploying in Arduino Microcontrollers

Unit IV: Audio classification & Wake-Word Detection: Audio classification and Keyword Spotting. Audio Data Capture, Audio Feature Extraction (MFCC), Implementation Strategies and Sensor Fusion, CNN training for sound classification, application Architecture, Walking Through the test, listening for wake words, Deploying to Microcontrollers, Training the New model, Using the model in the project, Training with own Data. Person Detection: Building an Application, Training Model Programming Arduino Tensor Flow Lite applications

Unit V: Magic Wand: Magic Wand Building an Application, Training Model, TensorFlow Lite for Microcontrollers, Designing TinyML Applications, Training a model in Magic wand

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understanding the fundamentals of machine learning

CO2: Understanding Python concepts for probability and statistics

CO3: Learn training model construction and implement a trained ML model on an embedded platform

CO4: Understand and implement wake word detection with the help of the architecture.

CO5: Learn & apply the knowledge to develop the model for the given application on an embedded platform

Text Books/ Reference Books

1. Wes McKinney, “Python for Data Analysis: Data Wrangling with Pandas, NumPy, and IPython”, Second Edition, O’reilly Media, Inc., First Edition, 2018.
2. Machine Laerning: a practitioner's approach, Chandra S.S., Vinod, Hareendran S., Anand, PHI Learning pvt. ltd., 2021
3. TinyML_ Machine Learning with TensorFlow Lite on Arduino and Ultra-Low-Power
4. Microcontrollers- Pete Warden, Daniel Situnayake -O'Reilly Media (2019)
5. https://www.coursera.org/learn/introduction-to-embedded-machinelearning# syllabus
6. https://sites.google.com/g.harvard.edu/tinyml/home
7. https://www.udemy.com/course/getting-started-with-embedded-ai-hands-onexperience//
8. Trevor Hastie, Robert Tibshirani, Jerome Friedman, “The Elements of Statistical Learning: Data Mining, Inference, and Prediction”, Second Edition, Springer, 2009.
9. Pete Warden, Daniel Situnayake, “TinyML: Machine Learning with TensorFlow Lite on Arduino and Ultra-Low-Power Microcontrollers”, O'Reilly Media; 1st edition (16 December 2019)
10. Christopher M. Bishop, “Pattern Recognition and Machine Learning”, Springer, 2nd edition 2011.
11. Tom M. Mitchell, “Machine Learning”, McGraw-Hill, 1st edition 1997.

Course Code	Course Name	L – T – P	**Credits**

EE647	RF Photonics	3-0-0	3

Course Objectives: The primary objectives of this course are to:

- Impart knowledge about RF Photonic.
- Introduce RF Signal Generation & Detection.
- Impart the knowledge of Photonics Signal Processing.
- Provide practical knowledge of Applications of RF Photonics.

Course Contents

Unit I: Introduction to RF and photonic systems: Introduction to microwave photonics, basic optical and RF components: sources, modulators, receivers, passive devices, RF mixers, wireless receivers; applications of microwave photonics, fibre/wireless links: basic configuration, signal generation, transport strategies, design and analysis, advantages and limitations, high-speed optical wireless links, multiple coherent photonic RF system operations, optically controlled phased array antennas.

Unit II: RF Signal generation and detection: Optoelectronic oscillators (generation, frequency combs); microwave photonic integrated circuits (different platforms of integration, filter designs, micro resonators, nonlinear effects), photonic-based tunable RF filter, multiple RoF and multiple RoFSO, CW, Pulsed, and FMCW signal generation and detection photonic system assembly, stretch processing, Dual and multiband operations, photonics detectors for RF regeneration, PHODIR architecture.

Unit III: Photonics signal processing: Microwave photonics signal processing: filters, photonics analog-digital-converters, true-time delay beamforming, electro-optic sampling, sampling signal generation, direct digitalization, optical vector mixing, RF down conversion, Photonic-assisted microwave channelization (SDM, WDM, TDM), far-field/near-field AoA measurement, Ultra-Wideband free space beamforming, SLM, optical PLL operation, wideband Programmable Microwave Photonic Signal Processing, Reconfigurable photonics,

Unit IV: Microwave M/MS using photonics: Microwave measurements, Electronics solutions and challenges, Introduction to photonics-based broadband microwave measurements, signal parameter measurement-electric field, Phase Noise, Spectrum Analysis, Instantaneous Frequency, IF based microwave/optical power monitoring, Multiple-Frequency Measurement Based on Frequency to-Time Mapping, Doppler Frequency Shift Estimation, measurements of other signal parameters (Time–frequency analysis, Compressive sensing for a spectrally sparse signal), Software-defined solutions for photonic microwave measurements.

Unit V: Contemporary applications of microwave photonics: Fully Photonic based radar, single photonic multiband software defined radar, SAR/ISAR imaging, quantum radar, THz generation, sensing/imaging and beamforming, LIDAR systems, Fiber/FSO- connected Distributed Radar System, Distributed MIMO chaotic radar based on WDM technology, Microwave Passive Direction Finding, STAR, Integrated Photonic Beamforming Architecture for Phased-Array Antennas, Future multifunctional photonics radar concepts, microwave photonics architecture for modern ultra-wide bandwidth wired/wireless communications.

Course Outcomes

CO1: Understand the fundamentals of microwave-photonics and have a brief idea of opto-electronic components (sources, modulators, receivers, etc.)

CO2: Learn about the photonic integrated circuits, tunable RF filters design, photonics-based pulsed and FMCW RF exciter, and multiband radar.

CO3: Acquire knowledge of microwave photonics signal processing, like filters, ADC, delay, sampling, photonic measurements, ultra-wideband free space beamforming, etc. **CO4**: Understand the concept of photonics-based broadband microwave measurements, signal parameter measurement- electric field, Phase Noise, Spectrum Analysis, Instantaneous Frequency, and time-frequency analysis **CO5:** Gain knowledge of full photonics radar, SAR/ISAR imaging, LIDAR systems, Fibre/FSO-connected Distributed Radar System

Course Code	Course Name	L – T – P	**Credits**
EE648	**VLSI Fabrication Technology**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand semiconductor materials and crystal growth processes.
- Learn wafer fabrication steps, including oxidation, lithography, diffusion, and deposition.
- Study etching, doping, and metallization techniques for IC fabrication.
- Explore cleanroom practices and process integration for VLSI manufacturing.
- Gain insight into advanced fabrication technologies and scaling trends.

Course Contents

Unit I: Overview and materials:

Introduction to microelectronic fabrication.

Semiconductor substrate: Phase diagram and solid solubility, Crystal structure, Crystal defects, Crystal growth.

Unit II: Hot processing and ION implantation:

Diffusion: Atomistic models of diffusion, Analytic solutions of Fick's law, Diffusion coefficients, Two-step diffusion, Diffusion system.

Thermal Oxidation: The Deal-Grove model, the initial oxidation, Oxide characterization, oxidation-induced stacking faults, Oxidation systems.

Ion implantation: Ion implantation system, Vertical projected range, Channeling effect, Implantation damage, Problems, and concerns.

Unit III: Pattern transfer:

Optical lithography: Overview, Source systems, Contact/proximity printers. Projection printers, Alignment.

Photoresist: Contrast curves, applying and developing photoresist.

Etching: Wet etching, Plasma etching, Ion milling, Reactive ion etching, Liftoff. Electron Beam Lithography: Overview, Types of electron beam lithography, Patterning Strategies, Electron beam lithography process.

Unit IV: Thin film deposition and characterization techniques:

Physical Vapor Deposition: Evaporation Systems, Sputtering Systems.

Chemical Vapor Deposition: CVD system, Advanced CVD systems.

Epitaxial growth: Wafer cleaning and native oxide removal, thermal dynamics, Surface reactions, Dopants, Defects in epitaxial growth, MOCVD, MBE, and CBE. Characterization Techniques:

XRD, FESEM, TEM, AFM, Raman Spectroscopy, Spectroscopic Ellipsometry, UV-Vis Measurement, Hall Measurement, CV and IV measurement. **Unit V: Process integration:** Contacts and metallization: Junction and oxide isolation, Si on insulator, Schottky and Ohmic contacts, Multilevel metallization. CMOS technologies: Device behavior, Basic 3 μm technologies, Device scaling. Circuit Manufacturing: Yield, Particle control, Design of experiments, Computer integrated manufacturing.
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Understand the various materials in the Crystal Level. **CO2:** Understand the Ion Implantation, Diffusion, and various fabrication processes of IC **CO3:** Learn the thin film deposition and characterization techniques **CO4:** Gain knowledge of various process integration
Text Books/Reference Books
1. Stephen A. Campbell, The Science and Engineering of Microelectronic Fabrication, 2nd edition (Oxford University Press, 2001).

Course Code	Course Name	L – T – P	**Credits**
EE650	**Semiconductor Devices for High-Speed and High-Power Applications**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand performance-limiting parameters in high-speed and high-power semiconductor devices.
- Explore the material properties and processing of III–V and wide bandgap semiconductors for advanced applications.
- Analyze current transport mechanisms and characteristics of Schottky and MOS devices.
- Study the operation and advantages of MESFETs, HEMTs, HBTs, and GaN-based devices in high-frequency domains.

Course Contents

Unit I: Review: performance parameters of high-speed devices and circuits: Introduction, basic concepts, transit time of charge carriers, junction capacitances, on-resistances and their dependence on the device geometry and size, carrier mobility, doping concentration and temperature; contact resistance and interconnection/interlayer capacitances, SOI, ECL.

Unit II: Materials requirement for high-speed devices and circuits: III –V binary and ternary compound semiconductors (GaAs, InP, InGaAs, AlGaAs etc.), silicon-germanium alloys and silicon carbide for high-speed devices, as compared to silicon-based devices; crystal structure, dopants and electrical properties such as carrier mobility, velocity versus electric field characteristics of these materials; material and device process technique for III-V and IV – IV semiconductors.

Unit III: Physical phenomena governing metal semiconductor contacts and metal insulator semiconductor, and MOS devices:
Metal semiconductor contacts, interface state density, Schottky barrier diode; thermionic Emission model for current transport and current-voltage (I-V) characteristics; effect of interface states and interfacial thin electric layer on the Schottky barrier height and the I-V characteristics.
Unit IV: MESFETs, HEMTs, HBTs: Pinch off voltage and threshold voltage of MESFETs; D.C. characteristics; velocity overshoot effects; sub-threshold characteristics, short channel effects, hetero-junction devices; MODFET- principle of operation and the unique features of HEMT, InGaAs/InP HEMT; HBT principle of operation, its benefits, GaAs and InP based HBT, the surface passivation for stable high gain high frequency performance, strained layer devices.
Unit V: III-Nitride HEMTs: GaN comparison with other materials, physics of group III-Nitrides, GaN HEMTs, GaN-based devices issues and solutions.

Course Outcomes

On completion of this course, the students will be able to:
CO1: Understand the performance parameters of high-speed devices and circuits, and materials required for high-speed devices
CO2: Understand the fundamentals of physical phenomena in MIS, MOS devices for high-speed applications
CO3: Gain knowledge of HEMTS, HBTs
CO4: Acquire knowledge of the latest technology in high-speed and high-power III-nitride HEMTs and their application in various domains

Text Books/Reference Books:

1. H. Beneking, High Speed Semiconductor Devices: Circuit aspects and fundamental behavior, Chapman and Hall, London, 1994.
2. C. Y. Chang & F. Kat, GaAs High Speed Devices: Physics, Technology and Circuit Applications, Wiley, NY 1994.
3. S. M. Sze, High Speed Semiconductor Devices, Willey, 1990.
4. Michael Shur, GaAs Devices and Circuits, Plenum Press, NY, 1987.
5. N. G. Einsprush and R. Weisseman, VLSI Electronics: GaAs Microelectronics, Academic Press, NY, 1985.
6. S. K. Ghandhi, VLSI Fabrication Principles, Wiley, NY, 1994.

Course Code	Course Name	L – T – P	**Credits**
EE653	**Quantum Transport in Nanoscale FETs.**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand quantum transport principles and atomistic models governing nanoscale FETs.
- Analyze energy bands, density of states, and quantum effects in low-dimensional systems.
- Learn self-consistent solutions of Schrödinger's equation and their application in nano-

devices.
- Study NEGF formalism and transport mechanisms in coherent and non-coherent regimes of 2D FETs.

Course Contents

Unit I: Preliminary concepts of atomistic view: Introduction, Energy level diagram, electrons flow, quantum of conductance formula, ballistic conductance, diffusive conductance, coulomb blockade, angular averaging, Drude formula, Ohm's law.

Unit II: Energy band: E(p) or E(k) relation, density of states, number of modes, electron density (n), quantum wells, wires, dots, nanotubes, conductivity vs. electron density (n), quantum capacitance, the nano transistor boundary condition, Quasi-Fermi Levels (QFL's), Landauer formulas, electrostatic potential, Boltzmann Equation, Spin Voltages.

Unit III: Schrodinger equation self-consistent solution: Hydrogen atom, method of finite differences, wave equation, differential to matrix equation, dispersion relation, counting states, Beyond 1–D, Basis functions, Graphene, Reciprocal Lattice / Valleys, self-consistent field (SCF) procedure.

Unit IV: Non-equilibrium green's function (NEGF) formalism: Semiclassical model, quantum model, equations, current operator, scattering mechanisms, transmission, resonant tunneling, dephasing, local density of states [LDOS].

Unit V: Coherent and non-coherent transport in 2D FETs: Density matrix, Inflow/outflow, quantum point contact, self-energy, surface Green's function, graphene, Fermi-Golden Rule, inelastic scattering.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understand the wave-particle duality nature of electrons, energy quantization, Hamiltonian, etc.

CO2: Understand the Schrodinger equation, graphene structure, self-consistent field (SCF) procedure for device simulations with quantum effects

CO3: Gain knowledge of NEGF with scattering parameters for realistic nano transistor simulations

CO4: Acquire knowledge of non-ideal effects present in nanoscale FETs, different types of scattering effects, etc.

Text Books/Reference Books

1. Supriyo Duttai, Quantum Transport Atom to Transistor, 5th edition, Cambridge University Press, 2005.
2. Mark S. Lundstrom, Jing Guo, Nanoscale transistors Device physics, modelling and simulation, Springer, 2006.
3. Supriyo Dutta, Electronic Transport in Mesoscopic Systems, Cambridge University Press, 1995.
4. Roger T Howe, Charles G Sodini, Microelectronics An integrated approach, Pearson education.
5. Behzad Razavi, Fundamentals of Microelectronics, John Wiley India Pvt. Ltd, 2008.
6. Sundaram Natarajan, Microelectronics – Analysis and Design, Tata McGraw-Hill, 2007.

Course Code	Course Name	L – T – P	**Credits**
EE 654	**Introduction to Space Technology**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Develop an understanding of Space fundamentals
- Provide knowledge of spacecraft configuration and structural design.
- Equip students with knowledge of space communication
- Introduce space power systems and thermal control

Course Contents

Unit I: Space fundamentals: Introduction, orbital mechanics, the atmosphere, orbit determination, gravity, engineering of Space systems, basics of astronomy, and management of space systems.

Unit II: Spacecraft configuration and structural design: Introduction, Design interfaces and concepts, launch vehicles, structural design and test criteria, structural dynamics, structural test verifications, quality & reliability engineering, and fabrication & test processes and standards.

Unit III: Space communication: Introduction and overview, Propagation of Radio waves, modulation, noise, link budget, remote sensing, and geospatial technologies.

Unit IV: Space environment and space missions: Earth's atmosphere, solar radiation, mission analysis and planning, telemetry tracking and command stations, prelaunch operations, launch operations, and postlaunch operations.

Unit V: Space power systems and thermal control: The space environment, energy sources, solar cell arrays, energy storage devices, space power systems, environmental variations, and thermal control.

Course Outcomes

After completing this course, the students will be able to:

CO1: Acquire knowledge of broad and multidisciplinary knowledge in space technology

CO2: Understand satellite orbits, satellite-to-ground links, and link budgets

CO3: Understand launch vehicle design, earth observation, navigation, and communication modules

CO4: Learn about the space environment, Earth's atmosphere, missions, and launch operations

CO5: Understand Space Power Systems and Thermal Control

Text Books

1. Vincent L. Pisacane and Robert C. Moore, Fundamentals of Space Systems, Oxford University Press, USA, 1994.
2. Thomas F. Mütsch and Matthias B. Kowalski, Space Technology: A Compendium for Space Engineering, De Gruyter Oldenbourg, Germany, 2016.

Reference Books

1. Wilfried Ley, Klaus Wittmann, and Willi Hallmann, Handbook of Space Technology, Wiley Blackwell, New Jersey, USA.
2. Ignacio Chechile, Space Technology: A Short Introduction, Springer International Publishing AG, 2023.

Course Code	Course Name	L – T – P	**Credits**
EE655	**IC Design: RTL to GDS implementation**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the complete VLSI design flow from RTL coding to GDSII generation.
- Explore RTL modeling, synthesis, verification, and logic optimization techniques.
- Analyze timing, power, testability, and physical constraints in IC design.
- Gain practical knowledge of chip planning, placement, routing, and sign-off processes.

Course Contents

Unit I: Basic Concepts -VLSI Design Flow : Basic Concepts of Integrated Circuit: Structure, Fabrication, Types, Design Styles, Designing vs. Fabrication, Economics, Figures of Merit Overview of VLSI Design Flow: Design Flows and Abstraction; Pre-RTL Methodologies: Hardware-software Partitioning, SoC Design, Intellectual Property (IP) Assembly, Behavioral Synthesis, Overview of VLSI Design Flow: RTL to GDS Implementation: Logic Synthesis, Physical Design; Verification and Testing; Post- GDS Processes

Unit II: Hardware Modeling, RTL synthesis & Optimization: Introduction to Verilog Functional verification using simulation: testbench, coverage, mechanism of simulation in Verilog, RTL Synthesis: Verilog Constructs to Hardware Logic Optimization: Definitions, Two-level logic optimization, Logic Optimization: Multi-level logic optimization, FSM Optimization Formal Verification: Introduction, Formal Engines: BDD, SAT Solver.

Unit III: Verification & STA: Formal Verification: Model Checking, Combinational Equivalence Checking Technology Library: Delay models of Combinational and Sequential Cells, Static Timing Analysis: Synchronous Behavior, Timing Requirements, Timing Graph, Mechanism, Delay Calculation, Graph-based Analysis, Path-based Analysis, Accounting for Variations.

Unit IV: Constraints & DFT: Clock, I/O, Timing Exceptions Technology Mapping, Timing-driven Optimizations. Power Analysis, Power-driven Optimizations Design for Test: Basics and Fault Models, Scan Design Methodology, Design for Test: ATPG, BIST Basic Concepts for Physical Design: IC Fabrication, FEOL, BEOL, Interconnects and Parasitics, Signal Integrity, Antenna Effect, LEF files.

Unit V: Chip Planning: Partitioning, Floorplanning, Power Planning Placement: Global Placement, Wirelength Estimates, Legalization, Detailed Placement, Timing-driven Placement, Scan Cell Reordering, Spare Cell Placement, Clock Tree Synthesis: Terminologies, Clock Distribution Networks, Clock Network Architectures, Useful, Skews Routing: Global and Detailed, Optimizations Physical Verification: Extraction, LVS, ERC, DRC, ECO and Sign-off

Course Outcomes

On completion of this course, the students will be able to:

CO1: Develop basic concepts of VLSI design Flow
CO2: Understand Hardware Modelling and RTL synthesis
CO3: Design and verify digital circuits and do static timing analysis
CO4: Develop a different Design for Test
CO5: Understand and develop the chip partitioning and floor planning.

Text Books/Reference Books
1. Introduction to VLSI Design Flow, Sneh Saurabh 2. N.A. Sherwani, “Algorithms for VLSI Physical Design Automation ", 1999. 3. VERILOG HDL SYNTHESIS: A PRACTICAL PRIMER by J Bhaskar 4. “Design Verification: Simulation and Formal Method based Approaches”, William K. Lam, Prentice Hall. 5. “The EDA Hand Book”, Dirk Jansen, Kluwer Academic Publishers.

Course Code	Course Name	L – T – P	**Credits**
EE656	**IC Testing & Verification**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the VLSI design flow with emphasis on fault models, simulation techniques, and verification strategies.
- Develop an understanding of functional and structural testing methodologies, including fault modeling, fault simulation, and test pattern generation.
- Enable students to apply sequential machine testing techniques and address challenges in deep submicron ICs and quiescent current testing.
- Impart knowledge of design-for-testability (DFT) approaches, built-in self-test (BIST), formal verification, and on-line testing methods.

Course Contents

Unit I: Design Flow of VLSI Systems: (1) Design and manufacturing defect models (2) Simulation-based design verification. Fault Simulation: (1) Parallel (2) Deductive (3) Concurrent

Unit II: Functional Testing Methodologies: (1) Exhaustive testings (2) Pseudo-exhaustive testing structure Based Testing: (1) Fault model-based testing: (A) Stuck-at faults; (B) Bridging faults; (C) Stuck-open faults; (D) Delay faults (2) Fault Grading (3) Automatic Test Pattern Generation Algorithms: (A) D-Algorithms; (B) PODEM; (C) FAN, etc.

Unit III: Sequential Machine Testing: (1) Machine identification experiments (2) Modified PODEM and D-algorithms Quiescent Current Testability Methods; deep submicron challenges

Unit IV: Design for Testability Methods: (1) Testable combinational/sequential circuits (2) Scan path design (3) Partial scan (4) Built-in Self Test (BIST) (5) Data compaction techniques

Unit V: Introduction to Formal Design Verification

On-Line Testing Methods: (1) Self-checking circuits (2) Error detecting/correcting codes.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understand the fundamentals of Design for Testability (DFT) concepts.
CO2: Understand built-in self-test (BIST) architectures
CO3: Perform Fault modeling, ATPG (Automatic Test Pattern Generation), scan chain design
CO4: Acquire knowledge of Verification methodologies, including simulation
CO5: Understand formal verification and emulation

Text Books/References Books
1. “SystemVerilog for Design”: A Guide to Using SystemVerilog for Hardware Design and Modeling Sutherland, Stuart, Davidmann, Simon, Flake, Peter2nd ed., 2006 2. “SystemVerilog for Verification”: A Guide to Learning the Testbench Language Features, Chris Spear, 2006 3. “Hardware Verification with System Verilog”: An Object-Oriented Framework Mintz, Mike, Ekendahl, Robert 2007 4. Introduction to VLSI Design Flow, Sneh Saurabh 5. N.A. Sherwani, “Algorithms for VLSI Physical Design Automation ", 1999. 6. VERILOG HDL SYNTHESIS: A PRACTICAL PRIMER by J Bhaskar 7. “Design Verification: Simulation and Formal Method based Approaches”, William K. Lam, Prentice Hall. 8. “The EDA Hand Book”, Dirk Jansen, Kluwer Academic Publishers.

Course Code	Course Name	L – T – P	**Credits**
EE657	**Low Power & High-Speed Analog Design**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the fundamentals of low-power and high-speed analog circuit design.
- Learn design techniques for high-speed amplifiers, comparators, and data converters.
- Analyze trade-offs between power, speed, noise, and area in analog circuits.
- Explore design challenges in deep-submicron CMOS technologies.
- Gain hands-on experience in optimizing analog and mixed-signal circuits.
- Apply concepts to real-world applications like wireless, biomedical, and high-speed I/O systems.

Course Contents

Unit I: Fundamentals of Low Power & High-Speed Analog Circuits: Introduction & Motivation: Understanding the necessity for low-power and high-speed circuits in modern integrated circuits (ICs). Trade-offs & Performance Metrics: Exploring power, speed, gain, noise, linearity, and area considerations. Technology Scaling & Challenges: Addressing short-channel effects, leakage power, and process variations. MOSFET Basics Revisited: weak inversion, subthreshold operation, and the gm/Id design approach. Design Constraints in CMOS: Focusing on low-power and high-speed design within CMOS technology.

Unit II: Low Power Design Techniques Sources of Power Dissipation: Identifying dynamic, static, short-circuit, and leakage power. Subthreshold & Weak Inversion Design: Applying the gm/Id methodology. Low-Power Biasing Circuits: Designing current mirrors and bandgap references. Low-Voltage Opamps & Comparators: Exploring Class AB, bulk-driven, and dynamic biasing techniques. Power Reduction Techniques: Implementing power gating, body biasing, and adaptive voltage scaling

Unit III: High-Speed Design Techniques High-Speed Amplifiers: Studying folded cascode, current-mode circuits, and active feedback. High-Speed Comparators: Designing dynamic comparators and sense amplifiers. Bandwidth Enhancement Techniques: Utilizing inductive peaking and negative capacitance. Current-Mode Signalling: Facilitating low-power high-speed data transfer. High-Speed Switched-Capacitor Circuits: Implementing efficient designs.

Unit IV: Low-Power & High-Speed Data Converters and Clocking Data Converter Fundamentals: ADC/DAC performance metrics. Low-Power ADC Architectures: SAR, ΣΔ, and pipeline ADCs. High-Speed ADC Architectures: Flash and time-interleaved ADCs. Clocking Techniques: PLLs and DLLs for high-speed systems. Jitter and Phase Noise: Low-power clock generation challenges.

Unit V

Case Studies, Industry Trends & Practical Design Industry Case Studies: Analyzing low-power, high-speed analog ICs. Power Management: Strategies for high-speed circuits. Mixed-Signal Design Challenges: Addressing contemporary issues. Emerging Technologies: AI-assisted design, Fin-FETs, and SOI CMOS.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understand the fundamentals of low-power & high-speed analog circuits

CO2: Choose the appropriate low-power design techniques

CO3: Acquire knowledge of high-speed design techniques

CO4: Understand Low-Power & High-Speed Data Converters and Clocking

CO5: Analyze the case studies, Industry Trends & Practical Design

Text Books/Reference Books

1. CMOS Analog Circuit Design by P.E. Allen & D.R. Holberg
2. Design of Analog CMOS Integrated Circuits by Behzad Razavi
3. Analysis and Design of Analog Integrated Circuits by P.R. Gray, P.J. Hurst, S.H. Lewis, R.G. Meyer
4. Low Power Design Methodologies by J. Rabaey
5. Low-Power CMOS Circuits: Technology, Logic Design, and CAD Tools by C. Piguet
6. Phase-Locking in High-Performance Systems – B. Razavi

Course Code	Course Name	L – T – P	**Credits**
EE658	**Hardware Accelerators**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the RISC-V instruction set architecture and simulation tools.
- Understand pipelining, out-of-order execution, and multicore CPU design.
- Study memory hierarchies, coherence, and consistency models.
- Explore GPU architectures, vector and array processing systems.
- Develop architectural understanding for machine learning and accelerator design.

Course Contents

Unit I: Intro to RISC V ISA, covering all Instructions of Integer ISA, simulating sample programs using spike RISC V ISA simulator

Unit II: Pipeling, Out-of-order processors, MULTI CORE CPUS

Unit III: Caches, main memory, Memory coherence and consistency

Unit IV: GPUS, VECTOR PROCESSING, ARRAY PROCESSING, SYSTOLLIC ARRAYS

Unit V: On-chip networks, Heterogenous design concepts, Accelerator design, interfacing accelerator with processor core, HLS etc. Architecture for machine learning.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understand the fundamentals of RISC-V and its ISA

CO2: Develop the concepts of Pipelining, Multicore CPUs

CO3: Grasp the Knowledge of memory in CPUs

CO4: Learn about the important GPU processors and their processing units

CO5: Develop the understanding and design of an architecture for machine learning.

Textbooks

1. Advanced Computer Architecture by Smruti R Sarangi | Jul 21, 2021

Reference Books

1. Advanced Computer Architecture by Smruti R Sarangi | Jul 21, 2021
2. RISC V READER BY DAVID PATTERSON
3. Computer Organization and Design RISC-V Edition: The Hardware Software Interface (The Morgan Kaufmann Series in Computer Architecture and Design)

Course Code	Course Name	L – T – P	**Credits**
EE659	**MEMS and Microsystems Design**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the fundamentals of MEMS technology, key application domains, and the influence of scaling laws on microsystem design.
- Develop an understanding of materials, micromachining techniques, and thin film deposition processes used in MEMS fabrication.
- Enable students to model and design MEMS devices using analytical and finite element methods.
- Explore various microactuators, microsensors, and real-world MEMS applications through case studies and emerging trends in smart systems and IoT.

Course Contents

Unit I: Introduction to MEMS and Microsystems: Overview of MEMS Technology, Applications of MEMS in Automotive, Biomedical, and Consumer Electronics, Scaling Laws and Microsystem Design Considerations.

Unit II: MEMS Materials and Fabrication: Materials for MEMS (Silicon, Polymers, Metals), Bulk Micromachining and Surface Micromachining, Thin Film Deposition Techniques **Unit III: MEMS Design and Modeling:** Design Methodologies for MEMS Devices, Finite Element Modeling and Simulation, Analytical Modeling Techniques **Unit IV: Microelectromechanical Systems:** Microactuators (Electrostatic, Piezoelectric, Thermal), Micro Sensors (Pressure, Accelerometers, Gyroscopes), RF MEMS Devices **Unit V: Case Studies and Applications:** Design Case Studies in MEMS, Emerging Trends in MEMS Technology, MEMS in IoT and Smart Systems
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Understand the fundamentals of MEMS technology **CO2:** Develop an understanding of MEMS materials and fabrication **CO3:** Learn concepts related to the design methodologies of MEMS **CO4:** Learn about MEMS devices and actuators **CO5:** Understand current trends in the MEMS industry
Text Books/References Books
1. "Microsystem Design" by Stephen D. Senturia, Springer. 2. "Fundamentals of Microfabrication" by Marc Madou, CRC Press. 3. "MEMS and Microsystems: Design and Manufacture" by Tai-Ran Hsu, McGraw Hill. 4. "The MEMS Handbook, MEMS introduction and Fundamentals, Mohammed Gad el Hak 5. The MEMS Handbook, MEMS Design and Fabrication, Mohammed Gad el Hak 6. The MEMS Handbook, MEMS Applications, Mohammed Gad el Hak Foundations of MEMS, Chang Liu 7. Handbook of Silicon based MEMS Materials and Technologies, Veikko Lindroos, Markku Tilli, Ahri Lehto, Teruaki Motooka

Course Code	Course Name	L – T – P	**Credits**
EE660	**MEMS Sensors and Actuators**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the classification, performance parameters, and integration aspects of sensors and actuators in MEMS systems.
- Develop an understanding of the design, operation, and simulation of mechanical, thermal, optical, and magnetic MEMS-based sensors and actuators.
- Explore the principles and applications of chemical, biomedical, and lab-on-chip sensors within the MEMS framework.
- Impart knowledge of signal conditioning, data conversion, and interfacing techniques for MEMS devices with microcontrollers and IoT systems.

Course Contents
Unit I: Introduction to Sensors and Actuators: Classification and Performance Parameters, Integration with MEMS Devices **Unit II: Mechanical and Thermal Sensors and Actuators:** Pressure Sensors, Accelerometers, Gyroscopes, Thermal Sensors and Microheaters, Design and Simulation **Unit III: Optical and Magnetic Sensors:** Photonic Sensors and Optical MEMS, Magnetic Sensors and Magnetometers, Case Studies and Applications **Unit IV: Chemical and Biomedical Sensors:** Gas and Chemical Sensors, Biosensors and BioMEMS, Lab-on-Chip Technologies **Unit V: Signal Conditioning and Interfacing:** Signal Amplification and Filtering, Analog to Digital Conversion Techniques, Interfacing with Microcontrollers and IoT Systems.
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Understand the fundamentals of sensors and actuators **CO2:** Learn different types of Mechanical and thermal sensors and actuators **CO3:** Knowledge of Optical and magnetic sensors **CO4:** Understand the working of chemical and biomedical sensors. **CO5:** Learn different techniques to interface sensors and actuators' signals to circuits and microcontrollers
Text Books/Reference Books
1. “Sensors and Actuators: Engineering System Instrumentation" by Clarence de Silva 2. "Micro and Smart Systems" Ananthsuresh et. Al. 3. "MEMS Sensors and Actuators" by M. Elwenspoek and R. Wiegerink 4. The MEMS Handbook, MEMS introduction and Fundamentals, Mohammed Gad el Hak 5. The MEMS Handbook, MEMS Design and Fabrication, Mohammed Gad el Hak 6. The MEMS Handbook, MEMS Applications, Mohammed Gad el Hak 7. Foundations of MEMS, Chang Liu 8. Handbook of Silicon based MEMS Materials and Technologies, Veikko Lindroos, Markku Tilli, Ahri Lehto, Teruaki Motooka

Course Code	Course Name	L – T – P	**Credits**
EE661	**Microfabrication Techniques and Processes**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the fundamentals of microfabrication and nanofabrication, including cleanroom protocols and silicon wafer processing.
- Develop an understanding of lithography, pattern transfer, and thin film deposition techniques used in micro- and nano-scale device fabrication.
- Enable students to analyze and apply various etching techniques, including both wet and dry etching, with focus on precision and selectivity.

- Explore emerging microfabrication techniques and their applications in MEMS, NEMS, and microfluidic systems.

Course Contents

Unit I: Fundamentals of Microfabrication: Introduction to Microfabrication and Nanofabrication, Clean Room Standards and Protocols, Silicon Wafer Processing

Unit II: Photolithography and Patterning: Optical Lithography and Mask Making, Advanced Lithography Techniques, Photoresists and Pattern Transfer

Unit III: Thin Film Deposition: Physical Vapor Deposition (PVD), Chemical Vapor Deposition (CVD), Atomic Layer Deposition (ALD)

Unit IV: Etching Techniques: Wet and Dry Etching Processes, Deep Reactive Ion Etching (DRIE), Selectivity and Anisotropy in Etching

Unit V: Emerging Techniques and Applications: Nanoimprint and Soft Lithography, Microfluidic Device Fabrication, Applications in MEMS and NEMS

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understand the fundamentals of Microfabrication

CO2: Learn the different steps involved in Photolithography and Patterning

CO3: Knowledge of Thin Film deposition, CVD, etc.

CO4: Study Etching Techniques

CO5: Acquire knowledge of Nanoimprint and Soft Lithography, Microfluidic Device Fabrication, Applications in MEMS and NEMS

Text Books/Reference Books

1. “Fundamentals of Microfabrication" by Marc Madou
2. "Introduction to Microelectronic Fabrication" by Richard C. Jaeger
3. "Microsystem Technology" by Wolfgang Menz
4. The MEMS Handbook, MEMS introduction and Fundamentals, Mohammed Gad el Hak
5. The MEMS Handbook, MEMS Design and Fabrication, Mohammed Gad el Hak
6. The MEMS Handbook, MEMS Applications, Mohammed Gad el Hak
7. Foundations of MEMS, Chang Liu

Course Code	Course Name	L – T – P	**Credits**
EE662	**RF MEMS**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the fundamentals of RF MEMS, their applications, and distinctions from traditional solid-state RF components.
- Develop understanding of mechanical and electromagnetic modeling techniques used in the design and analysis of RF MEMS devices.

- Familiarize students with MEMS fabrication processes and the design of key RF MEMS components such as switches, varactors, and inductors.
- Explore advanced RF MEMS systems, including phase shifters, filters, antennas, and address key research issues like reliability, packaging, and emerging architectures.

Course Contents

Unit I: Introduction to RF MEMS

Introduction to RF MEMS, RF MEMS vs. solid state components, Application areas and case studies, RF MEMS development around the world

Review of basic mechanics and elements of strength of materials, Stress and strain, Stresses of beams, Deflection of beams, and spring constants

Unit II: Mechanical modeling of MEMS switches Static analysis Dynamic analysis

Review of Electromagnetic analysis and modeling, Transmission lines & high-frequency effects, scattering parameters, Review of numerical techniques

Electromagnetic modeling of RF MEMS switches: distributed models, lumped-element models

Unit III: Review of MEMS fabrication, Bulk micromachining, surface micromachining

Case studies of RF MEMS switches

RF MEMS inductors

FR MEMS varactors.

Unit IV: Switching networks series and shunt configurations, capacitive vs. ohmic contact absorptive switches

RF MEMS Phase Shifters

RF MEMS filters

RF MEMS antennas.

Unit V: Research issues Reliability Packaging Novel system architectures.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understand the fundamentals of modeling, design, technology, and applications of RF Micro-Electro-Mechanical Systems (MEMS).

CO2: Develop a strong understanding of how RF MEMS technology benefits the fields of intelligent communication systems, radars, and sensors.

CO3: Know about linear and non-linear electromechanical models for RF MEMS devices through analytical and numerical techniques.

CO4: Understand the high potential of RF MEMS in building a variety of reconfigurable high-frequency components and systems.

CO5: Learn different research topics, including reliability, packaging, and novel architectures.

Text Books/Reference Books

1. RF MEMS - Theory, Design and Technology, 1st Edition, Gabriel M. Rebeiz , John Wiley & Sons , 2003 , ISBN No. 047120169

2. Schaum's Outline of Statics and Strength of Materials, 1st Edition, John J. Jackson, Harold G. Wirtz , McGraw-Hill , 1983 , ISBN No. 0070321213

3. Microsensors MEMS and Smart Devices, 1st Edition, Julian W. Gardner, Vijay K. Varadan, Osama O. Awadelkarim , John Wiley & Sons , 2001 , ISBN No. 047186109X.\

4. Microsystem Design, 1st Edition, Stephen D. Senturia , Kluwer Academic Publishers, 2000, ISBN No. 0792372468 5. RF MEMS & Their Applications, 1st Edition, Vijay K. Varadan, K.J. Vinoy, K.A. Jose, John Wiley & Sons, 2003, ISBN No. 047084308X

Course Code	Course Name	L – T – P	**Credits**
EE663	**MEMS Packaging**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the fundamentals of miniaturization, levels of packaging, and their role in MEMS and microelectronics integration.
- Develop understanding of key packaging processes, including interface challenges, dicing, bonding, sealing, and material selection.
- Enable students to explore advanced packaging techniques such as vacuum, RF, optical, and 3D packaging, along with application-specific solutions.
- Impart knowledge on environmental protection, reliability analysis, safety standards, and emerging research trends in MEMS packaging.

Course Contents

Unit I: Overview of Miniaturization, MEMS and Microelectronics-3levels of Packaging.

Unit II: Critical Issues viz., Interface, Testing & evaluation. Packaging Technologies like Wafer dicing, Bonding and Sealing.

Unit III: Design aspects and Process Flow, Materials for Packaging, Top-down System Approach. Different types of Sealing Technologies like brazing, Electron Beam welding and Laser welding.

Unit IV: Vacuum Packaging with Moisture Control. 3D Packaging examples. Bio Chips/Lab-on-a-chip and micro fluidics, Various RF Packaging, Optical Packaging, Packaging for Aerospace applications. Advanced and Special Packaging techniques–Monolithic, Hybrid etc., Transduction and Special packaging requirements for Absolute, Gauge and differential Pressure measurements, Temperature measurements, Accelerometer and Gyro packaging techniques,

Unit V: Environmental Protection and safety aspects in MEMS Packaging. Reliability Analysis and FMECA. Media Compatibility Case Studies, Challenges/ Opportunities/ Research frontier.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understand the fundamentals of Miniaturisation, MEMS, and Microelectronics.
CO2: Understand the critical issues in miniaturization and packaging.
CO3: Learn Design aspects and Process Flow, Different types of Sealing Technologies
CO4: Understand different packaging techniques.
CO5: Learn about environmental Protection and safety aspects in MEMS Packaging.

Text Books/Reference Books

1. "MEMS Packaging" by Tai-Ran Hsu
2. "MEMS / MOEMS packagibg" by Ken Gilleo doi.contentdirections.com

3. "Johan Liu, James E. Morris, Per-Erik Tegehall, Cristina Andersson, Jussi Sarkka, Olli Salmela
4. RF MEMS - Theory, Design and Technology, 1st Edition, Gabriel M. Rebeiz, John Wiley & Sons, 2003, ISBN No. 0471201693
5. Schaum's Outline of Statics and Strength of Materials, 1st Edition, John J. Jackson, Harold G. Wirtz, McGraw-Hill, 1983, ISBN No. 0070321213
6. Microsensors, MEMS and Smart Devices, 1st Edition, Julian W. Gardner, Vijay K. Varadan, Osama O. Awadelkarim, John Wiley & Sons, 2001, ISBN No. 047186109X
7. Microsystem Design, 1st Edition , Stephen D. Senturia , Kluwer Academic Publishers , 2000 , ISBN No. 0792372468
8. RF MEMS & Their Applications, 1st Edition, Vijay K. Varadan, K.J. Vinoy, K.A. Jose, John Wiley & Sons, 2003, ISBN No. 047084308X

Course Code	Course Name	L – T – P	**Credits**
EE664	**MEMS Packaging and Reliability**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the fundamental requirements, types, and challenges of MEMS packaging at wafer, chip, and system levels.
- Develop an understanding of materials, bonding methods, and sealing techniques used in MEMS packaging.
- Enable students to analyze interconnection technologies and assembly methods, including 3D integration and packaging for specialized MEMS devices.
- Impart knowledge of reliability testing, failure mechanisms, and advanced packaging trends through real-world MEMS case studies.

Course Contents

Unit I: Introduction to MEMS Packaging, Overview of MEMS Packaging Requirements, Types of Packaging: Wafer-level, Chip-scale, and System-level

Unit II: Packaging Materials and Techniques, Packaging Materials: Polymers, Metals, Ceramics, Adhesive Bonding, Anodic Bonding, and Glass Frit Bonding, Hermetic and Non-Hermetic Sealing Techniques

Unit III: Interconnection and Assembly, Electrical Interconnection Techniques: Wire Bonding, Flip-Chip Bonding, 3D Integration and Through-Silicon Vias (TSV), Packaging for RF MEMS and Optical MEMS

Unit IV: Reliability and Testing, Mechanical Reliability: Shock and Vibration Testing, Thermal Cycling and Humidity Testing, Failure Analysis and Quality Assurance

Unit V: Emerging Trends and Case Studies, Advanced Packaging for IoT and Wearable MEMS, Packaging for Biomedical MEMS, Case Studies: Automotive Sensors, Inertial Measurement Units

Course Outcomes

On completion of this course, the students will be able to:
CO1: Understand the fundamentals of Miniaturisation, MEMS, and Microelectronics.
CO2: Understand the critical issues in miniaturization and packaging.
CO3: Learn Design aspects and Process Flow, Different types of Sealing Technologies
CO4: Understand different packaging techniques.
CO5: Learn about environmental Protection and safety aspects in MEMS Packaging.

Text Books/Reference Books

1."MEMS Packaging" by Tai-Ran Hsu
2."MEMS / MOEMS packaging" by Ken Gilleo doi.contentdirections.com
3." Johan Liu, James E. Morris, Per-Erik Tegehall, Cristina Andersson, Jussi Sarkka, Olli Salmela
4. RF MEMS - Theory, Design and Technology, 1st Edition, Gabriel M. Rebeiz, John Wiley & Sons, 2003, ISBN No. 0471201693
5. Schaum's Outline of Statics and Strength of Materials, 1st Edition, John J. Jackson, Harold G. Wirtz, McGraw-Hill, 1983, ISBN No. 0070321213
6. Microsensors, MEMS and Smart Devices, 1st Edition, Julian W. Gardner, Vijay K. Varadan, Osama O. Awadelkarim, John Wiley & Sons, 2001, ISBN No. 047186109X
7. Microsystem Design, 1st Edition, Stephen D. Senturia, Kluwer Academic Publishers, 2000, ISBN No. 0792372468
8. RF MEMS & Their Applications, 1st Edition, Vijay K. Varadan, K.J. Vinoy, K.A. Jose, John Wiley & Sons, 2003, ISBN No. 047084308X

Course Code	Course Name	L – T – P	**Credits**
EE665	**Low-Power Digital IC Design**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the fundamentals of low-power VLSI design, its importance, and applications in modern digital systems.
- Develop an understanding of low-voltage device modeling and design methodologies using CMOS and BiCMOS technologies.
- Enable students to analyze and design low-power digital subsystems and architectures such as adders, multipliers, and PLLs.
- Impart knowledge of power estimation techniques and power reduction strategies at physical, circuit, architectural, and algorithmic levels.

Course Contents

Unit I: Low-Power VLSI Design: An Overview & Technology Low-Power Applications, Low-Power Design Methodology, Power Reduction Through Process Technology, Low-Voltage Process Technology, LOW-VOLTAGE PROCESS TECHNOLOGY, CMOS Process Technology, 2.5 BiCMOS Technology 36

Unit II: Low-Voltage Device Modeling: MOSFET structure and operation, spice models of the MOS transistor, CMOS power supply voltage scaling, low-voltage low-power VLSI CMOS, circuit design.

Unit III: Low-Voltage VLSI BiCMOS Circuit Design
Conventional BiCMOS Logic, Low-Voltage BiCMOS Families, Low-Voltage BiCMOS Applications

Unit IV: VLSI CMOS Subsystem Design
Parallel Adders, Parallel Multipliers, Data Path, Regular Structures, PLL

Unit V: Low-Power VLSI Design Methodology: LP Physical Design, LP Gate-Level Design, LP Architecture-Level Design, Algorithmic-Level Power Reduction, Power Estimation Techniques, Low-power neuromorphic computing systems, Emerging Devices: Architectural Approaches, System-Level Examples:

Course Outcomes

On completion of this course, the students will be able to:
CO1: Understand the fundamentals of low-power VLSI
CO2: Choose the appropriate low-power device modeling
CO3: Acquire knowledge of Low-Voltage VLSI BICMOS Circuit Design
CO4: Understand Low-Power VLSI CMOS Subsystem Design
CO5: Learn Low-Power VLSI Design Methodology & neuromorphic computing

Text Books/Reference Books

1. Low-Power Digital Vlsi Design Circuits and Systems, A. Bellaouar, M Elmasry
2. CMOS Analog Circuit Design by P.E. Allen & D.R. Holberg
3. Design of Analog CMOS Integrated Circuits by Behzad Razavi
4. Analysis and Design of Analog Integrated Circuits by P.R. Gray, P.J. Hurst, S.H. Lewis, R.G. Meyer.
5. Low Power Design Methodologies by J. Rabaey
6. Low-Power CMOS Circuits: Technology, Logic Design, and CAD Tools by C. Piguet
7. Phase-Locking in High-Performance Systems – B. Razavi.

Course Code	Course Name	L – T – P	**Credits**
EE666	**Optical Space Communication**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Impart knowledge about Optical Space Communication.
- Introduce different Modulation Techniques
- Impart the knowledge of Channel Modelling
- Provide knowledge of AI integration with OSA.

Course Contents

Unit I: Introduction to optical space communication: Calculating the power budget of a space communication link, considering losses and gains. Satellite communication, deep space probes, and high-speed data transfer between ground stations and space. Principles and applications of transmitting data using lasers and other optical devices in space. Fundamentals of optical communication, space link technology, and address specific challenges like atmospheric turbulence and signal processing techniques.

Unit II: Advanced modulation techniques: Design of both ground-based and space-based optical transmitters and receivers. Coherent detection techniques and their advantages in long-distance communication. Quantum communication, optical orbital angular momentum, and free-space optical networking.

Unit III: Channel modelling and link budget calculations: Techniques like equalization, adaptive filtering, and advanced modulation formats to enhance communication quality.

Unit IV: Channel turbulence effects measurement and mitigation: Optical transceivers, atmospheric effects on propagation, and pointing, acquisition, and tracking (PAT) systems. Addressing issues such as atmospheric turbulence, noise, and signal degradation in space communication.

Unit V: AI for optical space communications: AI-based adaptive optics techniques: reference wave in an adaptive optics system, wavefront sensors (quadrature sensors, phase difference sensors, Hartmann sensor), wavefront correctors (modal correctors, deformable mirrors, segmented correctors), modal phase correction, modal phase conjugation.

Course Outcomes

CO1: Acquire knowledge of optical space communication
CO2: Understand the modulation/demodulation schemes for high-data-rate space communications
CO3: Understand the atmospheric channel modelling and link budget calculations
CO4: Learn about the channel effects and mitigation techniques
CO5: Understand the AI requirements for space optical communications

Text Books/Reference Books

1. B. Djordjevic, Advanced Optical and Wireless Communications Systems. Springer International Publishing AG, 2018.
2. N. Zhao, X. Li, G. Li and J. M. Kahn "Capacity Limits of Spatially Multiplexed Free-Space Communication", Nature Photon., vol. 9, pp. 822-826, December 2015.
3. J. Wang, J. M. Kahn and K. Y. Lau "Minimization of Acquisition Time in Short-Range Free-Space Optical Communication", Applied Optics, vol. 41, no. 12, pp. 7592-7602, December 2002.
4. C. Andrews, R. L. Philips, Laser Beam Propagation through Random Media, 2nd Ed. SPIE Press, Bellingham, Washington, USA, 2005.
5. I. B. Djordjevic, Advanced Optical and Wireless Communications Systems, Springer, Dec. 2017/Jan. 2018.
6. Shlomi Arnon, Robert Schober, George Karagiannidis, John Barry, Murat Uysal, Advanced Optical Wireless Communication Systems, Cambridge University Press, 2012

Course Code	Course Name	L – T – P	**Credits**
EE667	**Mobile and Satellite Communication**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the fundamentals of wireless communication systems, including channel modeling, modulation techniques, diversity, and performance metrics.
- Analyze cellular communication systems covering capacity, frequency reuse, multiple access methods, equalization, diversity, and modern technologies like GSM, CDMA, OFDM, 4G, and 5G.
- Study mobile radio propagation mechanisms and models, including reflection, diffraction, scattering, fading, and their impact on communication systems.
- Gain knowledge of satellite communication principles, including orbital mechanics, space segment, earth segment, link budget, and environmental effects.
- Explore satellite access techniques and services such as FDMA, TDMA, CDMA, DBS, VSAT, GPS, and their applications in modern communication systems.

Course Contents

Prerequisite: Introduction to Wireless Communication, Motivation, Types of Wireless Communication, Wireless Channel Modeling, Random Variable, Fading Channels, Linear Transformation, Bit Error Rate (BER) and Symbol Error rate (SER), BER and SER performance for Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), M-ary Pulse Amplitude Modulation (PAM) and M-ary PSK in Additive White Gaussian Noise (AWGN), Diversity Techniques, Maximum Delay Spread, RMS Delay Spread, RMS delay based on power profile, Average Delay Spread in Outdoor Cellular Channels, Coherence Bandwidth in Wireless Communications, Inter symbol Interference (ISI), Doppler Fading.

Unit I: Cellular Communications: Introduction to Cellular Communications, Cell Capacity and Frequency reuse, Coverage Improvement, Multiple Access Technologies, Cellular Processes Call Setup, Handover, Teletraffic Theory, Equalization and Diversity Techniques, Modulation and Coding Techniques for Mobile Communication, GSM, CDMA, 4G, VOLTE and 5 G technologies, Introduction to Wireless OFDM – OFDM principles, system model – Generation of sub carrier using IFFT, windowing, choice of OFDM parameters, OFDM signal processing.

Unit II: Mobile Radio Propagation: Introduction to Mobile Radio Propagation, Reflection, Diffraction, Scattering, Propagation Models, Doppler Effect, Delay Spread, Ultra-Wideband Communication System, Fading, TDM, FDM, TDMA, FDMA, CDMA, OFDM.

Unit III: Overview of Satellite Systems: Frequency Allocations for Satellite Services, Kepler's Law, Orbital Elements, Apogee and Perigee, Orbital Perturbations, Effects of a Non-spherical Earth, Atmospheric Drag, Inclined Orbits, Sidereal Time, Equatorial Coordinate System, Predicting Satellite Position.

Unit IV: Space Segment & Earth Segment: Introduction, Antenna look angles, Limits of visibility, Near-geostationary orbits, Earth eclipse of satellite, Sun transit outage, Power supply, Attitude control, spinning satellite stabilization, Station keeping, Transponders, Antenna subsystem, Carrier-to-Noise ratio for uplink and downlink, System noise, Effects of rain, Rain-fade margin.

Unit V: Satellite Access & DBS Services: Preassigned FDMA, Demand-Assigned FDMA, FDMA downlink analysis, Companion of uplink power requirements for FDMA & TDMA. On-board signal processing for TDMA/FDMA operation, Satellite switched TDMA, CDMA, Orbital Spacings, Power Rating and Number of Transponders, Frequencies and Polarization,

Transponder Capacity, Bit Rates for Digital Television, MPEG Compression Standards, Forward Error Correction, Home Receiver Outdoor Unit (ODU), Home Receiver Indoor Unit (IDU), Downlink Analysis, Uplink, Problems, Satellite Mobile Services, VSATs, Radarsat, Global Positioning Satellite System.
Course Outcomes
On completion of this course, the students will be able to: **CO1:** Understand the basics of wireless communication, basic terms such as Bit error rate, symbol error rate, etc., and the advantages and disadvantages of different wireless communication techniques. **CO2:** Learn cellular communications basics and mobile radio propagation. **CO3:** Understand the basics of Satellite Systems, learning about orbital systems and sub-systems. **CO4:** Know about the Earth & Space segment, applications of direct satellite broadcasting, like GPS, and other mobile services. **CO5:** Know about the Uplink & Downlink Analysis, Satellite Mobile Services.
Text Books
1. Fundamentals of Wireless Communications – David Tse and Pramod Viswanath, Publisher Cambridge University Press. 2. Wireless Communications: Andrea Goldsmith, Cambridge University Press. 3. Satellite Communications, Dennis Roddy, McGraw-Hill Publication Third edition 2001. 4. Satellite Communications – Timothy Pratt, Charles Bostian and Jeremy Allnutt, WSE, Wiley Publications, 2nd Edition, 2003.
Reference Books
1. Wireless Communications – Andreas Molisch – Wiley IEEE Press. 2. Mobile Wireless Communications – Mischa Schwartz – Cambridge University Press. 3. Wilbur L. Pritchars Henri G.SuyderHond Robert A. Nelson, Satellite Communication Systems Engineering, Pearson Education Ltd., Second edition 2003. 4. Satellite Communications: Design Principles – M. Richharia, BS Publications, 2nd Edition, 2003.

Course Code	Course Name	L – T – P	**Credits**
EE668	**Machine Learning for Signal Processing**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the fundamentals of machine learning, including problem formulation, system design, and different learning paradigms.
- Learn supervised learning algorithms for regression and classification, including decision trees, neural networks, SVMs, and regularization techniques.
- Explore unsupervised learning methods such as clustering, Gaussian mixture models, and dimensionality-based approaches.
- Analyze model evaluation and selection techniques.
- Develop practical skills in Python for implementing regression, classification, and clustering algorithms.

Course Contents

Unit I: Well-posed learning problems, Designing a learning system, Perspectives and issues in machine learning. Types of Machine Learning-Supervised, Unsupervised, Reinforcement learning.

Unit II: Supervised Learning Algorithms- Regression and Classification- Linear, Polynomial Regularization, Regression based on Normal Equations, Instance-based learning- Decision Trees, Artificial Neural Networks, Support Vector Machines, Support Vector Regression.

Unit III: Unsupervised learning- k-means, Gaussian Mixture Models, Expectation Maximization, Hierarchical clustering, Spectral clustering.

Unit IV: Bias variance trade-off, VC dimension, Model selection, AUC-ROC, Metrics-Regression, Classification, Clustering, K-Fold cross-validation.

Unit V: Python Implementation of Regression, Classification, and Clustering Algorithms.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Learn the basic principles of designing a learning system and the types of machine learning.

CO2: Learn the concepts of Supervised Learning Algorithms with Regression and Classification.

CO3: Learn the basics of Unsupervised learning, including k-means, Gaussian Mixture Models, Expectation Maximization, Hierarchical clustering, and Spectral clustering.

CO4: Apply knowledge and skills to understand the bias-variance trade-off, VC dimension, Model selection, AUC-ROC, Metrics-Regression, and Clustering.

CO5: Acquire the knowledge of the Implementation of Regression, Classification, and Clustering Algorithms.

Text Books

1. E. Alpaydin, Introduction to Machine Learning, 3rd Edition, Prentice Hall (India) 2015.

2. R. O. Duda, P. E. Hart and D. G. Stork, Pattern Classification, 2nd Edn., Wiley India, 2007.

3. C. M. Bishop, Pattern Recognition and Machine Learning (Information Science and Statistics), Springer, 2006.

4. S. O. Haykin, Neural Networks and Learning Machines, 3rd Edition, Pearson Education (India), 2016.

Reference Books

1. Tom M. Mitchell, Machine Learning, Indian Ed., 2017, Tata McGraw Hill Education.

2. Stephen Marsland, Machine Learning: An Algorithmic Perspective, 2nd Ed., 2014, Taylor & Francis (CRC).
3. Kevin Murphy, Machine Learning, A probabilistic perspective, 2012, MIT Press.
4. O'Reilly, Hands on Machine Learning with Scikit-Learn, Keras & TensorFlow, 3rd Edition, 2022

Course Code	Course Name	L – T – P	**Credits**
EE669	**Deep Learning and Applications**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the fundamentals of neural network models.
- Apply dimensionality reduction and representation learning techniques.
- Implement regularization methods to improve generalization in deep learning models, including dropout, early stopping, and ensemble approaches.
- Explore advanced deep learning architectures.
- Develop practical skills for building and optimizing deep learning models using modern initialization, normalization, and training strategies.

Course Contents

Unit I: McCulloch Pitts Neuron, Thresholding Logic, Perceptrons, Perceptron Learning Algorithm. Multilayer Perceptrons (MLPs), Representation Power of MLPs, Sigmoid Neurons, Gradient Descent, Feedforward Neural Networks, Representation Power of Feedforward Neural Networks.

Unit II: Feed-Forward Neural Networks, Backpropagation, Gradient Descent (GD), Momentum Based GD, Nesterov Accelerated GD, Stochastic GD, AdaGrad, RMSProp, Adam, Eigenvalues and eigenvectors, Eigenvalue Decomposition, Basis.

Unit III: Principal Component Analysis and its interpretations, Singular Value Decomposition, Autoencoders and relation to PCA, Regularization in autoencoders, Denoising autoencoders, Sparse autoencoders, Contractive autoencoders.

Unit IV: Regularization: Bias Variance Tradeoff, L2 regularization, Early stopping, Dataset augmentation, Parameter sharing and tying, Injecting noise at input, Ensemble methods, Dropout.

Unit V: Greedy Layerwise Pre-training, Better activation functions, Better weight initialization methods, Batch Normalization, Learning Vectorial Representations Of Words. Convolutional Neural Networks, AlexNet, VGGNet, ResNet, Visualizing Convolutional Neural Networks, Guided Backpropagation. Recurrent Neural Networks, Backpropagation through time (BPTT), Vanishing and Exploding Gradients, GRU, LSTM.

Course Outcomes

On completion of this course, the students will be able to:
CO1: Learn the basics of the principles of spatial signals: Array processing fundamentals, signals in space and time.
CO2: Get the concepts of sensor arrays and Uniform linear arrays.
CO3: Learn the basics of beamforming-related concepts.
CO4: Apply knowledge and skills to understand the direction of arrival methods.
CO5: Acquire knowledge of compressed sensing and sparse signal processing.

Text Books/Reference Books

1.Deep Learning, An MIT Press book, Ian Goodfellow and Yoshua Bengio and Aaron Courville.

2.Deep Learning- Ian Goodfelllow, Yoshua Benjio, Aaron Courville, The MIT Press

3.Pattern Classification- Richard O. Duda, Peter E. Hart, David G. Stork, John Wiley & Sons Inc.

Course Code	Course Name	L – T – P	**Credits**
EE670	**Time Frequency Analysis**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the fundamentals of Fourier and spectral analysis.
- Analyze complex, analytic, and multicomponent signals using duration–bandwidth principles and density functions.
- Apply the Uncertainty Principle and explore time–frequency invariance properties for signal analysis.
- Learn and implement time–frequency transforms.
- Explore quadratic time–frequency methods.

Course Contents

Unit I: Basics of Fourier Analysis, Spectral Theory, Fundamentals of Time-frequency Analysis, Instantaneous Frequency and Instantaneous Bandwidth, Basic Concepts & Definition of Bandwidth Equation, AM-FM Contribution to the bandwidth, non-additivity of spectral property.

Unit II: Complex signal, Analytic Signal and its physical interpretation, Multicomponent Signals, Duration-Bandwidth Principle, Density function, One-dimensional density and its characteristic functions, two-dimensional densities, Joint Density.

Unit III: Uncertainty Principle, Proof of Uncertainty Principle, Local average, global average, time & frequency shift invariance.

Unit IV: Gabor Transform, The Short-Time Fourier Transform/Spectrogram, Time-Frequency Localization, Continuous Wavelet Transform/ Scalogram, Multiresolution Analysis.

Unit V: Quadratic Time-Frequency Transform, Wigner-Ville Distribution, Signal Processing Applications, Image Processing Applications.

Course Outcomes
On completion of this course, the students will be able to: **CO1:** Learn the fundamentals of Fourier Analysis, Spectral Theory, and Time-frequency. **CO2:** Acquire knowledge of various concepts such as Complex signal, Analytic Signal, Multicomponent Signals, Duration-Bandwidth, and Density function. **CO3:** Learn the basics of the uncertainty principle, Local and global average, time & frequency shift invariance. **CO4:** Apply knowledge and skills to understand the Gabor Transform, STFT, Spectrogram, TF Localization, and Wavelet Transform. **CO5:** Acquire the knowledge of Quadratic Time-Frequency and Wigner-Ville Distribution.
Text Books/Reference Books
1. L. Cohen, Time-Frequency Analysis, Prentice Hall, 1995, ISBN:0135945321. 2. S. Mallat, A Wavelet Tour of Signal Processing (2nd edition), Academic Press, 2008, ISBN: 012466606X 3. B. Boashash, Time-Frequency Signal Analysis and Processing: A Comprehensive Reference, Elsevier Science, 2003, ISBN-13: 978-0080443355.4. 4. R. M. Rao and A. S. Bopardikar, Wavelet Transforms: Introduction to Theory & Applications, Prentice Hall, 1998, ISBN-13: 978-0201634631

Course Code	Course Name	L – T – P	**Credits**
EE671	**Convex Optimization for Signal Processing**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the fundamentals of convex sets and convex functions.
- Formulate and analyze convex optimization problems.
- Develop skills in approximation and fitting techniques such as norm approximation, regularization, and robust fitting.
- Implement unconstrained optimization methods, including gradient descent, Newton's method, and steepest descent, for solving practical problems.

Course Contents

Unit I: Affine and Convex Sets, Operations that preserve convexity, Separating and supporting Hyperplanes, Convex Functions, Conjugate function, Quasi-convex function, Log-concave and log-convex function, Convexity with respect to generalized inequalities

Unit II: Convex optimization problems, Optimization problems, convex optimization, Linear optimization problems, Quadratic optimization problems, Geometric programming, generalized inequality constraints, Vector optimization.

Unit III: Duality, The Lagrange dual function, The Lagrange dual problem, Geometric interpretation, Saddle-point interpretation, Optimality conditions, Perturbation and sensitivity analysis, Generalized inequalities.

Unit IV: Approximation and fitting, Norm approximation, Least-norm problems, Regularized approximation, Robust approximation, Function fitting and interpolation.

Unit V: Unconstrained minimization problems, Descent methods, Gradient descent method, Steepest descent method, Newton's method, Self-concordance.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Learn the fundamentals of Affine and Convex Sets, Operations that preserve convexity, Separating and supporting Hyperplanes.

CO2: Learn the concepts of Optimization problems, convex optimization, Linear optimization problems, Quadratic optimization problems.

CO3: Learn the basics of Duality, the Lagrange dual function, Geometric interpretation, Saddle-point interpretation, Optimality conditions.

CO4: Apply knowledge and skills to understand the approximation and fitting, Norm approximation, Least-norm problems, regularized approximation, and Robust approximation.

CO5: Acquire the knowledge of Unconstrained minimization problems, Descent methods, the Gradient descent method, and the Steepest descent method.

Text Books/Reference Books

1. Optimization Models by G.C. Calafiore and L. El Ghaoui, Cambridge University Press, 2014. Link: https://people.eecs.berkeley.edu/~elghaoui/ optmodbook.html
2. Convex Optimization by Stephen Boyd and L. Vandenberghe, Cambridge University Press. Available online at: https://web.stanford.edu/~boyd/ cvxbook/
3. Algorithms for Convex Optimization by Nisheeth K. Vishnoi, Cambridge University Press. Available online at: https://convex-optimization. github.io
4. Optimization III: Convex and Nonlinear Programming by Ben-Tal and Nemirovski. Lecture Notes.

Course Code	Course Name	L – T – P	**Credits**
EE672	**Time Series Analysis and Forecasting**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Understand the fundamentals of time series analysis.
- Apply exponential smoothing techniques.
- Model stationary and nonstationary processes using AR, MA, ARMA, ARIMA, and related forecasting methods.
- Perform spectral analysis and advanced forecasting.

Course Contents

Unit I: Introduction to Time Series Analysis: Review of Time Series Analysis. Growth models: Modified Exponential Curve, Gompertz curve, Logistic curve and their Fitting;

Measurement of cyclical component: Harmonic analysis, auto regression series: Markoff and Yule's series, Periodogram and correlogram analysis, measurement of irregular component: variate difference method. Difference Equations, Lag Operators, pth-Order Difference Equations. White Noise, Expectations, Stationarity, and Ergodicity. Models of Nonstationary Time Series: Why Linear Time Trends and Unit Roots? Random Walk Models, Brownian Motion, Geometric Brownian Motion. Canonical Correlation Time Series Models of Heteroscedasticity: ARCH and GARCH model, Granger Causality Test ADF, KPSS Test for Stationary.

Unit II: Exponential Smoothing Methods: Trend adjusted exponential smoothing, double and triple exponential smoothing, Holt and Winters smoothing, Chow's adaptive control methods, brown's one parameter adaptive method:

Unit III: Detailed Study of the Stationary Processes: Linear Models, Autoregressive Processes, Moving Average (MA), Auto Regressive (AR), ARMA and AR Integrated MA(ARIMA)models - forecasting with ARIMA models.

Unit IV: Box-Jenkins models: Discussion (without proof) of estimation of mean, auto covariance and auto-correlation functions under large sample theory. Choice of AR and MA periods. Estimation of ARIMA model parameters.

Unit V: Spectral Analysis and Forecasting: Spectral analysis of a weakly stationary process. Periodogram and correlogram analyses. Computations based on the Fourier transform, principles of Forecasting, Forecasts with Gaussian Processes, Wold's Decomposition, and the Box-Jenkins Modelling Philosophy, Parameter Estimation, and Maximum Likelihood Estimation. Vector Auto regressions; Bivariate Granger Causality Tests. Understanding Kalman Filter.

Course Outcomes

On completion of this course, the students will be able to:

CO1: Learn about Exponential, Gompertz, and Logistic curves and their fitting.

CO2: Understand trend-adjusted exponential smoothing methods.

CO3: Study MA, AR, ARMA, and ARIMA models.

CO4: Understand Box-Jenkins models and estimate auto-covariance and auto-correlation functions.

CO5: Study Periodogram and Correlogram analyses.

Text Books/Reference Books

1. Time Series Analysis by James D. Hamilton, Princeton University Press, 2012.
2. Time Series Analysis and Its Applications: With R Examples by Robert H. Shumway, David S. Stoffer, Springer Texts in Statistics, 2017.
3. Understanding the Kalman Filter by Richard J. Meinhold, Nozer D. Singpurwalla, The American Statistician Vol. 37, No. 2, pp. 123-127, (May, 1983).
4. The Statistical Analysis of Time Series by Anderson, T.W., Wiley, 1971.
5. Forecasting and Time Series Analysis by Montgomery, D.C. and Johnson, L.A., McGraw Hill, 1977.

Course Code	Course Name	L – T – P	**Credits**
EE673	**Real-Time Operating Systems**	3-0-0	**3**

Course Objectives: The primary objectives of this course are to:

- Introduce the fundamentals of operating systems with emphasis on real-time concepts, system structures, process management, and inter-process communication.
- Develop an understanding of process synchronization, memory management, and methods for handling deadlocks in real-time environments.
- Enable students to analyze and implement real-time scheduling algorithms for uniprocessor and multiprocessor systems, including fault-tolerant approaches.
- Impart knowledge of RTOS standards, architectures, and applications through case studies, with practical exposure to Linux and TinyOS programming.

Course Contents

Unit I: Introduction to Real Time Operating System: Overview of Operating System, Fundamentals and keywords, structures, OS user view, system view, Interrupts, Storage structures, I/O structures, Single, Multi and clustered systems, Dual mode and multimode operation, Resource Management, Timers and I/O, virtualization and distributed systems, lists, stacks, Hash functions, computing environments, Building and Booting an operating system, operating system debugging, Queues, Trees.

Programming –Basics of Linux Operating System

Unit II: Process Management: Process Management, Process scheduling, Message queues, Mailboxes, Pipes, Inter-Process Communication (IPC), IPC in shared memory message passing systems, threads and concurrency, Multithreading models, implicit threading, threading issues, Kernel Structure Critical sections, tasks, task states, task scheduling, task control blocks, task management, time management, Device drivers.

Programming – System calls for Linux operating system and Shell programs

Unit III: Process Synchronization and Memory Management Synchronization tools, the critical section problem, Hardware support for synchronization, Mutex locks, Semaphores, semaphore usage and implementation, Monitors, implementation usingsemaphores, resuming processes within a monitor, Deadlocks, characterization, methods for handling, deadlock prevention, Deadlock avoidance, ‘deadlock detection, Recovery from Deadlock, Memory management, main memory allocation, contiguous memory allocation, paging, structure of the page table, virtual memory, allocating kernel memory

Programming - Producer consumer problem using Semaphores, IPC using Shared Memory, Bankers Algorithm for Deadlock avoidance, Algorithm for deadlock detection, Memory allocation methods

Unit IV: Real Time Scheduling and Scheduling Algorithms: Uniprocessor scheduling, types of scheduling, pre-emptive and non-preemptive scheduling, dispatcher, scheduling algorithms-FCFS, Round robin scheduling, priority based scheduling, thread scheduling, multiprocessor scheduling, Real Time CPU scheduling, Rate monotonic scheduling, Earliest DeadlineFirst scheduling, POSIX Real-Time Scheduling, Fault tolerant scheduling, aperiodic scheduling, Schedulability problem: classification- schedulability test, Worst Case Execution Time (WCET), spring algorithm, Sporadic scheduling, Programming – CPU Scheduling

Algorithms (Priority based scheduling, Round Robin Scheduling, First Come First Serve (FCFS) and shortest scheduling Algorithms)

Unit V: RTOS and Case Studies Introduction to POSIX, POSIX standards, Design of POSIX, RTOS-Tiny OS introduction, example application, Names and Program Structure, Basic Programming, component signatures, Interfaces, Component Implementation, Split phase interfaces, configurations, applications, Case Study-RTOS for Control Systems, Case Study-RTOS for Voice over IP Programming - File organization techniques, Tiny OS

Course Outcomes

On completion of this course, the students will be able to:

CO1: Understanding the fundamentals of an operating system.

CO2: Understanding and illustrating the process concepts and kernel structure

CO3: Learn and construct the process synchronization and memory management

CO4: Understand and analyze the design a scheduling algorithm.

CO5: Learn & apply the knowledge to use and design RTOS

Text Books/Reference Books

1. Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating System Concepts, Tenth edition, Wiley, 2018.
2. Jean J. Labrosse, The microC /OS-II The Real Time Kernel Optics, CMP Books, 2nd edition, 2011.
3. C.M. Krishna and G.Shin, Real Time Systems, McGraw-Hill International Edition, 2010(3rd Reprint) "MEMS Packaging" by Tai-Ran Hsu
4. Jim Cooling, "Real-Time Operating Systems Book 1: The Foundations", Lindtree Associates, 2018
5. Donald A. Lewine, POSIX Programmer's Guide, 1991. Philip Levis, David Gay, Tiny OS Programming Cambridge University Press 2009.

Course Code	Course Name	L – T – P	**Credits**
EE674	**Foundations of Hardware Security: Threats and Protections**	3-0-0	**03**

Course Objectives:

- Understanding of the fundamentals of hardware security and towards the protection of systems and mechanisms

Course Contents

Unit I: Introduction to Hardware Security: Hardware security fundamentals, threat models and attack surfaces, physical attacks (probing, fault injection), side-channel attacks (power, timing, EM analysis), reverse engineering of chips, security objectives (confidentiality, integrity, availability), secure hardware design principles, trusted computing base, real-world hardware attack case studies.

Unit II: Hardware Security Primitives: Cryptographic Hardware and their Implementation, Optimization of Cryptographic Hardware on FPGA, trusted digital system design, circuit obfuscation, trust platform modules, true random number generators, Physically Unclonable Functions (PUFs), PUF Implementations, PUF Quality Evaluation, Design Techniques to Increase PUF Response Quality, Computing systems security requirements: integrity and authentication; core security techniques: encryption algorithms, key distribution and management. Hardware logical realisation and implementations of encryption and decryption - symmetric and asymmetric cryptographic functions; Introduction to Hardware Security Modules (HSM), Hardware Root of Trust (H-RoT) & Trusted Platform Modules (TPM)

Unit III: Secure Boot and firmware architecture: Concept of secure boot and chain of trust, root of trust (RoT) in hardware, firmware authentication using cryptographic signatures, public key infrastructure (PKI) in embedded systems, bootloader security, anti-rollback protection, secure firmware updates, trusted execution environments (TEE), implementation of secure boot in microcontrollers and processors. Firmware Architecture & Secure System Integration: Basics of firmware architecture (bootloader, HAL, device drivers, RTOS concepts), hardware–firmware interaction, secure boot and chain of trust, firmware authentication and integrity verification, secure firmware updates (OTA, rollback protection), debug and test interface protection (JTAG, UART), system-level secure integration.

Unit IV: Formal Verification: Fundamentals of formal verification and its difference from simulation; specification of safety and liveness properties; model checking, equivalence checking, and theorem proving; HDL verification, tools, and methodologies; detecting security vulnerabilities through formal analysis; scalability challenges. Secure coding in Verilog/VHDL; information flow tracking (IFT); formal verification of security properties; control-path and FSM vulnerabilities; assertion-based verification; detection/removal of hardware backdoors; secure design validation techniques.

Unit V: Hardware Trojans: Hardware Trojan Nomenclature and Operating Modes, Countermeasures Such as Design and Manufacturing Techniques to Prevent/Detect

Hardware Trojans, Logic Testing and Side-channel Analysis based Techniques for Trojan Detection, Techniques to Increase Testing Sensitivity Infrastructure Security: Impact of Hardware Security Compromise on Public Infrastructure, Defense Techniques (Case Study: Smart-Grid Security) **Unit VI: Hardware Weaknesses:** Debug Access Control. Lock Bit Modification, Internal Asset Exposed to Unsafe Debug Access, On-Chip Debug and Test Interface with Improper Access Control, Security-Sensitive Hardware Controls with Missing Lock Bit Protection, Improper Restriction of Software Interfaces to Hardware Features, Improper Isolation of Shared Resources (SoC), Improper Handling of Overlap Between Protected Memory Regions
Course Outcomes
After completing this course, the students will be able to: **CO1:** Students will be able to understand and analyze hardware vulnerabilities **CO2:** Students will be able to understand hardware threats and protection mechanisms **CO3:** Students are able to understand and design new mechanism to protect the hardware. **CO4:** Students will be able to understand and design new secure design flow and security primitives
Text Books
1) Swarup Bhunia, Mark Tehranipoor, "Hardware Security A Hands-on Learning Approach" MK publishers, 2019
Reference Books
1) CWE: https://cwe.mitre.org/topHW/archive/2021/2021_CWE_MIHW.html

Course Code	Course Name	L – T – P	**Credits**
EE675	**Side-Channel and Fault Attacks: Analysis and Countermeasures**	3-0-0	**03**

Course Objectives:

- Understanding of the fundamentals of hardware security and towards the protection of systems and mechanisms

Course Contents

Unit I: Introduction to Side-Channel Leakage: Fundamentals of Side-Channel Attacks (SCA), sources of leakage (power consumption, timing variations, electromagnetic radiation, acoustic signals), reasons for information leakage due to physical implementation, vulnerable cryptographic functions (modular arithmetic, S-box operations, branching based on secret data, cache attacks), leakage models (Hamming weight, Hamming distance), attacker models and practical scenarios. Measurement setup. Impact of Hardware Security Compromise on Public Infrastructure, Defence Techniques (Case Study: Smart-Grid Security) .

Unit II: Simple Power Analysis (SPA) and Timing Analysis (TA): Concepts of Simple Power Analysis (SPA) and Timing Attacks (TA), analyzing single execution traces, identifying key-dependent execution patterns, exploiting timing differences in algorithms, extracting secret information from observable characteristics, limitations and practical considerations of SPA and TA. Template building, template matching, collision attack, SNR (Electronic noise/switching noise) operation dependency, data dependency.

Unit III: Differential Power Analysis (DPA): Introduction to Differential Power Analysis, statistical processing of multiple power traces, hypothesis testing and correlation methods, divide-and-conquer key extraction techniques, targeting intermediate computations, correlation power analysis (CPA) as an advanced form of DPA, Difference of means, Distance of means, General Maximum likelihood attack, Welch t-test, NICV, ANOVA.

Unit IV: Fault Analysis: Introduction to Differential Fault Analysis, General Principle of DFA of Block Ciphers, Fault Models. DFA and Associated Fault Models, Fault Models for DFA of AES, Faults Are Injected in Any Location and Any Round. Case study: Principle of Differential Fault Attacks on AES, Multiple-Byte DFA of AES-128, DFA of AES Targeting the Key Schedule.

Unit V: SCA Countermeasures: Circuit level, architectural level, algo level, masked dual rain pre-charge logic. Hiding methods (hiding time dimension, hiding amplitude dimension, static misalignment, dynamic misalignment), masking methods (secret sharing/Threshold Implementation (TI), Boolean vs arithmetic masking, secret sharing, blinding,). Attacks on hiding techniques, statics alignment, dynamic alignment, preprocessing power traces. Attack on masking techniques, higher order DPA. FI counter measures Hardware Redundancy, Time Redundancy, Information Redundancy, Hybrid Redundancy

Unit VI: Case study on the side channel and fault attack resistant implementation. Implementation of Hardware Security Solutions like TRNG, Symmetric algorithms – For power, area and timing optimisation Implementing case studies of SCA
Course Outcomes
After completing this course, the students will be able to: **CO1:** Students will be able to understand and analyze Side-channel and fault vulnerabilities **CO2:** Students will be able to understand evaluation methods and standards **CO3:** Students are able to understand and design new mechanism to protect the hardware against SCA and FA attacks
Text Books
1) Stefan Mangard, Thomas Popp, Elisabeth Oswald, "Power Analysis Attacks" Springers 2007
Reference Books
1) Debdeep Mukhopadhyay Rajat Subhra Chakraborty Indian Institute of Technology Kharagpur West Bengal, India, "HARDWARE SECURITY Design, Threats, and Safeguards". CRC press.

Course Code	Course Name	L – T – P	**Credits**
EESL01	**Signal Processing Laboratory I**	0-0-6	**3**

Course Outcomes:	
CO1	Understanding the basics of MATLAB and LabVIEW
CO2	Understand Model-based power spectral estimation techniques
CO3	Speech analysis using LPC
CO4	Digital filter design using MATLAB & implementation in FPGA
CO5	Design of Quadrature Mirror Filters (QMF)

List of experiments:

Sl. No	**Experiment**
1.	Introduction of MATLAB/Simulink, LabVIEW, and their toolboxes
2.	Sampling and Reconstruction of Signals
3.	Deterministic & Random Signal analysis using power spectral estimation techniques 1. Periodogram power spectral estimation technique 2. PSD through the correlogram technique 3. Spectrogram analysis
4.	Model-based power spectral estimation techniques 1. AR Model, MA Model, ARMA Model 2. Covariance methods
5.	Speech analysis using LPC. Performance analysis with respect to the Prediction Filter Order & SNR

6.	Digital filter design using MATLAB & implementation in FPGA a) FIR & IIR Filters
7.	High-Resolution pseudo-spectral estimation technique via a) MUSIC & ESPRIT
8.	Design of Quadrature Mirror Filters (QMF)

Course Code	Course Name	L – T – P	**Credits**
EESL02	**Signal Processing Laboratory II**	0-0-6	**3**

Course Outcomes:

CO1	Understanding the AM, FM, and PM waveforms
CO2	Design a FIR adaptive filter
CO3	Target Signal & Ambient Noise Simulation
CO4	Wavelet transform-based case study
CO5	Detection of targets using NP Criterion & target parameter

List of experiments:

Sr. No.	**Experiments**
1.	Simulation of multi-component sinusoidal, AM, FM, AM-FM signals and their frequency spectrum, time-frequency representation visualization.
2.	Simulation of multi-component sinusoidal, AM, FM, AM-FM signals in a noisy environment (AWGN level 5dB, 0dB, 5dB, 10dB, 20dB) and their frequency spectrum, time-frequency representation visualization.
3.	Simulation of the analytic form of signal possesses (a) a mono-component signal, (b) a multicomponent signal.
4.	Design a FIR adaptive filter to remove different types of noises from a natural signal, such as physiological signals, EEG, ECG, and speech signals.
5.	Wavelet transform-based case study
6.	Introduction of MATLAB/Simulink, LabVIEW, and its toolboxes to simulate Signal models in the presence of various ambient Noise models (correlated/uncorrelated, White/Colored with Gaussian mixture models)
7.	Target Signal & Ambient Noise Simulation (Scalar & Vector Sensor Array Data Vector Simulation): Generation of Multiple spatially separated targets in the presence of Strong interferences and Additive Correlated/Uncorrelated, White/Colored Ambient Noise
8.	Development of Detection Techniques for the following cases 1. Constant amplitude Signal in AWGN

	2. Time-varying Known Signals in AWGN 3. Unknown Signals in AWGN
9.	Development and performance comparison of the following Estimation techniques using a given signal & noise model (sensor data model) - MLE, MMSE, Bayes Estimator, MAP Estimator, Expectation Maximization (EM) algorithm
10.	Case Study: Detection of targets using NP Criterion & target parameter (Range, bearing, Doppler, etc.) estimation algorithms. Performance comparison of Conventional Energy Detectors and Coherent Matched Filter Techniques

Course Code	Course Name	L – T – P	**Credits**
EERL01	**Radar Laboratory I**	0-0-6	**3**
Course Outcomes:			
CO1	Understanding the basic FPGA Design Flow		
CO2	Familiarization with FPGA Boards		
CO3	Phased array radar design		
CO4	RCS measurement		
CO5	Characterization of radar subsystems/components		
List of experiments:			
SL No	**Experiments**		
1.	The Basic FPGA Design Flow 1. To understand the use of Xilinx ISE 2. To understand Xilinx Synthesis Technology or XST. 3. Familiarization with Xilinx Vivado Design Tools.		
2.	Familiarization with FPGA Boards 1. Xilinx FPGA Boards (Virtex 6, Kintex7) 2. Implementation of a Full adder, ALU, Memory, and FIFO on an FPGA		
3.	Fault Detection Logic Implementation on FPGA 1. Stuck at Fault 2. Memory BIST		
4.	Implementation of RISC CPU on FPGA and debugging using Embedded Logic Analyzers.		
5.	CW, Pulse, FMCW radar design		
6.	Phased array radar design		
7.	RCS measurement		
8.	Real-time signal acquisition and spectral profile computation		
9.	Doppler/speed measurement		
10.	Characterization of radar subsystems/ components		

Course Code	Course Name	L – T – P	**Credits**
EERL02	**Radar Laboratory II**	0-0-6	**3**

Course Outcomes:	
CO1	Understanding the fundamentals of radar.
CO2	Understand different pulse compression waveforms using MATLAB
CO3	Model an adaptive digital beam former using SAR
CO4	Formulate ISAR images of LSS targets
CO5	Design and characterization of different types of antennas

List of experiments:

Sr. No.	Experiments
1.	Radar clutter modeling and statistical analysis of various clutter distributions, Realization of N-pulses DLC MTI using FPGA, Analysis of detection performance improvement due to coherent/non-coherent pulse integration using MATLAB.
2.	Realization of various CFAR using FPGA, Generation and spectral analysis of different pulses compression waveforms using MATLAB.
3.	Realization of matched filtering operation and detection concept, analyzing the ambiguity diagram for different Radar waveforms, Modeling and simulation of micro-Doppler effect, and processing.
4.	Realization of adaptive Mono-pulse, Kalman, and other tracking algorithms.
5.	Simulating the phased array assisted tracking technique, the Realization of digital and non-adaptive beam forming, and Adaptive array processing using the LMS algorithm.
6.	Modeling an adaptive digital beam former using SAR simulation and a Moving platform (airborne, space-borne, and ship-borne) modeling using SystemVue.
7.	Targets direction finding using IQ signals
8.	Real-time analysis of micro-Doppler T-F imaging
9.	Formulation of ISAR images of LSS targets
10.	Design and characterization of different types of antennas

Course Code	Course Name	L – T – P	**Credits**
EEDL01	**D&S Laboratory I**	0-0-6	**3**

Course Outcomes:	
CO1	Understanding the basics of EM tools
CO2	Understand Measurements using VNA and SA
CO3	Knowledge of S-parameters
CO4	Design and fabricate transmission lines

CO5	Mini project to design and develop 4-port devices
List of experiments:	
Sr. No.	**Experiments**
1.	Hands-On with EM Simulator (ADS/CST/HFSS): Design and simulate a planar transmission line in an EM simulator
2.	Measure the S-parameters of a Transmission line using a Vector Network Analyzer (VNA): Understand the function of a VNA
3.	Calibration of VNA using the Mechanical calibration kit
4.	Measure parameters (input impedance, VSWR, S-parameters) of microwave passive components such as filters, power dividers, etc.
5.	Characterize the amplifiers using the spectrum analyzer: Understand the use of the Spectrum Analyzer
6.	Learn how to prepare the layout of the circuit in IntelliCAD/AutoCAD for production purposes
7.	Fabricate a prototype (planar microwave component) and measure its performance
8.	Observe the S-parameter (S_{11}) after terminating a Planer transmission line with different Impedances (open, load, short) and compare it with that obtained in simulations
9.	Design a planar filter and simulate its performance in terms of S-parameters
10.	Design a 4-port planar coupler and simulate its performance in terms of S-parameters

Course Code	Course Name	L – T – P	**Credits**
EEDL01	**D&S Laboratory II**	0-0-6	**3**

Course Outcomes:	
CO1	Understanding the fundamentals of antenna Measurements
CO2	Understand the Characterization of antennas
CO3	Knowledge of RF passive components
CO4	Design Passive probes for EMI
CO5	Mini project to understand the EMI and EMC
List of experiments:	
Sr. No.	**Experiments**
1.	Radiation pattern measurement using the DAMS controller and its connectivity to the antenna positioner inside the anechoic chamber, to the VNA.
2.	Measure the antenna gain using the Friis equation and a reference antenna with known gain
3.	Design two parallel planar transmission lines and observe the coupling between them while changing the spacing between them.

4.	Integrate the power combiner with the antenna array, and list the performance of the individual network
5.	Design and develop a microstrip patch antenna and compare simulated and measured results
6.	PCB Board Level EMC Simulation: Observe the effects of shielding, grounding, etc. in the EM simulator using appropriate probes
7.	Controlling Crosstalk: Frequency-Domain Perspective Objectives: i) To measure crosstalk in the frequency domain ii) To investigate the factors affecting the crosstalk level
8.	Characterize a mixer using a source and a spectrum analyzer
9.	Controlling Radiated Emission from Cable and PCB: To observe the frequency spectrum of the near-field electromagnetic (EM) radiation from cables and printed circuit board (PCB) traces using a near-field probe and a spectrum analyzer
10.	Study different types of probes of EMI/EMC that are used to measure the EMI (for H-field, E-field).

Course Code	Course Name	L – T – P	**Credits**
EEVL01	**VLSI&ES Laboratory I**	0-0-6	**3**

Course Outcomes:	
CO1	Understanding the fundamentals of Analog IC design
CO2	Knowledge of FPGA, circuit design using the device designed in an EDA tool
CO3	Design a circuit, do its verification, and STA

List of experiments:

Sr. No.	**Experiments**
1.	Logic Synthesis of Combination Circuits
2.	Logic Simulation of Electronic Circuits.
3.	Checking and violation of design constraints and mitigating the same in digital circuits.
4.	Application of Formal Verification methods in digital circuits
5.	Obtain and study the Static Timing Analysis of digital circuits
6.	The Basic FPGA Design Flow 1. To understand the use of Xilinx ISE 2. To understand Xilinx Synthesis Technology or XST. 3. Familiarization with Xilinx Vivado Design Tools.
7.	Familiarization with FPGA Boards

	1. Xilinx FPGA Boards (Virtex 6, Kintex7) 2. Implementation of a Full adder, ALU, Memory, and FIFO on an FPGA
8.	Fault Detection Logic Implementation on FPGA 1. Stuck at Fault 2. Memory BIST
9.	Implementation of RISC CPU on FPGA and debugging using Embedded Logic Analyzers.
10.	Use of SPICE for MOSFET modeling and simulation of Digital combinational Circuits.
11.	Schematic gate-level Simulation of Digital combinational circuits
12.	LVS simulation of Digital circuits.
13.	Schematic gate-level Simulation of Digital sequential circuits
14.	Simulation of memory circuits using PSPICE

Course Code	Course Name	L – T – P	**Credits**
EEVL02	**VLSI&ES Laboratory II**	0-0-6	**3**

Course Outcomes:

CO1	Knowledge of CTS, Physical design, Floor planning, etc.
CO2	Design an Analog and RF circuit, such as an OP amp circuit.
CO3	Mini project to understand the VLSI design flow from netlist to GDS

List of experiments:

Sr. No.	**Experiments**
1.	Physical Synthesis: Clock Tree Synthesis (CTS)
2.	Physical Synthesis: Placement
3.	Physical Synthesis: Power Net Synthesis (PNS)
4.	Physical Synthesis: Floor planning
5.	Chip Finishing
6.	Parasitic Extraction, STA, Physical Synthesis: Routing
7.	NAND DESIGN : Schematic Entry and Symbol Creation Building the NAND Test Design , Simulation with Spectre, Parametric Analysis, Creating Layout View of NAND Gate ,Physical Verification,Creating the Configuration View,Generating Stream Data.
8.	SRAM DESIGN: Schematic Entry and Symbol Creation Building the SRAM Test Design, Simulation with Spectre, Creating Layout View of SRAM, Physical Verification.
9.	Simulation of LNA using ADS/Matlab Software.
10.	Simulation of Power Amplifier using ADS/Matlab Software.
11.	Simulation of Mixer using ADS Software.
12.	Characterization of LNA and Power Amplifier using FieldFox

13.	Design and Simulation of a Low-Power Operational Amplifier
14.	Design and Analysis of a High-Speed Comparator
15.	Design and Simulation of a Low-Power Successive Approximation Register (SAR) ADC
16.	Implementation and Analysis of a Phase-Locked Loop (PLL) for High-Speed Clocking

Tools used: Synopsys, Cadence, Vivado EDA, Matlab, Quantumwise ATK, ADS

Course Code	Course Name	L – T – P	**Credits**
EECL01	**IC design Lab-I: Device Design, FPGA & Front-End Design**	0-0-6	**3**
Course Outcomes:			
CO1	Understanding the fundamentals of Device Design.		
CO2	Design HEMT, HBT, GaN HEMT, and understand its physics		
CO3	Knowledge of FPGA, circuit design using the device designed in an EDA tool		
CO4	Design a circuit, do its verification, and STA		
CO5	Mini project to understand the VLSI design flow from RTL to netlist		

List of experiments:

Sr. No.	**Experiments:**
1	DC characteristics of HEMTs
2	Logic Simulation of Electronic Circuits.
3	LDMOS characteristics
4	Logic Synthesis of Combination Circuits
5	DC Characteristics of HBTs
6	Checking and violation of design constraints and mitigating the same in digital circuits.
7	Power amplifier design using HEMTs
8	Application of Formal Verification methods in digital circuits
9	Device physics of GaN HEMTs
10	Obtain and study the Static Timing Analysis of digital circuits
11	The Basic FPGA Design Flow 1. To understand the use of Xilinx ISE 2. To understand Xilinx Synthesis Technology or XST. 3. Familiarization with Xilinx Vivado Design Tools.

12	Familiarization with FPGA Boards 1. Xilinx FPGA Boards (Virtex 6, Kintex7) 2. Implementation of a Full adder, ALU, Memory, and FIFO on an FPGA
13	Fault Detection Logic Implementation on FPGA 1. Stuck at Fault 2. Memory BIST
14	Implementation of RISC CPU on FPGA and debugging using Embedded Logic Analyzers.
15	Use of SPICE for MOSFET modeling and simulation of Digital combinational Circuits.
16	Schematic gate-level Simulation of Digital combinational circuits
17	LVS simulation of Digital circuits.
18	Schematic gate-level Simulation of Digital sequential circuits
19	Simulation of memory circuits using PSPICE
20	Mini Project- RTL to Netlist

Tools used: Synopsys, Cadence, Vivado EDA tools

Course Code	Course Name	L – T – P	**Credits**
EECL02	**IC design Lab-II: Mixed signal-RF IC & Back-End Design Lab**	0-0-6	**3**

Course Outcomes:

CO1	Understanding the fundamentals of Nano Device Design.
CO2	Quantum nanotransport & 2D material simulations
CO3	Knowledge of CTS, Physical design, Floor planning etc.
CO4	Design an Analog and RF circuit, such as an OP amp circuit.
CO5	Mini project to understand the VLSI design flow from netlist to GDS

List of Experiments:

Sr. No.	Experiments:
1	Physical Synthesis: Clock Tree Synthesis (CTS)
2	Physical Synthesis: Placement
3	Physical Synthesis: Power Net Synthesis (PNS)
4	Physical Synthesis: Floor planning
5	Chip Finishing
6	Parasitic Extraction, STA, Physical Synthesis: Routing
7	NAND DESIGN: Schematic Entry and Symbol Creation Building the NAND Test Design, Simulation with Spectre, Parametric Analysis, Creating Layout

	View of NAND Gate, Physical Verification,Creating the Configuration View,Generating Stream Data.
8	SRAM DESIGN: Schematic Entry and Symbol Creation Building the SRAM Test Design, Simulation with Spectre, Creating Layout View of SRAM, Physical Verification.
9	Simulation of LNA using ADS/Matlab Software.
10	Simulation of Power Amplifier using ADS/Matlab Software.
11	Simulation of Mixer using ADS Software.
12	Characterization of LNA and Power Amplifier using FieldFox
13	Characterization of MOSFET Parameters in Subthreshold Region
14	Design and Simulation of a Low-Power Operational Amplifier
15	Design and Analysis of a High-Speed Comparator
16	Design and Simulation of a Low-Power Successive Approximation Register (SAR) ADC
17	Implementation and Analysis of a Phase-Locked Loop (PLL) for High-Speed Clocking

Tools used: Synopsys, Cadence, Vivado EDA, Matlab, Quantumwise ATK, ADS

Course Code	Course Name	L – T – P	**Credits**
EECL03	**IC design Lab-III: Advanced SoC-CAO & Back-End Design Lab**	0-0-6	**3**

Course Outcomes:

CO1	Understanding the fundamentals of Nano Device Design.
CO2	Quantum nanotransport & 2D material simulations
CO3	Knowledge of CTS, Physical design, Floor planning, etc.
CO4	Design a Analog and RF circuits such as OP amp circuit.
CO5	Mini project to understand the VLSI design flow from netlist to GDS

List of Experiments:

Sr. No.	**Experiments:**
1	Verilog Simulation and RTL Verification a) Memory b) Clock Divider and Address Counter c) n-Bit Binary Counter and RTL Verification
2	Basic Verification environment for FIFO/UART
3	Verification Planning for FIFO/UART a) Development of the test cases as per the verification plan b) Generation and Analysis of Code coverage Reports
4	Writing assertions for FIFO
5	Typical Soc Design and Emulation on FPGA Platform
6	Write an example to demonstrate the user defined data type enum, struct, struct packed, union, typedef and string, the static array, multi-dimensional static

	array, dynamic array, associative array and queue type array, demonstrate a simple interface.
7	Write an example to demonstrate class constructor, inheritance, encapsulation, and polymorphism, randomization, rand casec, rand sequence, rand sequence abort., DPI (Direct Programming Interface), both sv to c and c to sv., semaphore, mailbox, virtual interface
8	Create SV based test and class-based test environment for a 1-bit adder.
9	Create a class-based test environment for RAM and FIFO memory given.
10	Create coverage and assertions for the decade counter and the ones counter.
11	Create coverage and assertions for the RAM previously created counter.
12	Create coverage and assertions for the FIFO memory previously created counter.
13	Physical Synthesis: Clock Tree Synthesis (CTS)
14	Physical Synthesis: Placement
15	Physical Synthesis: Power Net Synthesis (PNS)
16	Physical Synthesis: Floor planning
17	Chip Finishing
18	Parasitic Extraction, STA, Physical Synthesis: Routing
19	Coding of simple RISC-V programs in assembly and emulating them in Spike or QEMU simulator (Tools: QEMU, RISCV SPIKE), Modelling OF 32 bit single cycle RISCV CORE IN SYSTEM C/Verilog/Bluespec, and run baremetal software code in it (SYSTEM C SIMULATORS LIKE XCELIUM from cadence)
20	Modelling of a 32-bit 3-stage pipelined RISC-V CORE IN SYSTEM C/Verilog/Bluespec
21	MODELLING Cache Controllers AND BRANCH PREDICTORS IN C/SYSTEM C
22	MODELLING OF VARIOUS SYSTOLLIC ARRAY ARCHITECTURES IN SYSTEM C and performing performance benchmarking
23	Implementation of Accelerators for Various Mathematical Problems and performing performance benchmarking

Tools used: Synopsys, Cadence, Vivado EDA, Matlab, Quantumwise ATK, ADS

Course Code	Course Name	L – T – P	**Credits**
EECL04	**MEMS Design Lab**	0-0-6	**3**

Course Outcomes:

CO1	Understanding the fundamentals of MEMS Design.
CO2	Understand Microfabrication Techniques and Processes

CO3	Knowledge of CTS, Physical design, Floor planning etc.
CO4	Design a Analog and RF circuits such as OP amp circuit.
CO5	Mini project to understand the VLSI design flow from netlist to GDS

List of Experiments:

Sr. No.	**Experiments:**
1	Physical Synthesis: Clock Tree Synthesis (CTS)
2	Physical Synthesis: Placement
3	Physical Synthesis: Power Net Synthesis (PNS)
4	Physical Synthesis: Floorplanning
5	Chip Finishing
6	Parasitic Extraction, STA, Physical Synthesis: Routing
7	NAND DESIGN: Schematic Entry and Symbol Creation Building the NAND Test Design , Simulation with Spectre, Parametric Analysis ,Creating Layout View of NAND Gate ,Physical Verification,Creating the Configuration View,Generating Stream Data.
8	SRAM DESIGN: Schematic Entry and Symbol Creation Building the SRAM Test Design, Simulation with Spectre, Creating Layout View of SRAM, Physical Verification.
9	Simulation of LNA and power amplifier
10	Characterization of MOSFET Parameters in Subthreshold Region
11	Design and Simulation of a Low-Power Operational Amplifier
12	Design and Analysis of a High-Speed Comparator
13	Design and Simulation of a Low-Power Successive Approximation Register (SAR) ADC
14	Implementation and Analysis of a Phase-Locked Loop (PLL) for High-Speed Clocking
15	Design a MEMS Cantilever Beam and compare between Point Load & Surface Load
16	Design a MEMS Cantilever Beam having Multilayers
17	Detection of HIV-virus by Micro-Cantilever
18	MEMS Capacitance & Microgripper
19	Joule Heating of Microactuator
20	Microresistor Beam
21	Pressure Sensor
22	MEMS Comb Drive Actuator

Tools used: Synopsys, Cadence, Vivado EDA, Matlab, Quantumwise ATK, ADS, Coventorware, MEMS+ tools

Course Code	Course Name	L – T – P	**Credits**
EEHL01	**Hardware Security and Cryptology Lab-01**	0-0-6	**3**
Jointly taken by DIAT and SETS			

Tools used: Synopsys, Cadence, Vivado EDA, Matlab, Quantumwise ATK, ADS, Coventorware.

Course Code	Course Name	L – T – P	**Credits**
EEHL02	**Hardware Security and Cryptology Lab-02**	0-0-6	**3**
Jointly taken by DIAT and SETS			

Tools used: Synopsys, Cadence, Vivado EDA, Matlab, Quantumwise ATK, ADS, Coventorware.